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

for the wintersemester 2021/22

Department of Mathematics
Friedrich-Alexander-Universität Erlangen-Nürnberg

Last updated: October 11 2021
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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. Enrique Zuazua enrique.zuazua@fau.de Nicola De Nitti nicola.de.nitti@fau.de	MApA
4	**Module coordinator**	Prof. Dr. Günther Grün gruen@math.fau.de	
5	**Content**	1. **Describing the motion of a continuum**. Average density. Eulerian and Lagrangian descriptions; the material derivative. 2. **Conservation of Mass**. Derivation of the continuity equation. Reynolds transport theorem. Incompressible fluids. Traffic flow models. Parabolic equations arising in biology. Elliptic equations. 3. **Balance of Momentum**. The momentum equation. Ideal gas dynamics. The Shallow water system. Hyperbolic systems modeling traffic flow. 4. **Conservation of Energy**. Incompressible and isentropic fluids. 5. **Stress and Strain**. Measuring the strain. Elastic deformation of a bar. Linear wave equation. The beam equation. Nonlinear dispersive waves: the Korteweg-de Vries equation.	
6	**Learning objectives and skills**	Students are able to: • 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**	Recommended: basic knowledge of linear algebra and calculus; basic knowledge of functional analysis.	
8	**Integration into curriculum**	1st semester	
9	**Module compatibility**	• Mandatory module for M.Sc. in Computational and Applied Mathematics; • Mandatory elective module for M.Sc. in Mathematics (“Modelling, Simulation and Optimization” and “Analysis and Stochastics”)	
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**	Modeling in Continuum Mechanics: • Chorin, A. J., & Marsden, J. E., *Mathematical Introduction to Fluid Mechanics*. Springer, 1993. • Roberts, A. J. *A One-dimensional Introduction to Continuum Mechanics*. World Scientific, 1994. Partial Differential Equations: • Evans, L. C. *Partial Differential Equations*. AMS, 2010. • 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. Ordinary differential Equations: • Corduneau, C. *Principles of Differential and Integral Equations*. Allyn and Bacon Inc., 1971. Lecture notes will be distributed via StudOn.

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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. Eberhard Bänsch baensch@math.fau.de	NASi
4	**Module coordinator**	Prof. Dr. Eberhard Bänsch baensch@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 (in the field Applied Mathematics) * Mandatory elective Module for BSc Technomathematics (in the field Numerical Mathematics, Modelling and Optimization), * Mathematical mandatory elective module for BSc Mathematics and Economics * 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**	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

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1	**Module name**	**Module 10a:** **MaSe: Master's seminar MApA**	**ECTS 5**
2	**Courses/lectures**	Masterseminar	
3	**Lecturers**	Prof. Dr. Martin 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 10b:** **MaSe: Master's seminar NASi**	**ECTS 5**
2	**Courses/lectures**	Masterseminar	
3	**Lecturers**	Prof. Dr. Martin 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.	

1	**Module name**	**Module 10c:** **MaSe: Master's seminar Opti**	**ECTS 5**
2	**Courses/lectures**	Masterseminar	
3	**Lecturers**	Prof. Dr. Martin Burger martin.burger@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: MaThe: 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 15:** **IPReg: Inverse Problems and their Regularizations**	**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 Mandatory elective module for MSc in Data Science in the field of study “Simulation and Numerics” and “MSO” 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

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1	**Module name**	**Module 16: MoL: Mathematics of Learning**	**ECTS 5**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 2 semester hrs/week	
3	**Lecturers**	Prof. Dr. Frauke Liers	
4	**Module coordinator**	Prof. Dr. M. Burger martin.burger@fau.de	
5	**Content**	- 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 into curriculum**	1st semester or 3rd semester	
9	**Module compatibility**	Mandatory module for: - M. Sc. Data Sciences Mandatory elective module for: - M. Sc. Computational and Applied Mathematics Elective module for: - M. Sc. Mathematics - M. Sc. Mathematics and Economics	
10	**Method of examination**	written or oral exam, according to the Corona regulations	
11	**Grading Procedure**	100% based on written or oral exam	
12	**Module frequency**	Module frequency Wintersemester (annualy)	
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**	Courville, Goodfellow, Bengio, Deep Learning, MIT Press, 2015 Hastie, Tibshirani, Friedman, The Elements of Statistical Learning, 2008	

	Module name	**Module 23:** **MaMoLS: Mathematical Modeling in the Life Sciences**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	
3	**Lecturers**	Dr. Maria Neuss-Radu maria.neuss-radu@math.fau.de	**MApA**
4	**Module coordinator**	Dr. Maria Neuss-Radu maria.neuss-radu@math.fau.de	
5	**Content**	• 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 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 “Modelling, Analysis and Optimization”	
10	**Method of examination**	Oral exam (15 minutes)	
11	**Grading Procedure**	100% 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**	• 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

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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.baermann@math.uni-erlangen.de	Opti
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, Mandatory elective module for MSc in Data Science in the field of study “Databased optimization” 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

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1	**Module name**	**Module 37: Conic Optimization and Applications**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 1 semester hr/week	
3	**Lecturers**	Dr. Jan Rolfes jan.rolfes@fau.de	Opti
4	**Module coordinator**	Dr. Jan Rolfes jan.rolfes@fau.de	
5	**Content**	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 into curriculum**	1st or 3rd 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**	Winter semester (not annually) To check whether the course is offered in the current semester, see UnivISunivis.fau.de or module handbook of current semester
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**	- 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

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1	**Module name**	**Module 40: DiscTPFlow: Efficient discretization of two-phase flow**	**5 ECTS**
2	**Courses/lectures**	Seminar: 2 semester hrs/week	
3	**Lecturers**	Dr. Stefan Metzger stefan.metzger@fau.de	MApA NASi
4	**Module coordinator**	Dr. Stefan Metzger stefan.metzger@fau.de	
5	**Content**	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 into curriculum**	1st or 3rd semester	
9	**Module compatibility**	• Mandatory elective module for BSc in Mathematics, Applied Mathematics • Mandatory elective module for BSc in Technomathematics • 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**	Talk/presentation (60-80 minutes) with handout (5-10 pages)	
11	**Grading Procedure**	100% talk/presentation with handout	
12	**Module frequency**	Winter semester (not 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 41: AGT: Algorithmic Game Theory**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 1 semester hrs/week	
3	**Lecturers**	Prof. Dr. Yiannis Giannakopoulos yiannis.giannakopoulos@fau.de	Opti
4	**Module coordinator**	Prof. Dr. Yiannis Giannakopoulos yiannis.giannakopoulos@fau.de	
5	**Content**	The main goal of this course is to highlight the intriguing interplay between optimality, simplicity, efficiency and robustness in the design and analysis of systems involving many different selfish strategic players, with an emphasis in the intersection between Economics and Algorithmic Theory. Can we predict the possible outcomes of such dynamic situations? Can we motivate the players and design specific rules, so that those outcomes are stable and desirable? How well and how efficiently can we approximate the above objectives? These questions are very important and relevant in many modern, real-life applications, where the Internet has been established as the main platform for agent-interaction and computing.	
6	**Learning objectives and skills**	Upon successful completion of this module, students have a comprehensive understanding of the foundations of algorithmic game theory and algorithmic mechanism design. In particular, they can: - design and analyse efficient mechanisms for various settings involving rational selfish players, most notably Bayesian revenue-maximizing auctions - quantify the loss in performance of a system due to selfish behaviour (price of anarchy), most notably in traffic routing - understand the concept of differentiating between various equilibria outcomes and selecting the desired ones (potentials and equilibrium refinement) - understand the concept of learning dynamics in game-playing, such as best-responses	
7	**Prerequisites**	Recommended: Basic knowledge of - calculus - probability theory - linear/combinatorial optimization and/or algorithms & complexity	
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**	Oral exam (100%)
12	**Module frequency**	Winter semester (annually)
13	**Workload**	Attendance: 45 h Self-study: 105 h
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	- T. Roughgarden, “Twenty Lectures on Algorithmic Game Theory”, Cambridge University Press, 2016. - Nisan, Roughgarden, Tardos & Vazirani (Eds), “Algorithmic Game Theory”, Cambridge University Press, 2007

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1	**Module name**	**Module CGA: Convex Geometry and Applications (free elective)**	**ECTS 5**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 1 semester hr/week	
3	**Lecturers**	Prof. Dr. Timm Oertel timm.oertel@fau.de	
4	**Module coordinator**	Prof. Dr. Timm Oertel timm.oertel@fau.de	
5	**Content**	The module comprises of two parts. The first part is a general introduction to convex geometry, where basic concepts and tools will be introduced, such as separation and the classical results of Carathéodory, Helly and Radon. The second part will be more specialized, focusing on ellipsoids, including ellipsoidal approximation and volume concentration. Applications in optimization and data science will be highlighted throughout.	
6	**Learning objectives and skills**	Students • will learn the foundations of classical convex geometry • apply concepts and tools from convex geometry to modern applications in optimization and data science	
7	**Prerequisites**	Linear Algebra and Analysis is required Basic knowledge in Probability Theory is recommended	
8	**Integration into curriculum**	From 1st semester	
9	**Module compatibility**	Mandatory elective module for: • M. Sc. in Data Sciences “Data-oriented optimization” and “Mathematical Theory/Basics of Data Science” • M. Sc. in Mathematics within “Modelling, Simulation and Optimization” • M. Sc. in Mathematics and Economics within “Optimization and process management” Free elective module in M. Sc. Computational and Applied Mathematics	
10	**Method of examination**	Oral exam (15 minutes)	
11	**Grading Procedure**	100% oral exam	
12	**Module frequency**	Winter semester (not annually)	
13	**Workload**	Contact hours: 45 h Independent study: 105 h Total: 150 hrs, corresponding to 5 ECTS credits	
14	**Module duration**	One semester	

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15	**Teaching and examination language**	English (the examination can be done in German on request)
16	**Recommended reading**	TBA

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1	**Module name**	**Module TrPh: Transport Phenomena (free elective)**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Exercises: 0.5 semester hrs/week	MApA/NASi/Opti
3	**Lecturers**	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**	**Ordinary Differential Equations** 1. **Generalities on first order differential equations and preliminary material**. Equivalence of differential equation of order n to vector equation of the first order. Linear equations of the first order. Equations with separable variables. Exact differential equations. The uniqueness problem: an example. Some integral inequalities: Gronwall's lemma and Bihari's lemma. Generalities on Banach spaces. Banach fixed point theorem. 2. **Existence and uniqueness theorems for ODEs within the Cauchy-Lipschitz framework**. Local existence and uniqueness theorem for the Cauchy problem: proof of the result via the method of successive approximations and via Banach fixed point theorem. Ascoli-Arzelà theorem. Peano existence theorem: proof via the polygonal method and via Schauder point fixed theorem. Other uniqueness theorems. Some global problems for ordinary differential equations: global uniqueness, global existence and the behavior of saturated solutions. Dependence of solutions on initial values. Differential inequalities and the comparison method. A criterion of global existence. Stability theorems for ODEs: Lyapunov's theorems. 3. **Rough vector fields and DiPerna-Lions' theory**. Ambrosio's theory of regular Lagrangian flows; DiPerna-Lions' notion of flow; vector fields with Sobolev spatial regularity; vector fields with BV spatial regularity; quantitative ODE estimates for Sobolev vector fields. **Transport Equations** 4. **Method of characteristics and well-posedness.** Well-posedness of transport equation and continuity equation within the Cauchy-Lipschitz framework. Boundary conditions. Controllabilitty. Vanishing viscosity approximation. Upwind numerical schemes. Fourier analysis and numerical approximations of transport equations. An example in homogenization. 5. **Transport equations driven by rough velocity fields**. Connection between PDE and ODEs (with reference to point 3 above); superposition principle; renormalized solutions and well-posedness of the PDE.	

6	**Learning objectives and skills**	Students are able to: • use language and techniques of ordinary differential equations (with smooth or irregular vector fields), especially regarding local and global existence, uniqueness theorems, regularity and stability of the solutions; • use language and techniques related to transport equations with smooth and irregular velocity fields; • 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 into curriculum**	1^{st} semester
9	**Module compatibility**	M.Sc. Computational Applied Mathematics M. Sc. Data Science ("Simulation and Numerics") The course is open also to Ph.D. candidates in the Mathematics and Data Science Departments
10	**Method of examination**	Oral examination (20 minutes)
11	**Grading Procedure**	100% based on oral examination
12	**Module frequency**	Winter semester
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

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16	**Recommended reading**	Parts 1 & 2: • Ahmad, S. & Ambrosetti, A. *A Textbook on Ordinary Differential Equations*. Springer, 2015. • Corduneau, C. *Principles of Differential and Integral Equations*. Allyn and Bacon Inc., 1971. Part 4: • Evans, L. C. *Partial Differential Equations*. AMS, 2010. • Coron, J. M. *Control and Nonlinearity*. AMS, 2007. • Mishra, S., Fjordholm, U. S. & Abgrall, R. *Numerical methods for conservation laws and related equations*, 2019. • Quarteroni, A. & Valli, A. *Numerical Approximation of Partial Differential Equations.* Springer, 2014. • Vichnevetsky, R. & Bowles, J. B. *Fourier Analysis of Numerical Approximations of Hyperbolic Equations*. SIAM, 1982. • Tartar, L. (1989). Nonlocal Effects Induced by Homogenization. In: Colombini F., Marino A., Modica L., Spagnolo S. (eds) *Partial Differential Equations and the Calculus of Variations. Progress in Nonlinear Differential Equations and Their Applications*, vol 1. Birkhäuser, Boston, MA. Parts 3 & 5: • Ambrosio, L., & Crippa, G. (2014). Continuity equations and ODE flows with non-smooth velocity. Proceedings of the Royal Society of Edinburgh: Section A Mathematics, 144(6), 1191-1244. Lecture notes will be distributed via StudOn.

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