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

for the wintersemester 2019/20

Department of Mathematics
Friedrich-Alexander-Universität Erlangen-Nürnberg

Last updated: October 15th 2019
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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

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FAKULTÄT

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1	**Module name**	**Module 1:** **ModAna1: Modeling and Analysis in Continuum Mechanics I**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hr/week	
3	**Lecturers**	Prof. Dr. Martin Burger martin.burger@math.fau.de	
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	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 into curriculum**	1st semester	
9	**Module compatibility**	Compulsory module for MSc in Computational and Applied Mathematics Compulsory elective module for MSc in Mathematics	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter 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**	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.	

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1	**Module name**	**Module 5:** **ArchSup: Architectures of Supercomputers**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 2 semester hrs/week	
3	**Lecturers**	Johannes Hofmann johannes.hofmann@fau.de	
4	**Module coordinator**	**Prof. Dr. Dietmar Fey**	
5	**Content**	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**	Students can explain the functionality of modern processors used in supercomputers, recognise the special problems associated with energy consumption and programming in supercomputers, can explain the different ways of interconnecting parallel processes, can classify parallel computers with regard to their storage connection and basic processing principles, are able to make use of and run a supercomputer to solve their own technical or mathematical problem. Based on the examples demonstrated during the lecture, they are able to generalise challenges associated with the discovery of bottlenecks and use them to solve their specific problem, are able to characterise their problems (e.g. scientific or technical simulation experiments) with regard to the computing and memory requirements for a supercomputer in a way that is appropriate for the architecture, can make use of the performance-measuring methods for parallel computers to evaluate various computer architectures and select the appropriate architecture for their problem.	
7	**Prerequisites**	• Basic Linux skills • Basic programming skills (C or C++)	
8	**Integration into curriculum**	3rd semester	
9	**Module compatibility**	Compulsory module for MSc Computation and Applied Mathematics, Computational Engineering degree programmes (Computer-Assisted Engineering) (Master of Science) and Information Technology (Master of Science)	
10	**Method of examination**	oral exam (30 minutes):	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (annually)	

13	**Workload**	Contact hours: 60 hrs Independent study: 90 hrs Total: 150 hrs, corresponding to 5 ECTS credits
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	Quinn: Parallel Programming in C with MPI and OpenMP, McGraw-Hill Hennessy/Patterson: Computer Architecture - A Quantitative Approach, Morgen&Kaufmann

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1	**Module name**	**Module 8:** **NumPDE: Numerics of Partial Differential Equations**	**ECTS 10**
2	**Courses/lectures**	a) Lecture: 4 semester hrs/week b) Practical: 2 semester hr/week	
3	**Lecturers**	Prof. Dr. Günther Grün gruen@math.fau.de	
4	**Module coordinator**	Prof. Dr. Peter Knabner knabner@math.fau.de	
5	**Content**	Classical theory of linear elliptic boundary value problems (outline) Finite difference method (FDM) for Poisson's equation in two dimensions (including stability via inverse monotonicity) Finite element method (FEM) for Poisson's 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 (2^{nd} 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 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 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 into curriculum**	1st 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**	Weekly exercises and written exam (90 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (annually)	
13	**Workload**	Contact hours: 90 hrs Independent study: 210 hrs Total: 300 hrs, corresponding to 10 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 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 scripts on the homepage of the domain Modeling, Simulation, and Optimization of the department Mathematics, frequently updated

1	**Module name**	**Module 9: AdDiscTech: Advanced Discretization Techniques**	**ECTS 10**
2	**Courses/lectures**	a) Lecture: 4 semester hrs/week b) Practical: 1 semester hr/week	
3	**Lecturers**	Prof. Dr. Peter Knabner knabner@math.fau.de	
4	**Module coordinator**	Prof. Dr. Eberhard Bänsch baensch@math.fau.de	
5	**Content**	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 into curriculum**	1st semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics Compulsory elective module for MSc in Mathematics	
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: 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**	• 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

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1	**Module name**	**Module 10a:** **MaSe: Master's seminar MApA**	**ECTS 5**
2	**Courses/lectures**	Seminar: "Topics on control and numerics of Partial Differential Equations (PDE)"	
3	**Lecturers**	Prof. Dr. Enrique Zuazua enrique.zuazua@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 10b:** **MaSe: Master's seminar NASi**	**ECTS 5**
2	**Courses/lectures**	Seminar: "Topics on control and numerics of Partial Differential Equations (PDE)"	
3	**Lecturers**	Prof. Dr. Enrique Zuazua enrique.zuazua@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.	

1	**Module name**	**Module 10c: MaSe: Master's seminar Opti**	**ECTS 5**
2	**Courses/lectures**	Seminar: "Topics on control and numerics of Partial Differential Equations (PDE)"	
3	**Lecturers**	Prof. Dr. Enrique Zuazua enrique.zuazua@fau.de	
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 11:** **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**	
4	**Module coordinator**	**Prof. Dr. G. Grün**	
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 15:** **IPReg: Inverse Problems**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lecturers**	Prof. Dr. Martin Burger martin.burger@math.fau.de	
4	**Module coordinator**	Prof. Dr. Martin Burger martin.burger@math.fau.de	
5	**Content**	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**	Recommended: basic knowledge in functional analysis	
8	**Integration into curriculum**	1st or 3rd semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics Elective module for MSc in Mathematics Elective module for MSc in Mathematics and Economics	
10	**Method of examination**	Oral exam (15 minutes)	
11	**Grading Procedure**	100% Oral exam	
12	**Module frequency**	Winter 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**	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**	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**	**Module 25:** **AnFBP: Analysis of free-boundary problems in continuum mechanics**	**ECTS 5**
2	**Courses/lectures**	Lecture: 2 semester hrs/week Practical: 0.5 semester hrs/week	
3	**Lecturers**	Prof. Dr. Günther Grün gruen@math.fau.de	
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	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 porous-media 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 into curriculum**	3rd semester	
9	**Module compatibility**	Mandatory elective module MSc Computational and Applied Mathematics, Elective module MSc Mathematics (Analysis and Stochastics)	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of current semester	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	L.C. Evans: Partial Differential Equations, AMS, Original journal articles.	

1	**Module name**	**Module 29: DiscOpt I: Discrete Optimization I**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 1 weekly lecture hour	
3	**Lecturers**	Dr. Andreas Bärmann andreas.bärmann@math.uni-erlangen.de	
4	**Module coordinator**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
5	**Content**	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 into curriculum**	1st or 3rd semester	
9	**Module compatibility**	Mandatory elective module for MSc Computational and Applied Mathematics, Elective module for MSc in Mathematics, Elective module for MSc in 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 (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (not annually) To check whether the course is offered, see UnivIS: univis.fau.de	
13	**Workload**	Attendance: 45 h Self-study: 105 h	
14	**Module duration**	one semester	
15	**Teaching and examination language**	English	

16	**Recommended reading**	Lecture notes Conforti, Cornuéjols & Zambelli: Integer Programming, Springer 2014 B. Grünbaum: Convex Polytopes, Springer, 2003 B. Korte & J. Vygen: Combinatorial Optimization, Springer 2005 G. L. Nemhauser & L.A. Wolsey: Integer and Combinatorial Optimization, Wiley 1994 A. Schrijver: Theory of Linear and Integer Programming, Wiley 1986 L.A. Wolsey: Integer Programming, Wiley 1998 G. Ziegler: Lectures on Polytopes, Springer, 1995

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1	**Module name**	**Module 33:** **OptPDE: Optimization with Partial Differential Equations**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lecturers**	Prof. Dr. Günter Leugering guenter.leugering@fau.de	
4	**Module coordinator**	Prof. Dr. Michael Stingl michael.stingl@fau.de	
5	**Content**	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 into curriculum**	1st or 3rd semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics Elective module for MSc in Mathematics Elective module for MSc in Mathematics and Economics	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of 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**	- F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS, - G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser.	

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1	**Module name**	**Module 35: OptIE: Optimization in Industry and Economy**	**ECTS 5**
2	**Courses/lectures**	Lecture: Optimization in Industry and Economy Exercises: Optimization in Industry and Economy	
3	**Lecturers**	Dr. Francisco Javier Zaragoza Martínez franz@azc.uam.mx	
4	**Module coordinator**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
5	**Content**	Graph routing problems consist usually of an agent that must achieve a certain goal while traversing the arcs or vertices of a graph. Practical applications of graph routing include vehicle routing, pick-up and delivery services, mail delivery, meter reading, snow plowing, waste collection, and many others. Perhaps the simplest graph routing problems are the postman problem and the traveling salesman problem (covered in "Graph routing and applications"). In this course we are going to present some more complicated graph routing problems with practical applications, we are going to cover the mathematical programming techniques used to model these problems (usually as integer programs), and we are going to describe algorithmic methods of solution for some of them.	
6	**Learning objectives and skills**	At the end of this course, students should be able to (a) recognize the basic arc and edge graph routing problems, (b) solve graph routing problems using well-known combinatorial algorithms, (c) model more complex graph routing problems using integer programming, (d) apply mathematical programming techniques to solve practical graph routing problems.	
7	**Prerequisites**	Recommended: Modul LKOpt: Linear and combinatorial optimization	
8	**Integration into curriculum**	Master: 1st semester or later	
9	**Module compatibility**	Master elective modul (M-MA, TM-MA, WM-MA, CAM-MA-NASi, CAM-MA-Opti, CAM-MA-MApA)	
10	**Method of examination**	Oral exam (15 min)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (2019/2020)	
13	**Workload**	150 hr as follows: Lecture: 4 SWS x 7.5 = 30 hr Exercises: 2 SWS x 7.5 = 15 hr Self-study: 105 hr	
14	**Module duration**	Half a semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	There is a script prepared by the lecturer which will be available on StudOn	

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 37:** **GraphR: Graph Routing and Applications**	**ECTS 5**
2	**Courses/lectures**	Lecture: Graph Routing and Applications Exercises: Graph Routing and Applications	
3	**Lecturers**	Prof. Dr. Francisco Javier Zaragoza Martínez franz@azc.uam.mx	
4	**Module coordinator**	Prof. Dr. Alexander Martin alexander.martin@fau.de	
5	**Content**	The origins of graph theory are usually traced back to Euler's solution to the famous amusement known as the Königsberg bridges problem, that is, the problem of starting at some point, traversing each bridge exactly once, and returning to the original point. Since then, numerous generalizations and variants of this problem have been proposed. In this course we are going to present some basic graph routing problems (known as the postman problem and the traveling salesman problem), we are going to cover the necessary graph theoretical concepts and mathematical programming techniques used to model these problems (usually as linear integer programs), and we are going to describe algorithmic methods for their solution.	
6	**Learning objectives and skills**	At the end of this course, students should be able to (a) recognize the basic arc and edge graph routing problems, (b) solve graph routing problems using well-known combinatorial algorithms, (c) model more complex graph routing problems using integer programming, (d) apply mathematical programming techniques to solve practical graph routing problems.	
7	**Prerequisites**	Recommended: Modul LKOpt: Linear and combinatorial optimization	
8	**Integration into curriculum**	Bachelor: 5th semester or later Master: 1st semester or later	
9	**Module compatibility**	Bachelor elective modul (M-BA, TM-BA, WM-BA) Master elective modul (CAM-MA-NASi, CAM-MA-Opti, CAM-MA-MApA)	
10	**Method of examination**	Homeworks (weekly) Written examination (Klausur, 90 min.)	
11	**Grading Procedure**	Written examination (Klausur, 100%)	
12	**Module frequency**	Winter semester (2019/2020)	
13	**Workload**	150 h as follows: • Lecture: 4 SWS x 7.5 = 30 h • Exercises: 2 SWS x 7.5 = 15 h Self-study: 105 h	
14	**Module duration**	Half a semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	There is a script prepared by the lecturer which will be available on StudOn	