FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE
FAKULTÄT

List of modules for the Master's degree programme Computational and Applied Mathematics for the summer semester 2020

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: March 26, 2020
Reference: Examination regulations dated Feb 27, 2017

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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) Practical: 0.5 semester hrs/week	MApA
3	**Lectures**	**Prof. Dr. M. Burger**	
4	**Module coordinator**	**Prof. Dr. G. Grün**	
5	**Content**	At least two of the following three topics: • Shear-thinning liquids and monotone operators: analytical concepts, using the example of the p-Laplace equation • Poisson-Boltzmann equation: analysis of semilinear equations with monotone nonlinearities • Mathematical concepts of model reduction: homogenisation, gamma convergence, asymptotic analysis	
6	**Learning objectives and skills**	Students • explain various concepts for model reduction and apply them to derive mathematical models, • formulate and prove qualitative statements on solutions to quasilinear or semilinear partial differential equations in continuum mechanics.	
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 and Applied Mathematics in the fields of “Modeling, 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**	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**	• Braides: Gamma-convergence for beginners, Oxford University Press, • D. Cioranescu & P. Donato: An introduction to homogenization, Oxford University Press • R.E. Showalter: Monotone operators in Banach space and nonlinear partial differential equations, AMS	

1	**Module name**	**Module 3:** **MoSi: Practical Course: Modeling, Simulation, Optimization**	**ECTS 5**
2	**Courses/lectures**	Seminar: 3 semester hrs/week	MApA/NASi/Opti
3	**Lectures**	**Prof. Dr. M. Burger**	
4	**Module coordinator**	**Prof. Dr. M. Burger**	
5	**Content**	• Modelling, analysis, simulation or optimisation of problems in engineering or the natural sciences • (Partial) differential equation models (also with additional aspects) and corresponding numerical algorithms ((Mixed) Finite Element Method ((M)FEM), Finite Volume Method (FVM), Discontinuous Galerkin (DG)) • Mixed integer or continuous (non-)linear optimisation	
6	**Learning objectives and skills**	Students • work on a problem in engineering or the natural sciences as part of a team, but with assigned independent tasks, by constructing a suitable mathematical model and solving it using analytical and numerical methods, • are able to collect and evaluate relevant information and identify connections, • 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, • develop their communication skills and ability to work as a team through project work.	
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**	Talk/presentation (45 minutes) and final report (10 - 15 pages)	
11	**Grading Procedure**	Talk/presentation 50% final report 50%	
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**	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. G. Wellein**	
4	**Module coordinator**	**Prof. Dr. Gerhard Wellein**	
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

1	**Module name**	**Module 10:** **AdSolTech: Advanced Solution Techniques**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	NASi
3	**Lectures**	**Prof. Dr. E. Bänsch**	
4	**Module coordinator**	**Prof. Dr. P. E. Bänsch**	
5	**Content**	• Krylov subspace methods for large non-symmetric systems of equations • Multilevel methods, especially multigrid (MG) methods, nested and non-nested grid hierarchies • Parallel numerics, especially domain decomposition methods • Inexact Newton/Newton-Krylov methods for discretized nonlinear partial differential equations • Preconditioning and operator-splitting methods	
6	**Learning objectives and skills**	Students • are able to design application-specific own MG algorithms with the theory of multigrid methods and decide for which problems the MG algorithm is suitable to solve large linear systems of equations, • are able to solve sparse nonlinear/non-symmetric systems of equations with modern methods (also with parallel computers), • are able to develop under critical assessment complete and efficient methods for application-orientated problems.	
7	**Prerequisites**	Recommended: Advanced Discretization Techniques	
8	**Integration 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% 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**	• Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations • Further literature and scientific publications are announced during the lectures

1	**Module name**	**Module 11:** **RTpMNum: 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**	**Dr. Alexander Prechtel**	
4	**Module coordinator**	**Prof. Dr. S. Kräutle**	
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**	**Prof. Dr. E. Bänsch**	
4	**Module coordinator**	**Prof. Dr. E. Bänsch**	
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 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**	**Prof. Dr. M. Burger**	
4	**Module coordinator**	**Prof. Dr. M. Burger**	
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**	2^{nd} or 4^{th} semester	
9	**Module compatibility**	Mandatory elective module for MSc in Computational and Applied Mathematics Mandatory elective module in MSc 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**	Sommer 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**	• 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. N. Neuß	
4	**Module coordinator**	**PD Dr. N. Neuß**	
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” • Mandatory module for BSc Data Science	
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**	**Profs. Drs. M. Stingl**	
4	**Module coordinator**	**Prof. Dr. M. Stingl**	
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”, “Analysis and Stochastics” • 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.

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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**	**Prof. Dr.A. Martin**	
4	**Module coordinator**	**Prof. Dr. A. Martin**	
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 38:** **PdeConNum: Partial Differential Equations, Control and Numerics**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**MApA**
3	**Lecturers**	**Prof. Dr. E. Zuazua**	
4	**Module coordinator**	**Prof. Dr. E. Zuazua**	
5	**Content**	• Examples of PDE models arising in industrial applications, Biology and Social Sciences • Long time asymptotics • Control of trajectories • Numerics for long time dynamics and control • Some applications in the control of population dynamics	
6	**Learning objectives and skills**	Students • develop understanding for special aspects of dynamical systems control, • apply numerical methods to control problems and develop a basic understanding of their properties, • derive and solve inverse problems arising from applications.	
7	**Prerequisites**	Recommended: basic knowledge in functional analysis	
8	**Integration into curriculum**	2nd semester	
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Compulsory 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% 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**	• J. M. Coron, Control and nonlinearity, Mathematical Surveys and Monographs, 143, AMS, 2009 • E. Zuazua. Propagation, observation, and control of waves approximated by finite difference methods. SIAM Review, 47 (2) (2005), 197-243

1	**Module name**	**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. G. Grün**	
4	**Module coordinator**	**Prof. Dr. G. Grün**	
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.