FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE
FAKULTÄT

Module handbook for the Master's degree programme Computational and Applied Mathematics *for the summer semester 2018*

In the following you find only those modules which are offered in the summer semester 2018.

Department of Mathematics
Friedrich-Alexander-Universität Erlangen-Nürnberg

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Table of contents

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NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 2: ModAna2: Modeling and Analysis in Continuum Mechanics II**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lecturers**	**Prof. P. Knabner**	
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 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**	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**	• A. 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	

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1	**Module name**	**Module 3: MoSi: Practical Course: Modeling, Simulation, Optimization**	**5 ECTS credits**
2	**Courses/lectures**	Seminar: 3 semester hrs/week	
3	**Lecturers**	**Prof. F. Frank**	

4	**Module coordinator**	**Prof. Dr. P. Knabner**
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 Elective module for MSc in Mathematics Elective module for MSc in Mathematics and Economics
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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NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 4: PTfS-CAM: Programming Techniques for Supercomputers in CAM**	**10 ECTS credits**
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

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1	**Module name**	**Module 9: AdSolTech: Advanced Solution Techniques**	**5 ECTS-Punkte**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	
3	**Lecturers**	**Prof. Dr. E. Bänsch**	

4	**Module coordinator**	**Prof. Dr. P. Knabner**
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 • Compulsory elective module for MSc in Mathematics
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**	• A. 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

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NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 10:** **RTpMNum: Transport and Reaction in Porous Media: Modeling**	**5 ECTS-Punkte**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	
3	**Lecturers**	**Dr. N. Ray**	

4	**Module coordinator**	**Prof. Dr. S. Kräutle**
5	**Content**	• Modelling 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 for MSc in Computational and Applied Mathematics • Research module for MSc in Mathematics with field of "Modeling, Simulation, and Optimisation" • Mathematical elective module in all other fields of study in MSc Mathematics and in MSc Mathematics and Economics • Master Physics, non-physical elective module
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 www.mso.math.fau.de/fileadmin/am1/users/kraeutle/scripts/Skript-RT.pdf - 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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NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 12: NuIF1: Numerics of Incompressible Flows I**	**5 ECTS credits**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lecturers**	**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, incompress-ible 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 solu-tion 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 • Compulsory elective module for MSc in Mathematics
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. Girault & P.-A. Raviart: Finite element methods for the Navier-Stokes equations. Theory and algorithms. Springer 1986 • H. Elman, D. Silvester & A. Rathen: Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics. Oxford University Press 2014 • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

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1	**Module name**	**Module 15: ThSDE: Theory of Stochastic Evolution Equations**	**5 ECTS credits**
2	**Courses/lectures**	Lecture: 2 semester hrs/week Practical: 0.5 semester hrs/week	
3	**Lecturers**	**Prof. Dr. G. Grün**	

4	**Module coordinator**	**Prof. Dr. G. Grün**
5	**Content**	• Infinitely dimensional Wiener processes, • Stochastic integral in Hilbert spaces, • Ito-processes and stochastic differential equations, • Optionally: existence results for stochastic partial differential equations or further results on stochastic ODE (Fokker-Planck equations, . . .)
6	**Learning objectives and skills**	Students • characterize Gaussian measures on Hilbert spaces. They explain representation formulas for Q-Wiener processes as well as the derivation of the stochastic integral, • successfully apply concepts to solve stochastic differential equations explicitly and prove existence of solutions to stochastic evolution equations.
7	**Prerequisites**	Basic knowledge in probability theory or functional analysis is recommended.
8	**Integration into curriculum**	2nd semester
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics, • Mandatory 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**	Summer semester (not annually) To check whether the course is offered, see UnivIS: univis.fau.de
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**	• G. Da Prato & J. Zabczyk: Stochastic equations in infinite dimensions, Cambridge University Press • I. Karatzas & S.E. Shreve: Brownian motion and stochastic calculus, Springer • B. Oksendal: Stochastic differential equations, Springer • C. Prévôt & M. Röckner: A concise course on stochastic partial differential equations, Springer

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1	**Module name**	**Module 24: MSOpt: Introduction to Material and Shape Optimization**	**10 ECTS credits**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hr/week	
3	**Lecturers**	**Prof. Dr. 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 in Computational and Applied Mathematics • 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**	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 28:** **NALIP: Numerical Aspects of Linear and Integer Programming**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 0,5 weekly lecture hour	
3	**Lecturers**	**Prof. Dr. R. Bixby**	

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, • Elective module for MSc Mathematics, • Elective Module for MSc Mathematics and Economics, • Core/research module MSc Mathematics within "Modeling, simulation, optimization", MSc Mathematics and Economics within "Optimization and process management"
10	**Method of examination**	oral exam (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
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