Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science Computational and Applied Mathematics

(Version of examination regulation: 20192)

for the summer term 2024

Table of contents

1	**Module name** 65860	**Modeling and analysis in continuum mechanics I**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Theory of elasticity (geometrical non-linear modelling, objectivity and isotropy of energy functionals, linearised elasticity, polyconvexity, existence according to J. Ball) • Non-equilibrium thermodynamics and modelling in hydrodynamics (basic concepts in thermodynamics, balance equations, constitutive relations) • Parabolic function spaces and the Aubin-Lions lemma • Weak solution theory for incompressible Navier-Stokes equations
6	**Learning objectives and skills**	Students • derive mathematical models for fluid mechanics and elasticity theory, • evaluate the predictive power of models using physical modelling assumptions and the qualitative characteristics of solutions, • apply analytical techniques to rigorously prove qualitative properties of solutions.
7	**Prerequisites**	Basic knowledge in functional analysis and modelling is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P.G. Ciarlet: Mathematical elasticity, North-Holland, • S.R. De Groot & P. Mazur: Non-equilibrium thermodynamics, Dover, • C. Eck, H. Garcke & P. Knabner: Mathematical Modeling, Springer, • L.C. Evans: Partial differential equations, AMS, • I. Liu: Continuum mechanics, Springer,

			• R. Temam: The Navier-Stokes equations, AMS Chelsea Publishing.

1	**Module name** 65865	**Modeling and analysis in continuum mechanics II**	**5 ECTS**
2	Courses / lectures	Übung: Übungen zu Modeling and Analysis in Continuum Mechanics 2 (2.0 SWS) Vorlesung: Modeling and Analysis in Continuum Mechanics 2 (2.0 SWS)	0 ECTS 5 ECTS
3	Lecturers	Dr. Stefan Metzger	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Some (at least two) of the following topics: • Monotone operators and applications in continuum mechanics, e.g. shear-thinning liquids, • Mathematical concepts of model reduction: homogenization, gamma convergence, asymptotic analysis, • Reaction diffusion models from biology and social sciences; • Models in fluid dynamics (compressible and incompressible Navier-Stokes equations); • Wave phenomena and other hyperbolic equations in continuum mechanics
6	**Learning objectives and skills**	Students can: • derive mathematical models for several important applications in continuum mechanics. • apply analytical techniques to rigorously prove qualitative properties of solutions.
7	**Prerequisites**	Recommended: Modeling and Analysis in Continuum Mechanics I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• A. Braides: Gamma-convergence for beginners, Oxford University Press, • D. Cioranescu & P. Donato: An introduction to homogenization, Oxford University Press, • L.C. Evans. (2010). Partial differential equations. AMS. • T.A. Roberts (1994). A one-dimensional introduction to continuum mechanics. World Scientific.

		• R.E. Showalter: Monotone operators in Banach space and nonlinear partial differential equations, AMS • T. Temam and A. Miranville (2005). Mathematical modeling in continuum mechanics. Cambridge University Press. • Handouts and lecture notes distributed via StudOn.

1	**Module name** 44460	**Architekturen von Superrechnern** Architectures of supercomputers	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	
5	**Contents**	• Principles of computer and processor architectures • Modern processor architectures • Homogeneous and heterogeneous multi/many-core processors • Parallel computer architectures • Classification and principles of coupling parallel computers • High speed networks in supercomputers • Examples of supercomputers • Programming of supercomputers
6	**Learning objectives and skills**	Fachkompetenz Wissen Lernende können die Funktionsweise moderner in Superrechnern eingesetzter Prozessoren wiedergeben. Sie erkennen die besonderen Probleme im Zusammenahng mit dem Ernergieverbrauch und der Programmierung von Superrechnern. Verstehen Lernende können die Unterschiede bei der Kopplung paralleler Prozesse darstellen. Sie können Parallelrechner hinsichtlich ihrer Speicheranbindung und den grundlegenden Verarbeitungsprinzipien klassifizieren. Anwenden Lernenden sind in der Lage ein eigenes technisches oder mathematisches Problem zur Lösung auf einem Supercomputer umzusetzen und auszuführen. Anhand der in der Vorlesung gezeigten Beispiele sind sie in der Lage, Herausforderungen beim Auffinden von Flaschenhälsen zu verallgemeinern und für ihr konkretes Problem anzuwenden. Analysieren Lernende sind in der Lage, ihre Problemstellungen, z.B. naturwissenschaftliche oder technische Simulationsexperimente, hinsichtlich der Rechen- und Speicheranforderungen für einen Supercomputer geeignet für die Architekur zu charakterisieren. Evaluieren (Beurteilen) Lernende können mithilfe der aufgezeigten Methodiken zur Leistungsmesung von Parallerechnern unterschiedliche Rechnerarchitekturen bewerten und für ihre Problemstellung die passende Architektur auswählen.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!

9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written (30 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 120 h Independent study: 30 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 65875	**Programming techniques for supercomputers in CAM**	**10 ECTS**
2	Courses / lectures	Vorlesung: Programming Techniques for Supercomputers (4.0 SWS) Übung: Programming Techniques for Supercomputers - Exercises (2.0 SWS)	5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Gerhard Wellein	

4	**Module coordinator**	Prof. Dr. Gerhard Wellein
5	**Contents**	• Introduction to the architecture of modern supercomputers • Single core architecture and optimisation strategies • Memory hierarchy and data access optimization • Concepts of parallel computers and parallel computing • Efficient shared memory parallelisation (OpenMP) • Parallelisation approaches for multi-core processors including GPUs • Efficient distributed memory parallelisation (MPI) • Roofline performance model • Serial and parallel performance modelling • Complete parallel implementation of a modern iterative Poisson solver
6	**Learning objectives and skills**	Students • acquire a comprehensive overview of programming modern supercomputers efficiently for numerical simulations, • learn modern optimisation and parallelisation strategies, guided by structured performance modelling, • acquire an insight into innovative programming techniques and alternative supercomputer architectures, • are able to implement numerical methods to solve partial differential equations (PDEs) with finite difference (FD) discretization with high hardware efficiency on parallel computers.
7	**Prerequisites**	Recommended: Experience in C/C++ or Fortran programming; basic knowledge of MPI and OpenMP programming
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 120 h Independent study: 180 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• G. Hager & G. Wellein: Introduction to High Performance Computing for Scientists and Engineers. CRC Computational Science Series, 2010. ISBN 978-1439811924 • J. Hennessy & D. Patterson: Computer Architecture. A Quantitative Approach. Morgan Kaufmann Publishers, Elsevier, 2003. ISBN 1-55860-724-2

1	**Module name** 65870	**Modeling, simulation and optimization (Practical Course)** Modeling, simulation and optimization	**5 ECTS**
2	Courses / lectures	Praxisseminar: Modeling, Simulation and Optimization (practical course) (3.0 SWS) Praxisseminar: Karteileiche März 2024 (3.0 SWS)	5 ECTS 5 ECTS
3	Lecturers	Dr. Stefan Metzger	

4	**Module coordinator**	Prof. Dr. Carsten Gräser
5	**Contents**	• Modelling, analysis, simulation and/or optimization of problems in engineering or the natural sciences • Numerical algorithms for partial differential equation models (finite differences, finite elements, etc) • Continuous optimization and optimal control
6	**Learning objectives and skills**	Students • work on problems in engineering or the natural sciences by constructing a suitable mathematical model, • are able to simulate, analyze, and/or optimize the constructed mathematical model using numerical methods, • are able to implement processes using their own or specified software and critically evaluate the results, • are able to set out their approaches and results in a comprehensible and convincing manner, making use of appropriate presentation techniques, • are able to develop and set out in writing the theories and problem solutions they have developed.
7	**Prerequisites**	Recommended: Modeling and Analysis in Continuum Mechanics I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar paper and presentation Seminar paper and presentation
11	**Grading procedure**	Seminar paper and presentation (50%) Seminar paper and presentation (50%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 42 h Independent study: 108 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Project-dependent. Will be published on StudOn at the beginning of the semester.

1	**Module name** 1999	**Master's thesis (M.Sc. Computational and Applied Mathematics 20192)** Master's thesis	**25 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	The masters thesis is in the field of Modelling and Analysis, or Numerical Analysis and Simulation, or Optimization, and deals with a current research topic.
6	**Learning objectives and skills**	Students • are capable of independently follow up a scientific question in the fields of Modelling and Analysis, Numerical Analysis and Simulation or Optimization over an extended, specified period, • develop original ideas and concepts for solving scientific problems in these fields, • apply and improve mathematical methods rather independently - also in unfamiliar and interdisciplinary contexts, • present and explain mathematical or interdisciplinary contents clearly in a manner appropriate for the target audience, both in writing and orally, • improve their ability to plan and structure by implementing a thematic project.
7	**Prerequisites**	Successful participation in all mandatory modules (35 ECTS) and at least 20 ECTS from mandatory elective modules
8	**Integration in curriculum**	semester: 4
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written (6 Monate) Oral
11	**Grading procedure**	Written (90%) Oral (10%)
12	**Module frequency**	Every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 15 h Independent study: 735 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Individual, depending on topic of Masters Thesis.

1	**Module name** 1500	**Elective modules (as selected from FAU-modules)**	**15 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Pflichtmodul Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	no Module frequency information available!
13	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	**Module duration**	?? semester (no information for Module duration available)
15	**Teaching and examination language**	german or english
16	**Bibliography**	

Specialisation:Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi)

1	**Module name** 65885	**Master's seminar MApA** Master`s seminar MApA	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-

		Seminar: Homogenization of fluid flow in porous media	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	A topic from MApA that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the MApA specialisation: • make use of analytical techniques to rigorously prove the qualitative characteristics of solutions to mathematical models in applied sciences.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written Presentation (90 minutes)
11	**Grading procedure**	Written (25%) Presentation (75%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65890	**Master's seminar NASi**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	A topic from NASi that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the NASi specification: • can solve exemplary computational problems with given or self-developed software in order to illustrate or verify numerical methods under consideration.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65909	**Subspace correction methods**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Carsten Gräser
5	**Contents**	1) Subspace correction as an abstract framework to construct and analyse efficient iterative methods 2) Analysis of additive and multiplicative subspace correction 3) Multigrid and domain decomposition as subspace correction methods 4) Nonlinear subspace correction methods
6	**Learning objectives and skills**	Students are • familiar with the abstract subspace correction framework • can select problem adapted methods • can analyse specific methods within the framework
7	**Prerequisites**	Recommended: Introduction to numerical methods for PDEs Recommended: Basic knowledge of functional analysis (but the necessary terminology and results are briefly provided during the lecture)
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes) oral exam (15 min)
11	**Grading procedure**	Oral (100%) 100% based on oral exam
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	• H. Yserentant: Old and New Convergence Proofs for Multigrid Methods, Acta Numer. 1993 • J.-C. Xu: Iterative Methods by Space Decomposition and Subspace Correction, SIAM Rev., 1992 • Further literature and publications are announced during the lecture

1	**Module name** 65789	**Selected Topics in Mathematics of Learning** Selected topics in mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Advanced methods of mathematical data science, with a focus on teaching mathematical principles of learning processes.
6	**Learning objectives and skills**	Students gain fundamental theoretical knowledge of learning algorithms in Data Science and will be able to apply the methodologies in a Data Science context.
7	**Prerequisites**	Basic knowledge in numerical methods and optimization are recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	S. Wright, B. Recht: Optimization for Data Analysis (2022).

1	**Module name** 65068	**Wave Phenomena** Wave phenomena	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Motivations and applications. 2) Linear transport equation: method of characteristics; Fourier analysis and numerical approximations. 3) The wave equation: D'Alembert's representation formula; regularity of the solutions; finite speed of propagation of perturbations; Huygens' principle; geometric optics; wave models with sources or sinks; Kirchhoff's representation in R^3; Poisson's representation in R^2; the case of general odd and even space dimensions; energy methods: domain of dependence inequality and energy conservation; representation of solutions by using partial Fourier transform; subordination waves-heat; the reflection method and waves on the half-line; separation of variables. 4) Klein-Gordon equation: energy estimates; representation of solutions by using Fourier multipliers; von Wahl's transformation. 5) Damped wave equation: energy estimates; representation of solutions by using Fourier multipliers; decay behavior and decay rate. 6) Damped plate equation: estimates for the energy; estimates for the solution itself and its derivatives; 7) Semilinear wave equation: global existence for small data and global existence for large data. 8) Diffusion phenomena: parabolic structure of solutions to damped waves and damped plates; diffusion phenomena in thermo-elasticity; traveling waves and reaction-diffusion models. 9) Scalar conservation laws: occurrence of shocks and rarefaction waves. 10) Linear and nonlinear dispersive waves: Solitary waves for the Korteweg–de Vries equation; plane-wave solutions for the Airy equation and Schrödinger; Fourier analysis. 11) Maxwell equations: constitutive equations; special cases; boundary conditions; expansion into wave functions.
6	**Learning objectives and skills**	Students are able to: • identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • work interdisciplinary and in problem-oriented way; • use language and techniques related to partial differential equations; • work out the examples and applications that accompany the theory.

7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Ebert, M. R. & Reissig, M. Methods for Partial Differential Equations. Birkhäuser, 2018. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Kirsch, A. and Hettlich, F. The Mathematical Theory of Maxwell's Equations. Lecture Notes, 2013: • https://www.math.kit.edu/ianmip/lehre/maxwellequ2012w/media/main.pdf • Myint-U, T. & Debnath, L. Linear partial differential equations for scientists and engineers. Birkhäuser, 2007. • Reissig, M. Theory of hyperbolic equations. Lecture Notes, 2007: • https://tu-freiberg.de/sites/default/files/media/institut-fuer-angewandte-analysis-9030/reissig/pdehanoi1.pdf • Vichnevetsky, R. & Bowles, J. B. Fourier Analysis of Numerical Approximations of Hyperbolic Equations. SIAM, 1982 Lecture notes will be distributed via StudOn.

1	**Module name** 65887	**Modul Conservation Laws** Module: Conservation laws	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Dr. Lukas Pflug
5	**Contents**	• (Non-)local conservation laws in applications • Linear scalar transport equations and conservation laws • Linear multi-D transport equations and conservation laws • Method of characteristics • Fixed-point methods in Banach spaces • Existence and uniqueness of nonlocal conservation laws • Maximum principles • Regularity and stability of solutions • Local conservation laws, Entropy solutions; • The singular limit problem – approximation of local Entropy solutions by nonlocal conservation laws • Numerical methods
6	**Learning objectives and skills**	Students learn the basic theory on nonlocal conservation laws, apply approximation results, learn fixed-point approaches in Banach spaces and understand the applicability of conservation laws in the applied sciences.
7	**Prerequisites**	Some basic knowledge in PDE is of advantage, Sobolev spaces.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	• Bressan, Alberto. Hyperbolic systems of conservation laws: the one-dimensional Cauchy problem. Vol. 20. Oxford University Press on Demand, 2000.

		• Keimer, Alexander, and Lukas Pflug. "Existence, uniqueness and regularity results on nonlocal balance laws." Journal of Differential Equations 263.7 (2017): 4023-4069. • Coclite, Giuseppe Maria, et al. "A general result on the approximation of local conservation laws by nonlocal conservation laws: The singular limit problem for exponential kernels." Annales de l'Institut Henri Poincaré C (2022). • Blandin, Sebastien, and Paola Goatin. "Well-posedness of a conservation law with non-local flux arising in traffic flow modeling." Numerische Mathematik 132.2 (2016): 217-241. • Aggarwal, Aekta, Rinaldo M. Colombo, and Paola Goatin. "Nonlocal systems of conservation laws in several space dimensions." SIAM Journal on Numerical Analysis 53.2 (2015): 963-983.

1	**Module name** 65888	**Navier Stokes Equations** Navier stokes equations	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Emil Wiedemann
5	**Contents**	The incompressible Navier-Stokes equations (NSE) are a nonlinear system of partial differential equations fundamental for the modelling of fluid flow. They are extensively used in meteorology and oceanography, but also pose great mathematical challenges. Famously, global regularity of the three-dimensional NSE forms one of the seven Millennium Problems. This course serves as an introduction to the mathematical theory of these equations and includes the following topics: • existence of weak solutions of Leray-Hopf type; • local-in-time existence of strong solutions; • the Prodi-Serrin criteria for regularity and energy balance; • partial regularity theory; • the singular limit of vanishing viscosity. The course can be a good preparation for a subsequent master's thesis in the topic.
6	**Learning objectives and skills**	Students know and understand the basic theory of the Navier-Stokes equations and have mastered important methods for systems of non-linear partial differential equations. They have a basic understanding of mathematical fluid dynamics.
7	**Prerequisites**	Lineare Algebra, Analysis. Empfohlen: erste Kurse in partiellen Differentialgleichungen und Funktionalanalysis.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	

16	**Bibliography**	• J. C. Robinson, J. L. Rodrigo, W. Sadowski: The Three-Dimensional Navier-Stokes Equations. Cambridge University Press, 2016. • P. Constantin, C. Foias: Navier-Stokes Equations. University of Chicago Press, 1988. • W. Ożański: The Partial Regularity Theory of Caffarelli, Kohn, and Nirenberg and its Sharpness. Birkhäuser, 2019. • E. Wiedemann: Navier-Stokes Equations: Lecture Notes. Universität Ulm, 2018/19.

1	**Module name** 65083	**Efficient discretization of two-phase flow**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr. Stefan Metzger
5	**Contents**	Based on recent scientific publications, different discretization approaches for two-phase flow are discussed.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session, • learn to compare different discretization methods regarding their specific advantages and disadvantages.
7	**Prerequisites**	Recommended: Numerics of Partial Differential Equations I
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65089	**Scalar conservation laws**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Introduction: applications and examples of conservation laws. 2) Review of functional analysis: L^p spaces; functions of bounded variation. 3) The method of characteristics: semilinear equations with constant coefficients; semilinear equations with variable coefficients; quasilinear equations. 4) Entropy solutions: discontinuous solutions of conservation laws; Rankine-Hugoniot condition; entropy and entropy flux; entropy solutions; Liu condition; Kruzkhov's theorem; uniqueness and stability of entropy solutions. 5) Riemann problem: solutions of the Riemann problem for convex fluxes; solutions of the Riemann problem for general fluxes. 6) Front-tracking: construction of front-tracking approximations; existence of entropy solutions in BV. 7) Vanishing viscosity: viscous approximation; BV a priori estimates; existence of entropy solutions in BV. 8) Compensated compactness and applications to conservation laws: Young measures; Murat's lemma; div-curl lemma; Tartar's theorem; existence of entropy solutions in L^1 \cap L^\infty. 9) Oleinik's estimate: Oleink's estimate for conservation laws with convex fluxes; uniqueness via Oleinik's estimate. 10) Lax-Oleinik's formula: Legendre's transform; Lax-Oleinik's formula. 11) Hamilton-Jacobi equations: motivation; viscosity solutions; well-posedness of viscosity solutions; equivalence between entropy solutions of conservation laws and viscosity solutions of Hamilton-Jacobi equations. 12) Conservation laws on networks: motivations; entropy condition at a junction; vanishing viscosity approximation. 13) Nonlocal conservation laws: motivations; well-posedness of nonlocal conservation laws; the nonlocal-to-local singular limit problem.
6	**Learning objectives and skills**	Students are able to: • use language and techniques related to scalar conservation laws – especially regarding entropy solutions, Riemann problems, viscous approximations, and front tracking algorithms; • work out the examples and applications that accompany the theory.
7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis.
8	**Integration in curriculum**	semester: 2

9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Chapters 1-10: • Bressan, A. Hyperbolic Systems of Conservation Laws: The One-dimensional Cauchy Problem. Oxford University Press, 2000. • Coclite, G. M. Scalar Conservation Laws. Lecture Notes, 2022. • Dafermos, C. M. Hyperbolic Conservation Laws in Continuum Physics. Springer, 2016. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Godlewski, E. & Raviart P.-A. Numerical Approximation of Hyperbolic Systems of Conservation Laws. Springer, 2021. • Godlewski, E. & Raviart P.-A. Hyperbolic Systems of Conservation Laws. Ellipses, 1990. • Holden, H. & Risebro, N. H. Front Tracking for Hyperbolic Conservation Laws. Springer, 2015. • LeVeque, R. J. Numerical Methods for Conservation Laws. Birkhäuser, 1992. • Mishra, S., Fjordholm, U. S. & Abgrall, R. Numerical methods for conservation laws and related equations. Lecture Notes, 2019: https://metaphor.ethz.ch/x/2019/hs/401-4671-00L/literature/mishra_hyperbolic_pdes.pdf • Salsa, S. Partial differential equations in action. From modelling to theory. Springer, 2016. • Salsa, S. & Verzini, G. Partial differential equations in action. Complements and exercises. Springer, 2015. Chapter 11: • Bressan, A. Viscosity Solutions of Hamilton-Jacobi Equations and Optimal Control Problems. Lecture Notes, 2011: http://personal.psu.edu/axb62/PSPDF/HJ-lnotes.pdf.

- Corrias, L., Falcone, M. and Natalini, R. Numerical Schemes for Conservation Laws via Hamilton-Jacobi Equations. Mathematics of Computation. Vol. 64, No. 210 (Apr., 1995), pp. 555-580.
- Evans, L. C. Partial Differential Equations. AMS, 2010.
- Karlsen, K. H. & Risebro, N. H. A note on front tracking and the equivalence between viscosity solutions of Hamilton–Jacobi equations and entropy solutions of scalar conservation laws. Nonlinear Anal., Theory Methods Appl., Ser. A, Theory Methods 50, No. 4, 455-469 (2002).

Chapter 12:

- Andreianov, B. P., Coclite, G. M. & Donadello, C. Well-posedness for vanishing viscosity solutions of scalar conservation laws on a network. Discrete Contin. Dyn. Syst. 37, No. 11, 5913-5942 (2017).

Chapter 13:

- Coclite, G. M., De Nitti, N., Keimer, A. & Pflug, L. On existence and uniqueness of weak solutions to nonlocal conservation laws with BV kernels. Z. Angew. Math. Phys. 73, No. 6, Paper No. 241, 10 p. (2022).
- Coclite, G. M. Coron, J.-M., De Nitti, N., Keimer, A. & Pflug, L. A general result on the approximation of local conservation laws by nonlocal conservation laws: The singular limit problem for exponential kernels. Annales de l'Institut Henri Poincaré C, Analyse Non Linéaire (2022).
- Keimer, A. & Pflug, L. Existence, uniqueness and regularity results on nonlocal balance laws. J. Differ. Equations 263, No. 7, 4023-4069 (2017).

Lecture notes will be distributed via StudOn.

1	**Module name** 65095	**Practical course on finite element methods for phase-separation equations** Practical course on finite element methods for phase separation equations	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Finite element discretization for Cahn-Hilliard equations, • Storage concepts for sparse matrices, • Adaptive mesh refinement.
6	**Learning objectives and skills**	Students • implement a finite element solver for phase-separation equations, • are able to compare and implement different storage concepts for sparse matrices, • are able to implement finite element solvers based on adaptive meshes, • are able to derive and implement efficient discretizations for phase-separation equations, • are able to validate their implementation.
7	**Prerequisites**	Recommended: Numerics of Partial Differential Equations I
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer 2003 • D. Braess: Finite Elements. Cambridge University Press 2010 • B. Stroustrup: The C++ programming language, Addison-Wesley 2014

1	**Module name** 65785	**Mathematics of Learning** Mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Machine learning: empirical risk minimization, kernel methods and variational models • Mathematical aspects of deep learning • Ranking problems • Mathematical models of network interaction
6	**Learning objectives and skills**	Students • develop understanding of modern big data and state of the art methods to analyze them, • apply state of the art algorithms to large data sets, • derive models for network / graph structured data.
7	**Prerequisites**	Prerequisites: Basic knowledge in numerical methods and optimization is recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, Bengio, Courville, Deep Learning, MIT Press, 2015 • Hastie, Tibshirani, Friedman, The Elements of Statistical Learning, 2008

1	**Module name** 65863	**Practical course on finite element methods for phase-separation equations**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Finite-element discretization for Cahn-Hilliard equations • Storage concepts for sparse matrices • Adaptive mesh refinement
6	**Learning objectives and skills**	Students • implement a finite element solver for phase-separation equations, • are able to compare and implement different storage concepts for sparse matrices, • are able to implement finite element solvers based on adaptive meshes, • are able to derive and implement efficient discretizations for phase separation equations, • are able to validate their implementation.
7	**Prerequisites**	Recommended: Numerics of partial differential equations I
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann, Numerical methods for elliptic and parabolic differential equations, Springer 2003 • D. Braess, Finite elements, Cambridge University Press 2010 • B. Stoustrup, The C++ programming language, Addison-Wesley 2014

1	**Module name** 65900	**Advanced discretization techniques**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• conforming and non-conforming finite element methods • saddle point problems in Hilbert spaces • mixed finite element methods for saddle point problems, in particular for Darcy and Stokes • Streamline-Upwind Petrov-Galerkin (SUPG) and discontinuous Galerkin (dG) finite element methods (FEM) for convection dominated problems • Finite Volume (FV) methods and their relation to FEM • a posteriori error control and adaptive methods
6	**Learning objectives and skills**	Students • have a discriminating understanding, both theoretically and computationally of FE as well as FV methods for the numerical solution of partial differential equations (pde) (in particular of saddle point problems), • are capable of developing problem dependent FE or FV methods and judge on their properties regarding stability and effectiveness, • are familiar with a broad spectrum of pde problems and their computational solutions, • are capable of designing algorithms for adaptive mesh control.
7	**Prerequisites**	Recommended: Introduction to numerical methods for pdes, functional analysis
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• A. Ern, J.-L. Guermond: Theory and Practice of Finite Elements • A. Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer • D. A. Di Piettro & A. Ern: Mathematical aspects of discontinuous Galerkin methods. Springer 2012

1	**Module name** 65901	**Advanced solution techniques**	**5 ECTS**
2	Courses / lectures	Übung: Exercises for Advanced Solution Techniques (1.0 SWS) Vorlesung: Advanced Solution Techniques (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Krylov subspace methods for large non-symmetric systems of equations • Multilevel methods, especially multigrid (MG) methods, nested and non-nested grid hierarchies • Parallel numerics, especially domain decomposition methods • Inexact Newton/Newton-Krylov methods for discretized nonlinear partial differential equations • Preconditioning and operator-splitting methods
6	**Learning objectives and skills**	Students • are able to design application-specific own MG algorithms with the theory of multigrid methods and decide for which problems the MG algorithm is suitable to solve large linear systems of equations, • are able to solve sparse nonlinear/non-symmetric systems of equations with modern methods (also with parallel computers), • are able to develop under critical assessment complete and efficient methods for application-orientated problems.
7	**Prerequisites**	Recommended: Advanced Discretization Techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations • Further literature and scientific publications are announced during the lectures

1	**Module name** 65902	**Transport and reaction in porous media: Modelling**	**5 ECTS**
2	Courses / lectures	Vorlesung: Transport and Reaction in Porous Media: Modeling (2.0 SWS) Übung: Tutorial to Transport and Reaction in Porous Media: Modeling (0.0 SWS)	4 ECTS 1 ECTS
3	Lecturers	apl. Prof. Dr. Serge Kräutle	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Modeling of fluid flow through a porous medium: Groundwater models, saturated and unsaturated porous medium (Richards equation) • Advection, diffusion, dispersion of dissolved substances, (nonlinear) reaction-models (i.a. law of mass action, kinetic / reversible reactions in local equilibrium), the stoichiometric matrix • Models of partial (PDEs), ordinary (ODEs) differential equations, and local algebraic conditions • Nonnegativity, boundedness, global existence of solutions, necessary model assumptions in the case of a pure ODE model as well as for a PDE model • Existence and uniqueness of stationary solutions in the stoichiometric space (i.a. introduction to the Feinberg network theory)
6	**Learning objectives and skills**	Students • are able to model flow and reaction processes in porous media on macro- and micro-scale using partial differential equations, • possess the techniques and the analytical foundations to assess the global existence of solutions.
7	**Prerequisites**	Recommended: Basic knowledge in differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• S. Kräutle: lecture notes https://www.math.fau.de/kraeutle/vorlesungsskripte/ • C. Eck, H. Garcke, P. Knabner: Mathematical Modeling, Springer • J.D. Logan: Transport Modeling in Hydrogeochemical Systems, Springer • M. Feinberg: lecture notes https://cbe.osu.edu/chemical-reaction-network-theory

1	**Module name** 65903	**Transport and reaction in porous media: Simulation**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Degenerate parabolic differential equations as multiphase flow models: formulation, model derivation through asymptotic expansion, nonlinear solution methods, discretization methods • Sorption reactions and mineral precipitation-dissolution reactions, formulations as complementarity problems • Models for transport and reactions in porous media, consisting of coupled PDEs and ODEs, if necessary coupled to algebraic equations (AEs) and inequalities for the description of local equilibria (differential-algebraic system) • Different formulations of the system • Different numerical strategies: operator splitting, direct substitutional approach, change of variables and combination/ elimination of equations (xi-eta-method), as a basis for different software packages for numerical simulations, connection to optimisation (minimization of Gibbs free energy under constraints) • Treatment of numerical difficulties (nonsmooth equations, treatment of complementarity conditions, guarantee of nonnegativity of numerical solutions of the nonlinear problems, range of convergence of Newton's method, scaling problems, advection dominated problems
6	**Learning objectives and skills**	Students • use methods for the numerical solving of a class of problems whose complexity goes significantly beyond standard problems (Poisson and heat equation): coupled nonlinear partial and ordinary differential equations (PDEs, ODEs) and algebraic equations (AEs), • put strategies for the treatment of possible difficulties during the numerical solving into practice.
7	**Prerequisites**	• Recommended: Basic knowledge in differential equations, • Also useful: Transport and Reaction in Porous Media: Modeling
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192

		Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer • Journal articles will be named in the lecture • Handbooks of Software Packages https://en.www.math.fau.de/angewandte-mathematik-1/forschung/software-2

1	**Module name** 65904	**Numerics of incompressible flows I**	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of incompressible flows 1 (2.0 SWS) Übung: Übungen zu Numerics of incompressible flows 1	5 ECTS -
3	Lecturers	Dr. Stefan Metzger	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Mathematical modelling of (incompressible) flows • Variational formulation, existence and (non-)uniqueness of solutions to the stationary Navier-Stokes (NVS) equations • Stable finite element (FE) discretization of the stationary (Navier) Stokes equations • Error estimates • Solution techniques for the saddle point problem
6	**Learning objectives and skills**	Students • explain and apply the mathematical theory for the stationary, incompressible Navier-Stokes equations, • analyse FE discretization for the stationary Stokes equations and apply them to practical problems, • explain the meaning of the inf-sup condition, • choose the appropriate function spaces, stabilisation techniques and solution techniques and apply them to concrete problem settings.
7	**Prerequisites**	Recommended: Advanced discretization techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Girault, P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986

			• H. Elman, D. Silvester, A. Wathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65905	**Numerics of incompressible flows II**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Variational formulation of the instationary Stokes and Navier-Stokes (NVS) equations • Existence and uniqueness of solutions to the instationary Stokes and NVS equations • Time discretisation methods • Fully discrete equations and error estimates • Solution techniques • Operator splitting, projection methods • More general boundary conditions • Coupling of NVS with temperature equation • Computational experiments with academic or commercial codes
6	**Learning objectives and skills**	Students • discretize the instationary NVS equations in time and space, • explain and analyse discretisation schemes and operator splitting techniques, • choose appropriate algorithms for given flow problems and solve them with academic or commercial software.
7	**Prerequisites**	Recommended: Advanced discretization techniques, Numerics of incompressible flows I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• V. Girault & P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986 • H. Elman, D. Silvester & A. Rathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Glowinski: Finite Element Methods for Incompressible Viscous Flow, in : Handbook of Numerical Analysis vol. IX • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65906	**Mathematics of multiscale models**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	PD Dr. Nicolas Neuß
5	**Contents**	• Function spaces of periodic functions and asymptotic expansions • Two-scale convergence and unfolding method • Application to differential equation models in continuum mechanics • Multi-scale finite element methods • Numerical upscaling methods
6	**Learning objectives and skills**	Students • have profound expertise about the basic methods in multi-scale analysis and homogenisation, • are able to derive rigorously homogenised (effective) models and analyse the quality of the approximation.
7	**Prerequisites**	Recommended: Knowledge in modeling as well as analysis and numerics of partial differential equations
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• D. Cioranescu & P. Donato: An Introduction to Homogenization • U. Hornung (ed.): Homogenization and Porous Media • Y. Efendiev & T. Hou: Multiscale Finite Element Methods

1	**Module name** 65907	**Theory of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Infinitely dimensional Wiener processes, • Stochastic integral in Hilbert spaces, • Ito-processes and stochastic differential equations, • Optionally: existence results for stochastic partial differential equations or further results on stochastic ODE (Fokker-Planck equations, . . .)
6	**Learning objectives and skills**	Students • characterize Gaussian measures on Hilbert spaces. They explain representation formulas for Q-Wiener processes as well as the derivation of the stochastic integral, • successfully apply concepts to solve stochastic differential equations explicitly and prove existence of solutions to stochastic evolution equations.
7	**Prerequisites**	Basic knowledge in probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Da Prato & J. Zabczyk: Stochastic equations in infinite dimensions, Cambridge University Press • I. Karatzas & S.E. Shreve: Brownian motion and stochastic calculus, Springer • B. Oksendal: Stochastic differential equations, Springer

			• C. Prévôt & M. Röckner: A concise course on stochastic partial differential equations, Springerchastic Evolution Equations

1	**Module name** 65908	**Numerics of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Strong and weak approximations, explicit and implicit schemes for stochastic differential equations (SDEs), • Consistency, stability, convergence, • Monte Carlo methods, variance-reduction schemes.
6	**Learning objectives and skills**	Students • have critical understanding of capabilities of numerical schemes for stochastic differential equations, • are capable to use own or commercial software for SDEs and to judge results critically.
7	**Prerequisites**	Basic knowledge in probability theory and in numerics is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P.E. Kloeden & E. Platen: Numerical solution of stochastic differential equations • B. Lapeyre, E. Pardoux & R. Sentis: Introduction to Monte? Carlo methods for transport and diffusion equations

1	**Module name** 65911	**Mathematical modeling in the life sciences**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Maria Neuß
5	**Contents**	• Biochemical reaction networks, enzyme kinetics • Models for interacting populations (Predator-prey, competition, symbiosis) • Diffusion, reactions, and transport in biological cell tissues and vessels • Structured population models
6	**Learning objectives and skills**	Students • have profound knowledge in the area of mathematical modeling of processes in the life sciences • are able to identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • are able to work interdisciplinary and problem-oriented.
7	**Prerequisites**	Recommended: Modeling and Analysis in Continuum Mechanics I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. D. Murray: Mathematical Biology I: An Introduction, Mathematical Biology II: Spatial Models and Biomedical Applications • G. de Vries, T. Hillen, et al.: A course in Mathematical Biology • J. Prüss: Mathematische Modelle in der Biologie: Deterministische homogene Systeme

1	**Module name** 65914	**Partial differential equations in finance**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• models on pricing for financial derivatives, in particular for European and American-type options, selected deterministic equations of financial mathematics, • practical knowledge Ito-calculus and stochastic differential equations, • analysis and numerics for Black-Scholes equations, • variational inequalities and American-type options.
6	**Learning objectives and skills**	Students • explain mathematical models for financial markets and derivatives pricing, • apply Ito calculus, derive deterministic models based on pde or variational inequalities and discretize them numerically.
7	**Prerequisites**	Basis knowledge in differential equations, probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Capinski & T. Zastawniak: Mathematics for finance, Springer, • N. Hilber, O. Reichmann, C. Schwab & C. Winter: Computational methods for quantitative finance, Springer, • B. Oksendal: Stochastic differential equations, Springer.

1	**Module name** 65954	**Numerik der Optimalen Steuerungen** Numerics of optimal control	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerik der Optimalen Steuerungen (Numerics of optimal control)	5 ECTS
3	Lecturers	Prof. Dr. Hannes Meinlschmidt	

4	**Module coordinator**	Prof. Dr. Hannes Meinlschmidt
5	**Contents**	The following topics are covered: Discretization methods for differential equations, aspects of nonlinear optimization methods, direct discretization methods (fully and reduced discretized), indirect methods based on discretization of necessary optimality conditions as well as methods for efficient sensitivity calculations with internal numerical differentiation and adjoint equations. The material is presented in lecture form. Further acquisition of the essential concepts and techniques takes place through self-study of accompanying literature and the completion of exercises, supported by meetings within the tutorials. By default, the lecture will be given in English (in German only if all participants agree).
6	**Learning objectives and skills**	Students explain and use numerical methods for optimal control problems with ordinary differential equations and differential algebraic equations. They apply basic concepts of solution methodology using direct and indirect discretization methods for application problems, for example in technology or economics.
7	**Prerequisites**	Recommended: Basic knowledge in numerics, in theory of ordinary differential equations, and in optimization.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	M. Gerdts, Optimal Control of ODEs and DAEs, De Gruyter, 2012.

1	**Module name** 65993	**Numerics of Partial Differential Equations** Numerics of partial differential equations	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Classical theory of linear elliptic boundary value problems (outline) • Finite difference method (FDM) for Poissons equation in two dimensions (including stability via inverse monotonicity) • Finite element method (FEM) for Poissons equation in two dimensions (stability and convergence, example: linear finite elements, implementation) • Variational theory of linear elliptic boundary value problems (outline) • FEM for linear elliptic boundary value problems (2nd order) (types of elements, affin-equivalent triangulations, order of convergence, maximum principle) • Iterative methods for large sparse linear systems of equations (condition number of finite element matrices, linear stationary methods (recall), cg method (recall), preconditioning, Krylov subspace methods
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of problems and methods with a focus on conforming finite element methods for linear elliptic problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics, discretization, and optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer 2003 • S. Larssen & V. Thomee: Partial Differential Equations with Numerical Methods. Springer 2005 • D. Braess: Finite Elements. Cambridge University Press 2010 • lecture notes

1	**Module name** 65997	**Analysis of free-boundary problems in continuum mechanics**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Derivation of time-dependent free boundary problems in continuum mechanics, • Basic results on existence and qualitative behaviour, • Optimal estimates on the propagation of free boundaries, • Other approaches, e.g. relaxation by phase-field models.
6	**Learning objectives and skills**	Students • formulate free-boundary problems in hydrodynamics and in porousmedia flow • explain analytical concepts for existence and nonnegativity results for degenerate parabolic equations as well as techniques for optimal estimates on spreading rates • validate different modeling approaches in a critical way.
7	**Prerequisites**	Recommended: Basic knowledge of analysis of partial differential equations, corresponding to the syllabus of Modeling and Applied Analysis in Continuum Mechanics or that one of other pde-lectures.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• L.C. Evans: Partial Differential Equations, AMS, • Original journal articles.

1	**Module name** 65999	**Numerics of Partial Differential Equations II** Numerics of partial differential equations II	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of Partial Differential Equations II (2.0 SWS) Übung: Übungen zur Numerik PDGL II (Numerics of PDE II) (2.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Classical and weak theory for linear parabolic initial-boundary-value problems (IBVPs) (outline), • finite-element method (FEM) for 2nd-order linear parabolic IVBPs (semi-discretisation in space, time discretisation by one-step methods, stability, comparison principles, order of convergence), • FEM for semi-linear elliptic and parabolic equations (fixed-point- and Newton-methods, secondary iterations), • higher-order time discretisation, extrapolation, time-step control.
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of methods with a focus on conforming finite element methods for parabolic problems, extending these approaches also to nonlinear problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics and numerics of pde
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h

		Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner, L. Angermann, Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer, New York, 2003. • S. Larsson, V. Thomée, Partial Differential Equations with Numerical Methods, Springer, Berlin, 2005.

1	**Module name** 65787	**Seminar Applied Analysis** Seminar: Applied analysis	**5 ECTS**
2	Courses / lectures	Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Günther Grün	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Module ModAna1 is recommended
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics
10	**Method of examination**	Seminar achievement Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Seminar achievement (100%) Oral presentation (80%), presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen

1	**Module name** 48241	**Mathematical Image Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Mathematical Image Processing (2.0 SWS)	5 ECTS
		Tutorium: Tutorial for Mathematical Image Processing (0.5 SWS)	-
		This module is offered in every second summer term. The next course will be held in the summer semester 2024.	
3	Lecturers	Prof. Dr. Daniel Tenbrinck	

4	**Module coordinator**	Prof. Dr. Daniel Tenbrinck
5	**Contents**	This module covers mathematical image processing techniques based on Fourier domain filters, variational methods, and partial differential equations. In particular, the following content will be introduced to the students: • contrast enhancement • filtering in Fourier and image domain • Bayesian image denoising • image deblurring / deconvolution • pixel-based clustering • region-based segmentation • image inpainting • nonlocal image processing using graphs
6	**Learning objectives and skills**	Students following this course will • learn how image data can be modeled and analyzed mathematically • develop a deeper understanding of mathematical basics and methods for image processing • implement own algorithms for mathematical image processing • discover connections to related mathematical fields, e.g., inverse problems and convex analysis
7	**Prerequisites**	Knowledge in calculus and linear algebra is **recommended** to understand the mathematical foundations of image processing. Knowledge in functional analysis, numerical mathematics, or inverse problems is **helpful** to understand advanced concepts in mathematical image processing.
8	**Integration in curriculum**	semester: 2;1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written or oral Oral examination (20 min.) or written examination (60 min.) depending on size of course.
11	**Grading procedure**	Written or oral (100%) Oral exam (100%) or written exam (100%) depending on size of course.
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Aubert & P. Kornprobst: Mathematical problems in Image Processing, Springer • K. Bredies & D. Lorenz, Mathematical Image Processing, Springer • S. Osher & R. Fedkiw, Level Set Methods and Dynamic Implicit Surfaces, Springer • A. Elmoataz , O.Lezoray, S. Bougleux: Nonlocal Discrete Regularization on Weighted Graphs: a framework for Image and Manifold Processing, IEEE Transactions On Image Processing, 17 (7), pp: 1047-1060, 2008

1	**Module name** 65096	**Seminar Selected Topics of Applied Analysis**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Linear algebra and calculus are required. Basic knowledge in probability theory is recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics Summer or winter term after participation at ModAna1
10	**Method of examination**	Presentation Oral (90 minutes) Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Presentation (20%) Oral (80%)

		Oral presentation (80%) presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen

Specialisation: Modeling and applied analysis (MApA) and optimization (Opti)

1	**Module name** 65885	**Master's seminar MApA** Master`s seminar MApA	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-

		Seminar: Homogenization of fluid flow in porous media	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	A topic from MApA that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the MApA specialisation: • make use of analytical techniques to rigorously prove the qualitative characteristics of solutions to mathematical models in applied sciences.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written Presentation (90 minutes)
11	**Grading procedure**	Written (25%) Presentation (75%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65895	**Master seminar Opti**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
		Masterseminar: Material and Topology Optimization	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	A topic from Opti that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the Opti specialisation: • model theoretical and applied tasks as optimization problems and/or develop optimization algorithms for their solution and/or put these into practice.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65910	**Discrete optimization III**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture we will discuss selected topics in discrete and mixed-integer optimization. Possible topics include lattice methods, integer programming in fixed dimension, recent research on (mixed) integer linear and/or (mixed) integer nonlinear programming and so on. The specific topics may vary and will be announced in due time. FORMERLY: In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I and II
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005 • Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A - C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65068	**Wave Phenomena** Wave phenomena	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Motivations and applications. 2) Linear transport equation: method of characteristics; Fourier analysis and numerical approximations. 3) The wave equation: D'Alembert's representation formula; regularity of the solutions; finite speed of propagation of perturbations; Huygens' principle; geometric optics; wave models with sources or sinks; Kirchhoff's representation in R^3; Poisson's representation in R^2; the case of general odd and even space dimensions; energy methods: domain of dependence inequality and energy conservation; representation of solutions by using partial Fourier transform; subordination waves-heat; the reflection method and waves on the half-line; separation of variables. 4) Klein-Gordon equation: energy estimates; representation of solutions by using Fourier multipliers; von Wahl's transformation. 5) Damped wave equation: energy estimates; representation of solutions by using Fourier multipliers; decay behavior and decay rate. 6) Damped plate equation: estimates for the energy; estimates for the solution itself and its derivatives; 7) Semilinear wave equation: global existence for small data and global existence for large data. 8) Diffusion phenomena: parabolic structure of solutions to damped waves and damped plates; diffusion phenomena in thermo-elasticity; traveling waves and reaction-diffusion models. 9) Scalar conservation laws: occurrence of shocks and rarefaction waves. 10) Linear and nonlinear dispersive waves: Solitary waves for the Korteweg–de Vries equation; plane-wave solutions for the Airy equation and Schrödinger; Fourier analysis. 11) Maxwell equations: constitutive equations; special cases; boundary conditions; expansion into wave functions.
6	**Learning objectives and skills**	Students are able to: • identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • work interdisciplinary and in problem-oriented way; • use language and techniques related to partial differential equations; • work out the examples and applications that accompany the theory.

7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Ebert, M. R. & Reissig, M. Methods for Partial Differential Equations. Birkhäuser, 2018. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Kirsch, A. and Hettlich, F. The Mathematical Theory of Maxwell's Equations. Lecture Notes, 2013: • https://www.math.kit.edu/ianmip/lehre/maxwellequ2012w/media/main.pdf • Myint-U, T. & Debnath, L. Linear partial differential equations for scientists and engineers. Birkhäuser, 2007. • Reissig, M. Theory of hyperbolic equations. Lecture Notes, 2007: • https://tu-freiberg.de/sites/default/files/media/institut-fuer-angewandte-analysis-9030/reissig/pdehanoi1.pdf • Vichnevetsky, R. & Bowles, J. B. Fourier Analysis of Numerical Approximations of Hyperbolic Equations. SIAM, 1982 Lecture notes will be distributed via StudOn.

1	**Module name** 65928	**Inverse Problems**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	
5	**Contents**	• Examples of inverse and ill posed problems in engineering and medical imaging • Linear regularization methods in Hilbert spaces and singular value decomposition • Variational methods for regularization and image reconstruction problems • Tomographic reconstruction and Radon transforms
6	**Learning objectives and skills**	Students • develop understanding for special aspects of inverse problems and ill posedness, • apply regularization methods to inverse problems and develop a basic understanding of their properties, • derive and solve inverse problems arising from technical and biomedical applications.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• H. Engl, M. Hanke, A. Neubauer: Regularization Methods for Inverse Problems, Kluwer 1996 • M. Benning, M. Burger: Modern Regularization Methods for Inverse Problems, Acta Numerica 2018

1	**Module name** 65887	**Modul Conservation Laws** Module: Conservation laws	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Dr. Lukas Pflug
5	**Contents**	• (Non-)local conservation laws in applications • Linear scalar transport equations and conservation laws • Linear multi-D transport equations and conservation laws • Method of characteristics • Fixed-point methods in Banach spaces • Existence and uniqueness of nonlocal conservation laws • Maximum principles • Regularity and stability of solutions • Local conservation laws, Entropy solutions; • The singular limit problem – approximation of local Entropy solutions by nonlocal conservation laws • Numerical methods
6	**Learning objectives and skills**	Students learn the basic theory on nonlocal conservation laws, apply approximation results, learn fixed-point approaches in Banach spaces and understand the applicability of conservation laws in the applied sciences.
7	**Prerequisites**	Some basic knowledge in PDE is of advantage, Sobolev spaces.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	• Bressan, Alberto. Hyperbolic systems of conservation laws: the one-dimensional Cauchy problem. Vol. 20. Oxford University Press on Demand, 2000.

			• Keimer, Alexander, and Lukas Pflug. "Existence, uniqueness and regularity results on nonlocal balance laws." Journal of Differential Equations 263.7 (2017): 4023-4069. • Coclite, Giuseppe Maria, et al. "A general result on the approximation of local conservation laws by nonlocal conservation laws: The singular limit problem for exponential kernels." Annales de l'Institut Henri Poincaré C (2022). • Blandin, Sebastien, and Paola Goatin. "Well-posedness of a conservation law with non-local flux arising in traffic flow modeling." Numerische Mathematik 132.2 (2016): 217-241. • Aggarwal, Aekta, Rinaldo M. Colombo, and Paola Goatin. "Nonlocal systems of conservation laws in several space dimensions." SIAM Journal on Numerical Analysis 53.2 (2015): 963-983.

1	**Module name** 65888	**Navier Stokes Equations** Navier stokes equations	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Emil Wiedemann
5	**Contents**	The incompressible Navier-Stokes equations (NSE) are a nonlinear system of partial differential equations fundamental for the modelling of fluid flow. They are extensively used in meteorology and oceanography, but also pose great mathematical challenges. Famously, global regularity of the three-dimensional NSE forms one of the seven Millennium Problems. This course serves as an introduction to the mathematical theory of these equations and includes the following topics: • existence of weak solutions of Leray-Hopf type; • local-in-time existence of strong solutions; • the Prodi-Serrin criteria for regularity and energy balance; • partial regularity theory; • the singular limit of vanishing viscosity. The course can be a good preparation for a subsequent master's thesis in the topic.
6	**Learning objectives and skills**	Students know and understand the basic theory of the Navier-Stokes equations and have mastered important methods for systems of non-linear partial differential equations. They have a basic understanding of mathematical fluid dynamics.
7	**Prerequisites**	Lineare Algebra, Analysis. Empfohlen: erste Kurse in partiellen Differentialgleichungen und Funktionalanalysis.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	

16	**Bibliography**	• J. C. Robinson, J. L. Rodrigo, W. Sadowski: The Three-Dimensional Navier-Stokes Equations. Cambridge University Press, 2016. • P. Constantin, C. Foias: Navier-Stokes Equations. University of Chicago Press, 1988. • W. Ożański: The Partial Regularity Theory of Caffarelli, Kohn, and Nirenberg and its Sharpness. Birkhäuser, 2019. • E. Wiedemann: Navier-Stokes Equations: Lecture Notes. Universität Ulm, 2018/19.

1	**Module name** 65083	**Efficient discretization of two-phase flow**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr. Stefan Metzger
5	**Contents**	Based on recent scientific publications, different discretization approaches for two-phase flow are discussed.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session, • learn to compare different discretization methods regarding their specific advantages and disadvantages.
7	**Prerequisites**	Recommended: Numerics of Partial Differential Equations I
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65089	**Scalar conservation laws**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Introduction: applications and examples of conservation laws. 2) Review of functional analysis: L^p spaces; functions of bounded variation. 3) The method of characteristics: semilinear equations with constant coefficients; semilinear equations with variable coefficients; quasilinear equations. 4) Entropy solutions: discontinuous solutions of conservation laws; Rankine-Hugoniot condition; entropy and entropy flux; entropy solutions; Liu condition; Kruzkhov’s theorem; uniqueness and stability of entropy solutions. 5) Riemann problem: solutions of the Riemann problem for convex fluxes; solutions of the Riemann problem for general fluxes. 6) Front-tracking: construction of front-tracking approximations; existence of entropy solutions in BV. 7) Vanishing viscosity: viscous approximation; BV a priori estimates; existence of entropy solutions in BV. 8) Compensated compactness and applications to conservation laws: Young measures; Murat’s lemma; div-curl lemma; Tartar’s theorem; existence of entropy solutions in L^1 \cap L^\infty. 9) Oleinik’s estimate: Oleink’s estimate for conservation laws with convex fluxes; uniqueness via Oleinik’s estimate. 10) Lax-Oleinik’s formula: Legendre’s transform; Lax-Oleinik’s formula. 11) Hamilton-Jacobi equations: motivation; viscosity solutions; well-posedness of viscosity solutions; equivalence between entropy solutions of conservation laws and viscosity solutions of Hamilton-Jacobi equations. 12) Conservation laws on networks: motivations; entropy condition at a junction; vanishing viscosity approximation. 13) Nonlocal conservation laws: motivations; well-posedness of nonlocal conservation laws; the nonlocal-to-local singular limit problem.
6	**Learning objectives and skills**	Students are able to: • use language and techniques related to scalar conservation laws – especially regarding entropy solutions, Riemann problems, viscous approximations, and front tracking algorithms; • work out the examples and applications that accompany the theory.
7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis.
8	**Integration in curriculum**	semester: 2

9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Chapters 1-10: • Bressan, A. Hyperbolic Systems of Conservation Laws: The One-dimensional Cauchy Problem. Oxford University Press, 2000. • Coclite, G. M. Scalar Conservation Laws. Lecture Notes, 2022. • Dafermos, C. M. Hyperbolic Conservation Laws in Continuum Physics. Springer, 2016. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Godlewski, E. & Raviart P.-A. Numerical Approximation of Hyperbolic Systems of Conservation Laws. Springer, 2021. • Godlewski, E. & Raviart P.-A. Hyperbolic Systems of Conservation Laws. Ellipses, 1990. • Holden, H. & Risebro, N. H. Front Tracking for Hyperbolic Conservation Laws. Springer, 2015. • LeVeque, R. J. Numerical Methods for Conservation Laws. Birkhäuser, 1992. • Mishra, S., Fjordholm, U. S. & Abgrall, R. Numerical methods for conservation laws and related equations. Lecture Notes, 2019: https://metaphor.ethz.ch/x/2019/hs/401-4671-00L/literature/mishra_hyperbolic_pdes.pdf • Salsa, S. Partial differential equations in action. From modelling to theory. Springer, 2016. • Salsa, S. & Verzini, G. Partial differential equations in action. Complements and exercises. Springer, 2015. Chapter 11: • Bressan, A. Viscosity Solutions of Hamilton-Jacobi Equations and Optimal Control Problems. Lecture Notes, 2011: http://personal.psu.edu/axb62/PSPDF/HJ-lnotes.pdf.

		• Corrias, L., Falcone, M. and Natalini, R. Numerical Schemes for Conservation Laws via Hamilton-Jacobi Equations. Mathematics of Computation. Vol. 64, No. 210 (Apr., 1995), pp. 555-580. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Karlsen, K. H. & Risebro, N. H. A note on front tracking and the equivalence between viscosity solutions of Hamilton–Jacobi equations and entropy solutions of scalar conservation laws. Nonlinear Anal., Theory Methods Appl., Ser. A, Theory Methods 50, No. 4, 455-469 (2002). Chapter 12: • Andreianov, B. P., Coclite, G. M. & Donadello, C. Well-posedness for vanishing viscosity solutions of scalar conservation laws on a network. Discrete Contin. Dyn. Syst. 37, No. 11, 5913-5942 (2017). Chapter 13: • Coclite, G. M., De Nitti, N., Keimer, A. & Pflug, L. On existence and uniqueness of weak solutions to nonlocal conservation laws with BV kernels. Z. Angew. Math. Phys. 73, No. 6, Paper No. 241, 10 p. (2022). • Coclite, G. M. Coron, J.-M., De Nitti, N., Keimer, A. & Pflug, L. A general result on the approximation of local conservation laws by nonlocal conservation laws: The singular limit problem for exponential kernels. Annales de l'Institut Henri Poincaré C, Analyse Non Linéaire (2022). • Keimer, A. & Pflug, L. Existence, uniqueness and regularity results on nonlocal balance laws. J. Differ. Equations 263, No. 7, 4023-4069 (2017). Lecture notes will be distributed via StudOn.

1	**Module name** 65093	**Control, machine learning and numerics**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• several topics related to the control of Ordinary Differential Equations (ODE) and Partial Differential Equations (PDE), including controllability, observability, and some of the most fundamental work that has been done in the subject in recent years. • an introduction to Machine Learning, focusing mainly on the use of control techniques for the analysis of Deep Neural Networks as a tool to address, for instance, the problem of Supervised Learning. • some classical computational techniques related to the control of ODE and PDE, and machine learning.
6	**Learning objectives and skills**	Students are able to • understand some basic theory on control and machine learning. • learn about recent advances on control and machine learning. • implement some computational techniques using their own or specified software and critically evaluate the results, • set out their approaches and results in a comprehensible and convincing manner, making use of appropriate presentation techniques.
7	**Prerequisites**	Basic knowledge of calculus, linear algebra, ODE and PDE. Familiarity with scientific computing is helpful.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	1) L. Bottou, F. E. Curtis, and J. Nocedal, Optimization methods for large-scale machine learning. SIAM Review, 60 (2) (2018) , 223-311. 2) J. M. Coron, Control and Nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009. 3) I. Goodfellow, Y. Bengio, & A. Courville, Deep Learning. MIT press, 2016. 4) R. Glowinski, J. L. Lions, and J. He, Exact and Approximate Controllability for Distributed Parameter Systems: A Numerical Approach, Encyclopedia Math. Appl., Cambridge University Press, Cambridge, UK, 2008. 5) C. F. Higham, and D. J. Higham, Deep learning: An introduction for applied mathematicians. SIAM Review, 61 (4) (2019), 860-891. 6) J. Nocedal, and S. Wright, Numerical Optimization. Springer Science & Business Media, 2006. 7) D. Ruiz-Balet, and E. Zuazua, Neural ODE control for classification, approximation and transport. arXiv preprint arXiv:2104.05278, (2021). 8) E. Zuazua, Propagation, observation, and control of waves approximated by finite difference methods, SIAM Review, 47 (2) (2005), 197-243. 9) E. Zuazua, Controllability and observability of partial differential equations: some results and open problems, in Handbook of Differential Equations: Evolutionary Equations. Vol. 3. North-Holland, 2006. 527-621.

1	**Module name** 65700	**Lecture Series Partial Differential Equations, Control and Numerics (PdeConNum)** Lecture series: Partial differential equations, control and numerics (PdeConNum)	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• Examples of PDE models arising in industrial applications, Biology and Social Sciences • Long time asymptotics • Control of trajectories • Numerics for long time dynamics and control • Some applications in the control of population dynamics
6	**Learning objectives and skills**	Students • develop understanding for special aspects of dynamical systems control, • apply numerical methods to control problems and develop a basic understanding of their properties, • derive and solve inverse problems arising from applications.
7	**Prerequisites**	Recommended: basic knowledge in functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. M. Coron, Control and nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009 • E. Zuazua. Propagation, observation, and control of waves approximated by finite difference methods. SIAM Review, 47 (2) (2005), 197-243

1	**Module name** 65862	**Conic Optimization and Applications** Conic optimisation and applications	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Jan Rolfes
5	**Contents**	In modern Convex Optimization the theory of semidefinite optimization plays a central role. Semidefinite optimization is a generalization of linear optimization, where one wants to optimize linear functions over positive semidefinite matrices restricted by linear constraints. A wide class of convex optimization problems can be modeled using semidefinite optimization. On the one hand, there are algorithms to solve semidefinite optimization problems, which are efficient in theory and practice. On the other hand, semidefinite optimization is a tool of particular usefulness and elegance. Overview of topics: • Topological properties of cones • Foundations of conic optimization, theorems of the alternative, duality • Applications in Eigenvalue optimization and robust optimization • Approximations of combinatorial optimization problems such as MAXCUT, packing problems, coloring problems, Shannon capacity • Symmetry reduction of optimization
6	**Learning objectives and skills**	Students • gain insight of the fundamental concepts in conic optimization • apply algorithmic techniques to problems in the fields of combinatorics, geometry and algebra • extend their expertise in geometry, in particular about the interplay between the fields of geometry and optimization
7	**Prerequisites**	Recommended: at least one of the modules Linear and combinatorial optimization, robust optimization, discrete optimization
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Laurent, F. Vallentin: lecture notes • http://www.mi.uni-koeln.de/opt/wp-content/uploads/2015/10/laurent_vallentin_sdo_2012_05.pdf • Further literature and scientific publications are announced during the lectures

1	**Module name** 65902	**Transport and reaction in porous media: Modelling**	**5 ECTS**
2	Courses / lectures	Vorlesung: Transport and Reaction in Porous Media: Modeling (2.0 SWS) Übung: Tutorial to Transport and Reaction in Porous Media: Modeling (0.0 SWS)	4 ECTS 1 ECTS
3	Lecturers	apl. Prof. Dr. Serge Kräutle	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Modeling of fluid flow through a porous medium: Groundwater models, saturated and unsaturated porous medium (Richards equation) • Advection, diffusion, dispersion of dissolved substances, (nonlinear) reaction-models (i.a. law of mass action, kinetic / reversible reactions in local equilibrium), the stoichiometric matrix • Models of partial (PDEs), ordinary (ODEs) differential equations, and local algebraic conditions • Nonnegativity, boundedness, global existence of solutions, necessary model assumptions in the case of a pure ODE model as well as for a PDE model • Existence and uniqueness of stationary solutions in the stoichiometric space (i.a. introduction to the Feinberg network theory)
6	**Learning objectives and skills**	Students • are able to model flow and reaction processes in porous media on macro- and micro-scale using partial differential equations, • possess the techniques and the analytical foundations to assess the global existence of solutions.
7	**Prerequisites**	Recommended: Basic knowledge in differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• S. Kräutle: lecture notes https://www.math.fau.de/kraeutle/vorlesungsskripte/ • C. Eck, H. Garcke, P. Knabner: Mathematical Modeling, Springer • J.D. Logan: Transport Modeling in Hydrogeochemical Systems, Springer • M. Feinberg: lecture notes https://cbe.osu.edu/chemical-reaction-network-theory

1	**Module name** 65906	**Mathematics of multiscale models**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	PD Dr. Nicolas Neuß
5	**Contents**	• Function spaces of periodic functions and asymptotic expansions • Two-scale convergence and unfolding method • Application to differential equation models in continuum mechanics • Multi-scale finite element methods • Numerical upscaling methods
6	**Learning objectives and skills**	Students • have profound expertise about the basic methods in multi-scale analysis and homogenisation, • are able to derive rigorously homogenised (effective) models and analyse the quality of the approximation.
7	**Prerequisites**	Recommended: Knowledge in modeling as well as analysis and numerics of partial differential equations
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• D. Cioranescu & P. Donato: An Introduction to Homogenization • U. Hornung (ed.): Homogenization and Porous Media • Y. Efendiev & T. Hou: Multiscale Finite Element Methods

1	**Module name** 65907	**Theory of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Infinitely dimensional Wiener processes, • Stochastic integral in Hilbert spaces, • Ito-processes and stochastic differential equations, • Optionally: existence results for stochastic partial differential equations or further results on stochastic ODE (Fokker-Planck equations, . . .)
6	**Learning objectives and skills**	Students • characterize Gaussian measures on Hilbert spaces. They explain representation formulas for Q-Wiener processes as well as the derivation of the stochastic integral, • successfully apply concepts to solve stochastic differential equations explicitly and prove existence of solutions to stochastic evolution equations.
7	**Prerequisites**	Basic knowledge in probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Da Prato & J. Zabczyk: Stochastic equations in infinite dimensions, Cambridge University Press • I. Karatzas & S.E. Shreve: Brownian motion and stochastic calculus, Springer • B. Oksendal: Stochastic differential equations, Springer

			• C. Prévôt & M. Röckner: A concise course on stochastic partial differential equations, Springerchastic Evolution Equations

1	**Module name** 65911	**Mathematical modeling in the life sciences**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Maria Neuß
5	**Contents**	• Biochemical reaction networks, enzyme kinetics • Models for interacting populations (Predator-prey, competition, symbiosis) • Diffusion, reactions, and transport in biological cell tissues and vessels • Structured population models
6	**Learning objectives and skills**	Students • have profound knowledge in the area of mathematical modeling of processes in the life sciences • are able to identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • are able to work interdisciplinary and problem-oriented.
7	**Prerequisites**	Recommended: Modeling and Analysis in Continuum Mechanics I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. D. Murray: Mathematical Biology I: An Introduction, Mathematical Biology II: Spatial Models and Biomedical Applications • G. de Vries, T. Hillen, et al.: A course in Mathematical Biology • J. Prüss: Mathematische Modelle in der Biologie: Deterministische homogene Systeme

1	**Module name** 65914	**Partial differential equations in finance**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• models on pricing for financial derivatives, in particular for European and American-type options, selected deterministic equations of financial mathematics, • practical knowledge Ito-calculus and stochastic differential equations, • analysis and numerics for Black-Scholes equations, • variational inequalities and American-type options.
6	**Learning objectives and skills**	Students • explain mathematical models for financial markets and derivatives pricing, • apply Ito calculus, derive deterministic models based on pde or variational inequalities and discretize them numerically.
7	**Prerequisites**	Basis knowledge in differential equations, probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Capinski & T. Zastawniak: Mathematics for finance, Springer, • N. Hilber, O. Reichmann, C. Schwab & C. Winter: Computational methods for quantitative finance, Springer, • B. Oksendal: Stochastic differential equations, Springer.

1	**Module name** 65915	**Introduction to material- and shape optimization**	**10 ECTS**
2	Courses / lectures	Vorlesung: Introduction to Material and Shape Optimization (4.0 SWS)	10 ECTS
3	Lecturers	Prof. Dr. Michael Stingl	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	• shape-, material- and topology optimization models • linear elasticity and contact problems • existence of solutions of shape, material and topology optimization problems • approximation of shape, material and topology optimization problems by convergent schemes
6	**Learning objectives and skills**	Students • derive mathematical models for shape-, material and topology optimization problems, • apply regularization techniques to guarantee to existence of solutions, • approximate design problems by finite dimensional discretizations, • derive algebraic forms and solve these by nonlinear programming techniques.
7	**Prerequisites**	Recommended: • Knowledge in nonlinear optimization, • Basic knowledge in numerics of partial differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. Haslinger & R. Mäkinen: Introduction to shape optimization, SIAM, • M. P. Bendsoe & O. Sigmund: Topology Optimization: Theory, Methods and Applications, Springer.

1	**Module name** 65916	**Advanced algorithms for nonlinear optimization**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Trust region methods • Iterative methods in the presence of noisy data • Interior point methods for nonlinear problems • Modified barrier and augmented Lagrangian methods • Local and global convergence analysis
6	**Learning objectives and skills**	Students • use methods of nonlinear constrained optimization in finite dimensional spaces, • analyse convergence behaviour of these methods and derive robust and efficient realisations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• C.T. Kelley: Iterative Methods for Optimization, SIAM, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65917	**Discrete optimization I**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Theoretical and practical fundamentals of solving difficult mixed-integer linear optimization problems (MIPs) constitute the main focus of this lecture. At first, the concept of NP-completeness and a selection of common NP-complete problems will be presented. As for polyhedral theory, fundamentals concerning the structure of faces of convex polyhedra will be covered. Building upon these fundamentals, cutting plane algorithms as well as branch-and-cut algorithms for solving MIPs will be taught. Finally, some typical problems of discrete optimization, e.g., the knapsack problem, the traveling salesman problem or the set packing problem will be discussed.
6	**Learning objectives and skills**	Students • will gain basic theoretical knowledge of solving mixed-integer linear optimization problems (MIPs), • are able to solve MIPs with the help of state-of-the-art optimization software.
7	**Prerequisites**	Recommended: Linear and Combinatorial Optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 65918	**Robust optimization II**	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Robuste Optimierung 2 (2.0 SWS) Vorlesung: Robuste Optimierung 2 (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Frauke Liers-Bergmann Martina Kuchlbauer Florian Rösel	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• In practice, provided data for mathematical optimization problems is often not fully known. Robust optimization aims at finding the best solution which is feasible for input data varying within certain tolerances. The lecture covers advanced methods of robust optimization in theory and modeling. In particular, robust network flows, robust integer optimization and robust approximation are included. Further, state-of-the-art concepts, e.g., "light robustness" or "adjustable robustness" will be discussed by means of real-world applications.
6	**Learning objectives and skills**	Students • will be able to identify complex optimization problems under uncertainties as well as suitably model and analyze the corresponding robust optimization problem with the help of advanced techniques of robust optimization, • learn the handling of appropriate solving techniques and how to analyze the corresponding results.
7	**Prerequisites**	• Recommended: Robust Optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes, will be published on StudOn at the beginning of the semester.

1	**Module name** 65919	**Numerical aspects of linear and integer programming**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Revised Simplex (with bounds) • Simplex Phase I • Dual Simplex • LP Presolve/Postsolve • Scaling • MIP Solution Techniques
6	**Learning objectives and skills**	Students are able to explain and use methods and numerical approaches for solving linear and mixed-integer programs in practice.
7	**Prerequisites**	Knowledge in linear algebra and combinatorial optimization is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Chvátal: Linear Programming, W. H. Freeman and Company, New York, 1983 • L.A. Wolsey: Integer Programming, John Wiley and Sons, Inc., 1998

1	**Module name** 65920	**Advanced nonlinear optimization**	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Wolfgang Achtziger
5	**Contents**	• advanced optimality conditions and constraint qualifications for constrained optimization problems • penalty, barrier and augmented Lagrangian methods: theory and algorithms • interior point methods • sequential quadratic programming
6	**Learning objectives and skills**	Students • explain and extend their knowledge on theory and algorithms of nonlinear optimization problems, • apply solution techniques to different advanced types of optimization problems, • derive and solve optimization problems arising from technical and economical applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M.S. Bazaraa, H.D. Sherali & C.M. Shetty: Nonlinear Programming Theory and Algorithms, Wiley, New York, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65921	**Optimization with partial differential equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Optimization and control in Banach spaces • Concepts of controllability and stabilization • Optimal control of Partial differential equations • Singular Perturbations and asymptotic analysis • Numerical realizations of optimal controls • Technical, medical and economic applications
6	**Learning objectives and skills**	Students • explain and use theory as well as numerical methods for optimization, control and stabilization in the context of partial differential equations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in numerics, partial differential equations, and nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS • G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser

1	**Module name** 65923	**Optimization in industry and economy**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	This course focuses on modeling and solving real-world optimization problems occurring in industry and economics. Advantages and disadvantages of different modeling techniques will be outlined. In order to achieve efficient solution approaches, different reformulations and their numerical results will be discussed. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications. The latter may include but is not limited to the optimization of transport networks (gas, water, energy), air traffic management and mathematical modeling/optimization of market mechanisms in the energy sector.
6	**Learning objectives and skills**	Students • model complex real-world optimization problems with respect to efficient • solvability, • classify the models and use appropriate solution strategies, • evaluate the achieved computational results.
7	**Prerequisites**	Recommended: Modul LKOpt: Linear and combinatorial optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes (will be published on StudOn at the beginning of the semester) • Up-to-date research literature (will be published on StudOn at the beginning of the semester)

1	**Module name** 65924	**Project seminar optimization**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	A specific application is to be used to implement the knowledge of mathematical optimisation models and methods acquired during the degree programme thus far. The content is taken from a current problem, often in close collaboration with an industrial partner. Examples might be the water supply for a city, the design of an energy-efficient facade for an office building or railway construction site management.
6	**Learning objectives and skills**	Students • organise themselves into teams to carry out a large project in which they independently model a real problem, develop and implement solutions and apply their results in practical situations, • strengthen their communication skills by presenting and discussing the results of the project work, • discuss information, ideas, problems and solutions at an academic level with each other and with the lecturers.
7	**Prerequisites**	Recommended: knowledge in combinatorial optimisation
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar paper Presentation
11	**Grading procedure**	Seminar paper (50%) Presentation (50%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Project-dependent. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65933	**Discrete optimization II**	**5 ECTS**
2	Courses / lectures	Vorlesung: Discrete Optimization II (2.0 SWS) Übung: Übung Diskrete Optimierung II (1.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Michael Hartisch Florian Rösel	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005

			• Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A-C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65954	**Numerik der Optimalen Steuerungen** Numerics of optimal control	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerik der Optimalen Steuerungen (Numerics of optimal control)	5 ECTS
3	Lecturers	Prof. Dr. Hannes Meinlschmidt	

4	**Module coordinator**	Prof. Dr. Hannes Meinlschmidt
5	**Contents**	The following topics are covered: Discretization methods for differential equations, aspects of nonlinear optimization methods, direct discretization methods (fully and reduced discretized), indirect methods based on discretization of necessary optimality conditions as well as methods for efficient sensitivity calculations with internal numerical differentiation and adjoint equations. The material is presented in lecture form. Further acquisition of the essential concepts and techniques takes place through self-study of accompanying literature and the completion of exercises, supported by meetings within the tutorials. By default, the lecture will be given in English (in German only if all participants agree).
6	**Learning objectives and skills**	Students explain and use numerical methods for optimal control problems with ordinary differential equations and differential algebraic equations. They apply basic concepts of solution methodology using direct and indirect discretization methods for application problems, for example in technology or economics.
7	**Prerequisites**	Recommended: Basic knowledge in numerics, in theory of ordinary differential equations, and in optimization.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	M. Gerdts, Optimal Control of ODEs and DAEs, De Gruyter, 2012.

1	**Module name** 65959	**Theorie der Optimalsteuerungen** Optimal control theory	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Hannes Meinlschmidt
5	**Contents**	Grundlagen zu folgenden Themen: • Diskrete und kontinuierliche Dynamische Systeme in allgemeinen Räumen • Eingabe- und Ausgabeoperatoren, Beobachter und Aktuatoren • Lösungstheorie und qualitative Theorie • Steuerbarkeit und Stabilisierbarkeit • Restriktionen für Steuerungen und Zuständen • Open-Loop- und Closed-Loop-Steuerungen • Pontriagin'sches Maximum-Prinzip • Dynamische Programmierung • Numerische Realisierung optimaler Steuerungen Die Präsentation des Stoffes erfolgt in Vorlesungsform. Die weitere Aneignung der wesentlichen Begriffe und Techniken erfolgt durch Selbststudium begleitender Literatur, unterstützt durch Zusammenkünfte innerhalb der Übungen.
6	**Learning objectives and skills**	Die Studierenden
7	**Prerequisites**	empfohlen: • Grundkenntnisse der Numerik, der gewöhnlichen und partiellen Differentialgleichungen, der Optimierung
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• E. Sontag, Mathematical Control Theory, Springer-Verlag 2000 • F. Tröltzsch, Steuerungstheorie Partieller Differenialgleichungen, Vieweg Verlag, 2003

1	**Module name** 65997	**Analysis of free-boundary problems in continuum mechanics**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Derivation of time-dependent free boundary problems in continuum mechanics, • Basic results on existence and qualitative behaviour, • Optimal estimates on the propagation of free boundaries, • Other approaches, e.g. relaxation by phase-field models.
6	**Learning objectives and skills**	Students • formulate free-boundary problems in hydrodynamics and in porousmedia flow • explain analytical concepts for existence and nonnegativity results for degenerate parabolic equations as well as techniques for optimal estimates on spreading rates • validate different modeling approaches in a critical way.
7	**Prerequisites**	Recommended: Basic knowledge of analysis of partial differential equations, corresponding to the syllabus of Modeling and Applied Analysis in Continuum Mechanics or that one of other pde-lectures.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• L.C. Evans: Partial Differential Equations, AMS, • Original journal articles.

1	**Module name** 65787	**Seminar Applied Analysis** Seminar: Applied analysis	**5 ECTS**
2	Courses / lectures	Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Günther Grün	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Module ModAna1 is recommended
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics
10	**Method of examination**	Seminar achievement Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Seminar achievement (100%) Oral presentation (80%), presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen

1	**Module name** 65877	**Polynomial Optimization and Application**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Giovanni Fantuzzi
5	**Contents**	Polynomial optimization problems (POPs) form a broad class of optimization problems that find applications to control theory, dynamical systems, optimal transport, power flow networks, fluid mechanics, and many other fields. This course will introduce students to a modern approach to solving POPs through semidefinite programming techniques. More specifically, the course will cover: • The basics of semidefinite programs • The theory of sum-of-squares (SOS) polynomials • Moment-SOS hierarchies for polynomial optimization problems • Applications (e.g. to dynamical system analysis) Students will also have the opportunity to put the theory into practice with “hands-on” practical assignments.
6	**Learning objectives and skills**	By the end of the course, students should be able to: • Explain what polynomial optimization problems (POPs) are • Give examples of applications where POPs arise • Formulate semidefinite programming relaxations of POPs • Apply moment-SOS hierarchies to a range of problems • Solve POPs in practice using existing software
7	**Prerequisites**	Previous experience with optimization (especially convex and/or conic optimization) and with differential equations is desirable.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	
16	**Bibliography**	Lecture notes will be provided as the course progresses.A reading list will also be provided at the start of the course.

1	**Module name** 48241	**Mathematical Image Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Mathematical Image Processing (2.0 SWS) Tutorium: Tutorial for Mathematical Image Processing (0.5 SWS) This module is offered in every second summer term. The next course will be held in the summer semester 2024.	5 ECTS -
3	Lecturers	Prof. Dr. Daniel Tenbrinck	

4	**Module coordinator**	Prof. Dr. Daniel Tenbrinck
5	**Contents**	This module covers mathematical image processing techniques based on Fourier domain filters, variational methods, and partial differential equations. In particular, the following content will be introduced to the students: • contrast enhancement • filtering in Fourier and image domain • Bayesian image denoising • image deblurring / deconvolution • pixel-based clustering • region-based segmentation • image inpainting • nonlocal image processing using graphs
6	**Learning objectives and skills**	Students following this course will • learn how image data can be modeled and analyzed mathematically • develop a deeper understanding of mathematical basics and methods for image processing • implement own algorithms for mathematical image processing • discover connections to related mathematical fields, e.g., inverse problems and convex analysis
7	**Prerequisites**	Knowledge in calculus and linear algebra is **recommended** to understand the mathematical foundations of image processing. Knowledge in functional analysis, numerical mathematics, or inverse problems is **helpful** to understand advanced concepts in mathematical image processing.
8	**Integration in curriculum**	semester: 2;1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written or oral Oral examination (20 min.) or written examination (60 min.) depending on size of course.
11	**Grading procedure**	Written or oral (100%) Oral exam (100%) or written exam (100%) depending on size of course.
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Aubert & P. Kornprobst: Mathematical problems in Image Processing, Springer • K. Bredies & D. Lorenz, Mathematical Image Processing, Springer • S. Osher & R. Fedkiw, Level Set Methods and Dynamic Implicit Surfaces, Springer • A. Elmoataz , O.Lezoray, S. Bougleux: Nonlocal Discrete Regularization on Weighted Graphs: a framework for Image and Manifold Processing, IEEE Transactions On Image Processing, 17 (7), pp: 1047-1060, 2008

1	**Module name** 65970	**Stochastische Analysis** Stochastic analysis	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Torben Krüger
5	**Contents**	• Itokalkulus • Diffusionsprozesse • Stochastische Differentialgleichungen • Die Präsentation des Stoffes erfolgt in Vorlesungsform.
6	**Learning objectives and skills**	Die Studierenden erwerben die Fähigkeit komplexere Strukturen der Stochastik selbständig zu erfassen und auf exemplarische Problemstellungen anzuwenden. Diese bilden eine Basis für eine Spezialisierung in Stochastik undentsprechenden wirtschaftsmathematischen Themen.
7	**Prerequisites**	empfohlen: Kenntnisse der Wahrscheinlichkeitstheorie sind zum Verständnis hilfreich
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Die vorbereitende Literatur wird für jede Lehrveranstaltung jedes Semester neu festgelegt.

1	**Module name** 65096	**Seminar Selected Topics of Applied Analysis**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Linear algebra and calculus are required. Basic knowledge in probability theory is recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics Summer or winter term after participation at ModAna1
10	**Method of examination**	Presentation Oral (90 minutes) Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Presentation (20%) Oral (80%)

		Oral presentation (80%) presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen

Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti)

1	**Module name** 65890	**Master's seminar NASi**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	A topic from NASi that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the NASi specification: • can solve exemplary computational problems with given or self-developed software in order to illustrate or verify numerical methods under consideration.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65895	**Master seminar Opti**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
		Masterseminar: Material and Topology Optimization	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	A topic from Opti that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the Opti specialisation: • model theoretical and applied tasks as optimization problems and/or develop optimization algorithms for their solution and/or put these into practice.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65910	**Discrete optimization III**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture we will discuss selected topics in discrete and mixed-integer optimization. Possible topics include lattice methods, integer programming in fixed dimension, recent research on (mixed) integer linear and/or (mixed) integer nonlinear programming and so on. The specific topics may vary and will be announced in due time. FORMERLY: In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I and II
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005 • Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A - C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65909	**Subspace correction methods**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Carsten Gräser
5	**Contents**	1) Subspace correction as an abstract framework to construct and analyse efficient iterative methods 2) Analysis of additive and multiplicative subspace correction 3) Multigrid and domain decomposition as subspace correction methods 4) Nonlinear subspace correction methods
6	**Learning objectives and skills**	Students are • familiar with the abstract subspace correction framework • can select problem adapted methods • can analyse specific methods within the framework
7	**Prerequisites**	Recommended: Introduction to numerical methods for PDEs Recommended: Basic knowledge of functional analysis (but the necessary terminology and results are briefly provided during the lecture)
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes) oral exam (15 min)
11	**Grading procedure**	Oral (100%) 100% based on oral exam
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	• H. Yserentant: Old and New Convergence Proofs for Multigrid Methods, Acta Numer. 1993 • J.-C. Xu: Iterative Methods by Space Decomposition and Subspace Correction, SIAM Rev., 1992 • Further literature and publications are announced during the lecture

1	**Module name** 65068	**Wave Phenomena** Wave phenomena	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Motivations and applications. 2) Linear transport equation: method of characteristics; Fourier analysis and numerical approximations. 3) The wave equation: D'Alembert's representation formula; regularity of the solutions; finite speed of propagation of perturbations; Huygens' principle; geometric optics; wave models with sources or sinks; Kirchhoff's representation in R^3; Poisson's representation in R^2; the case of general odd and even space dimensions; energy methods: domain of dependence inequality and energy conservation; representation of solutions by using partial Fourier transform; subordination waves-heat; the reflection method and waves on the half-line; separation of variables. 4) Klein-Gordon equation: energy estimates; representation of solutions by using Fourier multipliers; von Wahl's transformation. 5) Damped wave equation: energy estimates; representation of solutions by using Fourier multipliers; decay behavior and decay rate. 6) Damped plate equation: estimates for the energy; estimates for the solution itself and its derivatives; 7) Semilinear wave equation: global existence for small data and global existence for large data. 8) Diffusion phenomena: parabolic structure of solutions to damped waves and damped plates; diffusion phenomena in thermo-elasticity; traveling waves and reaction-diffusion models. 9) Scalar conservation laws: occurrence of shocks and rarefaction waves. 10) Linear and nonlinear dispersive waves: Solitary waves for the Korteweg–de Vries equation; plane-wave solutions for the Airy equation and Schrödinger; Fourier analysis. 11) Maxwell equations: constitutive equations; special cases; boundary conditions; expansion into wave functions.
6	**Learning objectives and skills**	Students are able to: • identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • work interdisciplinary and in problem-oriented way; • use language and techniques related to partial differential equations; • work out the examples and applications that accompany the theory.

7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Ebert, M. R. & Reissig, M. Methods for Partial Differential Equations. Birkhäuser, 2018. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Kirsch, A. and Hettlich, F. The Mathematical Theory of Maxwell’s Equations. Lecture Notes, 2013: • https://www.math.kit.edu/ianmip/lehre/maxwellequ2012w/media/main.pdf • Myint-U, T. & Debnath, L. Linear partial differential equations for scientists and engineers. Birkhäuser, 2007. • Reissig, M. Theory of hyperbolic equations. Lecture Notes, 2007: • https://tu-freiberg.de/sites/default/files/media/institut-fuer-angewandte-analysis-9030/reissig/pdehanoi1.pdf • Vichnevetsky, R. & Bowles, J. B. Fourier Analysis of Numerical Approximations of Hyperbolic Equations. SIAM, 1982 Lecture notes will be distributed via StudOn.

1	**Module name** 65089	**Scalar conservation laws**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	1) Introduction: applications and examples of conservation laws. 2) Review of functional analysis: L^p spaces; functions of bounded variation. 3) The method of characteristics: semilinear equations with constant coefficients; semilinear equations with variable coefficients; quasilinear equations. 4) Entropy solutions: discontinuous solutions of conservation laws; Rankine-Hugoniot condition; entropy and entropy flux; entropy solutions; Liu condition; Kruzkhov's theorem; uniqueness and stability of entropy solutions. 5) Riemann problem: solutions of the Riemann problem for convex fluxes; solutions of the Riemann problem for general fluxes. 6) Front-tracking: construction of front-tracking approximations; existence of entropy solutions in BV. 7) Vanishing viscosity: viscous approximation; BV a priori estimates; existence of entropy solutions in BV. 8) Compensated compactness and applications to conservation laws: Young measures; Murat's lemma; div-curl lemma; Tartar's theorem; existence of entropy solutions in L^1 \cap L^\infty. 9) Oleinik's estimate: Oleink's estimate for conservation laws with convex fluxes; uniqueness via Oleinik's estimate. 10) Lax-Oleinik's formula: Legendre's transform; Lax-Oleinik's formula. 11) Hamilton-Jacobi equations: motivation; viscosity solutions; well-posedness of viscosity solutions; equivalence between entropy solutions of conservation laws and viscosity solutions of Hamilton-Jacobi equations. 12) Conservation laws on networks: motivations; entropy condition at a junction; vanishing viscosity approximation. 13) Nonlocal conservation laws: motivations; well-posedness of nonlocal conservation laws; the nonlocal-to-local singular limit problem.
6	**Learning objectives and skills**	Students are able to: • use language and techniques related to scalar conservation laws – especially regarding entropy solutions, Riemann problems, viscous approximations, and front tracking algorithms; • work out the examples and applications that accompany the theory.
7	**Prerequisites**	Recommended: knowledge of linear algebra and calculus; basic knowledge of functional analysis.
8	**Integration in curriculum**	semester: 2

9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Chapters 1-10: • Bressan, A. Hyperbolic Systems of Conservation Laws: The One-dimensional Cauchy Problem. Oxford University Press, 2000. • Coclite, G. M. Scalar Conservation Laws. Lecture Notes, 2022. • Dafermos, C. M. Hyperbolic Conservation Laws in Continuum Physics. Springer, 2016. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Godlewski, E. & Raviart P.-A. Numerical Approximation of Hyperbolic Systems of Conservation Laws. Springer, 2021. • Godlewski, E. & Raviart P.-A. Hyperbolic Systems of Conservation Laws. Ellipses, 1990. • Holden, H. & Risebro, N. H. Front Tracking for Hyperbolic Conservation Laws. Springer, 2015. • LeVeque, R. J. Numerical Methods for Conservation Laws. Birkhäuser, 1992. • Mishra, S., Fjordholm, U. S. & Abgrall, R. Numerical methods for conservation laws and related equations. Lecture Notes, 2019: https://metaphor.ethz.ch/x/2019/hs/401-4671-00L/literature/mishra_hyperbolic_pdes.pdf • Salsa, S. Partial differential equations in action. From modelling to theory. Springer, 2016. • Salsa, S. & Verzini, G. Partial differential equations in action. Complements and exercises. Springer, 2015. Chapter 11: • Bressan, A. Viscosity Solutions of Hamilton-Jacobi Equations and Optimal Control Problems. Lecture Notes, 2011: http://personal.psu.edu/axb62/PSPDF/HJ-lnotes.pdf.

		• Corrias, L., Falcone, M. and Natalini, R. Numerical Schemes for Conservation Laws via Hamilton-Jacobi Equations. Mathematics of Computation. Vol. 64, No. 210 (Apr., 1995), pp. 555-580. • Evans, L. C. Partial Differential Equations. AMS, 2010. • Karlsen, K. H. & Risebro, N. H. A note on front tracking and the equivalence between viscosity solutions of Hamilton–Jacobi equations and entropy solutions of scalar conservation laws. Nonlinear Anal., Theory Methods Appl., Ser. A, Theory Methods 50, No. 4, 455-469 (2002). Chapter 12: • Andreianov, B. P., Coclite, G. M. & Donadello, C. Well-posedness for vanishing viscosity solutions of scalar conservation laws on a network. Discrete Contin. Dyn. Syst. 37, No. 11, 5913-5942 (2017). Chapter 13: • Coclite, G. M., De Nitti, N., Keimer, A. & Pflug, L. On existence and uniqueness of weak solutions to nonlocal conservation laws with BV kernels. Z. Angew. Math. Phys. 73, No. 6, Paper No. 241, 10 p. (2022). • Coclite, G. M. Coron, J.-M., De Nitti, N., Keimer, A. & Pflug, L. A general result on the approximation of local conservation laws by nonlocal conservation laws: The singular limit problem for exponential kernels. Annales de l'Institut Henri Poincaré C, Analyse Non Linéaire (2022). • Keimer, A. & Pflug, L. Existence, uniqueness and regularity results on nonlocal balance laws. J. Differ. Equations 263, No. 7, 4023-4069 (2017). Lecture notes will be distributed via StudOn.

1	**Module name** 65083	**Efficient discretization of two-phase flow**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr. Stefan Metzger
5	**Contents**	Based on recent scientific publications, different discretization approaches for two-phase flow are discussed.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session, • learn to compare different discretization methods regarding their specific advantages and disadvantages.
7	**Prerequisites**	Recommended: Numerics of Partial Differential Equations I
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65093	**Control, machine learning and numerics**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• several topics related to the control of Ordinary Differential Equations (ODE) and Partial Differential Equations (PDE), including controllability, observability, and some of the most fundamental work that has been done in the subject in recent years. • an introduction to Machine Learning, focusing mainly on the use of control techniques for the analysis of Deep Neural Networks as a tool to address, for instance, the problem of Supervised Learning. • some classical computational techniques related to the control of ODE and PDE, and machine learning.
6	**Learning objectives and skills**	Students are able to • understand some basic theory on control and machine learning. • learn about recent advances on control and machine learning. • implement some computational techniques using their own or specified software and critically evaluate the results, • set out their approaches and results in a comprehensible and convincing manner, making use of appropriate presentation techniques.
7	**Prerequisites**	Basic knowledge of calculus, linear algebra, ODE and PDE. Familiarity with scientific computing is helpful.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	1) L. Bottou, F. E. Curtis, and J. Nocedal, Optimization methods for large-scale machine learning. SIAM Review, 60 (2) (2018) , 223-311. 2) J. M. Coron, Control and Nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009. 3) I. Goodfellow, Y. Bengio, & A. Courville, Deep Learning. MIT press, 2016. 4) R. Glowinski, J. L. Lions, and J. He, Exact and Approximate Controllability for Distributed Parameter Systems: A Numerical Approach, Encyclopedia Math. Appl., Cambridge University Press, Cambridge, UK, 2008. 5) C. F. Higham, and D. J. Higham, Deep learning: An introduction for applied mathematicians. SIAM Review, 61 (4) (2019), 860-891. 6) J. Nocedal, and S. Wright, Numerical Optimization. Springer Science & Business Media, 2006. 7) D. Ruiz-Balet, and E. Zuazua, Neural ODE control for classification, approximation and transport. arXiv preprint arXiv:2104.05278, (2021). 8) E. Zuazua, Propagation, observation, and control of waves approximated by finite difference methods, SIAM Review, 47 (2) (2005), 197-243. 9) E. Zuazua, Controllability and observability of partial differential equations: some results and open problems, in Handbook of Differential Equations: Evolutionary Equations. Vol. 3. North-Holland, 2006. 527-621.

1	**Module name** 65095	**Practical course on finite element methods for phase-separation equations** Practical course on finite element methods for phase separation equations	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Finite element discretization for Cahn-Hilliard equations, • Storage concepts for sparse matrices, • Adaptive mesh refinement.
6	**Learning objectives and skills**	Students • implement a finite element solver for phase-separation equations, • are able to compare and implement different storage concepts for sparse matrices, • are able to implement finite element solvers based on adaptive meshes, • are able to derive and implement efficient discretizations for phase-separation equations, • are able to validate their implementation.
7	**Prerequisites**	Recommended: Numerics of Partial Differential Equations I
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer 2003 • D. Braess: Finite Elements. Cambridge University Press 2010 • B. Stroustrup: The C++ programming language, Addison-Wesley 2014

1	**Module name** 65700	**Lecture Series Partial Differential Equations, Control and Numerics (PdeConNum)** Lecture series: Partial differential equations, control and numerics (PdeConNum)	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• Examples of PDE models arising in industrial applications, Biology and Social Sciences • Long time asymptotics • Control of trajectories • Numerics for long time dynamics and control • Some applications in the control of population dynamics
6	**Learning objectives and skills**	Students • develop understanding for special aspects of dynamical systems control, • apply numerical methods to control problems and develop a basic understanding of their properties, • derive and solve inverse problems arising from applications.
7	**Prerequisites**	Recommended: basic knowledge in functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. M. Coron, Control and nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009 • E. Zuazua. Propagation, observation, and control of waves approximated by finite difference methods. SIAM Review, 47 (2) (2005), 197-243

1	**Module name** 65785	**Mathematics of Learning** Mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Machine learning: empirical risk minimization, kernel methods and variational models • Mathematical aspects of deep learning • Ranking problems • Mathematical models of network interaction
6	**Learning objectives and skills**	Students • develop understanding of modern big data and state of the art methods to analyze them, • apply state of the art algorithms to large data sets, • derive models for network / graph structured data.
7	**Prerequisites**	Prerequisites: Basic knowledge in numerical methods and optimization is recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, Bengio, Courville, Deep Learning, MIT Press, 2015 • Hastie, Tibshirani, Friedman, The Elements of Statistical Learning, 2008

1	**Module name** 65862	**Conic Optimization and Applications** Conic optimisation and applications	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Jan Rolfes
5	**Contents**	In modern Convex Optimization the theory of semidefinite optimization plays a central role. Semidefinite optimization is a generalization of linear optimization, where one wants to optimize linear functions over positive semidefinite matrices restricted by linear constraints. A wide class of convex optimization problems can be modeled using semidefinite optimization. On the one hand, there are algorithms to solve semidefinite optimization problems, which are efficient in theory and practice. On the other hand, semidefinite optimization is a tool of particular usefulness and elegance. Overview of topics: • Topological properties of cones • Foundations of conic optimization, theorems of the alternative, duality • Applications in Eigenvalue optimization and robust optimization • Approximations of combinatorial optimization problems such as MAXCUT, packing problems, coloring problems, Shannon capacity • Symmetry reduction of optimization
6	**Learning objectives and skills**	Students • gain insight of the fundamental concepts in conic optimization • apply algorithmic techniques to problems in the fields of combinatorics, geometry and algebra • extend their expertise in geometry, in particular about the interplay between the fields of geometry and optimization
7	**Prerequisites**	Recommended: at least one of the modules Linear and combinatorial optimization, robust optimization, discrete optimization
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Laurent, F. Vallentin: lecture notes • http://www.mi.uni-koeln.de/opt/wp-content/uploads/2015/10/laurent_vallentin_sdo_2012_05.pdf • Further literature and scientific publications are announced during the lectures

1	**Module name** 65863	**Practical course on finite element methods for phase-separation equations**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Finite-element discretization for Cahn-Hilliard equations • Storage concepts for sparse matrices • Adaptive mesh refinement
6	**Learning objectives and skills**	Students • implement a finite element solver for phase-separation equations, • are able to compare and implement different storage concepts for sparse matrices, • are able to implement finite element solvers based on adaptive meshes, • are able to derive and implement efficient discretizations for phase separation equations, • are able to validate their implementation.
7	**Prerequisites**	Recommended: Numerics of partial differential equations I
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann, Numerical methods for elliptic and parabolic differential equations, Springer 2003 • D. Braess, Finite elements, Cambridge University Press 2010 • B. Stoustrup, The C++ programming language, Addison-Wesley 2014

1	**Module name** 65900	**Advanced discretization techniques**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• conforming and non-conforming finite element methods • saddle point problems in Hilbert spaces • mixed finite element methods for saddle point problems, in particular for Darcy and Stokes • Streamline-Upwind Petrov-Galerkin (SUPG) and discontinuous Galerkin (dG) finite element methods (FEM) for convection dominated problems • Finite Volume (FV) methods and their relation to FEM • a posteriori error control and adaptive methods
6	**Learning objectives and skills**	Students • have a discriminating understanding, both theoretically and computationally of FE as well as FV methods for the numerical solution of partial differential equations (pde) (in particular of saddle point problems), • are capable of developing problem dependent FE or FV methods and judge on their properties regarding stability and effectiveness, • are familiar with a broad spectrum of pde problems and their computational solutions, • are capable of designing algorithms for adaptive mesh control.
7	**Prerequisites**	Recommended: Introduction to numerical methods for pdes, functional analysis
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• A. Ern, J.-L. Guermond: Theory and Practice of Finite Elements • A. Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer • D. A. Di Piettro & A. Ern: Mathematical aspects of discontinuous Galerkin methods. Springer 2012

1	**Module name** 65901	**Advanced solution techniques**	**5 ECTS**
2	Courses / lectures	Übung: Exercises for Advanced Solution Techniques (1.0 SWS) Vorlesung: Advanced Solution Techniques (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Krylov subspace methods for large non-symmetric systems of equations • Multilevel methods, especially multigrid (MG) methods, nested and non-nested grid hierarchies • Parallel numerics, especially domain decomposition methods • Inexact Newton/Newton-Krylov methods for discretized nonlinear partial differential equations • Preconditioning and operator-splitting methods
6	**Learning objectives and skills**	Students • are able to design application-specific own MG algorithms with the theory of multigrid methods and decide for which problems the MG algorithm is suitable to solve large linear systems of equations, • are able to solve sparse nonlinear/non-symmetric systems of equations with modern methods (also with parallel computers), • are able to develop under critical assessment complete and efficient methods for application-orientated problems.
7	**Prerequisites**	Recommended: Advanced Discretization Techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations • Further literature and scientific publications are announced during the lectures

1	**Module name** 65903	**Transport and reaction in porous media: Simulation**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Degenerate parabolic differential equations as multiphase flow models: formulation, model derivation through asymptotic expansion, nonlinear solution methods, discretization methods • Sorption reactions and mineral precipitation-dissolution reactions, formulations as complementarity problems • Models for transport and reactions in porous media, consisting of coupled PDEs and ODEs, if necessary coupled to algebraic equations (AEs) and inequalities for the description of local equilibria (differential-algebraic system) • Different formulations of the system • Different numerical strategies: operator splitting, direct substitutional approach, change of variables and combination/ elimination of equations (xi-eta-method), as a basis for different software packages for numerical simulations, connection to optimisation (minimization of Gibbs free energy under constraints) • Treatment of numerical difficulties (nonsmooth equations, treatment of complementarity conditions, guarantee of nonnegativity of numerical solutions of the nonlinear problems, range of convergence of Newton's method, scaling problems, advection dominated problems
6	**Learning objectives and skills**	Students • use methods for the numerical solving of a class of problems whose complexity goes significantly beyond standard problems (Poisson and heat equation): coupled nonlinear partial and ordinary differential equations (PDEs, ODEs) and algebraic equations (AEs), • put strategies for the treatment of possible difficulties during the numerical solving into practice.
7	**Prerequisites**	• Recommended: Basic knowledge in differential equations, • Also useful: Transport and Reaction in Porous Media: Modeling
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192

		Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer • Journal articles will be named in the lecture • Handbooks of Software Packages https://en.www.math.fau.de/angewandte-mathematik-1/forschung/software-2

1	**Module name** 65904	**Numerics of incompressible flows I**	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of incompressible flows 1 (2.0 SWS) Übung: Übungen zu Numerics of incompressible flows 1	5 ECTS -
3	Lecturers	Dr. Stefan Metzger	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Mathematical modelling of (incompressible) flows • Variational formulation, existence and (non-)uniqueness of solutions to the stationary Navier-Stokes (NVS) equations • Stable finite element (FE) discretization of the stationary (Navier) Stokes equations • Error estimates • Solution techniques for the saddle point problem
6	**Learning objectives and skills**	Students • explain and apply the mathematical theory for the stationary, incompressible Navier-Stokes equations, • analyse FE discretization for the stationary Stokes equations and apply them to practical problems, • explain the meaning of the inf-sup condition, • choose the appropriate function spaces, stabilisation techniques and solution techniques and apply them to concrete problem settings.
7	**Prerequisites**	Recommended: Advanced discretization techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Girault, P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986

			• H. Elman, D. Silvester, A. Wathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65905	**Numerics of incompressible flows II**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Variational formulation of the instationary Stokes and Navier-Stokes (NVS) equations • Existence and uniqueness of solutions to the instationary Stokes and NVS equations • Time discretisation methods • Fully discrete equations and error estimates • Solution techniques • Operator splitting, projection methods • More general boundary conditions • Coupling of NVS with temperature equation • Computational experiments with academic or commercial codes
6	**Learning objectives and skills**	Students • discretize the instationary NVS equations in time and space, • explain and analyse discretisation schemes and operator splitting techniques, • choose appropriate algorithms for given flow problems and solve them with academic or commercial software.
7	**Prerequisites**	Recommended: Advanced discretization techniques, Numerics of incompressible flows I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• V. Girault & P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986 • H. Elman, D. Silvester & A. Rathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Glowinski: Finite Element Methods for Incompressible Viscous Flow, in : Handbook of Numerical Analysis vol. IX • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65908	**Numerics of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Strong and weak approximations, explicit and implicit schemes for stochastic differential equations (SDEs), • Consistency, stability, convergence, • Monte Carlo methods, variance-reduction schemes.
6	**Learning objectives and skills**	Students • have critical understanding of capabilities of numerical schemes for stochastic differential equations, • are capable to use own or commercial software for SDEs and to judge results critically.
7	**Prerequisites**	Basic knowledge in probability theory and in numerics is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P.E. Kloeden & E. Platen: Numerical solution of stochastic differential equations • B. Lapeyre, E. Pardoux & R. Sentis: Introduction to Monte? Carlo methods for transport and diffusion equations

1	**Module name** 65914	**Partial differential equations in finance**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• models on pricing for financial derivatives, in particular for European and American-type options, selected deterministic equations of financial mathematics, • practical knowledge Ito-calculus and stochastic differential equations, • analysis and numerics for Black-Scholes equations, • variational inequalities and American-type options.
6	**Learning objectives and skills**	Students • explain mathematical models for financial markets and derivatives pricing, • apply Ito calculus, derive deterministic models based on pde or variational inequalities and discretize them numerically.
7	**Prerequisites**	Basis knowledge in differential equations, probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Capinski & T. Zastawniak: Mathematics for finance, Springer, • N. Hilber, O. Reichmann, C. Schwab & C. Winter: Computational methods for quantitative finance, Springer, • B. Oksendal: Stochastic differential equations, Springer.

1	**Module name** 65915	**Introduction to material- and shape optimization**	**10 ECTS**
2	Courses / lectures	Vorlesung: Introduction to Material and Shape Optimization (4.0 SWS)	10 ECTS
3	Lecturers	Prof. Dr. Michael Stingl	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	• shape-, material- and topology optimization models • linear elasticity and contact problems • existence of solutions of shape, material and topology optimization problems • approximation of shape, material and topology optimization problems by convergent schemes
6	**Learning objectives and skills**	Students • derive mathematical models for shape-, material and topology optimization problems, • apply regularization techniques to guarantee to existence of solutions, • approximate design problems by finite dimensional discretizations, • derive algebraic forms and solve these by nonlinear programming techniques.
7	**Prerequisites**	Recommended: • Knowledge in nonlinear optimization, • Basic knowledge in numerics of partial differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. Haslinger & R. Mäkinen: Introduction to shape optimization, SIAM, • M. P. Bendsoe & O. Sigmund: Topology Optimization: Theory, Methods and Applications, Springer.

1	**Module name** 65916	**Advanced algorithms for nonlinear optimization**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Trust region methods • Iterative methods in the presence of noisy data • Interior point methods for nonlinear problems • Modified barrier and augmented Lagrangian methods • Local and global convergence analysis
6	**Learning objectives and skills**	Students • use methods of nonlinear constrained optimization in finite dimensional spaces, • analyse convergence behaviour of these methods and derive robust and efficient realisations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• C.T. Kelley: Iterative Methods for Optimization, SIAM, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65917	**Discrete optimization I**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Theoretical and practical fundamentals of solving difficult mixed-integer linear optimization problems (MIPs) constitute the main focus of this lecture. At first, the concept of NP-completeness and a selection of common NP-complete problems will be presented. As for polyhedral theory, fundamentals concerning the structure of faces of convex polyhedra will be covered. Building upon these fundamentals, cutting plane algorithms as well as branch-and-cut algorithms for solving MIPs will be taught. Finally, some typical problems of discrete optimization, e.g., the knapsack problem, the traveling salesman problem or the set packing problem will be discussed.
6	**Learning objectives and skills**	Students • will gain basic theoretical knowledge of solving mixed-integer linear optimization problems (MIPs), • are able to solve MIPs with the help of state-of-the-art optimization software.
7	**Prerequisites**	Recommended: Linear and Combinatorial Optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 65918	**Robust optimization II**	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Robuste Optimierung 2 (2.0 SWS) Vorlesung: Robuste Optimierung 2 (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Frauke Liers-Bergmann Martina Kuchlbauer Florian Rösel	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• In practice, provided data for mathematical optimization problems is often not fully known. Robust optimization aims at finding the best solution which is feasible for input data varying within certain tolerances. The lecture covers advanced methods of robust optimization in theory and modeling. In particular, robust network flows, robust integer optimization and robust approximation are included. Further, state-of-the-art concepts, e.g., "light robustness" or "adjustable robustness" will be discussed by means of real-world applications.
6	**Learning objectives and skills**	Students • will be able to identify complex optimization problems under uncertainties as well as suitably model and analyze the corresponding robust optimization problem with the help of advanced techniques of robust optimization, • learn the handling of appropriate solving techniques and how to analyze the corresponding results.
7	**Prerequisites**	• Recommended: Robust Optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes, will be published on StudOn at the beginning of the semester.

1	**Module name** 65919	**Numerical aspects of linear and integer programming**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Revised Simplex (with bounds) • Simplex Phase I • Dual Simplex • LP Presolve/Postsolve • Scaling • MIP Solution Techniques
6	**Learning objectives and skills**	Students are able to explain and use methods and numerical approaches for solving linear and mixed-integer programs in practice.
7	**Prerequisites**	Knowledge in linear algebra and combinatorial optimization is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Chvátal: Linear Programming, W. H. Freeman and Company, New York, 1983 • L.A. Wolsey: Integer Programming, John Wiley and Sons, Inc., 1998

1	**Module name** 65920	**Advanced nonlinear optimization**	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Wolfgang Achtziger
5	**Contents**	• advanced optimality conditions and constraint qualifications for constrained optimization problems • penalty, barrier and augmented Lagrangian methods: theory and algorithms • interior point methods • sequential quadratic programming
6	**Learning objectives and skills**	Students • explain and extend their knowledge on theory and algorithms of nonlinear optimization problems, • apply solution techniques to different advanced types of optimization problems, • derive and solve optimization problems arising from technical and economical applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M.S. Bazaraa, H.D. Sherali & C.M. Shetty: Nonlinear Programming Theory and Algorithms, Wiley, New York, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65921	**Optimization with partial differential equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Optimization and control in Banach spaces • Concepts of controllability and stabilization • Optimal control of Partial differential equations • Singular Perturbations and asymptotic analysis • Numerical realizations of optimal controls • Technical, medical and economic applications
6	**Learning objectives and skills**	Students • explain and use theory as well as numerical methods for optimization, control and stabilization in the context of partial differential equations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in numerics, partial differential equations, and nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS • G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser

1	**Module name** 65923	**Optimization in industry and economy**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	This course focuses on modeling and solving real-world optimization problems occurring in industry and economics. Advantages and disadvantages of different modeling techniques will be outlined. In order to achieve efficient solution approaches, different reformulations and their numerical results will be discussed. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications. The latter may include but is not limited to the optimization of transport networks (gas, water, energy), air traffic management and mathematical modeling/optimization of market mechanisms in the energy sector.
6	**Learning objectives and skills**	Students • model complex real-world optimization problems with respect to efficient • solvability, • classify the models and use appropriate solution strategies, • evaluate the achieved computational results.
7	**Prerequisites**	Recommended: Modul LKOpt: Linear and combinatorial optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes (will be published on StudOn at the beginning of the semester) • Up-to-date research literature (will be published on StudOn at the beginning of the semester)

1	**Module name** 65924	**Project seminar optimization**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	A specific application is to be used to implement the knowledge of mathematical optimisation models and methods acquired during the degree programme thus far. The content is taken from a current problem, often in close collaboration with an industrial partner. Examples might be the water supply for a city, the design of an energy-efficient facade for an office building or railway construction site management.
6	**Learning objectives and skills**	Students • organise themselves into teams to carry out a large project in which they independently model a real problem, develop and implement solutions and apply their results in practical situations, • strengthen their communication skills by presenting and discussing the results of the project work, • discuss information, ideas, problems and solutions at an academic level with each other and with the lecturers.
7	**Prerequisites**	Recommended: knowledge in combinatorial optimisation
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar paper Presentation
11	**Grading procedure**	Seminar paper (50%) Presentation (50%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Project-dependent. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65933	**Discrete optimization II**	**5 ECTS**
2	Courses / lectures	Vorlesung: Discrete Optimization II (2.0 SWS) Übung: Übung Diskrete Optimierung II (1.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Michael Hartisch Florian Rösel	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005

		• Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A-C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65954	**Numerik der Optimalen Steuerungen** Numerics of optimal control	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerik der Optimalen Steuerungen (Numerics of optimal control)	5 ECTS
3	Lecturers	Prof. Dr. Hannes Meinlschmidt	

4	**Module coordinator**	Prof. Dr. Hannes Meinlschmidt
5	**Contents**	The following topics are covered: Discretization methods for differential equations, aspects of nonlinear optimization methods, direct discretization methods (fully and reduced discretized), indirect methods based on discretization of necessary optimality conditions as well as methods for efficient sensitivity calculations with internal numerical differentiation and adjoint equations. The material is presented in lecture form. Further acquisition of the essential concepts and techniques takes place through self-study of accompanying literature and the completion of exercises, supported by meetings within the tutorials. By default, the lecture will be given in English (in German only if all participants agree).
6	**Learning objectives and skills**	Students explain and use numerical methods for optimal control problems with ordinary differential equations and differential algebraic equations. They apply basic concepts of solution methodology using direct and indirect discretization methods for application problems, for example in technology or economics.
7	**Prerequisites**	Recommended: Basic knowledge in numerics, in theory of ordinary differential equations, and in optimization.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 38 h Independent study: 112 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	M. Gerdts, Optimal Control of ODEs and DAEs, De Gruyter, 2012.

1	**Module name** 65959	**Theorie der Optimalsteuerungen** Optimal control theory	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Hannes Meinlschmidt
5	**Contents**	Grundlagen zu folgenden Themen: • Diskrete und kontinuierliche Dynamische Systeme in allgemeinen Räumen • Eingabe- und Ausgabeoperatoren, Beobachter und Aktuatoren • Lösungstheorie und qualitative Theorie • Steuerbarkeit und Stabilisierbarkeit • Restriktionen für Steuerungen und Zuständen • Open-Loop- und Closed-Loop-Steuerungen • Pontriagin'sches Maximum-Prinzip • Dynamische Programmierung • Numerische Realisierung optimaler Steuerungen Die Präsentation des Stoffes erfolgt in Vorlesungsform. Die weitere Aneignung der wesentlichen Begriffe und Techniken erfolgt durch Selbststudium begleitender Literatur, unterstützt durch Zusammenkünfte innerhalb der Übungen.
6	**Learning objectives and skills**	Die Studierenden
7	**Prerequisites**	empfohlen: • Grundkenntnisse der Numerik, der gewöhnlichen und partiellen Differentialgleichungen, der Optimierung
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• E. Sontag, Mathematical Control Theory, Springer-Verlag 2000 • F. Tröltzsch, Steuerungstheorie Partieller Differenialgleichungen, Vieweg Verlag, 2003

1	**Module name** 65993	**Numerics of Partial Differential Equations** Numerics of partial differential equations	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Classical theory of linear elliptic boundary value problems (outline) • Finite difference method (FDM) for Poissons equation in two dimensions (including stability via inverse monotonicity) • Finite element method (FEM) for Poissons equation in two dimensions (stability and convergence, example: linear finite elements, implementation) • Variational theory of linear elliptic boundary value problems (outline) • FEM for linear elliptic boundary value problems (2nd order) (types of elements, affin-equivalent triangulations, order of convergence, maximum principle) • Iterative methods for large sparse linear systems of equations (condition number of finite element matrices, linear stationary methods (recall), cg method (recall), preconditioning, Krylov subspace methods
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of problems and methods with a focus on conforming finite element methods for linear elliptic problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics, discretization, and optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer 2003 • S. Larssen & V. Thomee: Partial Differential Equations with Numerical Methods. Springer 2005 • D. Braess: Finite Elements. Cambridge University Press 2010 • lecture notes

1	**Module name** 65999	**Numerics of Partial Differential Equations II** Numerics of partial differential equations II	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of Partial Differential Equations II (2.0 SWS) Übung: Übungen zur Numerik PDGL II (Numerics of PDE II) (2.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Classical and weak theory for linear parabolic initial-boundary-value problems (IBVPs) (outline), • finite-element method (FEM) for 2nd-order linear parabolic IVBPs (semi-discretisation in space, time discretisation by one-step methods, stability, comparison principles, order of convergence), • FEM for semi-linear elliptic and parabolic equations (fixed-point- and Newton-methods, secondary iterations), • higher-order time discretisation, extrapolation, time-step control.
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of methods with a focus on conforming finite element methods for parabolic problems, extending these approaches also to nonlinear problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics and numerics of pde
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h

		Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner, L. Angermann, Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer, New York, 2003. • S. Larsson, V. Thomée, Partial Differential Equations with Numerical Methods, Springer, Berlin, 2005.

1	**Module name** 65877	**Polynomial Optimization and Application**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Giovanni Fantuzzi
5	**Contents**	Polynomial optimization problems (POPs) form a broad class of optimization problems that find applications to control theory, dynamical systems, optimal transport, power flow networks, fluid mechanics, and many other fields. This course will introduce students to a modern approach to solving POPs through semidefinite programming techniques. More specifically, the course will cover: • The basics of semidefinite programs • The theory of sum-of-squares (SOS) polynomials • Moment-SOS hierarchies for polynomial optimization problems • Applications (e.g. to dynamical system analysis) Students will also have the opportunity to put the theory into practice with “hands-on” practical assignments.
6	**Learning objectives and skills**	By the end of the course, students should be able to: • Explain what polynomial optimization problems (POPs) are • Give examples of applications where POPs arise • Formulate semidefinite programming relaxations of POPs • Apply moment-SOS hierarchies to a range of problems • Solve POPs in practice using existing software
7	**Prerequisites**	Previous experience with optimization (especially convex and/or conic optimization) and with differential equations is desirable.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	
16	**Bibliography**	Lecture notes will be provided as the course progresses.A reading list will also be provided at the start of the course.

1	**Module name** 65789	**Selected Topics in Mathematics of Learning** Selected topics in mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Advanced methods of mathematical data science, with a focus on teaching mathematical principles of learning processes.
6	**Learning objectives and skills**	Students gain fundamental theoretical knowledge of learning algorithms in Data Science and will be able to apply the methodologies in a Data Science context.
7	**Prerequisites**	Basic knowledge in numerical methods and optimization are recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	S. Wright, B. Recht: Optimization for Data Analysis (2022).

1	**Module name** 48241	**Mathematical Image Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Mathematical Image Processing (2.0 SWS)	5 ECTS
		Tutorium: Tutorial for Mathematical Image Processing (0.5 SWS)	-
		This module is offered in every second summer term. The next course will be held in the summer semester 2024.	
3	Lecturers	Prof. Dr. Daniel Tenbrinck	

4	**Module coordinator**	Prof. Dr. Daniel Tenbrinck
5	**Contents**	This module covers mathematical image processing techniques based on Fourier domain filters, variational methods, and partial differential equations. In particular, the following content will be introduced to the students: • contrast enhancement • filtering in Fourier and image domain • Bayesian image denoising • image deblurring / deconvolution • pixel-based clustering • region-based segmentation • image inpainting • nonlocal image processing using graphs
6	**Learning objectives and skills**	Students following this course will • learn how image data can be modeled and analyzed mathematically • develop a deeper understanding of mathematical basics and methods for image processing • implement own algorithms for mathematical image processing • discover connections to related mathematical fields, e.g., inverse problems and convex analysis
7	**Prerequisites**	Knowledge in calculus and linear algebra is **recommended** to understand the mathematical foundations of image processing. Knowledge in functional analysis, numerical mathematics, or inverse problems is **helpful** to understand advanced concepts in mathematical image processing.
8	**Integration in curriculum**	semester: 2;1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written or oral Oral examination (20 min.) or written examination (60 min.) depending on size of course.
11	**Grading procedure**	Written or oral (100%) Oral exam (100%) or written exam (100%) depending on size of course.
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Aubert & P. Kornprobst: Mathematical problems in Image Processing, Springer • K. Bredies & D. Lorenz, Mathematical Image Processing, Springer • S. Osher & R. Fedkiw, Level Set Methods and Dynamic Implicit Surfaces, Springer • A. Elmoataz , O.Lezoray, S. Bougleux: Nonlocal Discrete Regularization on Weighted Graphs: a framework for Image and Manifold Processing, IEEE Transactions On Image Processing, 17 (7), pp: 1047-1060, 2008

1	**Module name** 65096	**Seminar Selected Topics of Applied Analysis**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Linear algebra and calculus are required. Basic knowledge in probability theory is recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics Summer or winter term after participation at ModAna1
10	**Method of examination**	Presentation Oral (90 minutes) Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Presentation (20%) Oral (80%)

		Oral presentation (80%) presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen

Non-Specialisation modules

1	**Module name** 65071	**Seminar on Evolution Equations** Seminar: Evolution equations	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics in the complex of evolution equations, depending on the interest and previous knowledge of the attending students; possible topics include, but are not limited to: • semigroups of operators (Hille-Yosida theorem, Stone theorem, analytic semigroups,) • variational methods and Galerkin scheme • theory of Bochner function spaces (embeddings, Aubin-Lions-Simon compactness)
6	**Learning objectives and skills**	Students • work on and investigate an advanced topic in the complex of evolution equations, • report on and present their findings about their topic both orally and in written form by using appropriate means for presentation and communication, • understand the relationship and scope of their particular topic related to others considered within the complex of evolution equations, • discuss their and other participants topics and converse with the lecturer about questions and insights on an appropriate level
7	**Prerequisites**	Recommended: Functional Analysis, Differential Equations, basics in Lebesgue integration
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 21 h Independent study: 129 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Will be announced at a first meeting, depending on the topics considered

1	**Module name** 65700	**Lecture Series Partial Differential Equations, Control and Numerics (PdeConNum)** Lecture series: Partial differential equations, control and numerics (PdeConNum)	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• Examples of PDE models arising in industrial applications, Biology and Social Sciences • Long time asymptotics • Control of trajectories • Numerics for long time dynamics and control • Some applications in the control of population dynamics
6	**Learning objectives and skills**	Students • develop understanding for special aspects of dynamical systems control, • apply numerical methods to control problems and develop a basic understanding of their properties, • derive and solve inverse problems arising from applications.
7	**Prerequisites**	Recommended: basic knowledge in functional analysis
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. M. Coron, Control and nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009 • E. Zuazua. Propagation, observation, and control of waves approximated by finite difference methods. SIAM Review, 47 (2) (2005), 197-243

1	**Module name** 65785	**Mathematics of Learning** Mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Machine learning: empirical risk minimization, kernel methods and variational models • Mathematical aspects of deep learning • Ranking problems • Mathematical models of network interaction
6	**Learning objectives and skills**	Students • develop understanding of modern big data and state of the art methods to analyze them, • apply state of the art algorithms to large data sets, • derive models for network / graph structured data.
7	**Prerequisites**	Prerequisites: Basic knowledge in numerical methods and optimization is recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, Bengio, Courville, Deep Learning, MIT Press, 2015 • Hastie, Tibshirani, Friedman, The Elements of Statistical Learning, 2008

1	**Module name** 65885	**Master's seminar MApA** Master`s seminar MApA	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-

		Seminar: Homogenization of fluid flow in porous media	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	A topic from MApA that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the MApA specialisation: • make use of analytical techniques to rigorously prove the qualitative characteristics of solutions to mathematical models in applied sciences.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written Presentation (90 minutes)
11	**Grading procedure**	Written (25%) Presentation (75%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65890	**Master's seminar NASi**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

		Sonstige Lehrveranstaltung: Grundlagen kollektiver Entscheidung	-
		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	A topic from NASi that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the NASi specification: • can solve exemplary computational problems with given or self-developed software in order to illustrate or verify numerical methods under consideration.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65895	**Master seminar Opti**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar zur Algebraischen Geometrie (0.0 SWS)	-
		Masterseminar: Masterseminar "Theorie der diskreten Optimierung" (2.0 SWS)	-
		Masterseminar: Masterseminar "Theory of Discrete Optimization" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Deep Learning in Control Theory and vice versa" (2.0 SWS)	-
		Masterseminar: Masterseminar "Kryptographie" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Approximationstheorie" (2.0 SWS)	5 ECTS
		Hauptseminar: Masterseminar "Quantitatives Risikomanagement" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Mannigfaltigkeiten" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar über Horns Vermutung (2.0 SWS)	5 ECTS
		Masterseminar: Project Seminar 'Optimization' (2.0 SWS)	5 ECTS
		Hauptseminar: Seminar Spin Glasses with Applications to Deep Learning (2.0 SWS)	-
		Masterseminar: Masterseminar (2.0 SWS)	-
		Hauptseminar: Seminar "Wavelets" (2.0 SWS)	-
		Hauptseminar: Modeling and simulation of biomembranes (0.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Algebraische Stacks" (2.0 SWS)	5 ECTS
		Masterseminar: Masterseminar "Inverse Probleme" (2.0 SWS)	5 ECTS
		Seminar: Convex Optimization for Dynamical System Analysis (2.0 SWS)	5 ECTS
		Hauptseminar: Numerical methods for surface and geometric PDEs (0.0 SWS)	5 ECTS
		Hauptseminar / Masterseminar: Masterseminar MApA/ NASi - Seminar Applied Analysis (2.0 SWS)	5 ECTS
		Masterseminar: Numerical solutions for eigenvalue problems	-

4		Hauptseminar: Mixed topics in optimization (2.0 SWS)	5 ECTS
		Seminar: Control and machine learning (2.5 SWS)	5 ECTS
		Hauptseminar: Advanced Topics in Polynomial Optimization	-
		Seminar: Modellierungsseminar Data Science	-
		Masterseminar: Material and Topology Optimization	-
3	Lecturers	Prof. Dr. Peter Fiebig Prof. Dr. Ioannis Giannakopoulos Prof. Dr. Frauke Liers-Bergmann Prof. Dr. Jan Heiland apl. Prof. Dr. Wolfgang Ruppert PD Dr. Cornelia Schneider Prof. Dr. Wolfgang Stummer Prof. Dr. Karl Hermann Neeb Prof. Dr. Michael Stingl Dr. Bart Steirteghem Jorge Weston Fernández Prof. Dr. Torben Krüger Prof. Dr. Thorsten Neuschel Prof. Dr. Martin Burger Prof. Dr. Manuel Friedrich Prof. Dr. Carsten Gräser Prof. Dr. Friedrich Knop Prof. Dr. Giovanni Fantuzzi Prof. Dr. Günther Grün Prof. Dr. Michael Hartisch	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	A topic from Opti that relates to the compulsory elective modules offered.
6	**Learning objectives and skills**	Students • can use original literature to familiarise themselves with a current research topic, • can structure the content acquired both verbally and in writing and make their own contributions to its presentation and/or substance, • learn scientific content on the basis of academic lectures and actively discuss it at a plenary session. For the Opti specialisation: • model theoretical and applied tasks as optimization problems and/or develop optimization algorithms for their solution and/or put these into practice.
7	**Prerequisites**	All compulsory modules for the MSc in Computational and Applied Mathematics recommended
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Presentation (90 minutes) Written
11	**Grading procedure**	Presentation (75%) Written (25%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depending on topic. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65900	**Advanced discretization techniques**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• conforming and non-conforming finite element methods • saddle point problems in Hilbert spaces • mixed finite element methods for saddle point problems, in particular for Darcy and Stokes • Streamline-Upwind Petrov-Galerkin (SUPG) and discontinuous Galerkin (dG) finite element methods (FEM) for convection dominated problems • Finite Volume (FV) methods and their relation to FEM • a posteriori error control and adaptive methods
6	**Learning objectives and skills**	Students • have a discriminating understanding, both theoretically and computationally of FE as well as FV methods for the numerical solution of partial differential equations (pde) (in particular of saddle point problems), • are capable of developing problem dependent FE or FV methods and judge on their properties regarding stability and effectiveness, • are familiar with a broad spectrum of pde problems and their computational solutions, • are capable of designing algorithms for adaptive mesh control.
7	**Prerequisites**	Recommended: Introduction to numerical methods for pdes, functional analysis
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• A. Ern, J.-L. Guermond: Theory and Practice of Finite Elements • A. Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer • D. A. Di Piettro & A. Ern: Mathematical aspects of discontinuous Galerkin methods. Springer 2012

1	**Module name** 65901	**Advanced solution techniques**	**5 ECTS**
2	Courses / lectures	Übung: Exercises for Advanced Solution Techniques (1.0 SWS) Vorlesung: Advanced Solution Techniques (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Krylov subspace methods for large non-symmetric systems of equations • Multilevel methods, especially multigrid (MG) methods, nested and non-nested grid hierarchies • Parallel numerics, especially domain decomposition methods • Inexact Newton/Newton-Krylov methods for discretized nonlinear partial differential equations • Preconditioning and operator-splitting methods
6	**Learning objectives and skills**	Students • are able to design application-specific own MG algorithms with the theory of multigrid methods and decide for which problems the MG algorithm is suitable to solve large linear systems of equations, • are able to solve sparse nonlinear/non-symmetric systems of equations with modern methods (also with parallel computers), • are able to develop under critical assessment complete and efficient methods for application-orientated problems.
7	**Prerequisites**	Recommended: Advanced Discretization Techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations • Further literature and scientific publications are announced during the lectures

1	**Module name** 65902	**Transport and reaction in porous media: Modelling**	**5 ECTS**
2	Courses / lectures	Vorlesung: Transport and Reaction in Porous Media: Modeling (2.0 SWS)	4 ECTS
		Übung: Tutorial to Transport and Reaction in Porous Media: Modeling (0.0 SWS)	1 ECTS
3	Lecturers	apl. Prof. Dr. Serge Kräutle	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Modeling of fluid flow through a porous medium: Groundwater models, saturated and unsaturated porous medium (Richards equation) • Advection, diffusion, dispersion of dissolved substances, (nonlinear) reaction-models (i.a. law of mass action, kinetic / reversible reactions in local equilibrium), the stoichiometric matrix • Models of partial (PDEs), ordinary (ODEs) differential equations, and local algebraic conditions • Nonnegativity, boundedness, global existence of solutions, necessary model assumptions in the case of a pure ODE model as well as for a PDE model • Existence and uniqueness of stationary solutions in the stoichiometric space (i.a. introduction to the Feinberg network theory)
6	**Learning objectives and skills**	Students • are able to model flow and reaction processes in porous media on macro- and micro-scale using partial differential equations, • possess the techniques and the analytical foundations to assess the global existence of solutions.
7	**Prerequisites**	Recommended: Basic knowledge in differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• S. Kräutle: lecture notes https://www.math.fau.de/kraeutle/vorlesungsskripte/ • C. Eck, H. Garcke, P. Knabner: Mathematical Modeling, Springer • J.D. Logan: Transport Modeling in Hydrogeochemical Systems, Springer • M. Feinberg: lecture notes https://cbe.osu.edu/chemical-reaction-network-theory

1	**Module name** 65903	**Transport and reaction in porous media: Simulation**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	apl. Prof. Dr. Serge Kräutle
5	**Contents**	• Degenerate parabolic differential equations as multiphase flow models: formulation, model derivation through asymptotic expansion, nonlinear solution methods, discretization methods • Sorption reactions and mineral precipitation-dissolution reactions, formulations as complementarity problems • Models for transport and reactions in porous media, consisting of coupled PDEs and ODEs, if necessary coupled to algebraic equations (AEs) and inequalities for the description of local equilibria (differential-algebraic system) • Different formulations of the system • Different numerical strategies: operator splitting, direct substitutional approach, change of variables and combination/ elimination of equations (xi-eta-method), as a basis for different software packages for numerical simulations, connection to optimisation (minimization of Gibbs free energy under constraints) • Treatment of numerical difficulties (nonsmooth equations, treatment of complementarity conditions, guarantee of nonnegativity of numerical solutions of the nonlinear problems, range of convergence of Newton's method, scaling problems, advection dominated problems
6	**Learning objectives and skills**	Students • use methods for the numerical solving of a class of problems whose complexity goes significantly beyond standard problems (Poisson and heat equation): coupled nonlinear partial and ordinary differential equations (PDEs, ODEs) and algebraic equations (AEs), • put strategies for the treatment of possible difficulties during the numerical solving into practice.
7	**Prerequisites**	• Recommended: Basic knowledge in differential equations, • Also useful: Transport and Reaction in Porous Media: Modeling
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192

		Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer • Journal articles will be named in the lecture • Handbooks of Software Packages https://en.www.math.fau.de/angewandte-mathematik-1/forschung/software-2

1	**Module name** 65904	**Numerics of incompressible flows I**	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of incompressible flows 1 (2.0 SWS) Übung: Übungen zu Numerics of incompressible flows 1	5 ECTS -
3	Lecturers	Dr. Stefan Metzger	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Mathematical modelling of (incompressible) flows • Variational formulation, existence and (non-)uniqueness of solutions to the stationary Navier-Stokes (NVS) equations • Stable finite element (FE) discretization of the stationary (Navier) Stokes equations • Error estimates • Solution techniques for the saddle point problem
6	**Learning objectives and skills**	Students • explain and apply the mathematical theory for the stationary, incompressible Navier-Stokes equations, • analyse FE discretization for the stationary Stokes equations and apply them to practical problems, • explain the meaning of the inf-sup condition, • choose the appropriate function spaces, stabilisation techniques and solution techniques and apply them to concrete problem settings.
7	**Prerequisites**	Recommended: Advanced discretization techniques
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Girault, P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986

			• H. Elman, D. Silvester, A. Wathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65905	**Numerics of incompressible flows II**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Variational formulation of the instationary Stokes and Navier-Stokes (NVS) equations • Existence and uniqueness of solutions to the instationary Stokes and NVS equations • Time discretisation methods • Fully discrete equations and error estimates • Solution techniques • Operator splitting, projection methods • More general boundary conditions • Coupling of NVS with temperature equation • Computational experiments with academic or commercial codes
6	**Learning objectives and skills**	Students • discretize the instationary NVS equations in time and space, • explain and analyse discretisation schemes and operator splitting techniques, • choose appropriate algorithms for given flow problems and solve them with academic or commercial software.
7	**Prerequisites**	Recommended: Advanced discretization techniques, Numerics of incompressible flows I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• V. Girault & P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986 • H. Elman, D. Silvester & A. Rathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Glowinski: Finite Element Methods for Incompressible Viscous Flow, in : Handbook of Numerical Analysis vol. IX • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

1	**Module name** 65906	**Mathematics of multiscale models**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	PD Dr. Nicolas Neuß
5	**Contents**	• Function spaces of periodic functions and asymptotic expansions • Two-scale convergence and unfolding method • Application to differential equation models in continuum mechanics • Multi-scale finite element methods • Numerical upscaling methods
6	**Learning objectives and skills**	Students • have profound expertise about the basic methods in multi-scale analysis and homogenisation, • are able to derive rigorously homogenised (effective) models and analyse the quality of the approximation.
7	**Prerequisites**	Recommended: Knowledge in modeling as well as analysis and numerics of partial differential equations
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• D. Cioranescu & P. Donato: An Introduction to Homogenization • U. Hornung (ed.): Homogenization and Porous Media • Y. Efendiev & T. Hou: Multiscale Finite Element Methods

1	**Module name** 65907	**Theory of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Infinitely dimensional Wiener processes, • Stochastic integral in Hilbert spaces, • Ito-processes and stochastic differential equations, • Optionally: existence results for stochastic partial differential equations or further results on stochastic ODE (Fokker-Planck equations, . . .)
6	**Learning objectives and skills**	Students • characterize Gaussian measures on Hilbert spaces. They explain representation formulas for Q-Wiener processes as well as the derivation of the stochastic integral, • successfully apply concepts to solve stochastic differential equations explicitly and prove existence of solutions to stochastic evolution equations.
7	**Prerequisites**	Basic knowledge in probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Da Prato & J. Zabczyk: Stochastic equations in infinite dimensions, Cambridge University Press • I. Karatzas & S.E. Shreve: Brownian motion and stochastic calculus, Springer • B. Oksendal: Stochastic differential equations, Springer

			• C. Prévôt & M. Röckner: A concise course on stochastic partial differential equations, Springerchastic Evolution Equations

1	**Module name** 65908	**Numerics of stochastic evolution equations**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Strong and weak approximations, explicit and implicit schemes for stochastic differential equations (SDEs), • Consistency, stability, convergence, • Monte Carlo methods, variance-reduction schemes.
6	**Learning objectives and skills**	Students • have critical understanding of capabilities of numerical schemes for stochastic differential equations, • are capable to use own or commercial software for SDEs and to judge results critically.
7	**Prerequisites**	Basic knowledge in probability theory and in numerics is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P.E. Kloeden & E. Platen: Numerical solution of stochastic differential equations • B. Lapeyre, E. Pardoux & R. Sentis: Introduction to Monte? Carlo methods for transport and diffusion equations

1	**Module name** 65911	**Mathematical modeling in the life sciences**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Maria Neuß
5	**Contents**	• Biochemical reaction networks, enzyme kinetics • Models for interacting populations (Predator-prey, competition, symbiosis) • Diffusion, reactions, and transport in biological cell tissues and vessels • Structured population models
6	**Learning objectives and skills**	Students • have profound knowledge in the area of mathematical modeling of processes in the life sciences • are able to identify significant mechanisms and to apply suitable analytical and numerical methods for their analysis • are able to work interdisciplinary and problem-oriented.
7	**Prerequisites**	Recommended: Modeling and Analysis in Continuum Mechanics I
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. D. Murray: Mathematical Biology I: An Introduction, Mathematical Biology II: Spatial Models and Biomedical Applications • G. de Vries, T. Hillen, et al.: A course in Mathematical Biology • J. Prüss: Mathematische Modelle in der Biologie: Deterministische homogene Systeme

1	**Module name** 65914	**Partial differential equations in finance**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• models on pricing for financial derivatives, in particular for European and American-type options, selected deterministic equations of financial mathematics, • practical knowledge Ito-calculus and stochastic differential equations, • analysis and numerics for Black-Scholes equations, • variational inequalities and American-type options.
6	**Learning objectives and skills**	Students • explain mathematical models for financial markets and derivatives pricing, • apply Ito calculus, derive deterministic models based on pde or variational inequalities and discretize them numerically.
7	**Prerequisites**	Basis knowledge in differential equations, probability theory or functional analysis is recommended.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M. Capinski & T. Zastawniak: Mathematics for finance, Springer, • N. Hilber, O. Reichmann, C. Schwab & C. Winter: Computational methods for quantitative finance, Springer, • B. Oksendal: Stochastic differential equations, Springer.

1	**Module name** 65915	**Introduction to material- and shape optimization**	**10 ECTS**
2	Courses / lectures	Vorlesung: Introduction to Material and Shape Optimization (4.0 SWS)	10 ECTS
3	Lecturers	Prof. Dr. Michael Stingl	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	• shape-, material- and topology optimization models • linear elasticity and contact problems • existence of solutions of shape, material and topology optimization problems • approximation of shape, material and topology optimization problems by convergent schemes
6	**Learning objectives and skills**	Students • derive mathematical models for shape-, material and topology optimization problems, • apply regularization techniques to guarantee to existence of solutions, • approximate design problems by finite dimensional discretizations, • derive algebraic forms and solve these by nonlinear programming techniques.
7	**Prerequisites**	Recommended: • Knowledge in nonlinear optimization, • Basic knowledge in numerics of partial differential equations
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J. Haslinger & R. Mäkinen: Introduction to shape optimization, SIAM, • M. P. Bendsoe & O. Sigmund: Topology Optimization: Theory, Methods and Applications, Springer.

1	**Module name** 65916	**Advanced algorithms for nonlinear optimization**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Trust region methods • Iterative methods in the presence of noisy data • Interior point methods for nonlinear problems • Modified barrier and augmented Lagrangian methods • Local and global convergence analysis
6	**Learning objectives and skills**	Students • use methods of nonlinear constrained optimization in finite dimensional spaces, • analyse convergence behaviour of these methods and derive robust and efficient realisations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• C.T. Kelley: Iterative Methods for Optimization, SIAM, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65917	**Discrete optimization I**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Theoretical and practical fundamentals of solving difficult mixed-integer linear optimization problems (MIPs) constitute the main focus of this lecture. At first, the concept of NP-completeness and a selection of common NP-complete problems will be presented. As for polyhedral theory, fundamentals concerning the structure of faces of convex polyhedra will be covered. Building upon these fundamentals, cutting plane algorithms as well as branch-and-cut algorithms for solving MIPs will be taught. Finally, some typical problems of discrete optimization, e.g., the knapsack problem, the traveling salesman problem or the set packing problem will be discussed.
6	**Learning objectives and skills**	Students • will gain basic theoretical knowledge of solving mixed-integer linear optimization problems (MIPs), • are able to solve MIPs with the help of state-of-the-art optimization software.
7	**Prerequisites**	Recommended: Linear and Combinatorial Optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 65918	**Robust optimization II**	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Robuste Optimierung 2 (2.0 SWS) Vorlesung: Robuste Optimierung 2 (2.0 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Frauke Liers-Bergmann Martina Kuchlbauer Florian Rösel	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• In practice, provided data for mathematical optimization problems is often not fully known. Robust optimization aims at finding the best solution which is feasible for input data varying within certain tolerances. The lecture covers advanced methods of robust optimization in theory and modeling. In particular, robust network flows, robust integer optimization and robust approximation are included. Further, state-of-the-art concepts, e.g., "light robustness" or "adjustable robustness" will be discussed by means of real-world applications.
6	**Learning objectives and skills**	Students • will be able to identify complex optimization problems under uncertainties as well as suitably model and analyze the corresponding robust optimization problem with the help of advanced techniques of robust optimization, • learn the handling of appropriate solving techniques and how to analyze the corresponding results.
7	**Prerequisites**	• Recommended: Robust Optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes, will be published on StudOn at the beginning of the semester.

1	**Module name** 65919	**Numerical aspects of linear and integer programming**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	• Revised Simplex (with bounds) • Simplex Phase I • Dual Simplex • LP Presolve/Postsolve • Scaling • MIP Solution Techniques
6	**Learning objectives and skills**	Students are able to explain and use methods and numerical approaches for solving linear and mixed-integer programs in practice.
7	**Prerequisites**	Knowledge in linear algebra and combinatorial optimization is recommended.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• V. Chvátal: Linear Programming, W. H. Freeman and Company, New York, 1983 • L.A. Wolsey: Integer Programming, John Wiley and Sons, Inc., 1998

1	**Module name** 65920	**Advanced nonlinear optimization**	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Wolfgang Achtziger
5	**Contents**	• advanced optimality conditions and constraint qualifications for constrained optimization problems • penalty, barrier and augmented Lagrangian methods: theory and algorithms • interior point methods • sequential quadratic programming
6	**Learning objectives and skills**	Students • explain and extend their knowledge on theory and algorithms of nonlinear optimization problems, • apply solution techniques to different advanced types of optimization problems, • derive and solve optimization problems arising from technical and economical applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• M.S. Bazaraa, H.D. Sherali & C.M. Shetty: Nonlinear Programming Theory and Algorithms, Wiley, New York, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

1	**Module name** 65921	**Optimization with partial differential equations**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Michael Stingl
5	**Contents**	Several of the following topics: • Optimization and control in Banach spaces • Concepts of controllability and stabilization • Optimal control of Partial differential equations • Singular Perturbations and asymptotic analysis • Numerical realizations of optimal controls • Technical, medical and economic applications
6	**Learning objectives and skills**	Students • explain and use theory as well as numerical methods for optimization, control and stabilization in the context of partial differential equations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in numerics, partial differential equations, and nonlinear optimization is recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS • G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser

1	**Module name** 65923	**Optimization in industry and economy**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	This course focuses on modeling and solving real-world optimization problems occurring in industry and economics. Advantages and disadvantages of different modeling techniques will be outlined. In order to achieve efficient solution approaches, different reformulations and their numerical results will be discussed. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications. The latter may include but is not limited to the optimization of transport networks (gas, water, energy), air traffic management and mathematical modeling/optimization of market mechanisms in the energy sector.
6	**Learning objectives and skills**	Students • model complex real-world optimization problems with respect to efficient • solvability, • classify the models and use appropriate solution strategies, • evaluate the achieved computational results.
7	**Prerequisites**	Recommended: Modul LKOpt: Linear and combinatorial optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes (will be published on StudOn at the beginning of the semester) • Up-to-date research literature (will be published on StudOn at the beginning of the semester)

1	**Module name** 65924	**Project seminar optimization**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	A specific application is to be used to implement the knowledge of mathematical optimisation models and methods acquired during the degree programme thus far. The content is taken from a current problem, often in close collaboration with an industrial partner. Examples might be the water supply for a city, the design of an energy-efficient facade for an office building or railway construction site management.
6	**Learning objectives and skills**	Students • organise themselves into teams to carry out a large project in which they independently model a real problem, develop and implement solutions and apply their results in practical situations, • strengthen their communication skills by presenting and discussing the results of the project work, • discuss information, ideas, problems and solutions at an academic level with each other and with the lecturers.
7	**Prerequisites**	Recommended: knowledge in combinatorial optimisation
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Seminar paper Presentation
11	**Grading procedure**	Seminar paper (50%) Presentation (50%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Project-dependent. Will be published on StudOn at the beginning of the semester.

1	**Module name** 65933	**Discrete optimization II**	**5 ECTS**
2	Courses / lectures	Vorlesung: Discrete Optimization II (2.0 SWS) Übung: Übung Diskrete Optimierung II (1.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Michael Hartisch Florian Rösel	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005

		• Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A-C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65993	**Numerics of Partial Differential Equations** Numerics of partial differential equations	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Eberhard Bänsch
5	**Contents**	• Classical theory of linear elliptic boundary value problems (outline) • Finite difference method (FDM) for Poissons equation in two dimensions (including stability via inverse monotonicity) • Finite element method (FEM) for Poissons equation in two dimensions (stability and convergence, example: linear finite elements, implementation) • Variational theory of linear elliptic boundary value problems (outline) • FEM for linear elliptic boundary value problems (2nd order) (types of elements, affin-equivalent triangulations, order of convergence, maximum principle) • Iterative methods for large sparse linear systems of equations (condition number of finite element matrices, linear stationary methods (recall), cg method (recall), preconditioning, Krylov subspace methods
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of problems and methods with a focus on conforming finite element methods for linear elliptic problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics, discretization, and optimization
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer 2003 • S. Larssen & V. Thomee: Partial Differential Equations with Numerical Methods. Springer 2005 • D. Braess: Finite Elements. Cambridge University Press 2010 • lecture notes

1	**Module name** 65997	**Analysis of free-boundary problems in continuum mechanics**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Derivation of time-dependent free boundary problems in continuum mechanics, • Basic results on existence and qualitative behaviour, • Optimal estimates on the propagation of free boundaries, • Other approaches, e.g. relaxation by phase-field models.
6	**Learning objectives and skills**	Students • formulate free-boundary problems in hydrodynamics and in porousmedia flow • explain analytical concepts for existence and nonnegativity results for degenerate parabolic equations as well as techniques for optimal estimates on spreading rates • validate different modeling approaches in a critical way.
7	**Prerequisites**	Recommended: Basic knowledge of analysis of partial differential equations, corresponding to the syllabus of Modeling and Applied Analysis in Continuum Mechanics or that one of other pde-lectures.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• L.C. Evans: Partial Differential Equations, AMS, • Original journal articles.

1	**Module name** 65999	**Numerics of Partial Differential Equations II** Numerics of partial differential equations II	**5 ECTS**
2	Courses / lectures	Vorlesung: Numerics of Partial Differential Equations II (2.0 SWS) Übung: Übungen zur Numerik PDGL II (Numerics of PDE II) (2.0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Carsten Gräser	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	• Classical and weak theory for linear parabolic initial-boundary-value problems (IBVPs) (outline), • finite-element method (FEM) for 2nd-order linear parabolic IVBPs (semi-discretisation in space, time discretisation by one-step methods, stability, comparison principles, order of convergence), • FEM for semi-linear elliptic and parabolic equations (fixed-point- and Newton-methods, secondary iterations), • higher-order time discretisation, extrapolation, time-step control.
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical methods properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of methods with a focus on conforming finite element methods for parabolic problems, extending these approaches also to nonlinear problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics and numerics of pde
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h

		Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• P. Knabner, L. Angermann, Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer, New York, 2003. • S. Larsson, V. Thomée, Partial Differential Equations with Numerical Methods, Springer, Berlin, 2005.

1	**Module name** 65877	**Polynomial Optimization and Application**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Giovanni Fantuzzi
5	**Contents**	Polynomial optimization problems (POPs) form a broad class of optimization problems that find applications to control theory, dynamical systems, optimal transport, power flow networks, fluid mechanics, and many other fields. This course will introduce students to a modern approach to solving POPs through semidefinite programming techniques. More specifically, the course will cover: • The basics of semidefinite programs • The theory of sum-of-squares (SOS) polynomials • Moment-SOS hierarchies for polynomial optimization problems • Applications (e.g. to dynamical system analysis) Students will also have the opportunity to put the theory into practice with “hands-on” practical assignments.
6	**Learning objectives and skills**	By the end of the course, students should be able to: • Explain what polynomial optimization problems (POPs) are • Give examples of applications where POPs arise • Formulate semidefinite programming relaxations of POPs • Apply moment-SOS hierarchies to a range of problems • Solve POPs in practice using existing software
7	**Prerequisites**	Previous experience with optimization (especially convex and/or conic optimization) and with differential equations is desirable.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	
16	**Bibliography**	Lecture notes will be provided as the course progresses.A reading list will also be provided at the start of the course.

1	**Module name** 65789	**Selected Topics in Mathematics of Learning** Selected topics in mathematics of learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Advanced methods of mathematical data science, with a focus on teaching mathematical principles of learning processes.
6	**Learning objectives and skills**	Students gain fundamental theoretical knowledge of learning algorithms in Data Science and will be able to apply the methodologies in a Data Science context.
7	**Prerequisites**	Basic knowledge in numerical methods and optimization are recommended.
8	**Integration in curriculum**	semester: 1;3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	S. Wright, B. Recht: Optimization for Data Analysis (2022).

1	**Module name** 65093	**Control, machine learning and numerics**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Enrique Zuazua Iriondo
5	**Contents**	• several topics related to the control of Ordinary Differential Equations (ODE) and Partial Differential Equations (PDE), including controllability, observability, and some of the most fundamental work that has been done in the subject in recent years. • an introduction to Machine Learning, focusing mainly on the use of control techniques for the analysis of Deep Neural Networks as a tool to address, for instance, the problem of Supervised Learning. • some classical computational techniques related to the control of ODE and PDE, and machine learning.
6	**Learning objectives and skills**	Students are able to • understand some basic theory on control and machine learning. • learn about recent advances on control and machine learning. • implement some computational techniques using their own or specified software and critically evaluate the results, • set out their approaches and results in a comprehensible and convincing manner, making use of appropriate presentation techniques.
7	**Prerequisites**	Basic knowledge of calculus, linear algebra, ODE and PDE. Familiarity with scientific computing is helpful.
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 225 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	1) L. Bottou, F. E. Curtis, and J. Nocedal, Optimization methods for large-scale machine learning. SIAM Review, 60 (2) (2018) , 223-311. 2) J. M. Coron, Control and Nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009. 3) I. Goodfellow, Y. Bengio, & A. Courville, Deep Learning. MIT press, 2016. 4) R. Glowinski, J. L. Lions, and J. He, Exact and Approximate Controllability for Distributed Parameter Systems: A Numerical Approach, Encyclopedia Math. Appl., Cambridge University Press, Cambridge, UK, 2008. 5) C. F. Higham, and D. J. Higham, Deep learning: An introduction for applied mathematicians. SIAM Review, 61 (4) (2019), 860-891. 6) J. Nocedal, and S. Wright, Numerical Optimization. Springer Science & Business Media, 2006. 7) D. Ruiz-Balet, and E. Zuazua, Neural ODE control for classification, approximation and transport. arXiv preprint arXiv:2104.05278, (2021). 8) E. Zuazua, Propagation, observation, and control of waves approximated by finite difference methods, SIAM Review, 47 (2) (2005), 197-243. 9) E. Zuazua, Controllability and observability of partial differential equations: some results and open problems, in Handbook of Differential Equations: Evolutionary Equations. Vol. 3. North-Holland, 2006. 527-621.

1	**Module name** 65910	**Discrete optimization III**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Timm Oertel
5	**Contents**	In this lecture we will discuss selected topics in discrete and mixed-integer optimization. Possible topics include lattice methods, integer programming in fixed dimension, recent research on (mixed) integer linear and/or (mixed) integer nonlinear programming and so on. The specific topics may vary and will be announced in due time. FORMERLY: In this lecture, we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we show the equivalence between separation and optimization. Then, we present solution strategies for large-scale optimization problems, e.g., decomposition methods and approximation algorithms. Finally, we deal with conditions for the existence of integer polyhedra. We also discuss applications for example from the fields of engineering, finance, energy or public transport.
6	**Learning objectives and skills**	Students • use basic terms of discrete optimization • model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I and II
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Lecture notes • Bertsimas, Weismantel: Optimization over Integers, Dynamic Ideas, 2005 • Conforti, Cornuéjols, Zambelli: Integer Programming, Springer 2014 • Nemhauser, Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • Schrijver: Combinatorial optimization Vol. A - C, Springer 2003 • Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 • Wolsey: Integer Programming, Wiley, 2021

1	**Module name** 65909	**Subspace correction methods**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Carsten Gräser
5	**Contents**	1) Subspace correction as an abstract framework to construct and analyse efficient iterative methods 2) Analysis of additive and multiplicative subspace correction 3) Multigrid and domain decomposition as subspace correction methods 4) Nonlinear subspace correction methods
6	**Learning objectives and skills**	Students are • familiar with the abstract subspace correction framework • can select problem adapted methods • can analyse specific methods within the framework
7	**Prerequisites**	Recommended: Introduction to numerical methods for PDEs Recommended: Basic knowledge of functional analysis (but the necessary terminology and results are briefly provided during the lecture)
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (15 minutes) oral exam (15 min)
11	**Grading procedure**	Oral (100%) 100% based on oral exam
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	• H. Yserentant: Old and New Convergence Proofs for Multigrid Methods, Acta Numer. 1993 • J.-C. Xu: Iterative Methods by Space Decomposition and Subspace Correction, SIAM Rev., 1992 • Further literature and publications are announced during the lecture

1	**Module name** 65888	**Navier Stokes Equations** Navier stokes equations	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Emil Wiedemann
5	**Contents**	The incompressible Navier-Stokes equations (NSE) are a nonlinear system of partial differential equations fundamental for the modelling of fluid flow. They are extensively used in meteorology and oceanography, but also pose great mathematical challenges. Famously, global regularity of the three-dimensional NSE forms one of the seven Millennium Problems. This course serves as an introduction to the mathematical theory of these equations and includes the following topics: • existence of weak solutions of Leray-Hopf type; • local-in-time existence of strong solutions; • the Prodi-Serrin criteria for regularity and energy balance; • partial regularity theory; • the singular limit of vanishing viscosity. The course can be a good preparation for a subsequent master's thesis in the topic.
6	**Learning objectives and skills**	Students know and understand the basic theory of the Navier-Stokes equations and have mastered important methods for systems of non-linear partial differential equations. They have a basic understanding of mathematical fluid dynamics.
7	**Prerequisites**	Lineare Algebra, Analysis. Empfohlen: erste Kurse in partiellen Differentialgleichungen und Funktionalanalysis.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	

16	**Bibliography**	• J. C. Robinson, J. L. Rodrigo, W. Sadowski: The Three-Dimensional Navier-Stokes Equations. Cambridge University Press, 2016. • P. Constantin, C. Foias: Navier-Stokes Equations. University of Chicago Press, 1988. • W. Ożański: The Partial Regularity Theory of Caffarelli, Kohn, and Nirenberg and its Sharpness. Birkhäuser, 2019. • E. Wiedemann: Navier-Stokes Equations: Lecture Notes. Universität Ulm, 2018/19.

1	**Module name** 48241	**Mathematical Image Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Mathematical Image Processing (2.0 SWS)	5 ECTS
		Tutorium: Tutorial for Mathematical Image Processing (0.5 SWS)	-
		This module is offered in every second summer term. The next course will be held in the summer semester 2024.	
3	Lecturers	Prof. Dr. Daniel Tenbrinck	

4	**Module coordinator**	Prof. Dr. Daniel Tenbrinck
5	**Contents**	This module covers mathematical image processing techniques based on Fourier domain filters, variational methods, and partial differential equations. In particular, the following content will be introduced to the students: • contrast enhancement • filtering in Fourier and image domain • Bayesian image denoising • image deblurring / deconvolution • pixel-based clustering • region-based segmentation • image inpainting • nonlocal image processing using graphs
6	**Learning objectives and skills**	Students following this course will • learn how image data can be modeled and analyzed mathematically • develop a deeper understanding of mathematical basics and methods for image processing • implement own algorithms for mathematical image processing • discover connections to related mathematical fields, e.g., inverse problems and convex analysis
7	**Prerequisites**	Knowledge in calculus and linear algebra is **recommended** to understand the mathematical foundations of image processing. Knowledge in functional analysis, numerical mathematics, or inverse problems is **helpful** to understand advanced concepts in mathematical image processing.
8	**Integration in curriculum**	semester: 2;1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192

10	**Method of examination**	Written or oral Oral examination (20 min.) or written examination (60 min.) depending on size of course.
11	**Grading procedure**	Written or oral (100%) Oral exam (100%) or written exam (100%) depending on size of course.
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• G. Aubert & P. Kornprobst: Mathematical problems in Image Processing, Springer • K. Bredies & D. Lorenz, Mathematical Image Processing, Springer • S. Osher & R. Fedkiw, Level Set Methods and Dynamic Implicit Surfaces, Springer • A. Elmoataz , O.Lezoray, S. Bougleux: Nonlocal Discrete Regularization on Weighted Graphs: a framework for Image and Manifold Processing, IEEE Transactions On Image Processing, 17 (7), pp: 1047-1060, 2008

1	**Module name** 65970	**Stochastische Analysis** Stochastic analysis	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Torben Krüger
5	**Contents**	• Itokalkulus • Diffusionsprozesse • Stochastische Differentialgleichungen • Die Präsentation des Stoffes erfolgt in Vorlesungsform.
6	**Learning objectives and skills**	Die Studierenden erwerben die Fähigkeit komplexere Strukturen der Stochastik selbständig zu erfassen und auf exemplarische Problemstellungen anzuwenden. Diese bilden eine Basis für eine Spezialisierung in Stochastik undentsprechenden wirtschaftsmathematischen Themen.
7	**Prerequisites**	empfohlen: Kenntnisse der Wahrscheinlichkeitstheorie sind zum Verständnis hilfreich
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 37,5 Independent study: 112,5
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Die vorbereitende Literatur wird für jede Lehrveranstaltung jedes Semester neu festgelegt.

1	**Module name** 65096	**Seminar Selected Topics of Applied Analysis**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Günther Grün
5	**Contents**	Topics from Applied Analysis to deepen the theoretical contents of the lecture ModAna1
6	**Learning objectives and skills**	Students • are able to familiarize themselves with advanced topics using journal articles or graduate textbooks, • can present the acquired content orally in a structured manner, with, if necessary, own additions in content, • actively participate at discussions about mathematical topics raised by the presentations in the seminar.
7	**Prerequisites**	Linear algebra and calculus are required. Basic knowledge in probability theory is recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Non-Specialisation modules Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and numerical analysis and simulation (NASi) Master of Science Computational and Applied Mathematics 20192 Specialisation: Modeling and applied analysis (MApA) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Specialisation: Numerical analysis and simulation (NASi) and optimization (Opti) Master of Science Computational and Applied Mathematics 20192 Mandatory elective module in M.Sc. Computational and Applied Mathematics Summer or winter term after participation at ModAna1
10	**Method of examination**	Presentation Oral (90 minutes) Oral presentation (90min) and presentation document (4-8 pages)
11	**Grading procedure**	Presentation (20%) Oral (80%)

		Oral presentation (80%) presentation document (20%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 115 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Determined by the topic chosen