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

Not all of the listed modules are offered annually. On the other hand, additional modules may be offered in the future.

Department of Mathematics
Friedrich-Alexander-Universität Erlangen-Nürnberg

Last updated: March 06, 2020
Reference: Examination regulations dated July 15, 2019

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

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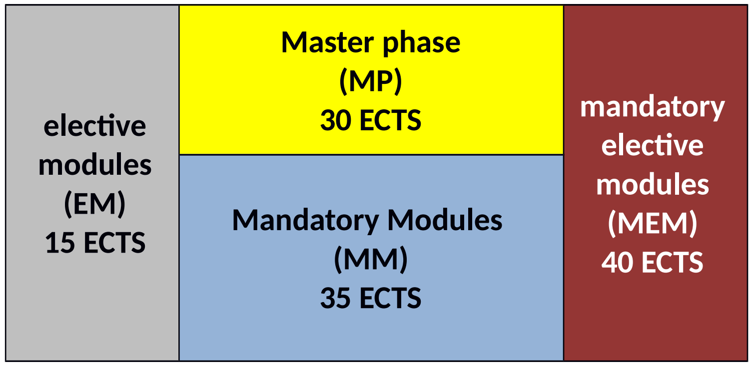
Curricular Overview



Not all listed mandatory elective modules below will be offered in every semester. On the other hand, additional modules might be offered.

The minimum number of ECTS points is 120.

Master's degree programme Computational and Applied Mathematics

Study plan

Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
Mandatory Modules													
MApA	**Module 1: Modeling and Analysis in Continuum Mechanics I**	Modeling and Analysis in Continuum Mechanics I	4				**10**	8				oral exam 20 min. 100%	1
		Tutorials to Part I		1				2					
	Module 2: Modeling and Analysis in Continuum Mechanics II	Modeling and Analysis in Continuum Mechanics II	2				**5**		4			oral exam 20 min. 100%	1
		Tutorials to Part II		1/2					1				
MApA/ NASi/ Opti	**Module 3: Modeling, Simulation and Optimization**	Practical Course: Modeling, Simulation and Optimization				3	**5**		5			talk/presentation 45 min. (50%), and final report 10–15 pages (50%)	1
HPC	**Module 4: Programming Techniques for Supercomputers in CAM**	Programming Techniques for Supercomputers	4				**10**		5			see examination regulations INF	1
		Tutorials to Programming Techniques for Supercomputers		2					5				
	Module 5: Architectures of Supercomputers	Architectures of Supercomputers	2				**5**			2,5		see examination regulations INF	1
		Tutorials to Architectures of Supercomputers		2						2,5			
			12	**5,5**	**0**	**3**	**35**	**10**	**20**	**5**	**0**		

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Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
Master phase													
MapA/ NASi/ Opti	**Module 6a:** Master's seminar MApA	Master's seminar MApA*				2	**5**			5		talk 70-80 min with written report 5–10 pages	1
	Module 6b: Master's seminar NASi	Master's seminar NASi*				2	**5**			5		talk 70-80 min with written report 5–10 pages	1
	Module 6c: Master's seminar Opti	Master's seminar Opti*				2	**5**			5		talk 70-80 min with written report 5–10 pages	1
	Module 7: Masterthesis	Master colloquium					**25**				2,5	oral exam 15 min. (10%) Thesis (90%)	1
		Master thesis									22,5		
			0	**0**	**0**	**2**	**30**	**0**	**0**	**5**	**25**		
mandatory elective modules													
NASi	**Module 8: Numerics of Partial Differential Equations I**	Numerics of Partial Differential Equations I	4				**10**	7				written exam 90 min. (100%) with exercises (0%)	1
		Tutorials to Numerics of Partial Differential Equations I		2				3					
NASi	**Module 9: Advanced Discretization Techniques**	Advanced Discretization Techniques	4				**10**	8		(8)		oral exam 20 min. 100%	1
		Tutorials to Advanced Discretization Techniques		1				2		(2)			
NASi	**Module 10: Advanced Solution Techniques**	Advanced Solution Techniques	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Advanced Solution Techniques		1/2					1				
MApA	**Module 11: Transport and Reaction in Porous Media: Modelling**	Transport and Reaction in Porous Media: Modelling	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Transport and Reaction in Porous Media: Modelling		1/2					1				
NASi	**Module 12: Transport and Reaction in Porous Media: Simulation**	Transport and Reaction in Porous Media: Simulation	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Transport and Reaction in Porous Media: Simulation		1/2						1			
NASi	**Module 13: Numerics of Incompressible Flows I**	Numerics of Incompressible Flows Part I	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Numerics of Incompressible Flows Part I		1/2					1				
NASi	**Module 14: Numerics of Incompressible Flows II**	Numerics of Incompressible Flows Part II	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Numerics of Incompressible Flows Part II		1/2						1			

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Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
MApA	**Module 15: Inverse Problems and their Regularization**	Inverse Problems and their Regularization	2				**5**	(4)		(4)		oral exam 15 min. 100%	1
		Tutorials to Inverse Problems and their Regularization		1/2				(1)		(1)			
NASi	**Module 16: Mathematical Methods for Learning and Ranking Large Data (Mathematical Data Science)**	Mathematical Methods for Learning and Ranking Large Data	2				**5**		4			Oral exam 15 min. 100%	1
		Tutorials to Mathematical Methods for Learning and Ranking Large Data		1/2					1				
MApA	**Module 17: Mathematical Models of Kinetic Theory**	Mathematical Models of Kinetic Theory	2				**5**			4		Oral exam 15 min. 100%	1
		Tutorials to Mathematical Models of Kinetic Theory		1/2						1			
MApA	**Module 18: Mathematics of Multiscale Models**	Mathematics of Multiscale Models	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Mathematics of Multiscale Models		1/2						1			

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Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
mandatory elective modules													
MApA	**Module 19: Theory of Stochastic Evolution Equations**	Theory of Stochastic Evolution Equations	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Theory of Stochastic Evolution Equations		1/2					1				
NASi	**Module 20: Numerics of Stochastic Evolution Equations**	Numerics of Stochastic Evolution Equations	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Numerics of Stochastic Evolution Equations		1/2						1			
NASi	**Module 21: Practical Course on Finite Element Methods for Phase-Separation Equations**	Seminar Practical Course on Finite Element Methods for Phase-Separation Equations				3	**5**	(5)		(5)		oral exam 30 min. 100%	1
MApA	**Module 22: Regularity Theory of Elliptic PDEs**	Regularity Theory of Elliptic PDEs	3				**5**	(4)		(4)		oral exam 20 min. 100%	1
		Tutorials to Regularity Theory of Elliptic PDEs				1		(1)		(1)			
MApA	**Module 23: Mathematical Modeling in the Life Sciences**	Mathematical Modelling in the Life Sciences	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Mathematical Modelling in the Life Sciences		1/2						1			
MApA/ NASi	**Module 24: Partial Differential Equations based image processing**	PDE based image processing	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to PDE based image processing		1/2					1				
MApA	**Module 25: Analysis of Free-Boundary Problems in Continuum Mechanics**	Analysis of free-boundary problems in continuum mechanics	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to Analysis of free-boundary problems in continuum mechanics		1/2						1			
MApA/ NASi	**Module 26: Partial Differential Equations in Finance**	PDEs in Finance	2				**5**			4		oral exam 15 min. 100%	1
		Tutorials to PDEs in Finance		1/2						1			
Opti	**Module 27: Introduction to Material- and Shape Optimization**	Introduction to Material- and Shape Optimization	4				**10**		8			oral exam 20 min. 100%	1
		Tutorials to Material- and Shape Optimization		1					2				

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Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
mandatory elective modules													
Opti	**Module 28: Advanced Algorithms for Nonlinear Optimization**	Advanced Algorithms for Nonlinear Optimization	2				**5**	4				oral exam 15 min. 100%	1
		Tutorials to Advanced Algorithms for Nonlinear Optimization		1/2				1					
Opti	**Module 29: Discrete Optimization I**	Discrete Optimization I	2				**5**	(4)		(4)		oral exam 15 min. 100%	1
		Tutorials to Discrete Optimization I		1				(1)		(1)			
Opti	**Module 30: Robust Optimization II**	Robust Optimization II	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Robust Optimization II		1					1				
Opti	**Module 31: Numerical Aspects of Linear and Integer Programming**	Numerical Aspects of Linear and Integer Programming	2				**5**		4			oral exam 15 min. 100%	1
		Tutorials to Numerical Aspects of Linear and Integer Programming		1/2					1				
Opti	**Module 32: Advanced Nonlinear Optimization**	Advanced Nonlinear Optimization	4				**10**	(8)		(8)		oral exam 20 min. 100%	1
		Tutorials to Advanced Nonlinear Optimization		1				(2)		(2)			
Opti	**Module 33: Optimization with Partial Differential Equations**	Optimization with Partial Differential Equations	2				**5**	(4)		(4)		oral exam 15 min. 100%	1
		Tutorials to Optimization with Partial Differential Equations		1/2				(1)		(1)			
Opti	**Module 34: Discrete Optimization II**	Discrete Optimization II	4				**10**		8			oral exam 20 min. 100%	1
		Tutorials to Discrete Optimization II		2					2				
Opti	**Module 35: Optimization in Industry and Economy**	Optimization in Industry and Economy	2				**5**	(4)		(4)		oral exam 15 min. 100%	1
		Tutorials to Optimization in Industry and Economy		1				(1)		(1)			
Opti	**Module 36: Project Seminar Optimization**	Practical Course: Optimization				2	**5**		(5)	(5)		Talk/presentation 45 min. (50%), final report 10-15 pages (50%)	1
Opti	**Module 38: Lecture Series Partial Differential Equations, Control and Numerics**	Lecture Series Partial Differential Equations, Control and Numerics	2				**5**		2			written exam 90 min. 100%	1
		Tutorials to Lecture Series Partial Differential Equations, Control and Numerics applications		1					1				
NASi	**Module 39: Numerics of Partial Differential Equations II**	Numerics of Partial Differential Equations II	2						2			oral exam 15 min. 100%	1
		Tutorials to Numerics of Partial Differential Equations II		1					1				
			16	4	0	0	40	10	10	20	0		

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Code	Title	Course	SWS				total ECTS	Workload-averaged in ECTS				spezification exam /ungraded task	Factor Grade
			V	Ü	P	S		1. Sem.	2. Sem.	3. Sem.	4. Sem.		
elective modules**													
EM	**elective modules**		0-2	0-2	0-2	0-2	**5**	5				according to the chosen module	1
EM	**elective modules**		0-2	0-2	0-2	0-2	**5**	5				according to the chosen module	1
EM	**elective modules**		0-2	0-2	0-2	0-2	**5**				5	according to the chosen module	1
			0-6	**0-6**	**0-6**	**0-6**	**15**	**10**	**0**	**0**	**5**		
								30	30	30	30		
			Total SWS: 42-48*				120	Total ECTS: 120					

HPC High Performance Computing
MApA Modeling and Applied Analysis
NASi Numerical Analysis and Simulation
Opti Optimization

* Master seminar MApA, Master seminar NASi or Master seminar Opti has to be chosen
** as selected from FAU-modules

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1	**Module name**	**Module 1: ModAna1: Modeling and Analysis in Continuum Mechanics I**	**10 ECTS credits**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hr/week	**MApA**
3	**Lecturers**	**Profs. Drs. G. Grün, M. Burger, N.N.**	
4	**Module coordinator**	**Prof. Dr. G. Grün**	
5	**Content**	• Theory of elasticity (geometrical non-linear modelling, objectivity and isotropy of energy functionals, linearised elasticity, polyconvexity, existence according to J. Ball) • Non-equilibrium thermodynamics and modelling in hydrodynamics (basic concepts in thermodynamics, balance equations, constitutive relations) • Parabolic function spaces and the Aubin-Lions lemma • Weak solution theory for incompressible Navier-Stokes equations	
6	**Learning objectives and skills**	Students • derive mathematical models for fluid mechanics and elasticity theory, • evaluate the predictive power of models using physical modelling assumptions and the qualitative characteristics of solutions, • apply analytical techniques to rigorously prove qualitative properties of solutions.	
7	**Prerequisites**	Basic knowledge in functional analysis and modelling is recommended.	
8	**Integration into curriculum**	1st semester	
9	**Module compatibility**	• Mandatory module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the fields of study “Modelling, Simulation and Optimization”, “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**	• P.G. Ciarlet: Mathematical elasticity, North-Holland, • S.R. De Groot & P. Mazur: Non-equilibrium thermodynamics, Dover, • C. Eck, H. Garcke & P. Knabner: Mathematical Modeling, Springer, • L.C. Evans: Partial differential equations, AMS, • I. Liu: Continuum mechanics, Springer, • R. Temam: The Navier-Stokes equations, AMS Chelsea Publishing.	

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1	Module name	Module 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	MApA
3	Lecturers	Profs. Drs. G. Grün, M. Burger, N.N.	

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**	• Mandatory module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the fields of study "Modeling, Simulation and Optimization", "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**	• 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	**MapA/NASi/Opti**
3	**Lecturers**	**Profs. Drs. M. Burger, G. Grün, A. Martin, N.N.**	

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**	• Mandatory module for MSc in Computational Applied Mathematics • Mandatory elective module for MSc in Mathematics in the field of study “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.

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	HPC
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**	Mandatory module for MSc Computational and Applied Mathematics
10	**Method of examination**	See examination regulations INF
11	**Grading procedure**	See examination regulations INF
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 5: ArchSup: Architectures of Supercomputers**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 2 semester hrs/week	**HPC**
3	**Lecturers**	**Prof. Dr. Dietmar Fey, Dr. Andreas Schäfer**	

4	**Module coordinator**	**Prof. Dr. Dietmar Fey**
5	**Content**	• Principles of computer and processor architectures • Modern processor architectures • Homogeneous and heterogeneous multi/many-core processors • Parallel computer architectures • Classification and principles of coupling parallel computers • High speed networks in supercomputers • Examples of supercomputers • Programming of supercomputers
6	**Learning objectives and skills**	Students • can explain the functionality of modern processors used in supercomputers, • recognise the special problems associated with energy consumption and programming in supercomputers, • can explain the different ways of interconnecting parallel processes, • can classify parallel computers with regard to their storage connection and basic processing principles, • are able to make use of and run a supercomputer to solve their own technical or mathematical problem. Based on the examples demonstrated during the lecture, they are able to generalise challenges associated with the discovery of bottlenecks and use them to solve their specific problem, • are able to characterise their problems (e.g. scientific or technical simulation experiments) with regard to the computing and memory requirements for a supercomputer in a way that is appropriate for the architecture, • can make use of the performance-measuring methods for parallel computers to evaluate various computer architectures and select the appropriate architecture for their problem.
7	**Prerequisites**	None
8	**Integration into curriculum**	3rd semester
9	**Module compatibility**	• Mandatory module for MSc Computation and Applied Mathematics • Mandatory module for Computational Engineering degree programmes (Computer-Assisted Engineering) (Master of Science) and Information Technology (Master of Science)
10	**Method of examination**	See examination regulations INF
11	**Grading procedure**	See examination regulations INF
12	**Module frequency**	Winter semester (annually)
13	**Workload**	Contact hours: 60 hrs Independent study: 90 hrs Total: 150 hrs, corresponding to 5 ECTS credits
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• Quinn: Parallel Programming in C with MPI and OpenMP, McGraw-Hill • Hennessy/Patterson: Computer Architecture - A Quantitative Approach, Morgen&Kaufmann

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1	**Module name**	**Module 6a:** **MaSe: Master's seminar MApA**	**5 ECTS credits**
2	**Courses/lectures**	Seminar: 2 semester hrs/week	**MApA**
3	**Lecturers**	**Profs. Drs. G. Grün, M. Burger, E. Zuazua**	

4	**Module coordinator**	**Prof. Dr. G. Grün**
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**	• Mandatory module for MSc in Computational and Applied Mathematics • Mandatory module for MSc in Mathematics • Mandatory module for MSc in Mathematics and Economics
10	**Method of examination**	talk/presentation (70-80 minutes) with handout (5-10 pages)
11	**Grading procedure**	100 %talk/presentation with handout
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 6b:** **MaSe: Master's seminar NASi**	**5 ECTS credits**
2	**Courses/lectures**	Seminar: 2 semester hrs/week	**NASi**
3	**Lecturers**	**Profs. Drs. E. Bänsch, G. Grün, M. Burger**	

4	**Module coordinator**	**Prof. Dr. E. Bänsch**
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**	• Mandatory module for MSc in Computational and Applied Mathematics • Mandatory module for MSc in Mathematics • Mandatory module for Msc in Mathematics and Economics
10	**Method of examination**	talk/presentation (70-80 minutes) with handout (5-10 pages)
11	**Grading procedure**	100% talk/presentation with handout
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 6c: MaSe: Master's seminar Opti**	**5 ECTS credits**
2	**Courses/lectures**	Seminar: 2 semester hrs/week	**Opti**
3	**Lecturers**	**Profs. Drs. F. Liers, A. Martin, M. Stingl**	

4	**Module coordinator**	**Prof. Dr. M. Stingl**
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**	• Mandatory module for MSc in Computational and Applied Mathematics • Mandatory module for MSc in Mathematics • Mandatory module for MSc in Mathematics and Economics
10	**Method of examination**	talk/presentation (70-80 minutes) with handout (5-10 pages)
11	**Grading procedure**	100% talk/presentation with handout
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 7: Master's Thesis**	**25 ECTS credits**
2	**Courses/lectures**	Oral examination Master's Thesis	**MapA/NASi/Opti**
3	**Lecturers**	**The lecturers for the degree programme in Computational and Applied Mathematics**	

4	**Module coordinator**	**Prof. Dr. G. Grün**
5	**Content**	The master’s thesis is in the field of *Modelling and Analysis*, or *Numerical Analysis and Simulation*, or *Optimization*, and deals with a current research topic.
6	**Learning objectives and skills**	Students • are capable of independently follow up a scientific question in the fields of “Modelling and Analysis”, “Numerical Analysis and Simulation” or “Optimization” over an extended, specified period, • develop original ideas and concepts for solving scientific problems in these fields, • apply and improve mathematical methods rather independently - also in unfamiliar and interdisciplinary contexts, • present and explain mathematical or interdisciplinary contents clearly in a manner appropriate for the target audience, both in writing and orally, • improve their ability to plan and structure by implementing a thematic project.
7	**Prerequisites**	Successful participation in all mandatory modules (35 ECTS) and at least 20 ECTS from mandatory elective modules
8	**Integration into curriculum**	4th semester
9	**Module compatibility**	Master’s degree programme in Computational and Applied Mathematics
10	**Method of examination**	Master’s thesis (scope according to examination regulations) Oral exam (15 minutes)
11	**Grading procedure**	90% Master’s thesis 10% Oral exam
12	**Module frequency**	Summer semester (annually)
13	**Workload**	Contact hours: 15 hrs Independent study: 735 hrs Total: 750 hrs, corresponding to 25 ECTS credits
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	Individual, depending on topic of Master’s Thesis.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 8: NumPDE I: Numerics of Partial Differential Equations I**	**10 ECTS credits**
2	**Courses/lectures**	a) Lecture: 4 semester hrs/week b) Practical: 2 semester hr/week	**NASi**
3	**Lecturers**	**Profs. Drs. E. Bänsch, G. Grün**	

4	**Module coordinator**	**Prof. Dr. E. Bänsch**
5	**Content**	• Classical theory of linear elliptic boundary value problems (outline) • Finite difference method (FDM) for Poisson's equation in two dimensions (including stability via inverse monotonicity) • Finite element method (FEM) for Poisson's equation in two dimensions (stability and convergence, example: linear finite elements, implementation) • Variational theory of linear elliptic boundary value problems (outline) • FEM for linear elliptic boundary value problems (2^{nd} order) (types of elements, affin-equivalent triangulations, order of convergence, maximum principle) • Iterative methods for large sparse linear systems of equations (condition number of finite element matrices, linear stationary methods (recall), cg method (recall), preconditioning, Krylov subspace methods
6	**Learning objectives and skills**	Students • apply algorithmic approaches for models with partial differential equations and explain and evaluate them, • are capable to judge on a numerical method's properties regarding stability and efficiency, • implement (with own or given software) numerical methods and critically evaluate the results, • explain and apply a broad spectrum of problems and methods with a focus on conforming finite element methods for linear elliptic problems, • collect and evaluate relevant information and realize relationships.
7	**Prerequisites**	Recommended: basic knowledge in numerics, discretization, and optimization
8	**Integration into curriculum**	1st semester
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for BSc Mathematics • Mandatory module for BSc Technomathematik • Non-Physics elective module for MSc Physics
10	**Method of examination**	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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 9: AdDiscTech: Advanced Discretization Techniques**	**10 ECTS credits**
2	**Courses/lectures**	a) Lecture: 4 semester hrs/week b) Practical: 1 semester hr/week	**NASi**
3	**Lecturers**	**Profs. Drs. E. Bänsch, G. Grün, N.N.**	

4	**Module coordinator**	**Prof. Dr. E. Bänsch**
5	**Content**	• conforming and non-conforming finite element methods • saddle point problems in Hilbert spaces • mixed finite element methods for saddle point problems, in particular for Darcy and Stokes • Streamline-Upwind Petrov-Galerkin (SUPG) and discontinuous Galerkin (dG) finite element methods (FEM) for convection dominated problems • Finite Volume (FV) methods and their relation to FEM • a posteriori error control and adaptive methods
6	**Learning objectives and skills**	Students • have a discriminating understanding, both theoretically and computationally of FE as well as FV methods for the numerical solution of partial differential equations (pde) (in particular of saddle point problems), • are capable of developing problem dependent FE or FV methods and judge on their properties regarding stability and effectiveness, • are familiar with a broad spectrum of pde problems and their computational solutions, • are capable of designing algorithms for adaptive mesh control.
7	**Prerequisites**	Recommended: Introduction to numerical methods for pdes, functional analysis
8	**Integration into curriculum**	1st or 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 “Modeling, Simulation and Optimization”
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**	• A. Ern, J.-L. Guermond: Theory and Practice of Finite Elements • A. Quarteroni & A. Valli: Numerical Approximation of Partial Differential Equations • P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Differential Equations, Springer • D. A. Di Piettro & A. Ern: Mathematical aspects of discontinuous Galerkin methods. Springer 2012

1	Module name	Module 10: AdSolTech: Advanced Solution Techniques	5 ECTS credits
2	Courses/lectures	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	NASi
3	Lecturers	Prof. Dr. E. Bänsch, N.N.	

4	**Module coordinator**	**Prof. Dr. 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 • Mandatory 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**	• 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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 11:** **RTpMNum: Transport and Reaction in Porous Media: Modeling**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	**MapA**
3	**Lecturers**	**Prof. Dr. S. Kräutle, Drs. N. Ray, A. Prechtel**	

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 • Mandatory elective module for MSc in Mathematics in the field of "Modeling, Simulation, and Optimisation" • Master Physics, non-physical elective module
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**	- S. Kräutle: lecture notes 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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 12:** **RTpMNum: Transport and Reaction in Porous Media: Simulation**	**5 ECTS creadits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**NASi**
3	**Lecturers**	**Prof. Dr. S. Kräutle, Drs. N. Ray, A. Prechtel**	

4	**Module coordinator**	**Prof. Dr. S. Kräutle**
5	**Content**	• Degenerate parabolic differential equations as multiphase flow models: formulation, nonlinear solution methods, discretization methods • Models for transport and reactions in porous media, consisting of coupled PDEs and ODEs, if necessary coupled to algebraic equations (AEs) and inequalities for the description of local equilibria (differential-algebraic system) • Different formulations of the system (operator splitting, change of variables, combination of the equations, elimination of AEs), as a basis for different software packages for numerical simulations, connection to optimisation (Gibbs energy) • Treatment of numerical difficulties (Guarantee of nonnegativity of numerical solutions of the (nonlinear) problems, scaling problems, convection dominated problems
6	**Learning objectives and skills**	Students • use methods for the numerical solving of a class of problems whose complexity goes significantly beyond standard problems (Poisson and heat equation): coupled nonlinear partial and ordinary differential equations (PDEs, ODEs) and algebraic equations (AEs), • put strategies for the treatment of possible difficulties during the numerical solving into practice.
7	**Prerequisites**	Recommended: Basic knowledge in differential equations, Transport and Reaction in Porous Media: Modeling
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 Optimisation" • Master Physics, non-physical elective module
10	**Method of examination**	Oral exam (15 minutes)
11	**Grading procedure**	100% based on oral exam
12	**Module frequency**	Winter semester (not 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**	- P. Knabner & L. Angermann: Numerical Methods for Elliptic and Parabolic Partial Differential Equations, Springer - Handbooks of Software Packages, https://en.www.math.fau.de/angewandte-mathematik-1/forschung/software-2

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 13: 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	**NASi**
3	**Lecturers**	**Prof. Dr. E. Bänsch, Prof. Dr. G. Grün**	

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 • Mandatory 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% 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

1	**Module name**	**Module 14: NuIF2: Numerics of Incompressible Flows II**	**5 ECTS credits**
2	**Courses/lectures**	a) Lecture: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**NASi**
3	**Lecturers**	**Prof. Dr. E. Bänsch, Prof. Dr. G. Grün**	

4	**Module coordinator**	**Prof. Dr. E. Bänsch**
5	**Content**	• Variational formulation of the instationary Stokes and Navier-Stokes (NVS) equations • Existence and uniqueness of solutions to the instationary Stokes and NVS equations • Time discretisation methods • Fully discrete equations and error estimates • Solution techniques • Operator splitting, projection methods • More general boundary conditions • Coupling of NVS with temperature equation • Computational experiments with academic or commercial codes
6	**Learning objectives and skills**	Students • discretize the instationary NVS equations in time and space, • explain and analyse discretisation schemes and operator splitting techniques, • choose appropriate algorithms for given flow problems and solve them with academic or commercial software.
7	**Prerequisites**	Recommended: Advanced discretization techniques, Numerics of incompressible flows 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 "Modeling, Simulation and Optimization"
10	**Method of examination**	oral exam (15 minutes)
11	**Grading procedure**	100% based on oral exam
12	**Module frequency**	Winter semester (annually)
13	**Workload**	Contact hours: 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. Glowinski: Finite Element Methods for Incompressible Viscous Flow, in : Handbook of Numerical Analysis vol. IX • R. Temam: Navier-Stokes equations. Theory and numerical analysis. North Holland

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 15: IPReg: Inverse Problems and their Regularization**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**MApA**
3	**Lecturers**	**Prof. Dr. M. Burger, Dr. D. Tenbrinck**	

4	**Module coordinator**	**Prof. Dr. M. Burger**
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 • 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**	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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 16:** **MaDS: Mathematical Data Science 1**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 1/2 semester hrs/week	**NASi**
3	**Lecturers**	**Prof. Dr. M. Burger, Dr. D. Tenbrinck**	

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**	2nd or 4th semester
9	**Module compatibility**	• Mandatory module for MSc in Data Science • 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**	Oral exam (20 minutes)
11	**Grading procedure**	100% Oral exam
12	**Module frequency**	Summer 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**	• I. Goodfellow, Y. Bengio, A. Courville: Deep Learning, MIT Press, 2015 • T. Hastie, R. Tibshirani, J. Friedman: The Elements of Statistical Learning, Springer, 2008

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 17: MaKiT: Mathematical Models of Kinetic Theory**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**MApA**
3	**Lecturers**	**Prof. Dr. M. Burger**	

4	**Module coordinator**	**Prof. Dr. M. Burger**
5	**Content**	• Microscopic stochastic interaction models and simulation • Mean-field and Boltzmann-Grad limit • Analysis of kinetic equations, linear and nonlinear Boltzmann equation • Hydrodynamic limits • Fokker-Planck and nonlinear diffusion equations
6	**Learning objectives and skills**	Students • develop understanding of modeling macroscopic phenomena emerging from local random interactions, • understand the advantages and limitations of different continuum descriptions, • derive and analyze models at different scales.
7	**Prerequisites**	Recommended: basic knowledge in modeling and 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 study “Modeling, Simulation and Optimization”
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**	• L. Pareschi, G. Toscani: Interacting Multiagent Systems: Kinetik Equations and Monte Carlo Methods, Oxford University Press 2013 • C. Cercignani, R. Illner, M. Pulvirenti: The Mathematical Theory of Dilute Gases. Applied Mathematical Sciences, 106, Springer, 1994

1	**Module name**	**Module 18:** **MaMM: Mathematics of Multiscale Models**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**MApA**
3	**Lecturers**	**Drs. M. Neuss-Radu, N. Neuß**	

4	**Module coordinator**	**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 study “Modeling, Simulation and Optimization”
10	**Method of examination**	Oral exam (15 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 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**	• 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 19: ThSDE: Theory of Stochastic Evolution Equations**	**5 ECTS credits**
2	**Courses/lectures**	Lecture: 2 semester hrs/week Practical: 0.5 semester hrs/week	**MApA**
3	**Lecturers**	**Prof. Dr. G. Grün, N.N.**	

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 in the field of "Analysis and Stochastics" • Mandatory elective module for MSc in Mathematics and Economics in the field of "Stochastics and Risk 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 currently offered, see UnivIS univis.fau.de or module handbook of current semester
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• 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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	Module name	Module 20: NuSDE: Numerics of Stochastic Evolution Equations	5 ECTS credits
2	Courses/lectures	Lectures: 2 semester hrs/week Practical: 0.5 semester hrs/week	NASi
3	Lecturers	Prof. Dr. G. Grün, N.N.	

4	**Module coordinator**	**Prof. Dr. G. Grün**
5	**Content**	• Strong and weak approximations, explicit and implicit schemes for stochastic differential equations (SDEs), • Consistency, stability, convergence, • Monte Carlo methods, variance-reduction schemes.
6	**Learning objectives and skills**	Students • have critical understanding of capabilities of numerical schemes for stochastic differential equations, • are capable to use own or commercial software for SDEs and to judge results critically.
7	**Prerequisites**	Basic knowledge in probability theory and in numerics is recommended.
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 “Analysis and Stochastics” • Mandatory elective module for MSc in Mathematics and Economics in the field of “Stochastics and Risk 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 currently offered, see UnivIS univis.fau.de or module handbook of current semester
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• P.E. Kloeden & E. Platen: Numerical solution of stochastic differential equations • B. Lapeyre, E. Pardoux & R. Sentis: Introduction to Monte-Carlo methods for transport and diffusion equations

1	Module name	Module 21: PcFem: Practical Course on Finite Element Methods for Phase-Separation Equations	5 ECTS credits
2	Courses/lectures	Seminar: 3 semester hrs/week	NASi
3	Lecturers	Dr. S. Metzger	

4	Module coordinator	Prof. Dr. G. Grün
5	Content	• Finite element discretization for Cahn-Hilliard equations, • Storage concepts for sparse matrices, • Adaptive mesh refinement.
6	Learning objectives and skills	Students • implement a finite element solver for phase-separation equations, • are able to compare and implement different storage concepts for sparse matrices, • are able to implement finite element solvers based on adaptive meshes, • are able to derive and implement efficient discretizations for phase-separation equations, • are able to validate their implementation.
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 • 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	Oral exam (30 minutes)
11	Grading procedure	100% Oral exam
12	Module frequency	Winter semester (not 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 Differential Equations, Springer 2003 • D. Braess: Finite Elements. Cambridge University Press 2010 • B. Stroustrup: The C++ programming language, Addison-Wesley 2014

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 22:** **RegPDE: Regularity theory of elliptic PDEs**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 3 semester hrs/week b) Practical: 1 semester hrs/week	**MApA**
3	**Lecturers**	**Dr. Cornelia Schneider**	

4	**Module coordinator**	**Dr. Cornelia Schneider**
5	**Content**	• Elliptic partial differential equations • Variational formulation • Function spaces • Regularity of solutions in Sobolev and Besov spaces
6	**Learning objectives and skills**	Students • see the relevance of regularity theory for practical problems, in particular, for the numerical treatment of PDEs; they get acquainted with the basic methods for proving regularity estimates • learn how methods from functional analysis, numerics and approximation theory interact • practice their mathematical skills (develop mathematical intuition and its formal justification, improve their ability to think about abstract problems, learn new methods of proof)
7	**Prerequisites**	Recommended: Analysis-modules of Bachelor programme, module NumPDE
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 Mathematics in the field of study “Analysis and stochastics”
10	**Method of examination**	Oral exam (20 minutes)
11	**Grading procedure**	100% Oral exam
12	**Module frequency**	Winter semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of current semester
13	**Workload**	Contact hours: 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**	• R. A. Adams, J. J. F. Fournier, Sobolev spaces, Pure and Applied mathematics 140, Elsevier, Academic Press (2003) • W. Hackbusch, Elliptic differential equations, Springer Series in Computational Mathematics, vol 18 (1992). • P. Grisvard, Elliptic problems in non smooth domains, Pitman, Boston (1985). • V. Kozlov, V. Maz’ya, J. Rossmann, Elliptic boundary value problems in domains with point singularities, AMS (1997).

1	Module name	Module 23: MaMoLS: Mathematical Modeling in the Life Sciences	5 ECTS credits
2	Courses/lectures	a) Lectures: 2 semester hrs/week b) Practical: 0,5 semester hrs/week	MApA
3	Lecturers	Dr. Neuss-Radu	

4	Module coordinator	Dr. Neuss-Radu
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

1	**Module name**	**Module 24:** **IPro: Partial Differential Equations Based Image Processing**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hr/week	**MApA/NASi**
3	**Lecturers**	**Prof. Dr. E.Bänsch, Dr. M. Fried**	

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 in the fields of study “Modeling, Simulation and Optimization” • Mandatory elective module MSc Integrated Life Science
10	**Method of examination**	oral exam (15 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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 25: AnFBP: Analysis of free-boundary problems in continuum mechanics**	**ECTS 5 credits**
2	**Courses/lectures**	Lecture: 2 semester hrs/week Practical: 0.5 semester hrs/week	**MApA**
3	**Lectures**	**Prof. Dr. G. Grün**	
4	**Module coordinator**	**Prof. Dr. G. Grün**	
5	**Content**	Derivation of time-dependent free boundary problems in continuum mechanics, Basic results on existence and qualitative behaviour, Optimal estimates on the propagation of free boundaries, Other approaches, e.g. relaxation by phase-field models.	
6	**Learning objectives and skills**	Students formulate free-boundary problems in hydrodynamics and in porous-media flow,, explain analytical concepts for existence and nonnegativity results for degenerate parabolic equations as well as techniques for optimal estimates on spreading rates, validate different modeling approaches in a critical way.	
7	**Prerequisites**	Recommended: Basic knowledge of analysis of partial differential equations, corresponding to the syllabus of "Modeling and applied analysis in continuum mechanics" or that one of other pde-lectures.	
8	**Integration into curriculum**	3rd semester	
9	**Module compatibility**	• Mandatory elective module MSc Computational and Applied Mathematics, • Mandatory elective module MSc Mathematics in the field of study "Analysis and Stochastics"	
10	**Method of examination**	oral exam (15 minutes)	
11	**Grading Procedure**	100% based on oral exam	
12	**Module frequency**	Winter semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of current semester	
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS	
14	**Module duration**	One semester	
15	**Teaching and examination language**	English	
16	**Recommended reading**	L.C. Evans: Partial Differential Equations, AMS, Original journal articles.	

1	**Module name**	**Module 26:** **PDFin: Partial Differential Equations in Finance**	**5 ECTS credits**
2	**Courses/lectures**	Lecture: 2 semester hrs/week Practical: 0.5 semester hrs/week	**MApA/NASi**
3	**Lecturers**	**Profs. Drs. E. Bänsch, G. Grün**	

4	**Module coordinator**	**Prof. Dr. G. Grün**
5	**Content**	• models on pricing for financial derivatives, in particular for European and American-type options, selected deterministic equations of financial mathematics, • practical knowledge Ito-calculus and stochastic differential equations, • analysis and numerics for Black-Scholes equations, • variational inequalities and American-type options.
6	**Learning objectives and skills**	Students • explain mathematical models for financial markets and derivatives pricing, • apply Ito calculus, derive deterministic models based on pde or variational inequalities and discretize them numerically.
7	**Prerequisites**	Basis knowledge in differential equations, probability theory or functional analysis is recommended.
8	**Integration into curriculum**	3rd semester
9	**Module compatibility**	• Mandatory elective module MSc Computational and Applied Mathematics, • Mandatory elective module MSc Mathematics in the field of study “Modelling, Analysis and Optimization” • Compulsory elective module MSc Mathematics and Economics in the field of study “Stochastics and Risk 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 or module handbook of current semester
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• M. Capiński & T. Zastawniak: Mathematics for finance, Springer, • N. Hilber, O. Reichmann, C. Schwab & C. Winter: Computational methods for quantitative finance, Springer, • B. Oksendal: Stochastic differential equations, Springer.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 27: 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	**Opti**
3	**Lecturers**	**Profs. Drs. M. Stingl, G. Leugering**	

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 • Mandatory elective module for MSc Mathematics in the fields of study "Modelling, Analysis and Computation", "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: 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.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	Module name	Module 28: AlgNLOpt: Advanced Algorithms for Nonlinear Optimization	5 ECTS credits
2	Courses/lectures	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	Opti
3	Lecturers	Prof. Dr. M. Stingl	

4	**Module coordinator**	**Prof. Dr. M. Stingl**
5	**Content**	Several of the following topics: • Trust region methods • Iterative methods in the presence of noisy data • Interior point methods for nonlinear problems • Modified barrier and augmented Lagrangian methods • Local and global convergence analysis
6	**Learning objectives and skills**	Students • use methods of nonlinear constrained optimization in finite dimensional spaces, • analyse convergence behaviour of these methods and derive robust and efficient realisations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration into curriculum**	1st semester
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for the MSc in Mathematics and Economics in the field of study “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 or module handbook of current sememster
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**	• C.T. Kelley: Iterative Methods for Optimization, SIAM, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 29:** **DiscOpt I: Discrete Optimization I**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 1 weekly lecture hour	**Opti**
3	**Lecturers**	**Profs. Drs. F. Liers, A. Martin**	

4	**Module coordinator**	**Prof. Dr. A. Martin**
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 Mathematics in the field of study “Modelling, Simulation and Optimization” • Mandatory elective module for the MSc in Mathematics and Economics in the field of study “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 or module handbook of current semester
13	**Workload**	Attendance: 45 h Self-study: 105 h Total: 150 hrs, corresponding to 5 ECTS credits
14	**Module duration**	one semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• Lecture notes • Conforti, Cornuéjols & Zambelli: Integer Programming, Springer 2014 • B. Grünbaum: Convex Polytopes, Springer, 2003 • B. Korte & J. Vygen: Combinatorial Optimization, Springer 2005 • G. L. Nemhauser & L.A. Wolsey: Integer and Combinatorial Optimization, Wiley 1994 • A. Schrijver: Theory of Linear and Integer Programming, Wiley 1986 • L.A. Wolsey: Integer Programming, Wiley 1998 • G. Ziegler: Lectures on Polytopes, Springer, 1995

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 30: RobOpt II: Robust Optimization II**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 1 weekly lecture hour	**Opti**
3	**Lecturers**	**Prof. Dr. F. Liers**	

4	**Module coordinator**	**Prof. Dr. F. Liers**
5	**Content**	In practice, provided data for mathematical optimization problems is often not fully known. Robust optimization aims at finding the best solution which is feasible for input data varying within certain tolerances. The lecture covers advanced methods of robust optimization in theory and modeling. In particular, robust network flows, robust integer optimization and robust approximation are included. Further, state-of-the-art concepts, e.g., "light robustness" or "adjustable robustness" will be discussed by means of real-world applications.
6	**Learning objectives and skills**	Students • will be able to identify complex optimization problems under uncertainties as well as suitably model and analyze the corresponding robust optimization problem with the help of advanced techniques of robust optimization, • learn the handling of appropriate solving techniques and how to analyze the corresponding results.
7	**Prerequisites**	Recommended: Robust Optimization I
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 study “Modelling, Simulation and Optimization” • Mandatory elective module for the MSc in Mathematics and Economics in the field of study “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 in the current semester, 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**	Lecture notes, will be published on StudOn at the beginning of the semester.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 31:** **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	**Opti**
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, • Mandatory elective module for MSc Mathematics in the field of study "Modelling, Simulation and Optimization" • Mandatory elective Module for MSc Mathematics and Economics in the field of study "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: 37.5 h Self-study: 122.5 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 32: AdvNLOpt: Advanced Nonlinear Optimization**	**10 ECTS credits**
2	**Courses/lectures**	a) Lectures: 4 semester hrs/week b) Practical: 1 semester hr/week	**Opti**
3	**Lecturers**	**Profs. Drs. W. Achtziger, M. Stingl**	

4	**Module coordinator**	**Prof. Dr. W. Achtziger**
5	**Content**	• advanced optimality conditions and constraint qualifications for constrained optimization problems • penalty, barrier and augmented Lagrangian methods: theory and algorithms • interior point methods • sequential quadratic programming
6	**Learning objectives and skills**	Students • explain and extend their knowledge on theory and algorithms of nonlinear optimization problems, • apply solution techniques to different advanced types of optimization problems, • derive and solve optimization problems arising from technical and economical applications.
7	**Prerequisites**	Basic knowledge in nonlinear optimization is recommended.
8	**Integration into curriculum**	1st or 3rd semester
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the field of study “Modelling, Simulation and Optimization” • Mandatory elective module for MSc in Mathematics and Economics in the field 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**	Winter semester (not annually) To check whether the course is offered, see UnivIS univis.fau.de or module handbook of current semester
13	**Workload**	Contact hours: 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**	• M.S. Bazaraa, H.D. Sherali & C.M. Shetty: Nonlinear Programming – Theory and Algorithms, Wiley, New York, • J. Nocedal & S. Wright: Numerical Optimization, Springer.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 33:** **OptPDE: Optimization with Partial Differential Equations**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**Opti**
3	**Lecturers**	**Profs. Drs. G. Leugering, M. Stingl**	

4	**Module coordinator**	**Prof. Dr. M. Stingl**
5	**Content**	Several of the following topics: • Optimization and control in Banach spaces • Concepts of controllability and stabilization • Optimal control of Partial differential equations • Singular Perturbations and asymptotic analysis • Numerical realizations of optimal controls • Technical, medical and economic applications
6	**Learning objectives and skills**	Students • explain and use theory as well as numerical methods for optimization, control and stabilization in the context of partial differential equations, • apply these abilities to technical and economic applications.
7	**Prerequisites**	Basic knowledge in numerics, partial differential equations, and nonlinear optimization is recommended.
8	**Integration into curriculum**	1st or 3rd semester
9	**Module compatibility**	• Mandatory elective module for MSc in Computational and Applied Mathematics • Mandatory elective module for MSc in Mathematics in the field of study “Modelling, Simulation and Optimization” • Mandatory elective module for MSc in Mathematics and Economics in the field of study “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 or module handbook of current semester
13	**Workload**	Contact hours: 37.5 hrs Independent study: 112.5 hrs Total: 150 hrs, corresponding to 5 ECTS credits
14	**Module duration**	One semester
15	**Teaching and examination language**	English
16	**Recommended reading**	- F. Tröltzsch: Optimal Control of Partial Differential Equations, AMS, - G. Leugering & P. Kogut: Optimal Control of PDEs in Reticulated Domains, Birkhäuser.

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 34: DiscOpt II: Discrete Optimization II**	**10 ECTS credits**
2	**Courses/lectures**	a) Lectures: 4 weekly lecture hours b) Practical: 2 weekly lecture hour	**Opti**
3	**Lecturers**	**Profs. Drs. F. Liers, A. Martin**	

4	**Module coordinator**	**Prof. Dr. A. 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, • Mandatory elective module for MSc Mathematics in the field of study “Modelling, Simulation and Optimization” • Mandatory elective module for MSc Mathematics and Economics in the field “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
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

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 35: OptIE: Optimization in Industry and Economy**	**5 ECTS credits**
2	**Courses/lectures**	a) Lectures: 2 weekly lecture hours b) Practical: 1 weekly lecture hour	**Opti**
3	**Lecturers**	**Profs. Drs. F. Liers, A. Martin**	

4	**Module coordinator**	**Prof. Dr. F. Liers**
5	**Content**	This course focuses on modeling and solving real-world optimization problems occurring in industry and economics. Advantages and disadvantages of different modeling techniques will be outlined. In order to achieve efficient solution approaches, different reformulations and their numerical results will be discussed. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications. The latter may include but is not limited to the optimization of transport networks (gas, water, energy), air traffic management and mathematical modeling/optimization of market mechanisms in the energy sector.
6	**Learning objectives and skills**	Students • model complex real-world optimization problems with respect to efficient solvability, • classify the models and use appropriate solution strategies, • evaluate the achieved computational results.
7	**Prerequisites**	Recommended: Knowledge in 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 Mathematics in the field of study "Modelling, Simulation and Optimization" • Mandatory elective module for MSc Mathematics and Economics in the field "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 (annually)
13	**Workload**	Attendance: 45 h Self-study: 105 h Total: 150 hrs, corresponding to 5 ECTS credits
14	**Module duration**	1 semester
15	**Teaching and examination language**	English
16	**Recommended reading**	• Lecture notes (will be published on StudOn at the beginning of the semester) • Up-to-date research literature (will be published on StudOn at the beginning of the semester)

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

1	**Module name**	**Module 36: ProjO: Project Seminar Optimization**	**5 ECTS credits**
2	**Courses/lectures**	Seminar: 2 semester hrs/week	**Opti**
3	**Lecturers**	**Profs. Drs. F. Liers, A. Martin**	

4	**Module coordinator**	**Prof. Dr. A. Martin**
5	**Content**	A specific application is to be used to implement the knowledge of mathematical optimisation models and methods acquired during the degree programme thus far. The content is taken from a current problem, often in close collaboration with an industrial partner. Examples might be the water supply for a city, the design of an energy-efficient facade for an office building or railway construction site management.
6	**Learning objectives and skills**	Students • organise themselves into teams to carry out a large project in which they independently model a real problem, develop and implement solutions and apply their results in practical situations, • strengthen their communication skills by presenting and discussing the results of the project work, • discuss information, ideas, problems and solutions at an academic level with each other and with the lecturers.
7	**Prerequisites**	Recommended: knowledge in combinatorial optimisation
8	**Integration into curriculum**	2^{nd} 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 study “Modelling, Simulation and Optimization” • Mandatory elective module for MSc Mathematics and Economics in the field “Optimization and Process Management”
10	**Method of examination**	Talk/presentation (45 minutes) with final report (10-15 pages)
11	**Grading procedure**	Talk/presentation (50%) final report (50%)
12	**Module frequency**	Summer or winter semester (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: 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**	Project-dependent. Will be published on StudOn at the beginning of the semester.

1	Module name	**Module 38:** **PdeConNum: Lecture Series Partial Differential Equations, Control and Numerics**	**5 ECTS credits**
2	Courses/lectures	a) Lectures: 2 semester hrs/week b) Practical: 0.5 semester hrs/week	**Opti**
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 • Mandatory elective module for MSc in Mathematics in the field of study “Modeling, Simulation and Optimization” • Mandatory elective module for MSc in Mathematics and Economics in the field of study “Optimization and Process Management”
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	5 ECTS credits
2	Courses/lectures	a) Lecture: 2 semester hrs/week b) Practical: 1 semester hr/week	NASi
3	Lecturers	Profs. Drs. E. Bänsch, 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.