Leibniz Universität Hannover

Bachelor's Programme Mathematics
Master programme Mathematics

Module catalogue

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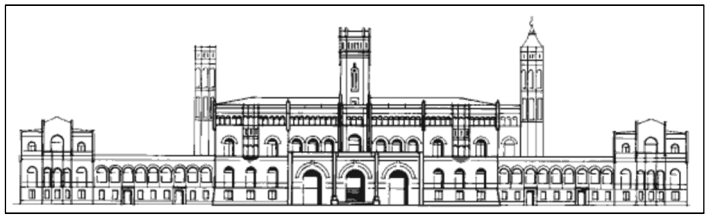
Faculty of Mathematics and Physics
of the Leibniz University Hannover



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Preface

The module catalogue mathematics consist of two parts, the module descriptions and the appendix with the course descriptions. Given that different courses can be chosen for elective module, these will be described in more detail in the appendix. In those cases the information of the Course Overview and the frequency of the course are found at the courses and not at the modules.

Please note that this here is a compilation of the courses of the mathematics that are offered on a regular basis. In particular further courses of the university calender" can be assigned to "compulsory elective module and den Elective module.

The module catalogue should also be understood as addition to the Examination regulations. The recent version of our Examination regulations can be found under

http://www.uni-hannover.de/de/studium/studiengaenge/mathe/ordnungen/index.php

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Curriculum Bachelor Course

	1. Semester	2. Semester	3. Semester	4. Semester	5. Semester	6. Semester	LP
Basics	Analysis I 10 LP, SL, PL	Analysis II 10 LP, SL, PL	(Analysis III 10 LP, SL, PL)	Probability and Statistics I 10 LP, SL, PL	Analysis III 10 LP, SL, PL		
	Lineare Algebra I 10 LP, SL, PL	Lineare Algebra II 10 LP, SL, PL	Algebra I 10 LP, SL, PL				
		Algorithmic programming 4 LP, PL	Numerical Mathematics I 10 LP, SL, PL				84
Key skills			Seminar 5 LP, SL				5
Proseminar			Proseminar 5 LP, PL				5
optional section				courses in an extent of 40 CP, 4xSL, 4xPL			40
Computer Science	Basics of theoretical Informatics 5 CP, SL, PL (also 3. Sem.)				Data Structur and Algorrithm 5 CP, SL, PL		10
application subject	application subjects are: business administration, Geodesy and Geoinformatics, Informatics, Philosophy, Physics and Economics. Other subjects are possible upon request. 18 CP						18
Seminar					Seminar 5 CP, PL		5
Bachelor thesis						Bachelorthesis 13 CP	13
Credit Points	30/4	24/2	According to individual planning variable				**180**

Modules of Bachelor Mathematics

Compulsory module Bachelor

Analysis I			0201
Frequency	Winter Semester, annually		
Responsible for Module	Elmar Schrohe, Institute of Analysis		
Type of Course (Semester Hours)	Lecture „Analysis I" (4 Semester Hours) Tutorial on „Analysis I" (2 Semester Hours)		
Major course assessment for acquisition of LP	Course Achievement: Tutorial Exam Performance: Exam		
Grade composition	Grade of exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	

Competences to acquire:

Competence in dealing with mathematical language. Basic understanding of the correct solution of mathematical problems by means of one-dimensional convergence considerations, differential and integral calculus. As a result of the exercise sessions, the students are familiar with mathematically exact formulations and conclusions in simple contexts and are able to present them.

Topics:

- Number systems; systematic introduction of real and complex numbers
- Sequences and series
- Convergence and continuity
- Differential calculus for functions of one variable
- Integral calculus for functions of one variable.
- Sequences of functions and power series

References

- 🕮 H. Amann & J. Escher: *Analysis I*, Birkhäuser Verlag, 2002
- 🕮 O. Forster: *Analysis 1*, Vieweg+Teubner 2008
- 🕮 K. Königsberger: *Analysis 1*, Springer Verlag 2004

Recommended prior knowledge:

School knowledge in Mathematics (gymnasiale Oberstufe)

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics
- Interdisciplinary Bachelor's Degree Programm

Analysis II			0202
Frequency	Summer Semester, annually		
Responsible for Module	Elmar Schrohe, Institute of Analysis		
Course (Semester Hours)	Lecture „Analysis II" (4 Semester Hours) Tutorial on „Analysis II" (2 Semester Hours)		
Major course assessment for acquisition of LP	Course Achievement: Tutorial Exam Performance: Exam		
Grade composition	Grade of exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	

Competences to acquire:

Basic understanding of the correct solution of mathematical and natural sciences tasks using multidimensional convergence considerations, differential and integral calculus. Secure mastery of the appropriate techniques and mathematical methods of proof. Teamwork by handling tasks in groups and discussing them in the exercise sessions.

Topics:

- Topological concepts such as metric and normed spaces, convergence, continuity, completeness, compactness;
- Differentiation of functions of several variables, total and partial differentiability, theorems on inverse functions and implicit functions, local extrema with and without constraints; vector fields and potentials; path integrals.
- Ordinary differential equations, existence, uniqueness, elementary methods of solution.

References

- 🕮 H. Amann & J. Escher: *Analysis II*, Birkhäuser Verlag, 1999
- 🕮 O. Forster: *Analysis 2*, Vieweg+Teubner, 2006
- 🕮 J. Jost: *Postmodern Analysis*, Springer Verlag 2005
- 🕮 K. Königsberger: *Analysis 2*, Springer Verlag 2004

Recommended prior knowledge:

- Linear Algebra I
- Analysis I

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics
- Interdisciplinary Bachelor's Degree Programm

Advanced Analytic Methods (Fortgeschrittene analytische Methoden)				0203
Frequency	Winter Semester, annually			
Responsible for Module	Elmar Schrohe, Institute of Analysis			
Course (Semester Hours)	Lecture „Analysis III" (4 Semester Hours) Tutorial on „Analysis III" (2 Semester Hours)			
Major course assessment for acquisition of LP	Course Achievement: Tutorial Exam Performance: Exam or oral examination			
Grade composition	Grade of exam or oral examination			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	

Competences to acquire:

Deepened understanding of analytical methods, especially in the theory of measures and integration as well as vector analysis. Ability to independently elaborate more difficult mathematical arguments on topics of the lecture and their presentation in the exercise groups.

Topics:

Elements of Lebesgue's measure theory, multidimensional Lebesgue integral along with essential theorems (monotone and dominated convergence, Fubini's theorem, transformation rule); vector calculus; Gauss' and Stokes' theorems; manifolds.

References

- 🕮 H. Amann & J. Escher: *Analysis III*
- 🕮 W. M. Boothby: *An introduction to differentiable manifolds and Riemannian geometry*, Academic Press
- 🕮 O. Forster: *Analysis 3*, Vieweg+Teubner, 2008
- 🕮 J. Jost: *Postmodern Analysis*, Springer Verlag 2005

Recommended prior knowledge:

- Analysis I + II

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Algebraic methods I (Algebraische Methoden I)			**0101**
Frequency	Winter Semester, annually		
Responsible for Module	Klaus Hulek, Institute of Algebraic Geometry		
Course (Semester Hours)	Lecture „Lineare Algebra I" (4 Semester Hours) Tutorial on „Lineare Algebra I" (2 Semester Hours)		
Major course assessment for acquisition of LP	The Course Achievement is to be performed at the tutorial to „Lineare Algebra I". Exam Performance: Exam for„Lineare Algebra I"		
Grade composition	Grade of exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	

Competences to acquire:

Basic understanding of the mathematical way of thinking and its application towards a variety of problems. Solid competence in handling systems of linear equations and the corresponding methods for solving them; sound knowledge of the underlying algebraic structures. Capability of expressing and presenting mathematical reasoning, and knowledge of adequate methods for this.

Topics:

Linear Algebra I:

- Basic properties of vector spaces (basis and dimension);
- linear maps and matrices;
- determinants;
- systems of linear equations and methods for solving them (Gauss algorithm);
- eigenvalues and eigenvectors;
- diagonalisation.

References

🕮 Lineare Algebra I: G. Fischer: *Lineare Algebra*

Recommended prior knowledge:

- School knowledge in Mathematics (gymnasiale Oberstufe)

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Key competence: Computerpraktikum					
Frequency	Winter Semester, irregular				
Responsible for Module	Matthias Schütt, Institute of Algebraic Geometry				
Course (Semester Hours)	Practical course „ Computerpraktikum" (3 Semester Hours)				
Major course assessment for acquisition of LP	Course Achievement of lecturer's choice				
Grade composition	oral or written exam				
Credit Points (ECTS): 5	**Study in Class (h):** 60		**Independent Study (h):** 90		

Competences to acquire:

Experience in appropriate use of computer algebra systems as tools for solving problems from Analysis and Linear Algebra; in particular: choice of appropriate tools, knowing and avoiding potential mistakes, knowing the limits of such systems, use of visualization tools and programming of smaller functions/methods/procedures.

Topics:

- Basic knowledge on the functioning and use of computer algebra systems
- Selected applications from Linear Algebra, e.g. solving linear systems of equations, linear maps, change of basis
- Selected applications from Analysis, e.g. zeros, differentiation, visualization of graphs of functions
- Selected applications to topics known from school: gcd, conic sections
- Small projects, e.g. solutions of polynomial equations with visualization, Chinese Remainder Theorem

References:

📖 T. Theobald, S. Iliman: *Einführung in die Computerorientierte Mathematik*, Springer Spektrum 2015

Recommended prior knowledge:

- Lineare Algebra, Analysis
- Some basic experience in the use of computers

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Algebraic methods II (Algebraische Methoden II)				**0102**
Frequency	Summer Semester, annually			
Responsible for Module	Klaus Hulek, Institute of Algebraic Geometry			
Course (Semester Hours)	Lecture „Lineare Algebra II" (4 Semester Hours) Tutorial zu „Lineare Algebra II" (2 Semester Hours)			
Major course assessment for acquisition of LP	The Course Achievement is to be performed at the tutorial Exam Performance: Exam			
Grade composition	Grade of exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	

Competences to acquire:

Extended mathematical competences regarding methods for dealing with linear structures
And a deepened understanding for algebraic methods and their relationship to geometric questions. Extended capability of expressing and presenting mathematical reasoning. Competence in applying mathematical theories.

Topics:

- Euclidean and unitary vector spaces
- orthonormalization algorithm
- orthogonal and unitary endomorphisms
- quadrics
- Jordan normal form
- multilinear algebra

References:

🕮 G. Fischer: *Lineare Algebra*

Recommended prior knowledge:

- Algebraic methods I

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Advanced algebraic methods (Fortgeschrittene algebraische Methoden)			0103
Frequency	Winter Semester, annually		
Responsible for Module	Christine Bessenrodt, Institute of Algebra, Number theory and Discrete Mathematics		
Course (Semester Hours)	Lecture „Algebra I" (4 Semester Hours) Tutorial on „Algebra I" (2 Semester Hours)		
Major course assessment for acquisition of LP	The Course Achievement is to be performed at the Tutorial Exam Performance: Exam or oral examination		
Grade composition	Grade of exam or of oral examination		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	

Competences to acquire:

Deepening of the understanding of algebraic structures; insight into the interconnectedness of mathematical fields via applications of algebraic methods in elementary number theory and towards the solution of classical geometric construction problems. Competence for independent development of advanced mathematical reasoning related to the topics of the course, and presentation in the problem classes.

Topics:

Arithmetic of the integers; groups (permutation groups, symmetry groups, group actions); rings (ideals, polynomial rings, divisibility, Euclidean rings, prime factorization); arithmetic modulo n (congruences, prime residue class groups); fields (algebraic field extensions, constructions with ruler and compass, cyclotomic fields, finite fields).

References:

- 🕮 G. Fischer: *Lehrbuch der Algebra*
- 🕮 E. Kunz: *Algebra*
- 🕮 J. Wolfart: *Einführung in die Zahlentheorie und Algebra*

Recommended prior knowledge:

- Algebraic methods I + II

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

As module „Algebra I" also for:

- Interdisciplinary Bachelor's Degree Programm
- Master's Teacher Training Course for Grammar Schools (Zweitfach)

Practical methods of mathematics (Praktische Verfahren der Mathematik)			0301
Frequency	Winter Semester and Summer Semester, annually		
Responsible for Module	Marc Steinbach, Institute of Applied Mathematics		
Course (Semester Hours)	Lecture „Numerische Mathematik I" (4 Semester Hours) Tutorial on „Numerische Mathematik I" (2 Semester Hours) Lecture „Algorithmisches Programmieren" (2 Semester Hours) Tutorial on „Algorithmisches Programmieren" (1 Semester Hours)		
Major course assessment for acquisition of LP	Course Achievement: the tutorial on „Numerische Mathematik I" Exam Performance: written exam of „Numerische Mathematik I" and practical programming exam of „Algorithmisches Programmieren"		
Grade composition	Weighted average of grades in written exam (weight 10) and in practical programming exam (weight 4)		
Credit Points (ECTS): 14	**Study in Class (h):** 210	**Independent Study (h):** 210	

Competences to acquire:

"Numerische Mathematik I": Knowledge of numerical methods for approximatively solving basic mathematical problems. Assessing the suitability of different methods. Being aware of areas of application and limitations of numerical methods.

"Algorithmic programming": Capability of using programming languages in modeling and in solving problems from various fields of mathematics and its application areas.

Topics:

Numerische Mathematik I: Interpolation of functions by polynomials and splines. Quadrature formulae for numerical integration. Direct methods for linear systems of equations: LU and Cholesky decomposition. Iterative methods for linear systems of equations: Jacobi, Gauss-Seidel, CG. Newton's method for systems of nonlinear equations. Condition of mathematical problems and stability of numerical algorithms.

Algorithmic programming:
Implementing and testlng basic numerical algorithms in a higher programming language.

References:

- P. Deuflhard, A. Hohmann: *Numerische Mathematik I*. De Gruyter.
- A. Quarteroni, R. Sacco, F. Saleri: *Numerische Mathematik I und II*,Springer-Verlag.

Recommended prior knowledge:

- Lineare Algebra I (and II) and Analysis I (and II)
- Algorithmisches Programmieren

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Stochastic Methods (Stochastische Methoden)				0401
Frequency	Summer Semester, Annually			
Responsible for Module	Sebastian Riedel, Institute of Analysis			
Course (Semester Hours)	Lecture „Mathematische Stochastik I" (4 Semester Hours) Tutorial „Mathematische Stochastik I" (2 Semester Hours)			
Major course assessment for acquisition of LP	Course Achievement: Tutorial Exam Performance: Exam			
Grade composition	Grade of exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	

Competences to acquire:

Basic knowledge of combinatorics, probability, and statistics. Students should understand elementary stochastic models and techniques, and be able to formulate, analyse and solve simple problems involving randomness.

Topics:
The lecture provides an introduction to probability and statistics.

Topics include:

- Combinatorics
- Axioms of probability theory
- Conditional Probability and independence
- Random variables and their distributions
- Expectation and variance
- Modes of convergence
- Limit theorems for sums of independent random variables
- Elementary statistics

References:

- 🕮 Georgii, H.: *Stochastik*, de Gruyter
- 🕮 Jacod, J. & Protter. P: *Probability Essentials*, Springer
- 🕮 Krengel, U.: *Einführung in die Wahrscheinlichkeitstheorie und Statistik*

Recommended prior knowledge:

- Lineare Algebra I (and II)
- Analysis I (and II)

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics
- Interdisciplinary Bachelor's Degree Programm (Erstfach)
- Master's Teacher Training Course for Grammar Schools (Zweitfach)

Proseminar			0001
Frequency	Winter Semester and Summer Semester, annual		
Responsible for Module	Dean of Studies Office		
Course (Semester Hours)	Proseminar (2 Semester Hours)		
Major course assessment for acquisition of LP	Seminar performance with written composition		
Grade composition	Grade of seminar performance		
Credit Points (ECTS): 5	**Study in Class (h):** 30	**Independent Study (h):** 120	

Competences to acquire:

Written description of a concrete mathematical topic, its surrounding and if so its historic background. Oral presentation of results. Ability to discuss with other participants. Use of suitable media (black board, PC, projector) for preparation and presentation.

Topics:
variable, depends on topic of proseminar.

References:
variable, depends on topic of proseminar.

Recommended prior knowledge:
Analytic and algebraic methods

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor's Programme Mathematics

Compulsory elective modules Bachelor

Basics Bachelor Algebra, number theory, discrete mathematics (Grundlagen Bachelor Algebra, Zahlentheorie, Diskrete Mathematik)			**0104**
Responsible for Module	Christine Bessenrodt, Institute of Algebra, Number Theory and Discrete Mathematics		
Course	Lecture with tutorial (4+2): **Algebra II** or **Discrete mathematics** (see appendix) Alternative courses can be assigned to this module in the university calendar.		
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Extended knowledge in an area of algebra or basic knowledge in number theory; understanding of relational and operational structures and their algebraic treatment. Knowledge of basic functions in combinatorics, including methods and applications. Solid grasp of mathmatical argumentation and methodology. Students are able to solve concrete problems using suitable methods.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor's Programme Mathematics			

Basics Bachelor Analysis (Grundlagen Bachelor Analysis)			**0204**
Responsible for Module	Wolfram Bauer, Institute of Analysis		
Course	Lecture with tutorial (4+2): **Complex analysis** or **Manifolds** (see appendix) Alternative courses can be assigned to this module in the university calendar.		
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Deepened acquisition of analytic thinking based on topics in complex analysis, topology and functional analysis. Sound knowledge and reliable command of mathematical thinking and argumentation. Students gain the ability to solve concrete tasks by applying suitable methods.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor's Programme Mathematics			

Basics Bachelor Geometry (Grundlagen Bachelor Geometrie)			0501
Responsible for Module	Matthias Schütt, Institute of Algebraic Geometry		
Course	Lecture with tutorial (4+2): **Algebra II** or **Manifolds** (see appendix) Alternative courses can be assigned to this module in the university calendar.		
Major course assessment for acquisition of LP	Course Achievement of lecturer's choice Examination: oral or written exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Understanding of geometric constructions, structures in space and the interplay of algebraic, geometric, analytic, and topological methods. Solid command of mathematical reasoning. Students are able to solve explicit problems using appropriate methods.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor's Programme Mathematics			

Basics Bachelor Numerics (Grundlagen Bachelor Numerik)			0302
Responsible for Module	Sven Beuchler, Institute of Applied Mathematics		
Course	Lecture and tutorial (4+2): **Numerical Mathematics II** (see appendix) Alternative courses can be assigned to this module in the university calendar.		
Major course assessment for acquisition of LP	Course Achievement: at the instructor's option Exam Performance: oral or written exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Knowledge of numerical methods for approximately solving demanding mathematical problems. Assessing the suitability of different methods depending on the circumstances and on the limitations of numerical methods. Proficiency in the mathematical way of thinking and argueing. Students are capable of solving concrete problems by applying suitable methods.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor's Programme Mathematics			

Basics Bachelor Stochastics (Grundlagen Bachelor Stochastik)				0402
Responsible for Module	Sebastian Riedel, Institute of Analysis			
Course	Lecture with tutorial (4+2): **Probability and Statistics II** (see appendix) Alternative courses can be assigned for this module in university calendar.			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: Probablility, Statistics and their Applications. Students understand key mathematical concepts and arguments, and can solve exercises using appropriate methods.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Bachelor's Programme Mathematics				

Specialization Bachelor Algebra, number theory, discrete mathematics (Spezialisierung Bachelor Algebra, Zahlentheorie, Diskrete Mathematik)				0105
Responsible for Module	Ulrich Derenthal, Institute of Algebra, Number Theory and Discrete Mathematics			
Course	Lectures that belong to this module can be found in appendix. Further courses can be assigned for this module in the university calendar.			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: Advanced understanding of algebraic arguments and methods, good knowledge of two areas of algebra or number theory. Advanced knowledge of the theory of relational and operational structures and their applications, for instance in coding theory, applied algebra or algebraic combinatorics. The students have a good grasp of the logical structures of the subject; they are able to derive the key results and produce the most important examples. They can analyse problems from the area and identify as well as apply methods suitable for solving them. The students are capable of explaining and justifying their approach.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Bachelor's Programme Mathematics				

Specialization Bachelor Analysis (Spezialisierung Bachelor Analysis)				0205
Responsible for Module	Wolfram Bauer, Institut für Analysis			
Course	Lectures that belong to this module can be found in appendix. Further courses can be assigned for this module in the university calendar.			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: Deepened understanding of general analytic, topological and complex analytical methods. Knowledge of qualitative methods for the investigation and solution of ordinary and partial differential equations. The students understand the logical structure of the area, they are able to deduce the most important theorems and they are aware of prominent examples. Students are capable to analyze problems of the area and to identify and apply suitable methods for their solution. They can justify and clearly explain their approach.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Bachelor's Programme Mathematics				

Specialization Bachelor Geometry (Spezialisierung Bachelor Geometrie)				0502
Responsible for Module	Knut Smoczyk, Institute of Differential Geometry			
Course	Lectures that belong to this module can be found in appendix. Further courses can be assigned for this module in the university calendar .			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: In depth knowledge of the relations between algebraic, geometric, analytic and topological structures connecting geometric intuition and axiomatic foundations of the field. Students are familiar with the logical structure of the field, are able to deduce the most important statements and know illustrating examples. Students are able to analyze problems in the subject area and to indentify and apply appropriate methods to tackle given problems. The know how to justify their approach and explain it clearly.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Bachelor's Programme Mathematics				

Specialization Bachelor Numerics (Spezialisierung Bachelor Numerik)			0303
Responsible for Module	Sven Beuchler, Institute of Applied Mathematics		
Course	Lectures in the appendix that belong to this module. Further courses can be assigned to this module in the university calendar.		
Major course assessment for acquisition of LP	Course Achievement: at the instructor's option Exam Performance: oral exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Deepened knowledge of numerical methods for approximately solving concrete mathematical problems. Students have comprehended the logical structure of the area. They are capable of deriving the most important facts and know prominent examples. Students are capable of analyzing problems in the area and to identify and apply suitable solution methods. They can substantiate their approach and explain it comprehensively.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor programme Mathematik			

Specialization Bachelor Stochastics (Spezialisierung Bachelor Stochastik)			0403
Responsible for Module	Sebastian Riedel, Institute of Analysis		
Course	Lectures that belong to this module can be found in appendix. Further courses can be assignedfor this module In the university calendar.		
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: Extended knowledge of probability, statistics and their applications. Students understand the key concepts and methods of the field, are able to prove the main results and know important examples and applications. Students can analyse problems, can identify suitable methods for their solution and are able to apply them appropriately. They can justify their solutions strategies and explain them clearly.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Bachelor programme Mathematics			

Seminar			0950
Frequency	Start all year long possible		
Responsible for Module	Institutes of mathematics		
Course (Semester Hours)	Seminar (2 SH)		
Major course assessment for acquisition of LP	Presentation with written elaboration		
Grade composition	Grade of seminar participation		
Credit Points (ECTS): 5	**Study in Class (h)** 30	**Independent Study (h):** 120	

Competences to acquire:

Ability of familiarization in a mathematical topic under guidance. Knowledge acquisition from partly English speaking books und professional journals. Academic writing skills. Presentation skills and use of media. Ability to discuss mathematical topics.

Topics:
Introduction to academic research and writing

- focused academic topic of mathematics after agreement with supervising tutor,
- use of specialist literature/ database;
- mathematic inscribing;
- presentation skills and use of media;

With this seminar the introduction of the bachelor thesis is getting prepared.

Referencesvariable, depends on topics of Seminars.

Recommended prior knowledge: variable, depends on topics of Seminars.
In-depth specialisation for a mathematical topic as part of a seminar

Where applicable entrance requirements and/or restricted number of participants:

Applicability:

- Bachelor programme Mathematik

Bachelorthesis	0901
Frequency	Start all year long possible
Responsible for Module	Dean of Studies Office
Course (Semester Hours)	Project „Bachelorarbeit" (13 LP)
Major course assessment for acquisition of LP	Exam Performance: Bachelorthesis
Grade composition	Grade of Bachelorthesis
Credit Points (ECTS): 13	**Study in Class (h) & Independent Study (h):** 390

Competences to acquire:

Ability to independently work in a research topic. Knowledge acquisition from partly english speaking books and professional journals. Ability for realistic planning, timing and for conducting an academic project with the help of academic methods under guidance. Academic writing skills. Ability to discuss own thesis and self-reflection skills.

Topics:
Introduction into academic research, independent projektwork under guidance, academic writing

- a focused academic topic of mathematics after agreement with supervising tutor,
- use of specialist literature/Database;
- mathematic inscribing;
- Presentation skills and use of media;
- Planning of Bachelorthesis.

References

Recommended prior knowledge: Deepening of a mathematic topic in context of a seminar

Where applicable entrance requirements and/or restricted number of participants: minimum of 120 LP

Applicability:

- Bachelor's Programme Mathematics

Examination procedure:
The topic of the bachelor thesis will be fixed by the examiner after consultation with examination candidate. The Issuing is to be put on record and the examination candidate as well as the Studiendekanat must be informed in written form. With the Issuing of the topic the examiner will be booked. During the making of thesis the student will be looked after by the examiner.

Modules of Master Mathematics

Pure Mathematics 1 (Reine Mathematik 1)			0004
Responsible for Module	Matthias Schütt, Institute of Algebraic Geometry		
Course (Semester Hours)	A lecture with tutorial (4 + 2)		
Major course assessment for acquisition of LP	Course Achievement of lecturer's choice Examination: oral or written exam		
Grade composition	Grade of oral exam or written exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Master programme mathematics			

Pure Mathematics 2 (Reine Mathematik 2)			0005
Responsible for Module	Matthias Schütt, Institute of Algebraic Geometry		
Course (Semester Hours)	A lecture with tutorial (4 + 2)		
Major course assessment for acquisition of LP	Course Achievement of lecturer's choice Examination: oral or written exam		
Grade composition	Grade of oral exam or written exam		
Credit Points (ECTS): 10	**Study in Class (h):** 90	**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Master programme mathematics			

Applied Mathematics (Angewandte Mathematik)				0056
Responsible for Module	Christoph Walker, Institute of Applied Mathematics			
Course (Semester Hours)	A lecture with tutorial (4 + 2)			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam			
Grade composition	Grade of oral exam or written exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Master programme mathematics				

Applied Mathematics 2 (Angewandte Mathematik 2)				0057
Responsible for Module	Christoph Walker, Institute of Applied Mathematics			
Course (Semester Hours)	A lecture with tutorial (4 + 2)			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam			
Grade composition	Grade of oral exam or written exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Master programme mathematics				

Elective module 1				0004
Responsible for Module	Dean of Studies Office			
Course (Semester Hours)	A lecture with tutorial (4 + 2)			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam			
Grade composition	Grade of oral exam or written exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Master programme mathematics				

Elective module 2				0004
Responsible for Module	Dean of Studies Office			
Course (Semester Hours)	A lecture with tutorial (4 + 2)			
Major course assessment for acquisition of LP	Course Achievement: at university lecturer's option Exam Performance: oral examination or Exam			
Grade composition	Grade of oral exam or written exam			
Credit Points (ECTS): 10	**Study in Class (h):** 90		**Independent Study (h):** 210	
Competences to acquire: The students widen their mathematic knowledge. They gain an insight into a chosen field of mathematics. They aquire the skill to deal competently with problems of that particular field.				
Where applicable entrance requirements and/or restricted number of participants:				
Applicability: • Master programme mathematics				

Seminar			0060
Frequency	Every semester		
Responsible for Module	Dean of Studies Office		
Course (Semester Hours)	Seminar (2 Semester Hours)		
Major course assessment for acquisition of LP	Exam Performance: Seminar performance		
Grade composition	Grade of Seminar performance		
Credit Points (ECTS): 5	**Study in Class (h):** 30	**Independent Study (h):** 30	
Competences to acquire: The students have the ability to independently work in a research topic. This contains especially the independent research of specialist literature for a given topic and the knowledge acquisition from specialised books and articels. Students can recognize connections in regard to content. They acquire knowledge of the English langugage to be able to study relevant specialist literature. The students are in the position to structure a complex topic of the modern mathematic in a suitable way and to understandable recite. They are capable of having an academic discussion and of self-reflecting. A continuous participation is required to achieve the Learning Outcomes of the seminar.			
Topics: Depends on lecture. Current topics of different mathematic fields.			
Where applicable entrance requirements and/or restricted number of participants:			
Applicability: • Master programme mathematics			

Key Skills (Schlüsselkompetenzen)			0061
Frequency	Every semester		
Responsible for Module	Dean of Studies Office		
Course (Semester Hours)	Two seminars (each 2 **Semester Hours**)		
Major course assessment for acquisition of LP	Exam Performance: Seminar performance in every seminar		
Grade composition	Overall average grade of both seminar performances		
Credit Points (ECTS): 10	**Study in Class (h):** 60	**Independent Study (h):** 240	
Competences to acquire: The students have the ability to independently work in a research topic. This contains especially the independent research of specialist literature for a given topic and the knowledge acquisition from specialised books and articels. Students can recognize connections in regard to content. They acquire knowledge of the English langugage to be able to study relevant specialist literature. The students are in the position to structure a complex topic of the modern mathematic in a suitable way and to understandable recite. They are capable of having an academic discussion and of self-reflecting.			
Topics: Depends on lecture. Current topics of different mathematic fields.			

Where applicable entrance requirements and/or restricted number of participants:
Applicability: • Master programme mathematics

Masterthesis (Masterarbeit)	0902
Frequency	Start all year long possible
Responsible for Module	Dean of Studies Office
Course (Semester Hours)	Projekt „Masterarbeit"
Major course assessment for acquisition of LP	Course Achievement: Presentation Exam Performance: Masterthesis
Grade composition	Grade of master thesis (Overall average grade of the two examiner opinions)
Credit Points (ECTS): 30	**Arbeitsaufwand(h):** 900

Competences to acquire:

The students can independently work in a research. They are able to structure, to prepare and to undertake scientific projects under guidance. They procure an overview over the recent literature and they analyse and solve complex problems. The students can hold critical discussions about their own and external research results and interact constructive with questions and critics. They have the competence to pose self-dependent mathematical facts.

Topics:

Introduction into academic research, independent projektwork under guidance, academic writing.

- a current academic topic of mathematics after agreement with supervising tutor,
- mathematic inscribing;
- current specialist literature/Database .

Where applicable entrance requirements and/or restricted number of participants: minimum 75 LP, Completion of the module key skills

Applicability:

- Master programme mathematics

Examination procedure:
The topic of the master thesis will be fixed by the first examiner after consultation with examination candidate. The Issuing is to be put on record and the examination candidate as well as the Studiendekanat must be informed in written form. With the Issuing of the topic the first examiner and second examiner will be booked. During the making of thesis the student will be looked after by the first examiner.

Appendix: Lectures for Bachelor and Master degree programme:

Below lectures will be described that can be taken for compulsory elective modules of the Bachelorstudy and for Mastermodules.

The Lectures in **Appendix A** can be taken for the Basics modules Bachelor and in parts for the Specialization modules Bachelor. The lectures in **Appendix B** can be taken for the Mastermodules and in parts for the Specialization modules Bachelor.

The letters **P** and **A** in the upper right-hand corner of the lecture descriptions define the assignment of the lecture to the **P**ure (German: Reinen) mathematics or **A**pplied (German: Angewandten) mathematics.

Those *** seen at the Semesterweekhours (Short: **Semester Hours**, in german: **S**emester**w**ochenstundenzahl) and Credit Points mean that the course is offered depending on overall supply of that particular Semester as lecture with 4+2 Semester Hours/ 10 CP or with 2+1 Semester Hours/ 5 CP or if applicable as seminar.
More detailed information can be found in the university calendar.

Those used abbreviation mean:
IAG „Institute of Algebraic Geometry";
IAZD „Institut für Algebra, Number Theory and Discrete Mathematics";
IDG „Institute of Differential Geometry";
IfAM „Institute of Applied Mathematics";
IfMS „Institute of Probaility and Statistics".

A. Lectures for basics modules Bachelor

Algebra II			**P**
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD and IAG
Frequency: annual, Summer Semester			
Topics: • Field theory (structure of finitely generated field extensions), Galois theory, solvability of algebraic equations • Modules and algebras (Noetherian rings, Hilbert's Basis Theorem, integral ring extensions, modules over principal ideal rings, Artin-Wedderburn Theorem, tensor products) **References** 🕮 J.C. Jantzen, J. Schwermer: *Algebra*, Springer 2006 **Recommended prior knowledge:** Algebra I			
Module affiliation: • Basics Bachelor Algebra, Number theory, Discrete mathematics • Basics Bachelor Geometry • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Specialization Bachelor Geometry			

Discrete Mathematics (Diskrete Mathematik)			**P**
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: annual, Summer Semester			
Topics: • Enumerations and Combinatorics • Generating functions • Theory of graphs • Error-correcting codes • Algebraic combinatorics or oriented matroids **References** 🕮 M. Aigner: *Diskrete Mathematik* 🕮 Harary: *Graphentheorie* 🕮 A. Björner et al.: *Oriented Matroids* **Recommended prior knowledge:** Algebra I			
Module affiliation: • Basics Bachelor Algebra, Number theory, Discrete mathematics			

Manifolds (Mannigfaltigkeiten)			**P**
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: annually, Summer Semester			

Topics:

- Topological and differentiable manifolds
- Tangent and cotangent spaces and bundles
- Differential forms, vector fields and flows
- Lie derivatives, Lie groups and algebras
- Integration on manifolds, theorems of Frobenius and Stokes
- Vector bundles and tensor fields
- Connections on vector bundles, parallel transport, covariant derivatives and holonomy

References:

- Boothby, William M., *An introduction to differentiable manifolds and Riemannian geometry,* Academic Press, Inc., Orlando, FL, 1986
- Milnor: *Topology from the Differentiable Viewpoint*, Princeton University Press
- Lee, John M., Introduction to smooth manifolds, Graduate Texts in Mathematics 218, Springer-Verlag, New York
- Warner, Frank W., Foundations of differentiable manifolds and Lie groups, Graduate Texts in Mathematics 94, Springer-Verlag New York-Berlin

Recommended prior knowledge: Analysis III

Module affiliation:

- Basic Bachelor Analysis
- Basic Bachelor Geometry
- Specialization Bachelor Analysis
- Specialization Bachelor Geometry

Classic Differential Geometry (Klassische Differentialgeometrie)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: annual, Winter Semester			

Topics:

- Regular submanifolds of arbitrary codimension
- Tangent spaces
- First fundamental form, length of a rectifiable curve, induced measure on regular submanifolds
- Second fundamental form, Gauß map, Weingarten map, principal curvatures, mean curvature, Gauß curvature
- Covariant derivatives on tangent and normal bundles
- Inner geometry
- Equations of Gauß (Theorema Egregium), Codazzi—Mainardi and Ricci
- Gobal theory of curves and surfaces: isoperimetric inequality, Umlaufsatz, theorems of Fenchel and Gauß-Bonnet

References:

- do Carmo, Manfredo P., *Differentialgeometrie von Kurven und Flächen,* Vieweg Studium: Aufbaukurs Mathematik, 1983
- Kühnel, Wolfgang: *Differentialgeometrie: Kurven - Flächen - Mannigfaltigkeiten,* Aufbaukurs Mathematik, Springer Spektrum

Recommended prior knowledge: Analysis I-II, Linear Algebra I

Module affiliation:

- Basic Bachelor Analysis
- Basic Bachelor Geometry
- Specialization Bachelor Analysis
- Specialization Bachelor Geometry

Complex Analysis (Funktionentheorie)			P
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Institute for Analysis
Frequency: annual, Summer Semester			
Topics: • Holomorphic und meromorphic functions • Cauchy's integral theorem • Local mapping properties of holomorphic functions • Residue theorem • Riemann mapping theorem **References:** • L. Ahlfors: *Complex Analysis*, *McGraw-Hill, New York,* 1978. • J. Conway: *Functions of one Complex Variable*, Springer-Verlag, New York 1995. • W. Rudin: *Real and Complex Analysis*,*McGraw-Hill, New York,* 1987. **Recommended prior knowledge:** Analysis I-III			
Module affiliation: • Basics Bachelor Analysis • Specialization Bachelor Analysis			

Numerical Mathematics II (Numerische Mathematik II)			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfAM
Frequency: annually, Summer Semester			
Topics: Numerical methods for eigenvalue problems: inverse Iteration, QR algorithm, Lanczos method. Initial value problems for ordinary differential equations: Runge-Kutta methods, adaptive stepsize control, stiff differential equations. **References:** 🕮 P. Deuflhard, V. Bornemann: *Scientific Computing with Ordinary Differential Equations*, Springer-Verlag. 🕮 A. Quarteroni, R. Sacco, F. Saleri: *NumerischeMathematik I and II*, Springer-Verlag. **Recommended prior knowledge:** Numerical Mathematics I			
Module affiliation: • Basics Bachelor Numerics • Specialization Bachelor Numerics **For an in-depth module it can be combined with:** • all lectures for applied mathematics or alternative lectures in agreement with examiner			

Probability and Statistics II (Mathematische Stochastik II)			**A**
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Sebastian Riedel, Institute of Analysis
Frequency: annually, Winter Semester			
Topics: • Measure Thoery • Limit Theorems • Martingales • Statistics: Estimators, Confidence Sets, Statistical Tests **References:** • P. Billingsley: *Probability and Measure*, Wiley, New York, 1995. • L. Rüschendorf: Mathematische Statistik, Springer, Berlin, 2014. • Georgii, H.: *Stochastik*, de Gruyter • Jacod, J. & Protter. P: *Probability Essentials*, Springer **Recommended prior knowledge:** Probability and Statistics I			
Module affiliation: • Basics Bachelor Stochastics • Specialization Bachelor Stochastics			

Algebraic Number Theory I (Algebraische Zahlentheorie I)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Winter Semester			
Topics: Introduction to algebraic number theory, detailed treatment of the following topics: • arithmetic of algebraic number fields • zeta- and L-series **References** 🕮 Neukirch: *Algebraische Zahlentheorie* **Recommended prior knowledge:** Algebra II			

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective module master Mathematics

B. Lectures for master modules

B.1 Algebra, Number theory and Discrete mathematics:

Algebraic Combinatorics (Algebraische Kombinatorik)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: irregular			

Topics:
In Algebraic Combinatorics, on the one hand methods from algebra, in particular group theory and representation theory, are applied towards combinatorial problems, on the other hand, combinatorial approaches are fruitfully employed in algebraic contexts. Topics in this area of interaction are in particular concerned with:
- Young tableaux and partitions
- symmetric functions
- weighted enumeration under group actions
- symmetric groups

References:
- 🕮 W. Fulton: *Young Tableaux*
- 🕮 R. Stanley: *Enumerative Combinatorics II*
- 🕮 R. Stanley: *Algebraic Combinatorics*

Recommended prior knowledge: Algebra I, Basics of combinatorics

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective Modules of Master Mathematics

For an in-depth module it can be combined with e.g.: Enumerative combinatorics, Representation theory

Algebraic Number Theory II (Algebraische Zahlentheorie II)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Summer Semester			

Topics:
Advanced treatment of algebraic number theory via one or more of the following topics:

- p-adic number fields
- class field theory
- algorithmic problems

References

- 🕮 Neukirch: *Algebraische Zahlentheorie*
- 🕮 Cohen: *Topics in Computational Algebraic Number Theory*

Recommended prior knowledge: Algebraic Number Theory I

Module affiliation:

- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective module master Mathematics

Algebras and their representations (Algebren und ihre Darstellungen)			**P**
Type of course	**Semester Hours**	**Credit Points (ECTS):**	**Responsibility**
Bachelor and Master	4+2	10	IAZD
Frequency: irregular			

Topics:

An example-driven introduction to the representation theory of finite-dimensional algebras and to representations of quivers. Topics covered include:

- Representations of finite-dimensional algebras: indecomposable modules and the Krull-Schmidt theorem; representation type; projective and injective modules; introduction to the language of categories and functors; Ext-functors.
- Representations of quivers: hereditary algebras; quadratic forms associated to quivers; reflection functors; Gabriel's theorem on the representation type of quivers; Dynkin diagrams.

References:

- 🕮 K. Erdmann, T. Holm: *Algebras and Representation Theory,* Springer Undergraduate Mathematics Series. Springer, 2018.
- 🕮 Assem, D. Simson, A. Skowronski: *Elements of the Representation theory of Associative Algebras 1: Techniques of Representation Theory*, London Mathematical Society Student Texts 65, Cambridge University Press,2006.

Recommended prior knowledge: (Einführung in die) Darstellungstheorie (A first course on representation theory.)

Module affiliation:

- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective module master Mathematics

Analytic Number Theory I (Analytische Zahlentheorie I)			**P**
Type of course	**Semester Hours**	**Credit Points (ECTS):**	**Responsibility**

Bachelor and Master	2+2	5	IAZD
Frequency: every other year, Winter Semester			
Topics: Introduction to analytic number theory, in particular: Arithmetic functions, Dirichlet series, Perron's formula, analytic properties of the zeta function, prime number theorem, introduction to sieve methods **References** 📖 J. Brüdern, Einführung in die analytische Zahlentheorie, Springer-Verlag, 1995. 📖 H. Davenport, Multiplicative Number Theory, Springer-Verlag, 2000. 📖 H.L. Montgomery and R.C.Vaughan, Multiplicative Number Theory, I. Classical Theory, Cambridge University Press, 2007. **Recommended prior knowledge:** Complex Analysis			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics In each case it can be combined with lectures of Algebra, Number theory, Discrete mathematics (in particular: Analytic Number theory II) or Analysis or alternative lectures in agreement with examiner.			

Analytic Number Theory II (Analytische Zahlentheorie II)			**P**
Type of course	**Semester Hours**	**Credit Points (ECTS):**	**Responsibility**

Bachelor and Master	2+2	5	IAZD
Frequency: every other year, Summer Semester			
Topics: Advanced treatment of analytic number theory. Possible topics include the the Bombieri-Vinogradov theorem, Tauberian theorems, mean values and distributions of additive and multiplicative functions, applications of the Selberg-Delange and of the saddle point method. **References** 📖 J. Brüdern, Einführung in die analytische Zahlentheorie, Springer-Verlag, 1995. 📖 H. Davenport, Multiplicative Number Theory, Springer-Verlag, 2000. 📖 H.L. Montgomery and R.C.Vaughan, Multiplicative Number Theory, I. Classical Theory, Cambridge University Press, 2007. 📖 G. Tenenbaum, Introduction to analytic and probabilistic number theory, Cambridge University Press, 1995. **Recommended prior knowledge:** Complex Analysis, Analytic Number Theory I In each case it can be combined with lectures of Algebra, Number theory, Discrete mathematics (in particular: Analytic Number theory I) or Analysis or alternative lectures in agreement with examiner			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics			

Arithmetic Geometry I (Arithmetische Geometrie I)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Winter Semester			
Topics: Introductory course in arithmetic geometry, based on one of the following topics: • curves over finite fields • elliptic curves **References** 📖 Lorenzini: *An Invitation to Arithmetic Geometry* 📖 Silverman: *The Arithmetic of Elliptic Curves* **Recommended prior knowledge:** Algebra II			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics			

Arithmetic Geometry II (Arithmetische Geometrie II)			**P**
Type of course Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Summer Semester			
Topics: Advanced course on one of the following topics: • modular forms and modularity • diophantine geometry • arithmetic fundamental groups **References** 🕮 Diamond, Shurman: *A first course in modular forms* 🕮 Hindry, Silverman: *Diophantine Geometry* **Recommended prior knowledge:** Arithmetic Geometry I or Algebraic Geometry			
Module affiliation: • Elective module master Mathematics			

Representation theory (Darstellungstheorie)			**P**
Type of course Bachelor und Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Winter Semester			
Topics: The course provides an introduction into the theory of semisimple (associative) algebras, with a focus on group algebras and characters. Central topics are • Modules and representations of groups and algebras (simple and semisimple modules, composition series, indecomposable modules, semisimple algebras, Jacobson radical, Artin-Wedderburn decomposition, Maschke's Theorem) • Fundamentals of the character theory of finite groups (irreducible characters, inner product for characters, orthogonality relations, computation of character tables, tensor products and products of characters) **References** 🕮 G. James, M. Liebeck: *Representations and Characters of Groups*, Cambridge University Press, 2001 (2nd Edition). 🕮 J. Jantzen, J. Schwermer: *Algebra* **Recommended prior knowledge:** Algebra I is necessary, Algebra II is desirable			

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective module master Mathematics

Representation theory of symmetric groups (Darstellungstheorie symmetrischer Gruppen)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD

Frequency: every other year, Winter Semester

Topics:
Topics both from ordinary and modular representation theory of symmetric groups are covered, in particular:
- classification and properties of the irreducible characters of the symmetric groups
- symmetric functions
- permutation modules and Specht modules
- representations in positive characteristic: simple modules and the decomposition of Specht modules

References
- 🕮 G. James, A. Kerber: *The Representation Theory of the Symmetric Group*
- 🕮 B. Sagan: *The Symmetric Group*
- 🕮 R. Stanley: *Enumerative Combinatorics II*

Recommended prior knowledge: Representation theory is necessary, Groups and their representations is desirable

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics
- Elective module master Mathematics

Enumerative combinatorics (Enumerative Kombinatorik)			**P**
Type of course Bachelor	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD

Frequency: irregular

Topics:
- generating functions for weighted combinatorial objects
- bijective combinatorics
- constructive combinatorics

References
- 🕮 R. Stanley: *Enumerative Combinatorics I, II*
- 🕮 D. Stanton, D. White: *Constructive Combinatorics*

Recommended prior knowledge: Algebra I

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics

Groups and their representations (Gruppen und ihre Darstellungen)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: every other year, Summer Semester			
Topics: Structure of finite groups and their ordinary and modular representations; in particular, the topics are: • continuation of the theory of complex characters: induced characters, Frobenius reciprocity, Mackey's Theorem, character degrees and character values • structure of groups: Sylow's theorems, solvable groups, Burnside's p^aq^b Theorem • modular representation theory: indecomposable representations, projective and simple modules, induced representations, decomposition numbers, blocks of representations **References** 🕮 G. James, M. Liebeck: *Representations and Characters of Groups* 🕮 H. Nagao, Y. Tsushima: *Representations of finite groups* **Recommended prior knowledge:** Algebra II, Representation theory			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics			

Homological Algebra (Homologische Algebra)			**P**
Type of course Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: irregular			
Topics: Exact sequences; groups of homomorphisms; tensor products of modules over rings; projective, injective and flat modules; categories and functors; chain complexes and cochain complexes; homology and cohomology of complexes; projective and injective resolutions; derived functors; Ext-functors; Tor-functors and applications. **References** 🕮 Rotman: *An Introduction to Homological Algebra* (Second Edition) 🕮 Weibel: *An introduction to homological algebra* **Recommended prior knowledge:** Algebra II			

Module affiliation:
- Elective module master Mathematics

Topology (Topologie)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAZD
Frequency: irregular			

Topics:

- Topological spaces, continuous maps
- connected spaces, separation axioms
- compactness
- constructions (products, quotients)
- homotopy of maps
- fundamental groups
- coverings

References:
- 🕮 K. Jänich: *Topologie*
- 🕮 G. Laures, M. Szymik: *Grundkurs Topologie*
- 🕮 B.v. Querenburg: *Mengentheoretische Topologie*
- 🕮 R. Stöcker, H. Zieschang: *Algebraische Topologie*

Recommended prior knowledge: Analysis I and II

Module affiliation:
- Specialization Bachelor Algebra, Number theory, Discrete mathematics

B.2 Algebraic Geometry

Algebraic Surfaces (Algebraische Flächen)			**P**
Type of course Master and GRK	**Semester Hours** ***	**Credit Points (ECTS):** ***	**Responsibility** IAG
Frequency: every 2 to 3 years, Summer Semester			
Topics: • birational maps betweem surfaces • intersecton theory • Kodaira classification **References:** 🕮 Beauville: *Complex algebraic surfaces*, CUP, 1983. **Recommended prior knowledge:** Algebraic Geometry, helpful: Algebra II			
Module affiliation: • Elective module master Mathematics			

Algebraic Geometry I (Algebraische Geometrie I)			**P**
Type of course Bachelor, Master and GRK	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: annual, Winter Semester			
Topics: • affine and projective varieties • morphisms and rational maps • dimension, degree, smoothness, singularities • sheaves and schemes **Recommended prior knowledge:** Algebra I; helpful: Algebra II, Complex analysis			
Module affiliation: • Specialization Bachelor Geometry • Elective module master Mathematics			

Algebraic Geometry II (Algebraische Geometrie II)			**P**
Type of course Bachelor, Master and GRK	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: annual, Summer Semester			
Topics: Key terms of modern algebraic geometry (schemes, sheaf cohomology, divisors) are introduced. Applications for the classification of algebraic curves and surfaces are presented.			
Module affiliation: • Specialization Bachelor Geometry • Elective module master Mathematics			

Algebraic topology (Algebraische Topologie)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: irregular			
Topics: • homology theory, singular homology, cell complex • cohomology theory • Poincaré duality **Recommended prior knowledge:** Algebra I, helpful: Algebra II			
Module affiliation: • Specialization Bachelor Geometry • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics			

Algorithmic Commutative Algebra (Algorithmische Kommutative Algebra)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: irregular			
Topics: • Polynomial systems • Groebner Bases, syzygies, free resolutions • Dimension, integral closure, primary decomposition **Recommended prior knowledge:** Algebra I; helpful: Algebra II			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Specialization Bachelor Geometry • Elective module master Mathematics			

Coding theory (Codierungstheorie)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2 (2+1)	**Credit Points (ECTS):** 10 (5)	**Responsibility** IAG
Frequency: irregular			
Topics: • linear codes • special good codes • decoding • cyclic codes **Recommended prior knowledge:** Algebra I			
Module affiliation: • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Specialization Bachelor Geometry • Elective module master Mathematics			

Plane Algebraic Curves (Ebene Algebraische Kurven)			**P**
Type of course Bachelor and Master, also Teaching profession	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IAG
Frequency: irregular			
Topics: • Intersection of plane curves, Bezout theorem • Tangents, points of inflection, smoothness and singularities • Polar curve, Hesse curve, dual curve, Plücker formulae **Recommended prior knowledge:** Algebra I			
Module affiliation: • Specialization Bachelor Geometry • Elective module master Mathematics			

Lattices and Codes (Gitter und Codes)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: irregular			
Topics: • Integral lattices • Linear codes • Weight enumerators and theta functions **References:** 🕮 W.Ebeling: *Lattices and Codes*, 3. Auflage, Springer, 2013. **Recommended prior knowledge:** Algebra I, Complex analysis			
Module affiliation: • Specialization Bachelor Geometry • Specialization Bachelor Algebra, Number theory, Discrete mathematics • Elective module master Mathematics			

Moduli Spaces (Modulräume)			**P**
Type of course Master and GRK	**Semester Hours** ***	**Credit Points (ECTS):** ***	**Responsibility** IAG
Frequency: every 2 to 3 years, Summer Semester			
Topics: • Moduli problems, coarse and fine moduli spaces • Construction of moduli spaces, geometric invariant theory • Examples of moduli spaces, in particular moduli of curves **Recommended prior knowledge:** Algebra II, Algebraic Geometry			
Module affiliation: • Elective module master Mathematics			

Singularity (Singularitäten)			**P**
Type of course Master and GRK	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IAG
Frequency: irregular			
Topics: • Holomorphic functions of several variables • Analytic set germs • Unfoldings and deformations • Classification of singularities **References:** 🕮 W. Ebeling: *Funktionentheorie, Differentialtopologie und Singularitäten*, Vieweg, 2001. **Recommended prior knowledge:** Algebra II			
Module affiliation: • Elective module master Mathematics			

B.3 Analysis

Functional Analysis (Funktionalanalysis)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Bauer, Escher, Schrohe, Walker
Frequency: annual			
Topics: • Baire's theorem • Hahn-Banach theorem, convexity • Principle of uniform boundedness • Open mapping theorem, closed graph theorem • Linear operators in Hilbert space • Compact operators • Unbounded operators **Recommended prior knowledge:** Analysis I-III, Linear Algebra I			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematik			

Index theory (Indextheorie)			**P**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Schrohe
Frequency: irregular			
Topics: • Fredholm operators in Banach spaces • Spectral theory of compact operators and the Fredholm alternative • Components of the Fredholm operators in Hilbert spaces • Toeplitz operators and their index • Computation of the index via the operator trace • Pseudodifferential operators • Fedosov's index formula **Recommended prior knowledge:** Analysis I-III, Linear Algebra I, Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematik			

Operator theory on Hilbert spaces (Operatortheorie auf Hilberträumen)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Bauer
Frequency: irregular			
Topics: • Schatten-p-classes • Bergman space and reproducing kernel • Toeplitz operators and Berezin transform • Quantization and Fock space • Bergman metric and oscillation • Hankel operators • Toeplitz algebra • Fredholm property and the index of Toeplitz operators **Recommended prior knowledge:** Analysis I-III, Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematics			

Analysis of Subriemannian Structures (Analysis Subriemannscher Strukturen)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Bauer
Frequency: irregular			
Topics: • Foundations of analysis on manifolds • Subriemannian manifolds • Non-holonomic constraints • Chow-Rashevskii Theorem • Geodesics in Subriemannian geometry and Hamiltonian formalism • Hörmanders Theorem and hypoelliptic operators • Subelliptic heat equation **Recommended prior knowledge:** Analysis I-III, Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematics			

Pseudodifferential Operators (Pseudodifferentialoperatoren)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Bauer, Escher, Schrohe
Frequency: irregular			
Topics: • Fourier transform • Tempered distributions • Sobolev spaces • Oscillatory integrals • Symbol classes • Continuity properties and calculus • Ellipticity and parametrix construction • Operators on manifolds • Wave front sets **Recommended prior knowledge:** Analysis I-III, Lineare Algebra I, Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematics			

Operator Algebras (Operatoralgebren)			**P**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Bauer, Escher, Schrohe
Frequency: irregular			
Topics: • Banach and C* Algebras • Gelfand transform and functional calculus • representations and GNS-construction • Gelfand-Naimark Theorem • von Neumann Algebras • Double Commutation Theorem • Projections in von Neumann Algebras • Relative dimension • Classification problem for von Neumann Factors **Recommended prior knowledge:** Analysis I-III, Lineare Algebra I, Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module Master Mathematics			

B.4 Applied Analysis

Semigroups and Evolution Equations (Halbgruppen und Evolutionsgleichungen)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Escher, Walker
Frequency: every 1 to 2 years			
Topics: • closed operators in Banach spaces • strongly continuous and analytic semigroups • generators of semigroups • characterization theorems • semilinear Cauchy problems • fractional powers of operators • maximal regularity **Recommended prior knowledge:** Analysis I-III, Linear Algebra I and II			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

Interpolation Theory and Applications (Interpolationstheorie und Anwendungen)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Escher, Walker
Frequency: irregular			
Topics: • real and complex interpolation method • reiteration and duality theorems • interpolation of Lebesgue and Sobolev spaces • fractional powers of operators • interpolation theory for elliptic boundary value problems • applications to semigroup theory **Recommended prior knowledge:** Semigroups and Evolution Equations or Functional Analysis			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

Nonlinear Functional Analysis (Nichtlineare Funktionalanalysis)			P/A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Escher, Walker
Frequency: every 1 to 2 years			
Topics: • implicit function theorem in Banach spaces • degree theory • bifurcation theory **Recommended prior knowledge:** Analysis I-III, Lineare Algebra I and II			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

Partial Differential Equations (Partielle Differentialgleichungen)			P/A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Bauer, Escher, Schrohe, Walker. Lankeit
Frequency: annual			
Topics: • method of characteristics • distribution theory • Laplace's equation, maximum principles • Sobolev spaces • variational methods • Fourier transform • wave equation • heat equation **Recommended prior knowledge:** Analysis I-III, Linear Algebra I and II			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

Nonlinear Partial Differential Equations (Nichtlineare partielle Differentialgleichungen)			**P/A**
Type of course Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Escher, Walker
Frequency: irregular			
Topics: • nonlinear elliptic and parabolic equations • fixed point methods • variational methods • compactness methods • monotone operators **Recommended prior knowledge:** Partial Differential Equations I			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

Qualitative Theory of Ordinary Differential Equations (Qualitative Theorie gewöhnlicher Differentialgleichungen)			**P/A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Escher,Walker
Frequency: annual			
Topics: • dynamical systems • invariant sets • limit sets • stability and linearization principles • periodic solutions **Recommended prior knowledge:** Analysis I-III, Linear Algebra I and II			
Module affiliation: • Specialization Bachelor Analysis • Elective module master Mathematics			

B.5 Numerical Mathematics and Optimization

Intoduction to Adaptive Finite Element Method (Einführung in die Adaptive Finite-Elemente-Methode)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: every 2 to 3 years			
Topics: • adaptive mesh refinement for FEM • A posteriori error analysis • error estimators: (e.g. residual) • convergence **References:** 🕮 Ainsworth/Oden: *A posteriori error estimation in finite element analysis.* Wiley 2000. 🕮 Nochetto/Siebert/Veeser: *Theory of adaptive finite element methods: an introduction.* In: Multiscale, nonlinear and adaptive approximation, 409–542, Springer, 2009. **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: • Specialization Bachelor Numerics • Elective module master Mathematics			

hp-Finite Element Methods (hp-Finite Element Methoden)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: regularly every 1 to 2 years			
Topics: • Error reduction by mesh refinement and increasing degree of polynomial • Proof of exponential convergence in FEM • Proof of exponential convergence ini Gauß quadrature • Application to mechanics and electrodynamics • Adaptive methods • New developments in numerical analysis **References:** 🕮 Standard literature, lecture notes **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: Specialization Bachelor Numerics			

Linear optimization (Lineare Optimierung)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** Steinbach
Frequency: regularly every 2 to 3 years			
Topics: • Simplex method • Theory of polyhedra • Farkas lemma and extensions • Duality theory **References:** 🕮 V. Chvátal: *Linear Programming* **Recommended prior knowledge:** Numerical Mathematics I, Algorithmic programming			
Module affiliation: • Specialization Bachelor Numerics			

Multigrid and split and merge technique (Multigrid und Gebietszerlegung)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: regularly every 1 to 2 years			
Topics: • Preconditioned iterative methods (Richardson, Jacobi) • Multigrid (for finite difference and finite element methods) • Multilevel methods (additive and multiplicative Schwarz methods) • Domain decomposition methods (Schwarz alternating method) **References:** 🕮 Standard literature, lecture notes **Recommended prior knowledge:** Numerical Mathematics I			
Module affiliation: • Specialization Bachelor Numerics			

Nonlinear optimization I (Nichtlineare Optimierung I)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Steinbach
Frequency: regularly every 2 to 3 years			
Topics: • Steepest descent method, Newton's method, line search, trust region • Theory of constrained optimization: KKT conditions, ... • Quadratic optimization: KKT factorizations, active set method • Maratos effect, merit functions, SQP method **References:** 🕮 J. Nocedal, S. Wright: *Numerical Optimization*, 2nd ed. **Recommended prior knowledge:** Numerical Mathematics I and II, Algorithmic programming			
Module affiliation: • Specialization Bachelor Numerics			

Nonlinear optimization II (Nichtlineare Optimierung II)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Steinbach
Frequency: regularly every 2 to 3 years			
Topics: • Nonlinear CG method • Techniques for high dimension models • Interior point methods • Further topics **References:** • J. Nocedal, S. Wright: *Numerical Optimization*, 2nd ed. **Recommended prior knowledge:** Nonlinear optimization I			
Module affiliation: • Specialization Bachelor Numerics			

Numerics for contact problems (Numerik für Kontaktprobleme)			A
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: regularly every 1 to 2 years			
Topics: • Existence and uniqueness of solutions for elliptic contact problems • Variational inequalities, mixed formulations • Penalty methods • Iterative algorithms: Uzawa, Semi-smooth Newton's method • Mulitfield problems (Mehrfeldprobleme), coupling with heat equation **References:** 🕮 Standard literature, lecture notes **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: • Specialization Bachelor Numerics			

Numerics for Partial Differential Equations (Numerik partieller Differentialgleichungen)			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfAM
Frequency: regularly every 1 to 2 years			
Topics: • Galerkin method for elliptic boundary value problems • Finite element spaces • A-posteriori error estimation • Methods for parabolic and hyperbolic differential equations **References:** 🕮 P. Knabner, L. Angermann: *Numerik partieller Differentialgleichungen* **Recommended prior knowledge:** Numerical Mathematics I and II			
Module affiliation: • Specialization Bachelor Numerics			

Numerical Methods in Continuum Mechanics (Numerische Methoden der Kontinuumsmechanik)			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfAM
Frequency: regularly every 1 to 2 years			

Topics:

- Modelling: linear elastcity and fluid dynamics
- Discretization: mixed finite elements
- error estimates for Stokes

References:

- 🕮 Brezzi/Fortin: *Mixed and hybrid finite element methods.* Springer 1991

Recommended prior knowledge: Numerical Mathematics I and Numerics for Partial Differential Equations

Module affiliation:

- Specialization Bachelor Numerics
- Elective module master Mathematics

Numerical Methods for coupled and nonlinear Problems (Numerische Methoden für gekoppelte und nichtlineare Probleme)			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfAM
Frequency: every 3 to 4 years			

Topics:

- Classification into nonlinear and coupled problems
- Regularisation, time and space discretization
- Nonlinear and linear solvers
- Adaptivity and inexacte solvers

References:

- 🕮 Wick: *Numerical methods for nonlinear and coupled PDEs*, Vorlesungsskriptum, available online https://www.ifam.uni-hannover.de/2120.html.
- 🕮 Glowinski: *Numerical methods for nonlinear variational problems.* Springer 1984.

Recommended prior knowledge: Numerical Mathematics I and Numerics for Partial Differential Equations

Module affiliation:

- Specialization Bachelor Numerics
- Elective module master Mathematics

Numerical methods for ordinary differential equations (Numerische Methoden für gewöhnliche Differentialgleichungen)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: irregular			
Topics: • One step methods • Stability • Differential-algebraic equations • Galerkin-method • Shot methods • Variational methods **References:** 🕮 Rannacher: *Einführung in die Numerische Mathematik*, Heidelberg University Publishing, 2017. **Recommended prior knowledge:** Numerical Mathematics I and II			
Module affiliation: • Specialization Bachelor Numerics • Elective module master Mathematics			

Optimization of Partial Differential Equations (Optimierung mit partiellen Differentialgleichungen)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: irregular			
Topics: • Linear-quadratic optimal control problems • Existence and uniqueness • adjoinded state • Diskretization and optimization: FEM **References:** 🕮 Troeltzsch: *Optimal control of partial differential equations.* AMS, 2010. **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: • Specialization Bachelor Numerics • Elective module master Mathematics			

Scientific Computing			A
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: irregular			
Topics: • Numerical algorithms and their parallelization **References:** 🕮 Bastian: *Lecture notes on parallel solution of large sparse linear system,* Vorlesungsskriptum, IWR Heidelberg, April 2018. **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: • Specialization Bachelor Numerics • Elective module master Mathematics			

Discontinuous Galerkin Methods (Unstetige Galerkinverfahren)			A
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfAM
Frequency: irregular			
Topics: • Basis ideas • DG for stationry advection (flows, upwinding) • DG for nonstationary PDE's of first order • DG for elliptic problems (SIP) **References:** 🕮 Ern/di Pietro: *Mathematical aspects of discontinuous Galerkin methods.* Springer 2012. **Recommended prior knowledge:** Numerical Mathematics I and Numerics for Partial Differential Equations			
Module affiliation: • Specialization Bachelor Numerics • Elective module master Mathematics			

B.6 Differential Geometry

Gauge theory (Eichfeldtheorie)			**P**
Type of course Bachelor, Master	**Semester Hours** 2+2	**Credit Points (ECTS):** 5	**Responsibility** IDG
Frequency: irregular			
Topics: • Connections on principle bundles and its curvature • Gauge transformations • Yang-Mills functional and Yang-Mills equation • self-dual and invariant connections • non-minimal Yang-Mills connections • magnetic monopoles and vortices **Recommended prior knowledge:** Manifolds			
Module affiliation: • Spezialization Bachelor Geometry • Elective module master Mathematics			

Geometric evolution equations (Geometrische Evolutionsgleichungen)			**P**
Type of course Bachelor, Master	**Semester Hours** 2+2	**Credit Points (ECTS):** 5	**Responsibility** IDG
Frequency: irregular (english)			
Topics: • Variational problems on manifolds • Harmonic map heat flow • Mean curvature flow, Lagrangian mean curvature flow • Ricci flow, Sasaki-Ricci flow • Hamilton's maximum principle for tensors • Short and longtime existence and convergence • Singularities, Self-similar solutions, solitons, monotonicity formulas **Recommended prior knowledge:** Analysis III, Manifolds, Riemannian geometry			
Module affiliation: • Spezialization Bachelor Geometry • Elective module master Mathematics			

Contact Geometry (Kontaktgeometrie)			**P**
Type of course Bachelor, Master	**Semester Hours** 2+2	**Credit Points (ECTS):** 5	**Responsibility** IDG
Frequency: irregular (english)			

Topics:

- Contact structures, Reeb vector fields
- Legendre submanifolds
- Tight and overtwisted contact structures
- Contact Riemannian manifolds
- Sasaki manifolds
- Basic cohomology
- Sasaki–Ricci flow
- Relation to Kähler geometry

References:

- Blair, David: *Riemannian geometry of contact and symplectic manifolds*, Progress in Mathematics, Birkhäuser, 2010

Recommended prior knowledge: Manifolds, Riemannian geometry

Module affiliation:

- Spezialization Bachelor Geometry
- Elective module master Mathematics

Classic Differential Geometry (Klassische Differentialgeometrie)			**P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: annual, Winter Semester			
Topics: • Regular submanifolds of arbitrary codimension • Tangent spaces • First fundamental form, length of a rectifiable curve, induced measure on regular submanifolds • Second fundamental form, Gauß map, Weingarten map, principal curvatures, mean curvature, Gauß curvature • Covariant derivatives on tangent and normal bundles • Inner geometry • Equations of Gauß (Theorema Egregium), Codazzi—Mainardi and Ricci • Gobal theory of curves and surfaces: isoperimetric inequality, Umlaufsatz, theorems of Fenchel and Gauß-Bonnet **References:** • do Carmo, Manfredo P., *Differentialgeometrie von Kurven und Flächen,* Vieweg Studium: Aufbaukurs Mathematik, 1983 • Kühnel, Wolfgang: *Differentialgeometrie: Kurven - Flächen - Mannigfaltigkeiten,* Aufbaukurs Mathematik, Springer Spektrum **Recommended prior knowledge:** Analysis I-II, Linear Algebra I			
Module affiliation: • Basic Bachelor Analysis • Basic Bachelor Geometry • Specialization Bachelor Analysis • Specialization Bachelor Geometry			

Riemannian Geometry (Riemannsche Geometrie)			**P**
Type of course Bachelor, Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: annual, Winter Semester			
Topics: • Riemannian metrics • Parallel transport and geodesics • Exponential map, injectivity radius and cut locus • Geodesic completeness, Hopf-Rinow theorem • Connections on vector bundles • Curvature of a connection • The Riemann curvature tensor of the Levi-Civita connection, first and second Bianchi identity • First and second variation of length and energy of a curve • Conjugated points, Jacobi vector fields • Symmetric and locally symmetric spaces • Harmonic differential forms • Hodge decomposition theorem **References:** • Jost, Jürgen: *Riemannian Geometry and Geometric Analysis*, Springer Verlag • Gallot, Hulin, Lafontaine: *Riemannian Geometry*, Universitext, Springer Verlag • Spivak, M.: *A comprehensive introduction to differential geometry I-V*, Publish or Perish **Recommended prior knowledge : M**anifolds			
Module affiliation: • Specialization Bachelor Geometry • Elective module master Mathematics			

Complex differential geometry	**P**

(Komplexe Differentialgeometrie)			
Type of course Bachelor, Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: annual, Summer Semester			
Topics: • Complex manifolds • falmost complex and complex structures, Nijenhuis tensor and integrability • Hermitian manifolds, Classification by Gray and Hervella • Kähler manifolds • Dolbeault operators, Dolbeault decomposition theorem • Hodge numbers, Serre duality • Chern classes, forms and numbers • Theorem of Gauß-Bonnet-Chern • Calabi-Yau manifolds **References:** • Kobayashi S., Nomizu, K.: Foundations of differential geometry, Vol. II, Wiley Classics Library **Recommended prior knowledge: M**anifolds, complex analysis			
Module affiliation: • Specialization Bachelor Geometry • Elective module master Mathematics			

Symplectic Geometry (Symplektische Geometrie)			**P**
Type of course Bachelor, Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IDG
Frequency: irregular			

Topics:

- Linear symplectic geometry
- symplectic manifolds
- Cotangent bundle and co-adjoint orbits as symplectic manifolds
- Moser's principle and Darboux' theorem
- Hamiltonian vector fields, Poisson bracket, Hamiltonian action and momentum map
- capacities
- pseudo-holomorphic curves
- Models in classical mechanics
- Legendre transformation

References:

- Aebischer, Borer, Kälin, Leuenberger, Reimann: *Symplectic geometry*, Progress in Mathematics, Birkhäuser, 1994
- McDuff, Salamon; *Introduction to symplectic topology*, Oxford Mathematical Monographs, The Clarendon Press, Oxford University

Recommended prior knowledge: Manifolds

Module affiliation:

- Specialization Bachelor Geometry
- Elective module master Mathematics

Differential topology (Differentialtopologie)			**P**
Type of course Bachelor, Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility:** IDG
Frequency: irregular			
Topics: • Regular and critical points and values • The theorems of Sard and Brown • Index of vektor fields, degree of a mapping, the theorem of Poincare-Hopf • Morse theory und Morse inequalities • Relative Cohomology • Long exact sequences, Mayer—Vietoris sequence **References:** • Milnor, John W.: *Topology from the differential view point*, Princeton University Press • Milnor, John W.: *Morse theory*, Princeton University Press **Recommended prior knowledge:** Analysis III, Manifolds			
Module affiliation: • Spezialization Bachelor Geometry • Elective module master Mathematics			

B.7 Mathematical Stochastics

Asymptotic Statistics (Asymptotische Statistik)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfMS
Frequency: irregular			
Topics: • contiguous distributions • local asymptotic normality • limit experiments • asymptotically optimal tests • asymptotic efficiency of estimators and tests **References** 🕮 Van der Vaart: *Asymptotic Statistics*, Cambridge University Press, Cambridge, 1998. **Recommended prior knowledge:** Probability and Statistics II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Financial Mathematics 1			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: annual			
Topics: • Arbitrage Pricing Theory • Preferences and Utlity • Opimality and Equilibrium • Risk Measures **References:** 🕮 H. Föllmer& A.Schied: *Stochastic Finance*, de Gruyter, Berlin/New York, 2016. **Recommended prior knowledge:** Probability and Statistics II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Financial Mathematics 2			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: annual			

Topics:

- Introduction to Stochastic Analysis
- Financial Mathematics in Continuous Time: Princing and Hedging of Financial Derivatives (Equity Derivatives, Interest rate Derivatives, and Credit Derivatives), Optimal Investment

References

📖 M. Musiela& R.Rutkowski: *Martingale Methods in Financial Modelling*, Springer, 2005.

Recommended prior knowledge: Probability and Statistics II, Financial Mathematics 1, possibly Stochastic Analysis

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module

Nonparametric Statistics (Nichtparametrische Statistik)			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfMS
Frequency: irregular			

Topics:

- order and rank statistics
- distribution free confidence regions
- locally best rank tests
- empirical distributions
- tests for goodness of fit
- nonparametric multivariate procedures

GrundlegendeLiteratur:

📖 J. Hajek, Z. Sidak, P. K. Sen: *Theory of Rank Tests*, Academic Press, 1999.

Recommended prior knowledge: Probability and Statistics II

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module

Actuarial Mathematics 1			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: annual			

Topics:

- Individual and Collective model
- Ruin Theory
- Premium Calculation
- Incurred But Not Reported Claims
- Risk Sharing and Reinsurance
- Interest Rates and Fixed Income
- Cash Flows and Mathematical Reserve
- Difference Equations and Differential Equations
- Hattendorf's Theorem
- Unit-linked policies
- Policies with Stochastic Interest Rate
- Market-Consistent Valuation

The lecture is split in Actuarial Mathematics I and Actuarial Mathematics 2.

References:

- 🕮 T. Mack: *Schadenversicherungsmathematik*, VVW Karlsruhe, 2002.
- 🕮 K. Schmidt: *Versicherungsmathematik*, Springer, 2006.
- 🕮 M. Koller: *Stochastische Modelle in der Lebensversicherungsmathematik*, Springer, 2000.
- 🕮 R. Norberg: *Basic Life Insurance Mathematics*, LSE, 2002.

Recommended prior knowledge: Probability and Statistics II

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module

Actuarial Mathematics 2			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: annual			

Topics:

- Individual and Collective model
- Ruin Theory
- Premium Calculation
- Incurred But Not Reported Claims
- Risk Sharing and Reinsurance
- Interest Rates and Fixed Income
- Cash Flows and Mathematical Reserve
- Difference Equations and Differential Equations
- Hattendorf's Theorem
- Unit-linked policies
- Policies with Stochastic Interest Rate
- Market-Consistent Valuation

The lecture is split in Actuarial Mathematics I and Actuarial Mathematics 2.

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- 🕮 K. Schmidt: *Versicherungsmathematik*, Springer, 2006.
- 🕮 M. Koller: *Stochastische Modelle in der Lebensversicherungsmathematik*, Springer, 2000.
- 🕮 R. Norberg: *Basic Life Insurance Mathematics*, LSE, 2002.

Recommended prior knowledge: Probability and Statistics II, Actuarial Mathematics I

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module

Game Theory (Spieltheorie)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfMS
Frequency: irregular			
Topics: • normal form of n-person games • points of equilibrium • mixed extensions • two-person zero sum games • minimax theorems and minimax strategies • matrix games • cooperative games • Shapley value **References** 🕮 F. Forgo, J. Szep, F. Szidarovszky: *Introduction to the Theory of Games: Concepts, Methods, Applications*, Kluwer, Dordrecht, 1999. **Recommended prior knowledge:** Probability and Statistics II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Statistical Decision Theory and Sequential Procedures (Statistische Entscheidungstheorie und Sequentialverfahren)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfMS
Frequency: irregular			
Topics: • decision kernels • Bayes and minimax procedures for estimation and testing • minimax theorems • optimal stopping • sequential Bayes procedures • sequential likelihood ratio tests • optimal sequential tests **References:** 🕮 Irle: *Sequentialanalyse: Optimale sequentielle Tests*, Teubner, Stuttgart, 1990. 🕮 H. Strasser: *Mathematical Theory of Statistics*, de Gruyter, Berlin, 1985. **Recommended prior knowledge:** Probability and Statistics II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Statistics (Statistische Verfahren)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: irregular			
Topics: • tests for goodness of fit, bootstrap, density estimation, robust procedures • models with covariates: regression, analysis of variance, generalized linear models **References** 🕮 W. N. Venables und B. D. Ripley: *Modern Applied Statistics with S-Plus*, third edition. Springer, New York,1999. **Recommended prior knowledge:** Probability and Statistics I and II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Stochastic Analysis (Stochastische Analysis)			**A/P**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** IfMS
Frequency: annual			
Topics: • Stochastic Processes in Continuous Time: Brownian Motion, (Local) Martingales, Semimartingales, Markovian Processes, Levy Processes • stochastic Integrals • Representations of Martingales • Girsanov's and its Applications • Stochastic Differential Equations • Applications to Financial Mathematics **References** 🕮 P. Protter: *Stochastic Integration and Differential Equations*, Springer, 2005 🕮 D. Revuz, M. Yor: *Continuous Martingales and Brownian Motion*, Springer, 1999. 🕮 L. C. G. Rogers, D. Williams: *Diffusions, Markov Processes and Martingales*, Volumes 1 & 2, Wiley, New York, 1987, 1994. **Recommended prior knowledge:** Probability and Statistics II			
Module affiliation: • Specialization Bachelor Stochastics • Master elective module			

Stochastic Simulation (Stochastische Simulation)			**A**
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Frequency: annual			

Topics:

- 🕮 General sampling method and principles of Monte Carlo method
- 🕮 Simulation of stochastic processes
- 🕮 Statistical and computational efficiency analysis
- 🕮 Variance reduction techniques
- 🕮 Stochastic optimization
- 🕮 Advanced topics by recent papers

References

- 🕮 S. Asmussen und Glynn, W. Peter: *Stochachstic Simulation Algorithms and Analysis*, Springer, New York, 2007.
- 🕮 H. J. Kushner und G. G. Yin: *Stochastic Approximation Algorithms and Applications*, 2003.

Recommended prior knowledge: Probability and Statistics I and II

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module

Time Series Analysis (Zeitreihenanalyse)			**A**
Type of course Bachelor and Master	**Semester Hours** 2+1	**Credit Points (ECTS):** 5	**Responsibility** IfMS
Frequency: irregular			

Topics:

- stationary time series
- autocovariance function and spectral measure
- autoregressive processes, moving average processes
- spectral representation
- Kolmogorov's prediction theory
- Statistics in the time domain (estimators for the mean and covariance function)
- Statistics in the frequency domain (periodogram, estimators for the spectral density)

References

- 🕮 J.-P. Kreiß,G. Neuhaus:*Einführung in die Zeitreihenanalyse*, Springer, Berlin, 2006.

Recommended prior knowledge: Probability and Statistics II

Module affiliation:

- Specialization Bachelor Stochastics

Quantitative Risk Management			A
Type of course Bachelor and Master	**Semester Hours** 4+2	**Credit Points (ECTS):** 10	**Responsibility** Weber
Regulariy: annual			

Topics:

- Risk measures and risk aggregation
- Extreme value theory
- Multivariate modelling
- Copulas and dependence structure
- Credit risk management

References:

- A. J. McNeil, R. Fey, and P. Embrechts: *Quantitative Risk Management: Concepts, Techniques, and Tools*, Princeton Series in Finance, 2015.

Recommended prior knowledge: Probability and Statistics I and II, possibly Financial Mathematics 1

Module affiliation:

- Specialization Bachelor Stochastics
- Master elective module