List of modules for the Master's degree programme Computational and Applied Mathematics for the summer semester 2021

Not all of the listed modules are offered annually. On the other hand, additional modules may be offered.

Department of Mathematics
Friedrich-Alexander-Universität Erlangen-Nürnberg

Last updated: June 01, 2021
Reference: Examination regulations dated Feb 27, 2017

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
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Last updated: June 01, 2021

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1	**Module name**	**Module 2: ModAna2: Modeling and Analysis in Continuum Mechanics II**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Exercises: 0.5 semester hrs/week	MApA
3	**Lectures**	Prof. Dr. Enrique Zuazua enrique.zuazua@fau.de Nicola De Nitti nicola.de.nitti@fau.de	
4	**Module coordinator**	Prof. Dr. G. Grün gruen@math.fau.de	
5	**Content**	At least two of the following three 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 into curriculum**	2nd semester	
9	**Module compatibility**	Mandatory module for MSc in Computational and Applied Mathematics Mandatory elective module for MSc in Mathematics in the fields of “Modeling, Simulation and Optimization” and “Analysis and Stochastics”	
10	**Method of examination**	oral examination (20 minutes)	
11	**Grading Procedure**	100% based on Oral examination	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 35 hrs Independent study: 115 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	• 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.

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1	**Module name**	**Module 3: MoSi: Modeling, Simulation, Optimization (Practical Course)**	**ECTS 5**
2	**Courses/lectures**	Seminar: 3 semester hrs/week	MApA/NASi/Opti
3	**Lectures**	Prof. Dr. Enrique Zuazua enrique.zuazua@fau.de Dr. Daniël Veldman daniel.veldman@math.fau.de	
4	**Module coordinator**	Prof. Dr. Martin Burger martin.burger@fau.de	
5	**Content**	• 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 into curriculum**	2nd semester	
9	**Module compatibility**	Compulsory module for MSc in Computational Applied Mathematics Mandatory elective module for MSc in Mathematics in the field of "Modeling, Simulation and Optimization"	
10	**Method of examination**	Weekly hand in assignments. Final project.	
11	**Grading Procedure**	Hand in assignments 20% Final project 80%	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 42 hrs Independent study: 108 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	Project-dependent. Will be published on StudOn at the beginning of the semester.

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1	**Module name**	**Module 4: PTfS-CAM: Programming Techniques for Supercomputers in CAM**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 2 semester hrs/week	
3	**Lecturers**	Prof. Dr. Gerhard Wellein Gerhard.Wellein@rrze.uni-erlangen.de	
4	**Module coordinator**	Prof. Dr. Gerhard Wellein Gerhard.Wellein@rrze.uni-erlangen.de	
5	**Content**	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 into curriculum**	2nd semester	
9	**Module compatibility**	Compulsory module for MSc Computational and Applied Mathematics	
10	**Method of examination**	oral exam (30 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 120 hrs Independent study: 180 hrs Total: 300 hrs, corresponding to 10 ECTS credits	
14	**Module duration**	One semester	

15	**Teaching and examination language**	English
16	**Recommended reading**	• 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

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1	**Module name**	**Module 6a:** **MaSe: Master's seminar MApA**	**ECTS 5**
2	**Courses/lectures**	"Mathematical Modeling and Data Analysis"	
3	**Lecturers**	Prof. Dr. Burger martin.burger@fau.de	
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	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 into curriculum**	3rd semester	
9	**Module compatibility**	Compulsory module for MSc in Computational and Applied Mathematics Compulsory module for MSc in Mathematics Compulsory module for MSc in Mathematics and Economics	
10	**Method of examination**	talk/presentation (90 minutes) and handout (5-10 pages)	
11	**Grading Procedure**	talk/presentation 75% handout 25%	
12	**Module frequency**	Winter semester (annually)	
13	**Workload**	Contact hours: 30 hrs Independent study: 120 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	Depending on topic. Will be published on StudOn at the beginning of the semester.	

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1	**Module name**	**Module 6b: MaSe: Master's seminar NASi**	**ECTS 5**
2	**Courses/lectures**	"Mathematical Modeling and Data Analysis"	
3	**Lecturers**	Prof. Dr. Burger martin.burger@fau.de	
4	**Module coordinator**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	
5	**Content**	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 into curriculum**	3rd semester	
9	**Module compatibility**	Compulsory module for MSc in Computational and Applied Mathematics Compulsory module for MSc in Mathematics Compulsory module for Msc in Mathematics and Economics	
10	**Method of examination**	talk/presentation (90 minutes) and handout (5-10 pages)	
11	**Grading Procedure**	talk/presentation 75% handout 25%	
12	**Module frequency**	Winter semester (annually)	
13	**Workload**	Contact hours: 30 hrs Independent study: 120 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	Depending on topic. Will be published on StudOn at the beginning of the semester.	

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1	**Module name**	**Module 6c:** **MaSe: Master's seminar Opti**	**ECTS 5**
2	**Courses/lectures**		
3	**Lecturers**		
4	**Module coordinator**	Prof. Dr. Michael Stingl michael.stingl@fau.de	
5	**Content**	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 into curriculum**	3rd semester	
9	**Module compatibility**	Compulsory module for MSc in Computational and Applied Mathematics Compulsory module for MSc in Mathematics Compulsory module for MSc in Mathematics and Economics	
10	**Method of examination**	talk/presentation (90 minutes) and handout (5-10 pages)	
11	**Grading Procedure**	talk/presentation 75% handout 25%	
12	**Module frequency**	Winter semester (annually)	
13	**Workload**	Contact hours: 30 hrs Independent study: 120 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	Depending on topic. Will be published on StudOn at the beginning of the semester.	

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1	**Module name**	**Module 7: Master's Thesis**	**ECTS 25**
2	**Courses/lectures**	Oral examination Master's Thesis	
3	**Lectures**	The lecturers for the degree programme in Computational and Applied Mathematics	MaPA/NASI/Opti
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	The master's 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 into curriculum**	4th semester	
9	**Module compatibility**	Master's degree programme in Computational and Applied Mathematics	
10	**Method of examination**	Master's thesis (scope according to examination regulations) Oral exam (15 minutes)	
11	**Grading Procedure**	90% Master's thesis 10% Oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 15 hrs Independent study: 735 hrs Total: 750 hrs, corresponding to 25 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	Individual, depending on topic of Master's Thesis.	

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1	**Module name**	**Module 11: RTpMMod: Transport and Reaction in Porous Media: Modeling**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	MApA
3	**Lectures**	Prof. Dr. Serge Kräutle kraeutle@math.fau.de	
4	**Module coordinator**	Prof. Dr. Serge Kräutle kraeutle@math.fau.de	
5	**Content**	• Modeling of fluid flow through a porous medium: Groundwater models (Richards' equation), multiphase flow • Advection, diffusion, dispersion of dissolved substances, (nonlinear) reaction-models (i.a. law of mass action, adsorption, kinetic / in local equilibrium, reactions with minerals) • Models of partial (PDEs), ordinary (ODEs) differential equations, and local 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 of stationary solutions (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 into curriculum**	2nd semester	
9	**Module compatibility**	Mandatory elective module: • MSc. Computational and Applied Mathematics • MSc Mathematics with field of "Modelling, Simulation, and Optimization” Non-physical elective module: • MSc Physics	
10	**Method of examination**	Oral exam (20 minutes)	
11	**Grading Procedure**	100% Oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	• 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 • crnt.osu.edu/LecturesOnReactionNetworks

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1	**Module name**	**Module 13:** **NuIF1: Numerics of Incompressible Flows I**	**ECTS 5**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	NASi
3	**Lectures**	Dr. Stefan Metzger metzger@math.fau.de	
4	**Module coordinator**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	
5	**Content**	• 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 into curriculum**	2nd semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics in the field of “Modeling, Simulation and Optimization”	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral examination	
12	**Module frequency**	summer semester (annually)	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	one semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	• V. Girault1 & 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. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

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1	**Module name**	**Module 14:** **NuIF2: Numerics of Incompressible Flows II**	**ECTS 5**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lecturers**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	NASi
4	**Module coordinator**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	
5	**Content**	• 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 into curriculum**	3rd semester	
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the field of study “Modeling, Simulation and Optimization”	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (annually)	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	

15	**Teaching and examination language**	English
16	**Recommended reading**	• 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

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1	**Module name**	**Module 16:** **MaDS: Mathematical Data Science 1**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 1/2 semester hrs/week	NASi
3	**Lecturers**	Dr. Leon Bungert leon.bungert@fau.de Dr. Daniel Tenbrinck daniel.tenbrinck@fau.de	
4	**Module coordinator**	Prof. Dr. Martin Burger martin.burger@fau.de	
5	**Content**	• Clustering and Classification Models • Machine learning: empirical risk minimization, kernel methods, and variational models • Ranking problems • Mathematical models of graph structured data	
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**	Recommended: basic knowledge in numerical methods and optimization	
8	**Integration into curriculum**	2nd or 4th semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics Mandatory elective module for MSc in Mathematics in the field of “Modeling, Simulation and Optimization”	
10	**Method of examination**	Project work with presentation and report	
11	**Grading Procedure**	50 % presentation and 50 % report	
12	**Module frequency**	Summer semester (not annually) To check whether the course is offered in the current semester, see UnivIS univis.fau.de or the module handbook of the current semester	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	• Goodfellow, Y. Bengio, A. Courville: Deep Learning, MIT Press, 2015 • T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer, 2008	

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1	**Module name**	**Module 18:** **MaMM: Mathematics of Multiscale Models**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	MApA
3	**Lecturers**	PD Dr. Nicolas Neuß neuss@math.fau.de	
4	**Module coordinator**	PD Dr. Nicolas Neuß neuss@math.fau.de	
5	**Content**	• 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 into curriculum**	3rd semester	
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the field of “Modeling, Simulation and Optimization”	
10	**Method of examination**	Oral exam (20 minutes)	
11	**Grading Procedure**	100% Oral exam	
12	**Module frequency**	At least once every two years To check whether the course is offered in the current semester, see UnivIS: univis.fau.de	
13	**Workload**	Contact hours: 37,5 hrs Independent study: 112,5 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	• D. Cioranescu & P. Donato: An Introduction to Homogenization • U. Hornung (ed.): Homogenization and Porous Media • Y. Efendiev & T. Hou: Multiscale Finite Element Methods	

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1	**Module name**	**Module 27: MSOpt: Introduction to Material and Shape Optimization**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hr/week	Opti
3	**Lecturers**	Prof. Dr. Michael Stingl michael.stingl@fau.de	
4	**Module coordinator**	Prof. Dr. Michael Stingl michael.stingl@fau.de	
5	**Content**	• 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 into curriculum**	2nd semester	
9	**Module compatibility**	• Mandatory elective module for MSc Computational and Applied Mathematics • Mandatory elective module for MSc Mathematics in the fields of “Modeling, Simulation and Optimization” • Mandatory elective module for MSc Mathematics and Economics in the fields of study “Optimization and Process Management”	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 75 hrs Independent study: 225 hrs Total: 300 hrs, corresponding to 10 ECTS credits	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	• J. Haslinger & R. Mäkinen: Introduction to shape optimization, SIAM, • M. P. Bendsoe & O. Sigmund: Topology Optimization: Theory, Methods and Applications, Springer.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 30:** **RobOpt II: Robust Optimization II**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 1 weekly lecture hour	Opti
3	**Lecturers**	Dr.Jan Rolfes jan.rolfes@fau.de	
4	**Module coordinator**	Prof. Dr. Frauke Liers frauke.liers@math.uni-erlangen.de	
5	**Content**	• 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 into curriculum**	2nd semester	
9	**Module compatibility**	• Mandatory elective module for MSc Computational and Applied Mathematics, • Mandatory elective module for MSc Mathematics in the field of study “Modelling, Simulation and Optimization” • Mandatory elective module for the MSc in Mathematics and Economics in the field of study “Optimization and process management”	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (not annually) To check whether the course is offered in the current semester, see UnivIS univis.fau.de or module handbook of current semester	
13	**Workload**	Total: 150 h • Attendance: 45 h • Self-study: 105 h	
14	**Module duration**	1 semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	• Lecture notes, will be published on StudOn at the beginning of the semester.

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1	**Module name**	**Module 31:** **NALIP: Numerical Aspects of Linear and Integer Programming**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 0.5 weekly lecture hour	Opti
3	**Lecturers**	Dr. Andreas Bärmann andreas.baermann@math.uni-erlangen.de	
4	**Module coordinator**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
5	**Content**	• 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 into curriculum**	2nd semester	
9	**Module compatibility**	• Mandatory elective module for MSc Computational and Applied Mathematics • Mandatory elective module for MSc Mathematics in the field of “Modeling, Simulation and Optimization” • Mandatory elective module for MSc Mathematics and Economics in the fields of “Optimization and Process Management”	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of current semester	
13	**Workload**	Attendance: 45 h Self-study: 105 h	
14	**Module duration**	1 semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	• 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**	**Module 34: DiscOpt II: Discrete Optimization II**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 weekly lecture hours b) Practical: 2 weekly lecture hour	
3	**Lecturers**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
4	**Module coordinator**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
5	**Content**	In this lecture we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we point out the equivalence between separation and optimization. Second, fundamental results of integral polyhedra, lattices and lattice polyhedra as well as its importance to discrete optimization are discussed. Furthermore, we introduce solution strategies for large-scale optimization problems, e.g., decomposition methods or approximation algorithms and heuristics based on linear programming. In addition, we discuss applications arising in engineering, finance, energy management 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 into curriculum**	2nd semester	
9	**Module compatibility**	Mandatory elective module for MSc Computational and Applied Mathematics, Elective module for MSc Mathematics, Elective module for MSc Mathematics and Economics, Core/research module MSc Mathematics within “Modeling, simulation, optimization”, MSc Mathematics and Economics within “Optimization and process management”	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Attendance: 90 h Self-study: 210 h	
14	**Module duration**	1 semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	Lecture notes D. Bertsimas & R. Weismantel: Optimization over Integers, Dynamic Ideas, 2005 Conforti, Cornuéjols & Zambelli: Integer Programming, Springer 2014 G. L. Nemhauser & L.A. Wolsey: Integer and Combinatorial Optimization, Wiley 1994 A. Schrijver: Combinatorial optimization Vol. A - C, Springer 2003 A. Schrijver: Theory of Linear and Integer Programming, Wiley, 1986 L.A. Wolsey: Integer Programming, Wiley

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1	**Module name**	**Module 39:** **NumPDE II: Numerics of Partial Differential Equations II**	**ECTS 5**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 1 semester hr/week	NASi
3	**Lecturers**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	• 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 method's 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 into curriculum**	2nd semester	
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for BSc Mathematics • Mandatory module for BSc Technomathematik • Non-Physics elective module for MSc Physics	
10	**Method of examination**	written exam (90 minutes) with exercises	
11	**Grading Procedure**	100% based on written exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Contact hours: 45 hrs Independent study: 105 hrs Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	

15	**Teaching and examination language**	English
16	**Recommended reading**	• 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.

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1	**Module name**	**Free elective module: A primer on functional-analytic methods for PDEs**	**ECTS 5**
2	**Courses/lectures**	Lectures: 2 semester hrs/week Exercises: 0,5 semester hrs/week	MApA/NASi/Opti
3	**Lecturers**	Prof. Dr. Hannes Meinlschmidt meinlschmidt@math.fau.de	
4	**Module coordinator**	Prof. Dr. G. Grün gruen@math.fau.de	
5	**Content**	Basics and foundations in the following topics: • Banach and Hilbert spaces, • dual spaces and weak topology, • compact operators, their spectral theory, • Sobolev spaces, approximation and trace theorems • variational formulation of PDEs, • Sobolev solutions to linear elliptic PDEs (Lax-Milgram/Fredholm alternative)	
6	**Learning objectives and skills**	Students are able to: • name and explain fundamental concepts in functional analysis, • navigate between weak and strong topologies and have an understanding of their relation and respective properties, • work with Sobolev spaces and weak derivatives and give qualitative information about Sobolev functions, • identify, set up and work with variational formulations of linear elliptic PDEs in order to derive existence/uniqueness of solutions in the Sobolev setting	
7	**Prerequisites**	Recommended: Basic knowledge in normed vector spaces, Lebesgue integration and Linear Algebra	
8	**Integration into curriculum**	1st semester or preparationary period for the CAM master	
9	**Module compatibility**	M. Sc. Computational Applied Mathematics - non-specialization	
10	**Method of examination**	Oral examination (15 min)	
11	**Grading Procedure**	100% Oral examination	
12	**Module frequency**	Summer semester	
13	**Workload**	Contact hours: 14x2 + 7x1 = 35 hrs Independent study: 115 hrs Total: 150 hrs, corresponding to 5 ECTS credits	

14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• H. W. Alt: Linear Functional Analysis, Springer • A. Bressan: Lecture Notes on Functional Analysis: With Applications to Linear Partial Differential Equations, AMS • H. Brezis: Functional Analysis, Sobolev Spaces and Partial Differential Equations , Springer • L. C. Evans: Partial Differential Equations, AMS • W. Hackbusch: Theorie und Numerik elliptischer Differentialgleichungen, Vieweg+Teubner • Lecture notes

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Last updated: June 01, 2021