

UNIVERSITÄT ZU LÜBECK

Module Guide for the Study Path

Master CLS 2023

Version from 14. April 2025



mathematics

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mathematics / computer science

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computer science

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computational life science / life sciences

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MML with specialization in Life Science

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Elective

Speech and Audio Signal Processing (CS5260-KP04, CS5260SJ14, SprachAu14)



Duration:	Turnus of offer:	Credit points:
Semester	each winter semester	8
ourse of study, specific field an	d term:	
Master CLS 2023 (compulse	ry) mathematics 1st semester	
Bachelor Biophysics 2024 (c	ompulsory), computer science, 5th	semester
Bachelor Robotics and Auto	nomous Systems 2020 (compulsor	y), Robotics and Autonomous Systems, 5th semester
Bachelor Computer Science	2019 (optional subject), major subj	ect informatics, Arbitrary semester
Bachelor Computer Science	2019 (compulsory), Canonical Spec	ialization Bioinformatics and Systems Biology, 5th semester
 Bachelor MES 2020 (compu 	lsory), computer science, 5th semes	ter
 Bachelor Media Informatics 	2020 (optional subject), computer s	cience, 5th or 6th semester
Bachelor Medical Information	s 2019 (optional subject), computer	r science, 4th to 6th semester
Bachelor Computer Science	2014 (compulsory), specialization fi	ield robotics and automation, 5th semester
Bachelor Computer Science	2014 (compulsory), specialization fi	ield bioinformatics, 5th semester
Bachelor Computer Science	2016 (compulsory), Canonical Spec	ialization Bioinformatics, 5th semester
Bachelor Computer Science Bachelor Computer Science	2016 (optional subject), major subj	ect informatics, Arbitrary semester
Master CLS 2016 (computer science)	2010 (compulsory), canonical spec	alization web and Data Science, Still semester
Bachelor Bobotics and Auto	nomous Systems 2016 (compulsory	() Robotics and Autonomous Systems, 5th semester
Bachelor IT-Security 2016 (c	potional subject), computer science.	Arbitrary semester
Bachelor Biophysics 2016 (c)	ompulsory), computer science, 5th	semester
Bachelor Medical Information	cs 2014 (compulsory), computer scie	ence, 5th semester
Bachelor MES 2014 (compu	lsory), computer science, 5th semes	ter
Bachelor Media Informatics	2014 (optional subject), computer s	science, 5th or 6th semester
 Bachelor Computer Science 	2014 (optional subject), central top	ics of computer science, 5th semester
Classes and lectures:		Workload:
Signal Processing (lecture 2)	2 (1//(5)	 110 Hours private studies
 Signal Processing (lecture, 2) Signal Processing (exercise) 	1 SWS)	 90 Hours in-classroom work
 Image Processing (lecture.) 	2 SWS)	 40 Hours example paration
Image Processing (exercise,	1 SWS)	
Contents of teaching:		
Linear time-invariant system	ns	
Impulse response		
Convolution		
Fourier transform		
 Transfer function 		
 Correlation and energy der 	sity of deterministic signals	
 Sampling 		
 Discrete-time signals and sy 	/stems	
Discrete-time Fourier transf	orm	
• z-Iransform		
FIR and IIR filters		
BIOCK diagrams EID filter design		
 Discrete Fourier transform (DET)	
Fast Fourier transform (FFT)		
Characterization and proce	ssing of random signals	
 Introduction, interest of vis 	ual information	
2D Sampling		
 Image enhancement 		
Image enhancementEdge detection		
 Image enhancement Edge detection Multiresolution concepts: G 	aussian and Laplacian Pyramid, way	<i>r</i> elets
 Image enhancement Edge detection Multiresolution concepts: G Principles of image comprese 	aussian and Laplacian Pyramid, wav ssion	/elets
 Image enhancement Edge detection Multiresolution concepts: G Principles of image compre Segmentation 	aussian and Laplacian Pyramid, wav ssion	velets



• Students work self-actingly and independently with regard to the roles of GSP of the University of Lübeck.
Qualification-goals/Competencies:
 Students are able to explain the fundamentals of linear system theory. They are able to define and competently explain the essential elements of signal processing mathematically. They will have a command of mathematical methods for the description and analysis of continuous-time and discrete-time signals and systems. They are able to design digital filters and know various structures for their implementation. They are able to explain the basic techniques for describing and processing of random signals. They will have basic knowledge of two-dimensional system theory. They are able to describe the main techniques for image analysis and image enhancement. They are able to apply the learned principles in practice.
Grading through:
written exam
Responsible for this module:
Prof. DrIng. Alfred Mertins
Teacher:
Institute for Signal Processing
Prof. DrIng. Alfred Mertins
Literature:
 A. Mertins: Signaltheorie: Grundlagen der Signalbeschreibung, Filterbänke, Wavelets, Zeit-Frequenz-Analyse, Parameter- und Signalschätzung - Springer-Vieweg, 3. Auflage, 2013 A. K. Jain: Fundamentals of Digital Image Processing - Prentice Hall, 1989 Rafael C. Gonzalez, Richard E. Woods: Digital Image Processing - Prentice Hall 2003
Language:
offered only in German
Notes:
Prerequisites for attending the module: - None
Prerequisites for the exam: - Successful completion of homework assignments during the semester (at least 50% of max. points).
Module exam: - CS3100-L1: Signal Processing, written exam, 90 min, 100% of module grade



MA3445-KP05 - Graph Theory (GraphTKP05)					
Duration:	Turnus of offer: Credit points:				
1 Semester	1 Semester irregularly 5				
Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject) Minor in Teaching Mathematics, Mas Bachelor Computer Science 2019 (op Minor in Teaching Mathematics, Mas Bachelor Computer Science 2016 (op Master CLS 2016 (optional subject), r Bachelor CLS 2016 (optional subject)	mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th s ster of Education 2023 (opti otional subject), Extended c ster of Education 2017 (opti otional subject), advanced o mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th s	rd semester emester ional subject), mathematics optional subjects, Arbitrary ional subject), mathematics curriculum, Arbitrary semes rd semester emester	5, 2nd or 3rd semester semester 5, 2nd or 3rd semester ster		
Classes and lectures:		Workload:			
 Graph theory (lecture, 2 SWS) Graph theory (exercise, 1 SWS) 		85 Hours private45 Hours in-class20 Hours exam p	studies room work reparation		
 Hamiltonian graphs and degree sequences of teachings. Menger's theorem - new proofs Matchings and decompositions of g The theorems of Turan and Ramsey Vertex and edge colourings The four colour theorem Qualification-goals/Competencies: Ability to solve discrete problems us Knowledge of proof techniques and Knowledge of fundamental and sele Ability to learn independently by stu 	Contents of teaching: Hamiltonian graphs and degree sequences Menger's theorem - new proofs Matchings and decompositions of graphs The theorems of Turan and Ramsey Vertex and edge colourings The four colour theorem Qualification-goals/Competencies: Ability to solve discrete problems using graph theoretical methods Knowledge of proof techniques and ideas of discrete mathematics Knowledge of fundamental and selected recent research results 				
Grading through: • Oral examination					
Requires: • Linear Algebra and Discrete Structur • Linear Algebra and Discrete Structur	es 2 (MA1500-KP08, MA150 es 1 (MA1000-KP08, MA100)0))0)			
Responsible for this module: • PD Dr. rer. nat. Christian Bey Teacher: • Institute for Mathematics • PD Dr. rer. nat. Christian Bey					
Literature: • F. Harary: Graph Theory - Reading, M • R. Diestel: Graphentheorie - Berlin: S • D. Jungnickel: Graphen, Netzwerke u • J. Bang-Jensen, G. Gutin: Digraphs: T • B. Bollobas: Modern Graph Theory - Language: • offered entry in Compare	1A:.Addison-Wesley 1969 pringer 2010 (4th edition) und Algorithmen - Mannhe heory, Algorithms and App Berlin: Springer 1998	im: Bl-Wissenschaftsverlag lications - London: Springe	I994 ≥r 2001		



Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA3445-L1: Graph Theory, oral exam, 30 min, 100 % of module grade



MA	MA4100-KP05 - Survival Analysis (UebAnaKP05)			
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
 Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject), Bachelor CLS 2016 (optional subject), Master CLS 2016 (optional subject), r 	mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th se mathematics, 5th or 6th se mathematics, 1st, 2nd, or 3	rd semester semester emester rd semester		
Classes and lectures:		Workload:		
Survival Analysis (lecture, 2 SWS) Survival Analysis (exercise, 1 SWS) Su			studies n project room work reparation	
Contents of teaching:				
 Introduction to survival analysis Kaplan-Meier method Log rank test The Cox regression model and its ch Evaluating the proportional hazards Stratified Cox model Parametric survival analysis Event time analyses for recurrent event time analysis for competing rise Design aspects for RCTs 	aracteristics assumption ents sks			
 The students are able to explain the They are able to define the most imp They are able to calculate point and They are able to calculate the log-ran They are able to explain the assump They are able to estimate Cox mode They are able to check the assumption They are able to calculate exponention They can explain the specifics of recurs They can design an RCT with a time- 	different censoring mecha portant terms of survival ar interval estimators for the nk test for two or more gro tion of proportionality of t ls. on of proportionality. fal and Weibull models. urrent events and competing ent events and competing to-event endpoint.	anisms leading to survival ar nalysis. Kaplan-Meier approach. pups. he Cox model. ng risks. risks.	nalysis.	
Grading through:				
Oral examination				
Requires:				
 Biostatistics 2 (MA2600-KP07) Biostatistics 1 (MA1600-KP04, MA1600, MA1600-MML) Stochastics 2 (MA4020-KP07) Stochastics 1 (MA2510-KP04, MA2510) 				
Responsible for this module:				
Dr. Maren Vens				
Teacher:				
Institute of Medical Biometry and Statistics				
Dr. Maren Vens				



Literature:

• Kleinbaum DG, Klein M: Survival Analysis: A Self-Learning Text - 3rd Edition - 2012

Language:

• English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

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Admission requirements for participation in module examination(s):

- Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4100-L1: Survival Analysis, oral exam, 30 min, 100 % of module grade



MA	4320-KP05 - Optimisation me	thods for machine le	earning (OptvML)		
Duration: Turnus of offer: Credit points:			Credit points:		
1 Semester irregularly 5			5		
Course of study, specific field • Bachelor CLS 2016 (opti • Master CLS 2016 (optior • Bachelor CLS 2023 (optior • Master CLS 2023 (optior	and term: onal subject), mathematics, 6th seme nal subject), mathematics, 2nd or 4th s onal subject), mathematics, 6th seme nal subject), mathematics, 2nd or 4th s	ster semester ster semester			
Classes and lectures:	Classes and lectures: Workload:				
 MA4320-V: Optimisation (lecture, 2 SWS) MA4320-Ü: Optimisation (exercise, 1 SWS) 	 MA4320-V: Optimisation methods for machine learning (lecture, 2 SWS) MA4320-Ü: Optimisation methods for machine learning (exercise, 1 SWS) 85 Hours private studies and exercises 45 Hours in-classroom work 20 Hours exam preparation 				
Contents of teaching:					
 Objective functions in n Optimisation methods f Applications (e.g. classif 	nachine learning (e.g. hinge loss, log l or machine learning (e.g. stochastic g ication, regression, speech and image	oss, expected risk, empiric radient method,Adam, sto recognition)	al risk) ochastic quasi-Newton method)		
Qualification-goals/Competer	ncies:				
 Students can model ma They understand the ad They can apply typical p They can select optimise Interdisciplinary aspects Students can put theore They have implementat They are able to abstract 	vantages and disadvantages and area proof techniques. ation methods and implement them i atical concepts into practice. ion experience. t practical problems.	n practice for new models	lual optimisation methods.		
Grading through:					
Written or oral exam as	announced by the examiner				
Requires: • Optimization (MA4030-ł • Optimization (Advanced	(P08, MA4030) I Mathematics) (MA4031-KP08)				
Responsible for this module:					
Prof. Dr. rer. nat. Jan Mo	dersitzki				
Teacher: Institute of Mathematics	and Image Computing				
 Prof. Dr. rer. nat. Jan Modersitzki Prof. Dr. rer. nat. Jan Lellmann Dr. rer. nat. Florian Mannel 					
Literature:					
 Goodfellow, Bengio, Co Bottou, Curtis, Nocedal: Bubeck: Convex Optimiz Lan: First-order and Store 	urville: Deep Learning - MIT Press Optimization Methods for Large-Scale zation: Algorithms and Complexity - N chastic Optimization Methods for Mac	e Machine Learning - SIAN Iow Publishers Inc hine Learning - Springer	1		
Language: • German and English skil	ls required				



Notes:

Admission requirements for taking the module:

- None (the competences of the modules mentioned under Requires are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Ungraded preliminary examinations are exercises and their presentation. These must have been completed and positively assessed before the first examination.

Module Exam(s):

- MA4320-L1: Optimisation methods for machine learning, written exam, 90min, or oral exam, 30min, according to the lecturer, 100% of the module grade



MA4330-KP05 - Biosignal analysis (BioSAKP05)				
Duration: Turnus of offer: Credit points:				
1 Semester	each summer semester		5	
Course of study, specific field and term: • Master CLS 2023 (compulsory), math • Master CLS 2016 (compulsory), math	ematics, 2nd semester ematics, 2nd semester			
Classes and lectures:		Workload:		
 Biosignal analysis (lecture, 2 SWS) Biosignal analysis (exercise, 1 SWS) 	 Biosignal analysis (lecture, 2 SWS) Biosignal analysis (exercise, 1 SWS) Biosignal analysis (exercise, 1 SWS) 45 Hours in-classroom work 20 Hours exam preparation 			
Contents of teaching:				
 Hilbert spaces Fourier series and Fourier transformation generalized functions discrete wavelet transformation least square techniques application to biological and medication 	ation Il data			
 Qualification-goals/Competencies: Students have in-depth knowledge of the mathematical background of signal analysis They master different methodsof one-dimensional signal analysis They have practical skills in the application of these methods They have skills in working with Mathematica or MatLab 				
Grading through: • Exercises • written exam				
Requires: • Analysis 2 (MA2500-KP04, MA2500)				
Responsible for this module: • Nachfolge von Prof. Dr. rer. nat. Karsten Keller Teacher: • Institute for Mathematics				
 Nachfolge von Prof. Dr. rer. nat. Karsten Keller Prof. Dr. rer. nat. Jürgen Prestin 				
 Literature: S. Mallat: A wavelet tour of signal processing - Academic Press, 1998 A. N. Kolmogorov, S.V. Fomin: Reelle Funktionen und Funktionalanalysis - Deutscher Verlag der Wissenschaften 1975 				
Language: • offered only in German				
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments during the semester

Module exam(s):

- MA4330-L1: Biosignal analysis, written exam (60 min), 100 % of the module grade



MA	4341-KP05 - Time se	ries analysis (ZeitAnK	P05)	
Duration:	uration: Turnus of offer: Credit points:			
1 Semester	irregularly		5	
Course of study, specific field and term: • Master CLS 2023 (optional subject), r • Bachelor CLS 2023 (optional subject) • Minor in Teaching Mathematics, Mas • Minor in Teaching Mathematics, Mas • Master CLS 2016 (optional subject), r • Bachelor CLS 2016 (optional subject)	nathematics, 1st, 2nd, or 3 , mathematics, 5th or 6th ter of Education 2023 (op ter of Education 2017 (op nathematics, 1st, 2nd, or 3 , mathematics, 5th or 6th	Brd semester semester tional subject), mathematics tional subject), mathematics Brd semester semester	s, 2nd or 3rd semester s, 2nd or 3rd semester	
Classes and lectures:		Workload:		
 Time series analysis (lecture, 2 SWS) Time series analysis (exercise, 1 SWS) 	Time series analysis (lecture, 2 SWS) Time series analysis (exercise, 1 SWS)			
Contents of teaching:				
 Linear time series models: MA-processes, AR-processes, ARIMA-processes Time series and models with long-range dependencies Time series in the frequency domain:autocorrelation function, spectral density and its estimation nonlinear methods by examples analysis and modelling of data from life sciences (software: R, Mathematica, SPSS) 				
Qualification-goals/Competencies:				
 Students have basic knowledge of co They master simple linear methods of They have competencies in analysis 	oncepts and ideas of time of time series analysis and modelling of real-wor	series analysis Id time series		
Grading through:				
Oral examination				
Requires:				
• Stochastics 2 (MA4020-KP07)				
Responsible for this module:				
 Nachfolge von Prof. Dr. rer. nat. Karst 	ten Keller			
Teacher:				
 Institute for Mathematics 				
Nachfolge von Prof. Dr. rer. nat. Karsten Keller				
Literature:				
 R. Schlittgen, B.Streitberg: Zeitreihen P.J. Brockwell, R.A. Davis: Time Series 	analyse - Oldenburg-Verla :: Theory and Methods - Sp	ag, München, Wien 1994 oringer, New York 1991		
Language: • offered only in German				
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4341-L1: Time series analysis, oral exam, 30 min, 100 % of module grade



	MA4345-KP05 - Func	tional Analysis (AKFunkk	(P05)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly	irregularly 5			
Course of study, specific field and Master CLS 2023 (optional s Bachelor CLS 2023 (optional Minor in Teaching Mathema Minor in Teaching Mathema Master CLS 2016 (antional st	I term: ubject), mathematics, 1st, 2nd subject), mathematics, 5th or itics, Master of Education 2023 itics, Master of Education 2017	, or 3rd semester 6th semester (optional subject), mathematic (optional subject), mathematic	s, 2nd or 3rd semester s, 2nd or 3rd semester		
 Master CLS 2016 (optional s Bachelor CLS 2016 (optional s 	ubject), mathematics, 1st, 2nd subject), mathematics, 5th or	, or 3rd semester 6th semester			
Classes and lectures.		Workload			
 Functional Analysis (lecture Functional Analysis (exercis) 	• Functional Analysis (lecture, 2 SWS) • Functional Analysis (exercise, 1 SWS) • Functional Analysis (exercise, 1 SWS) • 45 Hours in-classroom work • 20 Hours exam preparation				
Contents of teaching:					
 metric spaces elements of topology, in pa Banach and Hilbert spaces L^p-spaces duality bounded linear functionals 	 metric spaces elements of topology, in particular, compactness Banach and Hilbert spaces L^p-spaces duality bounded linear functionals and operators 				
Qualification-goals/Competencie • Understanding the transfer • Learning and applying tech	s: of simple analytic ideas to ger niques of functional analysis	neral structures			
Grading through: • written exam					
Requires: • Analysis 2 (MA2500-KP04, N	IA2500)				
Responsible for this module: • Nachfolge von Prof. Dr. rer. Teacher: • Institute for Mathematics • Nachfolge von Prof. Dr. rer.	nat. Karsten Keller nat. Karsten Keller				
literature					
A. N. Kolmogorov, S. V. Fom	in: Reelle Funktionen und Fun	ktionalanalysis - Deutscher Verla	ag der Wissenschaften, Berlin 1975		
Language: • offered only in German					
Notes:					



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4345-L1: Functional Analysis, oral exam, 30 min, 100 % of module grade



MA4400-KP05 - Chaos and Complexity (ChaKomKP05)					
Duration:	tion: Turnus of offer: Credit points:				
1 Semester	1 Semester irregularly 5				
Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject) Master Biophysics 2019 (optional subject) Bachelor CLS 2016 (optional subject), Master CLS 2016 (optional subject), r	mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th s oject), Elective, 1st or 2nd s), mathematics, 5th or 6th s mathematics, 1st, 2nd, or 3	rd semester emester emester emester rd semester			
Classes and lectures:		Workload:			
 Chaos and Complexity (lecture, 2 SW Chaos and Complexity (exercise, 1 SV 	 Chaos and Complexity (lecture, 2 SWS) Chaos and Complexity (exercise, 1 SWS) Chaos and Complexity (exercise, 1 SWS) 45 Hours in-classroom work 20 Hours exam preparation 				
Contents of teaching:					
 Time-discrete dynamical systems an Nonlinearity and chaos Ergodicity Symbolic dynamics Information-theoretic complexity me Ordinal time series analysis Biological and medical applications, 	 Time-discrete dynamical systems and stochastic processes Nonlinearity and chaos Ergodicity Symbolic dynamics Information-theoretic complexity measures Ordinal time series analysis Biological and medical applications, in particular EEG analysis 				
Qualification-goals/Competencies:					
 Students get insights into basic aspe They have skills in analyzing and mo They have competencies in simulating 	ects of nonlinear dynamics Ideling complex data and t ng and illustrating nonlinea	ime series ar dynamic phenomena			
Grading through:					
Written or oral exam as announced b	by the examiner				
Requires: • Stochastics 1 (MA2510-KP04, MA2510) • Analysis 1 (MA2000-KP08, MA2000)					
Responsible for this module:					
Nachfolge von Prof. Dr. rer. nat. Kars	ten Keller				
Teacher: • Institute for Mathematics					
Nachfolge von Prof. Dr. rer. nat. Karsten Keller					
l iteratura					
 M. Brin, G. Stuck: Introduction to Dynamical Systems - Cambridge University Press 2002 J. M. Amigó: Permutation Complexity in Dynamical Systems - Springer 2010 R. L. Devaney: An Introduction to Chaotic Dynamical Systems - Westview Press 2003 					
Language:					
depends on the chosen courses					
Notes:					



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4400-L1: Chaos and Complexity, oral exam, 30 min, 100 % of module grade

Lecture notes in English



MA4410-KP05 - Approximation Theory (ApproxKP05)					
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject) Minor in Teaching Mathematics, Mas Minor in Teaching Mathematics, Mas Bachelor CLS 2016 (optional subject), Master CLS 2016 (optional subject), r	 Course of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd semester Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semester Minor in Teaching Mathematics, Master of Education 2023 (optional subject), mathematics, 2nd or 3rd semester Minor in Teaching Mathematics, Master of Education 2017 (optional subject), mathematics, 2nd or 3rd semester Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd semester 				
Classes and lectures:		Workload:			
 Approximation theory (lecture, 2 SW Approximation theory (exercise, 1 SV 	YS) WS)	 65 Hours private 45 Hours in-classi 30 Hours work or 10 Hours exam private 	studies and exercises room work n project reparation		
 Fundamentals of functional analysis Best approximation Linear methods, trigonometric kernels Theorems of Jackson and Bernstein Moduli of continuity Singular integrals Theorem of Banach-Steinhaus Interpolation methods Stability inegualities 					
 Qualification-goals/Competencies: practicing mathematical techniques (developing mathematical intuition and its formal justification, training the ability to abstract, reasoning) application of basic concepts from functional analysis and the theory of function spaces Learning the basic principles of approximation theory Understanding the relationship between order of convergence and smoothness Knowledge of the basic approximation methods application of computer algebra for visualization and better understanding of the methods used 					
Grading through: • exercises, project, oral or written exa	ım				
Responsible for this module: Prof. Dr. rer. nat. Jürgen Prestin Teacher: Institute for Mathematics Prof. Dr. rer. nat. Jürgen Prestin 					
 Literature: P. L. Butzer, R. J. Nessel: Fourier Analysis and Approximation - Birkhäuser Verlag 1971 R. A. Devore, G. G. Lorentz: Constructive Approximation - Springer 1993 					
Language: • English, except in case of only Germa	an-speaking participants				
Notes:	Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4410-L1: Approximation Theory, oral exam, 30 min, 100 % of module grade



M	A4450-KP05 - Modeling	Biological Systems (Mo	BSKP05)	
Duration:	Turnus of offer:		Credit points:	
1 Semester	each winter semester		5	
Course of study, specific field and t • Master CLS 2023 (compulsory)	erm:), mathematics, 1st semester			
Classes and lectures:		Workload:		
 Modeling Biological Systems (Modeling Biological Systems (ns (lecture, 2 SWS) ns (exercise, 1 SWS) 45 Hours in-classroom work 20 Hours exam preparation 			
Contents of teaching: • Elementary time-discrete dete • Structured time-discrete popu • Galton-Watson processes • Modeling of data and data an	erministic models Ilation dynamics alysis			
Qualification-goals/Competencies: • Students have knowledge of e • They develop skills in connect • They have competencies in da • They develop competencies in	elementary time-discrete mod ing ideas from different fields ata analysis and modelling n interdisciplinary work	els for modeling biological pr of mathematics	ocesses	
Grading through: • exercises and project assignm • written exam	ents			
Responsible for this module: Nachfolge von Prof. Dr. rer. na Teacher: Institute for Mathematics Nachfolge von Prof. Dr. rer. na 	t. Karsten Keller t. Karsten Keller			
Literature: • F. Braer, C. Castillo-Chavez: Ma • H. Caswell: Matrix Population • S. N. Elaydi: An Introduction to • B. Huppert: Angewandte Line • U. Krengel: Einführung in die V • E. Seneta: Non-negative Matri Language: • offered only in German	athematical Models in Populat Models - Sunderland: Sinauer o Difference Equations - New N are Algebra - Berlin: de Gruyte Wahrscheinlichkeitstheorie un ces and Markov Chains - New	ion Biology - New York: Sprin Associates 2001 (ork: Springer 1999 r 1990 d Statistik - Wiesbaden: Viewe York: Springer 1981	ger 2000 2g 2002	
Notes:				
Admission requirements for taki - None (The competencies of the	ng the module: e modules listed under 'Requir	es' are needed for this modul	e, but are not a formal prerequisite)	
Admission requirements for participation in module examination(s): - Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.				
Module exam(s): - MA4450-L1: Modeling Biological Systems, written exam, 90 min, 100 % of module grade				



MA4453-KP05 - Evolutionary Dynamics: Popu	lation Genetic and Ecological Models (EDPGEMKP05)
Duration: Turnus of offer:	Credit points:
1 Semester irregularly	5
Course of study, specific field and term: • Master CLS 2023 (optional subject), mathematics, 1st, 2nd, of • Bachelor CLS 2023 (optional subject), mathematics, 5th or 6 • Master CLS 2016 (optional subject), mathematics, 1st, 2nd, of • Bachelor CLS 2016 (optional subject), mathematics, 5th or 6	or 3rd semester 5th semester or 3rd semester 5th semester
Classes and loctures	Wayland
 Evolutionary Dynamics: Population Genetic and Ecological Models (lecture, 2 SWS) Evolutionary Dynamics: Population Genetic and Ecological Models (exercise, 1 SWS) 	 Workload: 65 Hours private studies 45 Hours in-classroom work 30 Hours work on project 10 Hours exam preparation
 Contents of teaching: Basics of mathematical population genetics Discrete stochastic models Genetic drift Natural selection Coupling of genetic and ecological models Dynamics of infectious diseases Handling publicly available data on the spread of infectious 	s diseases
 The students can explain the basic biological and mathema The students can construct simple stochastic models and an The students can perform approximations of simple models The Students will be able to contextualize mathematical mathematical	atical concepts of population genetics. nalyse them formally. s. odels and data.
Oral examination	
Responsible for this module: • Prof. Dr. Arne Traulsen Teacher: • Max Planck Institute for Evolutionary Biology • Institute for Mathematics • Prof. Dr. Arne Traulsen • MitarbeiterInnen des Instituts	
 Dr. Christian Hilbe Dr. Hildegard Uecker Dr. Chaitanya Gokhale 	
Literature:S.P. Otto and T.Day: A Biologist s Guide to Mathematical Methods	lodeling in Ecology and Evolution Princeton University Press, 2007
Language: • offered only in English	
Notes:	



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4453-L1: Evolutionary Dynamics: Population Genetic and Ecological Models, oral exam, 30 min, 100 % of module grade



	MA4454-KP05 - Evolutionary [Dynamics: Game Th	eory (EvDyGTKP05)	
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific fi Master CLS 2023 (op Bachelor CLS 2023 (d Master CLS 2016 (op Bachelor CLS 2016 (d)	ield and term: htional subject), mathematics, 1st, 2nd, optional subject), mathematics, 5th or htional subject), mathematics, 1st, 2nd, optional subject), mathematics, 5th or	or 3rd semester 6th semester or 3rd semester 6th semester		
Classes and lectures:		Workload:		
 Evolutionary Game T Developments (lecture Evolutionary Game T Developments (exertion) 	Theory - from Basics to Recent ure, 2 SWS) Theory - from Basics to Recent cise, 1 SWS)	leory - from Basics to Recent• 65 Hours private studiese, 2 SWS)• 45 Hours in-classroom workleory - from Basics to Recent• 30 Hours work on projectse, 1 SWS)• 10 Hours exam preparation		
Contents of teaching:				
 Basics of classical ga Deterministic and st The evolution of coc Repeated games Applications in gene 	me theory ochastic evolutionary game theory operation and punishment etics, ecology and social dynamics			
Qualification-goals/Comp	etencies:			
 The students can ex They can construct e They can analyse ev	plain and apply the basic concepts of g evolutionary models based on game th olutionary games formally.	game theory. neoretic interactions.		
Grading through: • Oral examination				
Responsible for this modu	ıle:			
Prof. Dr. Arne Traulse	en			
Teacher:				
Max Planck InstituteInstitute for Mathem	for Evolutionary Biology natics			
 Prof. Dr. Arne Traulse N.N.	en			
Literature:				
M.A. Nowak: EvolutioBroom & Rychtar: Ga	onary Dynamics - Exploring the equation ame-Theoretical Models in Biology - Ch	ons of life - Harvard Univ 1apman & Hall, 2013	ersity Press, 2006	
Language:				
offered only in Engli	sh			
Notes: Admission requiremen - None (The competen	its for taking the module: icies of the modules listed under 'Requ	iires' are needed for this	module, but are not a formal prer	equisite)
Admission requiremen - Successful completio	nts for participation in module examina n of homework assignments as specifie	ition(s): ed at the beginning of th	ne semester	
Module exam(s): - MA4454-L1: Evolution	nary Dynamics: Game Theory, oral exar	m, 30 min, 100 % of mod	ule grade	



	MA4501-KP05 - Mathematic	cs of Image Processing	(MaBVKP05)
Duration:	Turnus of offer:		Credit points:
1 Semester	every second winter	semester	5
Course of study, specific fie • Master CLS 2023 (opti • Master CLS 2023 (com	ld and term: onal subject), mathematics, 3rd seme pulsory), mathematics, 1st semester	ster	
Classes and lectures:		Workload:	
 Mathematics in Image Processing (lecture, 2 SWS) Mathematics in Image Processing (exercise, 1 SWS) 45 Hours in-cl 30 Hours wor 10 Hours examples 			e studies and exercises ssroom work on project preparation
Contents of teaching: • Functional-analytic me • Well-posedness and re • Introduction to calcule • Image restauration • Segmentation and lift • Evolution equations in	odels egularization us of variations, Euler-Lagrange equa ing methods n image processing (discretization, sta	tion ability)	
Qualification-goals/Compet Students have a solid They can compare and They can derive typica They understand fund They understand typic They are able to imple Interdisciplinary qualit Students have advance They can translate the They are experienced They can think abstrace	encies: mathematical understanding of typic d assess typical mathematical image p al mathematical methods for image p lamental discretization techniques an cal numerical methods for image pro- ement fundamental numerical metho fications: red skills in modeling. coretical concepts into practical soluti in implementation. ctly about practical problems.	al image processing methods processing methods. rocessing. Id their numerical analysis. cessing. ds for image processing.	5.
Grading through: • Written or oral exam a	s announced by the examiner		
Requires: • Linear Algebra and Di • Analysis 2 (MA2500-KF	screte Structures 2 (MA1500-KP08, M. 209)	A1500)	
Responsible for this module • Prof. Dr. rer. nat. Jan M Teacher: • Institute of Mathemati • Prof. Dr. rer. nat. Jan M • Prof. Dr. rer. nat. Jan L	:: Iodersitzki ics and Image Computing Iodersitzki ellmann		
Literature: • Gonzales/Woods: Digi • Russ: The Image Proce • Handels: Medizinische	tal Image Processing - Prentice Hall essing Handbook - CRC Press Bildverarbeitung - Vieweg+Teubner		
Language: • German and English sl	kills required		



Notes:

Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Homework assignments and their presentation are ungraded examination prerequisites which have to be completed and positively evaluated before the first examination.

Examination:

- MA4501-L1: Mathematics in Image Processing, written examination (90 min) or oral examination (30 min) as decided by examiner, 100% of final mark



MA4510-KP05 - Wavelet Theory (WaveThKP05)				
Duration:	Turnus of offer:	Cr	redit points:	
1 Semester	irregularly	5		
 Course of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd semester Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semester Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd semester 				
Classes and lectures:	Classes and lectures: Workload:			
 Wavelet Theory (lecture, 2 SWS) Wavelet Theory (exercise, 1 SWS) 	 65 Hours private studies and exercises 45 Hours in-classroom work 30 Hours work on project 10 Hours exam preparation 		dies and exercises m work roject aration	
Contents of teaching:				
 Haar system Discrete Haar transformation Orthonormal wavelet bases Multiresolution Analysis Algorithms for reconstruction and decomposition Periodic wavelets Multivariate generalizations 				
 Qualification-goals/Competencies: practicing mathematical techniques (developing mathematical intuition and its formal justification, training the ability to abstract, reasoning) application of basic concepts from functional analysis and the theory of function spaces Knowledge of the basic principles of wavelet analysis Understanding the applications in signal analysis The students learn how to work with wavelet algorithms and wavelet software. application of computer algebra for visualization and better understanding of the methods used 				
Grading through:				
exercises, project, oral or written exa	m			
Responsible for this module: Prof. Dr. rer. nat. Jürgen Prestin Teacher: Institute for Mathematics Prof. Dr. rer. nat. Jürgen Prestin 				
Literature:				
 I. Daubechies: Ten lectures on wavelets - SIAM Publ., Philadelphia, 1992 A.K. Louis, P. Maass, A. Rieder: Wavelets - Teubner Studienbücher Mathematik, 1994 				
Language:English, except in case of only German-speaking participants				
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4510-L1: Wavelet Theory, oral exam, 30 min, 100 % of module grade



Γ

MA4610-KP05 - Stochastic processes (StoProKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	normally each year in the	e winter semester	5	
Course of study, specific field a • Master CLS 2023 (compul • Master CLS 2016 (compul	nd term: sory), mathematics, 1st or 3rd semest sory), mathematics, 1st or 3rd semest	er er		
Classes and lectures: • Stochastic processes (lect • Stochastic processes (exe	es: Workload: rocesses (lecture, 2 SWS) • 85 Hours private studies and exercises rocesses (exercise, 1 SWS) • 45 Hours in-classroom work • 20 Hours exam preparation			
Contents of teaching: • Conditional expectation • Stochastic processes • Filtrations • Martingales • Brownian motion				
Qualification-goals/Competence • To develop some insight • Training of a stochastic w • Application of basic ideas	ies: into stochastic processes based on se ay of thinking and concepts of stochastic analysis	elected classes of proce	sses	
Grading through: • written exam				
Requires: • Stochastics 2 (MA4020-KP • Stochastics 1 (MA2510-KP	07) 04, MA2510)			
Responsible for this module: • Prof. Dr. rer. nat. Andreas Teacher: • Institute for Mathematics • Prof. Dr. rer. nat. Andreas	Rößler Rößler			
Literature: • L. C. G. Rogers, D. William Press, 2000 • L. C. G. Rogers, D. William 2014 • Ioannis Karatzas, Steven E	s: Diffusions, Markov Processes, and N s: Diffusions, Markov Processes, and N :. Shreve: Brownian Motion and Stoch	Martingales, Vol. 1, Fou Martingales, Vol. 2, Ito (nastic Calculus - Spring	ndations - 2nd edition, Cambridge University Calculus - 2nd edition, Cambridge University Pre er Verlag, 2nd edition, 1991	ess,
Language: • English, except in case of	only German-speaking participants			
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.

Module exam(s):

- MA4610-L1: Stochastic processes, written exam, 90 min, 100 % of module grade



MA4611-KP05 - Markov Processes (MarkPrKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
 Course of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd semester Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semester Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd semester Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester 				
Classes and lectures:		Workload:		
 Markov Processes (lecture, 2 SWS) Markov Processes (exercise, 1 SWS) 45 Hours in 20 Hours e 		 85 Hours private 45 Hours in-class 20 Hours exam p 	rivate studies and exercises classroom work kam preparation	
Contents of teaching: Markov chains and random walks time-continuous Markov processes Brownian Motion Poisson process birth-and-death processes life science applications 				
 Qualification-goals/Competencies: Mastering some important classes of stochastic processes and understanding possible applications 				
Grading through: • Written or oral exam as announced by the examiner				
Responsible for this module: Nachfolge von Prof. Dr. rer. nat. Karsten Keller Teacher: Institute for Mathematics Nachfolge von Prof. Dr. rer. nat. Karsten Keller 				
Language: • offered only in German				
Notes:				
Admission requirements for taking the module: - None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite) Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester				
Module exam(s): - MA4611-L1: Markov Processes, oral exam, 30 min, 100 % of module grade				



on: Turnus of offer: ester irregularly se of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd sem Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semest Bachelor CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Mester CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Numerical methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations (exercise, 1 SWS) ents of teaching: Introduction to the theory of partial differential equations Numerics for partial differential equations Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner	Credit points: 5 ester er ester rkload: • 85 Hours private studies and exercises • 45 Hours in-classroom work • 20 Hours exam preparation
ester irregularly se of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd sem Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semest: Bachelor CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Naster CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Naster CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Naster CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Naster CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Naster CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Numerical methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations (exercise, 1 SWS) Introduction to the theory of partial differential equations Numerics for partial differential equations Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation Accomplished handling of essential concepts and results as well as of Nurten or oral exam as announced by the examiner	5 ester er ester rkload: • 85 Hours private studies and exercises • 45 Hours in-classroom work • 20 Hours exam preparation
 se of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd sem Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semest Bachelor CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Wo Numerical methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from results from results as well as of ing through: Written or oral exam as announced by the examiner 	ester er ester rkload: • 85 Hours private studies and exercises • 45 Hours in-classroom work • 20 Hours exam preparation
 Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semest Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semest Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd sem Merecal methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations (exercise, 1 SWS) Introduction to the theory of partial differential equations Numerical approximation schemes Error analysis Stability and consistency To impart basic principles of numerics for partial differential equation of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	er ester rkload: • 85 Hours private studies and exercises • 45 Hours in-classroom work • 20 Hours exam preparation
 We ses and lectures: Numerical methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations (exercise, 1 SWS) Introduction to the theory of partial differential equations Numerics for partial differential equations Discretization of initial and boundary value problems Numerical approximation schemes Error analysis Stability and consistency To impart basic principles of numerics for partial differential equation of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	rkload: • 85 Hours private studies and exercises • 45 Hours in-classroom work • 20 Hours exam preparation
 Numerical methods for partial differential equations (lecture, 2 SWS) Numerical methods for partial differential equations (exercise, 1 SWS) ents of teaching: Introduction to the theory of partial differential equations Numerics for partial differential equations Discretization of initial and boundary value problems Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation of results from results as well as the application of results from results as well as of Maccomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	 85 Hours private studies and exercises 45 Hours in-classroom work 20 Hours exam preparation
 Numerical methods for partial differential equations (exercise, 1 SWS) ents of teaching: Introduction to the theory of partial differential equations Numerics for partial differential equations Discretization of initial and boundary value problems Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from results from results and the process of the providence of the proof of the	20 Hours exam preparation
 ents of teaching: Introduction to the theory of partial differential equations Numerics for partial differential equations Discretization of initial and boundary value problems Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	
 Introduction to the theory of partial differential equations Numerics for partial differential equations Discretization of initial and boundary value problems Numerical approximation schemes Error analysis Stability and consistency ification-goals/Competencies: To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from n Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	
 ification-goals/Competencies: To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	
 To impart basic principles of numerics for partial differential equation To learn methods of proofs as well as the application of results from r Accomplished handling of essential concepts and results as well as of ing through: Written or oral exam as announced by the examiner 	
ing through:Written or oral exam as announced by the examiner	s umerics for partial differential equations selected advanced topics
 Written or oral exam as announced by the examiner 	
ires:	
• Numerics 2 (MA4040-KP06)	
 Linear Algebra and Discrete Structures 2 (MA1500-KP08, MA1500) 	
Linear Algebra and Discrete Structures 1 (MA1000-KP08, MA1000)	
 Analysis 2 (MA2500-KP09) Analysis 1 (MA2000-KP08, MA2000) 	
onsible for this module:	
Prof. Dr. rer. nat. Andreas Rößler	
her:	
Institute for Mathematics	
 Prof. Dr. rer. nat. Andreas Rößler MitarbeiterInnen des Instituts 	
uage:	
 English, except in case of only German-speaking participants 	
s:	



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4614-L1: Numerical methods for partial differential equations, written exam (90 min) or oral exam (30 min), 100 % of module grade

Literature will be announced in the lecture.



MA4615-KP05 - Numerical methods for stochastic processes (NuStPrKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
 Course of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd semester Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semester Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd semester 				
Classes and lectures: • Numerical methods for stochastic pr • Numerical methods for stochastic pr	lasses and lectures:Workload:• Numerical methods for stochastic processes (lecture, 2 SWS)• 85 Hours private studies and exercises• Numerical methods for stochastic processes (exercise, 1 SWS)• 45 Hours in-classroom work• 20 Hours exam preparation			
 Contents of teaching: Basic principles of stochastic processes in continuous time Stochastic differential equations Discrete time approximations for solutions of stochastic differential equations Numerical schemes for strong and weak approximations 				
 Qualification-goals/Competencies: To impart basic principles of stochastic processes and of some numerical schemes To learn methods of proof as well as the application of algorithms Accomplished handling of essential concepts and results as well as of selected advanced topics 				
Grading through: • Written or oral exam as announced by the examiner				
Requires: • Stochastic processes (MA4610-KP05) • Stochastics 2 (MA4020-KP07) • Stochastics 1 (MA2510-KP04, MA2510)				
Responsible for this module: • Prof. Dr. rer. nat. Andreas Rößler Teacher: • Institute for Mathematics • Prof. Dr. rer. nat. Andreas Rößler				
 Literature: P. E. Kloeden, E. Platen: Numerical Solution of Stochastic Differential Equations - Springer-Verlag, Berlin, 1999 P. E. Kloeden, E. Platen, H. Schurz: Numerical Solution of SDE Through Computer Experiments - Springer-Verlag, Berlin, 2003 G. N. Milstein, M. V. Tretyakov: Stochastic Numerics for Mathematical Physics - Springer-Verlag, Berlin, 2004 				
Language: English, except in case of only German-speaking participants 				
Notes:				


Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4615-L1: Numerical methods for stochastic processes, written exam (90 min) or oral exam (30 min), 100 % of module grade



MA	4616-KP05 - Advanced	d Numerics (HoeNum	КР05)
Duration:	Turnus of offer:		Credit points:
1 Semester	irregularly		5
Course of study, specific field and term: Master CLS 2023 (optional subject), Bachelor CLS 2023 (optional subjec) Minor in Teaching Mathematics, Ma Minor in Teaching Mathematics, Ma Bachelor CLS 2016 (optional subjec), Master CLS 2016 (optional subject),	mathematics, 1st, 2nd, or 3 t), mathematics, 5th or 6th s aster of Education 2023 (opt aster of Education 2017 (opt t), mathematics, 5th or 6th s mathematics, 1st, 2nd, or 3	rd semester semester ional subject), mathematic ional subject), mathematic semester rd semester	s, 2nd or 3rd semester s, 2nd or 3rd semester
Classes and lectures:		Workload:	
 Advanced Numerics (lecture, 2 SWS Advanced Numerics (exercise, 1 SW 	;) /S)	 85 Hours private 45 Hours in-class 20 Hours exam p 	studies and exercises froom work preparation
Contents of teaching:			
 Numerics for ordinary differential e One-step methods, local and globa Orders of consistence and converge Stiff differential equations, implicit 	quations l error analysis ence schemes, stability		
 Qualification-goals/Competencies: To impart basic principles of numer To learn methods of proofs as well Accomplished handling of essentia 	rics for differential equations as the application of results I concepts and results as we	s from numerics for differen ill as of selected advanced f	tial equations topics
Grading through: • Written or oral exam as announced	by the examiner		
Requires: • Numerics 2 (MA4040-KP06) • Numerics 1 (MA3110-KP06)			
Responsible for this module:			
Prof. Dr. rer. nat. Andreas Rößler			
Institute for Mathematics			
• Prof. Dr. rer. nat. Andreas Rößler			
Language: • English, except in case of only Gern	nan-speaking participants		
Notes:			
Admission requirements for taking th - None (The competencies of the mod	e module: Jules listed under 'Requires'	are needed for this module	e, but are not a formal prerequisite)
Admission requirements for participa - Successful completion of homework	tion in module examination assignments as specified at	(s): t the beginning of the seme	ester
Module exam(s): - MA4616-L1: Advanced Numerics, wr	itten exam (90 min) or oral o	exam (30 min), 100 % of me	odule grade
Literature will be announced in the le	cture.		



	MA4617-KP05 - Stochastic	differential equations (S	tDiGlKP05)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific fi • Master CLS 2023 (op • Master CLS 2016 (op	ield and term: itional subject), mathematics, 1st, 2nd, itional subject), mathematics, 1st, 2nd,	, or 3rd semester , or 3rd semester			
Classes and lectures:		Workload:			
Stochastic differentiStochastic differenti	al equations (lecture, 2 SWS) al equations (exercise, 1 SWS)	 85 Hours private studies and exercises 45 Hours in-classroom work 20 Hours exam preparation 			
Contents of teaching:					
 Stochastic processes Stochastic integratic Ito formula Stochastic differenti 	s, Brownian motion on al equations				
Qualification-goals/Comp	etencies:				
 To impart basic prin To learn methods of Accomplished hand 	ciples of stochastic processes and stoc proof as well as the application of res ling of essential concepts and results a	chastic differential equations sults from stochastic analysis as well as of selected advanced	topics		
Grading through: • Written or oral exam	as announced by the examiner				
Requires:					
 Stochastic processes Stochastics 2 (MA40 Stochastics 1 (MA25 	s (MA4610-KP05) 20-KP07) 10-KP04, MA2510)				
Responsible for this modu	ıle:				
• Prof. Dr. rer. nat. And	dreas Rößler				
Teacher:					
 Institute for Mathem 	natics				
• Prof. Dr. rer. nat. And	dreas Rößler				
Literature: • Bernt Oksendal: Stor • Ioannis Karatzas, Ste • Philip Protter: Stoch • K. L. Chung, R. J. Wil	chastic Differential Equations: An Intro even E. Shreve: Brownian Motion and S astic Integration and Differential Equa liams: Introduction to Stochastic Integ	duction with Applications - Spr Stochastic Calculus - Springer Ve tions - Springer Verlag, 2005 ration - Birkhäuser, 2nd edition,	inger Verlag, 6th edition, 2013 erlag, 2nd edition, 1991 , 1990		
Language: • English, except in ca	se of only German-speaking participa	nts			
Notes:					



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4617-L1: Stochastic differential equations, written exam (90 min) or oral exam (30 min), 100 % of module grade



MA4618-KP05 - II	ntroduction to stochastic p	oartial differential ec	quations (EinSPDKP05)	
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific field and te • Master CLS 2023 (optional subj • Master CLS 2016 (optional subj	rm: ect), mathematics, 1st, 2nd, or 3rc ect), mathematics, 1st, 2nd, or 3rc	l semester l semester		
 Classes and lectures: Introduction to stochastic parti 2 SWS) Introduction to stochastic parti (exercise, 1 SWS) 	al differential equations (lecture, al differential equations	 Workload: 85 Hours private studies and exercises 45 Hours in-classroom work 20 Hours exam preparation 		
Contents of teaching: • Gaussian measures on Hilbert s • Infinite-dimensional Brownian • Martingales on Banach spaces • Stochastic integration in Hilber • Existence of solutions for SPDE	paces motion t spaces s			
Qualification-goals/Competencies: • To impart basic principles of th • To learn methods of proofs as • Accomplished handling of esse	e theory for stochastic partial diff well as the application of results f ntial concepts and results as well	erential equations rom the theory for stocha as of selected advanced t	stic partial differential equations copics	
Grading through: • Written or oral exam as annour	iced by the examiner			
Requires: • Stochastic processes (MA4610- • Stochastics 2 (MA4020-KP07) • Stochastics 1 (MA2510-KP04, M	KP05) A2510)			
Responsible for this module: • Prof. Dr. rer. nat. Andreas Rößle Teacher: • Institute for Mathematics • Prof. Dr. rer. nat. Andreas Rößle • MitarbeiterInnen des Instituts	r r			
Language: • English, except in case of only (German-speaking participants			
Notes: Admission requirements for takin - None (The competencies of the Admission requirements for parti - Successful completion of homew Module exam(s): - MA4618-L1: Introduction to stoo grade	g the module: modules listed under 'Requires' a cipation in module examination(s work assignments as specified at t chastic partial differential equatio	re needed for this module ;): the beginning of the seme ns, written exam (90 min)	e, but are not a formal prerequisite) ester or oral exam (30 min), 100 % of module	

Literature will be announced in the lecture.





	MA4630-KP05 - Four	er Analysis (FouAnaKP05)		
Duration:	Turnus of offer:	Credit points:		
1 Semester	irregularly	5		
Course of study, specific field an Master CLS 2023 (optional Bachelor CLS 2023 (optional Bachelor CLS 2016 (optional Master CLS 2016 (optional	i d term: subject), mathematics, 1st, 2nd, or al subject), mathematics, 5th or 6t al suject), mathematics, 5th or 6th subject), mathematics, 1st, 2nd, or	3rd semester n semester semester 3rd semester		
Classes and lectures:		Workload:		
 Fourier Analysis (lecture, 2 Fourier Analysis (exercise, 	SWS) 1 SWS)	 65 Hours private studies 45 Hours in-classroom work 30 Hours work on project 10 Hours exam preparation 		
Contents of teaching: • Theory of the Fourier trans • Fourier transform in the Hi • Summability methods • Applying Fourier transform • Laplace and Mellin transfo • Numerical aspects and relation	form Ibert space ns in solving differential equations rms ation to discrete Fourier transform	3		
 Qualification-goals/Competenci Practicing mathematical tereasoning) Application of basic conce Knowledge of integral tran A comprehensive understation Application of computer all 	es: chniques (developing mathemation pts from functional analysis and th isforms anding for the Fourier transform Igebra for visualization and better	al intuition and its formal justification, training the ability to abstract, the theory of function spaces understanding of the methods used		
Grading through: • exercises, project, oral or w	<i>r</i> ritten exam			
Responsible for this module: • Prof. Dr. rer. nat. Jürgen Pro Teacher: • Institute for Mathematics • Prof. Dr. rer. nat. Jürgen Pro	estin			
Literature:				
 Chandrasekharan, K.: Class Pinsky, M. A.: Introduction 	ical Fourier Transforms - Springer to Fourier Analysis and Wavelets -	1989 Brooks/Cole 2002		
Language: • English, except in case of o	nly German-speaking participants			
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4630-L1: Fourier Analysis, oral exam, 30 min, 100 % of module grade



MA4650-KP05 - Matrix algebra (MatAlgKP05)				
Duration:	Turnus of offer:	Credit points:	Max. group size:	
1 Semester	every second year	5	20	
Course of study, specific • Master CLS 2023 (• Bachelor CLS 2023 • Master CLS 2016 (• Bachelor CLS 2016	field and term: optional subject), mathematics, 1st, 2 (optional subject), mathematics, 5th optional subject), mathematics, 1st, 2 (optional subject), mathematics, 5th	nd, or 3rd semester or 6th semester nd, or 3rd semester or 6th semester		
Classes and lectures:Workload:• Matrix algebra (lecture, 2 SWS)• 60 Hours private studies and exercises• Matrix algebra (exercise, 1 SWS)• 45 Hours in-classroom work• 30 Hours work on project• 15 Hours exam preparation				
Contents of teaching: Properties of matr Special matrices Quadratic forms Decompositions Generalized invers Differentiation Probability calcula Derivation and cal Design matrices Linear hypotheses Examples: multiple	ices ses ition culation of estimators e linear regression, weighted least-squ	uares estimation, shrinkage estimati	on	
Qualification-goals/Com • Students know nu • They understand p • They command m • They apply linear • They can deal with	apetencies: merous rules of matrix algebra. proofs, especially concerning generali atrix calculus. algebra to linear models. n practical problems from statistics in	zed linear models and multivariate an abstract manner.	procedures.	
Grading through: • written exam				
Requires: • Biostatistics 2 (MA • Biostatistics 1 (MA • Analysis 2 (MA250) Responsible for this moo • PD Dr. rer. pol. Rei Teacher: • Institute of Medica	2600-KP07) 1600-KP04, MA1600, MA1600-MML) 0-KP09) dule: nhard Vonthein al Biometry and Statistics			
 PD Dr. rer. pol. Rei MitarbeiterInnen	nhard Vonthein des Instituts			
Literature:				
 Schmidt, K., Trenk 9783540330073 Toutenburg, H.: Li 	ler, G.: Einführung in die Moderne Ma neare Modelle - Physica: Heidelberg 1	trix-Algebra: Mit Anwendungen in d 992 und 2006, ISBN 978-379081519	ler Statistik - Springer: Heidelberg 2006, ISBN 1	
• Fahrmeir, L., Kneik	o, T., Lang, S.: Regression: Modelle, Me	thoden und Anwendungen - Spring	er: Heidelberg 2007, ISBN 9783642343339	





MA4665-KP05 - Statistical Learning (StaLerKP05)					
Duration:	Turnus of offer:	Credit points:	Max. group size:		
1 Semester	every second year	5	20		
Course of study, spec Master Medical Master CLS 202 Bachelor CLS 20 Master CLS 201 Bachelor CLS 201 Bachelor CLS 20	ific field and term: Informatics 2019 (optional subject), Medi 3 (optional subject), mathematics, 1st, 2n 23 (optional subject), mathematics, 5th c 6 (optional subject), mathematics, 1st, 2n 16 (optional subject), mathematics, 5th c	ical Data Science / Artificial Intellige Id, or 3rd semester or 6th semester Id, or 3rd semester or 6th semester	ence, 1st or 2nd semester		
Classes and lectures:		Workload:			
 Statistical Learning (lecture, 2 SWS) Statistical Learning (exercise, 1 SWS) Statistical Learning (exercise, 1 SWS) 45 Hours in-classroom work 30 Hours work on project 15 Hours exam preparation 					
Contents of teaching					
 Application sce Study design at Overview of dif Development of Evaluation of p Comparison of Variable selectitie Extension to tir 	 Application scenarios and research questions for prediction models (focus: risk prediction) Study design and data preprocessing Overview of different machine learning methods (concepts, advantages and disadvantages) Development of prediction models Evaluation of prediction performance Comparison of prediction models Variable selection Extension to time-to-event outcomes with censoring 				
Qualification-goals/C • Students can de • They can explai • They can descri • They can descri • They can devel	ompetencies: efine research questions for applications n the individual steps in the developmen be frequently occurring errors and proble be central ideas of different machine lear op and evaluate models in the programm	of pediction models nt and evaluation of prediction mod ems as well als possible solutions rning methods and select suitable n ning language R	lels nethods for applications		
Grading through:					
 project work Viva Voce or test	it				
Requires: • Biostatistics 1 (I	/A1600-KP04, MA1600, MA1600-MML)				
Responsible for this r • Prof. Dr. rer. nat Teacher: • Institute of Mec • Prof. Dr. rer. nat • MitarbeiterInn	n odule: . Silke Szymczak lical Biometry and Statistics . Silke Szymczak en des Instituts				
Literature: • Thomas Gerds	und Michael Kattan: Medical Risk Predictio	on Models With Ties to Machine L	earning - CRC Press: Bota Raton, FL (2022)		
Language: • German or Eng	ish				
Notes:					



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - None

Module exam(s):

- MA4665-L1: Statistical Learning, oral exam (20 min) or written exam (60 min), 50 % of module grade

- MA4665-L2: Research project incl. presentation and code documentation, 50 % of module grade



MA4666-KP05 - Interpretable Statistical Learning (IStLern)				
Duration:	Turnus of offer:	Credit points:	Max. group size:	
1 Semester	every second year	5	20	
Course of study, specific field a Bachelor CLS 2023 (optio Bachelor CLS 2016 (optio Master CLS 2023 (optiona Master CLS 2016 (optiona Master Medical Informati	and term: nal subject), mathematics, 5th or 6th nal subject), mathematics, 5th or 6th al subject), mathematics, Arbitrary se al subject), mathematics, Arbitrary se cs 2019 (optional subject), Medical I	h semester h semester emester emester Data Science / Artificial Intellig	ence, 1st or 2nd semester	
Classes and lectures:		Workload:		
 Interpretable Statistical Learning (lecture, 2 SWS) Interpretable Statistical Learning (exercise, 1 SWS) 60 Hours private studies and exercises 45 Hours in-classroom work 30 Hours programming 15 Hours exam preparation 				
Contents of teaching:				
 Definition: Interpretable Interpretable models Global model-agnostic m Partial Dependence Plots Accumulated Local Effect Variable importance mea Local model-agnostic me Individual Conditional Ex Local Surrogates (LIME) Counterfactional Explana Shapley Werte, SHAP 	statistical learning ethods (PDP) (s (ALE) sures ethods pectation (ICE) tions			
Qualification-goals/Competen • Students can explain the • They know the difference • The can explain the diffe • They can choose suitable • They can implement and	cies: central ideas of interpretable statist between model-based and model- rences between different methods f methods for a given applicational s apply these methods in R.	tical learning. agnostic methods. for model interpretation. setting.		
Grading through:				
Viva Voce or test				
Requires: • Biostatistics 1 (MA1600-K	P04, MA1600, MA1600-MML)			
Teacher: • Institute of Medical Biom	etry and Statistics			
• Dr. rer. hum. biol. Björn-l	Hergen Laabs			
Literature: Molnar, C.: Interpretable Hastie, T., Tibshirani, R., F 2009 (2nd ed.) Wu, X., Kumar, V.: The To	Machine Learning: A Guide for Maki riedmann, J.: The Elements of Statis p Ten Algorithms in Data Mining - C	ng Black Box Models Explainal tical Learning: Data Mining, Inf RC Press, Boca Raton 2009	ble - Springer, New York 2022 (2nd ed.) ference and Prediction - Springer, New York	
Language: • English, except in case of	only German-speaking participants			



Notes:

Admission requirements for taking the module

- None (the competences of the modules mentioned under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- None

Module Exam(s):

- MA4666-L1: Interpretable Statistical Learning, oral exam (20 min) or written exam (60 min), 100% of the module grade



MA4670-KP05 - Combinatorics (KombiKP05)					
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific field and term: Master CLS 2023 (optional subject), Bachelor CLS 2023 (optional subject) Minor in Teaching Mathematics, Mas Minor in Teaching Mathematics, Mas Master CLS 2016 (optional subject), Bachelor CLS 2016 (optional subject)	mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th ster of Education 2023 (op ster of Education 2017 (op mathematics, 1st, 2nd, or 3), mathematics, 5th or 6th	Brd semester semester tional subject), mathematics tional subject), mathematics Brd semester semester	s, 2nd or 3rd semester s, 2nd or 3rd semester		
Classes and lectures:		Workload:			
 combinatorics (lecture, 2 SWS) combinatorics (exercise, 1 SWS) 		 85 Hours private 45 Hours in-class 20 Hours exam p 	studies room work reparation		
Contents of teaching:					
 Permutations, combinations, variations Partitions Generating functions Recurrence equations Sums and differences Inclusion - exclusion 	 Permutations, combinations, variations Partitions Generating functions Recurrence equations Sums and differences Inclusion - exclusion 				
Qualification-goals/Competencies:					
 Learning the basics of combinatoric Knowledge of different proof techni Teaching fundamental results and d Ability to learn independently by str 	s ques and combinatorial ap leepening some selected a udying relevant literature	oproaches spects of combinatorics			
Grading through:					
Oral examination					
Requires: • Linear Algebra and Discrete Structur • Linear Algebra and Discrete Structur • Analysis 1 (MA2000-KP08, MA2000)	res 2 (MA1500-KP08, MA15 res 1 (MA1000-KP08, MA10	00) 00)			
Responsible for this module:					
 PD Dr. rer. nat. Christian Bey Teacher: Institute for Mathematics PD Dr. rer. nat. Christian Bey 					
Literature: • Peter Tittmann: Einführung in die Ko • Richard A. Brualdi: Introductory Con	ombinatorik - Spektrum Ak 1binatorics - Pearson Prent	ademischer Verlag 2000 ice Hall 2004			
Language: • offered only in German					
Notes:					



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4670-L1: Combinatorics, oral exam, 30 min, 100 % of module grade



	MA4675-KP05 -	Algebra (Algebrk	(P05)
Duration:	Turnus of offer:		Credit points:
1 Semester	irregularly		5
Course of study, specific fie Master CLS 2023 (opt Bachelor CLS 2023 (opt Bachelor CLS 2016 (opt Master CLS 2016 (opt	eld and term: ional subject), mathematics, 1st, 2nd, c ptional subject), mathematics, 5th or 6 ptional subject), mathematics, 5th or 6 ional subject), mathematics, 1st, 2nd, c	or 3rd semester th semester th semester or 3rd semester	
Classes and lectures:		Workload:	
 Algebra (lecture, 2 SWS) Algebra (exercise, 1 SWS) Algebra (exercise, 1 SWS) 45 Hours in-classroom work 20 Hours exam preparation 			s private studies s in-classroom work s exam preparation
Contents of teaching:			
 Groups (semigroups, Rings (units, ring hon Field extensions (field splitting field of a pol Geometric construction 	subgroups, homomorphisms, invariant nomorphisms, polynomial rings, quotie d characteristic, prime fields, field degre lynomial) ons (compass-and-straightedge constr	t subgroups, isomorph ent fields, ideals) ee, algebraic and trans uction, field of constru	nism theorems, products of groups) scendent elements, algebraical field extensions, uctible points, constructing regular polygons)
 Learning the basics o Knowledge of differe Teaching fundamenta Ability to learn indep 	if algebra nt proof techniques and algebraic app al results and deepening some selected endently by studying relevant literatur	roaches d aspects of algebra e	
Grading through:			
Oral examination			
Requires: • Linear Algebra and D • Linear Algebra and D	iscrete Structures 2 (MA1500-KP08, MA iscrete Structures 1 (MA1000-KP08, MA	\1500) \1000)	
Responsible for this modul	e:		
• PD Dr. rer. nat. Christi	an Bey		
Teacher:			
 Institute for Mathema 	atics		
• PD Dr. rer. nat. Christi	an Bey		
Literature: • G. Fischer: Lehrbuch (• M. Artin: Algebra - Bir • B. L. van der Waerder	der Algebra - Vieweg, 2011 (2. Auflage) rkhäuser, 1998 n: Algebra I - Springer, 1993 (9. Auflage)	
Language:			
offered only in Germa	an		
Notes:			



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4675-L1: Algebra, oral exam, 30 min, 100 % of module grade



MA4735-KP05 - Geometry (GeoKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific field and Master CLS 2023 (optional sub- Bachelor CLS 2023 (optional Minor in Teaching Mathema Minor in Teaching Mathema Master CLS 2016 (optional sub- Bachelor CLS 2016 (optional	term: ubject), mathematics, 1st, 2nd, or subject), mathematics, 5th or 6th tics, Master of Education 2023 (o tics, Master of Education 2017 (o ubject), mathematics, 1st, 2nd, or subject), mathematics, 5th or 6th	r 3rd semester h semester ptional subject), mather ptional subject), mather r 3rd semester h semester	natics, 2nd or 3rd semester natics, 2nd or 3rd semester	
Classes and lectures:		Workload:		
 Geometry (lecture, 2 SWS) Geometry (exercise, 1 SWS) 		85 Hours pi45 Hours in20 Hours ex	ivate studies and exercises -classroom work am preparation	
Contents of teaching: • Euclidean Geometry • Non-Euclidean Geometries • Introduction to Differential (Geometry			
Qualification-goals/Competencies • Mastery of basic geometric i • Gaining an overview over di	s: results fferent geometries and their spec	cifics		
Grading through: • Written or oral exam as anno	ounced by the examiner			
Requires: • Analysis 2 (MA2500-KP09) • Analysis 1 (MA2000-KP08, M • Linear Algebra and Discrete • Linear Algebra and Discrete	A2000) Structures 2 (MA1500-KP08, MA1 Structures 1 (MA1000-KP08, MA1	1500) 1000)		
Responsible for this module: • PD Dr. rer. nat. Christian Bey Teacher: • Institute for Mathematics	,			
PD Dr. rer. nat. Christian Bey	/			
Literature: Bär: Elementare Differentiale Berger: Geometry I, II Coxeter: Introduction to Geo Knörrer: Geometrie Kumaresan, Santhanam: An Nikulin, Shafarevich: Geome McCleary: Geometry from a Rees: Notes on Geometry Sossinsky: Geometries Stahl: A Gateway to Modern	geometrie ometry Expedition to Geometry tries and Groups Differentiable Viewpoint Geometry, The Poincare Half-Pla	ine		
Language: • offered only in German				



Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4735-L1: Geometry, oral exam, 30 min, 100 % of module grade



	MA4750-KP05 -	· Topology (Topok	(P05)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific field • Master CLS 2023 (optio • Bachelor CLS 2023 (optio • Master CLS 2016 (optio • Bachelor CLS 2016 (option)	l and term: nal subject), mathematics, 1st, 2nd, ional subject), mathematics, 5th or 6 nal subject), mathematics, 1st, 2nd, o ional subject), mathematics, 5th or 6	or 3rd semester 5th semester or 3rd semester 5th semester			
Classes and lectures:		Workload:			
 Topology (lecture, 2 SV Topology (exercise, 1 S 	/S) WS)	 85 Hours 45 Hours 20 Hours 	s private studies and exercises s in-classroom work s exam preparation		
Contents of teaching: • Topological spaces and • Fundamental group an • Introduction to Homolo • Applications	continuous maps d covering spaces ogy				
Qualification-goals/Compete • Mastery of basic results • Understanding of appli	ncies: and proof techniques of topology cations of topological methods				
Grading through: • Written or oral exam as	announced by the examiner				
Requires: • Analysis 2 (MA2500-KP • Analysis 1 (MA2000-KP • Linear Algebra and Disc • Linear Algebra and Disc	09) 08, MA2000) crete Structures 2 (MA1500-KP08, M/ crete Structures 1 (MA1000-KP08, M/	A1500) A1000)			
Responsible for this module:					
 PD Dr. rer. nat. Christian Teacher: Institute for Mathemati PD Dr. rer. nat. Christian 	n Bey cs n Bey				
Language:					
offered only in German					
Notes:					
Admission requirements - None (The competencie	for taking the module: s of the modules listed under 'Requi	res' are needed for this	s module, but are not a formal prerequisite)		
Admission requirements - Successful completion c	Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester				
Module exam(s): - MA4750-L1: Topology, c	ral exam, 30 min, 100 % of module	grade			





N	A4760-KP05 - Integral The	eorems in Analysis (IntAnaKP05)	
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific field and • Master CLS 2023 (optional s • Bachelor CLS 2023 (optional • Master CLS 2016 (optional s • Bachelor CLS 2016 (optional	I term: ubject), mathematics, 1st, 2nd, or subject), mathematics, 5th or 6t ubject), mathematics, 1st, 2nd, or subject), mathematics, 5th or 6t	r 3rd semester h semester r 3rd semester h semester		
Classes and lectures:		Workload:		
 Integral Theorems in Analysis (lecture, 2 SWS) Integral Theorems in Analysis (exercise, 1 SWS) Integral Theorems in Analysis (exercise, 1 SWS) 20 Hours exam preparation 				
Contents of teaching:				
 Integration on submanifold Gauss' Integral Theorem an One-forms, line integrals, G Higher-order differential for Stokes' Integral Theorem ar Cauchy's Integral Theorem 4 	s d applications reen's Integral Theorem ms, Integration id applications and applications			
Qualification-goals/Competencie	s:			
Mastery of basic results andUnderstanding of application	proof techniques of vector analy ons of vector analysis	vsis		
Grading through: • Written or oral exam as ann	ounced by the examiner			
Requires: • Analysis 2 (MA2500-KP09) • Analysis 1 (MA2000-KP08, M • Linear Algebra and Discrete • Linear Algebra and Discrete	IA2000) Structures 2 (MA1500-KP08, MA1 Structures 1 (MA1000-KP08, MA1	1500) 1000)		
Responsible for this module:				
• PD Dr. rer. nat. Christian Be	у			
Institute for Mathematics				
PD Dr. rer. nat. Christian Be	y			
	, 			
offered only in German				
Notos				
Admission requirements for ta - None (The competencies of t	iking the module: the modules listed under 'Require	es' are needed for this mo	dule, but are not a formal prerequisit	te)
Admission requirements for p - Successful completion of ho	articipation in module examination mework assignments as specified	on(s): I at the beginning of the s	emester	
Module exam(s): - MA4760-L1: Integral Theorer	ns in Analysis, oral exam, 30 min,	100 % of module grade		



MA4801-KP05 - Elliptic Functions and Function Theory (EFFThKP05)				
Duration:	ation: Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific field Master CLS 2023 (option Bachelor CLS 2023 (option Master CLS 2016 (option Bachelor CLS 2016 (option	and term: al subject), mathematics, 1st, 2nd, or onal subject), mathematics, 5th or 6th al subject), mathematics, 1st, 2nd, or onal subject), mathematics, 5th or 6th	3rd semester n semester 3rd semester n semester		
Classes and lectures: Workload:				
 Elliptic Functions and Function Theory (lecture, 2 SWS) Elliptic Functions and Function Theory (exercise, 1 SWS) 		 60 Hours priv 45 Hours in-o 30 Hours wo 15 Hours exa 	 60 Hours private studies 45 Hours in-classroom work 30 Hours work on project 15 Hours exam preparation 	
Contents of teaching:				
 Complex analysis Periodic functions and la Simple and double perio Liouville Theorem, residu Weierstrass P-, Zeta- and The field of elliptic function Elliptic integrals Moduls of elliptic function 	ttices ds ue theorem Sigma-function ions			
 Getting familiar with and Extension of the backgro Getting familiar with Mai Developing competencie Gaining experience in pr 	d developing skills in concepts and te bund for different applications, e.a. si thematica in the considered topic es for self-sufficient problem solving oject work in the field	echiques in complex anal gnal processing, to devel	ysis op problem solving strategies	
Grading through:				
 exercises, project, oral or 	written exam			
Responsible for this module: Prof. Dr. Reinhard Schust Teacher: Institute for Mathematics Prof. Dr. Reinhard Schust 	er s			
l :*				
 Literature: Andrews, G. E., Askey, R. Armitage, J. V. and Eberle Hurwitz, A.: Vorlesungen Koecher, M und Krieg, A. Stramp, W., Ganzha, V. u Werner, A.: Elliptische Ku Whittaker, E. T. and Wats 	and Roy, R.: Special Functions - Caml ein, W. F.: Elliptic Functions - Cambrid über Allgemeine Funktionentheorie : Elliptische Funktionen und Modulfo nd Vorozhtsov, E.: Höhere Mathemat rven in der Kryptographie - Springer on, G. N.: A course of modern analys	bridge University Press 1 dge University Press 2006 and Elliptische Funktion ormen - Springer 2007 ik mit Mathematica - Vie 2002 is - Cambridge University	999 5 en - Springer 2000 weg 1997 7 Press 1902 (Reprinted 1999)	
Language:				
offered only in German				
Notes:				



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4801-L1: Elliptic Functions and Function Theory, written exam (90 min) or oral exam (30 min), 100 % of module grade



MA4802-KP05 - Theory of Relativity (RelaThKP05)			
Duration:	Turnus of offer:		Credit points:
1 Semester	irregularly		5
 Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject) Master CLS 2016 (optional subject), r Bachelor CLS 2016 (optional subject) 	nathematics, 1st, 2nd, or 3 , mathematics, 5th or 6th s nathematics, 1st, 2nd, or 3 , mathematics, 5th or 6th s	rd semester semester rd semester semester	
Classes and lectures: Workload:			
 Theory of Relativity (lecture, 2 SWS) Theory of Relativity (exercise, 1 SWS) 		 60 Hours private studies 45 Hours in-classroom work 30 Hours work on project 15 Hours exam preparation 	
Contents of teaching:			
 Electrodynamics, Lorentz and Minko Hyperbolic geometry und trigonome Time-like, space-like and light cone Relativistic kinematics Simultaneity and velocity addition Length contraction and time dilatati Twin paradox Mass and energy relativistic Part B, General Theory of Relativity: Four-dimensional space time as a ma Christoffel symbols, curvature tensor Coupling of matter and fields with g Equivalence principle for mass Qualification-goals/Competencies: Getting familiar with concepts and g Extension of the mathematic and ph 	wsky geometry etry on anifold c covariant derivative eometry by the Einstein ed aining competencies on s ysical background for diffe	quation pecial and general relativity erent applications to develo	, p problem solving strategies
 Getting familiar with Mathematica if Developing competencies for self-su Gaining experience in project work i 	fficient problem solving o n the field	f tasks on the theory of rela	tivity
Grading through: • exercises, project, oral or written exa	m		
Responsible for this module:			
Prof. Dr. Reinhard Schuster			
Institute for Mathematics			
Prof. Dr. Reinhard Schuster			
literature:			
 Baumann, G.: Mathematica for Theor Quantum Mechanics, General Relativ Goenner, H.: Spezielle Relativitätsthe Gray A., Abbena, E. and Salomon, S.: Chapman and Hall 2006 	etical Physics. Part 1: Class vity, and Fractals - Springer orie und die klassische Fel Modern Differential Geom	ical Mechanics and Nonline 2005 dtheorie - Spectrum 2003 etry of Surfaces with Mathe	ear Dynamics. Part 2: Electrodynamics, ematica. Studies in Advanced Mathematics -

• Haken, H. und Wolf, H. Ch.: Atom- und Quantenphysik. Einführung in die experimentellen und theoretischen Grundlagen - Springer



2003

- Hawking, S. W. and Ellis, G. F. R.: The large scale structure of space-time Cambridge Monographs on Mathematical Physics 1973, 2006
- Helgason, S.: Differential Geometry, Lie Groups and Symmetric Spaces. Graduate Studies in Mathematics American Mathematical Society 1978, 2001
- Kobayashi, S. and Nomizu, K.: Foundations of Differential Geometry I, II Interscience Publishers 1963
- Schröder, U. E.: Gravitation. Einführung in die Allgemeine Relativitätstheorie Harri Deutsch 2007
- Weber, H. J. und Arfen, G. B.: Essential Mathematical Methods for Physics Elsevier 2004
- Weil, H.: Raum Zeit Materie. Vorlesungen über allgemeine Relativitätstheorie Springer 1923
- Wald, R. M.: General Relativity The University of Chicago Press 1984

Language:

• offered only in German

Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4801-L1: Theory of Relativity, written exam (90 min) or oral exam (30 min), 100 % of module grade



MA4803-KP05 - Number Theory (ZahlThKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	irregularly		5	
Course of study, specific field and term Master CLS 2023 (optional subject Bachelor CLS 2023 (optional subject Minor in Teaching Mathematics, N Minor in Teaching Mathematics, N Master CLS 2016 (optional subject Bachelor CLS 2016 (optional subject	:), mathematics, 1st, 2nd, or 3r ct), mathematics, 5th or 6th s laster of Education 2023 (opti laster of Education 2017 (opti), mathematics, 1st, 2nd, or 3r ct), mathematics, 5th or 6th s	rd semester emester ional subject), mathematic ional subject), mathematic rd semester emester	s, 2nd or 3rd semester s, 2nd or 3rd semester	
 Classes and lectures: Number Theory (lecture, 2 SWS) Number Theory (exercise, 1 SWS) 		 Workload: 60 Hours private studies 45 Hours in-classroom work 30 Hours work on project 15 Hours exam preparation 		
 Contents of teaching: Divisibility of integers, Farey sequencees, Fibonacci Numbers Approximation of real numbers by rational numbers Modulo operations: Complete and reduced residue system, Theorems of Euler and Fermat Representation of natural numbers sums of 2, 3 or 4 squares Quadratic residues Quadratic reciprocity Prime number criteria and pseudo prime numbers Pythagorean triples Rational points on curves of degree 2 Number theorem, prime numbers in arithmetic progression Riemann zeta function and its functional equation Known problems and conjectures, i.e. Goldbach conjecture Excepteric prime numbers 				
Qualification-goals/Competencies: • Theoretical knowledge of the mentioned topics • Historical and most recent issues • Solve questions in this filed • Recognize interdisciplinary aspects				
Grading through:				
Responsible for this module: Prof. Dr. Reinhard Schuster Teacher: Institute for Mathematics Prof. Dr. Reinhard Schuster Literature: Chandrasekbaran: Einführung in c	lie analytische Zahlentheorie :	- Springer Lecture Notes 2	008	
 Grandrasekharan: Einführung in die anarytische Zahlentheorie - Springer Lecture Notes 2008 Bundschuh: Einführung in die Zahlentheorie - Springer 1992 Menzer: Zahlentheorie: Fünf ausgewählte Themenstellungen der Zahlentheorie - Oldenbourg Wissenschaftsverlag 2010 Remmert u. Ullrich: Elementare Zahlentheorie - Birkhäuser 1995 				

- Rempe: Primzahltests für Einsteiger: Zahlentheorie Algorithmik Kryptographie Vieweg+Teubner 2009
- Scharlau, Opolka: Von Fermat bis Minkowski: Eine Vorlesung über Zahlentheorie und ihre Entwicklung Springer 2009



- Scheid: Zahlentheorie Spektrum 2003
- Schmidt: Einführung in die algebraische Zahlentheorie Springer 2009
- Weil: Zahlentheorie Spektrum 1992
- Winogradow: Elemente der Zahlentheorie Prestel-Verlag 1956

Language:

• offered only in German

Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4803-L1: Number Theory, written exam (90 min) or oral exam (30 min), 100 % of module grade



Credit points: 5				
5				
semester nester nal subject), mathematics, 2nd or 3rd semester nal subject), mathematics, 2nd or 3rd semester semester nester				
Workload:				
 60 Hours private studies 45 Hours in-classroom work 30 Hours work on project 15 Hours exam preparation 				
 Algebraic operations with complex numbers Exponential function, angle functions, hyperbolic angle functions, derived functions Gamma and beta functions Hypergeometric function Bessel function, Legendre function, Laguerre function, Tscheybyscheff function, Hermite function, Jacobi hypergeometric function Elliptic functions, theta functions Number theoretic functions Riemann zeta function Used mathematical theories and concepts: Complex function theory Infinite products Differential equations (ordinary, partial) Functional equations Integral representation Taylor series expansions for eigenvalues and eigenfunctions (using space and time, defined on geometric objects) Producing functions (a Taylor series in two variables is considered as a series in one variable and the coefficients are special functions i the other variable) Addition theorems Fourier transformations Transformation groups, matrix groups 				
Qualification-goals/Competencies: • Theoretical knowlege of the mentioned topics • Historical and latest questions • Solve questions in this field • Recognize interdisciplinary aspects				
Grading through: • exercises, project, oral or written exam				
Inviriant - s s no				



- Andrews G.E., Askey R., Roy R.: Special Functions. Encyclopedia of Mathematics and its Application 71 Cambridge University Press 2006
- Courant, R., Hilbert, D.: Methoden der mathematischen Physik Springer 1993
- Erdélyi, A., Magnus, W., Oberhettinger, F., Tricomi, F.: Higher Transcendental Functions McGraw-Hill, New York, 1953
- Fichtenholz, G.M.: Differential- und Integralrechnung, Band 1-3 H. Deutsch 1997
- Hurwitz, A., Courant, R.: Vorlesungen über Allgemeine Funktionentheorie und Elliptische Funktionen Springer 2000
- Stegun, I. A., Abramowitz, M.: Handbook of Mathematical Functions Dover Press
- Strampp, W., Ganzha, V., Vorozhtsov, E.: Höhere Mathematik mit Mathematica, Bd.4, Funktionentheorie, Fouriertransformationen und Laplacetransformationen: Funktionentheorie, Fourier- und Laplacetransformation Vieweg 1997
- Wawrzynczyk, A.: Group Representations and Special Functions Reidel Publishing Company 1983
- Whittaker, E. T., Watson, G. N.: A Cource of Modern Analysis Cambridge University Press 1902 ... 1999

Language:

• offered only in German

Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4804-L1: Special Functions, written exam (90 min) or oral exam (30 min), 100 % of module grade



MA4940-KP05 - Test and estimation theory (TSchThKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each summer semester		5	
Course of study, specific field and term: • Master CLS 2023 (compulsory), math • Master CLS 2016 (compulsory), math	ematics, 2nd semester ematics, 2nd semester			
Classes and lectures:		Workload		
 Test and estimation theory (lecture, 2 SWS) Test and estimation theory (exercise, 1 SWS) 		 60 Hours private 45 Hours in-class 30 Hours work of 15 Hours exam p 	studies room work n project reparation	
Contents of teaching:				
 Parametric theory and nonparametric Properties of estimators: consistency Construction of estimators: score fur Lehmann-Schefé, multi-parametric e Properties of confidence intervals: ex Construction of Wald, score, and ML Properties of statistical tests: power for relative efficiency Construction of likelihood ratio, Wald 	ic hints about point and int y unbiasedness, sufficiency, nction, maximum likelihood exponential family kact, coverage probability, p confidence intervalls; delta function, unbiasedness, bes d, score, MLR, and conditior	erval estimation, and statis efficiency , bias correction, theorems pivot statistics method st tests, Lemma of Neyman nal tests	stical tests s of Rao-Crámer, Rao-Blackwell, and n and Pearson, consistency and asymptotic	
 Students know the definitions of central theoretical concepts in the theory of estimation and testing. They have understood properties and construction principles. They apply construction principles to problems with one or more parameters. They prove properties of estimators and tests. They assess tests and estimators by their properties. They construe statistical tests and confidence intervals for problems with distributions they did not know before. 				
written exam				
Requires: • Stochastics 2 (MA4020-KP07) • Stochastics 1 (MA2510-KP04, MA251 • Biostatistics 2 (MA2600-KP07) • Biostatistics 1 (MA1600-KP04, MA160	0) 00, MA1600-MML)			
Responsible for this module: • PD Dr. rer. pol. Reinhard Vonthein Teacher: • Institute of Medical Biometry and Statistics • PD Dr. rer. pol. Reinhard Vonthein				
 Literature: Lehmann, E.L., Romano, Joseph P.: Testing Statistical Hypotheses - ISBN-13 9780387988641 Lehmann, E.L., Casella, George: Theory of Point Estimation - ISBN-13 9780387985022 Held, L.: Methoden der statistischen Inferenz - Spektrum 2008 - ISBN 978-3-8274-1939-2 Rüger, B.: Test- und Schätztheorie: Band I: Grundlagen - Oldenbourg 1999 - ISBN 3 486-23650-4 Rüger, B.: Test- und Schätztheorie: Band II: Statistische Tests - Oldenbourg 2002 - ISBN 3 486-25130-9 				

Language:



• offered only in German

Notes:

Admission requirements for taking the module: - None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.

Module exam(s):

- MA4940-L1: Test and estimation theory, written exam, 90 min, 100 % of module grade



MA4944-KP05 - Multivariate Statistics (MulStaKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	every second year		5	
Course of study, specific field and term: • Master CLS 2023 (optional subject), r • Bachelor CLS 2023 (optional subject) • Bachelor CLS 2016 (optional subject), • Master CLS 2016 (optional subject), r	nathematics, 1st, 2nd, or 3), mathematics, 5th or 6th s), mathematics, 5th or 6th s nathematics, 1st, 2nd, or 3	rd semester semester semester rd semester		
Classes and lectures:Workload:• Multivariate Statistics (lecture, 2 SWS)• 55 Hours private studies• Multivariate Statistics (exercise, 1 SWS)• 45 Hours in-classroom work• 30 Hours work on project• 20 Hours exam preparation			studies room work n project reparation	
 Contents of teaching: Multivariate probability distributions Multiple and multivariate regression Discriminant analysis and logistic regression Cluster analysis with various distance and similarity measures Principal component and factor analysis Correspondence analysis and multidimensional scaling Structural equation models 				
 Qualification-goals/Competencies: Students command a broad repertoire of multivariate statistical methods. They are able to explain the ideas behind several representative methods. They apply these methods by hand and with R packages. They analyse problems and choose suitable methods. They are able to decide for a better option, e.g. standardization, variance structures, distance measures, factor numbers or rotations. They develop multivariate models. 				
Grading through: written exam 				
Requires: • Biostatistics 2 (MA2600-KP07) • Biostatistics 1 (MA1600-KP04, MA1600, MA1600-MML) • Stochastics 2 (MA4020-KP07) • Stochastics 1 (MA2510-KP04, MA2510)				
Responsible for this module: • PD Dr. rer. pol. Reinhard Vonthein Teacher: • Institute of Medical Biometry and Statistics • PD Dr. rer. pol. Reinhard Vonthein • MitarbeiterInnen des Instituts				
 Literature: Fahrmeir, Ludwig; Hamerle, Alfred; Tutz, Gerhard: Multivariate statistische Verfahren - ISBN-13 9783110138061 Johnson, R. J.; Wichern, D. W.: Applied Multivariate Statistical Analysis - 5. Ed. Prentice Hall, 2002 - ISBN-13: 000-0131877151 				
Language: offered only in German 				



Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4944-L1: Multivariate Statistics, written exam, 90 min, 100 % of module grade



MA4947-KP05 - Modern Nonparametric statistics (NpStatKP05)			
Duration: Turnus of offer:		Credit points:	
1 Semester	Semester every second year		5
Course of study, specific fi Master CLS 2023 (op Bachelor CLS 2023 (c Bachelor CLS 2016 (c Master CLS 2016 (op	eld and term: tional subject), mathematics, 1st, 2nd, or optional subject), mathematics, 5th or 6tl optional subject), mathematics, 5th or 6tl tional subject), mathematics, 1st, 2nd, or	3rd semester h semester h semester 3rd semester	
Classes and lectures:Workload:• Nonparametric statistics (lecture, 2 SWS)• 60 Hours private studies• Nonparametric statistics (exercise, 1 SWS)• 45 Hours in-classroom work• 30 Hours work on project• 15 Hours exam preparation			e studies sroom work n project preparation
Contents of teaching: • Application scenario • Permutation tests • Rank-based tests and • Evaluation of metho Qualification-goals/Comp • Knowledge of the m • Understanding of th • Competence in the s • Experience in planni	es for modern nonparametric methods d effect measures ds through simulation studies etencies: lost important nonparametric statistical r e respective advantages and disadvanta selection of appropriate methods in appl ng, conducting and interpreting simulat	nethods ges of parametric and nonpa ication situations ion studies for method s eva	arametric methods
Grading through: • project work • Viva Voce or test			
Requires: • Biostatistics 2 (MA26 • Biostatistics 1 (MA16	00-KP07) 00-KP04, MA1600, MA1600-MML)		
Responsible for this modu • Prof. Dr. rer. nat. Silk Teacher: • Institute of Medical f • Prof. Dr. rer. nat. Silk • MitarbeiterInnen de	i le: e Szymczak Biometry and Statistics e Szymczak es Instituts		
Literature: • Edgar Brunner, Arne Designs - ISBN 978	C. Bathke, Frank Konietschke: Rank and 3-3-030-02912-8	Pseudo-Rank Procedures for	Independent Observations in Factorial
Language: • offered only in Germ	an		
Notes:			



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - None

Module exam(s):

- MA4947-L1: Nonparametric statistics, oral exam (20 min) or written exam (60 min), 60 % of module grade

- MA4947-L2: Small group research project including lecture and code documentation, 40 % of module grade


MA4955-KP05 - Applied Multiple Regression (AMuRegKP05)							
Duration:	Turnus of offer:	Credit points:	Max. group size:				
1 Semester	every second year	5	20				
Course of study, specific field • Bachelor CLS 2023 (option • Master CLS 2023 (option • Bachelor CLS 2016 (option • Master CLS 2016 (option	Course of study, specific field and term: • Bachelor CLS 2023 (optional subject), mathematics, 5th or 6th semester • Master CLS 2023 (optional subject), mathematics, 1st, 2nd, or 3rd semester • Bachelor CLS 2016 (optional subject), mathematics, 5th or 6th semester • Master CLS 2016 (optional subject), mathematics, 1st, 2nd, or 3rd semester						
Classes and lectures: • Applied Multiple Regres • Applied Multiple Regres	sion (lecture, 2 SWS) sion (exercise, 1 SWS)	Workload: • 85 Hours private s • 45 Hours in-classr • 20 Hours exam pr	tudies oom work eparation				
Contents of teaching:							
 Need and use of multiva Types of outcome varial Incorporation of indepe Dealing with the issues Coding and entering the Assessing the regression Checking the underlying Communicating the response R programming for apple 	 Need and use of multivariable analyses in epidemiological and clinical research Types of outcome variables and available multivariable models Incorporation of independent variables in the model Dealing with the issues of limited sample size and missing data Coding and entering the variables in the model Assessing the regression coefficient and strength of the model Checking the underlying assumptions and improving the fit of the model Communicating the results to the publishing house R programming for applied regression 						
Qualification-goals/Competer • The students are able to	ncies: o understand different study design	ns and multivariable models.					
 They are able to underst They are able to underst They are able to design They are able to interpre They are able to commu They are able to program 	tand impact of a variable on an ou tand assumptions underlying the r their own multivariable analysis pl et and critically evaluate the publis inicate their own study results usir m multiple regression analyses in f	tcome in a multivariable model. model. lan. shed studies. ng the standard available guidelir ?.	nes.				
Grading through: • project work							
Requires: • Generalized Linear Models (MA4962-KP05) • Biostatistics 2 (MA2600-KP07)							
Responsible for this module:							
 PD Dr. rer. pol. Reinhard Vonthein Teacher: Institute of Medical Biometry and Statistics Louis Macias, Ph.D. 							
Literature:							
 Literature: John Fox. 2016: Applied Regression Analysis - 3rd ed. Los Angeles SAGE. ISBN -13: 978-1-4522-0566-3 Mitchell H. Katz 2011: Multivariable Analysis: A Practical Guide for Clinicians and Public Health Researchers - 3rd ed. Cambridge University Press. ISBN -13: 978-0-521-14107-9 Andrew Gelman, Jennifer Hill, Aki Vehtari, 2020: Regression and Other Stories - Cambridge University Press. ISBN 13: 978-0-521-14107-9 Werner Vach. 2012: Regression Models as a Tool in Medical Research - Chapman and Hall/CRC. ISBN: 978-1-466-51748-6 							



Language:

• offered only in English

Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4955-L1: Project work with documentation and presentation



Ν	1A4962-KP05 - Generaliz	zed Linear Models	(VLModKP05)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific field and • Master CLS 2023 (optional su • Bachelor CLS 2023 (optional su • Bachelor CLS 2016 (optional su • Master CLS 2016 (optional su	term: bject), mathematics, 1st, 2nd, c subject), mathematics, 5th and subject), mathematics, 5th or 6 bject), mathematics, 1st, 2nd, c	or 3rd semester I 6th semester 5th semester or 3rd semester			
Classes and lectures:		Workload:			
 Generalized Linear Models (le Generalized Linear Models (e 	Generalized Linear Models (lecture, 2 SWS) Generalized Linear Models (exercise, 1 SWS) Generalized Linear Models				
 Contents of teaching: General overview of generali iterated weighted least square Continuous response models Dichotomous response models Count data: Poisson, negative Ordinal response models: pro- Disordered categorial response 	zed linear models (GLM): - link res, - convergence, - quality of : Gaussian, log-normal, Gamm els: logit, probit, cloglog e binomial with over- and unde portional odds model se models: Multinomial logit a	and response function, the adaption, - residual a, log-Gamma for surviv erdispersion Ind probit model	- GLM algorithms: Newton-Raphson, Fisher Scoring s val analysis, inverse Gaussian		
Qualification-goals/Competencies: • The students are able to explain area • They are able to explain area • They are able to select a suita • They are able to estimate GLI	ain the theoretical bases of ge s of application for GLM. able GLM. Ms in R.	neralized linear models	(GLM).		
 They are able to explain the feet of the pare able to judge the restrict the pare able to evaluate alg They are able to explain concomplex of the pare able to explain concomplex of the pare able to apply regress. They are able to describe the pare able to list the statistic the stat	source code in a presentation sults of GLMs in R critically. orithmic challenges of GLMs. reptual problems of GLMs for c GLM in R. sion diagnostics to GLMs and t most important estimation alg tical properties of GLMs.	n. categorialresponse varia to judge the results. gorithms for GLMs.	ıbles.		
Grading through: • Viva Voce or test					
Requires: • Biostatistics 2 (MA2600-KP07))				
Responsible for this module: • Prof. Dr. rer. biol. hum. Inke K	önig				
eacher: Institute of Medical Biometry	and Statistics				
• Prof. Dr. rer. biol. hum. Inke K	Prof. Dr. rer. biol. hum. Inke König				
Literature: • Agresti, Alan: Foundations of	Linear and Generalized Linear	r Models - Wiley, 2015			
Language:					



• English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module: - None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments as specified at the beginning of the semester

Module exam(s):

- MA4962-L1: Generalized Linear Models, written exam (90 min) or oral exam (30 min), 100 % of module grade





MA4970-KP05 - Design of Experiments and Analysis of Variance (VerVarKP05)					
Duration:	Turnus of offer:		Credit points:		
1 Semester	irregularly		5		
Course of study, specific field and term: Master CLS 2023 (optional subject), r Bachelor CLS 2023 (optional subject) Master CLS 2016 (optional subject), r Bachelor CLS 2016 (optional subject)	mathematics, 1st, 2nd, or 3r), mathematics, 5th or 6th se mathematics, 1st, 2nd, or 3r), mathematics, 5th or 6th se	d semester emester d semester emester			
Classes and lectures:	Classes and lectures: Workload:				
 Design of Experiments and Variance Design of Experiments and Variance 	Analysis (lecture, 2 SWS) Analysis (exercise, 1 SWS)	 85 Hours private 45 Hours in-class 20 Hours exam p 	studies sroom work preparation		
Contents of teaching:					
 Regression modeling and analysis of Generalized inverse Singular linear models Factorial designs The Latin square and the Graeco-Lat Experiments with block factors Fixed and random effects The split-plot design 	f variance in square designs				
 Students know the differences betw Students can enumerate the advant Students can interpret correctly the Students can select and implement Students can formulate the analysis Students understand the statistical pmatrix. Students can estimate linear regress Students can create and interpret gr Acquisition of knowledge in English 	 Qualification-goals/Competencies: Students know the differences between planned experiments and observational studies. Students can enumerate the advantages of the statistical multi-factorial design. Students can interpret correctly the analysis of variance results of experimental designs. Students can select and implement an appropriate experimental design and conduct corresponding variance analysis. Students can formulate the analysis of variance as a regression model in matrix notation. Students understand the statistical properties of linear regression model with a singular design matrix and a singular hypothesis matrix. Students can estimate linear regression model with a singular design matrix and a singular hypothesis matrix. Students can create and interpret graphs for summarizing results and model diagnostics. 				
Grading through: • Viva Voce or test					
Requires: • Biostatistics 2 (MA2600-KP07) • Biostatistics 1 (MA1600-KP04, MA160	00, MA1600-MML)				
Responsible for this module: • PD Dr. rer. pol. Reinhard Vonthein Teacher: • Institute of Medical Biometry and Statistics • Dr. Maren Vens • Louis Macias, Ph.D.					
Literature: • Kursbuch: Montgomery, Douglas C. 1 978-1-119-49244-3 • Supplementary literature: Mason, Ro ed John Wiley & Sons, New York. IS	2012: Design and Analysis o bert L., Gunst, Richard F., H 5BN 0-471-37216-1	ıf Experiments. 10th ed J ess, James L. 2003: Statisti	John Wiley & Sons, New York. ISBN cal Design and Analysis of Experiments. 2nd		



Language:

• German or English

Notes:

Admission requirements for taking the module:

- MA1600-KP04: Biostatistics 1 and
- MA2600-KP07: Biostatistics 2 successfully completed

Admission requirements for participation in module examination(s): - Successful completion of exercises as specified at the beginning of the semester

Module exam(s):

- MA4970-L1: Experimental design and analysis of variance, written exam (90 min) or oral exam (30 min), 100% of module grade

(share of Institute of Medical Biometry and Statistics in V is 100%) (share of Institute of Medical Biometry and Statistics in Ü is 100%)





MA5008-KP05 - Mathematical course (PrakMaKP05)					
Duration:	Turnus of offer:	Credit points:			
1 Semester	on request	5 (Тур В)			
Course of study, specific field ar • Master CLS 2023 (optional • Bachelor CLS 2023 (option • Bachelor CLS 2016 (optional • Master CLS 2016 (optional	nd term: subject), mathematics, 2nd or 3rd al subject), mathematics, 5th or 6t al subject), mathematics, 5th or 6t subject), mathematics, 2nd or 3rd	semester h semester h semester semester			
Classes and lectures: • Mathematical course (prac	Classes and lectures: Workload: • Mathematical course (practical course, 5 SWS) • 120 Hours in-classroom work • 30 Hours written report				
Contents of teaching: Planning and execution of Presenting the methods and 	a scientific project by mathemati nd results in a detailed written rep	cal methods ort			
 Qualification-goals/Competenci Ability to analyze a given p Ability to make oneself far Ability to integrate partial Proficiency in documenting 	es: problem and to develop mathema niliar with adequate mathematica results into the overall solution g and presenting results	tical approaches for it structures without any help			
Grading through: • Written report					
Responsible for this module: • Prof. Dr. rer. nat. Jürgen Pr Teacher: • Institutes of the Departme • Alle prüfungsberechtigte	estin nt of Computer Science/ Engineer n Dozentinnen/Dozenten des Stud	ing Jienganges			
Language: • German or English					
Notes: Admission requirements for - None Admission requirements for - Written report Module exam(s): - MA5008-L1: Mathematical of	taking the module: participation in module examinati course, ungraded course, 0 % of m	on(s): iodule grade, must be passed			



MA5030-KP05 - Image Registration (BildreKP05)					
Duration:	Turnus of offer:		Credit points:		
1 Semester	every second winter seme	ster	5		
Course of study, specific field and term: Master CLS 2023 (optional subject), Master CLS 2023 (compulsory), math Bachelor CLS 2016 (optional subject), Master CLS 2016 (optional subject),	mathematics, 1st or 3rd sem nematics, 1st or 3rd semeste), mathematics, 5th semeste mathematics, 1st or 3rd sem	ester r r ester			
Classes and lectures: • Image Registration (lecture, 2 SWS) • Image Registration (exercise, 1 SWS)	Workload:SWS)65 Hours private studies and exercisesSWS)45 Hours in-classroom work30 Hours work on project30 Hours exam preparation				
Contents of teaching: Introduction and basic principles Interpolation Deformation models Landmark-based registration Parametric registration Non-parametric registration and reg	jularization strategies				
 Qualification-goals/Competencies: Students know the fundamental concepts of image registration. They are able to translate concrete problems into adequate models. They have experience with parametric registration and can determine optimal parameters. They understand nonparametric image registration. Interdisciplinary qualifications: Students have advanced skills in modeling. They can translate theoretical concepts into practical solutions. They are experienced in implementation. They can think abstractly about practical problems 					
Grading through: • Written or oral exam as announced l Requires: • Linear Algebra and Discrete Structur • Analysis 2 (MA2500-KP09)	by the examiner res 2 (MA1500-KP08, MA150	0)			
Responsible for this module: • Prof. Dr. rer. nat. Jan Modersitzki Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Modersitzki • Prof. Dr. rer. nat. Jan Lellmann					
Literature: Goshtasby: 2D and 3D Image Regist Modersitzki: Numerical Methods for Modersitzki: FAIR: Flexible Algorithm Rohr: Landmark-Based Image Analys	ration - Wiley Image Registration - Oxford ns for Image Registration - S sis - Kluwer	University Press IAM			
Language:					



German and English skills required

Notes:

Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Examination prerequisites can be determined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively assessed before the first examination.

Examination:

- MA5030-L1: Image Registration, written examination (90 min) or oral examination (30 min) as decided by examiner, 100 % of final mark





	MA5033-KP05 - Quantum Image Computing (QuantumIC)					
Duration:	Turnus of offer:	Turnus of offer: Credit points:				
1 Semester	each summer semester	5	5			
Course of study, specific field an • Master CLS 2023 (optional • Bachelor CLS 2023 (optional • Bachelor CLS 2016 (optional • Master CLS 2016 (optional	Id term: subject), mathematics, 2nd or 4th se al subject), mathematics, 6th semest al subject), mathematics, 6th semest subject), mathematics, 2nd or 4th se	mester er er mester				
Classes and lectures:Workload:• Quantum Image Computing (lecture, 2 SWS)• 65 Hours private studies and exercises• Quantum Image Computing (exercise, 1 SWS)• 45 Hours in-classroom work• 30 Hours work on project• 10 Hours exam preparation						
Contents of teaching: • Foundations (unitary trans • Quantum image models ar • Recent quantum image pro • Adiabatic quantum compu • Quantum optimization for	formations, qubits, measurements, on nd quantum image operations ocessing algorithms Iting computer vision	uantum circuits)				
Qualification-goals/Competenci Students know the mather Students are familiar with a Students are able to transla Students can implement a Interdisciplinary qualificati Students have advanced m Students can translate ther Students have implementa Students can think abstract	es: matical foundations of quantum com advanced quantum computing mod ate practical problems into working Igorithms on quantum computers in ons: modeling skills. pretical concepts into practical soluti ation experience. tly about practical problems.	puting and their application. els, in particular in image proc algorithms. a modern programming lang ons.	cessing and computer vision. guage.			
Grading through: • Written or oral exam as an	nounced by the examiner					
Requires: • Linear Algebra and Discret	e Structures 2 (MA1500-KP08, MA150	10)				
Responsible for this module: • Prof. Dr. rer. nat. Jan Lellmann Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Lellmann • Prof. Dr. rer. nat. Jan Lellmann						
Literature: • Nielsen, Chuang: Quantum • Yan, Venegas-Andraca: Qu	Computation and Quantum Inform antum Image Processing - Springer	ation - Cambridge University l	Press			
Language: • German and English skills r	equired					
Notes:						



Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Homework assignments and their presentation are ungraded examination prerequisites which have to be completed and positively evaluated before the first examination.

Examination:

- MA5033-L1: Quantum Image Computing, written examination (90 min) or oral examination (30 min) as decided by examiner, 100% of final mark





Duration: Turnus of offer: Credit points: 1 Semester every second summer semester 5 Course of study, specific field and term: . . • Master CL 5 2023 (priorial subject), mathematics, Oth semester . . • Bachelor CL 5 2023 (priorial subject), mathematics, Oth semester . . • Bachelor CL 5 2013 (priorial subject), mathematics, Oth semester . . • Master CL 5 2016 (optional subject), mathematics, Oth semester . . . • Calculus of Variations and Partial Differential Equations (lecture), 2 3WS) .	MA5034-KP05 - Calc	ulus of Variations and P	artial Differential Ec	uations (VarPDGKP05)		
1 Semester every second summer semester 5 Course of study, specific field and term: Attact CLS 2023 (optional subject), mathematics, of the semester Bachelor CLS 2021 (optional subject), mathematics, of the semester Bachelor CLS 2021 (optional subject), mathematics, of the semester Classes and lectures: Clackus of Variations and Partial Differential Equations (locture, 2009) Course of study, specific field and any provide the semester Classes and lectures: Clackus of Variations and Partial Differential Equations (locture, 2009) Course of study, specific field and terms Classes and lectures: Clackus of Variations and Partial Differential Equations (locture, 2009) Course of study, specific field and terms Classes and lectures: Classes and l	Duration:	Turnus of offer: Credi		Credit points:		
Course of study, specific field and term: Master (LS 2003 (optional subject), mathematics, dn or thi semester Bachelor (LS 2016 (optional subject), mathematics, dn semester Bachelor (LS 2016 (optional subject), mathematics, dn semester Classes and lectures • Calculus of Variations and Partial Differential Equations (lecture, 2 XWS) • Calculus of Variations and Partial Differential Equations (lecercise, 1 SWS) • Calculus of Variations and Partial Differential Equations (lecercise, 1 SWS) • The dual space, wask convergence, Sobolev spaces • Optimality conditions • The dual space, wask convergence, Sobolev spaces • Optimality conditions • Calculus of Variations and aptical differential equations • Calculus of Variations and the dual differential equations • The dual space, wask convergence, Sobolev spaces • Optimality conditions • Calculus of Variations and trypical partial differential equations • Calculus of Variations and trypical partial differential equations • Calculus of Variations and trypical partial differential equations • They can be to formulate basic physical problems in a variational setting. • They can derive optimality conditions • They can implement selected fundamental variational problems. • They can implement selected fundamental variational problems. • They can timula differential concels to variational setting. • They can timula subactorial problems. • They can timulate subactorial probl	1 Semester	every second summer sem	ester	5		
Classes and lectures: Workload: • Calculus of Variations and Partial Differential Equations (lecture 2 SWS) • 65 Hours private studies and exercises • Calculus of Variations and Partial Differential Equations (lecture 2 SWS) • 65 Hours private studies and exercises • Contents of taaching: • 10 Hours exam preparation • Motivation and application examples • 10 Hours exam preparation • Direct methods in the calculus of variations • 10 Hours exam preparation • Optimality conditions • Classification of partial differential equations and typical PDEs • Classification of partial differential equations and typical PDEs • Findamental Solutions, maximum principle • Finite elements for elliptical partial differential equations • Vortical and partial differential equations Qualification-goals/Competencies: • Students understand variational modeling. • They understand the connections between variational anethods and partial differential equations. • They can implement selected forcial aproblems in the variational problems. • They can implement selected parcial aproblems in the variational setting. • They can implement selected forcial aproblems in the variational setting. • They can implement selected forcial aproblems in the variational setting. • They can implement selected forcial aproblems in the variational setting. • They can implementaproblems in the variational setting.	Course of study, specific field and term: • Master CLS 2023 (optional subject) • Bachelor CLS 2023 (optional subject) • Bachelor CLS 2016 (optional subject) • Master CLS 2016 (optional subject)	, mathematics, 2nd or 4th sen ct), mathematics, 6th semester ct), mathematics, 6th semester), mathematics, 2nd or 4th sen	nester r r nester			
Contents of teaching: • Motivation and application examples • Functional-analytic foundations • Direct methods in the calculus of variations • The dual space, weak convergence, Soboler spaces • Optimility conditions • Classification of partial differential equations and typical PDEs • Fundamental solutions, maximum principle • Finite elements for elliptical partial differential equations Qualification-goals/Competencies: • Students understand variational modeling. • They understand the connections between variational setting. • They understand the connections between variational motelens. • They understand the econsections between variational problems. • They can derive optimality conditions for energy functionals. • They can derive optimality conditions for energy functionals. • They can formulate selected fundamental variational problems. • They can implement selected fundamental variational problems. • They can tornizet theoretical concepts in the variational setting. • Interdisciplinary qualifications: • Students have advanced skills in modeling. • They can translate theoretical concepts into practical solutions. • They can translate theoretical concepts into practical solutions. • They can think abstractly	 Classes and lectures: Calculus of Variations and Partial E 2 SWS) Calculus of Variations and Partial E (exercise, 1 SWS) 	tions and Partial Differential Equations (lecture, tions and Partial Differential Equations (lecture, tions and Partial Differential Equations tions and Partial Differential Equations				
Grading through: • Written or oral exam as announced by the examiner Responsible for this module: • Prof. Dr. rer. nat. Jan Modersitzki Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Modersitzki • Prof. Dr. rer. nat. Jan Lellmann Literature: • Vogel: Computational Methods for Inverse Methods - SIAM • Aubert, Kornprobst: Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations - Springer • Scherzer, Grasmair, Grossauer, Haltmeier, Lenzen: Variational Methods in Imaging - Springer	Contents of teaching: Motivation and application example Functional-analytic foundations Direct methods in the calculus of w The dual space, weak convergence Optimality conditions Classification of partial differential Fundamental solutions, maximum Finite elements for elliptical partia Qualification-goals/Competencies: Students understand variational m They are able to formulate basic p They understand the connections They can derive optimality conditi They can implement selected funct They can formulate selected pract Interdisciplinary qualifications: Students have advanced skills in m They are experienced in implement They can think abstractly about pr	 Contents of teaching: Motivation and application examples Functional-analytic foundations Direct methods in the calculus of variations The dual space, weak convergence, Sobolev spaces Optimality conditions Classification of partial differential equations and typical PDEs Fundamental solutions, maximum principle Finite elements for elliptical partial differential equations Qualification-goals/Competencies: Students understand variational modeling. They are able to formulate basic physical problems in a variational setting. They are able to formulate basic physical problems in a variational setting. They can derive optimality conditions for energy functionals. They can implement selected fundamental variational problems. They can implement selected practical problems in the variational setting. Interdisciplinary qualifications: Students have advanced skills in modeling. They can translate theoretical concepts in to practical solutions. They can translate theoretical concepts into practical solutions. 				
Responsible for this module: • Prof. Dr. rer. nat. Jan Modersitzki Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Modersitzki • Prof. Dr. rer. nat. Jan Lellmann Literature: • Vogel: Computational Methods for Inverse Methods - SIAM • Aubert, Kornprobst: Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations - Springer • Scherzer, Grasmair, Grossauer, Haltmeier, Lenzen: Variational Methods in Imaging - Springer	Grading through: • Written or oral exam as announced	d by the examiner				
 Literature: Vogel: Computational Methods for Inverse Methods - SIAM Aubert, Kornprobst: Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations - Springer Scherzer, Grasmair, Grossauer, Haltmeier, Lenzen: Variational Methods in Imaging - Springer 	Responsible for this module: • Prof. Dr. rer. nat. Jan Modersitzki Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Modersitzki • Prof. Dr. rer. nat. Jan Lellmann					
	Literature: • Vogel: Computational Methods for • Aubert, Kornprobst: Mathematical • Scherzer, Grasmair, Grossauer, Hal	r Inverse Methods - SIAM Problems in Image Processing tmeier, Lenzen: Variational Me	g: Partial Differential Equa thods in Imaging - Spring	tions and the Calculus of Variations - Springer er		



German and English skills required

Notes:

Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Homework assignments and their presentation are ungraded examination prerequisites which have to be completed and positively evaluated before the first examination.

Examination:

- MA5034-L1: Calculus of Variations and Partial Differential Equations, written examination (90 min) or oral examination (30 min) as decided by examiner, 100 % of final mark



MA5035-KP05 - Non-smooth Optimization and Analysis (NiOpAnKP05)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each winter semester		5	
Course of study, specific field and te • Master CLS 2023 (optional subj • Bachelor CLS 2023 (optional sul • Master CLS 2016 (optional subj • Bachelor CLS 2016 (optional sul	r m: ect), mathematics, 2nd or 4th se oject), mathematics, 6th semest ect), mathematics, 2nd or 4th se oject), mathematics, 6th semest	emester ter emester ter		
Classes and lectures:Workload:• Non-smooth Optimization and Analysis (lecture, 2 SWS)• 65 Hours private studies and exercises• Non-smooth Optimization and Analysis (exercise, 1 SWS)• 45 Hours in-classroom work• 30 Hours work on project• 10 Hours exam preparation				
Contents of teaching: Introduction to non-smooth an First- and higher-order numeric Approximation of discrete and Generalized derivatives and Cla Applications in image processing	alysis: convexity, subdifferentia al optimization methods: PDHG non-convex problems rke subdifferential, semismooth ng and computer vision	ls, existence, Legendre- Fer G and interior-point methoc h Newton methods	nchel conjugate, duality Is	
Qualification-goals/Competencies: • The students understand the st • They can devise and analyse m • They understand the advantag • They know how to select and s • Interdisciplinary qualifications: • Students have advanced skills i • They can translate theoretical c • They are experienced in impler • They can think abstractly about	rengths of non-smooth models odels for simple problems. es, disadvantages, and applicati pecialize a suitable optimization n modeling. oncepts into practical solutions nentation. : practical problems.	s. ion areas of each optimizati n method for a given mode s.	on method. I.	
Grading through: • Written or oral exam as annour	ced by the examiner			
Requires: • Optimization (Advanced Mathe • Optimization (MA4030-KP08, M	matics) (MA4031-KP08) A4030)			
Responsible for this module: • Prof. Dr. rer. nat. Jan Lellmann Teacher: • Institute of Mathematics and In • Prof. Dr. rer. nat. Jan Lellmann • Prof. Dr. rer. nat. Jan Modersitz	nage Computing			
Literature: • Rockafellar, Wets: Variational Al • Boyd, Vandenberghe: Convex C • Ben-Tal, Nemirovski: Lectures o • Paragios, Chen, Faugeras: Hanc	nalysis - Springer Optimization - Cambridge Unive n Modern Convex Optimizatior book of Mathematical Models i	ersity Press n - SIAM in Computer Vision - Spring	er	
Language: • German and English skills requi	red			



Notes:

Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Homework assignments and their presentation are ungraded examination prerequisites which have to be completed and positively evaluated before the first examination.

Examination:

- MA5035-L1: Non-smooth Optimization and Analysis, written examination (90min) or oral examination (30 min) as decided by examiner, 100 % of final mark



MA5037-KP05 - Optimization of Complex Systems (OpkoSy05)						
Duration:	Turnus of offer:		Credit points:			
1 Semester	irregularly		5			
Course of study, specific field and term: • Master CLS 2023 (optional subject) • Bachelor CLS 2023 (optional subject) • Master CLS 2016 (optional subject) • Bachelor CLS 2016 (optional subject)	 Course of study, specific field and term: Master CLS 2023 (optional subject), mathematics, 2nd or 4th semester Bachelor CLS 2023 (optional subject), mathematics, 6th semester Master CLS 2016 (optional subject), mathematics, 2nd or 4th semester Bachelor CLS 2016 (optional subject) mathematics, 6th semester 					
Classes and lectures:		Workload:				
 Optimization of Complex Systems Optimization of Complex Systems 	(lecture, 2 SWS) (exercise, 1 SWS)	 85 Hours private 45 Hours in-class 20 Hours exam p 	e studies and exercises sroom work preparation			
Contents of teaching: • Model problems (e.g. optimal cont • Optimum conditions • Optimization process	rol of heating processes, op	timal design)				
 Qualification-goals/Competencies: Students know how the control of selected complex systems can be modeled as an optimization problem.can be modeled as an optimization problem. They know the optimality conditions of these optimization problems. They can select optimization methods and implement them in practice for new models. Interdisciplinary aspects: Students can put theoretical concepts into practice. They have experience in implementation. They can abstract practical problems. 						
Grading through: Written or oral exam as announced by the examiner 						
Requires: • Optimization (Advanced Mathematics) (MA4031-KP08) • Optimization (MA4030-KP08, MA4030)						
Responsible for this module: • Prof. Dr. rer. nat. Jan Modersitzki Teacher: • Institute of Mathematics and Image Computing • Prof. Dr. rer. nat. Jan Lellmann • Prof. Dr. rer. nat. Jan Modersitzki • Dr. rer. nat. Florian Mannel						
Literature: • Tröltzsch:: Optimale Steuerung partieller Differentialgleichungen - Vieweg+Teubner Verlag • Hinze, Ulbrich, Ulbrich, Pinnau: Optimization with PDE Constraints - Springer Dordrecht • Ulbrich: Semismooth Newton Methods for Variational Inequalities and Constrained Optimization Problems in Function Spaces - SIAM						
Language: • German and English skills required						
Notes:						



Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Homework assignments and their presentation are ungraded examination prerequisites which have to be completed and positively evaluated before the first examination.

Examination:

- MA5035-L1: Optimization of Complex Systems, written examination (90min) or oral examination (30 min) as decided by examiner, 100% of final mark



	MA5008-KP04 - Mathe	ematical course (PrakMaKP04)	
Duration:	Turnus of offer:	Credit points:	
1 Semester	on request	4 (Тур В)	
Course of study, specific fie • Master CLS 2023 (opt • Master CLS 2016 (opt	eld and term: ional subject), mathematics / comput ional subject), mathematics / comput	ter science, 2nd or 3rd semester ter science, 2nd or 3rd semester	
Classes and lectures:		Workload:	
Mathematical course	(practical course, 4 SWS)	100 Hours in-classroom work20 Hours written report	
Contents of teaching: Planning and executi Presenting the method 	on of a scientific project by mathema ods and results in a detailed written re	itical methods eport	
Qualification-goals/Compe • Ability to analyze a g • Ability to make onese • Ability to integrate p • Proficiency in docum	etencies: iven problem and to develop mathem elf familiar with adequate mathematic artial results into the overall solution enting and presenting results	natical approaches for it cal structures without any help	
Grading through: • Written report			
Responsible for this modul • Prof. Dr. rer. nat. Jürg Teacher: • Institutes of the Depa • Alle prüfungsberech	le: en Prestin artment of Computer Science/ Engined atigten Dozentinnen/Dozenten des Stu	ering udienganges	
Language: • English, except in cas	e of only German-speaking participan	nts	



CS300	CS3000-KP04, CS3000 - Algorithm Design (AlgoDesign)				
Duration:	Turnus of offer:		Credit points:		
1 Semester	each winter semester		4		
Course of study, specific field and term: Master CLS 2023 (optional subject), Bachelor Computer Science 2019 (co Bachelor Robotics and Autonomous Bachelor Medical Informatics 2019 (Bachelor Computer Science 2016 (co Master CLS 2016 (optional subject), Bachelor Robotics and Autonomous Bachelor IT-Security 2016 (compulse Bachelor Medical Informatics 2014 (Bachelor Computer Science 2014 (co Bachelor CLS 2010 (optional subject Bachelor CLS 2010 (optional subject Bachelor Computer Science 2012 (co	computer science, 3rd sem ompulsory), foundations of Systems 2020 (optional su optional subject), compute ompulsory), foundations of computer science, 3rd sem Systems 2016 (optional su ory), computer science, 5th optional subject), compute ompulsory), foundations of), computer science, 5th or ompulsory), foundations of	ester computer science, 5th sem ibject), computer science, 5 r science, 4th to 6th semest computer science, 5th sem ester bject), computer science, 5 semester r science, 5th or 6th semest computer science, 5th sem 6th semester computer science, 5th sem	nester 5th or 6th semester ter nester th or 6th semester ter nester		
Classes and lectures:		Workload:			
 Algorithm Design (lecture, 2 SWS) Algorithm Design (exercise, 1 SWS) 		 65 Hours private 45 Hours in-class 10 Hours exam p 	studies and exercises sroom work preparation		
Contents of teaching:					
 Complex data structures and union Efficiency analysis and correctness p Probabilistic algorithms Online algorithms Graph, matching and scheduling pr String processing Approximation algorithms 	 Complex data structures and union find data structures Efficiency analysis and correctness proofs Probabilistic algorithms Online algorithms Graph, matching and scheduling problems String processing Approximation algorithms 				
Qualification-goals/Competencies:					
 The students can safely apply the p They can analyze algorithms with re They are able to apply these princip They can contribute their proficience 	rinciples of algorithm desig spect to correctness and e les to concrete problems. y in solving similar algorith	n. fficiency. mic problems.			
Grading through: • written exam					
Requires:					
 Stochastics 1 (MA2510-KP04, MA2510) Theoretical Computer Science (CS2000-KP08, CS2000) Algorithms and Data Structures (CS1001-KP08, CS1001) 					
Responsible for this module:					
Prof. Dr. Rüdiger Reischuk					
Teacher:					
Institute for Theoretical Computer S	cience				
 Prof. Dr. Rüdiger Reischuk Prof. Dr. rer. nat. Till Tantau 	 Prof. Dr. Rüdiger Reischuk Prof. Dr. rer. nat. Till Tantau 				
Literature:					
• J. Kleinberg, E. Tardos: Algorithm De	esign - Addison Wesley, 200)5			



- T. Cormen, C. Leiserson, R. Rivest, C. Stein: Introduction to Algorithms MIT Press, 2009
- S. Skiena: The Algorithmic Design Manual Springer, 2012

Language:

• offered only in German

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Notes:

- Prerequisites for attending the module:
- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Prerequisites for the exam:

- Successful completion of homework and project assignments as specified at the beginning of the semester.

Module exam(s):

- CS3000-L1: Algorithm Design, written exam, 90 min, 100 % of module grade



CS3420-KP04, CS3420 - Cryptology (Krypto14)					
Duration: Turnus of offer: Credit points:					
1 Semester	each winter semester		4		
Course of study, specific field and term: Master CLS 2023 (optional subject), computer science, 3rd semester Bachelor Computer Science 2019 (optional subject), major subject informatics, Arbitrary semester Bachelor Media Informatics 2020 (optional subject), computer science, 4th or 6th semester Bachelor Robotics and Autonomous Systems 2020 (optional subject), computer science, 5th or 6th semester Bachelor Medical Informatics 2019 (optional subject), computer science, 4th to 6th semester Bachelor Medical Informatics 2019 (optional subject), computer science, 4th to 6th semester Bachelor Computer Science 2016 (optional subject), computer science, 4th to 6th semester Bachelor Computer Science 2016 (optional subject), major subject informatics, Arbitrary semester Bachelor Computer Science 2016 (optional subject), major subject informatics, Arbitrary semester Bachelor Robotics and Autonomous Systems 2016 (optional subject), computer science, 5th or 6th semester Bachelor Robotics and Autonomous Systems 2016 (optional subject), computer science, 5th or 6th semester Bachelor Robotics and Autonomous Systems 2016 (optional subject), computer science, 5th or 6th semester Bachelor Robotics and Autonomous Systems 2016 (optional subject), computer science, 5th or 6th semester Bachelor IT-Security 2016 (compulsory), IT-Security, 3rd semester Bachelor IT-Security 2016 (compulsor					
Bachelor Computer Science	e 2014 (optional subject), central topi	lcs of computer science, 5t	n or oth semester		
Classes and lectures: • Cryptology (lecture, 2 SWS • Cryptology (exercise, 1 SW	i) /S)	 Workload: 65 Hours private studies and exercises 45 Hours in-classroom work 10 Hours exam preparation 			
Contents of teaching:					
 mathematical and algorith design principles for crypt symmetric crypto systems public key crypto systems, efficient implementation c methods in cryptoanalysis cryptographic protocols 	 mathematical and algorithmic basics design principles for cryptographic applications symmetric crypto systems public key crypto systems, digital signatures efficient implementation of crypto systems methods in cryptoanalysis cryptographic protocols 				
Qualification-goals/Competenci The students are able to m They know basic cryptogra They can recognize crypto They can apply standard to They can explain and asse	 Qualification-goals/Competencies: The students are able to model and analyze IT security. They know basic cryptographic primitives and protocols. They can recognize cryptographic weakness. They can apply standard techniques in cryptology. They can explain and assess the historical and social significance of encrypting information. 				
Grading through:					
• written exam					
Responsible for this module: • Prof. Dr. Maciej Liskiewicz Teacher: • Institute for Theoretical Co • Prof. Dr. Maciej Liskiewicz	omputer Science				
Literature:					
 Literature: J von zur Gathen: CryptoSchool - Springer 2015 A. Beutelspacher, H. Neumann, T. Schwarzpaul: Kryptopgrafie in Theorie und Praxis - Vieweg 2005 D. Wätjen: Kryptographie - Springer 2018 J. Katz, Y. Lindell: Introduction to Modern Cryptography - Chapman & Hall, 2008 C. Bauer: Secret History - The Story of Cryptology - CRC Press 2013 B. Schneier: Applied Cryptography - J. Wiley 1996 					



Т

.anguage:
English, except in case of only German-speaking participants
Notes:
Admission requirements for taking the module: - None
Admission requirements for participation in module examination(s):
- Successful completion of exercise sheets as specified at the beginning of the semester
Module exam(s):
- CS3420-L1: Cryptology, written exam, 90 minutes, 100% of module grade



CS4250-KP04, CS4250 - Computer Vision (CompVision)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each summer semester		4	
Course of study, specific field and term: Master CLS 2023 (optional subject), computer science, 2nd or 3rd semester Master CLS 2020 (optional subject), computer science / electrical engineering, Arbitrary semester Master Computer Science 2019 (optional subject), Elective, Arbitrary semester Master Media Informatics 2020 (optional subject), Elective, Arbitrary semester Master Media Informatics 2019 (optional subject), computer science, Arbitrary semester Master Biomedical Engineering (optional subject), Elective, 2nd semester Master Science 2019 (optional subject), Elective, 2nd semester Master Biomedical Engineering (optional subject), advanced curriculum, 2nd semester Master Metis 2014 (optional subject), computer science, 2nd or 3rd semester Master Metis 2014 (optional subject), computer science, Arbitrary semester Master Metis 2014 (optional subject), computer science, Arbitrary semester Master Computer Science 2012 (optional subject), advanced curriculum imaging systems, 2nd or 3rd semester Master CLS 2010 (compulsory), computational life science / imaging, 2nd semester Master Computer Science 2012 (optional subject), advanced curriculum signal and image processing, 2nd or 3rd semester Master Computer Science 2012 (optional subject), advanced curriculum signal and image processing, 2nd or 3rd semester Master Computer Science 2012 (compulsory), specialization field robotics and automation, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master Computer Science 2012 (compu				
Classes and lectures:		Workload:		
 Computer Vision (lecture, 2 SWS) Computer Vision (exercise, 1 SWS) 20 Hours exam preparation 		studies sroom work preparation		
 Contents or teacning: Introduction to human and computer vision Sensors, cameras, optics and projections Image features: edges, intrinsic dimension, Hough transform, Fourier descriptors, snakes Range imaging and 3-D cameras Motion and optical flow Object recognition Example applications 				
 Qualification-goals/Competencies: Students can understand the basics of computer vision. They can explain and perform camera choice and calibration. They can explain and apply the basic methods for feature extraction, motion estimation, and object recognition. They can indicate appropriate methods for different kinds of computer-vision applications. 				
Grading through: Oral examination				
Responsible for this module: • Prof. DrIng. Erhardt Barth Teacher: • Institute for Neuro- and Bioinformatics • Prof. DrIng. Erhardt Barth				
 Literature: Richard Szeliski: Computer Vision: Algorithms and Applications - Springer, Boston, 2011 David Forsyth and Jean Ponce: Computer Vision: A Modern Approach - Prentice Hall. 2003 				
Language:				



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CS4405-KP04, CS4405 - Neuroinformatics (NeuroInf)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each summer semester		4	
 Course of study, specific field and term: Master CLS 2023 (compulsory), computer science, 2nd semester Master Auditory Technology 2022 (optional subject), Auditory Technology, 2nd semester Master Auditory Technology 2017 (optional subject), Auditory Technology, 2nd semester Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester Master CLS 2016 (compulsory), computer science, 2nd semester Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester 				
 Bachelor MES 2011 (optional subject), optional subject medical engineering science, 6th semester Master Computer Science 2012 (optional subject), advanced curriculum organic computing, 2nd or 3rd semester Master MES 2011 (advanced curriculum), imaging systems, signal and image processing, 2nd semester Master Computer Science 2012 (optional subject), advanced curriculum intelligent embedded systems, 2nd or 3rd semester Master Computer Science 2012 (compulsory), specialization field robotics and automation, 2nd semester Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester Master CLS 2010 (compulsory), computer science, 2nd semester 				
Classes and lectures:		Workload:		
 Neuroinformatics (lecture, 2 SWS) Neuroinformatics (exercise, 1 SWS) 		55 Hours private45 Hours in-class20 Hours exam p	studies room work reparation	
 Contents of teaching: The human brain and abstract neuron models Learning with a single neuron:* Perceptrons* Max-Margin Classification* LDA and logistic Regression Network architectures:* Hopfield-Networks* Multilayer-Perceptrons* Deep Learning Unsupervised Learning:* k-means, Neural Gas and SOMs* PCA & ICA* Sparse Coding 				
Qualification-goals/Competencies:				
 The students are able to understand the principle function of a single neuron and the brain as a whole. They know abstract neuronal models and they are able to name practical applications for the different variants. They are able to derive a learning rule from a given error function. They are able to apply (and implement) the proposed learning rules and approaches to solve unknown practical problems. 				
Grading through: • Written or oral exam as appounced by the examiner				
Responsible for this module: Prof. Dr. rer. pat. Thomas Martinetz				
Teacher: Institute for Neuro- and Bioinformatics				
 Prof. Dr. rer. nat. Thomas Martinetz Prof. Dr. rer. nat. Amir Madany Mamlouk 				
Literature:				
 S. Haykin: Neural Networks - Londo J. Hertz, A. Krogh, R. Palmer: Introd T. Kohonen: Self-Organizing Maps H. Ritter, T. Martinetz, K. Schulten: I Addison Wesley, 1991 	n: Prentice Hall, 1999 uction to the Theory of Neura Berlin: Springer, 1995 Neuronale Netze: Eine Einführ	al Computation - Addison ' rung in die Neuroinformat	Wesley, 1991 ik selbstorganisierender Netzwerke - Bonn:	
Language:				



• offered only in German

Notes:

Admission requirements for taking the module:

- None

Admission requirements for participation in module examination(s): - Successful completion of exercises as specified at the beginning of the semester

Module Exam(s):

- CS4405-L1: Neuroinformatics, written exam, 90 min, 100% of module grade

According to the old version of the MES Bachelor Examination Regulations (until WS 2011/2012), an elective subject is scheduled for the 4th semester instead of the 6th semester.





CS4440-KP04, CS4440 - Molecular Bioinformatics (MolBioInfo)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each winter semester		4	
Course of study, specific field ar Master CLS 2023 (optional Master Molecular Life Scier Master CLS 2016 (optional Master MES 2011 (advance Master CLS 2010 (optional Master Computer Science 2	nd term: subject), computer science, 3rd sen nce 2023 (optional subject), mathen subject), computer science, 3rd sen ed curriculum), biophysics and biom subject), computer science, 1st or 3 2012 (compulsory), specialization fie	nester natics / computer science, 1 nester edical optics, 2nd semester rd semester eld bioinformatics, 1st seme	st semester	
Classes and lectures:		Workload:		
 Molecular Bioinformatics Molecular Bioinformatics ((lecture, 2 SWS) exercise, 1 SWS)	 55 Hours private studies 45 Hours in-classroom work 20 Hours exam preparation 		
Contents of teaching:				
 Methods for fast genome of Analysis of data describing Advanced usage of biolog 	comparison J gene expression profiles and seque ical databases (for sequences, motif	ence variation s, structures, gene regulatic	on and interactions)	
Qualification-goals/Competenci	es:			
 The students can apply inc They can use and design d They are able to detect state 	dexing based software to Next Gene latabases for molecularbiological re tistically significant changes in Micr	ration sequence data. search. oarray data.		
Grading through: • written exam				
Requires: • Introduction to Bioinforma	tics (CS1400-KP04, CS1400)			
Responsible for this module: • Prof. Dr. rer. nat. Thomas M Teacher: • Institute for Neuro- and Bio • Prof. Dr. Bernhard Haubolo • Prof. Dr. rer. nat. Thomas M • MitarbeiterInnen des Insti • Prof. Lars Bertram	Aartinetz Dinformatics I Nartinetz Ituts			
l iterature:				
 M. S. Waterman: Introducti B. Haubold, T. Wiehe: Intro R. Durbin, S. Eddy, A. Krogl Press J. Setubal, J. Meidanis: Intri D. M. Mount: Bioinformatic 	ion to Computational Biology - Lond duction to Computational Biology - h, G. Mitchison: Biological sequence oduction to computational molecul cs - Sequence and Genome - New Yo	don: Chapman and Hall 199 Birkhäuser 2007 analysis. Probabilistic mod ar - Pacific Grove: PWS Publ ork: Cold Spring Harbor Pres	5 els - Cambridge, MA: Cambridge University lishing Company ss	
Language:				
English, except in case of c	only German-speaking participants			
Notes:				



Prerequisites for the module: - None

Prerequisites for admission to the written examination:

- Successful completion of exercises as specified at the beginning of the semester

Module exam(s):

- CS4440-L1: Molecular Bioinformatics, written exam, 90 min, 100 % of module grade



CS5450-KP04, CS5450 - Machine Learning (MaschLern)				
Duration:	n: Turnus of offer:		Credit points:	
1 Semester	nester each winter semester		4	
 Course of study, specific field and term: Master CLS 2023 (optional subject), computer science, 3rd semester Master Auditory Technology 2022 (optional subject), computer science, 1st semester Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester Master Medical Informatics 2019 (optional subject), Medical Data Science / Artificial Intelligence, 1st or 2nd semester Master Auditory Technology 2017 (optional subject), computer science, 1st semester Master CLS 2016 (optional subject), computer science, 3rd semester Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester Master MES 2011 (optional subject), computer science / electrical engineering, Arbitrary semester Master MES 2011 (optional subject), computer science / electrical engineering, Arbitrary semester Master MES 2011 (optional subject), mathematics, 1st or 2nd semester Master MES 2011 (optional subject), computer science, 1st or 2nd semester Master MES 2011 (optional subject), computer science, 1st or 2nd semester Master MES 2011 (optional subject), computer science, 1st or 2nd semester Master MES 2011 (optional subject), computer science, 1st or 2nd semester Master CLS 2010 (optional subject), computer science, 1st or 2nd semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2010 (optional subject), computer science, Arbitrary semester Master CLS 2				
Classes and lectures:		Workload:		
 Machine Learning (lecture, 2 SWS) Machine Learning (exercise, 1 SWS) 		55 Hours private45 Hours in-class20 Hours exam p	studies sroom work preparation	
 Representation learning, including manifold learning Statistical learning theory VC dimension and support vector machines Boosting Deep learning Limits of induction and importance of data ponderation 				
 Qualification-goals/Competencies: Students can understand and explain various machine-learning problems. They can explain and apply different machine learning methods and algorithms. They can chose and then evaluate an appropriate method for a particular learning problem. They can understand and explain the limits of automatic data analysis. 				
Oral examination				
Responsible for this module: • Prof. DrIng. Erhardt Barth Teacher: • Institute for Neuro- and Bioinformatics • Prof. DrIng. Erhardt Barth • Prof. Dr. rer. nat. Thomas Martinetz				
 Literature: Chris Bishop: Pattern Recognition and Machine Learning - Springer ISBN 0-387-31073-8 Vladimir Vapnik: Statistical Learning Theory - Wiley-Interscience, ISBN 0471030031 				
English, except in case of only German-speaking participants				



Notes:

Admission requirements for taking the module:

- None

Admission requirements for participation in module examination(s): - None

Module exam(s):

- CS5450-L1: Machine Learning, oral examination, 100% of module grade





ME2451-KP04, ME2451 - Control Systems (RegTech)				
Duration:	Turnus of offer:		Credit points:	
Semester every summer semester			4	
Course of study, specific field Master CLS 2023 (option Master MES 2020 (option Master CLS 2016 (option Master MES 2014 (option Master MES 2011 (option	l and term: nal subject), computer science, 2nd or 4 nal subject), computer science / electric nal subject), computer science, 2nd or 4 onal subject), computer science / electric onal subject), advanced curriculum, 2nd	th semester cal engineering, Arbitrary se th semester cal engineering, 2nd or 4th s or 4th semester	emester semester	
Classes and lectures:		Workload:		
 Control Systems (lecture Control Systems (exerci 	Control Systems (lecture, 2 SWS) Control Systems (exercise, 1			
Contents of teaching:				
 Dynamic behavior of sy Feedback concepts Controller design in tim System representation i Stability Controller design in free 	stems ie domain in frequency domain quency domain			
 Students can model ph Students know the function of the students are able to de Students are able to an aperformance and robustions and the students are able to an aperformance and robustions are able to an approximately ap	ysical systems mathematically as well as damental tools and can formulate requin sign control loops using time and freque alyze stability of feedback systems and o stness.	s describe and analyze their rements with respect to sys ency domain-based tools. can evaluate the resulting d	dynamic behavior. tems in the time and frequency domain. lynamic properties with respect to control	
Grading through:				
• Written or oral exam as	announced by the examiner			
Responsible for this module: • Prof. Dr. Philipp Rostals Teacher: • Institute for Electrical Er • Prof. Dr. Philipp Rostals	ki ngineering in Medicine ki			
 Literature: G.F. Franklin, J.D. Powel J. Lunze: Regelungstech J. Lunze: Regelungstech 	ll, A. Emami-Naeini: Feedback Control of nnik 1 - Springer Verlag 2012 nnik 2 - Springer Verlag 2012	Dynamic Systems - Pearson	n Verlag - 2014	
Language: • German and English ski	lls required			
Notes:				
Holes.				



Admission requirements for taking the module: - None

Admission requirements for participation in module examination(s): - None

Module exam(s):

- ME2451-L1: Control Systems, oral exam, 100% of module grade



LS4020 C - Module part LS4020C: Single Molecule Methods (Einzelstru)				
Duration:	Turnus of offer:	Credit points:		
1 Semester	each winter semester	3		
Course of study, specific field a Master CLS 2023 (Module Master MLS 2018 (Module Master Infection Biology Master Biophysics 2019 (f Master CLS 2016 (Module Master MLS 2016 (Module Master Infection Biology Master CLS 2010 (module Master MLS 2009 (Module	and term: e part of a compulsory module), comp e part of a compulsory module), struct 2018 (Module part of a compulsory module part of a compulsory module), MML e part of a compulsory module), Struct 2012 (Module part of a compulsory module), struct e part), computational life science / life e part of a compulsory module), struct	outational life science / life sciences, 3rd semester ture biology, 1st semester iodule), Interdisciplinary modules, 1st semester), biophysics, 1st semester with specialization in Life Science, 3rd semester ture biology, 1st semester iodule), Interdisciplinary modules, 1st semester e sciences, 3rd semester ture biology, 1st semester		
Classes and lectures:		Workload:		
Single Molecule Methods	; (lecture, 2 SWS)	60 Hours private studies30 Hours in-classroom work		
Contents of teaching: Physical basics of fluorescence Photo physics Microscopy techniques Protein labeling Fluorescence resonance energy transfer Single molecule enzymology Single molecule protein folding Physical basics of optical tweezers Protein folding with optical tweezers Oualification-maals/Competencies:				
 Understanding of the phy Understanding of the being Understanding of the limit 	ysical basics of single molecule meth nefits of single molecule methods its of single molecule methods	ods		
Grading through: see Notes 				
Responsible for this module: • Siehe Hauptmodul Teacher: • Institute of Physics • Prof. Dr. rer. nat. Christian Hübner Literature: • Lakowicz, Joseph R: Principles of Fluorescence Spectroscopy - ISBN 978-0-387-46312-4 • Markus Sauer, Johan Hofkens, Jörg Enderlein: Handbook of Fluorescence Spectroscopy and Imaging: From Ensemble to Single Molecules - ISBN: 978-3-527-31669-4 Language:				
offered only in English				
Notes:				



Is module part of:

- LS4021-KP06 (former LS4020-IB) -> Prof. Hübner
- LS4020-KP06 (former LS4020-MLS) and LS4020-KP12 -> Prof. Peters
- LS4027-KP06 start 2023

This module part is identical to LS4020 C-MIW without seminar.



MA5009-KP03 - Master's Seminar mathematics (MSMathe03)				
Turnus of offer: Credit poin		:		
each semester 3 (Ty				
l term: ry), Interdisciplinary modules, 3rd s	emester			
Classes and lectures: • Advanced Master's Seminar mathematics (seminar, 2 SWS) • 30 Hours • 30 Hours • 15 Hours • 15 Hours		iding preparation)		
 Contents of teaching: The students study a scientific topic of their specialization. They present the topic in written form. They are able to give a scientific talk on the topic. 				
s: xperience of familiarizing themselv e result of their studies in comprehe wherent overview of a complex scie te in holding scientific discussions. presentations and know how to crit	es with the details of a given scientific topi nsible written form. tific area in a comprehensive oral presenta cally question them in open discussions.	ic. ation.		
Responsible for this module: • Prof. Dr. rer. nat. Jürgen Prestin Teacher: • Institute of Medical Biometry and Statistics • Institute of Mathematics and Image Computing • Institute for Mathematics • Prof. Dr. rer. nat. Jürgen Prestin • Prof. Dr. rer. nat. Jürgen Prestin • Prof. Dr. rer. nat. Jan Modersitzki • Prof. Dr. rer. nat. Andreas Rößler • Nachfolge von Prof. Dr. rer. nat. Karsten Keller • Prof. Dr. rer. nat. Jan Lellmann • Prof. Dr. rer. nat. Silke Szymczak				
 Language: English, except in case of only German-speaking participants 				
Notes: Admission requirements for taking the module: - None Admission requirements for participation in module examination(s): - Preparation and presentation of a scientific talk Module exam(s): - MA5009-1 1: Master's Seminar Mathematics, ungraded seminar, 0 % of module grade, must be passed				
	ABJOUS-KPOS - Master's Seminaries Turnus of offer: each semester I term: ry), Interdisciplinary modules, 3rd seminaries mathematics (seminar, 2 SWS) fic topic of their specialization. ritten form. ntific talk on the topic. s: xperience of familiarizing themselves eresult of their studies in comprehe observations and know how to critic stin y and Statistics d Image Computing stin stin sitin y and Statistics d Image Computing stin sitin sitin	Resource of a midster is seminar infattmentatics (instructives) Turnus of offer: credit points: each senester 3 (Typ B) Iterm: ry), Interdisciplinary modules, 3rd semester mathematics (seminar, 2 SWS) • 30 Hours private studies • 30 Hours private studies • 30 Hours private studies • 30 Hours private studies • 30 Hours oral presentation (incluing) fit topic of their specialization. • 15 Hours oral presentation (incluing) fit topic of their specialization. • 15 Hours oral presentation (incluing) fit topic of their specialization. • 15 Hours oral presentation (incluing) service of familiarizing themselves with the details of a given scientific topic • 15 Hours oral presentation (incluing) service in holding scientific discissions. • 15 Hours oral presentations. ore enabled of their studies in comprehensible written form. • 10 Hours oral present. stin • 10 Scientific discissions. • 10 Hours oral present. stin • 11 Studies in comprehensible written form. • 11 Studies stin • 11 Studies • 11 Studies stin • 11 Studies • 11 Studies stin • 11 Studies • 11 Studies sti		



MA5990-KP30, MA5990 - Master's thesis in Computational Life Science (MaArbMML)					
Duration:	Turnus of offer:		Credit points:		
1 Semester	each semester		30		
Course of study, specific field and term: • Master CLS 2023 (compulsory), Intero • Master CLS 2016 (compulsory), Intero • Master CLS 2010 (compulsory), math	disciplinary modules, 4th disciplinary modules, 4th ematics, 4th semester	n semester n semester			
Classes and lectures:	Classes and lectures: Workload:				
 Master's thesis (supervised self studies, 1 SWS) Colloquium (presentation (incl. preparation), 1 SWS) 870 Hours private studies 30 Hours oral presentation (including preparation) 			e studies esentation (including preparation)		
 Contents of teaching: Investigating a given problem in ma Writing a Master's Thesis Colloquium to present the results incomendation 	thematics or its applicat cluding a discussion with	ion areas and developing a g n the referees	ood solution		
 Qualification-goals/Competencies: The students are able to solve a complex scientific problem with state-of-the-art methods. Experience in writing a scientific thesis within a given time period Becoming an expert in a special subfield of mathematics Experience in working with scientific literature Presentation skills 					
Grading through: Written report colloquium 					
Responsible for this module: • Prof. Dr. rer. nat. Jürgen Prestin Teacher: • Institutes of the Department of Com • Alle prüfungsberechtigten Dozentin	puter Science/ Engineeri nnen/Dozenten des Stud	ing lienganges			
Language: • thesis can be written in German or E	nglish				
Notes: Admission requirements for taking the - The basic prerequisite for starting the Admission requirements for participati - Submission of a master's thesis Module examination(s): - MA5990-L1: Master's thesis in Compu	module: e master's thesis is the su on in module examination tational Life Science, ma	ccessful completion of 75 cre on(s): uster's thesis and colloquium,	edits. 100% of module grade		


	LS2300-KP08, LS2301 - Bi	iophysical Chemistry	(BPCKP08)
Duration:	Turnus of offer:		Credit points:
1 Semester	ter each summer semester		8
Course of study, specific field Master CLS 2023 (comp Bachelor Biophysics 20 Bachelor Molecular Life Bachelor MLS 2018 (com Bachelor MLS 2016 (com Master CLS 2016 (comp Bachelor Biophysics 20 Master CLS 2010 (option Bachelor MLS 2009 (com	d and term: bulsory), MML with specialization in L 24 (compulsory), biophysics, 4th sem Science 2024 (compulsory), Chemist mpulsory), Chemistry, 4th semester mpulsory), Chemistry, 4th semester bulsory), MML with specialization in L 16 (compulsory), biophysics, 4th sem nal subject), computational life scien mpulsory), life sciences, 4th semester	ife Science, 2nd semester lester try, 4th semester life Science, 2nd semester lester lice / life sciences, 2nd seme	ester
Classes and lectures:		Workload:	
Biophysical ChemistryBiophysical ChemistryBiophysical Chemistry	(lecture, 3 SWS) (exercise, 1 SWS) (practical course, 3 SWS)	160 Hours pr80 Hours in-c	ivate studies :lassroom work
 Basics of chemical ther Thermodynamics of lig Basics of chemical kine Basics of enzyme kinet Molecular Mechanics Practical works: NMR, Molecular Model 	modynamics and binding tics ics ing, experiments with a focus on the	rmodynamics and kinetics	
 Acquire basic knowled Insight into properties basic knowledge to co Application of laws of the recognition reactions in Acquire basic knowled Acquisition of skills to Lübeck and of the DFG 	incres: ge on spectroscopic techniques to ar (e.g. structure, dynamics, spectroscop mpute molecules hermodynamics to describe chemica n biological systems ge to analyze time courses of chemic work independently and self-determi -guidelines.	ומועצפ (bio)molecules. Focu pic properties) of molecule ו reactions and biological ו al reactions and biological: ined in the laboratory with	us is on NMR and mass spectrometry techniques es employing theoretical models. Acquisition of processes with a focus on binding and processes regard to the roles of GSP of the University of
Grading through: • written exam			
Requires: • Organic Chemistry (LS1	600-KP10, LS1600-MLS)		
Responsible for this module: • Prof. Dr. rer. nat. Ulrich Teacher: • Institute of Chemistry a • Prof. Dr. rer. nat. Ulrich	Günther Ind Metabolomics Günther		



• PD Dr. phil. nat. Thomas Weimar

Literature:

- Peter Atkins and Julio de Paula: Physical Chemistry for the Life Sciences Oxford, University Press, Freeman and Company, 2006, ISBN 0-1992-8095-9
- Thomas Engel und Philip Reid: Physikalische Chemie Pearson Studium, 2006, ISBN 13: 978-3-8273-7200-0
- van Holde, Johnson & HoPrentice Hall: Principles of Physical Biochemistry New Jersey, 1998, 2006, ISBN 0-13-720459-0
- Atkins: Physical Chemistry Oxford University Press, Oxford Mel-bourne Tokyo, 1998, ISBN 0-19-850101-3 Paperback, Deutsche Ausgabe (dritte Auflage) bei Wiley VCH, 2002: ISBN 3-527-30236-0 Wiley-VCH, Weinheim
- Fersht, W. H.: Structure and Mechanism in Protein Science New York, 1999, ISBN 0-7167-3268-8
- Cantor & Schimmel: Biophysical Chemistry, Parts I-III Freeman and Company, New York, 1980, ISBN 0-71671188-5 Paperback
- H. Friebolin: Ein- und zweidimensionale NMR-Spektroskopie Wiley-VCH
- James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated approach Oxford University Press, 2008; second ed. 2013

Language:

• offered only in German

Notes:

- Prerequisites for the modul:
- None
- Prerequisites for admission to the written examination:
- Successful completion of the excercises as specified at the beginning of the semester

Modul exam(s):

- LS2300-L1: Biophysical Chemistry, written exam, 90 min, 100 % of module grade
- LS2300-L2: Practical course Biophysical Chemistry, ungraded practical course, 0 % of module grade, has to be passed

MML: Optional course in the 2nd semester master program with specialisation in Life Science

Biophysics: some specific practicals

The practical course takes place in September as compact course. Prerequisite LS1600 and LS2600

The module is better understandable if the modules Physics 1 or 2 have been attended before.

(Share of Institute of Physics in practical course is 25%.)



ration: Turnus of offer: each winter semester each winter semester ourse of study, specific field and term: each winter semester Master CLS 2023 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), IGe science, 3rd semester Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2009 (compulsory), IGe science, 3rd semester Master CLS 2009 (compulsory), Iffe science, 3rd semester Bachelor MLS 2009 (compulsory), Iffe science, 3rd semester Iasses and lectures: Workload: • 120 Hour • Biological Chemistry (lecture, 4 SWS) • 120 Hour • 60 Hours ontents of teaching: • Lecture topics: • 120 Hour • 60 Hours • Under leading • Chemical reactions to modify proteins • Synthesis of peptides • Chemical leading • Chemical reactions to follow the fate of molecules in cells and whole organisms ualification-goals/Competencies: • The nature of chemical bonds - an in depth treatment based on quantum mechar • How to use synthetic organic chemistry and characterize compounds • • How to use synthetic organic chemistry to solve biological questions • • In-depth treatment of reaction mechanisms of chemical reactions important in bic • • In-depth	l	S2600-KP06, LS2601 - Biol	ogical Chemistr	y (BiolChem06)	
emester each winter semester each winter semester each winter semester example of study, specific field and term: Master CL5 2023 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), Chemistry, 3rd semester Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2009 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2009 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2009 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), Bite sciences, 3rd semester Bachelor MLS 2016 (compulsory), Bite Science, 3rd semester Bachelor Bachelor Metabolomics Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar Bachelor Mall	:	Turnus of offer:		Credit points:	
ourse of study, specific field and term: Master CLS 2023 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2016 (compulsory), Chemistry, 3rd semester Bachelor MLS 2016 (compulsory), MML with specialization in Life Science, 1st semest Bachelor MLS 2009 (compulsory), Iffe sciences, 3rd semester Master CLS 2009 (compulsory), Iffe sciences, 3rd semester Biological Chemistry (lecture, 4 SWS) Morkload: Biological Chemistry (lecture, 4 SWS) Morkload: 120 Hours ontents of teaching: Lecture topics: Workload: Chemical reactions to modify proteins Synthesis of peptides Chemical reactions to modify proteins Synthesis of peptides Chemical reactions to follow the fate of molecules in cells and whole organisms Matification-goals/Competencies: The nature of chemical bonds In-depth treatment of reaction mechanisms of chemical reactions important in bio Analytical techniques to identify and characterize compounds rading through: written exam esponsible for this module: Prof. Dr. rer. nat. Ulrich Günther Por. Avran Mallagaray Prof. Dr. rer. nat. Ulrich Günther Prof. Dr. rer. nat. Ulrich Günther Por. Avran Mallagaray Prof. Dr. rer. nat. Ulrich Günther Prof. Dr. rer. nat. Ulrich Günther Por. Avran Mallagaray Prof. Dr. rer. nat. Ulrich Günther Prof. Dr. rer. nat. Warsten Seeger PD Dr. phil. nat. Thomas Weimar terature: Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar Houre Seeler an	er	each winter semester		6	
lasses and lectures: Workload: Biological Chemistry (lecture, 4 SWS) 120 Hour ontents of teaching: 60 Hours Lecture topics: What is Biological Chemistry? The nature of chemical bonds Chemical reactions to modify proteins Synthesis of peptides Chemical analytics - MS and NMR Metabolic labeling Chemical reactions to follow the fate of molecules in cells and whole organisms ualification-goals/Competencies: The nature of chemical bonds - an in depth treatment based on quantum mechar How to use synthetic organic chemistry to solve biological questions In-depth treatment of reaction mechanisms of chemical reactions important in bio Analytical techniques to identify and characterize compounds • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • •	of study, specific field and Master CLS 2023 (compulso achelor Molecular Life Scie achelor MLS 2018 (compul achelor MLS 2016 (compul Master CLS 2016 (compulso achelor MLS 2009 (compul	I term: ry), MML with specialization in Life nce 2024 (compulsory), Chemistry sory), Chemistry, 3rd semester sory), life sciences, 3rd semester ry), MML with specialization in Life sory), life sciences, 3rd semester	e Science, 1st semes 7, 3rd semester 9 Science, 1st semes	ter ter	
 Biological Chemistry (lecture, 4 SWS) 120 Hours 60 Hours 61 Hours 62 Hours 63 Hours 64 Hours 64 Hours 65 Hours 64 Hours 65 Hours 65 Hours 64 Hours 65 Hours 65 Hours 66 Hours 66 Hours 66 Hours 66 Hours 67 Hours of Chemical Chemical Donds 67 Hours of Chemical reactions to modify proteins 68 Synthesis of peptides 69 Chemical reactions to follow the fate of molecules in cells and whole organisms 69 Hours 60 Hours 60 Hours 60 Hours 60 Hours 60 Hours 61 Hours of Chemical bonds 61 Hours of Chemical Pool 61 Hours of Chemical Pool 61 Hours of Chemical Competencies: 62 Hours of Chemical Pool 63 Hours of Chemical Pool 64 Hours of Chemical Pool 64 Hours of Chemical Pool 75 Hours of Chemical Pool 76 Hours of Chemistry and Metabolomics 76 Prof. Dr. ren. at. Ulrich Günther 76 Prof. Dr. ren. at. Wasten Seeger 76 Prof. Dr. ren. at. Kasten Seeger 76 Prof. Dr. Poil. nat. Thomas Weimar 77 Hour Y. Bruice: Organic Chemistry - Pearson Verlag <	and lectures:		Workload:		
ontents of teaching: Lecture topics: What is Biological Chemistry? The nature of chemical bonds Chemical reactions to modify proteins Synthesis of peptides Chemical analytics - MS and NMR Metabolic labeling Chemical reactions to follow the fate of molecules in cells and whole organisms ualification-goals/Competencies: The nature of chemical bonds - an in depth treatment based on quantum mechar How to use synthetic organic chemistry to solve biological questions In-depth treatment of reaction mechanisms of chemical reactions important in bio Analytical techniques to identify and characterize compounds written exam esponsible for this module: Prof. Dr. rer. nat. Ulrich Günther acher: Institute of Chemistry and Metabolomics Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar terature: Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 	iological Chemistry (lectur	e, 4 SWS)	 120 Hours private studies 60 Hours in-classroom work 		
 Lecture topics: What is Biological Chemistry? The nature of chemical bonds Chemical reactions to modify proteins Synthesis of peptides Chemical analytics - MS and NMR Metabolic labeling Chemical reactions to follow the fate of molecules in cells and whole organisms ualification-goals/Competencies: The nature of chemical bonds - an in depth treatment based on quantum mechar How to use synthetic organic chemistry to solve biological questions In-depth treatment of reaction mechanisms of chemical reactions important in bio Analytical techniques to identify and characterize compounds a rading through: written exam esponsible for this module: Prof. Dr. rer. nat. Ulrich Günther acher: Institute of Chemistry and Metabolomics Prof. Dr. rer. nat. Ulrich Günther Dr. Alvaro Mallagaray Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar terature: Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 	ts of teaching:				
 ualification-goals/Competencies: The nature of chemical bonds - an in depth treatment based on quantum mechar How to use synthetic organic chemistry to solve biological questions In-depth treatment of reaction mechanisms of chemical reactions important in bio Analytical techniques to identify and characterize compounds a a a a a a a a a b b c a a a a a b a a a a a a a a a b a b a a a a a a a b a a a a b a a a a b a a a b a a a a b a a a b a a a b a <li< td=""><th>The nature of chemical bon Chemical reactions to modi ynthesis of peptides Chemical analytics - MS and Aetabolic labeling Chemical reactions to follow</th><th>y: ds fy proteins I NMR v the fate of molecules in cells and</th><td>l whole organisms</td><td></td></li<>	The nature of chemical bon Chemical reactions to modi ynthesis of peptides Chemical analytics - MS and Aetabolic labeling Chemical reactions to follow	y: ds fy proteins I NMR v the fate of molecules in cells and	l whole organisms		
 rading through: written exam esponsible for this module: Prof. Dr. rer. nat. Ulrich Günther eacher: Institute of Chemistry and Metabolomics Prof. Dr. rer. nat. Ulrich Günther Dr. Alvaro Mallagaray Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar terature: Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 inguage: offered only in German 	n-depth treatment of react analytical techniques to ide	ion mechanisms of chemical react ntify and characterize compounds	ions important in bi s	ological systems	
 written exam esponsible for this module: Prof. Dr. rer. nat. Ulrich Günther eacher: Institute of Chemistry and Metabolomics Prof. Dr. rer. nat. Ulrich Günther Dr. Alvaro Mallagaray Prof. Dr. rer. nat. Karsten Seeger PD Dr. phil. nat. Thomas Weimar terature: Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 anguage: offered only in German 	ı through:				
esponsible for this module: • Prof. Dr. rer. nat. Ulrich Günther eacher: • Institute of Chemistry and Metabolomics • Prof. Dr. rer. nat. Ulrich Günther • Dr. Alvaro Mallagaray • Prof. Dr. rer. nat. Karsten Seeger • PD Dr. phil. nat. Thomas Weimar terature: • Paula Y. Bruice: Organic Chemistry - Pearson Verlag • James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 inguage: • offered only in German	vritten exam				
 iterature: Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 anguage: offered only in German 	sible for this module: rof. Dr. rer. nat. Ulrich Gür r: nstitute of Chemistry and M rof. Dr. rer. nat. Ulrich Gür Dr. Alvaro Mallagaray rof. Dr. rer. nat. Karsten See D Dr. phil. nat. Thomas We	ther letabolomics ther eger imar			
 Paula Y. Bruice: Organic Chemistry - Pearson Verlag James Keeler and Peter Wothers: Chemical Structure and Reactivity: An integrated 2013ISBN: 978-0-19-928930-1 anguage: offered only in German 	·····				
anguage: • offered only in German	aula Y. Bruice: Organic Che ames Keeler and Peter Wo 013ISBN: 978-0-19-928930	emistry - Pearson Verlag hers: Chemical Structure and Read -1	ctivity: An integrated	d approach - Oxford University Press, 2008; second	
offered only in German	ge:				
	ffered only in German				
otes:					



Prerequisites for the module: - None

Prerequisites for admission to the written examination: - None

Modul exam(s): - LS2600-L1: Biological Chemistry, written exam, 90 min, 100 % of module grade



LS4020 A - Module part LS4020A: Crystallography (StrAnaKris)				
Duration:	Turnus of offer:	Credit points:	Max. group size:	
1 Semester	each winter semester	3	60	
Course of study, specific field Master CLS 2023 (Mode Master Infection Biolog Master Infection Biolog Master Biophysics 2019 Master CLS 2016 (Mode Master MLS 2018 (Mode Master MLS 2016 (Mode	d and term: ule part of a compulsory module), N y 2018 (Module part of a compulso y 2012 (Module part of a compulso) (Module part of a compulsory mod ule part of a compulsory module), N ule part of a compulsory module), I ule part of a compulsory module), I	ML with specialization in Life Sciory module), Infection Biology, 1st ory module), Infection Biology, 1st dule), biophysics, 1st semester ML with specialization in Life Scio ife sciences, 1st semester ife sciences, 1st semester	ence, 3rd semester semester semester ence, 3rd semester	
Classes and lectures:		Workload:		
LS4021-V: Crystallogra	bhy (lecture, 2 SWS)	 60 Hours private s 30 Hours in-classro	tudies bom work	
 Contents of teaching: Crystal growth, precipitant and phase diagram, crystal morphology, symmetry and space groups, crystallogenesis X-rays, X-ray sources, X-ray diffraction, Bragg's law, reciprocal lattice and Ewald-sphere construction X-ray diffraction by electrons, Fourier analysis and synthesis Protein structure determination by X-ray diffraction, crystallographic phase problem, Patterson map, molecular replacement (MR), multiple isomorphous replacement (MR), multiple isomorphous replacement (MIR), multi-wavelength anomalous diffraction (MAD) Crystallography and the drug discovery process: studying protein-ligand interactions Practical exercises employing an X-ray generator (collection of a diffraction image) and the computer (MR; calculation and interpretation of electron density maps) Site visit at the Synchrotron DESY (Hamburg) Qualification-goals/Competencies: They have a general scientific competence in macromolecular X-ray diffraction analysis They have the methodological competence to grow protein crystals by hanging or sitting drops They have the methodological competence to correctly interpret (salt or protein) the diffraction image of a crystal using the Ewald Sphere construction 				
 They can calculate and interprete electron density maps They have the methodological competence, to apply structure- or fragment-based techniques for lead compound identification They have the communication competency to convey the principles of X-ray diffraction theory 				
Grading through: • see Notes				
Responsible for this module Siehe Hauptmodul Teacher: Institute of Biochemistr Dr. math. et dis. nat. Je	ry roen Mesters			
Literature: • Jan Drenth: Principles (of Protein X-ray Crystallography - So	cience+Business Media, LLC, New	York	
Language: • offered only in English				
Notes:				



Is part of Module:

- LS4021-KP06 (former LS4020-IB) -> Prof. Hübner
- LS4020-KP06 (former LS4020-MLS) and LS4020-KP12 -> Prof. Peters
- LS4026-KP06 start in 2023

4 exercises, 2 hours each, are offered in addition to the lecture. Dates are given at the start of the semester.

It is a compulsory module part for the Master MLS with a focus on structural biology.



Duration:Turnus of offer:1 Semestereach winter semester	Credit points: 3
1 Semester each winter semester	3
 Course of study, specific field and term: Master CLS 2023 (Module part of a compulsory module), MML Master MLS 2018 (Module part of a compulsory module), struct Master Infection Biology 2018 (Module part of a compulsory module) Master Biophysics 2019 (Module part of a compulsory module) Master CLS 2016 (Module part of a compulsory module), MML Master MLS 2016 (Module part of a compulsory module), struct Master Infection Biology 2012 (Module part of a compulsory module), struct Master Infection Biology 2012 (Module part of a compulsory module), struct Master CLS 2010 (module part), computational life science / life Master MLS 2009 (Module part of a compulsory module), struct 	with specialization in Life Science, 3rd semester ture biology, 1st semester nodule), Interdisciplinary modules, 1st semester), biophysics, 1st semester with specialization in Life Science, 3rd semester ture biology, 1st semester nodule), Interdisciplinary modules, 1st semester e sciences, 3rd semester ture biology, 1st semester
Classes and lectures:	Workload:
NMR-Spectroscopy (lecture, 2 SWS)	 60 Hours private studies 30 Hours in-classroom work
 Lecture topics: Assignment of NMR spectra Description of the NOESY experiment using the vector model Chemical Exchange and Transfer-NOEs Multidimensional NMR spectroscopy Assignment strategy for peptides Introduction into the product operator formalism (POF) Description of the COSY and of the HSQC experiment using PC NMR experiments for the assignment of proteins NMR structural analysis of proteins Experiments to probe the motions of protein)F
 Students are able to assign and analyze complex NMR spectra Understanding of NMR experiments based on the product ope Students are able to analyze structure and dynamics of proteir 	erator formalism ns through NMR experiments
Grading through: • see Notes	
Responsible for this module: • Prof. Dr. rer. nat. Ulrich Günther Teacher: • Institute of Chemistry and Metabolomics • Prof. Dr. rer. nat. Ulrich Günther • Dr. Alvaro Mallagaray	
Literature: James Keeler: Understanding NMR Spectroscopy - Wiley : Malcolm H. Levitt: Spin Dynamics - Basics of Nuclear Magnetic D. Neuhaus & M. P. Williamson: The Nuclear Overhauser Effect Timothy Claridge: High-Resolution NMR Techniques in Organic : Current scientific literature	Resonance - Wiley-VCH in Structural and Conformational Analysis - Wiley-VCH c Chemistry - Pergamon Press



offered only in English

Notes:

This lecture is a part of modules:

- LS4021-KP06 (former LS4020-IB) -> Prof. Hübner
- LS4020-KP06 (former LS4020-MLS) and LS4020-KP12 -> Prof. Peters
- LS4027-KP06 start 2023

Exercises are integrated into the lectures. It is a compulsory module part for the Master MLS with a focus on structural biology.

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LS4020 D - Module part LS4020D: Microscopy: Techniques and Applications (StrAnaMikr)				
Duration:	Turnus of offer:		Credit points:	
Semester each winter semester			3	
 Course of study, specific field and term: Master CLS 2023 (Module part of a compulsory module), MML with specialization in Life Science, 3rd semester Master MLS 2018 (Module part of a compulsory module), structure biology, 1st semester Master Infection Biology 2018 (Module part of a compulsory module), Interdisciplinary modules, 1st semester Master Biophysics 2019 (Module part of a compulsory module), biophysics, 1st semester Master CLS 2016 (Module part of a compulsory module), MML with specialization in Life Science, 3rd semester Master MLS 2016 (Module part of a compulsory module), structure biology, 1st semester Master MLS 2016 (Module part of a compulsory module), structure biology, 1st semester Master Infection Biology 2012 (Module part of a compulsory module), Interdisciplinary modules, 1st semester Master Infection Biology 2012 (Module part of a compulsory module), Interdisciplinary modules, 1st semester Master Infection Biology 2012 (Module part of a compulsory module), Interdisciplinary modules, 1st semester Master CLS 2010 (module part) computational life science / life sciences 3rd semester 				
Classes and lectures:		Workload:		
LS4027-V Optical Methods (lecture, 2	2 SWS)	60 Hours private30 Hours in-class	studies room work	
Contents of teaching: Basic principles of optics Light sources and detectors Classical light microscopy Photophysics, fluorescence microscopy Confocal microscopy Nonlinear microscopy Fluorescent dyes; GFP and genetically encoded fluorescent markers; live cell/intravital imaging: important experimental parameters Protein-protein interactions in living cells: FRET, FLIM; biosensors Photoactivatable/switchable fluorescent proteins; fluorescent timers Optogenetics: Cell manipulation by light Super-resolution 3D fluorescence microscopy: STED, PALM, STORM Optical tweezers as instrument for nanomanipulation Visualization and quantitative evaluation; data format and data storage media In vivo imaging in tissues and living animals Bioluminescence and optoacoustic imaging Flow cytometry & fluorescence activated cell sorting High-content screening; optical sensor technology 				
 Qualification-goals/Competencies: Students acquire professional competence in basic principles and concepts of optics. Students know the basics of light and fluorescence microscopy. They know and understand the most important methods for marking and microscopic visualization of proteins and sub-cellular structures. Students know the possible applications of live cell microscopy, intravital imaging, and quantitative fluorescence techniques in biological questions. They know basic techniques of 3-dimensional optical imaging of tissues and animals. Student are familiar with current research topics in the field of optical methods in the life sciences and are able to evaluate them in terms of their application maturity and potential. Students can classify optical methods according to their complexity and outline possible applications. The students have the social and communication skills to discuss given questions within group work for lecture preparation and lecture follow-up. 				
Responsible for this module: Siehe Hauptmodul				



Teacher:
Institute of Biomedical Optics
 Prof. Dr. rer. nat. Gereon Hüttmann Prof. Dr. rer. nat. Sebastian Karpf Dr. rer. nat. Norbert Linz Prof. Dr. rer. nat. Robert Huber
Literaturo
 J. B. Pawley, ed.: Handbook of Biological Confocal Microscopy, Springer V. V. Tučin: Handbook of optical biomedical diagnostics, SPIE Press L. V. Wang, and Hi. Wu: Biomedical optics principles and imaging, Wiley : :
Language:
offered only in English
Notes:
Is module part of: - LS4021-KP06 (former LS4020-IB) -> Prof. Hübner - LS4020-KP06 (former LS4020-MLS) and LS4020-KP12 -> Prof. Peters - LS4026-KP06 start 2023
(Share of Institute of Biomedical Optics to this lecture is 100%)





	LS4020-KP08 - Advanced Topie	cs in Life Science (Ve	rtLSKP08)
Duration:	Turnus of offer:		Credit points:
1 Semester	each winter semester		8
Course of study, specific fi	eld and term:		
Master CLS 2023 (corMaster CLS 2016 (cor	mpulsory), MML with specialization in Life S mpulsory), MML with specialization in Life S	cience, 3rd semester cience, 3rd semester	
Classes and lectures:		Workload:	
 See module part LS4 See module part LS4 See module part LS4 SWS) See module part LS4 applications (lecture, 	020 A: Crystallography (lecture, 2 SWS) 020 B: NMR-Spectroscopy (lecture, 2 SWS) 020 C: Single Molecule Methods (lecture, 2 020 D: Microscopy: techniques and , 2 SWS)	 180 Hours private 60 Hours in-class 	e studies room work
Contents of teaching: • See module parts LS	4020 A to D		
Oualification-goals/Compe	etencies:		
See module parts LS	4020 A to D		
Grading through:			
• written exam			
Responsible for this modu	le:		
• Prof. Dr. rer. nat. The	omas Peters		
Teacher:			
Institute of Physics			
 Institute for Biology Institute of Biochemi 	stry		
 Institute of Chemistry 	y and Metabolomics		
 Prof. Dr. rer. nat. The Prof. Dr. rer. nat. Rolf Dr. math. et dis. nat. Prof. Dr. rer. nat. Kars Prof. Dr. rer. nat. Chri Prof. Dr. rer nat. Raine 	omas Peters Hilgenfeld Jeroen Mesters sten Seeger istian Hübner er Duden		
Language:			
 English, except in cas 	se of only German-speaking participants		
Notes:			



Admission requirements for taking the module: - None

Admission requirements for participation in module examination(s):

- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.

Module exam(s):

- LS4020-L1: Advanced Topics in Life Science, 2 written exams (90 min each) or oral exams (30 min each), 2 x 50 % of module grade

The 2 credit points higher workload compared to the two submodules results from the required self-study for CLS students.

Two of the four above-mentioned courses must be selected. Both selected module parts count for 50% of the grade. There is a separate written exam for each module part. The two chosen module parts must be written on one date, i.e. on the first date at the end of the semester or on the second of the offered dates at the end of the vacations. The date may be spread over two days, as the examinations for different module parts may be offered on different days.

If only the partial exam for one module part is written, the exam is considered failed and will be counted as a failed attempt.



CS4336-KP08 - /	Artificial intelligence, image a	inalysis and compute	er graphics (MoKiBiCo)
Duration:	Turnus of offer:		Credit points:
1 Semester	each summer semester		8
Course of study, specific field and			
Master CLS 2023 (compulso)	rv) MMI with specialization in Image	Processing 2nd semester	
Classes and lectures:		Workload:	
 Model and Al-based image (SWS) 	processing in medicine (lecture, 2	 110 Hours private 90 Hours in-classre 	studies and exercises
 Model and Al-based image (SWS) 	processing in medicine (exercise, 1	• 40 Hours exam pre	eparation
 computer graphics (lecture, computer graphics (exercise	2 SWS) 2, 1 SWS)		
Contents of teaching:			
Methods and algorithms for	the analysis and visualization of mec	dical images including curr	rent research activities in the field of medical
image computing. The follo	wing methods and algorithms are exp	plained:	
Fundamentals of neural net	works in medical image processing	'	
 Convolutional Neural Netwo 	orks and Deep Learning in Medical Im	age Processing	
U-Nets for image segmentat	ion	. .	
Autoencoder and Generative Data augmentation tashning	e Adversarial Networks in Medical Im-	age Processing	
Bandom Decision Forests fo	ues r the segmentation of medical image	adata	
 Statistical shape models: get 	neration and application for image set	eqmentation	
 ROI-based segmentation and 	d cluster analysis for the segmentatic	on of multispectral image c	data
Live wire segmentation	, 5		
 Segmentation with active control 	ontour models and deformable mode	ls	
 Non-linear image registration 	'n		
Atlas-based segmentation a	nd multi-atlas segmentation using no	on-linear registration	
3D Visualization techniques	in medicine		
Geometric transformations i	n 2D and 3D		
Transformations between C	artesian coordinate systems		
Planar and perspective proje			
 Polygonal models 			
 Illumination models and sha 	ading methods		
Texture Mapping	-		
 Culling and clipping 			
 Hidden line and surface rem 	ioval		
Raster graphics algorithms			
Ray tracing Shadows reflections and tra			
 Basics of graphics program 	ning with OpenGL and GLSL		
Qualification-goals/Competencies	s:		
 Students can classify and ex 	plain advanced methods for medical	image analysis on the basi	is of their characteristics. They can select
these methods based on a g	jiven specific application.		
 They are able to explain adv Random Decision Forests an 	anced methods of cluster analysis an id to characterize them by their prop	d classification especially v erties.	with Convolutional Neural Networks and
They can explain the conception	otion of neural network architectures	of U-Nets, GANs or auto-e	ncoders in detail. They can explain in detail
the conception of neural ne	twork architectures of U-Nets, GANs of the second limits as well as a surger and	or auto-encoders.	ico of noural notworks in modical image
 mey know prerequisites, processing 	spiems and minus as well as augment	ration techniques for the u	ise of neural networks in medical image
 They know different approa 	ches to model-based segmentation, «	can describe the different ı	model assumptions made here and are able

- to explain the optimization strategies and algorithms used here.
- They are able to assess the properties of various non-linear image registration methods and to select and parametrize similarity measures and regularization terms for a specific registration problem.



 They are familiar with methods of multi-atlas segmentation and can explain and exemplify the properties of different label fusion approaches. They can differentiate between different medical visualization techniques, classify them according to their specific advantages and disadvantages, and select and apply them in a meaningful way depending on a specific application problem. Students know the basic concepts, algorithms and methods in computer graphics They are able to implement principle algorithms They are able to explain the learned techniques and to assess their possibilities and limitations 	
Grading through: • written exam	
Demuisee	
 Linear Algebra and Discrete Structures 2 (MA1500-KP08, MA1500) Linear Algebra and Discrete Structures 1 (MA1000-KP08, MA1000) Medical Image Computing (CS3310-KP04) 	
Responsible for this module:	
Prof. Dr. rer. nat. habil. Heinz Handels	
leacher:	
Institute of Medical Informatics	
 Prof. Dr. rer. nat. habil. Heinz Handels Dr. rer. nat. Jan Ehrhardt 	
iterature:	
 H. Handels: Medizinische Bildverarbeitung - 2. Auflage, Vieweg u. Teubner 2009 T. Lehmann: Handbuch der Medizinischen Informatik - München: Hanser 2005 M. Sonka, V. Hlavac, R. Boyle: Image Processing, Analysis and Machine - Elsevier, 2007 B. Preim, C. Botha: Visual Computing for Medicine - 2nd Edition, Elsevier, 2013 Foley et. al: Grundlagen der Computergrafik - Addison-Wesley, 1994 	
.anguage:	
Notes:	
Admission requirements for taking the module: - None (the competences of the modules mentioned under "requires" are needed for this module, but are not a formal prerequisite)	
Admission requirements for participation in module examination(s): - Successful completion of exercise assignments and programming projects as specified at the beginning of the semester	
Module Exam(s): - CS4332-L1: Model- and Al-based Image Processing in Medicine, written exam, 90 min, 50% of module grade	

- CS3205-L1: Computer Graphics, written exam, 90 min, 50% of module grade



Λ	/A5038-KP08 - Advanced Topics i	n Image Processing	J (VertBVKP08)
Duration:	Turnus of offer:		Credit points:
1 Semester	Semester each winter semester		8
Course of study, specific fie • Master CLS 2023 (com • Master CLS 2016 (com	l d and term: pulsory), MML with specialization in Image pulsory), MML with specialization in Image	e Processing, 3rd semeste e Processing, 3rd semeste	er er
Classes and lectures:		Workload:	
Advanced Topics in Ir courses, 3 SWS)	nage Processing (depends on the chosen	240 Hours overa courses	all workload, division depending on the choser
Contents of teaching: • Familiarization with a • Familiarization with th • Practical implementat • Details as in the descr	dvanced methods in image and signal pro- he underlying mathematical models and m tion, critical evaluation and interpretation o ription of the chosen courses	cessing nethods of the results	
 Students have advance The have an improved They can see their privile Interdisciplinary qualities Students have advance They can translate the They are experienced They can think abstract 	ced knowledge in a special or application a d overview of the diversity of the field. or knowledge in a different context and bu fications: ced skills in modeling. eoretical concepts into practical solutions. in implementation. ictly about practical problems.	area within the field of im uild new connections.	nage and signal processing.
Grading through: • see Notes			
Responsible for this module • Prof. Dr. rer. nat. Jan N • Prof. Dr. rer. nat. Jan L Teacher: • Institute of Mathemat • N.N.	e: Aodersitzki .ellmann :ics and Image Computing		
Language:			
German and English s	kills required		
Notes:			
The module comprises 8 signal processing. Impo	3 ECTS credit points, which must be accour rtant: The chosen combination must be ag	nted for by combining co reed upon in advance by	purses within the area of advanced image and / the person responsible for the module. Please

refer to the further information in the Moodle course Registration for



ME4411 T - Module part: Computed Tomography (CT)			
Duration:	Turnus of offer:		Credit points:
1 Semester	ster each winter semester		3
Course of study, specific field and term: Master CLS 2023 (Module part of a c Master MES 2020 (Module part of a c Master Entrepreneurship in Digital T Master CLS 2016 (Module part of a c Master Computer Science 2014 (mod Master Medical Informatics 2014 (mod Master Entrepreneurship in Digital T	ompulsory module), MML v compulsory module), medic echnologies 2020 (module ompulsory module), MML v dule part), Module part, Arb odule part), Module part, Arb echnologies 2014 (module	with specialization in Image cal engineering science, 1st part), Module part, Arbitra with specialization in Image pitrary semester rbitrary semester part), Module part, Arbitra	e Processing, 1st semester t semester ry semester e Processing, 1st semester ry semester
Master MES 2014 (Module part of a c	compulsory module), medic	cal engineering science, 1s	t semester
Classes and lectures: • Computed Tomography (lecture, 2 S	WS)	Workload: • 40 Hours private • 35 Hours in-class • 15 Hours exam p	studies sroom work preparation
Contents of teaching:		2	
 Signal processing (recapitulation of Mathematical methods in image rec X-Ray (fundamental principles, quan Computed Tomography * devices, * * algebraic and statistical image reco 	fundamental principles in s onstruction and signal prod tum statistics) current and past technolog onstruction, * image artifact	ignal processing) cessing gy, * signal processing, * Fo ts, * technical and clinical a	ourier-based 2D and 3D image reconstruction, applications, * dose.
 Qualification-goals/Competencies: Students are able to create an overview of the signal chain for medical imaging. They are able to explain the mathematical background for the reconstruction of CT images. They are able to explain the basics for the creation of X-ray. They are able to list all generations of CT devices and explain differences and advances. They are able to apply the Fourier transform. They are able to explain the mathematical basics for the two-dimensional image reconstruction. They are able to create and apply an algebraic approach for the reconstruction of CT images. They are able to create and apply an statistical approach for the reconstruction of CT images. They are able to outline the differences between two dimensional and three dimensional image reconstruction. They are able to transfer methods from two dimensional to three dimensional image reconstruction. 			
Grading through: • Oral examination			
 • Oral examination Responsible for this module: Siehe Hauptmodul Teacher: Institute of Medical Engineering Prof. Dr. rer. nat. Thorsten Buzug Literature: T. M. Buzug: Computed Tomography, From Photon Statistics to Modern Cone Beam CT - Springer-Verlag, Berlin/Heidelberg, 2008 T. M. Buzug: Einführung in die Computertomographie, Mathematisch-physikalische Grundlagen der Bildrekonstruktion - Springer-Verlag, Berlin/Heidelberg, 2004 			
German and English skills required			
Notes:			



Prerequisites for attending the module: - None

Prerequisites for participation in the exam(s): - None

Module exam(s):

- ME4411-L1: Computed Tomography, oral exam, 100 % of module grade

(Is module part of CS4512, ME4410-KP12, ME4415-KP06)



ME4412	T - Module part: Mag	netic Resonance Imag	ging (MRT)	
Duration:	Turnus of offer:		Credit points:	
1 Semester each winter semester		3		
Course of study, specific field and term: Master CLS 2023 (Module part of a of Master MES 2020 (Module part of a Master Entrepreneurship in Digital Master Medical Informatics 2019 (m Master CLS 2016 (Module part of a of Master Computer Science 2014 (mo Master Medical Informatics 2014 (mo Master Entrepreneurship in Digital Master Entrepreneurship in Digital Master MES 2014 (Module part of a	compulsory module), MML compulsory module), medi Fechnologies 2020 (module odule part), Module part, A compulsory module), MML dule part), Module part, Arl odule part), Module part, Ar fechnologies 2014 (module compulsory module), medi	with specialization in Image cal engineering science, 1st part), Module part, Arbitra rbitrary semester with specialization in Image pitrary semester rbitrary semester part), Module part, Arbitra cal engineering science, 1st	e Processing, 1st semester t semester ry semester e Processing, 1st semester ry semester t semester	
Classes and lectures:		Workload:		
Magnetic Resonance Imaging (lectu	ıre, 2 SWS)	 40 Hours private 30 Hours in-class 15 Hours exam p 	studies room work reparation	
 Contents of teaching: Physical fundamentals of magnetic resonance imaging: nuclear magnetic resonance, relaxation mechanisms, principles of position encodingprinciples of spatial encoding, relaxation) Construction of basic imaging sequences, weighting Concept of k-space Coherence pathways Hardware components of a clinical MR system Possible sources of hazard for patients Influence of measurement parameters on signal-to-noise ratio Causes of image artefacts 				
Qualification-goals/Competencies: • The students can explain the physic • They can explain the idea behind in • They can recognise the causes of in • The can list advantages and disadva • They can list possible sources of has	al principles of NMR and M nportant imaging sequence nportant image artefacts. antages of MRT, compared t zard for patients, explain th	RI. es, using a pulse sequence c to other imaging technique eir causes and point out str	diagram. es. rategies for avoiding these.	
Grading through: Oral examination				
Responsible for this module: Siehe Hauptmodul Teacher: Institute of Medical Engineering Prof. Dr. rer. nat. Martin Koch 				
 Literature: Liang, ZP., Lauterbur, P. C.: Principles of Magnetic Resonance Imaging: A Signal Processing Perspective - IEEE Press, New York 2000 				
Language: • German and English skills required				
Notes:				



Prerequisites for attending the module: - None

Prerequisites for participation in the exam(s): - None

Module exam(s):

- ME4412-L1: Magnetic Resonance Imaging, oral exam, 30 min, 100 % of module grade

(Is module part of CS4512, ME4410-KP12, ME4415-KP06, ME4414-KP06)



	ME4415-KP06 - Ima	iging (BildgbKP06)	
Duration: Turnus of offer: Credit points:			Credit points:
1 Semester	nester each winter semester		6
Course of study, specific fie • Master CLS 2023 (com • Bachelor CLS 2016 (op • Master CLS 2016 (com	Id and term: npulsory), MML with specialization in Image ptional subject), mathematics, 5th semeste npulsory), MML with specialization in Image	e Processing, 1st semester r e Processing, 1st semester	
Classes and lectures: • ME4411 T: Modul part • ME4412 T: Modul part SWS)	t: Computed Tomography (lecture, 2 SWS) t: Magnetic Resonance Imaging (lecture, 2	Workload: • 80 Hours private s • 70 Hours in-classr • 30 Hours exam pr	tudies oom work eparation
Contents of teaching: • as described for the n	nodule parts		
Qualification-goals/Competent • as described for the n	t encies: nodule parts		
Grading through: • Oral examination			
Responsible for this module • Prof. Dr. rer. nat. Thors Teacher: • Institute of Medical Er • Prof. Dr. rer. nat. Thors • Prof. Dr. rer. nat. Mart	e: sten Buzug ngineering sten Buzug in Koch		
Literature: • T. M. Buzug:			
Language: • German and English s	kills required		
Notes: Prerequisites for attendi - None Prerequisites for particip - None Module exam(s): - ME4415-L1: Imaging, c	ing the module: pation in the exam(s): pral exam, 30 min, 100 % of module grade		
(Consists of module par	ts ME4411 T, ME4412 T)		



MA4661-KP08, MA4661 - Genetic Epidemiology 2 (GenEpi2)					
Duration:	Turnus of offer:	Credit points:	Max. group size:		
1 Semester	each summer semester	8	20		
 Course of study, specific field and term: Master CLS 2023 (compulsory), MML with specialization in Genetic Statistics, 2nd semester Bachelor CLS 2023 (optional suject), mathematics, 6th semester Bachelor CLS 2016 (optional subject), mathematics, 6th semester Master CLS 2016 (compulsory), MML with specialization in Genetic Statistics, 2nd semester Bachelor CLS 2010 (optional subject), mathematics, 6th semester Bachelor CLS 2010 (optional subject), mathematics, 6th semester Master CLS 2010 (optional subject), mathematics, 6th semester Master CLS 2010 (optional subject), mathematics, 6th semester 					
Classes and lectures:		Workload:			
 Genetic Epidemiology 2 Genetic Epidemiology 2 Genetic Epidemiology 2 	(lecture, 2 SWS) (exercise, 1 SWS) (practical course, 2 SWS)	 135 Hours private stu 75 Hours in-classroor 30 Hours exam prepared 	udies n work aration		
 Contents of teaching: Classical methods of ger analysis - Linkage analysis Current topics in genetic randomization Analysis of genetic data studies (linkage and association) 	netic epidemiology: - Familial aggreg is for quantitative phenotypes - Linl e epidemiology, e.g.: - Association te using specialized software package pociation analyses)	gation and heritability - Model-bas kage analyses for quantitative phe ests for rare variants - Analysis of C s (such as PLINK and MERLIN): - Ge	sed linkage analysis - Model-free linkage motypes - Family-based association tests Omics data - Polygenic scores - Mendelian enome-wide association studies - Family		
Qualification-goals/Competen • Students will be able to • They know current analy • They can perform eleme • They will be able to use	 Qualification-goals/Competencies: Students will be able to name and describe the most important procedures for linkage and association analysis in family studies. They know current analysis methods in genetic epidemiology. They can perform elementary tests by hand and interpret the results. They will be able to use software for more complex testing procedures and interpret the results. 				
Grading through: • Written or oral exam as announced by the examiner					
Is requisite for: • Seminar Genetic Epidemiology (MA5129-KP04, MA5129)					
Requires: • Biostatistics 2 (MA2600-KP07) • Biostatistics 1 (MA1600-KP04, MA1600, MA1600-MML) • Genetic Epidemiology 1 (MA3200-KP04, MA3200)					
Responsible for this module: • Prof. Dr. rer. nat. Silke Szymczak Teacher: • Institute of Medical Biometry and Statistics • Prof. Dr. rer. nat. Silke Szymczak • MitarbeiterInnen des Instituts					
 Ziegler, Andreas; König Inke R (2010): A Statistical Approach to Genetic Epidemiology. Concepts and Applications - 2nd ed., Wiley-VCH: Weinheim Bickeböller, Heike; Fischer, Christine (2007): Einführung in die Genetische Epidemiologie - Springer: New York Recent review articles: (to be announced in lecture) 					



Language:
offered only in German
Notes:
Admission requirements for taking the module:
- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)
Admission requirements for participation in module examination(s):
- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.
Module exam(s):
- MA4661-L1: Genetic Epidemiology 2, written exam (90 min) or oral exam (30 min), 100 % of module grade
- MA4661-L2: Practical Course Genetic Epidemiology 2, ungraded practical course, 0 % of module grade, must be passed
(Share of Institute of Medical Biometry and Statistics in V is 100%)
(Share of Institute of Medical Biometry and Statistics in Ü is 100%)

(Share of Institute of Medical Biometry and Statistics in P is 100%)



M	A5129-KP04, MA5129 - Semi	nar Genetic Epide	emiology (SemGenEpi)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	each winter semeste	≥r	4 (Тур В)		
Course of study, specific fie Master CLS 2023 (com Master CLS 2016 (com Master CLS 2010 (opti Master CLS 2010 (com	Id and term: pulsory), MML with specialization in pulsory), MML with specialization in onal suject), mathematics, 3rd seme pulsory), computational life science	Genetic Statistics, 3rd Genetic Statistics, 3rd ster / biostatistics, 3rd sem	semester semester nester		
Classes and lectures:		Workload:			
• Seminar Genetic Epide	emiology (seminar, 2 SWS)	 90 Hou present 30 Hou 	rs work on an individual topic with written and oral tation rs in-classroom work		
Contents of teaching: • Become acquainted w written and oral form	rith current topics in genetic epidem	niology overall and in c	letail, typically using a current scientific publication, in		
Qualification goals/Compat	anaian				
 The students have the into scientific perspect They are competent to They have the communication of the provide the communication of the provide the providet the prov	 The students have the methodological competence to master the thorough analysis of a circumscribed scientific topic and to put it into scientific perspective. They are competent to present their results comprehensively in written form. They have the communication competence to orally present a scientifically complex topic in a coherent way. They have the communication competence to take an active part in a scientific discussion. 				
Grading through: • Oral presentation and	Grading through:Oral presentation and written report				
Requires:					
Genetic EpidemiologyGenetic Epidemiology	Genetic Epidemiology 2 (MA4661-KP08, MA4661) Genetic Epidemiology 1 (MA3200-KP04, MA3200)				
Responsible for this module • Prof. Dr. rer. nat. Silke Teacher: • Institute of Medical Bi- • Prof. Dr. rer. nat. Silke	:: Szymczak ometry and Statistics Szymczak				
Language:					
English, except in case	English, except in case of only German-speaking participants				
Notes: Admission requirements - None (The competenci Admission requirements - Examination prerequisi and positively evaluated Module exam(s):	for taking the module: es of the modules listed under 'Requ for participation in module examina ites can be defined at the beginning before the first examination.	uires' are needed for th ation(s): of the semester. If pre	nis module, but are not a formal prerequisite) Pliminary work is defined, it must have been completed		
Specialized literature will be named in class.					

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	MZ4010-KP04, MZ4010 - 0	Clinical Epidemiolo	ygy (KlinEpi)		
Duration:	Turnus of offer:		Credit points:		
Semester each winter semester 4			4		
Course of study, specific field a Master CLS 2023 (compul Bachelor Medical Informa Master CLS 2016 (compul Bachelor Medical Informa Bachelor Medical Informa Master CLS 2010 (compul Master Computer Science	nd term: sory), MML with specialization in Ge tics 2019 (optional subject), medical sory), MML with specialization in Ge tics 2014 (compulsory), medical con tics 2011 (compulsory), medical con sory), computational life science / bi 2012 (compulsory), specialization fi	netic Statistics, 3rd sem l computer science, 4th netic Statistics, 3rd sem nputer science, 5th sem nputer science, 3rd sem iostatistics, 1st semeste ield medical informatic:	nester I to 6th semester nester nester nester sr s, 3rd semester		
Classes and lectures:		Workload:			
 Clinical Epidemiology (lec Clinical Epidemiology (exit 	ture, 2 SWS) ercise, 1 SWS)	 55 Hours pi 45 Hours in 20 Hours ex 	rivate studies and exercises classroom work xam preparation		
 Contents of teaching: Introduction to epidemio Diagnosis Frequencies Registers and data source Geographical epidemiolo Study designs (RCT, cohore Effect measures Causality Chance, bias and confour Control of errors Outbreak investigation 	Contents of teaching: Introduction to epidemiology Diagnosis Frequencies Registers and data sources Geographical epidemiology Study designs (RCT, cohort study, case control study, cross sectional study) Effect measures Causality Chance, bias and confounding Control of errors 				
 Qualification-goals/Competencies: Students are able to explain technical terms such as disease register, incidence, prevalence, mortality, lethality, standardization. They are able to explain and interpret epidemiological measures. They are able to assess which study design is appropriate for a certain research question. They are able to identify possible sources of error, bias and confounding and how they affect the study results. They are able to assess causal inferences in the context of different study types. They are able to critically appraise data, results, and epidemiological research methods as well as scientific literature in the context of medicine and epidemiology. 					
Grading through:					
• written exam	• written exam				
Responsible for this module: • Prof. Dr. med. Alexander Katalinic Teacher: • Institute for Social Medicine and Epidemiology • Prof. Dr. med. Alexander Katalinic • MitarbeiterInnen des Instituts					
Literature: • L. Gordis: Epidemiology - • R. H. Fletcher: Clinical Epic • :	Oxford: Elsevier; 5th edition 2013 demiology. The Essentials Lippinco	ott Williams & Wilki; 5th	ı rev. edition 2012		
Language:					



• offered only in German

Notes:

Prerequisites for attending the module: - None

Prerequisites for participation in the exam(s): - None

Module exam(s): - MZ4010-L1, Clinical Epidemiology, written exam, 90 min, 100 % of module grade



MZ43	373-KP03, MZ4373 - H	Human Genetics (Hun	nGen)		
Duration:	Turnus of offer:		Credit points:		
1 Semester	each winter semester		3		
 Course of study, specific field and term: Master CLS 2023 (compulsory), MML with specialization in Genetic Statistics, 1st semester Master Medical Informatics 2019 (optional subject), bioinformatics, 1st or 2nd semester Master Medical Informatics 2014 (optional subject), bioinformatics, 1st or 2nd semester Master CLS 2016 (compulsory), MML with specialization in Genetic Statistics, 1st semester Master CLS 2016 (compulsory), computational life science / biostatistics, 1st semester Master CLS 2010 (compulsory), computational life science / biostatistics, 1st semester 					
Classes and lectures:		Workload:			
Human Genetics for MML (lecture, 2	SWS)	 40 Hours private 30 Hours in-class 20 Hours exam p 	studies room work reparation		
Contents of teaching: Human genome Heredity Genetics of mitochondria Mutations, detection and nomenclature of sequence variations Polymorphisms and SNP Linkage analyses Repetitive sequences Methods: isolation, amplification, screening, and analysis of nucleic acids Data bases Enjagenetics 					
 Qualification-goals/Competencies: Students are able to explain basic principles of heredity, the organization of the human genome, the relevance of sequence variations, and their application for medical biometrics. 					
Grading through: • written exam					
Responsible for this module: • Prof. Dr. rer. nat. Martin Kircher Teacher: • Institute of Human Genetics • Prof. Dr. rer. nat. Martin Kircher • Dr. Andreas Dalski • MitarbeiterInnen des Instituts					
Literature: • Tom Strachan & Andrew P. Read: Molekulare Humangenetik - 3. Auflage (2005)					
Form Strachan & Andrew F. Read. Molecular e Humangeneux - 5. Adnage (2005) Language: • German or English Notes:					



Prerequisites for attending the module: - None

Prerequisites for participation in the exam(s): - None

Module exam(s): - MZ4373-L1: Human Genetics, written exam, 90 min, 100 % of module grade



MZ4374-KP03, MZ4374 - Molecular Human Genetics (MolHumGen)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each winter semester		3 (Тур В)	
Course of study, specific field and te Master CLS 2023 (compulsory), Master Medical Informatics 20 Master CLS 2016 (compulsory), Master Medical Informatics 20 Master CLS 2010 (compulsory),	erm: MML with specialization in Ge 19 (optional subject), bioinform MML with specialization in Ge 4 (optional subject), bioinform computational life science / bi	netic Statistics, 1st semeste natics, 1st or 2nd semester netic Statistics, 1st semeste natics, 1st or 2nd semester iostatistics, 1st semester	er er	
Classes and lectures: • Molecular Human Genetics (pr	actical course, 2 SWS)	Workload: • 60 Hours privat • 30 Hours in-cla	te studies ssroom work	
Contents of teaching: Safety instructions Isolation of nucleic acids Preparation and separation of Amplification of nucleic acids Restriction of nucleic acids Theoretical consideration of pe Data base search	nucleic acids PCR) edigrees			
Qualification-goals/Competencies: • Students can perform fundam	ental molecular genetic experii	ments, they get basic know	ledge in laboratory work	
Grading through: • continuous, successful particip	ation in practical course, >80%	,		
Requires: • Human Genetics (MZ4373-KP0	3, MZ4373)			
Responsible for this module: • Prof. Dr. rer. nat. Martin Kirche Teacher: • Institute of Human Genetics • Prof. Dr. rer. nat. Martin Kirche • Dr. Andreas Dalski	er er			
Literature: Ecture notes: -				
Language:• offered only in German				
Notes: Prerequisites for attending the m - None (The competences of the Prerequisites for the exam:	odule: required modules are required	for this module, but the m	odules are not a prerequisite for admission.)	
- Regular and successful participation in the practical course, at least 80%				
Module exam(s): - MZ4374-L1: Molecular Human Genetics, ungraded practical course, 0 % of module grade, must be passed				



	MA3111-KP07 - Numerics (NumKP07)				
Duration:	Turnus of offer:		Credit points:		
1 Semester	each winter semester 7		7		
Course of study, specific field and term: • Master CLS 2023 (compulsory), 1st, • Master CLS 2016 (compulsory), 1st,	2nd, or 3rd semester 2nd, or 3rd semester				
Classes and lectures:		Workload:			
 Numerics (lecture, 2 SWS) Numerics (exercise, 2 SWS) 	 Numerics (lecture, 2 SWS) Numerics (exercise, 2 SWS) Numerics (exercise, 2 SWS) Numerics (exercise, 2 SWS) O Hours private studies and exercises O Hours in-classroom work O Hours additional private studies computational life s O Hours exam preparation 				
Contents of teaching: • Round-off errors and condition • Direct solvers for linear equations • LR decomposition • Perturbation theory • Cholesky decomposition • QR decomposition, least squares fit					
Qualification-goals/Competencies: Basic understanding of numeric tas Mastering the modern programmin Experience in the implementation of Ability to judge the quality of a met Grading through: written exam 	Qualification-goals/Competencies: • Basic understanding of numeric tasks • Mastering the modern programming language MATLAB • Experience in the implementation of theoretical algorithms • Ability to judge the quality of a method (accuracy, stability, complexity) Grading through: • written exam				
Requires: • Linear Algebra and Discrete Structu • Linear Algebra and Discrete Structu • Analysis 2 (MA2500-KP09) • Analysis 1 (MA2000-KP08, MA2000)	res 2 (MA1500-KP08, MA15 res 1 (MA1000-KP08, MA10	00) 00)			
Responsible for this module:					
 Prof. Dr. rer. nat. Andreas Rößler Teacher: Institute for Mathematics Prof. Dr. rer. nat. Andreas Rößler 					
Literature:					
 W. Dahmen, A. Reusken: Numerische Mathematik für Ingenieure und Naturwissenschaftler - 2. Auflage, Springer (2008) P. Deuflhard, A. Hohmann: Numerische Mathematik I - 4. Auflage, De Gruyter (2008) P. Deuflhard, F. Bornemann: Numerische Mathematik II - 4. Auflage, De Gruyter (2013) M. Hanke-Bourgeois: Grundlagen der Numerischen Mathematik und des Wissenschaftlichen Rechnens - 3. Auflage, Teubner (2009) H. R. Schwarz, N. Köckler: Numerische Mathematik - 8. Auflage, Teubner (2011) J. Stoer: Numerische Mathematik I - 10. Auflage, Springer (2007) J. Stoer, R. Bulirsch: Numerische Mathematik II - 6. Auflage, Springer (2011) A. M. Quarteroni, R. Sacco, F. Salieri: Numerical Mathematics - 2. Auflage, Springer (2007) 					
Language: • offered only in German					



Notes:

Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s):

- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.

Module exam(s):

- MA3111-L1: Numerics, written exam, 90 min, 100 % of module grade



	MA4021-KP07 - Sto	chastics (StochKP07)				
Duration:	Turnus of offer:	Credit points:				
1 Semester	each winter semester	7				
Course of study, specific field • Master CLS 2023 (comp	 Course of study, specific field and term: Master CLS 2023 (compulsory), 1st, 2nd, or 3rd semester 					
Classes and lectures:		Workload:				
 Stochastics (lecture, 3 S Stochastics (exercise, 2 	WS) SWS)	 115 Hours private studies and exercises 75 Hours in-classroom work 20 Hours exam preparation 				
Contents of teaching:						
 Lebesgue integral und transformations of mea product measures and moments and depende normally distributed ra characteristic functions conditional expectation basis ideas of informati 	sures and integrals Fubini's theorem ency measures ndom vectors and distributions closely fon theory	elated to the normal distribution				
Qualification-goals/Compete	ncies:					
 Studends get insights into basic stochastic structures They master techniques of integration being relevant to stochastics They master the treatment of (particularly normally distributed) random vectors and their distributions They acquire a basic understanding of information theory approaches They are able to formalize complex stochastic problems 						
Grading through:						
• written exam						
Requires: • Analysis 2 (MA2500-MN	1L)					
Responsible for this module:						
 Nachfolge von Prof. Dr. 	rer. nat. Karsten Keller					
Teacher:	cc.					
Institute for Mathematics						
Nachfolge von Prof. Dr. rer. nat. Karsten Keller						
 Literature: J. Elstrodt: Maß- und Integrationstheorie - Springer M. Fisz: Wahrscheinlichkeitsrechnung und mathematische Statistik - Deutscher Verlag der Wissenschaften 						
Language: • offered only in German						
Notes:						



Admission requirements for taking the module:

- None (The competencies of the modules listed under 'Requires' are needed for this module, but are not a formal prerequisite)

Admission requirements for participation in module examination(s): - Successful completion of homework assignments during the semester

Module exam(s):

- MA4021-L1: Stochastics, written exam, 90 min, 100 % of module grade

The lecture is identical to the one in module MA4020.



MA4031-KP08 - Optimization (Advanced Mathematics) (OptiKP08)				
Duration:	Turnus of offer:		Credit points:	
1 Semester	each summer semester		8	
Course of study, specific field and • Master CLS 2023 (compulsory • Master CLS 2016 (compulsory	term: י), 1st, 2nd, or 3rd semester ·), 1st, 2nd, or 3rd semester			
Classes and lectures:		Workload:		
 Optimization (lecture, 4 SWS) Optimization (exercise, 2 SWS) 	 Optimization (lecture, 4 SWS) Optimization (exercise, 2 SWS) 130 Hours private studies and exercises 90 Hours in-classroom work 20 Hours exam preparation 		rivate studies and exercises classroom work am preparation	
Contents of teaching:				
 Linear optimization (simplex Unconstrained nonlinear opt Equality- and inquality-constr Stochastic methods for mach 	method) imization (gradient descent, conj rained nonlinear optimization (La ine learning	ugate gradients, Newto agrange multipliers, acti	on method, Quasi-Newton methods, globalization) ive set methods)	
Qualification-goals/Competencies:				
 They understand central opti They can explain central opti They can compare and assess They can implement central of They can assess numerical researcher the control of th	 Students can model reachine problems as optimization problems. They understand central optimization techniques. They can explain central optimization techniques. They can implement central optimization techniques. They can assess numerical results. They can select suitable optimization techniques for practical problems. Interdisciplinary qualifications: Students can transfer theoretical concepts into practical solutions. They are experienced in implementation. They can think abstractly about practical problems. 			
Grading through: • Written or oral exam as anno	unced by the examiner			
ls requisite for:				
 Non-smooth Optimization an 	d Analysis (MA5035-KP05)			
Requires: • Linear Algebra and Discrete S • Analysis 2 (MA2500-KP09)	tructures 2 (MA1500-KP08, MA1	500)		
Responsible for this module:				
Prof. Dr. rer. nat. Jan Modersi	zki			
Teacher:				
Institute of Mathematics and Image Computing				
 Prof. Dr. rer. nat. Jan Lellmann Prof. Dr. rer. nat. Jan Modersitzki 				
Literature:				
 J. Nocedal, S. Wright: Numeri F. Jarre: Optimierung - Spring C. Geiger: Theorie und Nume 	cal Optimization - Springer Jer rik restringierter Optimierungsau	ıfgaben - Springer		
Language:				



• offered only in German

Notes:

Prerequisites for attending the module:

- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:

- Exercises and their presentation are ungraded preliminary examinations. These must have been completed and positively evaluated before the first examination.

Examination:

- MA4031-L1: Optimization, written examination (90 min) or oral examination (30 min) as decided by examiner, 100% of final mark

Variant of MA4030, MA4030-KP08 for students who did not attend a course on optimization in their Bachelor s program.



CS5260-KP04, CS	5260SJ14 - Speech a	nd Audio Signal Proce	ssing (SprachAu14)
Duration:	Turnus of offer:		Credit points:
1 Semester	every second semester		4
Course of study, specific field and term: Master CLS 2023 (optional subject), Master Robotics and Autonomous S Master MES 2020 (optional subject) Master Media Informatics 2020 (optional subject) Master Medical Informatics 2019 (o Master MES 2014 (optional subject) Master CLS 2010 (optional suject), o Master Medical Informatics 2014 (optional subject) Master Medical Informatics 2014 (optional subject)	Elective, Arbitrary semest systems 2019 (optional su , medical engineering scie ional subject), computer ptional subject), Medical I , medical engineering scie omputer science, Arbitrar ptional subject), computer	er bject), Elective, Arbitrary sem ence, Arbitrary semester science, Arbitrary semester Data Science / Artificial Intelli ence, Arbitrary semester y semester r science, 1st or 2nd semester science, Arbitrary semester	nester gence, 1st or 2nd semester er
Classes and lectures:		Workload:	
 Speech and Audio Signal Processin Speech and Audio Signal Processin 	g (lecture, 2 SWS) g (exercise, 1 SWS)	 55 Hours private 45 Hours in-class 20 Hours exam p 	e studies sroom work preparation
 Physical models of the auditory Sys Dynamic compression Spectral analysis: Spectrum and cep Spectral perception and masking Vocal tract models Linear prediction Coding in time and frequency dom Speech synthesis Noise reduction and echo compens Source localization and spatial repr Basics of automatic speech recogni 	tem ostrum ains ation oduction tion		
 Qualification-goals/Competencies: Students are able to describe the b They are able to describe the proce auditory perception. They are able to present basic know They can describe and use signal p 	asics of human speech pr ss of human auditory per vledge of statistical speec rocessing methods for sou	oduction and the correspond ception and the correspondi h modeling and automatic s urce separation and room-ac	ding mathematical models. ng signal processing tools for mimicing peech recognition. oustic measurements.
Grading through: • Written or oral exam as announced	by the examiner		
Responsible for this module: • Prof. DrIng. Markus Kallinger Teacher: • Institute for Signal Processing • Prof. DrIng. Markus Kallinger			
Literature: • L. Rabiner, BH. Juang: Fundament • J. O. Heller, J. L. Hansen, J. G. Proaki	als of Speech Recognition s: Discrete-Time Processir	- Upper Saddle River: Prention g of Speech Signals - IEEE Pr	ce Hall 1993 ress
Language: • offered only in German			



Notes:

Prerequisites for attending the module:

- None

Prerequisites for the exam:

- Successful completion of assignments during the semester.

Modul exam:

- CS5260-L1: Speech and Audio Signal Processing, written or oral exam, 100% of modul grade

Mentioned in SGO MML under CS5260 (without SJ14).