FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE
FAKULTÄT

List of modules for the Master's degree programme Computational and Applied Mathematics for the summer semester 2019

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 20, 2019
Reference: Examination regulations dated Feb 27, 2017

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Last updated: 20 March 2019

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	
3	**Lectures**	**Prof. Dr. G. Grün**	
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	

1	**Module name**	**Module 3:** **MoSi: Practical Course: Modeling, Simulation, Optimization**	**ECTS 5**
2	**Courses/lectures**	Seminar: 3 semester hrs/week	
3	**Lectures**	**Prof. Dr. G. Grün**	
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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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	**Lectures**	**Prof. Dr. G. Wellein**	
4	**Module coordinator**	**Prof. Dr. G. 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 10:** **AdSolTech: Advanced Solution Techniques**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	
3	**Lectures**	**Prof. Dr. P. Knabner**	
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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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	
3	**Lectures**	**Prof. Dr. S. Kräutle**	
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

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	
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 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: 12.5 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 14:** **MaMM: Mathematics of Multiscale Models**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	
3	**Lectures**	Dr. Nadja Ray	
4	**Module coordinator**	**Prof. Dr. P. Knabner**	
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 Elective module for MSc in Mathematics Elective module for MSc in Mathematics and Economics	
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	

1	**Module name**	**Module 24:** **IPro: Partial Differential Equations Based Image Processing**	**ECTS 5**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hr/week	
3	**Lectures**	**Prof. Dr. M. Burger**	
4	**Module coordinator**	**Dr. M. Fried**	
5	**Content**	basics of image processing deblurring using different partial differential equations Finite Element Method for variational methods in image restauration and image segmentation	
6	**Learning objectives and skills**	Students explain mathematical and algorithmic methods for image processing, apply above image processing methods in computerised practical exercises, apply analytical techniques to evaluate the qualitative characteristics of the above methods.	
7	**Prerequisites**	Basic knowledge in functional analysis and numerical methods for pdes 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 Compulsory elective module MSc Integrated Life Science	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	if requested: every second summer semester 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**	G. Aubert & P. Kornprobst: Mathematical problems in image processing, 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	
3	**Lectures**	**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, 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 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	

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1	**Module name**	**Module 33: OptPDE: Optimization with Partial Differential Equations**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hrs/week	
3	**Lectures**	**PD Dr. F. Hante**	
4	**Module coordinator**	**Prof. Dr. M. Stingl**	
5	**Content**	Several of the following topics: System and control theory for partial differential equations Optimization theory in Banach and Hilbert spaces Optimality conditions for problems with control and state constraints Sensitivity analysis, singular perturbations and asymptotics Optimization methods in Banach spaces Technical, medical and economic applications	
6	**Learning objectives and skills**	Students extensively explain and use the theory as well as numerical methods for optimization, control and stabilization in the broad of problems with 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**	2nd 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 (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 or module handbook of current semester	
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**	- F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS, - M. Hinze et al.: Optimization with PDE Constraints, Springer, - G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser.

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1	**Module name**	**Module 34:** **DiscOpt II: Discrete Optimization II**	**ECTS 10**
2	**Courses/lectures**	a) Lectures: 4 weekly lecture hours b) Practical: 2 weekly lecture hour	
3	**Lectures**	**Prof. Dr. Alexander Martin**	
4	**Module coordinator**	**Prof. Dr. Alexander Martin**	
5	**Content**	In this lecture we cover theoretical aspects and solution strategies for difficult integer and mixed-integer optimization problems. First, we point out the equivalence between separation and optimization. Second, fundamental results of integral polyhedra, lattices and lattice polyhedra as well as its importance to discrete optimization are discussed. Furthermore, we introduce solution strategies for large-scale optimization problems, e.g., decomposition methods or approximation algorithms and heuristics based on linear programming. In addition, we discuss applications arising in engineering, finance, energy management or public transport.	
6	**Learning objectives and skills**	Students use basic terms of discrete optimization, model real-world discrete optimization problems, determine their complexity and solve them with appropriate mathematical methods.	
7	**Prerequisites**	Recommended: Knowledge in linear and combinatorial optimization, discrete optimization I	
8	**Integration into curriculum**	2nd semester	
9	**Module compatibility**	Mandatory elective module for MSc Computational and Applied Mathematics, Elective module for MSc Mathematics, Elective module for MSc Mathematics and Economics, Core/research module MSc Mathematics within “Modeling, simulation, optimization”, MSc Mathematics and Economics within “Optimization and process management”	
10	**Method of examination**	oral exam (20 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Summer semester (annually)	
13	**Workload**	Attendance: 90 h Self-study: 210 h	
14	**Module duration**	1 semester	
15	**Teaching and examination language**	English	

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