

Module Manual

Master of Science (M.Sc.) Data Science

Cohort: Winter Term 2023 Updated: 3rd July 2023

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Program description

Content

The international master's program in data science is interdisciplinary and teaches a broad spectrum of methods for the representation, processing, modeling, provision, and storage of data. The program builds on the two pillars of mathematics and computer science and offers a variety of data science application fields in the third pillar. The program builds on the bachelor's degree in data science and is also open to bachelor's degree graduates in computer science or mathematics with relevant majors in data science, machine learning, or artificial intelligence.

The program is organized as a two-year program (four semesters) and begins each year in October. It consists of two and a half semesters of lectures and lab courses and one and a half semesters devoted to working in a research team (project work) and writing the master's thesis. The curriculum offers a lot of freedom to set your own focus in the field of data science. The academic degree of Master of Science is awarded. The language of study is English.

Graduates of the program are taught the fundamentals and knowledge required for successful work in the field of data science in an international environment. They acquire comprehensive knowledge of the mathematical and computer science foundations of this discipline and learn to practically apply the theoretical concepts in various application areas. Upon completion of the program, students are able to independently solve problems in the field of data science and related disciplines. Graduates are able to apply data science methods, critically examine results and further develop existing methods on the basis of new findings.

Career prospects

The master's program in data science optimally prepares graduates for a career in research and development in an academic or industrial environment. A data scientist typically works in an environment where large amounts of data are generated and is responsible for their analysis, algorithmic processing and feature extraction. He or she acquires knowledge in an application area and may work in an interdisciplinary team with application experts. A data scientist works in a research-oriented manner and is thus always up to date with the latest developments in this rapidly evolving field. Due to the high amount of computer science in the degree program, graduates are familiar with all the rules of software design, so that the career opportunities of classical computer scientists are also open to them. The degree program qualifies students for doctoral studies at a university.

Learning target

The master's program in data science is designed to prepare students for a professional career in research and development. The skills and knowledge required for this are taught as part of the degree program. In distinction to the bachelor's degree program in data science, the competencies mentioned here refer to complex problems, the consideration of uncertainty and working under given boundary conditions from application fields. The learning objectives of the program are achieved through the interaction of basic and advanced modules from data science, mathematics and computer science. The learning objectives are divided into the categories knowledge, skills, social competence and independence in the following.

Knowledge

Knowledge in data science is composed of theories and methods. It is acquired in the data science master's program in the following areas:

- 1. Graduates are able to describe the basic concepts in the field of data science.
- 2. Graduates are familiar with statistical models and can compare different approaches.
- 3. Graduates are familiar with methods for representing, processing, modeling, providing and storing large amounts of data and have in-depth knowledge of data management.
- 4. Graduates have in-depth knowledge in the field of computer science and can describe principles of modern software development.
- 5. Graduates have in-depth knowledge of machine learning and are familiar with data preparation, effective training and evaluation of trained models.
- 6. Graduates are familiar with different application areas of data science and can adapt the learned methodological knowledge to concrete applications.

Skills

- 1. The ability to apply the acquired knowledge to solve specific problems is fostered in the master's program data science in the following ways:
- 2. Graduates are able to systematically acquire data and store it in scalable data management systems.
- 3. Graduates are able to recognize patterns in unstructured data and to represent correlations appropriately.
- 4. Graduates are able to train data-driven models and can prepare data appropriately, select the model architecture appropriately, perform the training effectively, and evaluate the accuracy of the models appropriately.
- 5. Graduates are able to design and implement complex software systems.
- 6. Graduates are able to apply data science methods in various application areas, appropriately considering application-specific requirements.

Social skills

- 1. Graduates are able to communicate with experts and laymen about scientific contents and problems in the field of data science. They can respond appropriately to questions, additions and comments.
- Graduates are able to take responsibility for the development of group results, to divide and distribute tasks for this purpose, to jointly coordinate procedures, to combine results and, if necessary, to present them jointly. They are able to develop suitable solution strategies in the event of difficulties in the group.

Autonomy

- 1. Graduates are able to present the scientific approach and the resulting results of their work in a comprehensible way, both orally and in writing.
- 2. Graduates are able to research necessary information, to put it into the context of their knowledge and to evaluate its relevance.
- 3. Graduates are able to realistically assess their existing competencies, independently compensate for deficits and independently acquire additional competencies.
- 4. Graduates are able to develop research areas in a self-organized and self-motivated manner and to find and define new problems (lifelong research).

Program structure

The curriculum of the master's program in data science is structured as follows:

Core Qualification (48 CP in total)

The core qualification contains the compulsory modules (6 CP):

- Advanced Machine Learning
- Big Data
- Statistical Models

In addition, the core qualification contains a seminar (3 CP), a lecture on scientific methods (3 CP), a research project (12 CP) as well as the interdisciplinary compulsory modules on operations & management (6 CP) and on non-technical courses (6 CP).

Specialization I. Mathematics (total 6 CP)

Students choose one module (6 CP) from the following catalog in the compulsory specialization in mathematics:

- Hierachical Algorithms
- Linear and Nonlinear Optimization
- Matrix Algorithms
- Information Theory and Coding
- Numerical Methods for Ordinary Differential Equations •
- Numerical Mathematics II
- Randomised Algorithms and Random Graphs
- Probability Theory

Specialization II. Computer Science (6 CP in total)

Students choose one module (6 CP) from the following catalog in the compulsory specialization in computer science:

- Image Processing
- Digital Communications
- Massively Parallel Systems: Architecture and Programming •
- Security of Cyber-Physical Systems
- Software Verification Advanced Internet Computing
- Applied Cryptography
- Autonomous Cyber-Physical Systems
- Cybersecurity Data Science Secure Software Engineering
- GPU Architectures and Programming
- Software for Embedded Systems
- Software Testing

Specialization III. Applications (6 CP in total)

Students choose one module (6 CP) from the following catalog in the compulsory specialization application:

- Applied Humanoid Robotics
- Digital Health
- Intelligent Systems in Medicine
- Machine Learning for Physical Systems
- Medical Imaging •
- Operational Aspects in Aviation
- ٠ Causal Data Science for Business Analytics
- Data-Driven Innovation
- Machine Learning in Electrical Engineering and Information Technology
- Robotics and Navigation in Medicine
- Deep Learning for Social Analytics

Special Focus Area IV (24 CP in total)

Students choose four modules (24 CP in total) in the special focus area. The catalog combines the first three specializations and thus allows for an individual focus. As an additional module, specialization IV also contains a technical complementary course, where students can choose any module (6 CP) from the master courses of the TUHH.

Master's thesis (30 CP, 4th semester)

The program is completed with the Master's thesis, which has a scope of 30 CP and is written in the 4th semester.

Core Qualification

Module M0523: Busin	ess & Management
Module Responsible	Prof. Matthias Meyer
Admission Requirements	None
Recommended Previous	None
Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge Skills	 Students are able to find their way around selected special areas of management within the scope of business management. Students are able to explain basic theories, categories, and models in selected special areas of business management. Students are able to interrelate technical and management knowledge. Students are able to apply basic methods in selected areas of business management.
	• Students are able to explain and give reasons for decision proposals on practical issues in areas of business management.
Personal Competence	
Social Competence	• Students are able to communicate in small interdisciplinary groups and to jointly develop solutions for complex problems
Autonomy	• Students are capable of acquiring necessary knowledge independently by means of research and preparation of material.
Workload in Hours	Depends on choice of courses
Credit points	6

Courses

Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M1552: Adva	nced Machine Learning			
Courses				
Title		Тур	Hrs/wk	СР
Advanced Machine Learning (L2322	2)	Lecture	2	3
Advanced Machine Learning (L2323	3)	Recitation Section (small)	2	3
Module Responsible	Dr. Jens-Peter Zemke			
Admission Requirements	None			
Recommended Previous	1 Mathematics I III			
Knowledge	2 Numerical Mathematics 1/ Numerics			
	3 Programming skills preferably in Python			
Educational Objectives	After taking part successfully, students have reached	d the following learning results		
Professional Competence				
Knowledge	Students are able to name, state and classify state-	of-the-art neural networks and their corre	sponding mathe	ematical basics. They
	can assess the difficulties of different neural network	<s.< th=""><th></th><th></th></s.<>		
Skills	Students are able to implement, understand, and, ta	ilored to the field of application, apply ne	ural networks.	
Personal Competence				
Social Competence	Students can			
	 develop and document joint solutions in small 	teams:		
	 form groups to further develop the ideas and transfer them to other areas of applicability; 			
	 form a team to develop, build, and advance a software library. 			
Autonomy	Students are able to			
	 correctly assess the time and effort of self-defined work; 			
	 assess whether the supporting theoretical and practical excercises are better solved individually or in a team; 			
	 define test problems for testing and expanding the methods; 			
	assess their individual progess and, if necessa	ary, to ask questions and seek help.		
Workload in Hours	Independent Study Time 124, Study Time in Lecture	56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathematics: E	lective Compulsory		
Following Curricula	Data Science: Core Qualification: Compulsory			
	Computer Science in Engineering: Specialisation III.	Mathematics: Elective Compulsory		
	Mechatronics: Specialisation Intelligent Systems and	Robotics: Elective Compulsory		
	Mechatronics: Specialisation System Design: Elective	e Compulsory		
	Mechatronics: Core Qualification: Elective Compulso	ry		
	Technomathematics: Specialisation I. Mathematics:	Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisation R	obotics and Computer Science: Elective C	Compulsory	

Course L2322: Advanced Machine Learning		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Dr. Jens-Peter Zemke	
Language	DE/EN	
Cycle	WiSe	
Content	 Basics: analogy; layout of neural nets, universal approximation, NP-completeness Feedforward nets: backpropagation, variants of Stochastistic Gradients Deep Learning: problems and solution strategies Deep Belief Networks: energy based models, Contrastive Divergence CNN: idea, layout, FFT and Winograds algorithms, implementation details RNN: idea, dynamical systems, training, LSTM ResNN: idea, relation to neural ODEs Standard libraries: Tensorflow, Keras, PyTorch 	
	9. Recent trends	
Literature	 Skript Online-Werke: http://neuralnetworksanddeeplearning.com/ https://www.deeplearningbook.org/ 	

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Course L2323: Advanced Machine Learning		
Тур	Recitation Section (small)	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Dr. Jens-Peter Zemke	
Language	DE/EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M0524: Non-technical Courses for Master				
Module Responsible	Dagmar Richter			
Admission Requirements	None			
Recommended Previous Knowledge	None			
Educational Objectives	After taking part successfully, students have reached the following learning results			
Professional Competence Knowledge	The Nontechnical Academic Programms (NTA)			
	imparts skills that, in view of the TUHH's training profile, professional engineering studies require but are not able to cover fully. Self-reliance, self-management, collaboration and professional and personnel management competences. The department implements these training objectives in its teaching architecture , in its teaching and learning arrangements , in teaching areas and by means of teaching offerings in which students can qualify by opting for specific competences and a competence level at the Bachelor's or Master's level. The teaching offerings are pooled in two different catalogues for nontechnical complementary courses.			
	The Learning Architecture			
	consists of a cross-disciplinarily study offering. The centrally designed teaching offering ensures that courses in the nontechnical academic programms follow the specific profiling of TUHH degree courses.			
	The learning architecture demands and trains independent educational planning as regards the individual development of competences. It also provides orientation knowledge in the form of "profiles".			
	The subjects that can be studied in parallel throughout the student's entire study program - if need be, it can be studied in one to two semesters. In view of the adaptation problems that individuals commonly face in their first semesters after making the transition from school to university and in order to encourage individually planned semesters abroad, there is no obligation to study these subjects in one or two specific semesters during the course of studies.			
	Teaching and Learning Arrangements			
	provide for students, separated into B.Sc. and M.Sc., to learn with and from each other across semesters. The challenge of dealing with interdisciplinarity and a variety of stages of learning in courses are part of the learning architecture and are deliberately encouraged in specific courses.			
	Fields of Teaching			
	are based on research findings from the academic disciplines cultural studies, social studies, arts, historical studies, communication studies, migration studies and sustainability research, and from engineering didactics. In addition, from the winter semester 2014/15 students on all Bachelor's courses will have the opportunity to learn about business management and start-ups in a goal-oriented way.			
	The fields of teaching are augmented by soft skills offers and a foreign language offer. Here, the focus is on encouraging goal- oriented communication skills, e.g. the skills required by outgoing engineers in international and intercultural situations.			
	The Competence Level			
	of the courses offered in this area is different as regards the basic training objective in the Bachelor's and Master's fields. These differences are reflected in the practical examples used, in content topics that refer to different professional application contexts, and in the higher scientific and theoretical level of abstraction in the B.Sc.			
	This is also reflected in the different quality of soft skills, which relate to the different team positions and different group leadership functions of Bachelor's and Master's graduates in their future working life.			
	Specialized Competence (Knowledge)			
	Students can			
	 explain specialized areas in context of the relevant non-technical disciplines, outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the learning area, different specialist disciplines relate to their own discipline and differentiate it as well as make connections, 			
	 sketch the basic outlines of how scientific disciplines, paradigms, models, instruments, methods and forms of representation in the specialized sciences are subject to individual and socio-cultural interpretation and historicity, Can communicate in a foreign language in a manner appropriate to the subject. 			
Skills	Professional Competence (Skills)			
	In selected sub-areas students can			
	 apply basic and specific methods of the said scientific disciplines, aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline, to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner, 			
	 justify their decisions on forms of organization and application in practical questions in contexts that go beyond the technical relationship to the subject. 			

Social Competence Personal Competences (Social Skills)

	 Students will be able to learn to collaborate in different manner, to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees, to express themselves competently, in a culturally appropriate and gender-sensitive manner in the language of the country (as far as this study-focus would be chosen), to explain nontechnical items to auditorium with technical background knowledge.
Autonomy	Personal Competences (Self-reliance)
	Students are able in selected areas
	• to reflect on their own profession and professionalism in the context of real-life fields of application
	to organize themselves and their own learning processes
	 to reflect and decide questions in front of a broad education background
	 to communicate a nontechnical item in a competent way in writer form or verbaly to organize themselves as an entrepreneurial subject country (as far as this study focus would be chosen)
	• to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
Werkland in U.	Depende an choice of courses
workload in Hours	Peperios on choice or courses
Credit points	6

Courses

Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M1871: Big D	ata		
Courses			
Title	Тур	Hrs/wk	СР
Big Data (L3101)	Lecture	2	3
Big Data (L3102)	Project-/problem-based Learning	2	3
Module Responsible	Prof. Stefan Schulte		
Admission Requirements	None		
Recommended Previous	. Cool of the second is a size of investment the solid second size in a size of the second size		- dud -
Knowledge	Good software engineering and implementation skills are very important for the practical	part of this m	odule
	Previous knowledge in the fields of Distributed Systems and Databases is neipful		
Educational Objectives	After taking part successfully, students have reached the following learning results		
Professional Competence			
Knowledge	After successful completion of the course, students are able to:		
	Describe basis concents of methods and technologies to process and store your large am	ounts of data	
	Describe basic concepts of methods and technologies to process and store very large and Discuss and assess critical aspects of Big Data		
	Select and apply Big Data technologies for particular application areas		
	Design and develop practical solutions for the processing of very large amounts of data		
	Implement Big Data services		
Skills	The students acquire the ability to model Big Data systems and to work with these systems. This	s comprises es	specially the ability
	select and utilize fitting technologies for different application areas. Furthermore, students are	able to critical	ly assess the chose
	technologies.		
Personal Competence			
Social Competence	Students can work on complex problems both independently and in teams. They can exchange	ideas with eac	h other and use the
,	individual strengths to solve the problem.		
Autonomy	Students are able to independently investigate a complex problem and assess which competend	cies are requir	ed to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56		
Credit points	6		
Course achievement	None		
Examination	Subject theoretical and practical work		
Examination duration and	Group project incl. presentation, written exam		
scale			
Assignment for the	Data Science: Core Qualification: Compulsory		
Following Curricula			
Course L3101: Big Data			
Тур	Lecture		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		

Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Schulte
Language	EN
Cycle	SoSe
Content	This lecture discusses the fundamental concepts of modern Big Data systems. The following topics will be covered in the single
	lectures:
	Data models for Big Data
	NoSQL databases
	Lambda architecture including batch, speed and serving layers
	Kappa architecture
	Concepts and tools for data stream processing
	Current software tools for the processing of very large amounts of data
Literature	Lecture notes as well as current literature announced in the lecture.

Course L3102: Big Data	
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Schulte
Language	EN
Cycle	SoSe
Content	This project-/problem-oriented part of the module augments the theoretical content of the lecture by a concrete technical problem, which needs to be solved by the students in group work during the semester. The topics are from the field of Big Data, and address for instance data stream processing or batch processing
Literature	Lecture notes as well as current literature announced in the lecture.

Module M1870: Statis	tical Models			
Module M1070. Statis				
Courses				
Title		Тур	Hrs/wk	СР
Statistical Models (L3116)		Lecture	3	4
Statistical Models (L3118)		Recitation Section (small)	1	2
Module Responsible	Prof. Matthias Schulte			
Admission Requirements	None			
Recommended Previous	Preknowledge in probability and statistics			
Knowledge			-	
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowledge	Students know the fundamental statistical mod	els and are able to explain them using	appropriate exam	nples.
	Students can discuss logical connections between	en these concepts and are capable of	illustrating these	connections with the
	help of examples.			
	 Students know proof strategies and can reproduce 	uce them.		
Skille				
SKIIIS	Students can investigate statistical problems with the statis	th the help of the models studied in th	e course.	
	Students are able to explore and verify further	ogical connections between the conce	pts studied in the	course.
	 For a given problem, the students can develop 	p and execute a suitable approach, a	and are able to c	ritically evaluate the
	results.			
Personal Competence				
Social Competence				
	• Students are able to work together (e.g. on their regular home work) and to present their results appropriately (e.g. during			
	exercise class).			
	• In doing so, they can communicate new concepts and they can design examples to check and deepen the understanding of			
	their peers.			
Autonomy				
	 students are capable of checking their understanding of complex concepts on their own. They can specify open questions procisely and know where to get help in solving them 			
	precisely and know where to get help in solving them.			
	 Students can put their knowledge in relation to the contents of other rectures. Students have developed sufficient persistence to be able to work for longer periods in a goal-priented manner on hard. 			
	problems.	e to be uble to work for longer perio	15 in a goar oner	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 5	6		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathematics: Ele	ctive Compulsory		
Following Curricula	Computer Science in Engineering, Specialization III, M	thematica, Elective Compulsant		
	Computer Science in Engineering: Specialisation III. Ma	action and Computer Science: Elective	Compulsory	
	Theoretical Mechanical Engineering: Specialisation Rol	potics and Computer Science: Elective	Compulsory	

Course L3116: Statistical Mo	dels				
Тур	Lecture				
Hrs/wk	3				
СР	4				
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42				
Lecturer	rof. Matthias Schulte, Prof. Nihat Ay				
Language	EN				
Cycle	SoSe				
Content	Linear models and regression:				
	- Linear regression				
	- Nonlinear regression				
	- Logistic and Poisson regression				
	- Generalised linear models				
	Graphical Models and Causality:				
	- Conditional independence statements				
	- Hammersley-Clifford theorem				
	- Gibbs sampling				
	- Bayesian networks				
	- Causal inference				
	- Markov random fields				
	- Graphical and hierarchical models				
	- Applications				
Literature	D. Barber: Bayesian Reasoning and Machine Learning. Cambridge University Press (2012).				
	P. Dunn and G. Smyth: Generalized linear models with examples in R. Springer (2018).				
	L. Fahrmeir, T. Kneib, S. Lang and B. Marx: Regression - models, methods and applications. Second edition, Springer (2021).				
	S. Lauritzen: Graphical Models. Oxford University Press (1996, reprinted 2004).				
	J. Pearl: Causality: Models, Reasoning and Inference. Second edition, Cambridge University Press (2009).				

Course L3118: Statistical Models			
Тур	Recitation Section (small)		
Hrs/wk	1		
СР	2		
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14		
Lecturer	Prof. Matthias Schulte, Prof. Nihat Ay		
Language	EN		
Cycle	SoSe		
Content	See interlocking course		
Literature	See interlocking course		

Courses					
courses					
Title Research Preject Computer Science	(1.2252)	Typ Prejection Course	o Hrs/wk	CP 12	
Madula Daamawalkia		Fill Jection Course	0	12	
Module Responsible	Dozenten des SD E				
Admission Requirements	None	Martin and a			
Kecommended Previous	Basic knowledge and techniques from t	The Master courses in the semesters 1 and 2.			
Educational Objectives	After taking part successfully, students	have reached the following learning results			
Professional Competence	After taking part successionly, students	lave reached the following learning results			
Knowledge	Students are able to acquire advance	d knowledge in a subfield of Computer Science	e and can independ	ently acquire dee	
	knowledge in the field.				
Skills	s The students are able to formulate the scientific problems to be considered and to work out solutions in an independent m				
	and to realize them.				
Personal Competence					
Social Competence	The students are able to discuss propo	als for solutions of scientific problems within the	team. They are able	to present the res	
	in a clear and well structured manner.				
Autonomy	The students can provide a scientific w	rk in a timely manner and document the results i	in a detailed and well	readable form T	
hatohomy	are able to actively follow anticipate th	presentations of other students such that eventu	ually a scientific discu	ssion comes up.	
				•	
Workload in Hours	Independent Study Time 248, Study Tir	ne in Lecture 112			
Credit points	12				
Course achievement	None				
Examination	Study work				
Examination duration and	Vortrag				
scale					
Assignment for the	Computer Science: Core Qualification: (ompulsory			
Following Curricula	Data Science: Core Qualification: Comp	Ilsory			

Course L2353: Research Project Computer Science			
Тур	Projection Course		
Hrs/wk	8		
CP	12		
Workload in Hours	Independent Study Time 248, Study Time in Lecture 112		
Lecturer	Dozenten des SD E		
Language	DE/EN		
Cycle	WiSe		
Content	Current research topics of the chosen areas of specialization		
Literature	Wird vom Veranstalter bekanntgegeben.		

Module M1873: Scien	tific Methods						
Module M1075. Scien							
Courses							
Title		Тур	Hrs/wk	СР			
Scientific Methods (L3088)		Lecture	2	3			
Module Responsible	Prof. Stefan Schulte						
Admission Requirements	None						
Recommended Previous	Students should have first experiences with the principles of research work. Usually, this was acquired while working on the						
Knowledge	Bachelor thesis or in seminars during the Bachelor studies. We strongly recommend to first do the module "Research Methods",						
	and then the Master seminar.						
Educational Objectives	After taking part successfully, students have	reached the following learning results					
Professional Competence							
Knowledge	Systematic literature reviews						
	Experimental software engineering						
	Design science						
	Good scientific practice						
	Scientific writing						
	Presenting scientific results using LaTe	X					
	 Visualization of scientific results 						
Skills	After successful completion of the course, stu	idents are able to:					
	Assess which research methods from	the fields of Computer Science, Data Scie	nce and related discipl	ines are suitable for			
	which problems,						
	 describe and apply the steps necessar 	y to carry out a particular research method	l,				
	 structure a scientific text, 						
	 review and cite scientific sources, 						
	 apply Best Practice scientific behavior, 						
	 conduct evaluations and visualize their apply scientific methods within their M 	r results, and					
	• apply sciencific methods within their M	aster theses.					
Personal Competence							
Social Competence	Students are able to work on complex scienti	fic questions and to present their results.					
Autonomy	Students are able to independently investigat	te a complex problem and assess which co	mpetencies are require	d to solve it.			
Workload in Hours	Independent Study Time 62, Study Time in Le	ecture 28					
Credit points	3						
Course achievement	None						
Examination	Subject theoretical and practical work						
Examination duration and	Group project (written elaboration)						
scale							
Assignment for the	Data Science: Core Qualification: Compulsory						
Following Curricula							
Course L3088: Scientific Met	hods						
Тур	Lecture						

Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe
Content	
Literature	

Module M1874: Adva	nced Seminar Computer Science and	Communication Tech	nology					
Courses								
Title		Тур	Hrs/wk	СР				
Advanced Seminar Computer Scien	nce and Communication Technology I (L2352)	Seminar	2	3				
Module Responsible	Dozenten des SD E							
Admission Requirements	None							
Recommended Previous	Basic knowledge of Computer Science and Mathematics at the Master's level as well as first expertise in the area of scientific							
Knowledge	working, especially investigating a scientific topic as well as conceptual design and creation of scientific (survey) articles.							
	urthermore, knowledge in the presentation of scientific topics is helpful.							
Educational Objectives	After taking part successfully, students have reached	I the following learning results						
Professional Competence								
Knowledge	The students are able to							
	 evolution a specific topic in the field of Computer 	tor Science						
	 explicate a specific topic in the field of computed of complex issues, and 	נכו שנוכוונפ,						
	 present different views and evaluate in a critic 	al way.						
Skills	The students are able to							
	 familiarize themselves with a specific topic of 	Computer Science in limited time						
	 realize a literature survey on the specific topic 	and cite in a correct way,						
	 elaborate a presentation and give a lecture to 	 elaborate a presentation and give a lecture to a selected audience. 						
	 sum up the presentation in a paper, and 							
	answer questions in the final discussion.							
Personal Competence								
Social Competence	The students are able to							
	 elaborate and introduce a topic for a certain a 	udience,						
	 discuss the topic, content and structure of the 	presentation with the instructor,						
	 discuss certain aspects with the audience, and 	1						
	as the presenter listen and respond to questio	ns from the audience.						
Autonomy	The students are able to							
	define the task in question in an autonomous	way,						
	 develop the necessary knowledge, 							
	 use appropriate work equipment for investigat 	tion, presentation, and writing.						
Workload in Hours	Independent Study Time 62, Study Time in Lecture 2	8						
Credit points	3							
Course achievement	None							
Examination	Presentation							
Examination duration and	x							
scale								
Assignment for the	Data Science: Core Qualification: Compulsory							
Following Curricula								

Course L2352: Advanced Seminar Computer Science and Communication Technology I			
Тур	Seminar		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Dozenten des SD E		
Language	EN		
Cycle	WiSe/SoSe		
Content	- Seminar presentations by enrolled students about selected topics of computer science and communication technology		
	- Active participation in discussions		
Literature	Wird vom Veranstalter bekanntgegeben.		

Specialization I. Mathematics

Module M0716: Hiera	rchical Algorithms					
Courses						
Title		Тур	Hrs/wk	СР		
Hierarchical Algorithms (L0585)		Lecture	2	3		
Hierarchical Algorithms (L0586)	T	Recitation Section (small)	2	3		
Module Responsible	Prof. Sabine Le Borne					
Admission Requirements	None					
Recommended Previous	Mathematics I, II, III for Engineering students (gr	erman or english) or Analysis & Linear A	Algebra I + II as	well as Analysis III for		
Knowledge	Technomathematicians					
	Programming experience in C					
Educational Objectives	After taking part successfully, students have reached t	be following learning results				
Professional Competence	Alter taking part successiony, students have reached t					
Knowledae	Students are able to					
	name representatives of hierarchical algorithms	and list their characteristics,				
	explain construction techniques for hierarchical	algorithms,				
	Olscuss aspects regarding the enricent impleme	ntation of merarchical algorithms.				
Skills	Students are able to					
	• implement the hierarchical algorithms discussed	d in the lecture,				
	 analyse the storage and computational complexities of the algorithms, 					
	adapt algorithms to problem settings of various	applications and thus develop problem	adapted variant	is.		
Personal Competence						
Social Competence	Students are able to					
	 work together in beterogeneously composed to 	ame (i.e., teams from different study or	ourses and had			
	explain theoretical foundations and support eac	h other with practical aspects regarding	the implement	ation of algorithms.		
			1 110 1110-2	1001 of alg		
Autonomy	Students are capable					
	 to assess whether the supporting theoretical an 	d practical excercises are better solved	individually or in	n a team,		
	 to work on complex problems over an extended 	period of time,				
	to assess their individual progess and, if necess	ary, to ask questions and seek help.				
Workload in Hours	Independent Study Time 124, Study Time in Lecture 5	6				
Credit points	6					
Course achievement	None					
Examination	Oral exam					
Examination duration and	20 min					
scale						
Assignment for the	Computer Science: Specialisation III. Mathematics: Elec	ctive Compulsory				
Following Curricula	Data Science: Specialisation I. Mathematics: Elective C	Compulsory				
	Data Science: Specialisation IV. Special Focus Area: Ele	ective Compulsory				
	Theoretical Mochanical Engineering: Specialization Sig	ective Compulsory	n/			
	Theoretical Mechanical Engineering. Specialisation Sin	iulation rechnology. Elective compulso	r y			

Course L0585: Hierarchical A	lgorithms
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne
Language	DE/EN
Cycle	WiSe
Content	 Low rank matrices Separable expansions Hierarchical matrix partitions Hierarchical matrices Formatted matrix operations Applications Additional topics (e.g. H2 matrices, matrix functions, tensor products)
Literature	W. Hackbusch: Hierarchische Matrizen: Algorithmen und Analysis

Course L0586: Hierarchical Algorithms			
Тур	Recitation Section (small)		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sabine Le Borne		
Language	DE/EN		
Cycle	WiSe		
Content	See interlocking course		
Literature	See interlocking course		

Module M1428: Linea	r and Nonlinea	• Optimization						
Courses								
Title Linear and Nonlinear Optimization	(L2062)			Typ Lecture	Hrs/wk	CP 4		
Linear and Nonlinear Optimization	(L2063)			Recitation Section (large)	1	2		
Module Responsible	Prof. Matthias Mnich							
Admission Requirements	None	None						
Kecommended Previous Knowledge	 Discrete Algebric Mathematics I Graph Theory a 	raic Structures						
Educational Objectives	After taking part succ	essfully, students hav	e reached the follow	ing learning results				
Professional Competence Knowledge	 Students can name the basic concepts in linear and non-linear optimization. They are able to explain them using appropriate examples. Students can discuss logical connections between these concepts. They are capable of illustrating these connections with the help of examples. They know proof strategies and can reproduce them. 					em using appropriate ese connections with		
Skills	 Students can model problems in linear and non-linear optimization with the help of the concepts studied in this course. Moreover, they are capable of solving them by applying established methods. Students are able to discover and verify further logical connections between the concepts studied in the course. For a given problem, the students can develop and execute a suitable approach, and are able to critically evaluate the results. 							
Personal Competence Social Competence Autonomy	 Students are a In doing so, the design example Students are c precisely and k 	ole to work together in ey can communicate r es to check and deepe apable of checking th now where to get help	n teams. They are ca new concepts accord en the understanding eir understanding of o in solving them.	pable to use mathematics a ling to the needs of their co of their peers.	as a common langua ooperating partners ir own. They can spi	age. . Moreover, they can ecify open questions		
	 Students have problems. 	developed sufficient	persistence to be a	ble to work for longer peri	iods in a goal-orien	ted manner on hard		
Workload in Hours	Independent Study Ti	me 110, Study Time ir	n Lecture 70					
Credit points	6	F	Description					
Course achievement	No 20 %	Excercises	Description					
Examination	Written exam							
Examination duration and scale	90 min		_			_		
Assignment for the	Computer Science: Sp	ecialisation III. Mathe	matics: Elective Com	pulsory				
Following Curricula	Data Science: Special Data Science: Special Computer Science in	isation I. Mathematics isation IV. Special Foc Engineering: Specialis	: Elective Compulsor us Area: Elective Cor ation III. Mathematic	y npulsory s: Elective Compulsory				

Course L2062: Linear and No	onlinear Optimization
Тур	Lecture
Hrs/wk	4
CP	4
Workload in Hours	Independent Study Time 64, Study Time in Lecture 56
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	WiSe
Content	 Modelling linear programming problems Graphical method Algebraic background Convexity Polyhedral theory Simplex method Degeneracy and convergence duality interior-point methods quadratic optimization integer linear programming
Literature	 A. Schrijver: Combinatorial Optimization: Polyhedra and Efficiency. Springer, 2003 B. Korte and T. Vygen: Combinatorial Optimization: Theory and Algorithms. Springer, 2018 T. Cormen, Ch. Leiserson, R. Rivest, C. Stein: Introduction to Algorithms. MIT Press, 2013

Course L2063: Linear and Nonlinear Optimization	
Тур	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0720: Matri	x Algorithms				
Module M0720. Mach	Algorithms				
Courses					
Title		Тур	Hrs/wk	СР	
Matrix Algorithms (L0984)		Lecture	2	3	
Matrix Algorithms (L0985)	r	Recitation Section (small)	2	3	
Module Responsible	Dr. Jens-Peter Zemke				
Admission Requirements	None				
Recommended Previous	Mathematics I - III				
Knowledge	Numerical Mathematics 1/ Numerics				
	Basic knowledge of the programming langua	ges Matlab and C			
Educational Objectives	After taking part successfully, students have reach	ed the following learning results			
Professional Competence	Alter taking part successiony, students have reach	ed the following learning results			
Knowledae	Students are able to				
	1. name, state and classify state-of-the-art Kry	iov subspace methods for the solution of	the core problen	is of the enginee	ering
	sciences, namely, eigenvalue problems, solu	tion of linear systems, and model reductio	'n;		
	state approaches for the solution of matrix e	quations (Sylvester, Lyapunov, Riccati).			
Skills	Students are capable to				
	1 implement and assess basic Krylov subspace	e methods for the solution of eigenvalue	problems linear	systems and n	nodel
	reduction:	e methods for the solution of eigenvalue	problems, intear	systems, and n	nouci
	 assess methods used in modern software with 	th respect to computing time, stability, and	d domain of appl	cability;	
	3. adapt the approaches learned to new, unkno	own types of problem.	-	-	
Personal Competence	Churchen ann				
Social Competence	Students can				
	 develop and document joint solutions in small 	II teams;			
	form groups to further develop the ideas and	I transfer them to other areas of applicabil	ity;		
	 form a team to develop, build, and advance 	a software library.			
Autonomy	Students are able to				
		en l'accorda			
	correctly assess the time and effort of self-de	etined work;	dividually or in a	toom	
	 define test problems for testing and expandit 	ng the methods:	uividually of ill a	team,	
	 assess their individual progess and, if neces; 	sarv. to ask questions and seek help.			
Workload in Hours	Independent Study Time 124, Study Time in Lectur	e 56			
Credit points	6				
Course achievement	None				
Examination	Oral exam				
Examination duration and	25 min				
scale	Computer Science: Specialization III. Mathematica				
Eollowing Curricula	Data Science: Specialisation III. Mathematics:	Elective Compulsory			
Following curricula	Data Science: Specialisation I. Mathematics: Electiv				
	Duta Science: Specialisation I. Hathematics: Electiv	ecompaisory			
	Mechatronics: Specialisation Intelligent Systems an	d Robotics: Elective Compulsory			
	Mechatronics: Specialisation Intelligent Systems an Mechatronics: Specialisation System Design: Electiv	d Robotics: Elective Compulsory /e Compulsory			
	Mechatronics: Specialisation Intelligent Systems an Mechatronics: Specialisation System Design: Electiv Mechatronics: Core Qualification: Elective Compuls	d Robotics: Elective Compulsory ve Compulsory ory			
	Mechatronics: Specialisation Intelligent Systems an Mechatronics: Specialisation System Design: Electiv Mechatronics: Core Qualification: Elective Compulse Technomathematics: Specialisation I. Mathematics:	d Robotics: Elective Compulsory /e Compulsory ory Elective Compulsory			

Course L0984: Matrix Algorit	hms
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	WiSe
Content	 Part A: Krylov Subspace Methods: Basics (derivation, basis, Ritz, OR, MR) Arnoldi-based methods (Arnoldi, GMRes) Lanczos-based methods (Lanczos, CG, BiCG, QMR, SymmLQ, PvL) Sonneveld-based methods (IDR, BiCGStab, TFQMR, IDR(s)) Part B: Matrix Equations: Sylvester Equation Lyapunov Equation Algebraic Riccati Equation
Literature	 Skript (224 Seiten) Ergänzend können die folgenden Lehrbücher herangezogen werden: Saad, Yousef. Numerical methods for large eigenvalue problems: revised edition. Society for Industrial and Applied Mathematics, 2011. Saad, Yousef. Iterative methods for sparse linear systems. Society for Industrial and Applied Mathematics, 2003. Van der Vorst, Henk A. Iterative Krylov methods for large linear systems. No. 13. Cambridge University Press, 2003. Liesen, Jörg, and Zdenek Strakos. Krylov subspace methods: principles and analysis. Oxford University Press, 2013.

Course L0985: Matrix Algorithms	
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0711: Nume	erical Mathematics II			
Courses				
Title		Тур	Hrs/wk	СР
Numerical Mathematics II (L0568)		Lecture	2	3
Numerical Mathematics II (L0569)		Recitation Section (small)	2	3
Module Responsible	Prof. Sabine Le Borne			
Admission Requirements	None			
Recommended Previous				
Knowledge	Numerical Mathematics I Python knowledge			
Educational Objectives	After taking part successfully, students have re	eached the following learning results		
Professional Competence				
Knowledge	Students are able to			
	 name advanced numerical methods problems, nonlinear root finding problem repeat convergence statements for the explain practical aspects of numerical m explain aspects regarding the practical complexity. 	for interpolation, approximation, integration ns and explain their core ideas, numerical methods, sketch convergence proofs wethods concerning runtime and storage needs implementation of numerical methods with r	n, eigenvalue p 5, espect to compt	roblems, eigenvalue
Skills	Students are able to			
	 implement, apply and compare advance justify the convergence behaviour of nu it to related problems, for a given problem, develop a suitab execute this approach and to critically e 	d numerical methods in Python, merical methods with respect to the problem le solution approach, if necessary through c valuate the results	and solution algo omposition of se	rithm and to transfe everal algorithms, to
Personal Competence				
Social Competence	Students are able to			
	 work together in heterogeneously comp explain theoretical foundations and supp 	osed teams (i.e., teams from different study p port each other with practical aspects regarding	rograms and bac g the implementa	kground knowledge) ation of algorithms.
Autonomy	Students are capable			
	 to assess whether the supporting theore to assess their individual progess and, if 	tical and practical excercises are better solved necessary, to ask questions and seek help.	l individually or in	n a team,
Workload in Hours	Independent Study Time 124, Study Time in Le	ecture 56		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	25 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathemat	cics: Elective Compulsory		
Following Curricula	Data Science: Specialisation I. Mathematics: El	ective Compulsory		
	Data Science: Specialisation IV. Special Focus	Area: Elective Compulsory		
	Computer Science in Engineering: Specialisation	on III. Mathematics: Elective Compulsory		
	Technomathematics: Specialisation I. Mathema	atics: Elective Compulsory		
	Theoretical Mechanical Engineering: Core Qual	ification: Elective Compulsory		

Course L0568: Numerical Mathematics II	
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne, Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	SoSe
Content	 Error and stability: Notions and estimates Rational interpolation and approximation Multidimensional interpolation (RBF) and approximation (neural nets) Quadrature: Gaussian quadrature, orthogonal polynomials Linear systems: Perturbation theory of decompositions, structured matrices Eigenvalue problems: LR-, QD-, QR-Algorithmus Nonlinear systems of equations: Newton and Quasi-Newton methods, line search (optional) Krylov space methods: Arnoldi-, Lanczos methods (optional)
Literature	 Skript Stoer/Bulirsch: Numerische Mathematik 1, Springer Dahmen, Reusken: Numerik f ür Ingenieure und Naturwissenschaftler, Springer

Course L0569: Numerical Mathematics II	
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne, Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0673: Inform	nation Theory and Coding				
Courses					
Titlo		Tun	Hrc /wk	CD	
Information Theory and Coding (10	436)	I yp	HIS/WK	4	
Information Theory and Coding (Lo	438)	Recitation Section (large)	2	2	
Module Responsible	Prof. Gerhard Bauch				
Admission Requirements	None				
Pacammandad Provious	None				
Knowledge	Mathematics 1-3				
Kilowieuge	 Probability theory and random processes 				
	Basic knowledge of communications engine	ering (e.g. from lecture "Fundamenta	ls of Communi	cations and Random	
	Processes")				
Educational Objectives	After taking part successfully, students have reached	the following learning results			
Professional Competence					
Knowledge	The students know the basic definitions for quantifica	ation of information in the sense of info	mation theory.	They know Shannon's	
	source coding theorem and channel coding theorem	and are able to determine theoretical	limits of data co	mpression and error-	
	free data transmission over noisy channels. They und	derstand the principles of source coding	as well as erro	r-detecting and error-	
	correcting channel coding. They are familiar with t	the principles of decoding, in particula	ar with modern	methods of iterative	
	decoding. They know fundamental coding schemes, t	heir properties and decoding algorithms			
	The students are familiar with the contents of lecture	and tutorials. They can explain and app	ly them to new p	problems.	
Skills	The students are able to determine the limits of da	ta compression as well as of data tran	smission throug	h noisy channels and	
	based on those limits to design basic parameters of a transmission scheme. They can estimate the parameters of an error-				
	detecting or error-correcting channel coding scheme for achieving certain performance targets. They are able to compare the				
	properties of basic channel coding and decoding s	schemes regarding error correction ca	pabilities, deco	ding delay, decoding	
	complexity and to decide for a suitable method. T	hey are capable of implementing bas	ic coding and o	decoding schemes in	
	software.				
Personal Competence					
Social Competence	The students can jointly solve specific problems.				
Autonomy	The students are able to acquire relevant informa	ation from appropriate literature sour	ces. They can	control their level of	
	knowledge during the lecture period by solving tutoria	al problems, software tools, clicker syste	em.		
Workload in Hours	Independent Study Time 110, Study Time in Lecture	70			
Credit points	6				
Course achievement	None				
Examination	Written exam				
Examination duration and	90 min				
scale					
Assignment for the	Data Science: Specialisation I. Mathematics: Elective	Compulsory			
Following Curricula	Data Science: Specialisation IV. Special Focus Area: E	lective Compulsory			
	Electrical Engineering: Specialisation Information and	Communication Systems: Elective Com	pulsory		
	Electrical Engineering: Specialisation Wireless and Se	nsor Technologies: Elective Compulsory			
	Computer Science in Engineering: Specialisation II. Er	gineering Science: Elective Compulsory			
	Information and Communication Systems: Core Quality	ication: Compulsory			
	International Management and Engineering: Specialis	ation II. Electrical Engineering: Elective	Compulsory		
	Mechatronics: Technical Complementary Course: Elec	tive Compulsory			

Course L0436: Information T	heory and Coding
Тур	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	 Introduction to information theory and coding Definitions of information: Self information, entropy Binary entropy function Source coding theorem Entropy of continuous random variables: Differential entropy, differential entropy of uniformly and Gaussian distributed random variables Source coding Principles of lossless source coding Optimal source codes Prefix codes, prefix-free codes, instantaneous codes Morse code Huffman code Shannon code
	 Bounds on the average codeword length
	[26]

- Relative entropy, Kullback-Leibler distance, Kullback-Leibler divergence
- Cross entropy
- Lempel-Ziv algorithm
- Lempel-Ziv-Welch (LZW) algorithm
- Text compression and image compression using variants of the Lempel-Ziv algorithm
- Channel models
 - AWGN channel
 - Binary-input AWGN channel
 - Binary symmetric channel (BSC)
 - Relationship between AWGN channel and BSC
 - Binary error and erasure channel (BEEC)
 - Binary erasure channel (BEC)
 - Discrete memoryless channels (DMC)
- · Definitions of information for multiple random variables
 - Mutual information and channel capacity
 - Entropy, conditional entropy
 - Chain rules for entropy and mutual information
- Channel coding theorem
- Channel capacity of fundamental channels: BSC, BEC, AWGN channel, binary-input AWGN channel etc.
- Power-limited vs. bandlimited transmission
- Capacity of parallel AWGN channels
 - Waterfilling
 - Examples: Multiple input multiple output (MIMO) channels, complex equivalent baseband channels, orthogonal frequency division multiplex (OFDM)
- Source-channel coding theorem, separation theorem
- Multiuser information theory
 - Multiple access channel (MAC)
 - Broadcast channel
 - · Principles of multiple access, time division multiple access (TDMA), frequency division multiple access (FDMA), nonorthogonal multiple access (NOMA), hybrid multiple access
 - Achievable rate regions of TDMA and FDMA with power constraint, energy constraint, power spectral density constraint, respectively
 - Achievable rate region of the two-user and K-user multiple access channels
 - Achievable rate region of the two-user and K user broadcast channels
 - Multiuser diversity
- Channel coding
 - Principles and types of channel coding
 - · Code rate, data rate, Hamming distance, minimum Hamming distance, Hamming weight, minimum Hamming weight
 - Error detecting and error correcting codes
 - Simple block codes: Repetition codes, single parity check codes, Hamming code, etc.
 - Syndrome decoding
 - Representations of binary data
 - Non-binary symbol alphabets and non-binary codes
 - Code and encoder, systematic and non-systematic encoders
 - Properties of Hamming distance and Hamming weight
 - Decoding spheres
 - Perfect codes
 - Linear codes
 - Decoding principles
 - Syndrome decoding
 - Maximum a posteriori probability (MAP) decoding and maximum likelihood (ML) decoding
 - Hard decision and soft decision decoding
 - Log-likelihood ratios (LLRs), boxplus operation
 - MAP and ML decoding using log-likelihood ratios
 - Soft-in soft-out decoders
 - Error rate performance comparison of codes in terms of SNR per info bit vs. SNR per code bit
 - Linear block codes
 - Generator matrix and parity check matrix, properties of generator matrix and parity check matrix Dual codes
 - Low density parity check (LDPC) codes
 - Sparse parity check matrix
 - Tanner graphs, cycles and girth
 - Degree distributions
 - Code rate and degree distribution
 - Regular and irregular LDPC codes
 - Message passing decoding
 - Message passing decoding in binary erasure channels (BEC)
 - Systematic encoding using erasure message passing decoding
 - Message passing decoding in binary symmetric channels (BSC)
 - Extrinsic information
 - Bit-flipping decoding
 - Effects of short cycles in the Tanner graph
 - Alternative bit-flipping decoding
 - Soft decision message passing decoding: Sum product decoding
 - Bit error rate performance of LDPC codes

	Repeat accumulate codes and variants of repeat accumulate codes
	 Message passing decoding and turbo decoding of repeat accumulate codes
	Convolutional codes
	 Encoding using shift registers
	Trellis representation
	 Hard decision and soft decision Viterbi decoding
	 Bit error rate performance of convolutional codes
	 Asymptotic coding gain
	 Viterbi decoding complexity
	 Free distance and optimum convolutional codes
	 Generator polynomial description and octal description
	Catastrophic convolutional codes
	 Non-systematic and recursive systematic convolutional (RSC) encoders
	 Rate compatible punctured convolutional (RCPC) codes
	 Hybrid automatic repeat request (HARQ) with incremental redundancy
	 Unequal error protection with punctured convolutional codes
	Error patterns of convolutional codes
	Concatenated codes
	Serial concatenated codes
	 Parallel concatenated codes, Turbo codes
	 Iterative decoding, turbo decoding
	Bit error rate performance of turbo codes
	Interleaver design for turbo codes
	Coded modulation
	 Principle of coded modulation
	 Achievable rates with PSK/QAM modulation
	Irelis coded modulation (ICM) Characteristics
	Set partitioning
	Ungerbock codes
	 Multilever county Pit interdent modulation
	 bit-interleaved coded modulation
Literature	Bossert. M.: Kanalcodierung. Oldenbourg.
	Friedrichs, B.: Kanalcodierung. Springer.
	Lin, S., Costello, D.: Error Control Coding. Prentice Hall.
	Roth, R.: Introduction to Coding Theory.
	Johnson, S.: Iterative Error Correction. Cambridge.
	Richardson, T., Urbanke, R.: Modern Coding Theory. Cambridge University Press.
	Gallager, R. G.: Information theory and reliable communication. Whiley-VCH
	Cover, T., Thomas, J.: Elements of information theory. Wiley.

Course L0438: Information Theory and Coding	
Тур	Recitation Section (large)
Hrs/wk	2
СР	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1405: Rand	omised Algorithms and Random Grap	hs		
Courses				
Title Randomised Algorithms and Rando	om Graphs (L2010)	Typ Lecture Recitation Section (Jarce)	Hrs/wk	CP 3
Madula Bosponsible	Brof Anucch Toroz	Rectation Section (large)	2	2
Admission Boguiroments	Nono			
Recommended Provious	None			
Knowledge				
Educational Objectives	After taking part successfully, students have reached t	he following learning results		
Professional Competence	Firef taking part successiony, stadents have reached t			
Knowledge	 Students can describe basic concepts in the are bounds, fingerprinting and algebraic technique. They are able to explain them using appropriate. Students can discuss logical connections betwee the help of examples. They know proof strategies and can apply them 	a of Randomized Algorithms and Rar is, first and second moment method e examples. ien these concepts. They are capab	ndom Graphs such a ds, and various ran le of illustrating the	is random walks, tail idom graph models. ise connections with
Skills	 Students can model problems with the help of them by applying established methods. Students are able to explore and verify further l For a given problem, the students can develop results. 	the concepts studied in this course ogical connections between the conc o and execute a suitable technique,	Moreover, they ar epts studied in the and are able to cr	e capable of solving course. itically evaluate the
Personal Competence <i>Social Competence</i> <i>Autonomy</i>	 Students are able to work together in teams. Th In doing so, they can communicate new concept design examples to check and deepen the underst students are capable of checking their underst precisely and know where to get help in solving Students have developed sufficient persistence problems. 	ey are capable to establish a commo its according to the needs of their co rstanding of their peers. anding of complex concepts on their them. e to be able to work for longer perio	n language. operating partners. ⁻ own. They can spe ods in a goal-orient	Moreover, they can ecify open questions ted manner on hard
Workload in Hours	Independent Study Time 124, Study Time in Lecture 5	6		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathematics: Elec	ctive Compulsory		
Following Curricula	Data Science: Specialisation I. Mathematics: Elective C	ompulsory		
	Data Science: Specialisation IV. Special Focus Area: Ele	ective Compulsory		
	Computer Science in Engineering: Specialisation III. Ma	thematics: Elective Compulsory		

Course L2010: Randomised A	Algorithms and Random Graphs
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Anusch Taraz, Prof. Volker Turau
Language	DE/EN
Cycle	SoSe
Content	Randomized Algorithms:
	 introduction and recalling basic tools from probability randomized search random walks text search with fingerprinting parallel and distributed algorithms online algorithms Random Graphs: typical properties first and second moment method tail bounds thresholds and phase transitions probabilistic method models for complex networks
Literature	 Motwani, Raghavan: Randomized Algorithms Worsch: Randomisierte Algorithmen Dietzfelbinger: Randomisierte Algorithmen Bollobas: Random Graphs Alon, Spencer: The Probabilistic Method Frieze, Karonski: Random Graphs van der Hofstad: Random Graphs and Complex Networks

Course L2011: Randomised Algorithms and Random Graphs	
Тур	Recitation Section (large)
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Anusch Taraz, Prof. Volker Turau
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0714: Nume	erical Methods for Ordinary Different	ial Equations		
Courses				
Title		Тур	Hrs/wk	СР
Numerical Treatment of Ordinary E	Differential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary E)ifferential Equations (L0582)	Recitation Section (small)	2	3
Module Responsible	Prof. Daniel Ruprecht			
Admission Requirements	None			
Recommended Previous	Mathematik I, II, III for Engineers (German	o or English) or Analysis & Linear A	laehra I + II	nlus Analysis III for
Knowledge	Technomathematiker.	Tor English, or Analysis a English	Igeora i	plus Analysis III
1	Basic knowledge of MATLAB, Python or a simil:	ar programming language.		
	······································			
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowledge	Students are able to			
	 name numerical methods for the solution of or 	dinary differential equations and explain	their core ideas	,
	• formulate convergence statements for the t	aught numerical methods (including th	e necessary as	sumptions about the
	solved problem),			
	explain aspects regarding the practical realisation	tion of a method,		
	• select the appropriate numerical method for se	pecific problems, implement the numeric	al algorithms eff	iciently and interpret
	the numerical results.			
Skille	Students are able to			
Skiiis				
	 implement, apply and compare numerical met 	hods for the solution of ordinary different	ial equations,	
	explain the convergence behaviour of nume	rical methods, taking into consideratio	n the solved p	roblem and selected
	algorithm,			
	develop a suitable solution approach for a	given problem, if necessary by combin	ing multiple alg	orithms, realise this
	approach and critically evaluate results.			
Personal Competence				
Social Competence	Students are able to			
	work together in heterogeneous teams (i.e.	e., teams from different study progra	ms and with d	different background
	algorithms	nd support each other with practical asp	ects regarding t	ne implementation of
	algorianns.			
Autonomy	Students are capable			
	 to assess whether the provided theoretical and 	nactical excercises are better solved in	dividually or in a	team and
	 to assess their individual progress and if nece 	search to ask questions and seek help		
	• to assess their individual progress and, if nece	ssary, to ask questions and seek help.		
Workload in Hours	Independent Study Time 124, Study Time in Lecture	56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Bioprocess Engineering: Specialisation A - General Bi	oprocess Engineering: Elective Compulso	rv	
Following Curricula	Chemical and Bioprocess Engineering: Specialisation	Chemical Process Engineering: Elective (Compulsory	
-	Chemical and Bioprocess Engineering: Specialisation	General Process Engineering: Elective Co	mpulsory	
	Computer Science: Specialisation III. Mathematics: El	ective Compulsory		
	Data Science: Specialisation I. Mathematics: Elective	Compulsory		
	Data Science: Specialisation IV. Special Focus Area: E	lective Compulsory		
	Electrical Engineering: Specialisation Control and Pov	ver Systems Engineering: Elective Compu	lsory	
	Energy Systems: Core Qualification: Elective Compute	sory		
	Aircraft Systems Engineering: Core Qualification: Elec	tive Compulsory		
	Interdisciplinary Mathematics: Specialisation II. Nume	erical - Modelling Training: Compulsory		
	Aeronautics: Core Qualification: Elective Compulsory			
	Mechatronics: Core Qualification: Elective Compulsor	у		
	Technomathematics: Specialisation I. Mathematics: E	lective Compulsory		
	Theoretical Mechanical Engineering: Core Qualification	n: Compulsory		
	Process Engineering: Specialisation Chemical Process	Engineering: Elective Compulsory		
	Process Engineering: Specialisation Process Engineer	ing: Elective Compulsory		

Course L0576: Numerical Tre	eatment of Ordinary Differential Equations
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	Numerical methods for Initial Value Problems
Literature	 E. Hairer, S. Noersett, G. Wanner: Solving Ordinary Differential Equations I: Nonstiff Problems. E. Hairer, G. Wanner: Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems. D. Griffiths, D. Higham: Numerical Methods for Ordinary Differential Equations.

course L0582: Numerical Treatment of Ordinary Differential Equations	
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

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Courses				
Title		Тур	Hrs/wk	CP
Probability Theory (L2643)		Lecture Recitation Section (small)	3	4
		Reclation Section (Shan)	T	Z
Module Responsible	Prof. Matthias Schulte			
Admission Requirements	None			
Recommended Previous	Familiarity with the basic concepts of probab	ility		
Knowleage				
Educational Objectives	After taking part successfully, students have	reached the following learning results		
Professional Competence				
Knowledge	 Students can name the basic concept 	s in probability theory. They are able to explain th	nem using appro	priate examples.
	Students can discuss logical connecti	ons between these concepts. They are capable	of illustrating th	ese connections with
	the help of examples.	· ·	-	
	They know proof strategies and can re	produce them.		
Skills				
l	Students can model problems from p	robability theory with the help of the concepts s	tudied in this co	ourse. Moreover, they
	are capable of solving them by applyin	ng established methods.		
	Students are able to explore and verified	y further logical connections between the concep	its studied in the	course.
	For a given problem, the students ca	an develop and execute a suitable technique, a	nd are able to c	ritically evaluate the
	results.			
Personal Competence				
Social Competence				
l	Students are able to work together (e	.g. on their regular home work) and to present t	heir results appr	opriately (e.g. auring
	exercise class).	the second of their case	- the superstances	•• they ee
	In doing so, they can communicate ne	ew concepts according to the needs of their coop	perating partners	. Moreover, they car
	design examples to check and deeper	the understanding of their peers.		
Autonomy				
	Students are capable of checking the	ir understanding of complex concepts on their o	wn. They can sp	ecify open questions
	precisely and know where to get help	In solving them.		
	Students can put their knowledge in re- Chudents have developed sufficient r	elation to the contents of other lectures.	- in a goal origi	t
	 Students have developed sufficient p problems 	PRISTERCE to be able to work for longer period	5 lii a guai-unei	ited manner on hard
l	problems.			
Workload in Hours	Independent Study Time 124, Study Time in	Lecture 56		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathem	natics: Elective Compulsory		
Following Curricula	Data Science: Specialisation IV. Special Focu	s Area: Elective Compulsory		
	Data Science: Specialisation I. Mathematics:	Elective Compulsory		
	Interdisciplinary Mathematics: Specialisation	II. Numerical - Modelling Training: Compulsory		
1	Technomathematics: Specialisation I. Mather	matics: Elective Compulsory		

Course L2643: Probability Th	neory
Тур	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Matthias Schulte
Language	EN
Cycle	SoSe
Content	 Measure and probability spaces Integration and expectation Types of stochastic convergence Law of large numbers Central limit theorem Radon-Nikodym theorem Conditional expectation Martingales Markov chains Poisson processes
Literature	 H. Bauer, Probability theory and elements of measure theory, second edition, Academic Press, 1981. A. Klenke, Probability Theory: A Comprehensive Course, second edition, Springer, 2014. G. F. Lawler, Introduction to Stochastic Processes, second edition, Chapman & Hall/CRC, 2006. A. N. Shiryaev, Probability, second edition, Springer, 1996.

Course L2644: Probability Theory	
Тур	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Matthias Schulte
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Specialization II. Computer Science

Module M1598: Image	e Processing			
Courses				
Title		Тур	Hrs/wk	СР
Image Processing (L2443)		Lecture	2	4
Image Processing (L2444)		Recitation Section (small)	2	2
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Signal and Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the fo	llowing learning results		
Professional Competence				
Knowledge	The students know about			
	visual perception			
	multidimonsional signal processing			
	multidimensional signal processing			
	sampling and sampling theorem filtering			
	image enhancement			
	odge detection			
	 multi-resolution procedures: Gauss and Laplace pyra. 	mid wavelets		
	 image compression 			
	image segmentation			
	morphological image processing			
	- morphological image processing			
Skills	The students can			
	 analyze, process, and improve multidimensional image 	ge data		
	 implement simple compression algorithms 			
	 design custom filters for specific applications 			
Personal Competence				
Social Competence	Students can work on complex problems both independent	y and in teams. They can exchang	e ideas with eac	h other and use their
	individual strengths to solve the problem.			
Autonomy	Students are able to independently investigate a complex p	roblem and assess which compete	encies are require	ed to solve it.
Mandaland In Harris	lades endert Chulu Time 124. Chulu Time in Lesture 50			
Credit points				
	Name			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Data Science: Core Qualification: Elective Compulsory			
Following Curricula	Data Science: Specialisation I. Mathematics/Computer Science	ice: Elective Compulsory		
	Data Science: Specialisation II. Computer Science: Elective C	Compulsory		
	Electrical Engineering: Engineering Engineering	Compulsory	ulcon.	
	Electrical Engineering: Specialisation Information and Comm	lactive Compulson	Juisory	
	Information and Communication Systems: Specialization Co	munication Systems, Focus Sign	al Procossing: El	octivo Compulsory
	Information and Communication Systems, Specialisation Co	Secure and Dependence IT C	ustems Focus 9	offware and Signal
	Processing: Elective Compulsory	Secure and Dependable IT S	sterns, rocus s	ortware and Signar
	International Management and Engineering: Specialisation I	I Information Technology: Elective	Compulsory	
	Mechatronics: Specialisation Intelligent Systems and Roboti	cs: Elective Compulsory	2 compaisory	
	Mechatronics: Specialisation System Design: Elective Comp	ulsory		
	Mechatronics: Core Qualification: Elective Compulsory			
	Microelectronics and Microsystems: Specialisation Commun	ication and Signal Processing: Fler	tive Compulsory	
	Theoretical Mechanical Engineering: Specialisation Robotics	and Computer Science: Elective C	Compulsory	

Course L2443: Image Proces	sing
Тур	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	 Visual perception Multidimensional signal processing Sampling and sampling theorem Filtering Image enhancement Edge detection Multi-resolution procedures: Gauss and Laplace pyramid, wavelets Image Compression Segmentation Morphological image processing
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Pratt, Digital Image Processing, Wiley, 2001 Bernd Jähne: Digitale Bildverarbeitung - Springer, Berlin 2005

Course L2444: Image Processing				
Тур	Recitation Section (small)			
Hrs/wk	2			
CP	2			
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28			
Lecturer	Prof. Tobias Knopp			
Language	DE/EN			
Cycle	WiSe			
Content	See interlocking course			
Literature	See interlocking course			
Courses				
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Title		Typ	Hrc/wk	CP
Security of Cyber-Physical Systems	(L2691)	Lecture	2	3
Security of Cyber-Physical Systems	(L2692)	Recitation Section (small)	2	3
Module Responsible	Prof. Sibylle Fröschle			
Admission Requirements	None			
Recommended Previous	IT security, programming skills, statistics			
Knowledge				
Educational Objectives	After taking part successfully, students hav	ve reached the following learning results		
Knowledge	The students know and can explain			
	- the threats posed by cyber attacks to cyb	per-physical systems (CPS)		
	- concrete attacks at a technical level, e.g.	on bus systems		
	- security solutions specific to CPS with the	ir capabilities and limitations		
	- examples of security architectures for CP	S and the requirements they guarantee		
	- standard security engineering processes	for CPS		
Skills	The students are able to			
	 identify security threats and assess the r 	isks for a given CPS		
	 apply attack toolkits to analyse a networ 	ked control system, and detect attacks beyond tho	se taught in class	5
	 identify and apply security solutions suita 	able to the requirements		
	 follow security engineering processes to 	develop a security architecture for a given CPS		
	 recognize challenges and limitations, e.g 	. posed by novel types of attack		
Personal Competence				
Social Competence	The students are able to			
	 expertly discuss security risks and incid experts 	lents of CPS and their mitigation in a solution-ori	ented fashion wi	th experts and n
	- foster a security culture with respect to C	PS and the corresponding critical infrastructures		
Autonomy	The students are able to			
	- follow up and critically assess current dev	velopments in the security of CPS including relevan	t security inciden	ts
	- master a new topic within the area by sel	f-study and self-initiated interaction with experts a	nd peers.	
Workload in Hours	Independent Study Time 124, Study Time i	in Lecture 56		
Credit points	6			
Course achievement	Compulsory Bonus Form	Description	N 1 1 1	
Fremination	No 10% Excercises	Die Ubungsaufgaben finden semesterbegl	eitend statt.	
Examination	120 min			
scale				
Assignment for the	Computer Science: Specialisation I. Compu	ter and Software Engineering: Elective Compulsory	1	
Following Curricula	Data Science: Specialisation II. Computer S	Science: Elective Compulsory		
	Data Science: Specialisation IV. Special For	cus Area: Elective Compulsory		
	Computer Science in Engineering: Specialis	sation I. Computer Science: Elective Compulsory		
	Information and Communication System	s: Specialisation Secure and Dependable IT Sy	ystems, Focus S	oftware and Sig
	Processing: Elective Compulsory			

Course L2691: Security of Cy	/ber-Physical Systems
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Fröschle
Language	EN
Cycle	WiSe
Content	Embedded systems in energy, production, and transportation are currently undergoing a technological transition to highly networked automated cyber-physical systems (CPS). Such systems are potentially vulnerable to cyber attacks, and these can have physical impact. In this course we investigate security threats, solutions and architectures that are specific to CPS. The topics are as follows:
	Fundamentals and motivating examples Networked and embedded control systems Bus system level attacks Interview detection systems (IDS), in particular physics based IDS
	System security architectures, including cryptographic solutions Adversarial machine learning attacks in the physical world Aspects of Location and Localization
	Wireless networks and infrastructures for critical applications Communication security architectures and remaining threats Intruder detection systems (IDS), in particular data-centric IDS Resilience against multi-instance attacks Security Engineering of CPS: Process and Norms
Literature	Recent scientific papers and reports in the public domain.

Course L2692: Security of Cyber-Physical Systems		
Тур	Recitation Section (small)	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Sibylle Fröschle	
Language	EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Courses						
Title			Tree	Ll ro	- Aude	CD
IITIE Massively Parallel Systems: Archite	ecture and Programming	(1 2936)	I yp	HIS 2	5/WK	3
Massively Parallel Systems: Archite	ecture and Programming	(L2937)	Project-/problem-l	based Learning 2		3
Module Responsible	Prof. Sohan Lal					
Admission Requirements	None					-
Recommended Previous	An introductory modu	Ile on computer Enginee	ing or computer architecture, good	programming skills i	in C/C++.	
Knowledge						
Educational Objectives	After taking part succ	essfully, students have r	eached the following learning result	S		
Professional Competence						
Knowledge Skills Personal Competence Social Competence Autonomy	The course starts wit shared-memory para implementation, and correctness of shared important topics of m accelerators such as systems, programmir API/libraries such as C After completing this able to evaluate diffe program parallel syst The course will enco teamwork. Today, parallel co computers independe	h parallel computers cla: llel systems, multiproc limitations. Next, stude d-memory multithreaded nemory consistency and GPUs will also be discu- ing them is also very chal CUDA/OpenCL/MPI/OpenN course, students will be erent design choices and ems (ranging from an en- murage students to work- mputers are presen- ently, but also understan	sification, multithreading, and cover essor cache coherence, snooping nts study interconnection networks programs, independent of the spi- synchronization will be covered in enging. The course will also cover line. The course will also cover line. able to understand the architecture make decisions while designing a ubedded system to a supercompute in small groups to solve complex everywhere. Students will d their underlying organization and	ers the architecture of / directory-based s and routing in par eed of execution of detail. As a case stu- ing the architecture how to program mas and organization of parallel system. In a r) using CUDA/Open(x problems, thus, in be able to not architecture. This w	of centrali cache co allel syste their indi idy, the ar and orga ssively par parallel sy addition, t CL/MPI/Op nculcating t only <i>i</i> ll further	zed and distribute herence protocol: ems. To ensure the vidual threads, the chitecture of a fer- inization of paralle rallel systems usin extems. They will be they will be able the enMP. the importance of program paralle help to understan
	the performance issu	es of parallel application	and provide insights to improve th	em.		
Workload in Hours	Independent Study Ti	me 124, Study Time in L	ecture 56			
Credit points	6					
Course achievement	CompulsoryBonusYes20 %	Form Subject theoretical practical work	Description and			
Examination	Oral exam					
Examination duration and	25 min					
scale						
Assignment for the	Computer Science: Sp	pecialisation I. Computer	and Software Engineering: Elective	Compulsory		
Following Curricula	Data Science: Special	isation II. Computer Scie	nce: Elective Compulsory			
	Data Science: Special	isation IV. Special Focus	Area: Elective Compulsory			
	Computer Science in	Engineering: Specialisati	on I. Computer Science: Elective Co	mpulsory		
	Information and Com	munication Systems: Spe	cialisation Communication Systems	, Focus Software: Ele	ective Con	npulsory
	Microelectronics and	Microsystems: Specialisa	tion Embedded Systems: Elective C	ompulsory		

Course L2936: Massively Para	allel Systems: Architecture and Programming
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	WiSe
Content	Brief outline:
	 Parallel computers and their classification Centralized and distributed shared-memory architectures: snooping vs directory-based cache coherence protocols, implementation, and limitations Chip multiprocessors: software-based, block (coarse-grain), interleaved (fine-grain), simultaneous multithreading Synchronization: high-level primitives and implementation, memory consistency models: sequential and weaker memory consistency models Interconnection networks: topologies (direct and indirect networks) and routing techniques Graphics Processing Units (GPUs) architecture and programming using CUDA/OpenCL Parallel programming with message passing interface (MPI), OpenMP
Literature	 Michel Dubois, Murali Annavaram, and Per Stenström, Parallel Computer Organization and Design (Book) David A Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, Elsevier (Book) David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book)

Course L2937: Massively Par	allel Systems: Architecture and Programming
Тур	Project-/problem-based Learning
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	WiSe
Content	 There will be 3-4 assignments for project-based learning consisting of the following: Implement and compare different cache coherence protocols using a simulator or a high-level, event-driven simulation interface such as SystemC Programming massively parallel systems to solve computationally intensive problems such as password cracking using CUDA/OpenCL/MPI/OpenMP
Literature	 The following literature will be useful for project-based learning. The further required resources will be discussed during the course. David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book) MPI Forum, https://www.mpi-forum.org/ SystemC, https://www.accellera.org/community/systemc

Module M0753: Softv	vare Verificatio	า					
Courses							
Title					Тур	Hrs/wk	СР
Software Verification (L0629)					Lecture	2	3
Software Verification (L0630)					Recitation Section (small)	2	3
Module Responsible	Prof. Sibylle Schupp						
Admission Requirements	None						
Recommended Previous	A standard the s						
Knowledge	Automata theo		inguages				
	Object-orientee	logic I programming	algorithms a	and data struct	uroc		
	Eunctional proc	ramming or pr	ocedural prog	ramming	ures.		
	Concurrency	furthing of pro-	occurrar progr	running			
	concurrency						
Educational Objectives	After taking part succ	essfully, studer	nts have reach	ned the following	ng learning results		
Professional Competence							
Knowledge	•						
	Students apply the m	ajor verification	techniques in	n model checki	ing and deductive verification	on. They explain ir	n formal terms syntax
	and semantics of the	underlying log	lics, and asse	ess the express	sivity of different logics as	well as their limit	tations. They classify
	formal properties of s	oftware system	s. They find fla	aws in formal	arguments, arising from mo	odeling artifacts or	underspecification.
Skills	Students formulate p	rovable propert	ies of a softwa	are system in	a formal language. They de	velop logic-based	models that properly
	abstract from the sof	tware under ve	rification and,	where necess	ary, adapt model or prope	rty. They construct	proofs and property
	checks by hand or us	ng tools for mo	del checking o	or deductive v	erification, and reflect on th	e scope of the res	ults. Presented with
	verification problem i	n natural langua	age, they sele	ct the appropr	iate verification technique	and justify their ch	ioice.
Personal Competence			-				
Social Competence	Students discuss rele	vant topics in cl	ass. They defe	end their solut	ions orally. They communic	ate in English.	
Autonomy	Using accompanying	on-line materi	al for self stu	udy, students	can assess their level of	knowledge contin	uously and adjust i
	appropriately. Worki	ng on exercise	problems, the	ey receive ad	ditional feedback. Within li	mits, they can se	t their own learning
	goals. Upon successf	I completion, s	tudents can ic	dentify and pre	ecisely formulate new probl	ems in academic o	or applied research ir
	the field of software	verification. Wi	thin this field,	, they can con	duct independent studies t	o acquire the nec	essary competencies
	and compile their find	lings in academ	ic reports. The	ey can devise	plans to arrive at new solut	ions or assess exis	sting ones.
Workload in Hours	Independent Study Ti	me 124 Study	Time in Lectur	re 56			
Cradit points	6	ine 124, Study	Time in Lectur	10 50			
Course achievement	Compulsory Bonus	Form		Description			
course achievement	Yes 15 %	Excercises					
Examination	Written exam						
Examination duration and	90 min						
scale							
Assignment for the	Computer Science: S	ecialisation I. C	Computer and	Software Engi	neering: Elective Compulso	ry	
Following Curricula	Data Science: Specia	isation IV. Spec	ial Focus Area	a: Elective Com	pulsory		
_	Data Science: Specia	isation II. Comp	uter Science:	Elective Comp	oulsory		
	Computer Science in	Engineering: Sp	ecialisation I.	Computer Scie	ence: Elective Compulsory		
	Information and Com	munication Syst	ems: Specialis	sation Secure	and Dependable IT Systems	s: Compulsory	
	Information and Com	munication Syst	ems: Specialis	sation Commu	nication Systems, Focus So	ftware: Elective Co	ompulsory
	International Manage	ment and Engin	eering: Specia	alisation II. Info	ormation Technology: Electi	ve Compulsory	

Course L0629: Software Veri	fication
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	 Model checking (bounded model checking, CTL, LTL) Real-time model checking (TCTL, timed automata) Deductive verification (Hoare logic) Tool support Recent developments of verification techniques and applications
Literature	 C. Baier and J-P. Katoen, Principles of Model Checking, MIT Press 2007. M. Huth and M. Bryan, Logic in Computer Science. Modelling and Reasoning about Systems, 2nd Edition, 2004. Selected Research Papers

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Course L0630: Software Verification		
Тур	Recitation Section (small)	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Sibylle Schupp	
Language	EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M0676: Digita	al Communications				
5					
Courses					
Title			Тур	Hrs/wk	СР
Digital Communications (L0444)			Lecture	2	3
Digital Communications (L0445)			Recitation Section (large)	2	2
Laboratory Digital Communications	(L0646)		Practical Course	1	1
Module Responsible	Prof. Gerhard Bauch				
Admission Requirements	None				
Recommended Previous	Mathematics 1-3				
Knowledge	 Signals and Systems 				
	 Fundamentals of Communications and 	nd Random Processes			
Educational Objectives	After taking part successfully, students have	ve reached the followi	ng learning results		
Professional Competence					
Knowledge	The students are able to understand, comp	pare and design mode	rn digital information transmi	ssion schemes. T	hey are familiar with
	the properties of linear and non-linear digit	tal modulation metho	ds. They can describe distorti	ons caused by tr	ansmission channels
	and design and evaluate detectors include	ding channel estimat	ion and equalization. They I	know the princip	oles of single carrier
	transmission and multi-carrier transmission	n as well as the funda	mentals of basic multiple acce	ess schemes.	
	The students are familiar with the contents	of lecture and tutoria	als. They can explain and app	ly them to new p	roblems.
Skille	The students are able to design and analysis	se a digital informatio	n transmission scheme inclus	ling multiple acc	ass. They are able to
SKIIIS	choose a digital modulation scheme taking	into account transmi	ssion rate, required handwidt	h error probabili	ty and further signa
	properties. They can design an approp	riate detector inclu	ting channel estimation an	d equalization	taking into account
	performance and complexity properties of	suboptimum solutions	They are able to set parame	eters of a single of	arrier or multi carrie
	transmission scheme and trade the properties of	ties of both approach	es against each other	sters of a single t	
Personal Competence	dansmission scheme and dade the propert		es against each other.		
Social Competence	The students can jointly solve specific problems				
Social competence	The students can jointly solve specific prob	icilia.			
Autonomy	The students are able to acquire releva	ant information from	appropriate literature source	es. They can c	ontrol their level of
	knowledge during the lecture period by sol	ving tutorial problems	s, software tools, clicker syste	m.	
Workload in Hours	Independent Study Time 110, Study Time i	n Lecture 70			
Credit points	6				
Course achievement	Compulsory Bonus Form	Description			
	Yes None Written elaboration				
Examination	Written exam				
Examination duration and	90 min				
scale					
Assignment for the	Data Science: Specialisation II. Computer S	cience: Elective Com	oulsory		
Following Curricula	Data Science: Specialisation IV. Special Foc	cus Area: Elective Con	npulsory		
	Electrical Engineering: Core Qualification: C	Compulsory			
	Computer Science in Engineering: Specialis	ation II. Engineering	Science: Elective Compulsory		
	Information and Communication Systems:	Specialisation Commu	inication Systems: Compulsor	У	
	Information and Communication Systems:	Specialisation Secure	and Dependable IT Systems,	Focus Networks:	Elective Compulsory
	International Management and Engineering	g: Specialisation II. Inf	ormation Technology: Elective	e Compulsory	
	International Management and Engineering	g: Specialisation II. Ele	ctrical Engineering: Elective (Compulsory	
	Microelectronics and Microsystems: Core O	ualification: Elective (Compulsory		

Course L0444: Digital Comm	unications
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	- Departition: Decale and Transmission
	Repetition: Baseband Transmission A Pulse shaping: Non-return to zero (NPZ) rectangular pulses, raised cosino pulses, square reet raised cosino pulses.
	 Power spectral density (nsd) of baseband signals
	 Intersymbol interference (ISI)
	 First and second Nyquist criterion
	AWGN channel
	Matched filter
	Matched-filter receiver and correlation receiver
	Noise whitening matched filter
	Discrete-time AWGN channel model
	 Representation of bandpass signals and systems in the equivalent baseband
	Quadrature amplitude modulation (QAM)
	Equivalent baseband signal and system
	Analytical signal
	 Equivalent baseband random process, equivalent baseband white Gaussian noise process

- Equivalent baseband AWGN channel
- $\circ~$ Equivalent baseband channel model with frequency-offset and phase noise
- Equivalent baseband Rayleigh fading and Rice fading channel models
- Equivalent baseband frequency-selective channel model
- Discrete memoryless channels (DMC)
- Bandpass transmission via carrier modulation
 - Amplitude modulation, frequency modulation, phase modulation
 - Linear digital modulation methods
 - On-off keying, M-ary amplitude shift keying (M-ASK), M-ary phase shift keying (M-PSK), M-ary quadrature amplitude modulation (M-QAM), offset-QPSK
 - Signal space representation of transmit signal constellations and signals
 - Energy of linear digital modulated signals, average energy per symbol
 - Power spectral density of linear digital modulated signals
 - Bandwidth efficiency
 - Correlation coefficient of elementary signals
 - Error probabilities of linear digital modulation methods
 - Error functions
 - Gray mapping and natural mapping
 - Bit error probabilities, symbol error probabilities, pairwise symbol error probabilities
 - Euclidean distance and Hamming distance
 - Exact and approximate computation of error probabilities
 - Performance comparison of modulation schemes in terms of per bit SNR vs. per symbol SNR
 - Hierarchical modulation, multilevel modulation
 - Effects of carrier phase offset and carrier frequency offset
 - Differential modulation
 - M-ary differential phase shift keying (M-PSK)
 - Coherent and non-coherent detection of DPSK
 - p/M-differential phase shift keying (p/M-DPSK)
 - Differential amplitude and phase shift keying (DAPSK)
 - Non-linear digital modulation methods
 - Frequency shift keying (FSK)
 - Modulation index
 - Minimum shift keying (MSK)
 - Offset-QPSK representation of MSK
 - MSK with differential precoding and rotation
 - Bit error probabilities of MSK
 - Gaussian minimum shift keying (GMSK)
 - Power spectral density of MSK and GMSK
 - Continuous phase modulation (CPM)
 - General description of CPM signals
 - Frequency pulses and phase pulses
 - Coherent and non-coherent detection of FSK
 - Performance comparison of linear and non-linear digital modulation methods
- Frequency-selective channels, ISI channels
 - Intersymbol interference and frequency-selectivity
 - RMS delay spread
 - Narrowband and broadband channels
 - Equivalent baseband transmission model for frequency-selective channels
 - Receive filter design
- Equalization
 - Symbol-spaced and fractionally-spaced equalizers
 - Inverse system
 - Non-recursive linear equalizers
 - Linear zero-forcing (ZF) equalizer
 - Linear minimum mean squared error (MMSE) equalizer
 - Non-linear equalization:
 - Decision feedback equalizer (DFE)
 - Tomlinson-Harashima precoding
 - Maximum a posteriori probability (MAP) and maximum likelihood equalizer, Viterbi algorithm
- Single-carrier vs. multi-carrier transmission
- Multi-carrier transmission
 - General multicarrier transmission
 - Orthogonal frequency division multiplex (OFDM)
 - OFDM implementation using the Fast Fourier Transform (FFT)
 - Cyclic guard interval
 - Power spectral density of OFDM
 - Peak-to-average power ratio (PAPR)
- Multiple access
 - Principles of time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), non-orthogonal multiple access (NOMA), hybrid multiple access
- Spread spectrum communications
 - Direct sequence spread spectrum communications
 - Frequency hopping
 - Protection against eavesdropping
 - Protection against narrowband jammers

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	 Short vs. long spreading codes 				
	 Direct sequence spread spectrum communications in frequency-selective channels 				
	Rake receiver				
	Code division multiple access (CDMA)				
	 Design criteria of spreading sequences, autocorrelation function and crosscorrelation function of spreading sequences 				
	 Intersymbol interference (ISI) and multiple access interference (MAI) 				
	 Pseudo noise (PN) sequences, maximum length sequences (m-sequences), Gold codes, Walsh-Hadamard codes, orthogonal variable spreading factor (OVSF) codes 				
	Multicode transmission				
	 CDMA in uplink and downlink of a wireless communications system 				
	 Single-user detection vs. multi-user detection 				
Literature	K. Kammeyer: Nachrichtenübertragung, Teubner				
	P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.				
	3. Proakis, M. Salehi: Digital Communications. McGraw-Hill.				
	Haykin: Communication Systems. Wiley				
	R.G. Gallager: Principles of Digital Communication. Cambridge				
	A. Goldsmith: Wireless Communication. Cambridge.				
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.				

Course L0445: Digital Communications		
Тур	Recitation Section (large)	
Hrs/wk	2	
CP	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Lecturer	Prof. Gerhard Bauch	
Language	EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Course L0646: Laboratory Di	gital Communications
Тур	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/EN
Cycle	WiSe
Content	- DSL transmission
	- Random processes - Digital data transmission
Literature	 K. Kammeyer: Nachrichtenübertragung, Teubner P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner. J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill. S. Haykin: Communication Systems. Wiley R.G. Gallager: Principles of Digital Communication. Cambridge A. Goldsmith: Wireless Communication. Cambridge. D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.

Module M1774: Adva	ced Internet Computing					
Courses						
Title		Тур		Hrs/wk	СР	
Advanced Internet Computing (L29	5)	Lecture		2	3	
Advanced Internet Computing (L29	(L2917) Project-/problem-based Learning 2 3				3	
Module Responsible	Prof. Stefan Schulte					
Admission Requirements	None					
Recommended Previous	Good programming skills are necessary. Previous knowledge in the field of distributed systems is helpful.					
Knowledge						
Educational Objectives	After taking part successfully, students hav	ve reached the following learnir	ng results			
Professional Competence						
Knowledge	After successful completion of the course,	students are able to:				
	 Describe basic concents of Cloud Co 	mouting the Internet of Things	(IoT) and blockchain t	echnologies		
	 Describe basic concepts of cloud computing, the interfet of mining (of), and biocchain technologies Discuss and accors critical acrosts of Cloud Computing the IAT and blockshain technologies 					
	Select and apply cloud and IoT technologies for particular application areas					
	Design and develop practical solutions for the integration of smart objects in IoT. Cloud, and blockchain software					
	Implement IoT services					
Skills	The students acquire the ability to model Internet-based distributed systems and to work with these systems. This comprises					
	especially the ability to select and utilize fitting technologies for different application areas. Furthermore, students are able to					
	critically assess the chosen technologies.					
Personal Competence						
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their					
	individual strengths to solve the problem.					
Autonomy	5tudents are able to independently investi	gate a complex problem and as	sess which competenci	es are require	d to solve it.	
Workload in Hours	ndependent Study Time 124, Study Time	in Lecture 56				
Credit points	5					
Course achievement	None					
Examination	Subject theoretical and practical work					
Examination duration and	Group project incl. presentation (50 %), wr	itten exam (60 min, 50 %)				
scale						
Assignment for the	Computer Science: Specialisation I. Compu	ter and Software Engineering: I	Elective Compulsory			
Following Curricula	Data Science: Specialisation II. Computer S	Science: Elective Compulsory				
	Data Science: Specialisation IV. Special Fo	cus Area: Elective Compulsory				
	Computer Science in Engineering: Speciali	sation I. Computer Science: Elec	ctive Compulsory			
	nformation and Communication Systems:	Specialisation Communication S	Systems, Focus Softwar	e: Elective Co	mpulsory	
	nformation and Communication Systems:	Specialisation Secure and Depe	endable IT Systems, Foc	us Networks:	Elective Compulsory	

Course L2916: Advanced Inte	ernet Computing
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Schulte
Language	EN
Cycle	SoSe
Content	 This lecture discusses modern Internet-based distributed systems in three blocks: (i) Cloud computing, (ii) the Internet of Things, and (iii) blockchain technologies. The following topics will be covered in the single lectures: Cloud Computing Elastic Computing Technologies for identification for the IoT: RFID & EPC Communication in the IoT: Standards and protocols Security and trust in the IoT: Concerns and solution approaches Edge and Fog Computing Application areas: Smart factories, smart cities, smart healthcare Blockchain technologies Consensus
Literature	Lecture notes as well as current literature announced in the lecture.

ourse L2917: Advanced Internet Computing			
Тур	Project-/problem-based Learning		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Stefan Schulte		
Language	EN		
Cycle	SoSe		
Content	This project-/problem-oriented part of the module augments the theoretical content of the lecture by a concrete technical problem,		
	which needs to be solved by the students in group work during the semester. Possible topics are (blockchain-based) sensor data		
	integration, Big Data processing, Cloud-based redundant data storages, and Cloud-based Onion Routing.		
Literature	Lecture notes as well as current literature announced in the lecture.		

Module M1	301: Software Testing
Courses	
Title	Typ Hrs/wk CP
Software Testing (I	(L1791) Lecture 2 3
Software Testing (I	(L1792) Project-/problem-based Learning 2 3
Module	Prof. Sibylle Schupp
Responsible	s
Admission	None
Requirements	•
Recommended	
Previous	Software Engineering
Knowledge	Higher Programming Languages
	Object-oriented Fridgramming Algorithms and Data Structures
	Algoritatins and bada solutions Evantians and bada solutions Evantiance with (Small) Software Projects
	Statistics
Educational	After taking part successfully, students have reached the following learning results
Objectives	·
Professional	
Competence	2
Knowledge	
	scudents explain the different phases of testing, describe fundamental
	techniques of the corresponding tech process. They give examples of
	principles of the corresponding test process. They give examples of
	software development scenarios and the corresponding test type and
	techniques and describe advantages and limitations
	techniques and describe possible advantages and initiations.
Skills	5
	Students identify the appropriate testing type and technique for a given
	problem. They adapt and execute respective algorithms to execute a
	concrete test technique properly. They interpret testing results and
	execute corresponding steps for proper re-test scenarios. They write and
	analyze test specifications. They apply bug finding techniques for
	non-urivial problems.
Personal	
Competence	
Social	/ Students discuss relevant topics in class. They defend their solutions orally.
Competence	They communicate in English.
,	
Autonomy	Students can assess their level of knowledge continuously and adjust it appropriately, based on feedback and on self-guided studies. Within limits, the
	own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field
	testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reput
	devise plans to arrive at new solutions or assess existing ones
Workload in	Independent Study Time 124, Study Time in Lecture 56
Hours	
Cradit points	
Creat points	
achievement	
Examination	Subject theoretical and practical work
Examination	Softwara
duration and	
scale	
Assignment	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory
for the	Data Science: Specialisation II. Computer Science: Elective Compulsory
Following	Data Science: Specialisation II. Computer Science: Elective Compulsory
Curricula	Information and Communication Systems: Specialisation Communication Systems: Focus Software: Elective Compulsory
	Information and Communication Systems; Specialisation Secure and Dependable IT Systems. Focus Software and Signal Processing: Elective Compulso

Course L1791: Software Test	ing
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	SoSe
Content	 Fundamentals of software testing Model-based testing Test automation Criteria-based testing
Literature	 M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008. P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2016. A. Zeller: "Why Programs Fail: A Guide to Systematic Debugging", 2nd edition 2012.

Course L1792: Software Testing		
Тур	Project-/problem-based Learning	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Sibylle Schupp	
Language	EN	
Cycle	SoSe	
Content	 Fundamentals of software testing Model-based testing Test automation Criteria-based testing 	
	 M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008. P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2015. 	

Module M1682: Secur	e Software Eng	jineering					
Courses							
Title				Тур	Hrs/wk	СР	
Secure Software Engineering (L266	57)			Lecture	2	3	
Secure Software Engineering (L266	re Software Engineering (L2668) Project-/problem-based Learning 2 3			3			
Module Responsible	Prof. Riccardo Scanda	rof. Riccardo Scandariato					
Admission Requirements	None						
Recommended Previous	Familiarity with basic software engineering concepts (e.g., requirements, design) and basic security concepts (e.g., confidentiality,						
Knowledge	integrity, availability)						
Educational Objectives	After taking part succ	essfully, students have re	eached the followir	ng learning results			
Professional Competence							
Knowledge	Students can:						
	 Elicit socurity r 	oquiromonts in a softwar	o project				
	Model and door	Encir security requirements in a software project Model and document security measures in a software design					
	Use threat and	Inouer and document security measures in a soluware design					
	 Understand hor 	Understand how security code reviews are performed					
	Understand the	Inderstand the core definitions of concents related to privacy					
	Understand the	Onderstand une core deminions of concepts related to privacy Inderstand privacy ophancing tochnologies					
	 Onderstand pri 	Understand privacy enhancing technologies					
Skills	Select appropriate se	elect appropriate security assurance techniques to be used in a security assurance program					
Personal Competence							
Social Competence	None						
Autonomy	Students can apply th	ne knowledge acquired th	roughout the cours	se to the resolution of industrial	case studies.	Students should also	
	be capable to acquire new knowledge independently from academic publications, techical standards, and white papers.						
Workload in Hours	Independent Study Ti	me 124, Study Time in Le	ecture 56				
Credit points	6						
Course achievement	Compulsory Bonus	Form	Description	it with a lateral lateral Table a lateral and an	- dawa Dawalah	Ciele e ele e it	
	NO 5%	Subject theoretical	andGruppenarbe	it mit aktuellen Technologien au	s dem Bereicr	Sicherneit	
E		practical work					
Examination	written exam						
Examination duration and	120 min						
scale	Computer Colones - Co		and Caffman English				
Assignment for the	Computer Science: Sp	beclalisation I. Computer	and Software Engl	neering: Elective Compulsory			
Following Curricula	Data Science: Special	lisation II. Computer Scier	ice: Elective Comp	Juisory			
	Data Science: Special	isation IV. Special Focus	Area: Elective Com	ipulsory	-		
	Information and Com	munication Systems: Spe	cialisation Commu	nication Systems, Focus Softwar	e: Elective Co	ompuisory	
	Information and Cor	mmunication Systems: S	specialisation Sec	ure and Dependable IT Syste	ems, Focus S	ottware and Signal	
	Processing: Elective C	compulsory					

Course L2667: Secure Softwa	are Engineering
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	 Secure software development processes and maturity models Techniques to define security requirements Techniques to create, document and analyse the design of secure applications Threat and risk analysis techniques Security code reviews Program repair techniques for security vulnerabilities Privacy engineering
Literature	Sindre, G. and Opdahl, A.L., 2005. Eliciting security requirements with misuse cases. Requirements engineering, 10(1), pp.34-44.
	Mead, N.R. and Stehney, T., 2005. Security quality requirements engineering (SQUARE) methodology. ACM SIGSOFT Software Engineering Notes, 30(4), pp.1-7.
	Mirakhorli, M., Shin, Y., Cleland-Huang, J. and Cinar, M., 2012, June. A tactic-centric approach for automating traceability of quality concerns. In 2012 34th international conference on software engineering (ICSE) (pp. 639-649). IEEE.
	Jürjens, J., UMLsec: Extending UML for secure systems development, International Conference on The Unified Modeling Language, 2002
	Lund, M.S., Solhaug, B. and Stølen, K., 2011. A guided tour of the CORAS method. In Model-Driven Risk Analysis (pp. 23-43). Springer, Berlin, Heidelberg.
	Howard, M.A., 2006. A process for performing security code reviews. IEEE Security & privacy, 4(4), pp.74-79
	Diaz, C. and Gürses, S., 2012. Understanding the landscape of privacy technologies. Proceedings of the information security summit, 12, pp.58-63.

Course L2668: Secure Software Engineering			
Тур	Project-/problem-based Learning		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Riccardo Scandariato		
Language	EN		
Cycle	SoSe		
Content	 Secure software development processes and maturity models Techniques to define security requirements Techniques to create, document and analyse the design of secure applications Threat and risk analysis techniques Security code reviews Program repair techniques for security vulnerabilities Privacy engineering 		
Literature	Lecture notes as well as current literature announced in the lecture.		

Fite Fite Architectures and Programmin FPU Architectures and Programmin Module Responsible Admission Requirements Recommended Previous	g (L3039) g (L3040) Prof. Sohan Lal	Typ Lecture Project-/problem-based Learning	Hrs/wk	СР		
PU Architectures and Programmin PU Architectures and Programmin Module Responsible Admission Requirements Recommended Previous	g (L3039) g (L3040) Prof. Sohan Lal	Lecture Project-/problem-based Learning	2	ei		
PU Architectures and Programmin Module Responsible Admission Requirements Recommended Previous	g (L3040) Prof. Sohan Lal	Project-/problem-based Learning		3		
Module Responsible Admission Requirements Recommended Previous	Prof. Sohan Lal		mming (L3040) Project-/problem-based Learning 4 3			
Admission Requirements Recommended Previous						
Recommended Previous	None					
	An introductory module on computer engineering or computer architecture, and good programming skills in C/C++.					
Knowledge						
Educational Objectives	After taking part successfully, students have reached the following learning results					
Professional Competence						
Knowledge						
Skills						
Personal Competence						
Social Competence						
Autonomy						
Workload in Hours	Independent Study Time 96, Study Time in Lecture	84				
Credit points	6					
Course achievement	None					
Examination	Oral exam					
Examination duration and	30 min					
scale						
Assignment for the	Computer Science: Specialisation I. Computer and S	Software Engineering: Elective Compulsory				
Following Curricula	Data Science: Specialisation II. Computer Science: E	Elective Compulsory				
	Data Science: Specialisation IV. Special Focus Area:	Elective Compulsory				
	Information and Communication Systems: Specia	alisation Secure and Dependable IT Syste	ems, Focus S	oftware and Signa		
	Processing: Elective Compulsory					
	Microelectronics and Microsystems: Specialisation E	mbedded Systems: Elective Compulsory				
ourse L3039: GPU Architect	ures and Programming					

Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	SoSe
Content	- Review of computer architecture basics - measuring performance, benchmarks, five-stage RISC pipeline, caches
	- GPU basics - evolution of GPU computing, a high-level overview of a GPU architecture
	- GPU programming with CUDA - program structure, CUDA threads organization, warp/thread-block scheduling
	- GPU (micro) architecture - streaming multiprocessors, single instruction multiple threads (SIMT) core design, tensor/RT cores,
	mixed-precision support
	- GPU memory hierarchy - banked register file and operand collectors, shared memory, GPU caches (differences w.r.t. CPU caches),
	global memory
	- Branch and memory divergence - branch handling, stack-based reconvergence, memory coalescing, coalescer design
	- Barriers and synchronization
	- Temporal and spatial locality exploitation challenges in GPU caches
	- Global memory- high throughput requirements, GDDR/HBM, memory bandwidth optimization techniques
	- GPU research issues - performance bottlenecks, GPU power modeling, high-power consumption/energy efficiency, GPU security
	- Application case study - deep learning
	- Cycle-accurate simulators for GPUs
	The learning in the lectures will be augmented by a semester-long problem-based project.
Literature	 David B. Kirk, Wen-mei W. Hwu, Programming Massively Parallel Processors - A Hands-on Approach, Second Edition (Book) David A. Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, 5th Edition (Book)

Course L3040: GPU Architectures and Programming				
Тур	Project-/problem-based Learning			
Hrs/wk	4			
CP	3			
Workload in Hours	Independent Study Time 34, Study Time in Lecture 56			
Lecturer	Prof. Sohan Lal			
Language	EN			
Cycle	SoSe			
Content	A semester-long problem-based project will augment the learning in the lectures. Several topics related to GPUs will be proposed. You are required to choose a topic and work on it. It is possible to work in groups. There will be (bi-) weekly meetings to discuss progress and problems. In addition to the semester-long project, there will be assignments to teach CUDA programming.			
Literature	 David B. Kirk, Wen-mei W. Hwu, Programming Massively Parallel Processors - A Hands-on Approach, Second Edition (Book) David A. Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, 5th Edition (Book) 			

Module M1810: Autor	nomous Cyber-Physical System	IS				
Courses						
Title		Тур	Hrs/wk	СР		
Autonomous Cyber-Physical Syster	ms (L3000)	Lecture	2	3		
Autonomous Cyber-Physical Syster	ns (L3001)	Recitation Section (small)	2	3		
Module Responsible	Prof. Bernd-Christian Renner					
Admission Requirements	None					
Recommended Previous	- Very seed knowledge and presting	I avantiance in programming in the C/C I		mandula. Dranadura		
Knowledge	Very good knowledge and practical Programming for Computer Scientists	n experience in programming in the C/C++	language (e.g.,	module: Procedura		
	Basic knowledge in software engineer	ring				
	Basic knowledge in wired and wireles	s communication protocols				
	Principal understanding of simple electron	ctronic circuits				
Educational Objectives	After taking part successfully, students have	e reached the following learning results				
Professional Competence						
Knowledge	Cyber-Physical Systems form the basis for	ir many modern control tasks in automation	and for method	is for monitoring the		
	on wireless technologies and their auto	aspects in the implementation of such systems	of regenerative c	nergy sources After		
	successfully attending this event the studer	nts are able to	r regenerative e	anergy sources. Arte		
	to present the special features of cyb	er-physical systems and the associated challeng	jes and concepts,			
	describe and evaluate wired and wire	less communication on different layers of the IS	0/OSI model,			
	explain and compare methods of regenerations of the second s	enerative energy production,				
	 discuss and evaluate procedures for t 	ne autonomous and sen-sumclent operation of	such systems.			
Skills	Students will be able to					
	 to implement programs for cyber-phy 	sical systems in high-level languages and using	existing libraries			
	 to implement programs for cyber-physical systems in high-rever languages and using existing initialles, to assess which communication and networking protocols can be used most sensibly in which application and to use 					
	in real scenarios,	J	,			
	 select and implement suitable methods for adapting the tasks based on the energy consumption and the future expect 					
	energy yield,					
	plan and evaluate scientific experime	nts.				
Personal Competence						
Social Competence	After completing the module, the students	are able to work on similar tasks alone or in a	a group and to pr	esent the results in a		
Social competence	suitable way.		group and to pr			
Autonomy	After completing the module, the students a	re able to independently work on sub-areas of t	he subject using s	specialist literature, to		
	summarize and present the knowledge they	have acquired and to link it to the content of ot	her courses.			
Workload in Hours	Independent Study Time 124, Study Time in	Lecture 56				
Credit points	6					
Course achievement	Compulsory Bonus Form	Description				
	No 10 % Attestation					
Examination	Written exam					
Examination duration and	90 min					
Scale	Computer Science: Specialization I. Compute	er and Coffman Engineering, Elective Computer				
Assignment for the	Data Science: Specialisation II. Computer Science:	er and sontware engineering: Elective Compulso	лУ			
i onowing curricula	Data Science: Specialisation IV Special Foc	Is Area: Elective Compulsory				
	Electrical Engineering: Specialisation Wirele	ss and Sensor Technologies: Elective Compulsor	v			
	Computer Science in Engineering: Specialisa	ation II. Engineering Science: Elective Compulso	Y			
	Information and Communication Systems	: Specialisation Secure and Dependable IT	Systems, Focus	Software and Signa		
	Processing: Elective Compulsory			5		
	Mechatronics: Core Qualification: Elective Co	ompulsory				

Course L3000: Autonomous Cyber-Physical Systems		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Bernd-Christian Renner	
Language	EN	
Cycle	SoSe	
Content		
Literature		

Course L3001: Autonomous Cyber-Physical Systems					
Тур	citation Section (small)				
Hrs/wk	2				
СР	3				
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28				
Lecturer	Prof. Bernd-Christian Renner				
Language	EN				
Cycle	SoSe				
Content	See interlocking course				
Literature	See interlocking course				

Module M1773: Cyber	rsecurity Data S	Science					
Courses							
Title				Тур	Hrs/wk	СР	
Cybersecurity Data Science (L2914	.)			Lecture	2	3	
Exercise Cybersecurity Data Science	ce (L2915)			Project-/problem-based Learning	2	3	
Module Responsible	Prof. Riccardo Scanda	ariato					
Admission Requirements	None						
Recommended Previous	Basic knowledge of p	robabilities and statis	tics. Familiarity with	object oriented programming.			
Knowledge							
Educational Objectives	After taking part succ	essfully, students hav	ve reached the follow	ring learning results			
Professional Competence							
Knowledge	Students can:						
	Apply data scie	ence methods to the r	esolution of complex	cybersecurity problems.			
	Use of data sci	ence methods to qua	ntify risks and optimi	ze cybersecurity operations.			
	 Identify strength 	ths and limitations of	state-of-the-art meth	nods			
	 Select the perf 	ormance indicators o	f data-oriented cyber	security solutions.			
	 Understand cy 	Understand cybersecurity threats in data science methods.					
Skills	Implement and evaluate data-driven models for the identification, treatment, and mitigation of cybersecurity risks						
Personal Competence							
Social Competence	None	None					
Autonomy	Students can apply the knowledge acquired throughout the course to the resolution of industrial case studies. Students should also						
	be capable to acquire	be canable to acquire new knowledge independently from academic publications, technical standards, and white papers					
		5	, ,				
Workload in Hours	Independent Study Ti	me 124, Study Time	in Lecture 56				
Credit points	6						
Course achievement	Compulsory Bonus	Form	Description				
	No 5 %	Subject theoretic	al andGruppenarb	eit mit aktuellen Technologien au	s dem Bereich	n Sicherheit	
		practical work					
Examination	Written exam						
Examination duration and	120 min						
scale							
Assignment for the	Computer Science: Sp	pecialisation I. Compu	ter and Software Eng	gineering: Elective Compulsory			
Following Curricula	Data Science: Special	lisation II. Computer S	cience: Elective Com	pulsory			
	Data Science: Special	isation IV. Special Fo	cus Area: Elective Co	mpulsory			
	Information and Com	munication Systems:	Specialisation Secure	e and Dependable IT Systems: Ele	ctive Compuls	sory	

Course L2914: Cybersecurity	Data Science
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations:
	Introduction to data science
	Supervised and unsupervised learning
	 Data science methods (e.g., clustering, decision trees, artificial neural networks)
	Performance metrics
	Cybersecutrity Applications:
	Spam detection
	Phishing detection
	Intrusion detection
	Access-control prediction
	Denial of Service (DoS) prediction
	Vulnerability/malware prediction
	Adversarial machine learning
Literature	[1] Sarker, I.H., Kaves, A.S.M., Badsha, S., Algahtani, H., Watters, P. and Ng. A., 2020, Cybersecurity data science: an overview
	from machine learning perspective. Journal of Big data, 7(1), pp.1-29.
	[2] Iruong, I.C., Zelinka, I., Plucar, J., Candik, M. and Sulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and
	Tuture. In Artificial intelligence and evolutionary computations in engineering systems (pp. 551-565). Springer, Singapore.
	[3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press.
	[4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of Machine Learning in Computer Security.
	[5] Torres, J.M., Comesaña, C.I. and Garcia-Nieto, P.J., 2019. Machine learning techniques applied to cybersecurity. International Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836.
	[6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

Course L2915: Exercise Cybe	rsecurity Data Science
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations:
	Introduction to data science
	Supervised and unsupervised learning
	 Data science methods (e.a., clustering, decision trees, artificial neural networks)
	Performance metrics
	Cybersecutrity Applications:
	Spam detection
	Phishing detection
	Intrusion detection
	Access-control prediction
	Denial of Service (DoS) prediction
	Vulnerability/malware prediction
	Adversarial machine learning
Literature	[1] Sarker, I.H., Kayes, A.S.M., Badsha, S., Algahtani, H., Watters, P. and Ng, A., 2020. Cybersecurity data science: an overview
	from machine learning perspective. Journal of Big data, 7(1), pp.1-29.
	Di Tranz T.C. Zaliala I. Diversi I. Častili. M. and Čala V. 2020. Attificial intelligence and a barransistic Data analysis
	[2] Iruong, T.C., Zelinka, I., Plucar, J., Candik, M. and Suic, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (np. 351-362). Springer, Singapore
	Tuture. In Artificial intelligence and evolutionary computations in engineering systems (pp. 551-565), springer, singapore.
	[3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press.
	[4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of
	recently in compared occurry.
	[5] Torres, J.M., Comesaña, C.I. and Garcia-Nieto, P.J., 2019. Machine learning techniques applied to cybersecurity. International Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836.
	[6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

ed Cryp	tograp	hy				
				Тур	Hrs/wk	СР
				Lecture	3	4
				Recitation Section (small)	1	2
Prof. Sibyll	e Fröschle	2				
None						
After takin	g part suc	cessfully, students	have reached the follow	ving learning results		
Independe	nt Study 1	Гіте 124, Study Ti	me in Lecture 56			
6						
Compulsory	Bonus	Form	Description			
No	10 %	Excercises	Die Übungs	aufgaben finden semesterbeg	leitend statt	
Written ex	am					
120 min						
Computer	Science: S	Specialisation I. Co	mputer and Software En	gineering: Elective Compulsor	у	
Data Scien	ce: Specia	alisation II. Comput	er Science: Elective Con	npulsory		
Data Scien	ce: Specia	alisation IV. Specia	Focus Area: Elective Co	ompulsory		
Information	n and Con	nmunication System	ms: Specialisation Comm	nunication Systems, Focus Sof	tware: Elective Co	ompulsory
Informatio	n and Con	nmunication System	ms: Specialisation Secur	e and Dependable IT Systems	Focus Networks:	Elective Compulsory
	Prof. Sibyll None After takin After takin Independe 6 Compulsory No Written ex 120 min Computer Data Scien Informatio Informatio	Prof. Sibylle Fröschle None After taking part suc After taking part suc Independent Study 1 6 Computsory Bonus No 10 % Written exam 120 min Computer Science: Specia Data Science: Specia Information and Con Information and Con	Prof. Sibylle Fröschle None After taking part successfully, students Independent Study Time 124, Study Tim G Computsory Bonus Form No 10 % Excercises Written exam 120 min Computer Science: Specialisation I. Corp Data Science: Specialisation II. Comput Data Science: Specialisation IV. Special Information and Communication Syster Information II. Compute III. III. III. III. III. III. III. III	Prof. Sibylle Fröschle None After taking part successfully, students have reached the follow Independent Study Time 124, Study Time in Lecture 56 6 Compulsory Bonus Form Description No 10 % Excercises Die Übungs Written exam 120 min Computer Science: Specialisation I. Computer and Software En Data Science: Specialisation II. Computer Science: Elective Cor Data Science: Specialisation IV. Special Focus Area: Elective Cor Information and Communication Systems: Specialisation Communication Systems: Specialisation Security	ed Cryptography Typ Lecture Recitation Section (small) Prof. Sibylle Fröschle None After taking part successfully, students have reached the following learning results Independent Study Time 124, Study Time in Lecture 56 6 Computory Bonus Form Description No 10 % Excercises Die Übungsaufgaben finden semesterbeg Written exam 120 min Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsor Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems	Typ Hrs/wk Lecture 3 Recitation Section (small) 1 Prof. Sibylle Fröschle 1 None

Course L2954: Applied Cryptography				
Тур	Lecture			
Hrs/wk	3			
CP	4			
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42			
Lecturer	Prof. Sibylle Fröschle			
Language	EN			
Cycle	SoSe			
Content	This module provides a comprehensive knowledge in modern cryptography and how it plays a key role in securing the digital world we live in today. We will thoroughly treat cryptographic primitives such as symmetric and asymmetric encryption schemes, cryptographic hash functions, message authentication codes, and digital signatures. Moreover, we will cover aspects of practical deployment such as key management, public key infrastructures, and secure storage of keys. We will see how everything comes together in applications such as the ubiquitous security protocols of the Internet (e.g. TLS and WPA3) and/or the Internet-of-things. We also discuss current challenges such as the need for post-quantum cryptography.			
Literature	Introduction to Modern Cryptography, Third Edition, Jonathan Katz and Jehuda Lindell, Chapman & Hall/CRC, 2021 Sicherheit und Kryptographie im Internet, 5th Edition, Jörg Schwenk, Springer-Verlag, 2020			

Course L2955: Applied Cryptography			
Тур	Recitation Section (small)		
Hrs/wk	1		
СР	2		
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14		
Lecturer	Prof. Sibylle Fröschle		
Language	EN		
Cycle	SoSe		
Content	See corresponding lecture		
Literature	Siehe korrespondierende Vorlesung		

Module M0924: Softw	are for Embedded Systems				
Courses					
Title		Түр	Hrs/wk	СР	
Software for Embdedded Systems ((L1069)	Lecture	2	3	
Software for Embdedded Systems ((L1070)	Recitation Section (small)	3	3	
Module Responsible	Prof. Bernd-Christian Renner				
Admission Requirements	None				
Recommended Previous	 Very Good knowledge and practical experier 	nce in programming in the C language and	its compilation p	rocess	
Knowledge	Basic knowledge in software engineering				
	Basic understanding of assembly language				
	Basic knowledge of electrical engineering				
Educational Objectives	After taking part successfully, students have reach	ed the following learning results			
Professional Competence					
Knowledge					
	 Students know the basic principles and proce They are able to describe the usage and adult 	edures of software engineering for embed	ded systems.		
	 They are able to describe the usage and dov They know the components and functions of 	a concrete microcontroller	ig interrupts.		
	 The participants explain requirements of rea 	l time systems.			
	They know at least three scheduling algorith	ms for real time operating systems include	ing their pros and	cons.	
Skille					
SKIIIS	 Students design and write hardware-orie 	ented software modules for an embe	dded system b	ased on a specific	
	microcontroller.				
	They learn to interact with peripherals (time	r, ADC, EEPROM), including interrupt-base	d processing and	program flow.	
	They build and use a (preemptive) scheduler They learn to write independent, reveable as	for an embedded system.			
	 They learn to write independent, reusable so 	ntware components.			
Personal Competence					
Social Competence	Students are able to work goal-oriented in small mixed groups.				
	They learn and broaden their teamwork abilities.				
	They learn to define and split tasks within th	e team.			
Autonomy	Students are able				
Autonomy					
	• to solve assignments related to this lecture independently with instructional direction.				
	• to design, implement, and test software components for an embedded system independently based on a textual				
	 to read and understand data sheets and mail 	nuals of electronic components (such as m	vicro-controllers a	nd sensors)	
		indus of electronic components (such as in			
Workload in Hours	Independent Study Time 110, Study Time in Lectur	e 70			
Credit points	6				
Course achievement	Compulsory Bonus Form	Description			
Examination	Written exam				
Examination duration and	90 min				
scale					
Assignment for the	Computer Science: Specialisation I. Computer and S	Software Engineering: Elective Compulsory	/		
Following Curricula	Data Science: Specialisation II. Computer Science:	Elective Compulsory			
	Data Science: Specialisation IV. Special Focus Area	Elective Compulsory			
	Electrical Engineering: Specialisation Information and	nd Communication Systems: Elective Com	pulsory		
	Information and Communication Systems: Specialis	ation Communication Systems, Focus Soft	tware: Elective Co	ompulsory	
	Mechatronics: Core Qualification: Elective Compulse				
	Theoretical Mechanical Engineering: Specialisation E	Empeuded Systems: Elective Compulsory	Compulsory		
	Theoretical Mechanical Engineering, Specialisation	Robotics and Computer Science: Elective	Compulsory		
Assignment for the Following Curricula	Data Science: Specialisation I. Computer and S Data Science: Specialisation II. Computer Science: I Data Science: Specialisation IV. Special Focus Area: Electrical Engineering: Specialisation Information and Information and Communication Systems: Specialis Mechatronics: Core Qualification: Elective Compulse Microelectronics and Microsystems: Specialisation f Theoretical Mechanical Engineering: Specialisation Theoretical Mechanical Engineering: Specialisation	Elective Compulsory Elective Compulsory Ind Communication Systems: Elective Com Ind Communication Systems, Focus Soft ory Embedded Systems: Elective Compulsory Robotics and Computer Science: Elective Robotics and Computer Science: Elective	y pulsory ware: Elective Co Compulsory Compulsory	ompulsory	

Course L1069: Software for E	Embdedded Systems
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	DE/EN
Cycle	SoSe
Content	 General-Purpose Processors Programming the Atmel AVR Interrupts C for Embedded Systems Standard Single Purpose Processors: Peripherals Finite-State Machines Memory Operating Systems for Embedded Systems Real-Time Embedded Systems Boot loader and Power Management
Literature	 Embedded System Design, F. Vahid and T. Givargis, John Wiley Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP The Art of Designing Embedded Systems, J. Ganssle, Newnses Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

Course L1070: Software for Embdedded Systems						
Тур	ation Section (small)					
Hrs/wk	3					
CP	3					
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42					
Lecturer	Prof. Bernd-Christian Renner					
Language	DE/EN					
Cycle	SoSe					
Content	See interlocking course					
Literature	See interlocking course					

Specialization III. Applications

Module M0623: Intell	gent Systems in Medicine							
Courses								
Title Intelligent Systems in Medicine (LO Intelligent Systems in Medicine (LO Intelligent Systems in Medicine (LO	331) 334) 333)		Typ Lecture Project Seminar Beritation Section (small)	Hrs/wk 2 2	CP 3 2			
Module Responsible	Recitation Section (Smail)							
Admission Requirements								
Recommended Previous Knowledge	 principles of math (algebra, analy principles of stochastics principles of programming, Java/ advanced programming skills 	ysis/calculus) C++ and R/Matlab						
Educational Objectives	After taking part successfully, students	have reached the follow	ing learning results					
Professional Competence								
Knowledge	The students are able to analyze and s optimization, and planning. They are at in clinical contexts. The students can co in the context of clinical data and expl and safety requirements.	solve clinical treatment p ole to explain methods fo ompare different method lain challenges due to th	planning and decision support or classification and their respe ds for representing medical kn ne clinical nature of the data a	problems using ective advantage owledge. They ca and its acquisition	methods for search, as and disadvantages an evaluate methods n and due to privacy			
Skills	The students can give reasons for sele the methods based on actual patient da	ecting and adapting meth ata and evaluate the imp	nods for classification, regress lemented methods.	sion, and predict	ion. They can assess			
Personal Competence								
Social Competence Autonomy	The students are able to grasp practical tasks in groups, develop solution strategies independently, define work processes and work on them collaboratively. The students can critically reflect on the results of other groups, make constructive suggestions for improvement and also incorporate them into their own work. The students can assess their level of knowledge and document their work results. They can critically evaluate the results achieved and present them in an appropriate argumentative manner to the other groups.							
Workload in Hours	Independent Study Time 110, Study Tir	ne in Lecture 70						
Credit points	6							
Course achievement	Compulsory Bonus Form Yes 10 % Written elaborat Yes 10 % Presentation	Description						
Examination	Written exam							
Examination duration and scale	90 minutes							
Assignment for the	Computer Science: Specialisation II: Inte	elligence Engineering: El	ective Compulsory					
Following Curricula	Data Science: Specialisation III. Applical Data Science: Specialisation IV. Special Electrical Engineering: Specialisation Mu Interdisciplinary Mathematics: Specialis Mechatronics: Specialisation Intelligent Mechatronics: Core Qualification: Electiv Biomedical Engineering: Specialisation Biomedical Engineering: Specialisation	tions: Elective Compulso Focus Area: Elective Cor edical Technology: Electi sation Computational Mel Systems and Robotics: E ve Compulsory Artificial Organs and Reg Implants and Endoprosth Management and Busine	ry mpulsory ve Compulsory chods in Biomedical Imaging: C elective Compulsory menerative Medicine: Elective Co meses: Elective Compulsory	Compulsory				
	Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory							

Course L0331: Intelligent Systems in Medicine					
Тур	Lecture				
Hrs/wk	2				
CP	3				
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28				
Lecturer	Prof. Alexander Schlaefer				
Language	EN				
Cycle	WiSe				
Content	 methods for search, optimization, planning, classification, regression and prediction in a clinical context representation of medical knowledge understanding challenges due to clinical and patient related data and data acquisition The students will work in groups to apply the methods introduced during the lecture using problem based learning. 				
Literature	Russel & Norvig: Artificial Intelligence: a Modern Approach, 2012 Berner: Clinical Decision Support Systems: Theory and Practice, 2007 Greenes: Clinical Decision Support: The Road Ahead, 2007 Further literature will be given in the lecture				

Course L0334: Intelligent Systems in Medicine						
Тур	Project Seminar					
Hrs/wk	2					
CP	CP 2					
Workload in Hours	lependent Study Time 32, Study Time in Lecture 28					
Lecturer	of. Alexander Schlaefer					
Language	EN					
Cycle	WiSe					
Content	See interlocking course					
Literature	See interlocking course					

Course L0333: Intelligent Systems in Medicine						
Тур	itation Section (small)					
Hrs/wk	1					
CP	1					
Workload in Hours	lependent Study Time 16, Study Time in Lecture 14					
Lecturer	ıf. Alexander Schlaefer					
Language	EN					
Cycle	WiSe					
Content	See interlocking course					
Literature	See interlocking course					

Module M1302: Appli	ed Humanoid Robotics			
Module M1502. Appli				
Courses				
Title		Тур	Hrs/wk	СР
Applied Humanoid Robotics (L1794)	Project-/problem-based Learning	6	6
Module Responsible	Patrick Göttsch			
Admission Requirements	None			
Recommended Previous	Object oriented programming: algorithms and data	ta structuros		
Knowledge	 Introduction to control systems 			
	 Control systems theory and design 			
	Mechanics			
Educational Objectives	After taking part successfully, students have reached the	ne following learning results		
Professional Competence				
Knowledge	Ctudents can evolain humaneid rebets			
	 Students can explain humanou robots. Students can explain the basic concepts relation 	oshins and methods of forward- and invers	e kinematics	
	 Students can explain the basic concepts, relation Students learn to apply basic control concepts for 	r different tasks in humanoid robotics.	ie kinematies	
	· · · · · · · · · · · · · · · · · · ·			
Skills	 Students can implement models for humanoid ro 	botic systems in Matlab and C++, and us	e these mode	ls for robot motion o
	other tasks.			
	They are capable of using models in Matlab for s	simulation and testing these models if nec	essary with C	C++ code on the real
	robot system.			
	 They are capable of selecting methods for solv 	ring abstract problems, for which no star	ndard method	ls are available, and
	apply it successfully.			
Personal Competence				
Social Competence	Chudanta and daudan isint adultancia minada.			
	 Students can develop joint solutions in mixed tea They can provide appropriate feedback to other 	ams and present these.	boir own roci	ulte
	• They can provide appropriate recuback to others	, and constructively handle reeuback on		uits
Autonomy	Students are able to obtain required information	on from provided literature sources, and	to put in int	a the context of the
	lecture.	in nom provided interactive sources, and		o the context of the
	 They can independently define tasks and apply t 	he appropriate means to solve them.		
Workload in Hours	c			
Course achievement	o None			
Examination	Written elaboration			
Examination duration and	5-10 pages			
scale				
Assignment for the	Computer Science: Specialisation II: Intelligence Engine	ering: Elective Compulsory		
Following Curricula	Data Science: Specialisation III. Applications: Elective C	ompulsory		
	Data Science: Specialisation IV. Special Focus Area: Ele	ctive Compulsory		
	Electrical Engineering: Specialisation Control and Powe	r Systems Engineering: Elective Compulso	ry	
	Mechatronics: Core Qualification: Elective Compulsory	and Madical Task adams. Flashing Co.		
	I neoretical Mechanical Engineering: Specialisation Bio-	and Medical Technology: Elective Computer	sory	
	meoretical mechanical Engineering, specialisation Rob	ones and computer science. Elective Com	ipuisoi y	

Course L1794: Applied Humanoid Robotics				
Тур	Project-/problem-based Learning			
Hrs/wk	6			
CP	6			
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84			
Lecturer	Patrick Göttsch			
Language	DE/EN			
Cycle	WiSe/SoSe			
Content	 Fundamentals of kinematics Static and dynamic stability of humanoid robotic systems Combination of different software environments (Matlab, C++, etc.) Introduction to the necessary software frameworks Team project Presentation and Demonstration of intermediate and final results 			
Literature	• B. Siciliano, O. Khatib. "Handbook of Robotics. Part A: Robotics Foundations", Springer (2008)			

Module M1881: Digita	al Health	n					
Courses							
					_		
Litle					lyp	Hrs/wk	CP
Digital Health Seminar (13100)					Project-/problem-based Learning	3	3
Module Responsible	Prof. Moritz	z Göldner			roject (problem based Learning	5	5
Admission Requirements	None						
Recommended Previous							
Knowledge							
Educational Objectives	After taking	g part suc	cessfully, students	have reached the followi	ng learning results		
Professional Competence							
Knowledge							
Skills							
Personal Competence							
Social Competence							
Autonomy							
Workload in Hours	Independer	nt Study T	ime 96, Study Tim	e in Lecture 84			
Credit points	6						
Course achievement	Compulsory	Bonus	Form	Description			
	Yes	20 %	Excercises	Erfolgreiche	Teilnahme PBL-Übung		
Examination	Written exa	am					
Examination duration and	90 min						
scale							
Assignment for the	Data Scien	Data Science: Specialisation III. Applications: Elective Compulsory					
Following Curricula	Data Scien	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory					
	Biomedical	Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory					
	Biomedical	Engineeri	ing: Specialisation	Artificial Organs and Reg	enerative Medicine: Elective Con	npulsory	
	Biomedical	3iomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory					
	Biomedical	Engineeri	ing: Specialisation	Medical Technology and	Control Theory: Elective Compuls	sory	

Course L3099: Digital Health	
Тур	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Moritz Göldner
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3100: Digital Health Seminar				
Тур	Project-/problem-based Learning			
Hrs/wk	3			
CP	3			
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42			
Lecturer	Prof. Moritz Göldner			
Language	EN			
Cycle	WiSe			
Content				
Literature				

Module M1807: Mach	ne Learning for Physical Systems			
Courses				
Title		Тур	Hrs/wk	СР
Machine Learning for Physical System	ems (L2987)	Lecture	2	3
Machine Learning for Physical Systemeters	ems (L2988)	Project-/problem-based Learning	2	3
Module Responsible	Prof. Christian Cyron			
Admission Requirements	None			
Recommended Previous				
Knowledge				
Educational Objectives	After taking part successfully, students have reac	hed the following learning results		
Professional Competence				
Knowledge				
Skills				
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 124, Study Time in Lectu	ure 56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	60 min			
scale				
Assignment for the	General Engineering Science (German program, 7	semester): Specialisation Advanced Materials:	Compulsory	
Following Curricula	Data Science: Specialisation IV. Special Focus Are	a: Elective Compulsory		
	Data Science: Specialisation III. Applications: Elect	tive Compulsory		
	Engineering Science: Specialisation Advanced Ma	terials: Compulsory		
	Engineering Science: Specialisation Advanced Ma	terials: Elective Compulsory		
	Mechatronics: Specialisation Dynamic Systems an	nd AI: Elective Compulsory		
	Mechatronics: Specialisation Robot- and Machine-	Systems: Elective Compulsory		

Course L2987: Machine Learning for Physical Systems	
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	NN
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2988: Machine Learning for Physical Systems	
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	NN
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Module M1249: Media	al Imaging			
Courses				
Title		Тур	Hrs/wk	СР
Medical Imaging (L1694)		Lecture	2	3
Medical Imaging (L1695)		Recitation Section (small)	2	3
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Basic knowledge in linear algebra, numerics, ar	nd signal processing		
Knowledge				
Educational Objectives	After taking part successfully, students have re	ached the following learning results		
Professional Competence				
Knowledge	After successful completion of the module, stud	lents are able to describe reconstruction meth	ods for different	tomographic imaging
	modalities such as computed tomography and	I magnetic resonance imaging. They know th	ne necessary bas	ics from the fields o
	signal processing and inverse problems and a	are familiar with both analytical and iterative	e image reconstr	uction methods. The
	students have a deepened knowledge of the im	aging operators of computed tomography and	d magnetic reson	ance imaging.
Skille	The students are able to implement reconstr	uction methods and test them using tomos	ranhic measurer	nent data. They car
JKIIIS	visualize the reconstructed images and evalu	ate the quality of their data and results. In	addition studer	nts can estimate the
	temporal complexity of imaging algorithms	are the quality of their data and results. In	dualition, studer	
	complexity of inaging algorithms.			
Personal Competence				
Social Competence	Students can work on complex problems both i	ndependently and in teams. They can exchan	ge ideas with eac	h other and use thei
	individual strengths to solve the problem.			
Autonomy	Students are able to independently investigate	a complex problem and assess which compet	oncios aro roquir	od to colvo it
Autonomy	Students are able to independently investigate	a complex problem and assess which compet	encies are require	ed to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Le	cture 56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation II: Intelligence	e Engineering: Elective Compulsory		
Following Curricula	Data Science: Specialisation III. Applications: El	ective Compulsory		
	Data Science: Specialisation IV. Special Focus A	rea: Elective Compulsory		
	Electrical Engineering: Specialisation Medical T	echnology: Elective Compulsory		
	Computer Science in Engineering: Specialisatio	n I. Computer Science: Elective Compulsory		
	Interdisciplinary Mathematics: Specialisation Co	omputational Methods in Biomedical Imaging:	Compulsory	
	Microelectronics and Microsystems: Specialisat	on Communication and Signal Processing: Ele	ctive Compulsory	
	Technomathematics: Specialisation II. Informat	ics: Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisat	ion Bio- and Medical Technology: Elective Cor	npulsory	

Course L1694: Medical Imagi	ng
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	 Overview about different imaging methods Signal processing Inverse problems Computed tomography Magnetic resonance imaging Compressed Sensing Magnetic particle imaging
Literature	Bildgebende Verfahren in der Medizin; O. Dössel; Springer, Berlin, 2000 Bildgebende Systeme für die medizinische Diagnostik; H. Morneburg (Hrsg.); Publicis MCD, München, 1995 Introduction to the Mathematics of Medical Imaging; C. L.Epstein; Siam, Philadelphia, 2008 Medical Image Processing, Reconstruction and Restoration; J. Jan; Taylor and Francis, Boca Raton, 2006 Principles of Magnetic Resonance Imaging; ZP. Liang and P. C. Lauterbur; IEEE Press, New York, 1999

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Course L1695: Medical Imaging	
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1739: Opera	ational Aspekts in Aviation			
Courses				
Title		Тур	Hrs/wk	СР
Airline Operations (L1310)		Lecture	3	3
Flight Guidance I (Introduction) (L0	848)	Lecture	2	2
Flight Guidance I (Introduction) (L0	854)	Recitation Section (large)	1	1
Airport Operations (L1276)		Lecture	3	3
Airport Planning (L1275)		Lecture	2	2
Airport Planning (L1469)		Recitation Section (small)	1	1
Aviation and Environment (L2376)		Lecture	3	3
Module Responsible	Prof. Volker Gollnick			
Admission Requirements	None			
Recommended Previous	Air Transportation Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowledge	Analysis and description of the interaction between p	people and aircraft in operation		
Skills	Understanding and application of design and calculat	ion methods		
	Understanding of interdisciplinary and integrative int	erdependencies		
	Evaluation of operational issues in aviation and deve	lopment of operational solution options		
Personal Competence				
Social Competence	Working in teams for focused solutions			
	communication, assertiveness, technical persuasion			
Autonomy	Organisation of worksflows and strategies for solution	ns		
	structured task analysis and definition of solutions			
Workload in Hours	Depends on choice of courses			
Credit points	6			
Assignment for the	Data Science: Specialisation III. Applications: Elective	Compulsory		
Following Curricula	International Management and Engineering: Specialis	sation II. Aviation Systems: Elective Comp	oulsory	
	International Management and Engineering: Specialis	sation II. Logistics: Elective Compulsory		
	Logistics, Infrastructure and Mobility: Specialisation F	Production and Logistics: Elective Compul	sory	
	Logistics, Infrastructure and Mobility: Specialisation I	nfrastructure and Mobility: Elective Comp	oulsory	

Course L1310: Airline Operat	tions
Тур	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Klausur
Examination duration and	90 min
scale	
Lecturer	Prof. Volker Gollnick, Dr. Karl Echtermeyer
Language	DE
Cycle	SoSe
Content	 Introdution and overview Airline business models Interdependencies in flight planning (network management, slot management, netzwork structures, aircraft circulation) Operative flight preparation (weight & balance, payload/range, etc.) fleet policy Aircraft assessment and fleet planning Aircraft maintenance, repair and overhaul
Literature	Volker Gollnick, Dieter Schmitt: The Air Transport System, Springer Berlin Heidelberg New York, 2014 Paul Clark: "Buying the Big Jets", Ashgate 2008 Mike Hirst: The Air Transport System, AIAA, 2008

Course L0848: Flight Guidance I (Introduction)		
Тур	Lecture	
Hrs/wk	2	
CP	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Examination Form	Klausur	
Examination duration and	60 min	
scale		
Lecturer	Prof. Volker Gollnick	
Language	DE	
Cycle	WiSe	
Content	Introduction and motivation Flight guidance principles (airspace structures, organization of air navigation services, etc.)	
	Cockpit systems and Avionics (cockpit design, cockpit equipment, displays, computers and bus systems)	
	Principles of flight measurement techniques (Measurement of position (geometric methods, distance measurement, direction	
	measurement) Determination of the anciait attitude (magnetic neit- and merital sensors) Measurement of speed	
	Principles of Navigation	
	Radio navigation	
	Satellite navigation	
	Airspace surveillance (radar systems)	
	Commuication systems	
	Integrated Navigation and Guidance Systems	
Literature	Rudolf Brockhaus, Robert Luckner, Wolfgang Alles: "Flugregelung", Springer Berlin Heidelberg New York, 2011	
	Holger Flühr: "Avionik und Flugsicherungssysteme", Springer Berlin Heidelberg New York, 2013	
	Volker Gollnick, Dieter Schmitt "Air Transport Systems", Springer Berlin Heidelberg New York, 2016	
	R.P.G. Collinson "Introduction to Avionics", Springer Berlin Heidelberg New York 2003	

Course L0854: Flight Guidance I (Introduction)	
Тур	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Examination Form	Klausur
Examination duration and	60 min
scale	
Lecturer	Prof. Volker Gollnick
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L1276: Airport Opera	tions
Тур	Lecture
Hrs/wk	3
СР	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Klausur
Examination duration and	90 min
scale	
Lecturer	Prof. Volker Gollnick, Dr. Peter Willems
Language	DE
Cycle	WiSe
Content	FA-F Flight Operations Flight Operations - Production Infrastructures Operations Planning Master plan Airport capacity Ground
	handling Terminal operations
Literature	Richard de Neufville, Amedeo Odoni: Airport Systems, McGraw Hill, 2003

Course L1275: Airport Planning	
Тур	Lecture
Hrs/wk	2
СР	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and	60 min
scale	
Lecturer	Prof. Volker Gollnick, Dr. Ulrich Häp
Language	DE
Cycle	WiSe
Content	 Introduction, definitions, overviewg Runway systems Air space strucutres around airports Airfield lightings, marking and information Airfield and terminal configuration
Literature	N. Ashford, Martin Stanton, Clifton Moore: Airport Operations, John Wiley & Sons, 1991 Richard de Neufville, Amedeo Odoni: Airport Systems, Aviation Week Books, MacGraw Hill, 2003

Course L1469: Airport Planning	
Тур	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Examination Form	Klausur
Examination duration and	60 min
scale	
Lecturer	Prof. Volker Gollnick, Dr. Ulrich Häp
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L2376: Aviation and Environment					
Тур	Lecture				
Hrs/wk	3				
CP	3				
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42				
Examination Form	Klausur				
Examination duration and	90 min				
scale					
Lecturer	Prof. Volker Gollnick				
Language	DE				
Cycle	SoSe				
Content	The lecture provides the necessary basics and methods for understanding the interactions between air traffic and the environment,				
	both in terms of the effects of weather / climate on flying and with regard to the effects of air traffic on pollutant emissions, noise				
	and climate.				
	The following topics are covered:				
	Atmospheric physics / chemistry				
	 Structure and statics 				
	 Dynamics (water cycle, formation of weather events, high and low pressure areas, wind, gusts and turbulence) 				
	 Cloud physics (thermodynamics, contrails) 				
	 Radiation physics (energy balance, greenhouse effect) 				
	Photochemistry (ozone chemistry)				
	Impact of weather on hying Atmospheric influences on flight performance				
	Elight planning				
	 Disturbances due to weather, e.g. thunderstorms, winter weather (icing), clear air turbulence, visibility 				
	 Effects of climate change and adaptation 				
	Effects of air traffic on the environment and climate				
	Aviation pollutant emissions				
	 Effect of emissions on concentrations in the atmosphere 				
	 Climate metrics / models and background scenarios 				
	Emissions inventories				
	Mitigation measures				
	 Technological measures, e.g. climate-optimized aircraft design 				
	Alternative fuels				
	Operational measures, e.g. climate-optimized night planning Savienzettel activity measures a c.g. FULTEC CODCIDE				
	Potentials and comparison, concept of eco-efficiency				
	Local environmental impacts				
	 Local air quality (particulate matter, other emissions near the ground) 				
	 Noise (noise sources, noise metrics, noise impact, measurement, certification, psychoacoustics, noise mitigation) 				
	• Health effects				
	Aspects of sustainability				
	 Other aspects, including life cycle emissions, disposal/recycling 				
	Relation to global goals, e.g. United Nations goals for sustainable development, Paris climate agreement				
Literature	Ruijgrok, G.: Elements of Aircraft Pollution, Delft University Press, 2005				
	 Friedrich, R., Reis, S.: Emissions of Air Pollutants, Springer 2004 				
	Janic, M.: The Sustainability of Air Transportation, Ashgate, 2007				
	Schumann, U. (ed.): Atmospheric Physics: Background - Methods - Trends, Springer, Berlin, Heidelberg, 2012				
	Spiridonov, V., Curic, M.: Fundamentals of Meteorology, Springer, 2021				
	Kaltschmitt, M., Neuling, U.: Biokerosene - Status and Prospects, Springer, 2018				
	Roedel, W., Wagner, T.: Physik unserer Umwelt: Die Atmosphäre, Springer, 2017				
	W. Bräunling: Flugzeugtriebwerke. Springer-Verlag Berlin, Deutschland, 2009				
	G. Bruning, X. Hafer, G. Sachs: Flugleistungen, Springer, 1993				
Driven Inn	overtien				
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Driven inne	ovation				
			Тур	Hrs/wk	СР
			Lecture	3	3
3115)			Project-/problem-based Learning	2	3
Prof. Moritz Göl	dner				
None					
After taking pa	rt successfully, st	udents have reached the follow	ving learning results		
Independent St	udy Time 110, St	udy Time in Lecture 70			
6					
Compulsory Bon	us Form	Description			
Yes 20	% Excercise	es Erfolgreiche	e Teilnahme PBL-Übung		
Written exam					
90 min					
Data Science: 9	pecialisation III. A	Applications: Elective Compulso	bry		
Data Science: Specialisation IV. Special Focus Area: Elective Compulsory					
Global Technol	ogy and Innovatio	on Management & Entrepreneu	rship: Core Qualification: Elective	Compulsory	
International M	anagement and E	Engineering: Specialisation II. In	formation Technology: Elective C	ompulsory	
	Driven Inne	Driven Innovation Triven Innovation Prof. Moritz Göldner None After taking part successfully, st Independent Study Time 110, St Compulsory Bonus Form Yes 20 % Excercise Written exam 90 min Data Science: Specialisation III. , Data Science: Specialisation IV. Global Technology and Innovatio International Management and E	Driven Innovation 3115) Prof. Moritz Göldner None After taking part successfully, students have reached the follow Independent Study Time 110, Study Time in Lecture 70 6 Compulsory Bonus Form Yes 20 % Excercises Erfolgreiche Written exam 90 min Data Science: Specialisation III. Applications: Elective Compulsor Area: Elective Co Global Technology and Innovation Management & Entrepreneu International Management and Engineering: Specialisation II. In	Driven Innovation Typ Lecture Prof. Moritz Göldner None After taking part successfully, students have reached the following learning results After taking part successfully, students have reached the following learning results Independent Study Time 110, Study Time in Lecture 70 6 Compulsory Bonus Form Ves 20 % Excercises Erfolgreiche Teilnahme PBL-Übung Written exam 90 min Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Global Technology and Innovation Management & Entrepreneurship: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective C	Typ Hrs/wk Lecture 3 3115) Project-/problem-based Learning 2 Prof. Moritz Göldner 2 None 3 After taking part successfully, students have reached the following learning results 3 Independent Study Time 110, Study Time in Lecture 70 6 Compulsory Bonus Form Description Yes 20 % Excercises Erfolgreiche Teilnahme PBL-Übung Written exam 90 min 90 min 10 Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Global Technology and Innovation Management & Entrepreneurship: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L3114: Data-Driven Innovation			
Тур	Lecture		
Hrs/wk	3		
CP	3		
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42		
Lecturer	Prof. Moritz Göldner		
Language	EN		
Cycle	SoSe		
Content	This course aims to combine the principles of design thinking with data science, focusing on all steps of the design thinking process from understanding the problem, investigating user's needs and integrating these needs into the development and testing in a data-driven manner. Students will learn several methods to accelerate the innovation process (such as generative AI and modern market research platforms) as well as more general data science methodologies to streamline the innovation process. Established and modern, data-driven methods will be compared and critically evaluated, including ethical and privacy-related considerations. Through a series of lectures, hands-on exercises, and project presentations, students will not only develop a robust theoretical understanding of these topics, but will also gain practical experience applying these concepts in realistic innovation scenarios.		
Literature	Luo, J. (2023). Data-driven innovation: What is it?. IEEE Transactions on Engineering Management, 70(2), 784-790. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9707478		

Course L3115: Data-Driven Innovation Seminar		
Тур	Project-/problem-based Learning	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Moritz Göldner	
Language	EN	
Cycle	SoSe	
Content		
Literature		

Module M0630: Robo	tics and Naviga	tion in Medicine			
Courses					
Title Robotics and Navigation in Medicin Robotics and Navigation in Medicin	e (L0335) e (L0338)		Typ Lecture Project Seminar	Hrs/wk 2 2	CP 3 2
Robotics and Navigation in Medicin	ie (L0336)		Recitation Section (sma	all) 1	1
Module Responsible	Prof. Alexander Schla	efer			
Admission Requirements	None				
Kecommended Previous Knowledge	 principles of m principles of pr solid R or Matla 	ath (algebra, analysis/calcu ogramming, e.g., in Java or b skills	lus) C++		
Educational Objectives	After taking part succ	essfully, students have rea	ched the following learning results		
Professional Competence					
Knowledge	The students can exp detail. Systems can systems regarding de	plain kinematics and track be evaluated with respect sign and limitations.	ing systems in clinical contexts and to collision detection and safety a	illustrate systems and regulations. Stud	and their components in dents can assess typical
Skills	The students are able	to design and evaluate na	vigation systems and robotic systems	for medical applicat	ions.
Personal Competence					
Social Competence	The students are able work on them collabo The students are able software managemen The students can crit	e to grasp practical tasks ratively. e to collaboratively organi: t tools.	in groups, develop solution strategies ze their work processes and software	s independently, de	fine work processes and tual communication and
Autonomy	The students can as document their work manner to the other o	sess their level of knowled results. They can critically roups.	lge and independently control their evaluate the results achieved and pr	learning processes esent them in an ap	on this basis as well as
Workload in Hours	Independent Study Ti	me 110, Study Time in Lect	cure 70		
Credit points	6				
Course achievement	CompulsoryBonusYes10 %Yes10 %	Form Written elaboration Presentation	Description		
Examination	Written exam	resentation			
Examination duration and	90 minutes				
scale					
Assignment for the	Computer Science: Sp	ecialisation II: Intelligence	Engineering: Elective Compulsory		
Following Curricula	Data Science: Special	sation III. Applications: Ele	ctive Compulsory		
	Data Science: Special	sation IV. Special Focus Ar	ea: Elective Compulsory		
	Electrical Engineering	: Specialisation Medical Tee	hnology: Elective Compulsory		
	Computer Science in	Engineering: Specialisation	II. Engineering Science: Elective Comp	oulsory	
	International Manager	nent and Engineering: Spe	cialisation II. Electrical Engineering: El	ective Compulsory	
	International Manager	ment and Engineering: Spe	cialisation II. Process Engineering and	Biotechnology: Elec	tive Compulsory
	Riemodical Engineerin	ualification: Elective Compl	lisory	octivo Compulsony	
	Biomedical Engineerir	ig. Specialisation Artificial (and Endoprostheses: Elective Compute	sorv	
	Biomedical Engineerin	ig: Specialisation Medical T	echnology and Control Theory: Electiv	e Compulsorv	
	Biomedical Engineerin	g: Specialisation Managem	ent and Business Administration: Elec	tive Compulsory	
	Product Development	, Materials and Production:	Specialisation Product Development:	Elective Compulsory	/
	Product Development	, Materials and Production:	Specialisation Production: Elective Co	mpulsory	
	Product Development	, Materials and Production:	Specialisation Materials: Elective Com	pulsory	
	Theoretical Mechanica	al Engineering: Specialisation	on Bio- and Medical Technology: Electi	ve Compulsory	

Course L0335: Robotics and	Navigation in Medicine
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	SoSe
Content	- kinematics
	- calibration
	- tracking systems
	- navigation and image guidance
	- motion compensation
	The seminar extends and complements the contents of the lecture with respect to recent research results.
Literature	Spong et al.: Robot Modeling and Control, 2005
	Troccaz: Medical Robotics, 2012
	Further literature will be given in the lecture.

Course L0338: Robotics and Navigation in Medicine		
Тур	Project Seminar	
Hrs/wk	2	
CP	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Lecturer	Prof. Alexander Schlaefer	
Language	EN	
Cycle	SoSe	
Content	See interlocking course	
Literature	See interlocking course	

Course L0336: Robotics and Navigation in Medicine		
Тур	Recitation Section (small)	
Hrs/wk	1	
СР	1	
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14	
Lecturer	Prof. Alexander Schlaefer	
Language	EN	
Cycle	SoSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1785: Mach	ine Learning in Electrical Engineer	ing and Information Tech	nology	
Courses				
Title		Тур	Hrs/wk	СР
General Introduction Machine Learn	ning (L3004)	Lecture	1	2
Machine Learning Applications in E	lectric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnet	tic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequence	y Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Comr	nunications (L3005)	Lecture	1	1
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	The module is designed for a diverse audience, i.	e. students with different background	. It shall be suitable for	both students with
Knowledge	deeper knowledge in machine learning methods	but less knowledge in electrical en	gineering, e.g. math o	r computer science
	students, and students with deeper knowledge i	n electrical engineering but less know	wledge in machine lea	rning methods, e.g.
	electrical engineering students. Machine learning	methods will be explained on a relat	ively high level indicat	ing mainly principle
	ideas. The focus is on specific applications in elect	rical engineering and information tech	nology.	5 51 1
	The chapters of the course will be understandable	e in different depth depending on the	individual background	of the student. The
	individual background of the students will be take	n into consideration in the oral exam.		
Educational Objectives	After taking part successfully, students have reach	ned the following learning results		
Professional Competence				
Knowledge	The students know basic machine learning conce	pts and learning strategies. They are	aware of specific oppor	tunities, challenges
_	and approaches of machine learning in various	fields of electrical engineering. They	know exemplary appl	ications of machine
	learning in electrical engineering	······		
	······································			
	The students are familiar with the contents of the	module courses. They can explain and	l apply them to new pro	blems.
Chille	The students are able to easily matheds from me	akina laavaina ta nyaklawa in alaatuisa	l engineering They are	abla ta datarmina
5K1115	The students are able to apply methods from man	chine learning to problems in electrica	a engineering. They are	able to determine,
	dimension and implement suitable approaches	such as types of deep learning net	works and learning str	ategies for specific
	engineering problems. In particular, they are abl	e to include domain knowledge in m	achine learning archite	ctures and learning
	strategies. They are able to critically assess the le	arning results based on domain knowl	edge.	
Personal Competence				
Social Compositorica	The students can jointly solve specific problems			
Social competence	The students can jointly solve specific problems.			
Autonomy	The students are able to acquire relevant info	rmation from appropriate literature	sources. They can co	ntrol their level of
	knowledge during the lecture period e.g. by solvin	g tutorial problems or using software t	tools.	
Workload in Hours	Independent Study Time 110, Study Time in Lectu	ire 70		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Data Science: Specialisation III. Applications: Elect	ive Compulsory		
Following Curricula	Data Science: Specialisation IV. Special Focus Area	a: Elective Compulsory		
	Electrical Engineering: Specialisation Information	and Communication Systems: Elective	Compulsory	
	Electrical Engineering: Specialisation Microwave E	ngineering Ontics and Electromagnet	ic Compatibility: Electiv	e Compulsory
	Electrical Engineering: Specialisation Microwave E	Power Systems Engineering: Elective C	`ompulsory	c compaisory
	Electrical Engineering, Specialisation Control and	Sonsor Tochnologios: Elective Computer	loon	
	Computer Science in Engineering, Specialisation wireless and	Engineering Science: Elective Compu	lson	
	computer science in Engineering: Specialisation II	Engineering Science: Elective Compu	ilsory	
	Information and Communication Systems: Special	isation Communication Systems, Focus	s Software: Elective Cor	npulsory

Course L3004: General Intro	duction Machine Learning
Тур	Lecture
Hrs/wk	1
СР	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe
Content	
	From Rule-Based Systems to Machine Learning
	Brief overview recent advances in ML in various domain
	Outline and expected learning outcomes
	Basics statistical inference and statistics
	Basics of information theory
	The Notions of Learning in Machine Learning
	 Unsupervised and supervised machine learning
	 Model-based and data-driven machine learning
	Hybrid modelling
	Online/offline/meta/transfer learning
	General loss functions
	Introduction to Deep Learning
	Variants of neural networks
	• MLP
	Conv. neural networks
	Recurrent neural networks
	Training neural networks
	(Stochastic) Gradient Descent
	Regression vs. Classification
	 Classification as supervised learning problem
	Hands-On Session
	Representation Learning and Generative Models
	AutoEncoders
	Directed Generative Models
	Undirected Generative Models
	Generative Adversarial Neural Networks
	Probabilistic Graphical Models
	Bayesian Networks
	 Variational inference (variational autoencoder)
Literature	Lecture notes as well as current literature announced in the lecture.

Course L3008: Machine Learning Applications in Electric Power Systems			
Тур	Lecture		
Hrs/wk	1		
СР	1		
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14		
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh		
Language	EN		
Cycle	SoSe		
Content	This part of the course focuses on how to utilize ML methods to model and operate electric power systems. Electric power systems consist of generation units such as PV, loads or consumers and the grid that connects those actors and supports to transport energy. This part of the course helps to understand the data-driven modelling of generation units (e.g. PV & fuel cells), modelling of load behavior, and to formulate and solve a state estimation problem for distribution grids using neural networks. This part of the course includes lectures to introduce the basics that are followed by practical examples and coding.		
Literature	Lecture notes as well as current literature announced in the lecture.		

Cours	se L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering

Тур	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and
	electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application.
	Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the
	operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and
	ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give
	an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to
	expand todays physcis-based approaches in EMC Engineering.
Literature	Lecture notes as well as current literature announced in the lecture
Literature	Lecture notes us wen as current interature dimoniced in the lecture.

Course L3007: Machine Learning in High-Frequency Technology and Radar

Тур	Lecture
Hrs/wk	1
СР	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	Modern high-frequency systems benefit massively from machine learning methods. In applications where rule-based algorithms reach their limits, these data-driven approaches enable a significant increase in resolution and accuracy. This is exemplified by current research challenges, namely for the classification of targets in autonomous driving radar systems, radar-based gesture recognition for smart home applications and device control as well as in the field of medical technology for the contactless monitoring of human vital signs.
Literature	Lecture notes as well as current literature announced in the lecture.

Course L3005: Machine Learning in Wireless Communications			
Тур	Lecture		
Hrs/wk	1		
CP	1		
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14		
Lecturer	Dr. Maximilian Stark		
Language	EN		
Cycle	SoSe		
Content			
	Supervised Learning Application - Channel Coding		
	Recap channel coding and block codes		
	 Block codes as trainable neural networks 		
	 Tanner graph with trainable weights 		
	Hands-on session		
	Supervised Learning Application - Modulation Detection		
	Recap wireless modulation schemes		
	 Convolutional neuronal networks for blind detection of modulation schemes 		
	Hands-on session		
	Autoencoder Application - Constellation Shaping I		
	Recap channel capacity and constellation shaping,		
	 Capacity achieving machine learning systems 		
	 Information theoretical explanation of the autoencoder training 		
	Hands-on session		
	Autoencoder Application - Constellation Shaping II		
	Training without a channel model		
	Mutual information neural estimator		
	Hands-on session		
	Generative Adversarial Network Application - Channel Modelling		
	 Recap realistic channels with non-linear hardware impairments 		
	 Training a digital twin of a realistic channel with insufficient training data 		
	Hands-on session		
	Recurrent Neural Network Application - Channel prediction		
	Recap time-varying channel models		
	Recurrent neural networks for temporal prediction		
	Hands-on session		
Literature	Lecture notes as well as current literature announced in the lecture.		

Module M1879: Causa	al Data Science for Business Analytics				
Courses					
Title		Тур	Hrs/wk	СР	
Business Analytics with Causal Dat	a Science (L3096)	Project-/problem-based Learning	2	3	
Causal Data Science (L3095)		Lecture	2	3	
Module Responsible	Prof. Christoph Ihl				
Admission Requirements	None				
Recommended Previous	- Linear Algebra				
Knowledge	- Basics of programming				
	- School knowledge in economics				
Educational Objectives	After taking part successfully, students have reached the	following learning results			
Professional Competence					
Knowledge	After completing the module, students will be able to:				
	- understand the difference between "correlation" and "ca	ausation".			
	- understand the shortcomings of current correlation-base	ed approaches.			
	- discuss the conceptual ideas behind various causal data	- discuss the conceptual ideas behind various causal data science tools and algorithms.			
	- critical examination of (study) results and spurious corre	lations.			
	- understanding of application of methods in business and	l practice.			
Skills	- develop causal knowledge relevant for specific data-driv	en decisions.			
	- carry out state-of the art causal data analyses.				
	- isolating causal effects despite the existence of confounding factors.				
	- programming in relevant programming languages.				
	- selection of the appropriate method depending on the p	roblem.			
Personal Competence					
Social Competence	Students can work on the problems both individually and	in groups during the exercise times and	l also ask ques	tions and contribute	
	to the solution of other people's problems outside the exe	ercise times in a dedicated forum for the	e course (Matte	ermost). In addition,	
	students learn to prepare and present their results during	the course.			
Autonomy	Students learn to transfer the knowledge and skills they	/ have learned to other subject areas	and to link the	em to new learning	
	content. To obtain information and solve problems, espec	cially those related to programming error	ors, they learn	n to use appropriate	
	resources to help themselves.				
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56				
Credit points	6				
Course achievement	None				
Examination	Subject theoretical and practical work				
Examination duration and	Solutions to coding problem sets after each class session				
scale					
Assignment for the	Data Science: Specialisation III. Applications: Elective Com	npulsory			
Following Curricula	Data Science: Specialisation IV. Special Focus Area: Electi	ve compulsory	mpulsory		
1	micemational management and Engineering: Specialisation	i in mormation rechnology: Elective Co	mpuisury		

Course L3096: Business Anal	ytics with Causal Data Science		
Тур	Project-/problem-based Learning		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer			
Cvcle	SoSe		
Content	Most managerial decision problems require answers to questions such as "what happens to Y if we do X?", or "was it X that caused Y to change?" In other words, practical business decision-making requires knowledge about cause-and-effect. While most data science and machine learning approaches are designed to efficiently detect patterns in high-dimensional data, they are not able to distinguish causal relationships from simple correlations. That means, commonly used approaches to business analytics often fall short to provide decision makers with important causal knowledge. Therefore, many leading companies currently try to develop specific causal data science capabilities.		
	This module will provide an introduction into the topic of causal inference with the help of modern data science and machine learning approaches and with a focus on applications to practical business problems from various management areas. Based on an overarching framework for causal data science, the course will guide students to detect sources of confounding influence factors, understand the problem of selective measurement in data collection, and extrapolate causal knowledge across different business contexts. We also cover several tools for causal inference, such as A/B testing and experiments, difference-in-differences, instrumental variables, matching, regression discontinuity designs, etc. A variety of hands-on examples will be discussed that allow students to apply their newly obtained knowledge and carry out state-of-the-art causal analyses by themselves.		
	Topics covered:		
	. Introduction and Overview		
	2. Probability and Regression Review		
	3. Potential Outcomes Causal Model		
	. Directed Acyclic Graphs		
	i. Experiments and A/B-Testing		
	. Matching and Subclassification		
	7. Regression Discontinuity		
	8. Instrumental Variables		
	9. Panel Data		
	10. Difference-in-Differences		
	11. Synthetic Control		
	12. Heterogeneous Treatment Effects		
	13. Mediation Analysis		
Literature	 Angrist, J. D., & Pischke, J. S. (2014). Mastering metrics: The path from cause to effect. Princeton university press. Cunningham, Scott (2021). Causal Inference: The Mixtape, New Haven: Yale University Press. Hernán Miguel A., and Robins James M. (2020). Causal Inference: What If. Boca Raton: Chapman & Hall/CRC. Huntington-Klein, Nick. The effect (2021). An introduction to research design and causality. Chapman and Hall/CRC. Imbens, G. W., & Rubin, D. B. (2015). Causal inference in statistics, social, and biomedical sciences. Cambridge University Press. Mullainathan, Sendhil, and Jann Spiess. (2017). Machine Learning: An Applied Econometric Approach. Journal of Economic Perspectives, 31(2): 87-106. Pearl, Judea, and Dana Mackenzie (2018). The Book of Why. Basic Books, New York, NY. Pearl, Judea, Madelyn Glymour, and Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Inc., New York, NY. 		

Course L3095: Causal Data S	cience		
Тур	Lecture		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Christoph Ihl		
Language	EN		
Cycle	SoSe		
Content	Y to change?" In other words, practical business decision-making requires knowledge about cause-and-effect. While most data science and machine learning approaches are designed to efficiently detect patterns in high-dimensional data, they are not able to distinguish causal relationships from simple correlations. That means, commonly used approaches to business analytics often fall short to provide decision makers with important causal knowledge. Therefore, many leading companies currently try to develop specific causal data science capabilities.		
	This module will provide an introduction into the topic of causal inference with the help of modern data science and machine learning approaches and with a focus on applications to practical business problems from various management areas. Based on an overarching framework for causal data science, the course will guide students to detect sources of confounding influence factors, understand the problem of selective measurement in data collection, and extrapolate causal knowledge across different business contexts. We also cover several tools for causal inference, such as A/B testing and experiments, difference-in-differences, instrumental variables, matching, regression discontinuity designs, etc. A variety of hands-on examples will be discussed that allow students to apply their newly obtained knowledge and carry out state-of-the-art causal analyses by themselves.		
	Topics covered:		
	1. Introduction and Overview		
	. Probability and Regression Review		
	. Potential Outcomes Causal Model		
	. Directed Acyclic Graphs		
	. Experiments and A/B-Testing		
	. Matching and Subclassification		
	7. Regression Discontinuity		
	8. Instrumental Variables		
	9. Panel Data		
	10. Difference-in-Differences		
	11. Synthetic Control		
	12. Heterogeneous Treatment Effects		
	13. Mediation Analysis		
Literature	 Angrist, J. D., & Pischke, J. S. (2014). Mastering metrics: The path from cause to effect. Princeton university press. Cunningham, Scott (2021). Causal Inference: The Mixtape, New Haven: Yale University Press. Hernán Miguel A., and Robins James M. (2020). Causal Inference: What If. Boca Raton: Chapman & Hall/CRC. Huntington-Klein, Nick. The effect (2021). An introduction to research design and causality. Chapman and Hall/CRC. Imbens, G. W., & Rubin, D. B. (2015). Causal inference in statistics, social, and biomedical sciences. Cambridge University Press. Mullainathan, Sendhil, and Jann Spiess. (2017). Machine Learning: An Applied Econometric Approach. Journal of Economic Perspectives, 31(2): 87-106. Pearl, Judea, and Dana Mackenzie (2018). The Book of Why. Basic Books, New York, NY. Pearl, Judea, Madelyn Glymour, and Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Inc., New York, NY. 		

Module M1880: Deep	Learning for Social Analytics			
Courses				
Title Deep Learning for Text and Graphs Social Analytics with Deep Learning	: (L3097) 1 (L3098)	Typ Lecture Project-/problem-based Learning	Hrs/wk	СР 3 3
Module Responsible	Prof Christoph Ibl		-	5
Admission Requirements	Nono			
Recommended Previous Knowledge	Basic knowledge of Python Familiarity with probability theory, linear	algebra and statistics		
Educational Objectives	After taking part successfully, students have rea	ached the following learning results		
Professional Competence				
Knowledge	 Understand how text and graphs can be transformed into data Identify underlying relational structures of data that can be represented as graphs Discuss the conceptual ideas behind various deep learning architectures Decide about suitable deep learning architectures for a given task 			
Skills	 Proficiency in Python for deep learning applications Apply basic natural language processing methods such as embedding and dependency parsing Model complex data using graph representations Set up deep learning architectures for different tasks Make predictions employing deep learning models 			
Personal Competence <i>Social Competence</i> <i>Autonomy</i>	 Collaboration on projects and assignment Communication regarding computational Maneuver in the field of deep learning ind Solve computational, algorithmic, and mo Critical thinking skills Self-sufficient problem-solving regarding 	ts , algorithmic and modeling challenges cluding scientific literature and models odeling challenges related to deep learning mode coding issues	els	
Worklood in Hours	Sen-sumcient problem-solving regarding			
Crodit points	6	Lure Ju		
Course achievement	None			
Examination	Subject theoretical and practical work			
Examination duration and scale	Solutions to coding problem sets after each clas	is session		
Assignment for the	Data Science: Specialisation IV. Special Focus A	rea: Elective Compulsory		
Following Curricula	Data Science: Specialisation III. Applications: Ele	ective Compulsory		
	International Management and Engineering: Spe	ecialisation II. Information Technology: Elective C	ompulsory	

Course L3097: Deep Learning	g for Text and Graphs		
Тур	Lecture		
Hrs/wk	2		
СР	3		
Workload in Hours	ndependent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Christoph Ihl		
Language	EN		
Cycle	wise Today, massive amounts of valuable data come in dinital, yet often unstructured forms such as text or graphs. People		
	communicate almost everything in language: e.g., social media, web search, product reviews, advertising, emails, customer service, language translation, chatbots, medical reports, etc. At the same time, they choose to interact with other people, products or websites. These networked interaction patterns can be represented as graphs of relationships between people and objects. Analyzing these new data sources and forms can help decision makers to significantly improve the effectiveness and efficiency of products, services and processes.		
	This course introduces the fundamentals and current state of machine learning for natural language processing (NLP) and graphs in terms of content, users, and social relations. The course has a particular emphasis on key advancements in deep learning (or neural network) architectures, which in recent years have obtained very high performance across many different tasks, using single end-to-end models that do not require traditional, task-specific feature engineering. The course focuses on the computational, algorithmic, and modeling challenges specific to learning architecture for text and graphs. Students will gain a thorough introduction to modern deep learning algorithms. Through lectures and coding labs, students will learn the necessary skills to design, implement, and understand their own deep learning models. We will use Python and the deep learning framework PyTorch (Geometric).		
	Topics Covered:		
	1. Intro: Text and Graphs as Data		
	. Word Embeddings		
	3. Fundamentals of Deep Learning		
	4. Dependency Parsing		
	5. Recurrent Neural Networks for Text		
	6. Contextual Word Embeddings with Transformers		
	7. Analyzing Graphs		
	8. Graph Embeddings		
	9. Graph Embeddings for Complex Graphs		
	10. Graph Neural Networks (GNNs)		
	11. GNNs for Complex Graphs		
	12. GNNs for Text		
	13. Deep Generative Models for Text and Graphs		
Literature	 Chollet, F., & Allaire, J. J. (2018). Deep Learning mit R und Keras: Das Praxis-Handbuch von den Entwicklern von Keras und RStudio. MITP-Verlags GmbH & Co. KG. Hamilton, William L. (2020). Graph Representation Learning. Synthesis Lectures on Artificial Intelligence and Machine Learning, Vol. 14, No. 3, Pages 1-159. Hapke, H., Howard, C., & Lane, H. (2019). Natural Language Processing in Action: Understanding, analyzing, and generating text with Python. Simon and Schuster. Hvitfeldt, E., & Silge, J. (2021). Supervised machine learning for text analysis in R. Ma, Y., & Tang, J. (2021). Deep learning on graphs. Cambridge University Press. Rao, D., & McMahan, B. (2019). Natural language processing with PyTorch: build intelligent language applications using deep learning. O'Reilly Media, Inc. 		

Course L3098: Social Analyti	cs with Deep Learning		
Тур	Project-/problem-based Learning		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Christoph Ihl		
Language	EN		
Cycle	WiSe		
Content	communicate almost everything in language: e.g., social media, yet often unsudcured forms such as text of graphs. People communicate almost everything in language: e.g., social media, web search, product reviews, advertising, emails, customer service, language translation, chatbots, medical reports, etc. At the same time, they choose to interact with other people, products or websites. These networked interaction patterns can be represented as graphs of relationships between people and objects. Analyzing these new data sources and forms can help decision makers to significantly improve the effectiveness and efficiency of products, services and processes.		
	This course introduces the fundamentals and current state of machine learning for natural language processing (NLP) and graphs in terms of content, users, and social relations. The course has a particular emphasis on key advancements in deep learning (or neural network) architectures, which in recent years have obtained very high performance across many different tasks, using single end-to-end models that do not require traditional, task-specific feature engineering. The course focuses on the computational, algorithmic, and modeling challenges specific to learning architecture for text and graphs. Students will gain a thorough introduction to modern deep learning algorithms. Through lectures and coding labs, students will learn the necessary skills to design, implement, and understand their own deep learning models. We will use Python and the deep learning framework PyTorch (Geometric).		
	Topics Covered:		
	1. Intro: Text and Graphs as Data		
	2. Word Embeddings		
	3. Fundamentals of Deep Learning		
	4. Dependency Parsing		
	5. Recurrent Neural Networks for Text		
	6. Contextual Word Embeddings with Transformers		
	7. Analyzing Graphs		
	8. Graph Embeddings		
	9. Graph Embeddings for Complex Graphs		
	10. Graph Neural Networks (GNNs)		
	11. GNNs for Complex Graphs		
	12. GNNs for Text		
	13. Deep Generative Models for Text and Graphs		
Literature	 Chollet, F., & Allaire, J. J. (2018). Deep Learning mit R und Keras: Das Praxis-Handbuch von den Entwicklern von Keras und RStudio. MITP-Verlags GmbH & Co. KG. Hamilton, William L. (2020). Graph Representation Learning. Synthesis Lectures on Artificial Intelligence and Machine Learning, Vol. 14, No. 3, Pages 1-159. Hapke, H., Howard, C., & Lane, H. (2019). Natural Language Processing in Action: Understanding, analyzing, and generating text with Python. Simon and Schuster. Hvitfeldt, E., & Silge, J. (2021). Supervised machine learning for text analysis in R. Ma, Y., & Tang, J. (2021). Deep learning on graphs. Cambridge University Press. Rao, D., & McMahan, B. (2019). Natural language processing with PyTorch: build intelligent language applications using deep learning. O'Reilly Media, Inc. Silge, J., & Robinson, D. (2017). Text mining with R: A tidy approach. O'Reilly Media, Inc. 		

Specialization IV. Special Focus Area

Module M1807: Mach	ne Learning for Physical Systems			
Courses				
Title		Тур	Hrs/wk	СР
Machine Learning for Physical Syste	ms (L2987)	Lecture	2	3
Machine Learning for Physical Syste	ms (L2988)	Project-/problem-based Learning	2	3
Module Responsible	Prof. Christian Cyron			
Admission Requirements	None			
Recommended Previous				
Knowledge				
Educational Objectives	After taking part successfully, students have reached the	following learning results		
Professional Competence				
Knowledge				
Skills				
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56			
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	60 min			
scale				
Assignment for the	General Engineering Science (German program, 7 semest	er): Specialisation Advanced Materials:	Compulsory	
Following Curricula	Data Science: Specialisation IV. Special Focus Area: Electiv	ve Compulsory		
	Data Science: Specialisation III. Applications: Elective Com	pulsory		
	Engineering Science: Specialisation Advanced Materials: C	ompulsory		
	Engineering Science: Specialisation Advanced Materials: E	lective Compulsory		
	Mechatronics: Specialisation Dynamic Systems and AI: Ele	ctive Compulsory		
	Mechatronics: Specialisation Robot- and Machine-Systems	: Elective Compulsory		

Course L2987: Machine Learning for Physical Systems		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	NN	
Language	EN	
Cycle	WiSe/SoSe	
Content		
Literature		

Course L2988: Machine Learning for Physical Systems		
Тур	Project-/problem-based Learning	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	NN	
Language	EN	
Cycle	WiSe/SoSe	
Content		
Literature		

Module M1249: Medica	al Imaging			
Courses				
Courses		True		CP.
Medical Imaging (L1694)		I yp	Hrs/WK	3
Medical Imaging (L1695)		Recitation Section (small)	2	3
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Basic knowledge in linear algebra, numerics, and sigr	al processing		
Knowledge				
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowledge	After successful completion of the module, students a	re able to describe reconstruction metho	ds for different f	omographic imaging
	modalities such as computed tomography and mag	netic resonance imaging. They know the	necessary basi	cs from the fields o
2	signal processing and inverse problems and are familiar with both analytical and iterative image reconstruction methods. The			
2	students have a deepened knowledge of the imaging	operators of computed tomography and	magnetic resona	ance imaging.
Skills	The students are able to implement reconstruction	methods and test them using tomogr	anhic measuren	ent data. They car
Skins	visualize the reconstructed images and evaluate the	e quality of their data and results. In	addition studen	ts can estimate the
1	temporal complexity of imaging algorithms	e quality of their data and results. In	addition, studen	to can estimate the
Personal Competence				
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their			
i	individual strengths to solve the problem.			
Autonomy	Students are able to independently investigate a com	plex problem and assess which compete	ncies are require	ed to solve it.
-				
Workload in Hours	Independent Study Time 124, Study Time in Lecture	56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation II: Intelligence Engli	neering: Elective Compulsory		
Following Curricula	Data Science: Specialisation III. Applications: Elective			
	Data science. Specialisation IV. Special FOCUS Area: E			
	Computer Science in Engineering: Specialisation Medical Technol	muter Science: Elective Compulsory		
	Interdisciplinary Mathematics: Specialisation Comput-	ational Methods in Biomedical Imaging: C	ompulsony	
	Microelectronics and Microsystems: Specialisation Computer	mmunication and Signal Processing, Eloc	tive Compulsory	
-	Technomathematics: Specialisation II Informatics: Fle	ective Compulsory	ave compuisory	
	recurrent action opecialisation in informatics. Ele	care compulsory		

Course L1694: Medical Imagi	ng
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	 Overview about different imaging methods Signal processing Inverse problems Computed tomography Magnetic resonance imaging Compressed Sensing Magnetic particle imaging
Literature	Bildgebende Verfahren in der Medizin; O. Dössel; Springer, Berlin, 2000 Bildgebende Systeme für die medizinische Diagnostik; H. Morneburg (Hrsg.); Publicis MCD, München, 1995 Introduction to the Mathematics of Medical Imaging; C. L.Epstein; Siam, Philadelphia, 2008 Medical Image Processing, Reconstruction and Restoration; J. Jan; Taylor and Francis, Boca Raton, 2006 Principles of Magnetic Resonance Imaging; ZP. Liang and P. C. Lauterbur; IEEE Press, New York, 1999

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Course L1695: Medical Imaging		
Тур	Recitation Section (small)	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Tobias Knopp	
Language	DE/EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1302: Appli	ed Humanoid Robotics			
Courses				
Title		Тур	Hrs/wk	СР
Applied Humanoid Robotics (L1794)	Project-/problem-based Learning	6	6
Module Responsible	Patrick Göttsch			
Admission Requirements	None			
Recommended Previous	 Object oriented programming; algorithms and data 	a structures		
Knowledge	Introduction to control systems			
	 Control systems theory and design 			
	Mechanics			
Educational Objectives	After taking part successfully, students have reached the	e following learning results		
Professional Competence				
Knowledge	 Students can explain humanoid rebets 			
	 Students can explain humanoid robots. Students can explain the basic concepts relations 	hips and methods of forward- and invers	e kinematics	
	 Students learn to apply basic control concepts for 	different tasks in humanoid robotics.		
Skills	 Students can implement models for humanoid rob 	otic systems in Matlab and C++, and us	e these model	s for robot motion or
	other tasks.			
	 They are capable of using models in Matlab for sir 	nulation and testing these models if nec	essary with C	++ code on the real
	robot system.			
	• They are capable of selecting methods for solving abstract problems, for which no standard methods are available, and			
	apply it successfully.			
Personal Competence				
Social Competence				
	 Students can develop joint solutions in mixed team They can provide appropriate feedback to others 	ns and present these.	their own recu	lte
	 They can provide appropriate reedback to others, 	and constructively handle reedback on	lneir own resu	ILS
Autonomy	Students are able to obtain required information	from provided literature courses and	to put in inte	the context of the
	lecture	i nom provided interature sources, and	to put in inte	the context of the
	 They can independently define tasks and apply the 	e appropriate means to solve them.		
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84			
Course achievement	None			
Examination	Written elaboration			
Examination duration and	5-10 pages			
scale				
Assignment for the	Computer Science: Specialisation II: Intelligence Enginee	ring: Elective Compulsory		
Following Curricula	Data Science: Specialisation III. Applications: Elective Con	mpulsory		
	Data Science: Specialisation IV. Special Focus Area: Elect	tive Compulsory		
	Electrical Engineering: Specialisation Control and Power	Systems Engineering: Elective Compulso	ry	
	Mechatronics: Core Qualification: Elective Compulsory			
	Theoretical Mechanical Engineering: Specialisation Bio- a	nd Medical Technology: Elective Compu	sory	
	medieucal Mechanical Engineering: Specialisation Robot	lics and computer science: Elective Com	ipuisory	

Course L1794: Applied Humanoid Robotics				
Тур	ject-/problem-based Learning			
Hrs/wk	6			
СР	6			
Workload in Hours	dependent Study Time 96, Study Time in Lecture 84			
Lecturer	Patrick Göttsch			
Language	DE/EN			
Cycle	viSe/SoSe			
Content	 Fundamentals of kinematics Static and dynamic stability of humanoid robotic systems Combination of different software environments (Matlab, C++, etc.) Introduction to the necessary software frameworks Team project Presentation and Demonstration of intermediate and final results 			
Literature	B. Siciliano, O. Khatib. "Handbook of Robotics. Part A: Robotics Foundations", Springer (2008)			

Module M1668: Proba	ability Theory			
Courses				
Title Probability Theory (L2643) Probability Theory (L2644)		Typ Lecture Becitation Section (small)	Hrs/wk 3	CP 4
Module Besnonsible	Prof Matthias Schulte		-	-
Admission Requirements	None			
Recommended Previous	Familiarity with the basic concepts of probability			
Knowledge				
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence Knowledge	 Students can name the basic concepts in probability theory. They are able to explain them using appropriate examples. Students can discuss logical connections between these concepts. They are capable of illustrating these connections with the help of examples. They know proof strategies and can reproduce them. 			
Skills	 Students can model problems from probability theory with the help of the concepts studied in this course. Moreover, they are capable of solving them by applying established methods. Students are able to explore and verify further logical connections between the concepts studied in the course. For a given problem, the students can develop and execute a suitable technique, and are able to critically evaluate the results. 			
Personal Competence				
Social Competence	 Students are able to work together (e.g. on their regular home work) and to present their results appropriately (e.g. during exercise class). In doing so, they can communicate new concepts according to the needs of their cooperating partners. Moreover, they can design examples to check and deepen the understanding of their peers. 			
Autonomy	 Students are capable of checking their unders precisely and know where to get help in solving Students can put their knowledge in relation to Students have developed sufficient persistence problems. 	tanding of complex concepts on their o them. the contents of other lectures. e to be able to work for longer period	wn. They can sp s in a goal-orien	ecify open questions ted manner on harc
Workload in Hours	Independent Study Time 124, Study Time in Lecture 5	66		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and scale	I 30 min			
Assignment for the	Computer Science: Specialisation III. Mathematics: Ele	ective Compulsory		
Following Curricula	Data Science: Specialisation IV. Special Focus Area: E	ective Compulsory		
	Data Science: Specialisation I. Mathematics: Elective	Compulsory		
	Interdisciplinary Mathematics: Specialisation II. Nume	rical - Modelling Training: Compulsory		
	Leconomathematics: Specialisation I. Mathematics: El	ective Compulsory		

Course L2643: Probability Theory				
Тур	ecture			
Hrs/wk				
CP	4			
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42			
Lecturer	Prof. Matthias Schulte			
Language	EN			
Cycle	SoSe			
Content	 Measure and probability spaces Integration and expectation Types of stochastic convergence Law of large numbers Central limit theorem Radon-Nikodym theorem Conditional expectation Martingales Markov chains Poisson processes 			
Literature	 H. Bauer, Probability theory and elements of measure theory, second edition, Academic Press, 1981. A. Klenke, Probability Theory: A Comprehensive Course, second edition, Springer, 2014. G. F. Lawler, Introduction to Stochastic Processes, second edition, Chapman & Hall/CRC, 2006. A. N. Shiryaev, Probability, second edition, Springer, 1996. 			

Course L2644: Probability Theory		
Тур	Recitation Section (small)	
Hrs/wk	1	
CP	2	
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14	
Lecturer	Prof. Matthias Schulte	
Language	EN	
Cycle	SoSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M13	301: Software Testing		
Courses			
Title	Tvp Hrs/wk CP		
Software Testing (I	(L1791) Lecture 2 3		
Software Testing (I	(L1792) Project-/problem-based Learning 2 3		
Module	Prof. Sibylle Schupp		
Responsible			
Admission	None		
Requirements	; 		
Recommended	Software Engineering		
Previous	Higher Programming Languages		
Knowledge	Object-Oriented Programming		
	Algorithms and Data Structures		
	Experience with (Small) Software Projects		
	Statistics		
Educational	I After taking part successfully, students have reached the following learning results		
Objectives			
Professional	()		
Competence			
Knowledge	Students syntain the different phases of testing describe fundemental		
	students explain the different phases of testing, describe fundamental		
	nrinciples of the corresponding test process. They give examples of		
	software development scenarios and the corresponding test type and		
	technique. They explain algorithms used for particular testing		
	techniques and describe possible advantages and limitations.		
Skills	; Students identify the appropriate testing type and technique for a given		
	problem. They adapt and execute respective algorithms to execute a		
	concrete test technique properly. They interpret testing results and		
	execute corresponding steps for proper re-test scenarios. They write and		
	analyze test specifications. They apply bug finding techniques for		
	non-trivial problems.		
Personal			
Competence			
Social	/ Students discuss relevant topics in class. They defend their solutions orally.		
Competence	They communicate in English.		
Autonomu	Chudanta ann annan bhair leucl af braudadra anntinuauch and adiuct it annranúctalu, basad an faedhach and an adf guided studios. Within limite, tha		
Autonomy	own learning goals. Then revel of knowledge continuously and adjust it appropriately, based on reedback and on self-guided studies, within limits, they own learning goals. Then successful completion, students can identify and precisely formulate new problems in academic or applied research in the first students.		
	testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic report		
	devise plans to arrive at new solutions or assess existing ones		
Workload in	r Independent Study Time 124, Study Time in Lecture 56		
Hours	, 		
Credit points	i 6		
Course	r None		
Examination	Subject theoretical and practical work		
Examination	Software		
duration and			
scale			
Assignment	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory		
for the	Data Science: Specialisation II. Computer Science: Elective Compulsory		
Following	J Data Science: Specialisation IV. Special Focus Area: Elective Compulsory		
Curricula	Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory		
	Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsor		

Course L1791: Software Testing			
Тур	ture		
Hrs/wk	2		
CP	3		
Workload in Hours	ndependent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sibylle Schupp		
Language	EN		
Cycle	SoSe		
Content	 Fundamentals of software testing Model-based testing Test automation Criteria-based testing 		
Literature	 M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008. P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2016. A. Zeller: "Why Programs Fail: A Guide to Systematic Debugging", 2nd edition 2012. 		

Course L1792: Software Testing			
Тур	oject-/problem-based Learning		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sibylle Schupp		
Language	EN		
Cycle	SoSe		
Content	 Fundamentals of software testing Model-based testing Test automation Criteria-based testing 		
Literature	 M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008. P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2015. 		

iven Innovat	on			
		Тур	Hrs/wk	СР
5)		Lecture	3	3
5)		Project-/problem-based Learning	2	3
of. Moritz Göldner				
one				
ter taking part succ	essfully, students hav	ve reached the following learning results		
dependent Study Ti	me 110, Study Time i	n Lecture 70		
mpulsory Bonus	Form	Description		
s 20 %	Excercises	Erfolgreiche Teilnahme PBL-Übung		
ritten exam				
min				
Data Science: Specialisation III. Applications: Elective Compulsory				
Data Science: Specialisation IV. Special Focus Area: Elective Compulsory				
obal Technology an	d Innovation Manager	ment & Entrepreneurship: Core Qualification: Elective	Compulsory	
ernational Manager	nent and Engineering	: Specialisation II. Information Technology: Elective C	ompulsory	
	i) if. Moritz Göldner ne er taking part succo er taking part succo iependent Study Tir npulsory Bonus is 20 % itten exam min ta Science: Speciali ta Science: Speciali ubal Technology an ernational Manager	i) if. Moritz Göldner ne er taking part successfully, students hav ependent Study Time 110, Study Time i npulsory Bonus Form is 20 % Excercises itten exam min ta Science: Specialisation III. Application ta Science: Specialisation IV. Special Foo ibal Technology and Innovation Manage ernational Management and Engineering	Typ Lecture Project-/problem-based Learning if. Moritz Göldner ne Image: Comparison of the team of the team of te	Typ Hrs/wk Lecture 3 Project-/problem-based Learning 2 Af. Moritz Göldner - ne - er taking part successfully, students have reached the following learning results -

Course L3114: Data-Driven Innovation			
Тур	Lecture		
Hrs/wk	3		
CP	3		
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42		
Lecturer	Prof. Moritz Göldner		
Language	EN		
Cycle	SoSe		
Content	This course aims to combine the principles of design thinking with data science, focusing on all steps of the design thinking process from understanding the problem, investigating user's needs and integrating these needs into the development and testing in a data-driven manner. Students will learn several methods to accelerate the innovation process (such as generative AI and modern market research platforms) as well as more general data science methodologies to streamline the innovation process. Established and modern, data-driven methods will be compared and critically evaluated, including ethical and privacy-related considerations. Through a series of lectures, hands-on exercises, and project presentations, students will not only develop a robust theoretical understanding of these topics, but will also gain practical experience applying these concepts in realistic innovation scenarios.		
Literature	Luo, J. (2023). Data-driven innovation: What is it?. IEEE Transactions on Engineering Management, 70(2), 784-790. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9707478		

Course L3115: Data-Driven Innovation Seminar			
Тур	Project-/problem-based Learning		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Moritz Göldner		
Language	EN		
Cycle	SoSe		
Content			
Literature			

Module M1842: GPU /	Architectures and Programming			
Courses				
Title		Тур	Hrs/wk	СР
GPU Architectures and Programmir	ng (L3039)	Lecture	2	3
GPU Architectures and Programmir	ng (L3040)	Project-/problem-based Learnir	ig 4	3
Module Responsible	Prof. Sohan Lal			
Admission Requirements	None			
Recommended Previous	An introductory module on computer engineeri	ng or computer architecture, and good program	nming skills in C	C/C++.
Knowledge				
Educational Objectives	After taking part successfully, students have re	ached the following learning results		
Professional Competence				
Knowledge				
Skills				
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 96, Study Time in Lect	ure 84		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer a	nd Software Engineering: Elective Compulsory		
Following Curricula	Data Science: Specialisation II. Computer Scien	ce: Elective Compulsory		
	Data Science: Specialisation IV. Special Focus A	rea: Elective Compulsory		
	Information and Communication Systems: S	pecialisation Secure and Dependable IT Sy	stems, Focus	Software and Signa
	Processing: Elective Compulsory			
	Microelectronics and Microsystems: Specialisati	on Embedded Systems: Elective Compulsory		
Course L3039: GPU Architect	tures and Programming			
Тур	Lecture			

Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	SoSe
Content	- Review of computer architecture basics - measuring performance, benchmarks, five-stage RISC pipeline, caches
	- GPU basics - evolution of GPU computing, a high-level overview of a GPU architecture
	- GPU programming with CUDA - program structure, CUDA threads organization, warp/thread-block scheduling
	- GPU (micro) architecture - streaming multiprocessors, single instruction multiple threads (SIMT) core design, tensor/RT cores,
	mixed-precision support
	- GPU memory hierarchy - banked register file and operand collectors, shared memory, GPU caches (differences w.r.t. CPU caches),
	global memory
	- Branch and memory divergence - branch handling, stack-based reconvergence, memory coalescing, coalescer design
	- Barriers and synchronization
	- Temporal and spatial locality exploitation challenges in GPU caches
	- Global memory- high throughput requirements, GDDR/HBM, memory bandwidth optimization techniques
	- GPU research issues - performance bottlenecks, GPU power modeling, high-power consumption/energy efficiency, GPU security
	- Application case study - deep learning
	- Cycle-accurate simulators for GPUs
	The learning in the lectures will be augmented by a semester-long problem-based project.
Literature	 David B. Kirk, Wen-mei W. Hwu, Programming Massively Parallel Processors - A Hands-on Approach, Second Edition (Book) David A. Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, 5th Edition (Book)

Course L3040: GPU Architect	Course L3040: GPU Architectures and Programming				
Тур	Project-/problem-based Learning				
Hrs/wk	4				
CP	3				
Workload in Hours	Independent Study Time 34, Study Time in Lecture 56				
Lecturer	Prof. Sohan Lal				
Language	EN				
Cycle	SoSe				
Content	A semester-long problem-based project will augment the learning in the lectures. Several topics related to GPUs will be proposed. You are required to choose a topic and work on it. It is possible to work in groups. There will be (bi-) weekly meetings to discuss progress and problems. In addition to the semester-long project, there will be assignments to teach CUDA programming.				
Literature	 David B. Kirk, Wen-mei W. Hwu, Programming Massively Parallel Processors - A Hands-on Approach, Second Edition (Book) David A. Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, 5th Edition (Book) 				

ed Cryp	tograp	hy				
				Тур	Hrs/wk	СР
				Lecture	3	4
				Recitation Section (small)	1	2
Prof. Sibyll	e Fröschle	2				
None						
After takin	g part suc	cessfully, students	have reached the follow	ving learning results		
Independe	nt Study 1	Гіте 124, Study Ti	me in Lecture 56			
6						
Compulsory	Bonus	Form	Description			
No	10 %	Excercises	Die Übungs	aufgaben finden semesterbeg	leitend statt	
Written ex	am					
120 min						
Computer	Science: S	Specialisation I. Co	mputer and Software En	gineering: Elective Compulsor	у	
Data Scien	ce: Specia	alisation II. Comput	er Science: Elective Con	npulsory		
Data Scien	ce: Specia	alisation IV. Specia	Focus Area: Elective Co	ompulsory		
Information	n and Con	nmunication System	ms: Specialisation Comm	nunication Systems, Focus Sof	tware: Elective Co	ompulsory
Informatio	n and Con	nmunication System	ms: Specialisation Secur	e and Dependable IT Systems	Focus Networks:	Elective Compulsory
	Prof. Sibyll None After takin After takin Independe 6 Compulsory No Written ex 120 min Computer Data Scien Informatio Informatio	Prof. Sibylle Fröschle None After taking part suc After taking part suc Independent Study 1 6 Computsory Bonus No 10 % Written exam 120 min Computer Science: Specia Data Science: Specia Information and Con Information and Con	Prof. Sibylle Fröschle None After taking part successfully, students Independent Study Time 124, Study Tim G Computsory Bonus Form No 10 % Excercises Written exam 120 min Computer Science: Specialisation I. Corp Data Science: Specialisation II. Comput Data Science: Specialisation IV. Special Information and Communication Syster Information II. Compute III. III. III. III. III. III. III. III	Prof. Sibylle Fröschle None After taking part successfully, students have reached the follow Independent Study Time 124, Study Time in Lecture 56 6 Compulsory Bonus Form Description No 10 % Excercises Die Übungs Written exam 120 min Computer Science: Specialisation I. Computer and Software En Data Science: Specialisation II. Computer Science: Elective Cor Data Science: Specialisation IV. Special Focus Area: Elective Cor Information and Communication Systems: Specialisation Communication Systems: Specialisation Security	ed Cryptography Typ Lecture Recitation Section (small) Prof. Sibylle Fröschle None After taking part successfully, students have reached the following learning results Independent Study Time 124, Study Time in Lecture 56 6 Computory Bonus Form Description No 10 % Excercises Die Übungsaufgaben finden semesterbeg Written exam 120 min Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsor Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems	Typ Hrs/wk Lecture 3 Recitation Section (small) 1 Prof. Sibylle Fröschle 1 None

Course L2954: Applied Crypt	ography
Тур	Lecture
Hrs/wk	3
СР	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Sibylle Fröschle
Language	EN
Cycle	SoSe
Content	This module provides a comprehensive knowledge in modern cryptography and how it plays a key role in securing the digital world we live in today. We will thoroughly treat cryptographic primitives such as symmetric and asymmetric encryption schemes, cryptographic hash functions, message authentication codes, and digital signatures. Moreover, we will cover aspects of practical deployment such as key management, public key infrastructures, and secure storage of keys. We will see how everything comes together in applications such as the ubiquitous security protocols of the Internet (e.g. TLS and WPA3) and/or the Internet-of-things. We also discuss current challenges such as the need for post-quantum cryptography.
Literature	Introduction to Modern Cryptography, Third Edition, Jonathan Katz and Jehuda Lindell, Chapman & Hall/CRC, 2021 Sicherheit und Kryptographie im Internet, 5th Edition, Jörg Schwenk, Springer-Verlag, 2020

Course L2955: Applied Cryptography		
Тур	Recitation Section (small)	
Hrs/wk	1	
СР	2	
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14	
Lecturer	Prof. Sibylle Fröschle	
Language	EN	
Cycle	SoSe	
Content	See corresponding lecture	
Literature	Siehe korrespondierende Vorlesung	

Module M1810: Autor	nomous Cyber-Physical System	s		
Module Mibio. Autor	iomous cyser-r nysicar system.	3		
Courses				
Title		Тур	Hrs/wk	СР
Autonomous Cyber-Physical Syster	ns (L3000)	Lecture	2	3
Autonomous Cyber-Physical Syster	ns (L3001)	Recitation Section (small)	2	3
Module Responsible	Prof. Bernd-Christian Renner			
Admission Requirements	None			
Recommended Previous	Very good knowledge and practical	experience in programming in the $C/C+4$	- language (e.g	module: Procedura
Knowledge	Programming for Computer Scientists)	experience in programming in the even	language (e.g.,	module. Procedulu
	Basic knowledge in software engineeri	ng		
	Basic knowledge in wired and wireless	communication protocols		
	 Principal understanding of simple elect 	tronic circuits		
Educational Objectives	After taking part successfully, students have	reached the following learning results		
Professional Competence				
Knowledge	Cyber-Physical Systems form the basis for	many modern control tasks in automation	and for method	ls for monitoring the
	environment, infrastructure, etc. Essential as	spects in the implementation of such systems	are their network	king, especially based
	on wireless technologies, and their auton	omous operation, especially on the basis o	of regenerative e	energy sources. After
	successfully attending this event, the student	ts are able to		
	 to present the special features of cybe 	r-physical systems and the associated challen	ges and concepts,	
	describe and evaluate wired and wirele	ess communication on different layers of the IS	SO/OSI model,	
	explain and compare methods of reger	nerative energy production,		
	 discuss and evaluate procedures for the 	e autonomous and self-sufficient operation of	such systems.	
Skills	Students will be able to			
	 to implement programs for cyber physical 	ical systems in high lovel languages and using	ovicting librarios	
	 to implement programs for cyber-physic to assess which communication and n 	etworking protocols can be used most sensib	ly in which applic:	, ation and to use them
	in real scenarios	etworking protocols can be used most sensib	y in which applied	
	 select and implement suitable method 	ds for adapting the tasks based on the energy	v consumption an	d the future expected
	energy yield,			
	 plan and evaluate scientific experiment 	ts.		
Personal Competence				
Social Competence	After completing the module, the students a	are able to work on similar tasks alone or in	a group and to pr	esent the results in a
	suitable way.			
Autonomy	After completing the module, the students an	e able to independently work on sub-areas of	the subject using s	specialist literature, to
	summarize and present the knowledge they h	nave acquired and to link it to the content of o	ther courses.	
Workload in Hours	Independent Study Time 124, Study Time in I	actura E6		
Credit neinte		Lecture 50		
Credit points	0 Compulsory Bonus Form	Description		
Course achievement	No 10 % Attestation	Description		
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer	r and Software Engineering: Elective Compulso	ory	
Following Curricula	Data Science: Specialisation II. Computer Scie	ence: Elective Compulsory	,	
2	Data Science: Specialisation IV. Special Focus	Area: Elective Compulsory		
	Electrical Engineering: Specialisation Wireless	s and Sensor Technologies: Elective Compulso	ry	
	Computer Science in Engineering: Specialisat	ion II. Engineering Science: Elective Compulso	ry	
	Information and Communication Systems:	Specialisation Secure and Dependable IT	Systems, Focus	Software and Signa
	Processing: Elective Compulsory			
	Mechatronics: Core Qualification: Elective Con	mpulsory		

Course L3000: Autonomous Cyber-Physical Systems		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Bernd-Christian Renner	
Language	EN	
Cycle	SoSe	
Content		
Literature		

Course L3001: Autonomous Cyber-Physical Systems			
Тур	Recitation Section (small)		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Bernd-Christian Renner		
Language	EN		
Cycle	SoSe		
Content	See interlocking course		
Literature	See interlocking course		

Module M1773: Cyber	rsecurity Data S	Science				
Courses						
Title				Тур	Hrs/wk	СР
Cybersecurity Data Science (L2914	.)			Lecture	2	3
Exercise Cybersecurity Data Science	ce (L2915)			Project-/problem-based Learning	2	3
Module Responsible	Prof. Riccardo Scanda	riato				
Admission Requirements	None					
Recommended Previous	Basic knowledge of pr	robabilities and statis	tics. Familiarity with	object oriented programming.		
Knowledge						
Educational Objectives	After taking part succ	essfully, students hav	ve reached the follow	ving learning results		
Professional Competence						
Knowledge	Students can:					
	Apply data scie	ence methods to the r	esolution of complex	cybersecurity problems.		
	Use of data sci	ence methods to qua	ntity risks and optimi			
	Identify strengt	Identify strengths and limitations of state-of-the-art methods				
	 Select the perf 	 Select the performance indicators of data-oriented cybersecurity solutions. 				
	 Understand cyl 	bersecurity threats in	data science metho	ds.		
Skills	Implement and evaluation	ate data-driven mode	Is for the identification	on, treatment, and mitigation of c	ybersecurity r	isks
Personal Competence						
Social Competence	None					
Autonomy	Students can apply the knowledge acquired throughout the course to the resolution of industrial case studies. Students should also					
-	be capable to acquire	new knowledge inde	pendently from acad	emic publications, techical stand	ards, and whit	e papers.
		-				
Workload in Hours	Independent Study Ti	me 124, Study Time i	n Lecture 56			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description			
	No 5 %	Subject theoretic	al andGruppenarb	eit mit aktuellen Technologien au	is dem Bereich	n Sicherheit
		practical work				
Examination	Written exam					
Examination duration and	120 min					
scale						
Assignment for the	Computer Science: Sp	pecialisation I. Compu	ter and Software Eng	gineering: Elective Compulsory		
Following Curricula	Data Science: Special	isation II. Computer S	cience: Elective Com	npulsory		
	Data Science: Special	isation IV. Special Foo	cus Area: Elective Co	mpulsory		
	Information and Com	munication Systems:	Specialisation Secure	e and Dependable IT Systems: Ele	ctive Compuls	sory

Course L2914: Cybersecurity	Data Science
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations:
	Introduction to data science
	Supervised and unsupervised learning
	 Data science methods (e.g., clustering, decision trees, artificial neural networks)
	Performance metrics
	Colores subsite Ann Banking
	Cybersecutrity Applications:
	Spam detection
	Phishing detection
	Intrusion detection
	Access-control prediction
	Denial of Service (DoS) prediction
	Vulnerability/malware prediction
	Adversarial machine learning
Literature	[1] Sarker, I.H., Kayes, A.S.M., Badsha, S., Alqahtani, H., Watters, P. and Ng, A., 2020. Cybersecurity data science: an overview
	from machine learning perspective. Journal of Big data, 7(1), pp.1-29.
	[2] Trung T.C. Zelinka I. Divers I. Čandik M. and Čula V. 2020. Artificial intelligence and subgrassivity. Dash pressure and
	[2] Huong, H.G., Zemina, L., Fucar, J., Canuix, M. and Suic, V., 2020. Atticida intergence and cybersecurity: rast, presence, and future in Artificial intergence and evolutionary computations in analyzation systems (no. 251-262). Springer, Singapore
	ratare. In Arancia intelligence and evolutionary computations in engineering systems (pp. 552-565), springer, singupore.
	[3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press.
	[4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of
	Machine Learning in Computer Security.
	[5] Torres I.M. Comesaña, C.L. and Garcia-Nieto, PL, 2019, Machine learning techniques applied to cybersecurity. International
	Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836.
	[6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

Course L2915: Exercise Cybe	rsecurity Data Science
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations:
	Introduction to data science
	Supervised and unsupervised learning
	 Data science methods (e.g., clustering, decision trees, artificial neural networks)
	Performance metrics
	Cubareacutrity Applications
	Cybersecutity Applications.
	Spam detection
	Phishing detection
	Intrusion detection
	Access-control prediction
	Denial of Service (DoS) prediction
	Vulnerability/malware prediction
	Adversarial machine learning
Literature	[1] Sarker, I.H., Kayes, A.S.M., Badsha, S., Alqahtani, H., Watters, P. and Ng, A., 2020. Cybersecurity data science: an overview
	from machine learning perspective. Journal of Big data, 7(1), pp.1-29.
	Contractor T.C. Zelizika I. Diverse I. Condition M. and Cula V. 2020. Artificial intelligence and subsense with Dark assesses and
	[2] Huong, H.G., Zemika, H., Huda, J., Galuk, M. and Sulc, V. 2020. Atticida integrated and cybersecurity. Fast, presence, and fature in Artificial Intelligence and evolutionary computations in analyzation cytome (no. 251 262). Springer, Singapore
	ratare. In Arancial meingence and evolutionary compatations in engineering systems (pp. 551-565), springer, singapore.
	[3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press.
	[4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of
	Machine Learning in Computer Security.
	[5] Torres I.M. Comesaña, C.L. and Garcia-Nieto, PL 2019, Machine learning techniques applied to cybersecurity. International
	Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836.
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	[6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

Module M0924: Softw	vare for Embedded Systems				
Courses					
Title		Тур	Hrs/wk	СР	
Software for Embdedded Systems ((L1069)	Lecture	2	3	
Software for Embdedded Systems (edded Systems (L1070) Recitation Section (small) 3 3				
Module Responsible	Prof. Bernd-Christian Renner				
Admission Requirements	None				
Recommended Previous	 Very Good knowledge and practical exper 	ience in programming in the C language and	its compilation p	rocess	
Knowledge	Basic knowledge in software engineering				
	 Basic understanding of assembly languag 	e			
	Basic knowledge of electrical engineering				
Educational Objectives	After taking part successfully, students have rea	ched the following learning results			
Professional Competence		5 5			
Knowledge					
	Students know the basic principles and pr	ocedures of software engineering for embed	ded systems.		
	 They are able to describe the usage and a They know the components and functions 	of a concrete microcontroller	ig interrupts.		
	 The participants explain requirements of r 	real time systems.			
	• They know at least three scheduling algor	ithms for real time operating systems includi	ng their pros and	cons.	
Chille-					
Skills	Students design and write hardware-o	priented software modules for an embe	dded system b	ased on a specific	
	microcontroller.				
	They learn to interact with peripherals (tir	mer, ADC, EEPROM), including interrupt-base	d processing and	program flow.	
	They build and use a (preemptive) schedu	ller for an embedded system.			
	 They learn to write independent, reusable 	software components.			
Personal Competence					
Social Competence	 Students are able to work goal-oriented in small mixed groups 				
	Students are able to work goal-oriented in small mixed groups. They learn and broaden their teamwork abilities				
	They learn to define and split tasks within	the team.			
A. (Chudanta ang alda				
Autonomy	Students are able				
	 to solve assignments related to this lecture 	re independently with instructional direction.			
	 to design, implement, and test software 	re components for an embedded system	independently	based on a textual	
	description.	······	·		
	 to read and understand data sheets and n 	nanuals of electronic components (such as m	icro-controllers a	na sensors)	
Workload in Hours	Independent Study Time 110, Study Time in Lect	ture 70			
Credit points	6				
Course achievement	Compulsory Bonus Form	Description			
Fuendantien	No 10% Attestation				
Examination Examination duration and					
scale					
Assignment for the	Computer Science: Specialisation I. Computer an	nd Software Engineering: Elective Compulsory	/		
Following Curricula	Data Science: Specialisation II. Computer Science	e: Elective Compulsory			
	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory				
	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory				
	Mechatronics: Core Qualification: Elective Compo	ulsory			
	Microelectronics and Microsystems: Specialisatio	n Embedded Systems: Elective Compulsory			
	Theoretical Mechanical Engineering: Specialisation	on Robotics and Computer Science: Elective	Compulsory		
	Theoretical Mechanical Engineering: Specialisation	on Robotics and Computer Science: Elective	Compulsory		

Course L1069: Software for I	Embdedded Systems
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	DE/EN
Cycle	SoSe
Content	 General-Purpose Processors Programming the Atmel AVR Interrupts C for Embedded Systems Standard Single Purpose Processors: Peripherals Finite-State Machines Memory Operating Systems for Embedded Systems Real-Time Embedded Systems Boot loader and Power Management
Literature	 Embedded System Design, F. Vahid and T. Givargis, John Wiley Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP The Art of Designing Embedded Systems, J. Ganssle, Newnses Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

Course L1070: Software for Embdedded Systems		
Тур	Recitation Section (small)	
Hrs/wk	3	
CP	3	
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42	
Lecturer	Prof. Bernd-Christian Renner	
Language	DE/EN	
Cycle	SoSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1682: Secur	e Software Eng	jineering				
Courses						
Title				Тур	Hrs/wk	СР
Secure Software Engineering (L266	57)			Lecture	2	3
Secure Software Engineering (L266	68)			Project-/problem-based Learning	2	3
Module Responsible	Prof. Riccardo Scanda	riato				
Admission Requirements	None					
Recommended Previous	Familiarity with basic	software engineering cor	ncepts (e.g., requir	ements, design) and basic secu	rity concepts	(e.g., confidentiality,
Knowledge	integrity, availability)					
Educational Objectives	After taking part succ	essfully, students have re	eached the followir	ig learning results		
Professional Competence						
Knowledge	Students can:					
	 Elicit cocurity r 	oquiromonto in a coftwar	o project			
	Elicit Security I Model and deci	umont socurity mossures	in a software desi	an		
	Iso throat and	Model and document security measures in a software design				
	Understand here	Use threat and risk analysis techniques				
	Understand the	Understand how security code reviews are performed				
	Understand the	Understand the core definitions of concepts related to privacy				
	 Onderstand pri 	Understand privacy enhancing technologies				
Skills	Select appropriate se	Select appropriate security assurance techniques to be used in a security assurance program				
Personal Competence						
Social Competence	None					
Autonomy	Students can apply th	e knowledge acquired th	roughout the cours	e to the resolution of industrial	case studies.	Students should also
	be capable to acquire	new knowledge indepen	dently from acade	mic publications, techical standa	ards, and white	e papers.
Workload in Hours	Independent Study Ti	me 124, Study Time in Le	ecture 56			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description	t with a later a line ∓a also a la si an an	- dawa Dawai da	Ciele e de cit
	NO 5%	Subject theoretical	andGruppenarbei	t mit aktuellen Technologien au	s dem Bereicr	Sicherneit
E		practical work				
Examination	written exam					
Examination duration and	120 min					
scale	Computer Colones - Co					
Assignment for the	Computer Science: Sp	insting II. Computer	and Software Engli	eering: Elective Compulsory		
Following Curricula	Data Science: Special	isation II. Computer Scier	ice: Elective Comp	uisory		
	Data Science: Special	isation IV. Special Focus	Area: Elective Com	pulsory	e Flassi - F	
	Information and Com	munication Systems: Spe	cialisation Commu	nication Systems, Focus Softwar	e: Elective Co	mpulsory
	Information and Cor	nmunication Systems: S	specialisation Sec	ure and Dependable IT Syste	ems, Focus S	ottware and Signal
	Processing: Elective C	compulsory				

Course L2667: Secure Softwa	are Engineering
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	 Secure software development processes and maturity models Techniques to define security requirements Techniques to create, document and analyse the design of secure applications Threat and risk analysis techniques Security code reviews Program repair techniques for security vulnerabilities Privacy engineering
Literature	Sindre, G. and Opdahl, A.L., 2005. Eliciting security requirements with misuse cases. Requirements engineering, 10(1), pp.34-44.
	Fontaine, P.J., Van Lamsweerde, A., Letier, E. and Darimont, R., 2001. Goal-oriented elaboration of security requirements.
	Mead, N.R. and Stehney, T., 2005. Security quality requirements engineering (SQUARE) methodology. ACM SIGSOFT Software Engineering Notes, 30(4), pp.1-7.
	Mirakhorli, M., Shin, Y., Cleland-Huang, J. and Cinar, M., 2012, June. A tactic-centric approach for automating traceability of quality concerns. In 2012 34th international conference on software engineering (ICSE) (pp. 639-649). IEEE.
	Jürjens, J., UMLsec: Extending UML for secure systems development, International Conference on The Unified Modeling Language, 2002
	Lund, M.S., Solhaug, B. and Stølen, K., 2011. A guided tour of the CORAS method. In Model-Driven Risk Analysis (pp. 23-43). Springer, Berlin, Heidelberg.
	Howard, M.A., 2006. A process for performing security code reviews. IEEE Security & privacy, 4(4), pp.74-79
	Diaz, C. and Gürses, S., 2012. Understanding the landscape of privacy technologies. Proceedings of the information security summit, 12, pp.58-63.

Course L2668: Secure Software Engineering			
Тур	Project-/problem-based Learning		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Riccardo Scandariato		
Language	EN		
Cycle	SoSe		
Content	 Secure software development processes and maturity models Techniques to define security requirements Techniques to create, document and analyse the design of secure applications Threat and risk analysis techniques Security code reviews Program repair techniques for security vulnerabilities Privacy engineering 		
Literature	Lecture notes as well as current literature announced in the lecture.		

Module M0630: Robo	tics and Naviga	tion in Medicine	e			
Courses						
Title Robotics and Navigation in Medicin Robotics and Navigation in Medicin	ne (L0335) ne (L0338)			Typ Lecture Project Seminar	Hrs/wk 2 2	CP 3 2
Robotics and Navigation in Medicin	Navigation in Medicine (L0336) Recitation Section (small) 1					1
Module Responsible	Prof. Alexander Schla	efer				
Admission Requirements	None					
Knowledge	 principles of ma principles of pr solid R or Matla 	ath (algebra, analysis/c ogramming, e.g., in Jav ab skills	calculus) va or C++			
Educational Objectives	After taking part succ	essfully, students have	reached the following	g learning results		
Professional Competence						
Knowledge	The students can ex detail. Systems can systems regarding de	plain kinematics and to be evaluated with resp sign and limitations.	racking systems in c pect to collision dete	linical contexts and illus oction and safety and re	trate systems and egulations. Student	their components in s can assess typical
Skills	The students are able	to design and evaluate	e navigation systems	and robotic systems for r	nedical applications	i.
Personal Competence Social Competence	 The students are able to grasp practical tasks in groups, develop solution strategies independently, define work processes and work on them collaboratively. The students are able to collaboratively organize their work processes and software solutions using virtual communication and a function and a function. 					
Autonomy	The students can cri incorporate them into The students can as document their work manner to the other o	tically reflect on the n their own work. sess their level of kno results. They can critic groups.	results of other grou wledge and indepen ally evaluate the resu	ips, make constructive s dently control their learr ults achieved and presen	suggestions for imp ning processes on t t them in an approp	provement, and also this basis as well as priate argumentative
Workload in Hours	Independent Study Ti	me 110, Study Time in	Lecture 70			
Credit points	6					
Course achievement	CompulsoryBonusYes10 %Yes10 %	Form Written elaboration Presentation	Description			
Examination	Written exam					
Examination duration and	90 minutes					
scale						
Assignment for the	Computer Science: Sp	ecialisation II: Intellige	nce Engineering: Elec	tive Compulsory		
Following Curricula	Data Science: Special Data Science: Special Electrical Engineering Computer Science in International Manager International Manager Mechatronics: Core Q Biomedical Engineerin Biomedical Engineerin Biomedical Engineerin	isation III. Applications: isation IV. Special Focu : Specialisation Medica Engineering: Specialisa ment and Engineering: ment and Engineering: ualification: Elective Co ng: Specialisation Artific ng: Specialisation Impla ng: Specialisation Medic	Elective Compulsory is Area: Elective Comp I Technology: Elective tion II. Engineering So Specialisation II. Elec Specialisation II. Proc impulsory cial Organs and Reger ants and Endoprosthe cal Technology and Co	oulsory e Compulsory cience: Elective Compulso trical Engineering: Electiv ess Engineering and Biot nerative Medicine: Electiv ses: Elective Compulsory ontrol Theory: Elective Co	ory re Compulsory echnology: Elective re Compulsory mpulsory	Compulsory
	Biomedical Engineerir Product Development Product Development Product Development Theoretical Mechanica	ng: Specialisation Mana , Materials and Product , Materials and Product , Materials and Product al Engineering: Speciali	gement and Business tion: Specialisation Pro- tion: Specialisation Pro- tion: Specialisation Ma sation Bio- and Medic	Administration: Elective oduct Development: Elect oduction: Elective Compu aterials: Elective Compuls al Technology: Elective C	Compulsory tive Compulsory lsory ory compulsory	

Course L0335: Robotics and	Navigation in Medicine				
Тур	Lecture				
Hrs/wk	2				
CP	3				
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28				
Lecturer	Prof. Alexander Schlaefer				
Language	EN				
Cycle	SoSe				
Content	- kinematics				
	- calibration				
	- tracking systems				
	- navigation and image guidance				
	- motion compensation				
	The seminar extends and complements the contents of the lecture with respect to recent research results.				
Literature	Spong et al.: Robot Modeling and Control, 2005				
	Troccaz: Medical Robotics, 2012				
	Further literature will be given in the lecture.				

Course L0338: Robotics and	ourse L0338: Robotics and Navigation in Medicine			
Тур	Project Seminar			
Hrs/wk	2			
CP	2			
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28			
Lecturer	Prof. Alexander Schlaefer			
Language	EN			
Cycle	SoSe			
Content	See interlocking course			
Literature	See interlocking course			

Course L0336: Robotics and Navigation in Medicine			
Тур	Recitation Section (small)		
Hrs/wk	1		
СР	1		
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14		
Lecturer	Prof. Alexander Schlaefer		
Language	EN		
Cycle	SoSe		
Content	See interlocking course		
Literature	See interlocking course		

Module M1921: Technical Complementary Course for DSMS (according to Subject Specific Regulations)					
Courses					
Title	Тур	Hrs/wk	СР		
Module Responsible	Prof. Tobias Knopp				
Admission Requirements	None				
Recommended Previous	See selected module according to Subject Specific Regulations				
Knowledge					
Educational Objectives	After taking part successfully, students have reached the following learning results				
Professional Competence					
Knowledge	See selected module according to Subject Specific Regulations				
Skills	See selected module according to Subject Specific Regulations				
Personal Competence					
Social Competence	See selected module according to Subject Specific Regulations				
Autonomy	See selected module according to Subject Specific Regulations				
Workload in Hours	Depends on choice of courses				
Credit points	6				
Assignment for the	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory				
Following Curricula					
Module M1879: Causa	al Data Science for Business Analytic	S			
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Courses					
Title		Ţγp	Hrs/wk	СР	
Business Analytics with Causal Data	a Science (L3096)	Project-/problem-based Learning	2	3	
Causal Data Science (L3095)		Lecture	2	3	
Module Responsible	Prof. Christoph Ihl				
Admission Requirements	None				
Recommended Previous	- Linear Algebra				
Knowledge	- Basics of programming				
	- School knowledge in economics				
Educational Objectives	After taking part successfully, students have reached	the following learning results			
Professional Competence					
Knowledge	After completing the module, students will be able to	:			
	- understand the difference between "correlation" and	d "causation".			
	- understand the shortcomings of current correlation-	based approaches.			
	- discuss the conceptual ideas behind various causal	data science tools and algorithms.			
	- critical examination of (study) results and spurious of	correlations.			
	- understanding of application of methods in business	and practice.			
Skills	- develop causal knowledge relevant for specific data	-driven decisions.			
	- carry out state-of the art causal data analyses.				
	- isolating causal effects despite the existence of cont	founding factors.			
	- programming in relevant programming languages.				
	- selection of the appropriate method depending on t	he problem.			
Personal Competence					
Social Competence	Students can work on the problems both individually	and in groups during the exercise times and	l also ask ques	tions and contribute	
	to the solution of other people's problems outside the	e exercise times in a dedicated forum for the	e course (Matte	ermost). In addition,	
	students learn to prepare and present their results du	iring the course.			
Autonomy	Students learn to transfer the knowledge and skills	they have learned to other subject areas	and to link th	em to new learning	
	content. To obtain information and solve problems, e	especially those related to programming en	ors, they learn	n to use appropriate	
	resources to help themselves.				
Workload in Hours	Independent Study Time 124, Study Time in Lecture	56			
Credit points	6				
Course achievement	None				
Examination	Subject theoretical and practical work				
Examination duration and	Solutions to coding problem sets after each class ses	sion			
scale					
Assignment for the	Data Science: Specialisation III. Applications: Elective	Compulsory			
Following Curricula	Data Science: Specialisation IV. Special Focus Area: E	lective Compulsory	moulceri		
1	International Management and Engineering: Specialis	acion il informacion rechnology: Elective Ci	JIIIPUISOFY		

Course L3096: Business Anal	ytics with Causal Data Science
Тур	Project-/problem-based Learning
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	
Cvcle	SoSe
Content	Most managerial decision problems require answers to questions such as "what happens to Y if we do X?", or "was it X that caused Y to change?" In other words, practical business decision-making requires knowledge about cause-and-effect. While most data science and machine learning approaches are designed to efficiently detect patterns in high-dimensional data, they are not able to distinguish causal relationships from simple correlations. That means, commonly used approaches to business analytics often fall short to provide decision makers with important causal knowledge. Therefore, many leading companies currently try to develop specific causal data science capabilities.
	This module will provide an introduction into the topic of causal inference with the help of modern data science and machine learning approaches and with a focus on applications to practical business problems from various management areas. Based on an overarching framework for causal data science, the course will guide students to detect sources of confounding influence factors, understand the problem of selective measurement in data collection, and extrapolate causal knowledge across different business contexts. We also cover several tools for causal inference, such as A/B testing and experiments, difference-in-differences, instrumental variables, matching, regression discontinuity designs, etc. A variety of hands-on examples will be discussed that allow students to apply their newly obtained knowledge and carry out state-of-the-art causal analyses by themselves.
	Topics covered:
	1. Introduction and Overview
	2. Probability and Regression Review
	3. Potential Outcomes Causal Model
	4. Directed Acyclic Graphs
	5. Experiments and A/B-Testing
	6. Matching and Subclassification
	7. Regression Discontinuity
	8. Instrumental Variables
	9. Panel Data
	10. Difference-in-Differences
	11. Synthetic Control
	12. Heterogeneous Treatment Effects
	13. Mediation Analysis
Literature	 Angrist, J. D., & Pischke, J. S. (2014). Mastering metrics: The path from cause to effect. Princeton university press. Cunningham, Scott (2021). Causal Inference: The Mixtape, New Haven: Yale University Press. Hernán Miguel A., and Robins James M. (2020). Causal Inference: What If. Boca Raton: Chapman & Hall/CRC. Huntington-Klein, Nick. The effect (2021). An introduction to research design and causality. Chapman and Hall/CRC. Imbens, G. W., & Rubin, D. B. (2015). Causal inference in statistics, social, and biomedical sciences. Cambridge University Press. Mullainathan, Sendhil, and Jann Spiess. (2017). Machine Learning: An Applied Econometric Approach. Journal of Economic Perspectives, 31(2): 87-106. Pearl, Judea, and Dana Mackenzie (2018). The Book of Why. Basic Books, New York, NY. Pearl, Judea, Madelyn Glymour, and Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Inc., New York, NY.

Course L3095: Causal Data S	cience
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Christoph Ihl
Language	EN
Cycle	SoSe
	Y to change?" In other words, practical business decision-making requires knowledge about cause-and-effect. While most data science and machine learning approaches are designed to efficiently detect patterns in high-dimensional data, they are not able to distinguish causal relationships from simple correlations. That means, commonly used approaches to business analytics often fall short to provide decision makers with important causal knowledge. Therefore, many leading companies currently try to develop specific causal data science capabilities. This module will provide an introduction into the topic of causal inference with the help of modern data science and machine learning approaches and with a focus on applications to practical business problems from various management areas.
	an overarching approaches and with a rocus on applications to practical business problems from various management areas. Based on an overarching framework for causal data science, the course will guide students to detect sources of confounding influence factors, understand the problem of selective measurement in data collection, and extrapolate causal knowledge across different business contexts. We also cover several tools for causal inference, such as A/B testing and experiments, difference-in-differences, instrumental variables, matching, regression discontinuity designs, etc. A variety of hands-on examples will be discussed that allow students to apply their newly obtained knowledge and carry out state-of-the-art causal analyses by themselves.
	Topics covered:
	2. Probability and Regression Review
	3. Potential Outcomes Causal Model
	4. Directed Acyclic Graphs
	5. Experiments and A/B-Testing
	6. Matching and Subclassification
	7. Regression Discontinuity
	8. Instrumental Variables
	9. Panel Data
	10. Difference-in-Differences
	11. Synthetic Control
	12. Heterogeneous Treatment Effects
	13. Mediation Analysis
Literature	 Angrist, J. D., & Pischke, J. S. (2014). Mastering metrics: The path from cause to effect. Princeton university press. Cunningham, Scott (2021). Causal Inference: The Mixtape, New Haven: Yale University Press. Hernán Miguel A., and Robins James M. (2020). Causal Inference: What If. Boca Raton: Chapman & Hall/CRC. Huntington-Klein, Nick. The effect (2021). An introduction to research design and causality. Chapman and Hall/CRC. Imbens, G. W., & Rubin, D. B. (2015). Causal inference in statistics, social, and biomedical sciences. Cambridge University Press. Mullainathan, Sendhil, and Jann Spiess. (2017). Machine Learning: An Applied Econometric Approach. Journal of Economic Perspectives, 31(2): 87-106. Pearl, Judea, and Dana Mackenzie (2018). The Book of Why. Basic Books, New York, NY. Pearl, Judea, Madelyn Glymour, and Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Inc., New York, NY.

Module M1785: Mach	ine Learning in Electrical Enginee	ring and Information Tech	nology	
Courses				
Title		Тур	Hrs/wk	СР
General Introduction Machine Learn	ning (L3004)	Lecture	1	2
Machine Learning Applications in E	lectric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnet	tic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequence	cy Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Comr	nunications (L3005)	Lecture	1	1
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	The module is designed for a diverse audience, i	e. students with different background	. It shall be suitable fo	or both students with
Knowledge	deeper knowledge in machine learning methods	s but less knowledge in electrical en	gineering, e.g. math o	or computer science
	students, and students with deeper knowledge	in electrical engineering but less know	wledge in machine lea	arning methods, e.g.
	electrical engineering students. Machine learning	methods will be explained on a relat	tively high level indica	ting mainly principle
	ideas. The focus is on specific applications in elec	trical engineering and information tech	nnology.	
	The chapters of the course will be understandable	a in different denth depending on the	individual backgroups	d of the student. The
	individual background of the students will be take	e in unerent depth depending on the		a of the student. The
	individual background of the students will be take	n into consideration in the oral exam.		
Educational Objectives	After taking part successfully, students have reac	hed the following learning results		
Professional Competence				
Knowledge	The students know basic machine learning conce	pts and learning strategies. They are	aware of specific oppo	ortunities, challenges
	and approaches of machine learning in various	fields of electrical engineering. They	know exemplary app	lications of machine
	learning in electrical engineering.			
	The students are familiar with the contents of the	modulo coursos. Thoy can ovalain and	apply them to new pr	abloms
	The students are familiar with the contents of the	module courses. mey can explain and	a apply them to new pr	obientis.
Skills	The students are able to apply methods from ma	chine learning to problems in electrica	al engineering. They ar	re able to determine,
	dimension and implement suitable approaches	such as types of deep learning net	works and learning st	rategies for specific
	engineering problems. In particular, they are ab	le to include domain knowledge in m	achine learning archite	ectures and learning
	strategies. They are able to critically assess the le	arning results based on domain knowl	edge.	
Personal Competence				
Social Competence	The students can jointly solve specific problems.			
Autonomy	The students are able to acquire relevant info	prmation from appropriate literature	sources They can c	ontrol their level of
Autonomy	knowledge during the lecture period e.g. by solving	a tutorial problems or using coffware	tools	ontroi their level of
	knowledge during the lecture period e.g. by solvin	ig tatonal problems of using software		
Workload in Hours	Independent Study Time 110, Study Time in Lectu	ire 70		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Data Science: Specialisation III. Applications: Elect	tive Compulsory		
Following Curricula	Data Science: Specialisation IV. Special Focus Are	a: Elective Compulsory		
,	Electrical Engineering: Specialisation Information	and Communication Systems: Elective	Compulsory	
	Electrical Engineering: Specialisation Microwayo E	ingineering Ontics and Electromagnet	tic Compatibility: Electi	ive Compulsory
	Electrical Engineering: Specialisation Control and	Power Systems Engineering, Elective (Computery	ive compaisory
	Electrical Engineering: Specialisation Control and	Sonsor Tochnologias: Elective Communication		
	Computer Colonee in Engineering: Specialisation Wireless and	- Sensor rechnologies: Elective Compu	lisui y	
	Computer Science in Engineering: Specialisation I	I. Engineering Science: Elective Compu	JISOTY	
	Information and Communication Systems: Special	isation Communication Systems, Focu	s Software: Elective Co	ompulsory

Course L3004: General Intro	duction Machine Learning
Тур	Lecture
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe
Content	
	From Rule-Based Systems to Machine Learning
	 Brief overview recent advances in ML in various domain Children and ensemble advances in ML in various domain
	Outline and expected learning outcomes
	Basics statistical inference and statistics
	Basics of information theory
	The Notions of Learning in Machine Learning
	 Unsupervised and supervised machine learning
	 Model-based and data-driven machine learning
	Hybrid modelling
	Online/offline/meta/transfer learning
	General loss functions
	Introduction to Deep Learning
	Variants of neural networks
	• MLP
	Conv. neural networks
	Recurrent neural networks
	Training neural networks
	(Stochastic) Gradient Descent
	Regression vs. Classification
	 Classification as supervised learning problem
	Hands-On Session
	Representation Learning and Generative Models
	AutoEncoders
	Directed Generative Models
	Undirected Generative Models
	Generative Adversarial Neural Networks
	Probabilistic Graphical Models
	Bayesian Networks
	 Variational inference (variational autoencoder)
Literatura	Lecture notes as well as current literature announced in the lecture
Literature	

Course L3008: Machine Learning Applications in Electric Power Systems		
Тур	Lecture	
Hrs/wk	1	
СР	1	
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14	
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh	
Language	EN	
Cycle	SoSe	
Content	This part of the course focuses on how to utilize ML methods to model and operate electric power systems. Electric power systems consist of generation units such as PV, loads or consumers and the grid that connects those actors and supports to transport energy. This part of the course helps to understand the data-driven modelling of generation units (e.g. PV & fuel cells), modelling of load behavior, and to formulate and solve a state estimation problem for distribution grids using neural networks. This part of the course includes lectures to introduce the basics that are followed by practical examples and coding.	
Literature	Lecture notes as well as current literature announced in the lecture.	

Course L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering

Тур	Lecture
Hrs/wk	1
СР	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and
	electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application.
	Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the
	operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and
	ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give
	an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to
	expand todays physcis-based approaches in EMC Engineering.
Literature	Lecture notes as well as current literature announced in the lecture.

Course L3007: Machine Learning in High-Frequency Technology and Radar

Тур	Lecture
Hrs/wk	1
СР	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	Modern high-frequency systems benefit massively from machine learning methods. In applications where rule-based algorithms reach their limits, these data-driven approaches enable a significant increase in resolution and accuracy. This is exemplified by current research challenges, namely for the classification of targets in autonomous driving radar systems, radar-based gesture recognition for smart home applications and device control as well as in the field of medical technology for the contactless monitoring of human vital signs.
Literature	Lecture notes as well as current literature announced in the lecture.

Course L3005: Machine Learning in Wireless Communications		
Тур	Lecture	
Hrs/wk	1	
СР	1	
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14	
Lecturer	Dr. Maximilian Stark	
Language	EN	
Cycle	SoSe	
Content	 Supervised Learning Application - Channel Coding Recap channel coding and block codes Block codes as trainable neural networks Tanner graph with trainable weights Hands-on session Supervised Learning Application - Modulation Detection Recap wireless modulation schemes Convolutional neuronal networks for blind detection of modulation schemes Hands-on session Autoencoder Application - Constellation Shaping I Recap channel capacity and constellation shaping, Capacity achieving machine learning systems Information theoretical explanation of the autoencoder training Hands-on session Autoencoder Application - Constellation Shaping II Training without a channel model Mutual information neural estimator Hands-on session 	
	 Training a digital twin of a realistic channel with insufficient training data Hands-on session Recurrent Neural Network Application - Channel prediction Recap time-varying channel models Recurrent neural networks for temporal prediction Hands-on session 	
Literature	Lecture notes as well as current literature announced in the lecture.	

Module M1405: Rando	omised Algorithms and Random (Graphs		
Courses				
Title Randomised Algorithms and Rando	m Graphs (L2010)	Typ Lecture Restriction Section (James)	Hrs/wk	CP 3
Randomised Algorithms and Rando		Recitation Section (large)	Z	3
Module Responsible	None			
Recommended Provious	None			
Knowledge				
Educational Objectives	After taking part successfully, students have rea	ached the following learning results		
Professional Competence	After taking part successivity, statents have rec	the following featuring results		
Knowledge	 Students can describe basic concepts in t bounds, fingerprinting and algebraic tec They are able to explain them using appr Students can discuss logical connections the help of examples. They know proof strategies and can apply 	the area of Randomized Algorithms and Ra hniques, first and second moment metho opriate examples. between these concepts. They are capa / them.	ndom Graphs such a ds, and various rar ble of illustrating the	as random walks, tai ndom graph models. ese connections with
Skills	 Students can model problems with the h them by applying established methods. Students are able to explore and verify fu For a given problem, the students can or results. 	help of the concepts studied in this course inther logical connections between the con develop and execute a suitable technique	e. Moreover, they ar cepts studied in the e, and are able to cr	re capable of solving course. ritically evaluate the
Personal Competence <i>Social Competence</i> <i>Autonomy</i>	 Students are able to work together in tea In doing so, they can communicate new ordersign examples to check and deepen the Students are capable of checking their uprecisely and know where to get help in s Students have developed sufficient persproblems. 	ms. They are capable to establish a comm concepts according to the needs of their o e understanding of their peers. nderstanding of complex concepts on the olving them. istence to be able to work for longer per	on language. ooperating partners ir own. They can sp iods in a goal-orien	. Moreover, they car ecify open questions ted manner on hard
Workload in Hours	Independent Study Time 124, Study Time in Lec	ture 56		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathematic	cs: Elective Compulsory		
Following Curricula	Data Science: Specialisation I. Mathematics: Ele	ctive Compulsory		
	Data Science: Specialisation IV. Special Focus Ar Computer Science in Engineering: Specialisation	rea: Elective Compulsory III. Mathematics: Elective Compulsory		

Course L2010: Randomised Algorithms and Random Graphs		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Anusch Taraz, Prof. Volker Turau	
Language	DE/EN	
Cycle	SoSe	
Content	Randomized Algorithms:	
	 introduction and recalling basic tools from probability randomized search random walks text search with fingerprinting parallel and distributed algorithms online algorithms Random Graphs: typical properties first and second moment method tail bounds thresholds and phase transitions probabilistic method 	
Literature	 models for complex networks Motwani, Raghavan: Randomized Algorithms Worsch: Randomisierte Algorithmen Dietzfelbinger: Randomisierte Algorithmen Bollobas: Random Graphs Alon, Spencer: The Probabilistic Method Frieze, Karonski: Random Graphs van der Hofstad: Random Graphs and Complex Networks 	

Course L2011: Randomised A	Algorithms and Random Graphs
Тур	Recitation Section (large)
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Anusch Taraz, Prof. Volker Turau
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Courses				
Title		Тур	Hrs/wk	СР
Numerical Mathematics II (L0568)		Lecture	2	3
	Purf Caking La Dama	Kecitation Section (Sman)	Z	3
	None			
Recommended Provious	None			
Keconiniended Previous	Numerical Mathematics I			
Knowledge	Python knowledge			
Educational Objectives	After taking part successfully, students hav	e reached the following learning results		
Professional Competence	After taking part successivity, students hav			
Knowledge	Students are able to			
	name advanced numerical method	ds for interpolation, approximation, integratio	n, eigenvalue p	roblems, eigenvalu
	problems, nonlinear root finding prob	plems and explain their core ideas,	ie.	
	repeat convergence statements for t	I methods concerning runtime and storage pool	5,	
	explain practical aspects of numerical	ical implementation of numerical methods with	, respect to comp	itational and storag
	complexity	indimplementation of numerical methods with	espect to compt	
	complexity			
<i>ci 11</i>				
Skills	Students are able to			
	 implement, apply and compare adva 	nced numerical methods in Python,		
	 justify the convergence behaviour of 	numerical methods with respect to the problem	and solution algo	rithm and to transf
	it to related problems,			
	 for a given problem, develop a sui 	table solution approach, if necessary through o	composition of se	everal algorithms,
	execute this approach and to critical	ly evaluate the results		
Personal Competence				
Social Competence	Students are able to			
	• work together in beteregeneously co	mposed teams (i.e., teams from different study r	programs and bac	karound knowlodge
	explain theoretical foundations and s	support each other with practical aspects regarding	in the implement:	ation of algorithms
	explain dicorcacal foundations and s	apport even other with protected aspects regular	g the implemente	and a gontains.
Autonomy	Students are capable			
	 to assess whether the supporting the 	eoretical and practical excercises are better solve	d individually or in	n a team,
	to assess their individual progess and	d, if necessary, to ask questions and seek help.	-	
Workload in Hours	Independent Study Time 124, Study Time is	a Loctura E6		
Workload in Hours		1 Lecture 56		
Course achievement	None		-	
Examination	Oral exam			
Examination duration and	25 min			
scale	25 11111			
Assignment for the	Computer Science: Specialisation III. Mathe	matics: Elective Compulsory		
Following Curricula	Data Science: Specialisation I. Mathematics	: Elective Compulsory		
2	Data Science: Specialisation IV. Special Foc	us Area: Elective Compulsory		
	Computer Science in Engineering: Specialis	ation III. Mathematics: Elective Compulsory		
	Technomathematics: Specialisation I. Mathe	ematics: Elective Compulsory		

Course L0568: Numerical Ma	thematics II
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne, Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	SoSe
Content	 Error and stability: Notions and estimates Rational interpolation and approximation Multidimensional interpolation (RBF) and approximation (neural nets) Quadrature: Gaussian quadrature, orthogonal polynomials Linear systems: Perturbation theory of decompositions, structured matrices Eigenvalue problems: LR-, QD-, QR-Algorithmus Nonlinear systems of equations: Newton and Quasi-Newton methods, line search (optional) Krylov space methods: Arnoldi-, Lanczos methods (optional)
Literature	 Skript Stoer/Bulirsch: Numerische Mathematik 1, Springer Dahmen, Reusken: Numerik f ür Ingenieure und Naturwissenschaftler, Springer

Course L0569: Numerical Mathematics II	
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne, Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1774: Advai	ced Internet Computing			
Courses				
Title		Тур	Hrs/wk	СР
Advanced Internet Computing (L29	6)	Lecture	2	3
Advanced Internet Computing (L29	7)	Project-/problem-based Learn	ng 2	3
Module Responsible	Prof. Stefan Schulte			
Admission Requirements	None			
Recommended Previous	Good programming skills are necessary. Pr	evious knowledge in the field of distributed syster	ns is helpful.	
Knowledge				
Educational Objectives	After taking part successfully, students hav	e reached the following learning results		
Professional Competence				
Knowledge	After successful completion of the course,	students are able to:		
	 Describe basic concepts of Cloud Co 	mputing, the Internet of Things (IoT), and blockch	ain technologies	
	 Discuss and assess critical aspects of 	of Cloud Computing, the IoT, and blockchain techn	ologies	
	 Select and apply cloud and IoT tech 	nologies for particular application areas		
	 Design and develop practical solution 	ns for the integration of smart objects in IoT. Clou	. and blockchair	software
	Implement IoT services		.,	
Skills	The students acquire the ability to mode	I Internet-based distributed systems and to work	with these sys	tems. This comprises
	especially the ability to select and utilize	fitting technologies for different application are	s. Furthermore,	students are able to
	critically assess the chosen technologies.			
Personal Competence				
Social Competence	Students can work on complex problems b	oth independently and in teams. They can exchan	ge ideas with eac	ch other and use their
	ndividual strengths to solve the problem.			
Autonomy	Chudente ere elle te independently investi	were a complex problem and access which compare		ad to coluce it
Autonomy	students are able to independently investig	gate a complex problem and assess which compete		ed to solve it.
Workload in Hours	ndependent Study Time 124, Study Time i	n Lecture 56		
Credit points	6			
Course achievement	None			
Examination	Subject theoretical and practical work			
Examination duration and	Group project incl. presentation (50 %), wr	itten exam (60 min, 50 %)		
scale				
Assignment for the	Computer Science: Specialisation I. Compu	ter and Software Engineering: Elective Compulsor	/	
Following Curricula	Data Science: Specialisation II. Computer S	cience: Elective Compulsory		
	Data Science: Specialisation IV. Special Foo	cus Area: Elective Compulsory		
	Computer Science in Engineering: Specialis	ation I. Computer Science: Elective Compulsory		
	nformation and Communication Systems:	Specialisation Communication Systems, Focus Sof	ware: Elective C	ompulsory
	nformation and Communication Systems:	Specialisation Secure and Dependable IT Systems	Focus Networks	: Elective Compulsory

Course L2916: Advanced Inte	ernet Computing
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Schulte
Language	EN
Cycle	SoSe
Content	 This lecture discusses modern Internet-based distributed systems in three blocks: (i) Cloud computing, (ii) the Internet of Things, and (iii) blockchain technologies. The following topics will be covered in the single lectures: Cloud Computing Elastic Computing Technologies for identification for the IoT: RFID & EPC Communication in the IoT: Standards and protocols Security and trust in the IoT: Concerns and solution approaches Edge and Fog Computing Application areas: Smart factories, smart cities, smart healthcare Blockchain technologies Consensus
Literature	Lecture notes as well as current literature announced in the lecture.

Course L2917: Advanced Inte	ernet Computing
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Stefan Schulte
Language	EN
Cycle	SoSe
Content	This project-/problem-oriented part of the module augments the theoretical content of the lecture by a concrete technical problem,
	which needs to be solved by the students in group work during the semester. Possible topics are (blockchain-based) sensor data
	integration, Big Data processing, Cloud-based redundant data storages, and Cloud-based Onion Routing.
Literature	Lecture notes as well as current literature announced in the lecture.

Module M0714: Nume	erical Methods for Ordinary Different	ial Equations		
Courses				
Title		Тур	Hrs/wk	СР
Numerical Treatment of Ordinary D	ifferential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary D	ifferential Equations (L0582)	Recitation Section (small)	2	3
Module Responsible	Prof. Daniel Ruprecht			
Admission Requirements	None			
Recommended Previous	Mathematik I, II, III for Engineers (German	or English) or Analysis & Linear A	lgebra I + II	plus Analysis III for
Knowledge	Technomathematiker.		5	-
	Basic knowledge of MATLAB, Python or a simila	r programming language.		
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence	After taking part successiony, stadents have reached			
Knowledae	Students are able to			
	name numerical methods for the solution of orce	linary differential equations and explain	their core ideas,	,
	 formulate convergence statements for the tage 	ught numerical methods (including th	e necessary as	sumptions about the
	 explain aspects regarding the practical realisat 	on of a method		
	 select the appropriate numerical method for sp 	ecific problems, implement the numeric	al algorithms eff	iciently and interpret
	the numerical results.			
CL 11				
SKIIIS	Students are able to			
	 implement, apply and compare numerical methods 	ods for the solution of ordinary different	tial equations,	
	explain the convergence behaviour of numer	ical methods, taking into consideration	n the solved p	roblem and selected
	algorithm,			
	develop a suitable solution approach for a g	iven problem, if necessary by combin	ing multiple alg	jorithms, realise this
	approach and critically evaluate results.			
Personal Competence				
Social Competence	Students are able to			
	 work together in heterogeneous teams (i.e 	, teams from different study progra	ms and with o	different background
	knowledge), explain theoretical foundations an	d support each other with practical asp	ects regarding tl	he implementation of
	algorithms.			
Autonomy	Students are canable			
Autonomy				
	 to assess whether the provided theoretical and 	practical excercises are better solved in	ndividually or in a	a team and
	 to assess their individual progress and, if necess 	sary, to ask questions and seek help.		
Workload in Hours	Independent Study Time 124, Study Time in Lecture 5	6		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Bioprocess Engineering: Specialisation A - General Bio	process Engineering: Elective Compulso	ry	
Following Curricula	Chemical and Bioprocess Engineering: Specialisation	Chemical Process Engineering: Elective (Compulsory	
	Chemical and Bioprocess Engineering: Specialisation	General Process Engineering: Elective Co	ompulsory	
	Computer Science: Specialisation III. Mathematics: Ele	ctive Compulsory		
	Data Science: Specialisation I. Mathematics: Elective	Compulsory		
	Data Science: Specialisation IV. Special Focus Area: El	ective Compulsory		
	Electrical Engineering: Specialisation Control and Pow	er Systems Engineering: Elective Compu	ilsory	
	Energy Systems: Core Qualification: Elective Compuls	bry		
	Aircraft Systems Engineering: Core Qualification: Elect	ive Compulsory		
	Aeronautics: Core Qualification: Elective Compulsory	ical - Modeling training. Compusory		
	Mechatronics: Core Qualification: Elective Compulsory			
	Technomathematics: Specialisation I. Mathematics: El	ective Compulsory		
	Theoretical Mechanical Engineering: Core Oualification	n: Compulsory		
	Process Engineering: Specialisation Chemical Process	Engineering: Elective Compulsory		
	Process Engineering: Specialisation Process Engineeri	ng: Elective Compulsory		

Course L0576: Numerical Tre	eatment of Ordinary Differential Equations
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	Numerical methods for Initial Value Problems single step methods multistep methods stiff problems differential algebraic equations (DAE) of index 1 Numerical methods for Boundary Value Problems multiple shooting method difference methods
Literature	 E. Hairer, S. Noersett, G. Wanner: Solving Ordinary Differential Equations I: Nonstiff Problems. E. Hairer, G. Wanner: Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems. D. Griffiths, D. Higham: Numerical Methods for Ordinary Differential Equations.

Course L0582: Numerical Tre	eatment of Ordinary Differential Equations
Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0673: Inform	mation Theory and Coding				
Courses					
The		T	11 41-	<u></u>	
Litle	426)	locture	Hrs/wk	CP 4	
Information Theory and Coding (LO	438)	Recitation Section (large)	2	4	
Information meory and county (Lo	Prof. Carle and Bassel	Recitation Section (large)	2	2	
Module Responsible					
Admission Requirements	None				
Recommended Previous	Mathematics 1-3				
Knowledge	 Probability theory and random processes 				
	Basic knowledge of communications engin	eering (e.g. from lecture "Fundamenta	ls of Communi	cations and Random	
	Processes")				
Educational Objectives	After taking part successfully, students have reached	d the following learning results			
Professional Competence					
Knowledge	The students know the basic definitions for quantified	cation of information in the sense of info	rmation theory.	They know Shannon's	
	source coding theorem and channel coding theorem	n and are able to determine theoretical	limits of data co	mpression and error-	
	free data transmission over holsy channels. They up	the principles of deceding in perticul	g as well as erro	r-detecting and error-	
	decoding. They know fundemental and ing achemica	the principles of decoding, in particula	ar with modern	methods of iterative	
	decoding. They know fundamental coding schemes, their properties and decoding algorithms.				
	The students are familiar with the contents of lecture	e and tutorials. They can explain and app	ly them to new	problems.	
Skills	The students are able to determine the limits of data compression as well as of data transmission through noisy channels and				
	based on those limits to design basic parameters of a transmission scheme. They can estimate the parameters of an error-				
	detecting or error-correcting channel coding scheme for achieving certain performance targets. They are able to compare the				
	properties of basic channel coding and decoding	schemes regarding error correction ca	apabilities, deco	ding delay, decoding	
	complexity and to decide for a suitable method.	They are capable of implementing bas	sic coding and	decoding schemes in	
	software.				
Personal Competence					
Social Competence	The students can jointly solve specific problems.				
Autonomy	The students are able to acquire relevant inform	nation from appropriate literature sour	ces. They can	control their level of	
	knowledge during the lecture period by solving tutor	ial problems, software tools, clicker syste	em.		
Workload in Hours	Independent Study Time 110, Study Time in Lecture	70			
Credit points	6				
Course achievement	None				
Examination	Written exam				
Examination duration and	90 min				
scale					
Assignment for the	Data Science: Specialisation I. Mathematics: Elective	e Compulsory			
Following Curricula	Data Science: Specialisation IV. Special Focus Area:	Elective Compulsory			
	Electrical Engineering: Specialisation Information an	d Communication Systems: Elective Com	pulsory		
	Electrical Engineering: Specialisation Wireless and S	ensor Technologies: Elective Compulsory			
	Computer Science in Engineering: Specialisation II. E	ngineering Science: Elective Compulsory	,		
	Information and Communication Systems: Core Qua	lification: Compulsory			
	International Management and Engineering: Speciali	sation II. Electrical Engineering: Elective	Compulsory		
	Mechatronics: Technical Complementary Course: Ele	ective Compulsory			

Course L0436: Information T	heory and Coding
Тур	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	 Introduction to information theory and coding Definitions of information: Self information, entropy Binary entropy function Source coding theorem Entropy of continuous random variables: Differential entropy, differential entropy of uniformly and Gaussian distributed random variables Source coding Principles of lossless source coding Optimal source codes Prefix codes, prefix-free codes, instantaneous codes Morse code Huffman code Shannon code Bounds on the average codeword length
1	[123]

- Relative entropy, Kullback-Leibler distance, Kullback-Leibler divergence
- Cross entropy
- Lempel-Ziv algorithm
- Lempel-Ziv-Welch (LZW) algorithm
- Text compression and image compression using variants of the Lempel-Ziv algorithm
- Channel models
 - AWGN channel
 - Binary-input AWGN channel
 - Binary symmetric channel (BSC)
 - Relationship between AWGN channel and BSC
 - Binary error and erasure channel (BEEC)
 - Binary erasure channel (BEC)
 - Discrete memoryless channels (DMC)
- Definitions of information for multiple random variables
 - Mutual information and channel capacity
 - Entropy, conditional entropy
 - Chain rules for entropy and mutual information
- Channel coding theorem
- Channel capacity of fundamental channels: BSC, BEC, AWGN channel, binary-input AWGN channel etc.
- Power-limited vs. bandlimited transmission
- Capacity of parallel AWGN channels
 - Waterfilling
 - Examples: Multiple input multiple output (MIMO) channels, complex equivalent baseband channels, orthogonal frequency division multiplex (OFDM)
- Source-channel coding theorem, separation theorem
- Multiuser information theory
 - Multiple access channel (MAC)
 - Broadcast channel
 - Principles of multiple access, time division multiple access (TDMA), frequency division multiple access (FDMA), nonorthogonal multiple access (NOMA), hybrid multiple access
 - Achievable rate regions of TDMA and FDMA with power constraint, energy constraint, power spectral density constraint, respectively
 - Achievable rate region of the two-user and K-user multiple access channels
 - Achievable rate region of the two-user and K user broadcast channels
 - Multiuser diversity
- Channel coding
 - Principles and types of channel coding
 - Code rate, data rate, Hamming distance, minimum Hamming distance, Hamming weight, minimum Hamming weight
 - Error detecting and error correcting codes
 - Simple block codes: Repetition codes, single parity check codes, Hamming code, etc.
 - Syndrome decoding
 - · Representations of binary data
 - Non-binary symbol alphabets and non-binary codes
 - Code and encoder, systematic and non-systematic encoders
 - Properties of Hamming distance and Hamming weight
 - Decoding spheres
 - Perfect codes
 - Linear codes
 - Decoding principles
 - Syndrome decoding
 - Maximum a posteriori probability (MAP) decoding and maximum likelihood (ML) decoding
 - Hard decision and soft decision decoding
 - Log-likelihood ratios (LLRs), boxplus operation
 - MAP and ML decoding using log-likelihood ratios
 - Soft-in soft-out decoders
 - Error rate performance comparison of codes in terms of SNR per info bit vs. SNR per code bit
 - Linear block codes
 - Generator matrix and parity check matrix, properties of generator matrix and parity check matrix
 Dual codes
 - Dual codes
 - Low density parity check (LDPC) codes
 - Sparse parity check matrix
 - Tanner graphs, cycles and girth
 - Degree distributions
 - Code rate and degree distribution
 - Regular and irregular LDPC codes
 - Message passing decoding
 - Message passing decoding in binary erasure channels (BEC)
 - Systematic encoding using erasure message passing decoding
 - Message passing decoding in binary symmetric channels (BSC)
 - Extrinsic information
 - Bit-flipping decoding
 - Effects of short cycles in the Tanner graph
 - Alternative bit-flipping decoding
 - Soft decision message passing decoding: Sum product decoding
 - Bit error rate performance of LDPC codes

	 Repeat accumulate codes and variants of repeat accumulate codes
	 Message passing decoding and turbo decoding of repeat accumulate codes
	Convolutional codes
	Encoding using shift registers
	 Trellis representation
	 Hard decision and soft decision Viterbi decoding
	 Bit error rate performance of convolutional codes
	 Asymptotic coding gain
	Viterbi decoding complexity
	 Free distance and optimum convolutional codes
	 Generator polynomial description and octal description
	Catastrophic convolutional codes
	 Non-systematic and recursive systematic convolutional (RSC) encoders
	 Rate compatible punctured convolutional (RCPC) codes
	 Hybrid automatic repeat request (HARQ) with incremental redundancy
	 Unequal error protection with punctured convolutional codes
	 Error patterns of convolutional codes
	Concatenated codes
	 Serial concatenated codes
	 Parallel concatenated codes, Turbo codes
	 Iterative decoding, turbo decoding
	Bit error rate performance of turbo codes
	 Interleaver design for turbo codes
	Coded modulation
	 Principle of coded modulation
	 Achievable rates with PSK/QAM modulation
	 Trellis coded modulation (TCM)
	Set partitioning
	Ungerbäck codes
	 Multilevel coding
	 Bit-interleaved coded modulation
Literature	Bossert, M.: Kanalcodierung. Oldenbourg.
	Friedrichs, B.: Kanalcodierung. Springer.
	Lin, S., Costello, D.: Error Control Coding. Prentice Hall.
	Roth, R.: Introduction to Coding Theory.
	Johnson S Iterative Error Correction Cambridge
	Dishardana T. Ukharla, D. Madam Cadim Theory, Combridge University Dece
	Richardson, L., orbanke, R., Modern Couling Theory, Cambridge University Press.
	Gallager, R. G.: Information theory and reliable communication. Whiley-VCH
	Cover, T., Thomas, J.: Elements of information theory. Wiley.

Course L0438: Information Theory and Coding		
Тур	Recitation Section (large)	
Hrs/wk	2	
СР	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Lecturer	Prof. Gerhard Bauch	
Language	EN	
Cycle	SoSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1881: Digita	al Health	n					
Courses							
					_		
Litle					lyp	Hrs/wk	CP
Digital Health Seminar (13100)					Project-/problem-based Learning	3	3
Module Responsible	Prof. Moritz	z Göldner			roject (problem based Learning	5	5
Admission Requirements	None						
Recommended Previous							
Knowledge							
Educational Objectives	After taking	g part suc	cessfully, students	have reached the followi	ng learning results		
Professional Competence							
Knowledge							
Skills							
Personal Competence							
Social Competence							
Autonomy							
Workload in Hours	Independer	nt Study T	ime 96, Study Tim	e in Lecture 84			
Credit points	6						
Course achievement	Compulsory	Bonus	Form	Description			
	Yes	20 %	Excercises	Erfolgreiche	Teilnahme PBL-Übung		
Examination	Written exa	am					
Examination duration and	90 min						
scale							
Assignment for the	Data Scien	ce: Specia	lisation III. Applica	tions: Elective Compulsor	ТУ		
Following Curricula	Data Scien	ce: Specia	lisation IV. Special	Focus Area: Elective Con	npulsory		
	Biomedical	Engineeri	ing: Specialisation	Implants and Endoprosth	eses: Elective Compulsory		
	Biomedical	Engineeri	ing: Specialisation	Artificial Organs and Reg	enerative Medicine: Elective Con	npulsory	
	Biomedical	3iomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory					
	Biomedical	Engineeri	ing: Specialisation	Medical Technology and	Control Theory: Elective Compuls	sory	

Course L3099: Digital Health	
Тур	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Moritz Göldner
Language	EN
Cycle	WiSe
Content	
Literature	

Course L3100: Digital Health Seminar			
Тур	Project-/problem-based Learning		
Hrs/wk	3		
CP	3		
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42		
Lecturer	Prof. Moritz Göldner		
Language	EN		
Cycle	WiSe		
Content			
Literature			

Module M0720: Matri	x Algorithms			
Module M0720. Mach	X Algorithms			
Courses				
Title		Тур	Hrs/wk	СР
Matrix Algorithms (L0984)		Lecture	2	3
Matrix Algorithms (L0985)		Recitation Section (small)	2	3
Module Responsible	Dr. Jens-Peter Zemke			
Admission Requirements	None			
Recommended Previous	Mathematics I - III			
Knowledge	Numerical Mathematics 1/ Numerics			
	Basic knowledge of the programming lang	juages Matlab and C		
Educational Objectives	After taking part successfully, students have rea	ched the following learning results		
Professional Competence	And thing part outcool any,			
Knowledge	Students are able to			
-				
1	1. name, state and classify state-of-the-art K	irylov subspace methods for the solution of	the core problen	ns of the engineering
	Sciences, namely, eigenvalue problems, so	Slution of linear systems, and model reduction of several systems (Sylvestor Lyapunov, Riccati)	n;	
	2. State approaches for the solution of many	(equations (sylvester, Lyapunov, Neccas).		
Skills	Students are capable to			
	1. implement and assess basic Krylov subsr	pace methods for the solution of eigenvalue	problems, linear	svstems, and mode
	reduction;			
	2. assess methods used in modern software	with respect to computing time, stability, and	d domain of appl	icability;
	3. adapt the approaches learned to new, unk	nown types of problem.		
Personal Competence				
Social Competence	Students can			
	develop and document joint solutions in si	mall teams;		
	form groups to further develop the ideas a	and transfer them to other areas of applicabil	ity;	
	 form a team to develop, build, and advance 	ce a software library.		
Autonomy	Students are able to			
	 correctly access the time and effort of self 	f defined work.		
	 assess whether the supporting theoretical 	and practical excercises are better solved in	dividually or in a	team:
	 define test problems for testing and expansion 	nding the methods:		team,
	 assess their individual progess and, if nec 	essary, to ask questions and seek help.		
Maulda ad In Harris	1. J. J. M. Churke Time 124. Churke Time in Levi			
Workload In Hours	Independent Study Time 124, Study Time in Lect	ure 56		
Course achievement	6 Name			
Course achievement				
Examination duration and				
scale	25 min			
Assignment for the	Computer Science: Specialisation III. Mathematic	s: Elective Compulsory		
Following Curricula	Data Science: Specialisation IV. Special Focus Ar	ea: Elective Compulsory		
-	Data Science: Specialisation I. Mathematics: Elec	tive Compulsory		
	Mechatronics: Specialisation Intelligent Systems	and Robotics: Elective Compulsory		
	Mechatronics: Specialisation System Design: Electronics	ctive Compulsory		
	Mechatronics: Core Qualification: Elective Compu	llsory		
	Technomathematics: Specialisation I. Mathemati	cs: Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisation	on Simulation Technology: Elective Compulso	ory	

Course L0984: Matrix Algorit	hms
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Jens-Peter Zemke
Language	DE/EN
Cycle	WiSe
Content	 Part A: Krylov Subspace Methods: Basics (derivation, basis, Ritz, OR, MR) Arnoldi-based methods (Arnoldi, GMRes) Lanczos-based methods (Lanczos, CG, BiCG, QMR, SymmLQ, PvL) Sonneveld-based methods (IDR, BiCGStab, TFQMR, IDR(s)) Part B: Matrix Equations: Sylvester Equation Lyapunov Equation Algebraic Riccati Equation
Literature	 Skript (224 Seiten) Ergänzend können die folgenden Lehrbücher herangezogen werden: Saad, Yousef. Numerical methods for large eigenvalue problems: revised edition. Society for Industrial and Applied Mathematics, 2011. Saad, Yousef. Iterative methods for sparse linear systems. Society for Industrial and Applied Mathematics, 2003. Van der Vorst, Henk A. Iterative Krylov methods for large linear systems. No. 13. Cambridge University Press, 2003. Liesen, Jörg, and Zdenek Strakos. Krylov subspace methods: principles and analysis. Oxford University Press, 2013.

course L0985: Matrix Algorithms		
Тур	Recitation Section (small)	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Dr. Jens-Peter Zemke	
Language	DE/EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1598: Image	e Processing			
Courses				
Title		Түр	Hrs/wk	СР
Image Processing (L2443)		Lecture	2	4
Image Processing (L2444)		Recitation Section (small)	2	2
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Signal and Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reache	d the following learning results		
Professional Competence				
Knowledge	The students know about			
	visual perception			
	multidimensional signal processing			
	sampling and sampling theorem filtering			
	image onbancomont			
	edge detection			
	multi-resolution procedures: Gauss and Lapla	ce nyramid wavelets		
	image compression	ce pyranna, wavelets		
	image segmentation			
	 morphological image processing 			
Skills	The students can			
	analyze process and improve multidimensio	nal image data		
	 implement simple compression algorithms 			
	 design custom filters for specific applications 			
Personal Competence				
Social Competence	Students can work on complex problems both indep	endently and in teams. They can exchang	e ideas with eac	h other and use their
	individual strengths to solve the problem.			
Autonomy	Students are able to independently investigate a co	mplex problem and assess which compete	encies are require	ed to solve it.
		·····		
Workload in Hours	Independent Study Time 124, Study Time in Lecture	2 56		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Data Science: Core Qualification: Elective Compulso	ry		
Following Curricula	Data Science: Specialisation I. Mathematics/Comput	er Science: Elective Compulsory		
	Data Science: Specialisation II. Computer Science: E	lective Compulsory		
	Data Science: Specialisation IV. Special Focus Area:	Elective Compulsory		
	Electrical Engineering: Specialisation Information ar	d Communication Systems: Elective Com	oulsory	
	Electrical Engineering: Specialisation Medical Techn	ology: Elective Compulsory		
	Information and Communication Systems: Specialis	ation Communication Systems, Focus Sign	al Processing: Ele	ective Compulsory
	Information and Communication Systems: Specia	alisation Secure and Dependable IT Sy	stems, Focus S	oftware and Signa
	Processing: Elective Compulsory			
	International Management and Engineering: Special	isation II. Information Technology: Elective	e Compulsory	
	Mechatronics: Specialisation Intelligent Systems and	Robotics: Elective Compulsory		
	Mechatronics: Specialisation System Design: Electiv	e Compulsory		
	Mechatronics: Core Qualification: Elective Compulso	iry		
	Microelectronics and Microsystems: Specialisation C	communication and Signal Processing: Elec	tive Compulsory	
	i neoretical Mechanical Engineering: Specialisation l	Rodotics and Computer Science: Elective (ompulsory	

Course L2443: Image Proces	sing			
Тур	Lecture			
Hrs/wk	2			
CP				
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28			
Lecturer	Prof. Tobias Knopp			
Language	DE/EN			
Cycle	WiSe			
Content	 Visual perception Multidimensional signal processing Sampling and sampling theorem Filtering Image enhancement Edge detection Multi-resolution procedures: Gauss and Laplace pyramid, wavelets Image Compression Segmentation Morphological image processing 			
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Pratt, Digital Image Processing, Wiley, 2001 Bernd Jähne: Digitale Bildverarbeitung - Springer, Berlin 2005			

Course L2444: Image Processing			
Тур	Recitation Section (small)		
Hrs/wk	2		
CP	2		
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28		
Lecturer	Prof. Tobias Knopp		
Language	DE/EN		
Cycle	WiSe		
Content	See interlocking course		
Literature	See interlocking course		

Courses							
The		T		11	67		
FITE Security of Cyber-Physical Systems	(12691)	l yp Lecture		Hrs/wk 2	3		
Security of Cyber-Physical Systems	s (L2692)	Recitation Sec	tion (small)	2	3		
Module Responsible	Prof. Sibylle Fröschle						
Admission Requirements	None						
Recommended Previous	IT security, programming skills, statistic	CS					
Knowledge							
Educational Objectives	After taking part successfully, students	have reached the following learning res	sults				
Professional Competence	The students know and can evaluate						
Knowledge	The students know and can explain						
	- the threats posed by cyber attacks to	cyber-physical systems (CPS)					
	- concrete attacks at a technical level,	e.g. on bus systems					
	- security solutions specific to CPS with	their capabilities and limitations					
	- examples of security architectures for	CPS and the requirements they guaran	tee				
	 standard security engineering process 	ses for CPS					
Skills	The students are able to						
	 identify security threats and assess the second seco	ne risks for a given CPS					
	 apply attack toolkits to analyse a net 	worked control system, and detect attac	cks beyond thos	se taught in class			
	 identify and apply security solutions 	suitable to the requirements					
	 follow security engineering processes 	- follow security engineering processes to develop a security architecture for a given CPS					
	 recognize challenges and limitations, 	e.g. posed by novel types of attack					
Personal Competence							
Social Competence	The students are able to						
	 expertly discuss security risks and in experts 	ncidents of CPS and their mitigation ir	a solution-orie	ented fashion wi	th experts and no		
	- foster a security culture with respect t	to CPS and the corresponding critical inf	rastructures				
Autonomy	The students are able to						
	- follow up and critically assess current	developments in the security of CPS inc	luding relevant	security inciden	ts		
	- master a new topic within the area by	self-study and self-initiated interaction	with experts ar	nd peers.			
Workload in Hours	Independent Study Time 124, Study Tir	ne in Lecture 56					
Credit points	6						
Course achievement	Compulsory Bonus Form	Description					
Evening time	No 10 % Excercises	Die Ubungsaufgaben finder	n semesterbegle	eitend statt.			
Examination	120 min						
scale	120 mm						
Assignment for the	Computer Science: Specialisation I. Cor	nputer and Software Engineering: Electi	ve Compulsory				
Following Curricula	Data Science: Specialisation II. Comput	er Science: Elective Compulsory	. ,				
	Data Science: Specialisation IV. Special	Focus Area: Elective Compulsory					
	Computer Science in Engineering: Spec	ialisation I. Computer Science: Elective	Compulsory				
	Information and Communication Sys	tems: Specialisation Secure and Dep	endable IT Sy	stems, Focus S	oftware and Sigr		
	Processing: Elective Compulsory						

Course L2691: Security of Cy	/ber-Physical Systems
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Fröschle
Language	EN
Cycle	WiSe
Content	Embedded systems in energy, production, and transportation are currently undergoing a technological transition to highly networked automated cyber-physical systems (CPS). Such systems are potentially vulnerable to cyber attacks, and these can have physical impact. In this course we investigate security threats, solutions and architectures that are specific to CPS. The topics are as follows:
	Fundamentals and motivating examples Networked and embedded control systems Bus system level attacks Intruder detection systems (IDS), in particular physics-based IDS
	System security architectures, including cryptographic solutions Adversarial machine learning attacks in the physical world Aspects of Location and Localization Wireless networks and infrastructures for critical applications
	Communication security architectures and remaining threats Intruder detection systems (IDS), in particular data-centric IDS Resilience against multi-instance attacks Security Engineering of CPS: Process and Norms
Literature	Recent scientific papers and reports in the public domain.

Course L2692: Security of Cyber-Physical Systems			
Тур	Recitation Section (small)		
Hrs/wk	2		
СР	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sibylle Fröschle		
Language	EN		
Cycle	WiSe		
Content	See interlocking course		
Literature	See interlocking course		

Module M1880: Deep	Learning for Social Analytics					
Courses						
Title Deep Learning for Text and Graphs	; (L3097)	Typ Lecture	Hrs/wk	CP 3		
Social Analytics with Deep Learning	(LSU96)	Project-/problem-based Lear	ning z	3		
Module Responsible	Proi. Christoph Ini					
Recommended Previous Knowledge	Basic knowledge of Python Familiarity with probability theory, linear algebra and statistics					
Educational Objectives	After taking part successfully, students have r	eached the following learning results				
Professional Competence Knowledge	 Understand how text and graphs can be Identify underlying relational structures Discuss the conceptual ideas behind va Decide about suitable deep learning are 	e transformed into data of data that can be represented as graphs rious deep learning architectures :hitectures for a given task				
Skills	 Proficiency in Python for deep learning applications Apply basic natural language processing methods such as embedding and dependency parsing Model complex data using graph representations Set up deep learning architectures for different tasks Make predictions employing deep learning models 					
Personal Competence <i>Social Competence</i> <i>Autonomy</i>	 Collaboration on projects and assignme Communication regarding computation Maneuver in the field of deep learning i Solve computational, algorithmic, and r Critical thinking skills Self-sufficient problem-solving regardin 	nts al, algorithmic and modeling challenges ncluding scientific literature and models nodeling challenges related to deep learning g coding issues	models			
Workload in Hours	Independent Study Time 124, Study Time in L	ecture 56				
Credit points	6					
Course achievement	- None					
Examination	Subject theoretical and practical work					
Examination duration and scale	Solutions to coding problem sets after each cl	ass session				
Assignment for the	Data Science: Specialisation IV. Special Focus	Area: Elective Compulsory				
Following Curricula	Data Science: Specialisation III. Applications: E International Management and Engineering: S	ilective Compulsory pecialisation II. Information Technology: Elect	ive Compulsory			

Course L3097: Deep Learning	g for Text and Graphs
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Christoph Ihl
Language	EN
Cycle	wise Today, massive amounts of valuable data come in dinital, yet often unstructured forms such as text or graphs. People
	communicate almost everything in language: e.g., social media, web search, product reviews, advertising, emails, customer service, language translation, chatbots, medical reports, etc. At the same time, they choose to interact with other people, products or websites. These networked interaction patterns can be represented as graphs of relationships between people and objects. Analyzing these new data sources and forms can help decision makers to significantly improve the effectiveness and efficiency of products, services and processes.
	This course introduces the fundamentals and current state of machine learning for natural language processing (NLP) and graphs in terms of content, users, and social relations. The course has a particular emphasis on key advancements in deep learning (or neural network) architectures, which in recent years have obtained very high performance across many different tasks, using single end-to-end models that do not require traditional, task-specific feature engineering. The course focuses on the computational, algorithmic, and modeling challenges specific to learning architecture for text and graphs. Students will gain a thorough introduction to modern deep learning algorithms. Through lectures and coding labs, students will learn the necessary skills to design, implement, and understand their own deep learning models. We will use Python and the deep learning framework PyTorch (Geometric).
	Topics Covered:
	1. Intro: Text and Graphs as Data
	2. Word Embeddings
	3. Fundamentals of Deep Learning
	4. Dependency Parsing
	5. Recurrent Neural Networks for Text
	6. Contextual Word Embeddings with Transformers
	7. Analyzing Graphs
	8. Graph Embeddings
	9. Graph Embeddings for Complex Graphs
	10. Graph Neural Networks (GNNs)
	11. GNNs for Complex Graphs
	12. GNNs for Text
	13. Deep Generative Models for Text and Graphs
Literature	 Chollet, F., & Allaire, J. J. (2018). Deep Learning mit R und Keras: Das Praxis-Handbuch von den Entwicklern von Keras und RStudio. MITP-Verlags GmbH & Co. KG. Hamilton, William L. (2020). Graph Representation Learning. Synthesis Lectures on Artificial Intelligence and Machine Learning, Vol. 14, No. 3, Pages 1-159. Hapke, H., Howard, C., & Lane, H. (2019). Natural Language Processing in Action: Understanding, analyzing, and generating text with Python. Simon and Schuster. Hvitfeldt, E., & Silge, J. (2021). Supervised machine learning for text analysis in R. Ma, Y., & Tang, J. (2021). Deep learning on graphs. Cambridge University Press. Rao, D., & McMahan, B. (2019). Natural language processing with PyTorch: build intelligent language applications using deep learning. O'Reilly Media, Inc.

Course L3098: Social Analyti	cs with Deep Learning					
Тур	Project-/problem-based Learning					
Hrs/wk	2					
СР	3					
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28					
Lecturer	Prof. Christoph Ihl					
Language	EN					
Cycle	WiSe					
Content	loday, massive amounts of valuable data come in digital, yet often unstructured forms such as text or graphs. People communicate almost everything in language: e.g., social media, web search, product reviews, advertising, emails, customer service, language translation, chatbots, medical reports, etc. At the same time, they choose to interact with other people, products or websites. These networked interaction patterns can be represented as graphs of relationships between people and objects. Analyzing these new data sources and forms can help decision makers to significantly improve the effectiveness and efficiency of products, services and processes.					
	This course introduces the fundamentals and current state of machine learning for natural language processing (NLP) and graphs in terms of content, users, and social relations. The course has a particular emphasis on key advancements in deep learning (or neural network) architectures, which in recent years have obtained very high performance across many different tasks, using single end-to-end models that do not require traditional, task-specific feature engineering. The course focuses on the computational, algorithmic, and modeling challenges specific to learning architecture for text and graphs. Students will gain a thorough introduction to modern deep learning algorithms. Through lectures and coding labs, students will learn the necessary skills to design, implement, and understand their own deep learning models. We will use Python and the deep learning framework PyTorch (Geometric).					
	Topics Covered:					
	ntro: Text and Graphs as Data					
	2. Word Embeddings					
	3. Fundamentals of Deep Learning					
	4. Dependency Parsing					
	5. Recurrent Neural Networks for Text					
	6. Contextual Word Embeddings with Transformers					
	7. Analyzing Graphs					
	8. Graph Embeddings					
	9. Graph Embeddings for Complex Graphs					
	10. Graph Neural Networks (GNNs)					
	11. GNNs for Complex Graphs					
	12. GNNs for Text					
	13. Deep Generative Models for Text and Graphs					
Literature	 Chollet, F., & Allaire, J. J. (2018). Deep Learning mit R und Keras: Das Praxis-Handbuch von den Entwicklern von Keras und RStudio. MITP-Verlags GmbH & Co. KG. Hamilton, William L. (2020). Graph Representation Learning. Synthesis Lectures on Artificial Intelligence and Machine Learning, Vol. 14, No. 3, Pages 1-159. Hapke, H., Howard, C., & Lane, H. (2019). Natural Language Processing in Action: Understanding, analyzing, and generating text with Python. Simon and Schuster. Hvitfeldt, E., & Silge, J. (2021). Supervised machine learning for text analysis in R. Ma, Y., & Tang, J. (2021). Deep learning on graphs. Cambridge University Press. Rao, D., & McMahan, B. (2019). Natural language processing with PyTorch: build intelligent language applications using deep learning. O'Reilly Media, Inc. Silge, J., & Robinson, D. (2017). Text mining with R: A tidy approach. O'Reilly Media, Inc. 					

Module M0753: Softw	vare Verificatio	า					
Courses							
Title					Тур	Hrs/wk	СР
Software Verification (L0629)					Lecture	2	3
Software Verification (L0630)					Recitation Section (small)	2	3
Module Responsible	Prof. Sibylle Schupp						
Admission Requirements	None						
Recommended Previous	a Automoto theo	w, and farmalls					
Knowledge	Automata theo		inguages				
	Object-oriented	logic I programming	algorithms a	and data struct	uroc		
	Eunctional proc	ramming or pr	ocedural prog	ramming	ures.		
	Concurrency	furthing of pro-	occurran progr	running			
	concurrency						
Educational Objectives	After taking part succ	essfully, studer	nts have reach	ned the following	ng learning results		
Professional Competence							
Knowledge	•						
	Students apply the m	ajor verification	techniques ir	n model checki	ing and deductive verification	on. They explain ir	n formal terms synta:
	and semantics of the	underlying log	lics, and asse	ess the expres	sivity of different logics as	well as their limit	tations. They classify
	formal properties of s	oftware system	s. They find fl	aws in formal	arguments, arising from mo	deling artifacts or	underspecification.
Skills	Students formulate p	rovable propert	ies of a softwa	are system in a	a formal language. They de	velop logic-based	models that properly
	abstract from the sof	tware under ve	rification and.	where necess	arv. adapt model or prope	rty. They construct	proofs and property
	checks by hand or us	ng tools for mo	del checking d	or deductive v	erification, and reflect on th	e scope of the res	ults. Presented with
	verification problem i	n natural langua	age, they sele	ct the appropr	iate verification technique	and justify their ch	oice.
Personal Competence							
Social Competence	Students discuss rele	vant topics in cl	ass. They dete	end their solut	ions orally. They communic	ate in English.	
Autonomy	Using accompanying	on-line materi	al for self stu	udy, students	can assess their level of	knowledge contin	uously and adjust i
	appropriately. Worki	ng on exercise	problems, the	ey receive ad	ditional feedback. Within li	mits, they can se	t their own learning
	goals. Upon successf	I completion, s	tudents can ic	dentify and pre	ecisely formulate new probl	ems in academic o	or applied research in
	the field of software	verification. Wi	thin this field,	, they can con	duct independent studies t	o acquire the nec	essary competencies
	and compile their find	lings in academ	ic reports. The	ey can devise	plans to arrive at new solut	ions or assess exis	sting ones.
Workload in Hours	Indopondont Study Ti	mo 124 Study	Timo in Loctu	ro 56			
Credit points	6	ine 124, Study	Time in Lectu	10 50			
Course achievement	Compulsory Bonus	Form		Description			
course achievement	Yes 15 %	Excercises					
Examination	Written exam						
Examination duration and	90 min						
scale							
Assignment for the	Computer Science: Sp	ecialisation I. C	Computer and	Software Engi	neering: Elective Compulso	ry	
Following Curricula	Data Science: Special	isation IV. Spec	ial Focus Area	a: Elective Com	pulsory		
_	Data Science: Special	isation II. Comp	uter Science:	Elective Comp	oulsory		
	Computer Science in	Engineering: Sp	ecialisation I.	Computer Scie	ence: Elective Compulsory		
	Information and Com	munication Syst	ems: Speciali	sation Secure	and Dependable IT Systems	s: Compulsory	
	Information and Com	munication Syst	ems: Speciali	sation Commu	nication Systems, Focus So	ftware: Elective Co	ompulsory
	International Manage	ment and Engin	eering: Specia	alisation II. Info	ormation Technology: Electi	ve Compulsory	

Course L0629: Software Veri	fication
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	 Model checking (bounded model checking, CTL, LTL) Real-time model checking (TCTL, timed automata) Deductive verification (Hoare logic) Tool support Recent developments of verification techniques and applications
Literature	 C. Baier and J-P. Katoen, Principles of Model Checking, MIT Press 2007. M. Huth and M. Bryan, Logic in Computer Science. Modelling and Reasoning about Systems, 2nd Edition, 2004. Selected Research Papers

Course L0630: Software Verification			
Тур	Recitation Section (small)		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sibylle Schupp		
Language	EN		
Cycle	WiSe		
Content	See interlocking course		
Literature	See interlocking course		

Courses							
Title				Тур	Hrs/wk	СР	
Massively Parallel Systems: Architecture and Programming (L2936)			I	Lecture	2	3	
Massively Parallel Systems: Archite	ecture and Programming	(L2937)		Project-/problem-based Learning	2	3	
Module Responsible	Prof. Sohan Lal						
Admission Requirements	None						
Recommended Previous	An introductory modu	Ile on computer Enginee	ring or computer arc	hitecture, good programming	skills in C/C++		
Knowledge							
Educational Objectives	After taking part succ	essfully, students have r	eached the following	g learning results			
Professional Competence							
Kilowiedge	shared-memory para implementation, and correctness of share important topics of m accelerators such as systems, programmir API/libraries such as C	allel systems, multiproc limitations. Next, stude d-memory multithreaded hemory consistency and GPUs will also be discu ng them is also very chal CUDA/OpenCL/MPI/OpenN	essor cache coher nts study interconn d programs, indeper synchronization will issed in detail. Besi lenging. The course AP.	ence, snooping / directory-b ection networks and routing in dent of the speed of executi be covered in detail. As a ca des understanding the archite will also cover how to program	ased cache of in parallel sys ion of their in- se study, the a ecture and org n massively pa-	systems. They will be	
Personal Competence	able to evaluate diffe program parallel syst	erent design choices and ems (ranging from an en	I make decisions when the second s	ile designing a parallel system a supercomputer) using CUDA/	n. In addition, OpenCL/MPI/O	, they will be able to penMP.	
Social Competence	The course will enco teamwork.	ourage students to work	in small groups to	o solve complex problems, th	nus, inculcatin	g the importance o	
Autonomy	Today, parallel co computers independe the performance issu	emputers are present ently, but also understan es of parallel application	t everywhere. Si d their underlying o s and provide insigh	tudents will be able to rganization and architecture. ⁻ ts to improve them.	not only This will furthe	program paralle r help to understand	
Workload in Hours	Independent Study Ti	me 124, Study Time in L	ecture 56				
Credit points	6						
Course achievement	CompulsoryBonusYes20 %	Form Subject theoretical practical work	Description and				
Examination	Oral exam						
Examination duration and	25 min						
scale							
Assignment for the	Computer Science: Sp	pecialisation I. Computer	and Software Engin	eering: Elective Compulsory			
Following Curricula	Data Science: Special	isation II. Computer Scie	nce: Elective Compu	Ilsory			
	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory						
	Computer Science in	Engineering: Specialisati	on I. Computer Scier	nce: Elective Compulsory			
	Information and Com	munication Systems: Spe	ecialisation Commun	ication Systems, Focus Softwa	re: Elective Co	ompulsory	
	Microelectronics and	Microsystems: Specialisa	tion Embedded Syst	ems: Elective Compulsory			

Course L2936: Massively Par	allel Systems: Architecture and Programming
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	WiSe
Content	Brief outline:
	 Parallel computers and their classification Centralized and distributed shared-memory architectures: snooping vs directory-based cache coherence protocols, implementation, and limitations Chip multiprocessors: software-based, block (coarse-grain), interleaved (fine-grain), simultaneous multithreading Synchronization: high-level primitives and implementation, memory consistency models: sequential and weaker memory consistency models Interconnection networks: topologies (direct and indirect networks) and routing techniques Graphics Processing Units (GPUs) architecture and programming using CUDA/OpenCL Parallel programming with message passing interface (MPI), OpenMP
Literature	 Michel Dubois, Murali Annavaram, and Per Stenström, Parallel Computer Organization and Design (Book) David A Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, Elsevier (Book) David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book)

Course L2937: Massively Par	allel Systems: Architecture and Programming
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	WiSe
Content	 There will be 3-4 assignments for project-based learning consisting of the following: Implement and compare different cache coherence protocols using a simulator or a high-level, event-driven simulation interface such as SystemC Programming massively parallel systems to solve computationally intensive problems such as password cracking using CUDA/OpenCL/MPI/OpenMP
Literature	 The following literature will be useful for project-based learning. The further required resources will be discussed during the course. David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book) MPI Forum, https://www.mpi-forum.org/ SystemC, https://www.accellera.org/community/systemc

Module M1428: Linea	r and Nonlinea	Optimization						
Courses								
Title Linear and Nonlinear Optimization	(L2062)			Typ Lecture	Hrs/wk	CP 4		
Linear and Nonlinear Optimization	(L2063)			Recitation Section (large)	1	2		
Module Responsible	Prof. Matthias Mnich							
Admission Requirements	None							
Knowledge	 Discrete Algebric Mathematics I Graph Theory a 	aic Structures						
Educational Objectives	After taking part succ	essfully, students hav	e reached the follow	ing learning results				
Professional Competence Knowledge	 Students can name the basic concepts in linear and non-linear optimization. They are able to explain them using appropriat examples. Students can discuss logical connections between these concepts. They are capable of illustrating these connections wit the help of examples. They know proof strategies and can reproduce them. 							
Skills	 Students can i Moreover, they Students are al For a given pri results. 	nodel problems in lin are capable of solving ole to discover and ve oblem, the students of	ear and non-linear o g them by applying e rify further logical co can develop and exo	optimization with the help established methods. Innections between the con ecute a suitable approach,	of the concepts stu cepts studied in the and are able to cr	udied in this course. course. itically evaluate the		
Personal Competence Social Competence Autonomy	 Students are al In doing so, the design example Students are c precisely and k Students have problems. 	ole to work together in ey can communicate r es to check and deepe apable of checking th now where to get help developed sufficient	n teams. They are ca new concepts accord en the understanding eir understanding of p in solving them. persistence to be ai	pable to use mathematics a ling to the needs of their co of their peers. complex concepts on thei ble to work for longer peri	as a common langua poperating partners r own. They can sp iods in a goal-orien	age. . Moreover, they can ecify open questions ted manner on hard		
Workload in Hours	Independent Study Ti	me 110, Study Time ir	n Lecture 70					
Credit points	6							
Course achievement	Compulsory Bonus	Form Excercises	Description					
Examination	Written exam	Excercises						
Examination duration and scale	90 min							
Assignment for the	Computer Science: Sp	ecialisation III. Mathe	matics: Elective Com	pulsory				
Following Curricula	Data Science: Special Data Science: Special Computer Science in	sation I. Mathematics sation IV. Special Foc Engineering: Specialis	: Elective Compulsor us Area: Elective Cor ation III. Mathematic	y mpulsory s: Elective Compulsory				

Course L2062: Linear and No	nlinear Optimization
Тур	Lecture
Hrs/wk	4
CP	4
Workload in Hours	Independent Study Time 64, Study Time in Lecture 56
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	WiSe
Content	 Modelling linear programming problems Graphical method Algebraic background Convexity Polyhedral theory Simplex method Degeneracy and convergence duality interior-point methods quadratic optimization integer linear programming
Literature	 A. Schrijver: Combinatorial Optimization: Polyhedra and Efficiency. Springer, 2003 B. Korte and T. Vygen: Combinatorial Optimization: Theory and Algorithms. Springer, 2018 T. Cormen, Ch. Leiserson, R. Rivest, C. Stein: Introduction to Algorithms. MIT Press, 2013

Course L2063: Linear and Nonlinear Optimization	
Тур	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Courses						
litle .				Тур	Hrs/wk	СР
ntelligent Systems in Medicine (LO	331)			Lecture	2	3
ntelligent Systems in Medicine (LO	334)			Project Seminar	2	2
Medule Deepensible	555) Brof, Alexander Cabl	aafar		Recitation Section (Smail)	1	I
Admission Requirements	None	deler				
Recommended Previous	None					
Knowledge	 principles of n 	math (algebra, analysis/c	alculus)			
	 principles of s 	tochastics				
	 principles of p 	programming, Java/C++	and R/Matlab			
	 advanced pro 	gramming skills				
Educational Objectives	After taking part suc	cessfully, students have	reached the followin	g learning results		
Professional Competence						
Knowledge	The students are ab	le to analyze and solve	clinical treatment pla	anning and decision suppor	t problems using	methods for searc
	optimization, and pla	anning. They are able to	explain methods for	classification and their resp	ective advantage	es and disadvantag
	in clinical contexts.	The students can compa	re different methods	for representing medical k	nowledge. They o	an evaluate metho
	in the context of clin	nical data and explain c	hallenges due to the	clinical nature of the data	and its acquisition	on and due to priva
	and safety requirem	ents.				
Skills	The students can give	ve reasons for selecting	and adapting metho	ods for classification, regres	sion, and predict	tion. They can asse
	the methods based of	on actual patient data ar	nd evaluate the imple	emented methods.		-
Personal Competence						
Social Competence	work on them collaboratively.					
	work on them collaboratively. The students can critically reflect on the results of other groups, make constructive suggestions for improvement and also					
	incorporate them int	to their own work.	febulto of other gro		ggestions for m	
Autonomy	The students can assess their level of knowledge and document their work results. They can critically evaluate the results achieve					
	and present them in an appropriate argumentative manner to the other groups.					
Workload in Hours	Independent Study T	Time 110, Study Time in	Lecture 70			
Credit points	6 Commulating Renue	Form	Description			
Course achievement	Yes 10 %	Presentation	Description			
	Yes 10 %	Written elaboration				
Examination	Written exam					
Examination duration and	90 minutes					
scale						
Assignment for the	Computer Science: S	Specialisation II: Intellige	nce Engineering: Elec	ctive Compulsory		
Following Curricula	Data Science: Specia	alisation III. Applications:	Elective Compulsory	1		
	Data Science: Specia	alisation IV. Special Focu	s Area: Elective Com	pulsory		
	Electrical Engineerin	ig: Specialisation Medica	l Technology: Elective	e Compulsory		
	Interdisciplinary Mat	hematics: Specialisation	Computational Meth	ods in Biomedical Imaging:	Compulsory	
	Mechatronics: Specia	alisation Intelligent Syste	ems and Robotics: Ele	ective Compulsory		
	Mechatronics: Core (Qualification: Elective Co	mpulsory			
	Biomedical Engineer	ring: Specialisation Artific	cial Organs and Rege	nerative Medicine: Elective	Compulsory	
	Biomedical Engineer	ring: Specialisation Impla	ints and Endoprostne	ses: Elective Compulsory		
	Biomedical Engineer	ring: Specialisation Mana	gement and Business	s Administration: Elective C	ompuisory	
	Biomedical Engineer	ring: Specialization Modi	al Technology and C	ontrol Theory: Compulsory		

Course L0331: Intelligent Systems in Medicine		
Тур	Lecture	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Alexander Schlaefer	
Language	EN	
Cycle	WiSe	
Content	 methods for search, optimization, planning, classification, regression and prediction in a clinical context representation of medical knowledge understanding challenges due to clinical and patient related data and data acquisition The students will work in groups to apply the methods introduced during the lecture using problem based learning. 	
Literature	Russel & Norvig: Artificial Intelligence: a Modern Approach, 2012 Berner: Clinical Decision Support Systems: Theory and Practice, 2007 Greenes: Clinical Decision Support: The Road Ahead, 2007 Further literature will be given in the lecture	

Course L0334: Intelligent Systems in Medicine		
Тур	Project Seminar	
Hrs/wk	2	
CP	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Lecturer	Prof. Alexander Schlaefer	
Language	EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Course L0333: Intelligent Systems in Medicine	
Тур	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Courses				
Lourses				
Fitle		Тур	Hrs/wk	СР
Herarchical Algorithms (L0585)		Lecture Recitation Section (small)	2	3
	Duraf Caldina La Davia	Reclation Section (smail)	2	5
Module Responsible	Prof. Sabine Le Borne			
Admission Requirements	None			
Recommended Previous	• Mathematics I, II, III for Engineering students	(german or english) or Analysis & Linear	Algebra I + II as v	vell as Analysis III
Knowledge	Technomathematicians		-	-
	Programming experience in C			
Educational Objectives	After taking part successfully, students have reache	d the following learning results		
Professional Competence	After taking part successiony, students have reache	a the following learning results		
Knowlodge	Students are able to			
Knowledge				
	name representatives of hierarchical algorithm	ms and list their characteristics,		
	explain construction techniques for hierarchie	al algorithms,		
	 discuss aspects regarding the efficient impler 	mentation of hierarchical algorithms.		
Skills	Students are able to			
	 implement the hierarchical algorithms discuss 	sed in the lecture,		
	 analyse the storage and computational comp 	lexities of the algorithms,		
	 adapt algorithms to problem settings of vario 	us applications and thus develop problem	adapted variant	S.
Personal Competence				
Social Competence	Students are able to			
	work together in heterogeneously composed	teams (i.e., teams from different study p	rograms and back	kground knowledg
	explain theoretical foundations and support e	ach other with practical aspects regarding	g the implementa	ition of algorithms
Autonomy	Students are capable			
	- to concer whether the supportion the evolution	and avastical everyticas are better achiev	lindividually ar in	
	to assess whether the supporting theoretical	and practical excercises are better solved	i individualiy of ir	i a team,
	 to work on complex problems over an extend to access their individual progess and if page 	ed period of time,		
	• to assess their individual progess and, if nece	ssary, to ask questions and seek help.		
Workload in Hours	Independent Study Time 124, Study Time in Lecture	2 56		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	20 min			
scale				
Assignment for the	Computer Science: Specialisation III. Mathematics: E	Elective Compulsory		
Following Curricula	Data Science: Specialisation I. Mathematics: Elective	e Compulsory		
	Data Science: Specialisation IV. Special Focus Area:	Elective Compulsory		
	Technomathematics: Specialisation I. Mathematics:	Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisation S	Simulation Technology: Elective Compulso	ry	

Lourse LUS85: Hierarchical Algorithms	
Тур	Lecture
Hrs/wk	2
СР	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne
Language	DE/EN
Cycle	WiSe
Content	 Low rank matrices Separable expansions Hierarchical matrix partitions Hierarchical matrices Formatted matrix operations Applications Additional topics (e.g. H2 matrices, matrix functions, tensor products)
Literature	W. Hackbusch: Hierarchische Matrizen: Algorithmen und Analysis
Course L0586: Hierarchical Algorithms	
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Тур	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sabine Le Borne
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0676: Digita	al Communications				
Courses					
Title			Тур	Hrs/wk	СР
Digital Communications (L0444)			Lecture	2	3
Laboratory Digital Communications (L0445)	(1.0646)		Recitation Section (large)	2	2
Modulo Bosnonsible	Brof Corbord Pouch		Tractical Course	1	1
Admission Bequirements	None				
Recommended Previous					
Knowledge	 Mathematics 1-3 				
Kilomeuge	 Signals and Systems 				
	 Fundamentals of Communications a 	nd Random Processes	5		
Educational Objectives	After taking part successfully, students have	ve reached the followi	ng learning results		
Professional Competence			5 5		
Knowledge	The students are able to understand, comp	oare and design mode	rn digital information transmi	ssion schemes. T	hey are familiar wit
	the properties of linear and non-linear digi	tal modulation metho	ds. They can describe distort	ons caused by tr	ansmission channel
	and design and evaluate detectors inclu	ding channel estimat	ion and equalization. They	now the princip	oles of single carrie
	transmission and multi-carrier transmission	n as well as the funda	mentals of basic multiple acco	ess schemes.	
	The students are familiar with the contents	s of lecture and tutoria	als. They can explain and app	y them to new p	roblems.
Skills	The students are able to design and analy	se a digital informatio	n transmission scheme includ	ling multiple acc	ess. They are able t
	choose a digital modulation scheme taking	into account transmi	ssion rate, required bandwidt	h, error probabili	ty, and further signa
	properties. They can design an approp	oriate detector inclu	ding channel estimation an	d equalization	taking into accoun
	performance and complexity properties of	suboptimum solutions	s. They are able to set parame	eters of a single of	arrier or multi carrie
	transmission scheme and trade the proper	ties of both approache	es against each other.	-	
Personal Competence			-		
Social Competence	The students can jointly solve specific prob	olems.			
Autonomy	The students are able to acquire releva	ant information from	appropriate literature source	es. They can c	ontrol their level o
	knowledge during the lecture period by sol	lving tutorial problems	s, software tools, clicker syste	m.	
Workload in Hours	Independent Study Time 110, Study Time	in Lecture 70			
Credit points	6				
Course achievement	Compulsory Bonus Form	Description			
	Yes None Written elaboration				
Examination	Written exam				
Examination duration and	90 min				
scale					
Assignment for the	Data Science: Specialisation II. Computer S	Science: Elective Com	pulsory		
Following Curricula	Data Science: Specialisation IV. Special For	cus Area: Elective Con	npulsory		
	Electrical Engineering: Core Qualification: 0	Compulsory			
	Computer Science in Engineering: Specialis	sation II. Engineering	Science: Elective Compulsory		
	Information and Communication Systems:	Specialisation Commu	unication Systems: Compulsor	У	
	Information and Communication Systems:	Specialisation Secure	and Dependable IT Systems,	Focus Networks:	Elective Compulsor
	International Management and Engineering	g: Specialisation II. Inf	ormation Technology: Elective	e Compulsory	
	International Management and Engineering	g: Specialisation II. Ele	ectrical Engineering: Elective	Compulsory	
	Microelectronics and Microsystems: Core Q	ualification: Elective (Compulsory		

Course L0444: Digital Comm	unications
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	Papetition Decelord Transmission
	Nepetition. Baseballo Transmission Dulse shaning: Non-return to zero (NR7) rectangular pulses, raised-cosine pulses, square-root raised-cosine pulses
	 Power spectral density (psd) of baseband signals
	 Intersymbol interference (ISI)
	 First and second Nyquist criterion
	AWGN channel
	Matched filter
	Matched-filter receiver and correlation receiver
	Noise whitening matched filter
	Discrete-time AWGN channel model
	 Representation of bandpass signals and systems in the equivalent baseband
	Quadrature amplitude modulation (QAM)
	 Equivalent baseband signal and system
	Analytical signal
	 Equivalent baseband random process, equivalent baseband white Gaussian noise process

- Equivalent baseband AWGN channel
- $\circ~$ Equivalent baseband channel model with frequency-offset and phase noise
- Equivalent baseband Rayleigh fading and Rice fading channel models
- Equivalent baseband frequency-selective channel model
- Discrete memoryless channels (DMC)
- Bandpass transmission via carrier modulation
 - Amplitude modulation, frequency modulation, phase modulation
 - Linear digital modulation methods
 - On-off keying, M-ary amplitude shift keying (M-ASK), M-ary phase shift keying (M-PSK), M-ary quadrature amplitude modulation (M-QAM), offset-QPSK
 - Signal space representation of transmit signal constellations and signals
 - Energy of linear digital modulated signals, average energy per symbol
 - Power spectral density of linear digital modulated signals
 - Bandwidth efficiency
 - Correlation coefficient of elementary signals
 - Error probabilities of linear digital modulation methods
 - Error functions
 - Gray mapping and natural mapping
 - Bit error probabilities, symbol error probabilities, pairwise symbol error probabilities
 - Euclidean distance and Hamming distance
 - Exact and approximate computation of error probabilities
 - Performance comparison of modulation schemes in terms of per bit SNR vs. per symbol SNR
 - Hierarchical modulation, multilevel modulation
 - Effects of carrier phase offset and carrier frequency offset
 - Differential modulation
 - M-ary differential phase shift keying (M-PSK)
 - Coherent and non-coherent detection of DPSK
 - p/M-differential phase shift keying (p/M-DPSK)
 - Differential amplitude and phase shift keying (DAPSK)
 - Non-linear digital modulation methods
 - Frequency shift keying (FSK)
 - Modulation index
 - Minimum shift keying (MSK)
 - Offset-QPSK representation of MSK
 - MSK with differential precoding and rotation
 - Bit error probabilities of MSK
 - Gaussian minimum shift keying (GMSK)
 - Power spectral density of MSK and GMSK
 - Continuous phase modulation (CPM)
 - General description of CPM signals
 - Frequency pulses and phase pulses
 - Coherent and non-coherent detection of FSK
 - Performance comparison of linear and non-linear digital modulation methods
- Frequency-selective channels, ISI channels
 - Intersymbol interference and frequency-selectivity
 - RMS delay spread
 - Narrowband and broadband channels
 - Equivalent baseband transmission model for frequency-selective channels
 - Receive filter design
- Equalization
 - Symbol-spaced and fractionally-spaced equalizers
 - Inverse system
 - Non-recursive linear equalizers
 - Linear zero-forcing (ZF) equalizer
 - Linear minimum mean squared error (MMSE) equalizer
 - Non-linear equalization:
 - Decision feedback equalizer (DFE)
 - Tomlinson-Harashima precoding
 - Maximum a posteriori probability (MAP) and maximum likelihood equalizer, Viterbi algorithm
- Single-carrier vs. multi-carrier transmission
- Multi-carrier transmission
 - General multicarrier transmission
 - Orthogonal frequency division multiplex (OFDM)
 - OFDM implementation using the Fast Fourier Transform (FFT)
 - Cyclic guard interval
 - Power spectral density of OFDM
 - Peak-to-average power ratio (PAPR)
- Multiple access
 - Principles of time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), non-orthogonal multiple access (NOMA), hybrid multiple access
- Spread spectrum communications
 - Direct sequence spread spectrum communications
 - Frequency hopping
 - Protection against eavesdropping
 - Protection against narrowband jammers

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	 Short vs. long spreading codes Direct sequence spread spectrum communications in frequency-selective channels Rake receiver Code division multiple access (CDMA) Design criteria of spreading sequences, autocorrelation function and crosscorrelation function of spreading
	 sequences Intersymbol interference (ISI) and multiple access interference (MAI) Pseudo noise (PN) sequences, maximum length sequences (m-sequences), Gold codes, Walsh-Hadamard codes, orthogonal variable spreading factor (OVSF) codes Multicode transmission CDMA in uplink and downlink of a wireless communications system Single-user detection vs. multi-user detection
Literature	K. Kammeyer: Nachrichtenübertragung, Teubner
	P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.
	J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.
	S. Haykin: Communication Systems. Wiley
	R.G. Gallager: Principles of Digital Communication. Cambridge
	A. Goldsmith: Wireless Communication. Cambridge.
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.

Course L0445: Digital Communications	
Тур	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0646: Laboratory Digital Communications	
Тур	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/EN
Cycle	WiSe
Content	- DSL transmission
	- Random processes - Digital data transmission
Literature	K. Kammeyer: Nachrichtenübertragung, Teubner P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner. J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill. S. Haykin: Communication Systems. Wiley R.G. Gallager: Principles of Digital Communication. Cambridge A. Goldsmith: Wireless Communication. Cambridge.
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.

	Thesis
Module M-002: Maste	er Thesis
Courses	
Title	Typ Hrs/wk CP
Module Responsible	Professoren der TUHH
Admission Requirements	According to General Regulations §21 (1):
	At least 50 gradit points have to be achieved in study programme. The evaminations heard decides an exceptions
	At least do treut points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous	
Knowledge	A Grande Line and a supervised by the device and the definition of the state of the
Educational Objectives	After taking part successfully, students have reached the following learning results
Knowledge	
	 The students can use specialized knowledge (facts, theories, and methods) of their subject competently on specialized
	issues.
	 The students can explain in depth the relevant approaches and terminologies in one of more areas of their subject, describing current developments and taking up a critical position on them.
	• The students can place a research task in their subject area in its context and describe and critically assess the state of
	research.
Chille	
SKIIIS	The students are able:
	• To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question.
	 To apply knowledge they have acquired and methods they have learnt in the course of their studies to complex and/or incompletely defined problems in a solution-oriented way.
	 To develop new scientific findings in their subject area and subject them to a critical assessment.
Social Competence	Students can
Social competence	
	Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured
	 Deal with issues competently in an expert discussion and answer them in a manner that is appropriate to the addressees
	while upholding their own assessments and viewpoints convincingly.
Autonomy	Students are able:
	 To structure a project of their own in work packages and to work them off accordingly.
	• To work their way in depth into a largely unknown subject and to access the information required for them to do so.
	 To apply the techniques of scientific work comprehensively in research of their own.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination Examination duration and	I hesis
scale	
Assignment for the	Civil Engineering: Thesis: Compulsory
Following Curricula	Bioprocess Engineering: Thesis: Compulsory
	Chemical and Bioprocess Engineering: Thesis: Compulsory
	Data Science: Thesis: Compulsory
	Electrical Engineering: Thesis: Compulsory
	Energy Systems: Thesis: Compulsory
	Environmental Engineering: Thesis: Compulsory
	Aircraft Systems Engineering: Thesis: Compulsory
	Computer Science in Engineering: Thesis: Compulsory
	Information and Communication Systems: Thesis: Compulsory
	Interdisciplinary Mathematics: Thesis: Compulsory
	International Production Management: Thesis: Compulsory
	International Management and Engineering: Thesis: Compulsory Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory
	Logistics, Infrastructure and Mobility: Thesis: Compulsory
	Aeronautics: Thesis: Compulsory
	Materials Science and Engineering: Thesis: Compulsory
	Materials Science: Thesis: Compulsory
	Mechatronics: Thesis: Compulsory
	Biomedical Engineering: Thesis: Compulsory

Microelectronics and Microsystems: Thesis: Compulsory
Product Development, Materials and Production: Thesis: Compulsory
Renewable Energies: Thesis: Compulsory
Naval Architecture and Ocean Engineering: Thesis: Compulsory
Ship and Offshore Technology: Thesis: Compulsory
Teilstudiengang Lehramt Metalltechnik: Thesis: Compulsory
Theoretical Mechanical Engineering: Thesis: Compulsory
Process Engineering: Thesis: Compulsory
Water and Environmental Engineering: Thesis: Compulsory
Certification in Engineering & Advisory in Aviation: Thesis: Compulsory