TUHH
Hamburg
University of
Technology

Module Manual

Master of Science (M.Sc.)

Data Science

Cohort: Winter Term 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.
2. 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
- 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: Business & Management

Module Responsible	Prof. Matthias Meyer
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• 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.
Skills	• 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: Advanced Machine Learning

Courses

Title	Typ	Hrs/wk	CP
Advanced Machine Learning (L2322)	Lecture	2	3
Advanced Machine Learning (L2323)	Recitation Section (small)	2	3

Module Responsible	Dr. Jens-Peter Zemke
Admission Requirements	None
Recommended Previous Knowledge	1. Mathematics I-III 2. Numerical Mathematics 1/ Numerics 3. Programming skills, preferably in Python
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to name, state and classify state-of-the-art neural networks and their corresponding mathematical basics. They can assess the difficulties of different neural networks.
Skills	Students are able to implement, understand, and, tailored to the field of application, apply neural 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 necessary, 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 scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory 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 Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2322: Advanced Machine Learning

Typ	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	1. Basics: analogy; layout of neural nets, universal approximation, NP-completeness 2. Feedforward nets: backpropagation, variants of Stochastistic Gradients 3. Deep Learning: problems and solution strategies 4. Deep Belief Networks: energy based models, Contrastive Divergence 5. CNN: idea, layout, FFT and Winograds algorithms, implementation details 6. RNN: idea, dynamical systems, training, LSTM 7. ResNN: idea, relation to neural ODEs 8. Standard libraries: Tensorflow, Keras, PyTorch 9. Recent trends
Literature	1. Skript 2. Online-Werke: ∘ http://neuralnetworksanddeeplearning.com/ ∘ https://www.deeplearningbook.org/

Course L2323: Advanced Machine Learning	
Typ	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.
Personal Competence	
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 writen form or verbaly • to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
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 M1871: Big Data

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
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 Knowledge	• Good software engineering and implementation skills are very important for the practical part of this module • Previous knowledge in the fields of Distributed Systems and Databases is helpful
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 basic concepts of methods and technologies to process and store very large amounts of data • 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 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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	Group project incl. presentation, written exam
Assignment for the Following Curricula	Data Science: Core Qualification: Compulsory

Course L3101: Big Data

Typ	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 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

Typ	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: Statistical Models

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Statistical Models (L3116)	Lecture	3	4
Statistical Models (L3118)	Recitation Section (small)	1	2

Module Responsible	Prof. Matthias Schulte
Admission Requirements	None
Recommended Previous Knowledge	Preknowledge in probability and statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students know the fundamental statistical models and are able to explain them using appropriate examples. • Students can discuss logical connections between these concepts and are capable of illustrating these connections with the help of examples. • Students know proof strategies and can reproduce them.
Skills	• Students can investigate statistical problems with the help of the models studied in the course. • 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 approach, 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 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 precisely and know where to get help in solving them. • Students can put their knowledge in relation to the contents of other lectures. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard 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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Core Qualification: Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L3116: Statistical Models	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. 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	
Typ	Recitation Section (small)
Hrs/wk	1
CP	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

Module M1563: Research Project Computer Science

Courses

Title	Typ	Hrs/wk	CP
Research Project Computer Science (L2353)	Projection Course	8	12

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge and techniques from the Master courses in the semesters 1 and 2.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to acquire advanced knowledge in a subfield of Computer Science and can independently acquire deeper knowledge in the field.
Skills	The students are able to formulate the scientific problems to be considered and to work out solutions in an independent manner and to realize them.
Personal Competence	
Social Competence	The students are able to discuss proposals for solutions of scientific problems within the team. They are able to present the results in a clear and well structured manner.
Autonomy	The students can provide a scientific work in a timely manner and document the results in a detailed and well readable form. They are able to actively follow anticipate the presentations of other students such that eventually a scientific discussion comes up.
Workload in Hours	Independent Study Time 248, Study Time in Lecture 112
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	Vortrag
Assignment for the Following Curricula	Computer Science: Core Qualification: Compulsory Data Science: Core Qualification: Compulsory

Course L2353: Research Project Computer Science

Typ	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: Scientific Methods

Courses

Title	Typ	Hrs/wk	CP
Scientific Methods (L3088)	Lecture	2	3

Module Responsible	Prof. Stefan Schulte
Admission Requirements	None
Recommended Previous Knowledge	Students should have first experiences with the principles of research work. Usually, this was acquired while working on the 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 LaTeX • Visualization of scientific results
Skills	After successful completion of the course, students are able to: • Assess which research methods from the fields of Computer Science, Data Science and related disciplines are suitable for which problems, • describe and apply the steps necessary to carry out a particular research method, • structure a scientific text, • review and cite scientific sources, • apply Best Practice scientific behavior, • conduct evaluations and visualize their results, and • apply scientific methods within their Master theses.
Personal Competence	
Social Competence	Students are able to work on complex scientific questions and to present their results.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	Group project (written elaboration)
Assignment for the Following Curricula	Data Science: Core Qualification: Compulsory

Course L3088: Scientific Methods

Typ	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: Advanced Seminar Computer Science and Communication Technology

Courses

Title	Typ	Hrs/wk	CP
Advanced Seminar Computer Science and Communication Technology I (L2352)	Seminar	2	3

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of Computer Science and Mathematics at the Master's level as well as first expertise in the area of scientific working, especially investigating a scientific topic as well as conceptual design and creation of scientific (survey) articles. Furthermore, knowledge in the presentation of scientific topics is helpful.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to • explicate a specific topic in the field of Computer Science, • describe complex issues, and • present different views and evaluate in a critical 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 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 audience, • discuss the topic, content and structure of the presentation with the instructor, • discuss certain aspects with the audience, and • as the presenter listen and respond to questions 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 investigation, presentation, and writing.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Presentation
Examination duration and scale	x
Assignment for the Following Curricula	Data Science: Core Qualification: Compulsory

Course L2352: Advanced Seminar Computer Science and Communication Technology I

Typ	Seminar
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/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: Hierarchical Algorithms

Courses

Title	Typ	Hrs/wk	CP
Hierarchical Algorithms (L0585)	Lecture	2	3
Hierarchical Algorithms (L0586)	Recitation Section (small)	2	3

Module Responsible	Prof. Sabine Le Borne
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics I, II, III for Engineering students (german or english) or Analysis & Linear Algebra I + II as well as Analysis III for Technomathematicians • Programming experience in C
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • name representatives of hierarchical algorithms and list their characteristics, • explain construction techniques for hierarchical algorithms, • discuss aspects regarding the efficient implementation of hierarchical algorithms.
Skills	Students are able to • implement the hierarchical algorithms discussed 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 variants.
Personal Competence	
Social Competence	Students are able to • work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the supporting theoretical and practical excercises are better solved individually or in a team, • to work on complex problems over an extended period of time, • to assess their individual progess and, if necessary, 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	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory

Course L0585: Hierarchical Algorithms

Typ	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	
Typ	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: Linear and Nonlinear Optimization

Courses

Title	Typ	Hrs/wk	CP
Linear and Nonlinear Optimization (L2062)	Lecture	4	4
Linear and Nonlinear Optimization (L2063)	Recitation Section (large)	1	2

Module Responsible	Prof. Matthias Mnich
Admission Requirements	None
Recommended Previous Knowledge	• Discrete Algebraic Structures • Mathematics I • Graph Theory and Optimization
Educational Objectives	After taking part successfully, students have reached the following 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.
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	• Students are able to work together in teams. They are capable to use mathematics as a common language. • 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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard problems.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 20 % / Excercises /
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory

Course L2062: Linear and Nonlinear Optimization	
Typ	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	
Typ	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: Matrix Algorithms

Courses

Title	Typ	Hrs/wk	CP
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 Knowledge	• Mathematics I - III • Numerical Mathematics 1/ Numerics • Basic knowledge of the programming languages Matlab and C
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to 1. name, state and classify state-of-the-art Krylov subspace methods for the solution of the core problems of the engineering sciences, namely, eigenvalue problems, solution of linear systems, and model reduction; 2. state approaches for the solution of matrix equations (Sylvester, Lyapunov, Riccati).
Skills	Students are capable to 1. implement and assess basic Krylov subspace methods for the solution of eigenvalue problems, linear systems, and model reduction; 2. assess methods used in modern software with respect to computing time, stability, and domain of applicability; 3. adapt the approaches learned to new, unknown types of problem.
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 necessary, 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	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory

Course L0984: Matrix Algorithms	
Typ	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: 1. Saad, Yousef. Numerical methods for large eigenvalue problems: revised edition. Society for Industrial and Applied Mathematics, 2011. 2. Saad, Yousef. Iterative methods for sparse linear systems. Society for Industrial and Applied Mathematics, 2003. 3. Van der Vorst, Henk A. Iterative Krylov methods for large linear systems. No. 13. Cambridge University Press, 2003. 4. Liesen, Jörg, and Zdenek Strakos. Krylov subspace methods: principles and analysis. Oxford University Press, 2013.

Course L0985: Matrix Algorithms	
Typ	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: Numerical Mathematics II

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
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 reached the following learning results
Professional Competence	
Knowledge	Students are able to • name advanced numerical methods for interpolation, approximation, integration, eigenvalue problems, eigenvalue problems, nonlinear root finding problems and explain their core ideas, • repeat convergence statements for the numerical methods, sketch convergence proofs, • explain practical aspects of numerical methods concerning runtime and storage needs • explain aspects regarding the practical implementation of numerical methods with respect to computational and storage complexity.
Skills	Students are able to • implement, apply and compare advanced numerical methods in Python, • justify the convergence behaviour of numerical methods with respect to the problem and solution algorithm and to transfer it to related problems, • for a given problem, develop a suitable solution approach, if necessary through composition of several algorithms, to execute this approach and to critically evaluate the results
Personal Competence	
Social Competence	Students are able to • work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the supporting theoretical and practical excercises are better solved individually or in a team, • to assess their individual progess and, if necessary, 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	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L0568: Numerical Mathematics II	
Typ	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	1. Error and stability: Notions and estimates 2. Rational interpolation and approximation 3. Multidimensional interpolation (RBF) and approximation (neural nets) 4. Quadrature: Gaussian quadrature, orthogonal polynomials 5. Linear systems: Perturbation theory of decompositions, structured matrices 6. Eigenvalue problems: LR-, QD-, QR-Algorithmus 7. Nonlinear systems of equations: Newton and Quasi-Newton methods, line search (optional) 8. Krylov space methods: Arnoldi-, Lanczos methods (optional)
Literature	• Skript • Stoer/Bulirsch: Numerische Mathematik 1, Springer • Dahmen, Reusken: Numerik für Ingenieure und Naturwissenschaftler, Springer

Course L0569: Numerical Mathematics II	
Typ	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: Information Theory and Coding

Courses

Title	Typ	Hrs/wk	CP
Information Theory and Coding (L0436)	Lecture	3	4
Information Theory and Coding (L0438)	Recitation Section (large)	2	2

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Probability theory and random processes • Basic knowledge of communications engineering (e.g. from lecture "Fundamentals of Communications 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 quantification of information in the sense of information theory. They know Shannon's source coding theorem and channel coding theorem and are able to determine theoretical limits of data compression and error-free data transmission over noisy channels. They understand the principles of source coding as well as error-detecting and error-correcting channel coding. They are familiar with the principles of decoding, in particular 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 and tutorials. They can explain and apply 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 capabilities, decoding delay, decoding complexity and to decide for a suitable method. They are capable of implementing basic 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 information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory

Course L0436: Information Theory and Coding

Typ	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

  - 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), non-orthogonal 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 - Trellis coded modulation (TCM) - Set partitioning - Ungerböck 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. 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	
Typ	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	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1405: Randomised Algorithms and Random Graphs

Courses

Title	Typ	Hrs/wk	CP
Randomised Algorithms and Random Graphs (L2010)	Lecture	2	3
Randomised Algorithms and Random Graphs (L2011)	Recitation Section (large)	2	3

Module Responsible	Prof. Anusch Taraz
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can describe basic concepts in the area of Randomized Algorithms and Random Graphs such as random walks, tail bounds, fingerprinting and algebraic techniques, first and second moment methods, and various random graph models. 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 apply them.
Skills	• Students can model problems 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 in teams. They are capable to establish a common language. • 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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard 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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory

Course L2010: Randomised Algorithms and Random Graphs	
Typ	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	
Typ	Recitation Section (large)
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	See interlocking course
Literature	See interlocking course

Module M0714: Numerical Methods for Ordinary Differential Equations

Courses

Title	Typ	Hrs/wk	CP
Numerical Treatment of Ordinary Differential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary Differential Equations (L0582)	Recitation Section (small)	2	3

Module Responsible	Prof. Daniel Ruprecht
Admission Requirements	None
Recommended Previous Knowledge	• Mathematik I, II, III for Engineers (German or English) or Analysis & Linear Algebra I + II plus Analysis III for Technomathematiker. • Basic knowledge of MATLAB, Python or a similar 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 ordinary differential equations and explain their core ideas, • formulate convergence statements for the taught numerical methods (including the necessary assumptions about the solved problem), • explain aspects regarding the practical realisation of a method, • select the appropriate numerical method for specific problems, implement the numerical algorithms efficiently and interpret the numerical results.
Skills	Students are able to • implement, apply and compare numerical methods for the solution of ordinary differential equations, • explain the convergence behaviour of numerical methods, taking into consideration the solved problem and selected algorithm, • develop a suitable solution approach for a given problem, if necessary by combining multiple algorithms, 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 programs and with different background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the provided theoretical and practical excercises are better solved individually or in a team and • to assess their individual progress and, if necessary, 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 scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0576: Numerical Treatment of Ordinary Differential Equations	
Typ	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 Treatment of Ordinary Differential Equations	
Typ	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 M1668: Probability Theory

Courses

Title	Typ	Hrs/wk	CP
Probability Theory (L2643)	Lecture	3	4
Probability Theory (L2644)	Recitation Section (small)	1	2

Module Responsible	Prof. Matthias Schulte
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with the basic concepts of probability
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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students can put their knowledge in relation to the contents of other lectures. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard 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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory

Course L2643: Probability Theory	
Typ	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	
Typ	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 Processing

Courses

Title	Typ	Hrs/wk	CP
Image Processing (L2443)	Lecture	2	4
Image Processing (L2444)	Recitation Section (small)	2	2

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Signal and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about • visual perception • multidimensional signal processing • sampling and sampling theorem • filtering • image enhancement • edge detection • multi-resolution procedures: Gauss and Laplace pyramid, wavelets • image compression • image segmentation • morphological image processing
Skills	The students can • analyze, process, and improve multidimensional image data • implement simple compression algorithms • design custom filters for specific applications
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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	90 min
Assignment for the Following Curricula	Data Science: Core Qualification: Elective Compulsory Data Science: Specialisation I. Mathematics/Computer Science: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2443: Image Processing	
Typ	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	
Typ	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

Module M1694: Security of Cyber-Physical Systems

Courses

Title	Typ	Hrs/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 Knowledge	IT security, programming skills, statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
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 guarantee - standard security engineering processes for CPS
Skills	The students are able to - identify security threats and assess the risks for a given CPS - apply attack toolkits to analyse a networked control system, and detect attacks beyond those taught in class - identify and apply security solutions suitable 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 incidents of CPS and their mitigation in a solution-oriented fashion with experts and non-experts - foster a security culture with respect to CPS and the corresponding critical infrastructures
Autonomy	The students are able to - follow up and critically assess current developments in the security of CPS including relevant security incidents - master a new topic within the area by self-study and self-initiated interaction with experts and peers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory**: No; **Bonus**: 10 %; **Form**: Excercises; **Description**: Die Übungsaufgaben finden semesterbegleitend statt.
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L2691: Security of Cyber-Physical Systems	
Typ	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	
Typ	Recitation Section (small)
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	See interlocking course
Literature	See interlocking course

Module M1780: Massively Parallel Systems: Architecture and Programming

Courses

Title	Typ	Hrs/wk	CP
Massively Parallel Systems: Architecture and Programming (L2936)	Lecture	2	3
Massively Parallel Systems: Architecture and Programming (L2937)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Sohan Lal
Admission Requirements	None
Recommended Previous Knowledge	An introductory module on computer Engineering or computer architecture, good programming skills in C/C++.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The course starts with parallel computers classification, multithreading, and covers the architecture of centralized and distributed shared-memory parallel systems, multiprocessor cache coherence, snooping / directory-based cache coherence protocols, implementation, and limitations. Next, students study interconnection networks and routing in parallel systems. To ensure the correctness of shared-memory multithreaded programs, independent of the speed of execution of their individual threads, the important topics of memory consistency and synchronization will be covered in detail. As a case study, the architecture of a few accelerators such as GPUs will also be discussed in detail. Besides understanding the architecture and organization of parallel systems, programming them is also very challenging. The course will also cover how to program massively parallel systems using API/libraries such as CUDA/OpenCL/MPI/OpenMP.
Skills	After completing this course, students will be able to understand the architecture and organization of parallel systems. They will be able to evaluate different design choices and make decisions while designing a parallel system. In addition, they will be able to program parallel systems (ranging from an embedded system to a supercomputer) using CUDA/OpenCL/MPI/OpenMP.
Personal Competence	
Social Competence	The course will encourage students to work in small groups to solve complex problems, thus, inculcating the importance of teamwork.
Autonomy	Today, parallel computers are present everywhere. Students will be able to not only program parallel computers independently, but also understand their underlying organization and architecture. This will further help to understand the performance issues of parallel applications and provide insights to improve them.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 20 %; **Form** Subject theoretical and practical work; **Description**
Examination	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2936: Massively Parallel Systems: Architecture and Programming

Typ	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 Parallel Systems: Architecture and Programming	
Typ	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 M0753: Software Verification

Courses

Title	Typ	Hrs/wk	CP
Software Verification (L0629)	Lecture	2	3
Software Verification (L0630)	Recitation Section (small)	2	3

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Automata theory and formal languages • Computational logic • Object-oriented programming, algorithms, and data structures • Functional programming or procedural programming • Concurrency
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major verification techniques in model checking and deductive verification. They explain in formal terms syntax and semantics of the underlying logics, and assess the expressivity of different logics as well as their limitations. They classify formal properties of software systems. They find flaws in formal arguments, arising from modeling artifacts or underspecification.
Skills	Students formulate provable properties of a software system in a formal language. They develop logic-based models that properly abstract from the software under verification and, where necessary, adapt model or property. They construct proofs and property checks by hand or using tools for model checking or deductive verification, and reflect on the scope of the results. Presented with a verification problem in natural language, they select the appropriate verification technique and justify their choice.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Using accompanying on-line material for self study, students can assess their level of knowledge continuously and adjust it appropriately. Working on exercise problems, they receive additional feedback. Within limits, they can set their own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of software verification. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. They can devise plans to arrive at new solutions or assess existing ones.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes, **Bonus** 15 %, **Form** Excercises, **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0629: Software Verification

Typ	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	
Typ	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: Digital Communications

Courses

Title	Typ	Hrs/wk	CP
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 Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of Communications and Random Processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and design modern digital information transmission schemes. They are familiar with the properties of linear and non-linear digital modulation methods. They can describe distortions caused by transmission channels and design and evaluate detectors including channel estimation and equalization. They know the principles of single carrier transmission and multi-carrier transmission as well as the fundamentals of basic multiple access schemes. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to design and analyse a digital information transmission scheme including multiple access. They are able to choose a digital modulation scheme taking into account transmission rate, required bandwidth, error probability, and further signal properties. They can design an appropriate detector including channel estimation and equalization taking into account performance and complexity properties of suboptimum solutions. They are able to set parameters of a single carrier or multi carrier transmission scheme and trade the properties of both approaches against each other.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes · **Bonus** None · **Form** Written elaboration · **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Core Qualification: Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0444: Digital Communications

Typ	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	• Repetition: Baseband Transmission
	  ◦ Pulse shaping: Non-return to zero (NRZ) 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
    - 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

	◦ 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	
Typ	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	
Typ	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.

Module M1774: Advanced Internet Computing

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Advanced Internet Computing (L2916)	Lecture	2	3
Advanced Internet Computing (L2917)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Stefan Schulte
Admission Requirements	None
Recommended Previous Knowledge	Good programming skills are necessary. Previous knowledge in the field of distributed systems is helpful.
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 basic concepts of Cloud Computing, the Internet of Things (IoT), and blockchain technologies • Discuss and assess critical aspects of Cloud Computing, the IoT, and blockchain 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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	Group project incl. presentation (50 %), written exam (60 min, 50 %)
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2916: Advanced Internet Computing

Typ	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 Internet Computing	
Typ	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 M1301: Software Testing

Courses

Title	Typ	Hrs/wk	CP
Software Testing (L1791)	Lecture	2	3
Software Testing (L1792)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Software Engineering • Higher Programming Languages • Object-Oriented Programming • Algorithms and Data Structures • Experience with (Small) Software Projects • Statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students explain the different phases of testing, describe fundamental techniques of different types of testing, and paraphrase the basic principles 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 Competence	Students discuss relevant topics in class. They defend their solutions orally. 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, they can own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. T devise plans to arrive at new solutions or assess existing ones
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 scale	Software
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory 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 Compulsory

Course L1791: Software Testing	
Typ	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	
Typ	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
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.

Module M1682: Secure Software Engineering

Courses

Title	Typ	Hrs/wk	CP
Secure Software Engineering (L2667)	Lecture	2	3
Secure Software Engineering (L2668)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with basic software engineering concepts (e.g., requirements, design) and basic security concepts (e.g., confidentiality, integrity, availability)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Elicit security requirements in a software project • Model and document security measures in a software design • Use threat and risk analysis techniques • Understand how security code reviews are performed • Understand the core definitions of concepts related to privacy • Understand privacy enhancing technologies
Skills	Select appropriate security assurance techniques to be used in a security assurance program
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 independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 5 % / Subject theoretical and practical work / Gruppenarbeit mit aktuellen Technologien aus dem Bereich Sicherheit
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory 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 Compulsory

Course L2667: Secure Software Engineering	
Typ	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	• 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	
Typ	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 M1842: GPU Architectures and Programming

Courses

Title	Typ	Hrs/wk	CP
GPU Architectures and Programming (L3039)	Lecture	2	3
GPU Architectures and Programming (L3040)	Project-/problem-based Learning	4	3

Module Responsible	Prof. Sohan Lal
Admission Requirements	None
Recommended Previous Knowledge	An introductory module on computer engineering or computer architecture, and good programming skills in C/C++.
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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L3039: GPU Architectures and Programming

Typ	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	
Typ	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: Autonomous Cyber-Physical Systems

Courses

Title	Typ	Hrs/wk	CP
Autonomous Cyber-Physical Systems (L3000)	Lecture	2	3
Autonomous Cyber-Physical Systems (L3001)	Recitation Section (small)	2	3

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	• Very good knowledge and practical experience in programming in the C/C++ language (e.g., module: Procedural Programming for Computer Scientists) • Basic knowledge in software engineering • Basic knowledge in wired and wireless communication protocols • Principal understanding of simple electronic 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 methods for monitoring the environment, infrastructure, etc. Essential aspects in the implementation of such systems are their networking, especially based on wireless technologies, and their autonomous operation, especially on the basis of regenerative energy sources. After successfully attending this event, the students are able to • to present the special features of cyber-physical systems and the associated challenges and concepts, • describe and evaluate wired and wireless communication on different layers of the ISO/OSI model, • explain and compare methods of regenerative energy production, • discuss and evaluate procedures for the autonomous and self-sufficient operation of such systems.
Skills	Students will be able to • to implement programs for cyber-physical systems in high-level languages and using existing libraries, • to assess which communication and networking protocols can be used most sensibly in which application and to use them in real scenarios, • select and implement suitable methods for adapting the tasks based on the energy consumption and the future expected energy yield, • plan and evaluate scientific experiments.
Personal Competence	
Social Competence	After completing the module, the students are able to work on similar tasks alone or in a group and to present the results in a suitable way.
Autonomy	After completing the module, the students are able to independently work on sub-areas of the subject using specialist literature, to summarize and present the knowledge they have acquired and to link it to the content of other 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 scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory

Course L3000: Autonomous Cyber-Physical Systems

Typ	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	
Typ	Recitation Section (small)
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	See interlocking course
Literature	See interlocking course

Module M1773: Cybersecurity Data Science

Courses

Title	Typ	Hrs/wk	CP
Cybersecurity Data Science (L2914)	Lecture	2	3
Exercise Cybersecurity Data Science (L2915)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of probabilities and statistics. Familiarity with object oriented programming.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Apply data science methods to the resolution of complex cybersecurity problems. • Use of data science methods to quantify risks and optimize cybersecurity operations. • Identify strengths and limitations of state-of-the-art methods • Select the performance indicators of data-oriented cybersecurity solutions. • 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
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 independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** No; **Bonus** 5 %; **Form** Subject theoretical and practical work; **Description** Gruppenarbeit mit aktuellen Technologien aus dem Bereich Sicherheit
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L2914: Cybersecurity Data Science	
Typ	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., 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] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). 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 Cybersecurity Data Science	
Typ	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 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] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). 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.

Module M1794: Applied Cryptography

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Applied Cryptography (L2954)	Lecture	3	4
Applied Cryptography (L2955)	Recitation Section (small)	1	2

Module Responsible	Prof. Sibylle Fröschle
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	**Compulsory** / **Bonus** / **Form** / **Description** No / 10 % / Excercises / Die Übungsaufgaben finden semesterbegleitend statt
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2954: Applied Cryptography

Typ	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

Typ	Recitation Section (small)
Hrs/wk	1
CP	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: Software for Embedded Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
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 Knowledge	• Very Good knowledge and practical experience in programming in the C language and its compilation process • Basic knowledge in software engineering • Basic understanding of assembly language • Basic knowledge of electrical engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students know the basic principles and procedures of software engineering for embedded systems. • They are able to describe the usage and advantages of event-based programming using interrupts. • They know the components and functions of a concrete microcontroller. • The participants explain requirements of real time systems. • They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	• Students design and write hardware-oriented software modules for an embedded system based on a specific microcontroller. • They learn to interact with peripherals (timer, ADC, EEPROM), including interrupt-based processing and program flow. • They build and use a (preemptive) scheduler 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. • They learn and broaden their teamwork abilities. • They learn to define and split tasks within the team.
Autonomy	Students are able • 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 description. • to read and understand data sheets and manuals of electronic components (such as micro-controllers and sensors)
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 10 % · **Form** Attestation · **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1069: Software for Embdedded Systems	
Typ	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	1. Embedded System Design, F. Vahid and T. Givargis, John Wiley 2. Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly 3. C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP 4. The Art of Designing Embedded Systems, J. Ganssle, Newnses 5. Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg 6. Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

Course L1070: Software for Embdedded Systems	
Typ	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

Specialization III. Applications

Module M0623: Intelligent Systems in Medicine

Courses

Title	Typ	Hrs/wk	CP
Intelligent Systems in Medicine (L0331)	Lecture	2	3
Intelligent Systems in Medicine (L0334)	Project Seminar	2	2
Intelligent Systems in Medicine (L0333)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of stochastics • principles of programming, Java/C++ and R/Matlab • advanced programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to analyze and solve clinical treatment planning and decision support problems using methods for search, optimization, and planning. They are able to explain methods for classification and their respective advantages and disadvantages in clinical contexts. The students can compare different methods for representing medical knowledge. They can evaluate methods in the context of clinical data and explain challenges due to the clinical nature of the data and its acquisition and due to privacy and safety requirements.
Skills	The students can give reasons for selecting and adapting methods for classification, regression, and prediction. They can assess the methods based on actual patient data and evaluate the implemented methods.
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 can critically reflect on the results of other groups, make constructive suggestions for improvement and also incorporate them into their own work.
Autonomy	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 Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 10 % / Written elaboration Yes / 10 % / Presentation
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective 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	
Typ	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	
Typ	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	
Typ	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

Module M1302: Applied Humanoid Robotics

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Applied Humanoid Robotics (L1794)	Project-/problem-based Learning	6	6

Module Responsible	Patrick Göttsch
Admission Requirements	None
Recommended Previous Knowledge	• Object oriented programming; algorithms and data structures • Introduction to control systems • Control systems theory and design • Mechanics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain humanoid robots. • Students can explain the basic concepts, relationships and methods of forward- and inverse kinematics • Students learn to apply basic control concepts for different tasks in humanoid robotics.
Skills	• Students can implement models for humanoid robotic systems in Matlab and C++, and use these models for robot motion or other tasks. • They are capable of using models in Matlab for simulation and testing these models if necessary 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 teams and present these. • They can provide appropriate feedback to others, and constructively handle feedback on their own results
Autonomy	• Students are able to obtain required information from provided literature sources, and to put in into the context of the lecture. • They can independently define tasks and apply the appropriate means to solve them.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	5-10 pages
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1794: Applied Humanoid Robotics

Typ	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: Digital Health

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Digital Health (L3099)	Lecture	3	3
Digital Health Seminar (L3100)	Project-/problem-based Learning	3	3

Module Responsible	Prof. Moritz Göldner
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 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 20 % / Excercises / Erfolgreiche Teilnahme PBL-Übung
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory

Course L3099: Digital Health

Typ	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

Typ	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: Machine Learning for Physical Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Machine Learning for Physical Systems (L2987)	Lecture	2	3
Machine Learning for Physical Systems (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 scale	60 min
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Advanced Materials: Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Engineering Science: Specialisation Advanced Materials: Compulsory Engineering Science: Specialisation Advanced Materials: Elective Compulsory Mechatronics: Specialisation Dynamic Systems and AI: Elective Compulsory Mechatronics: Specialisation Robot- and Machine-Systems: Elective Compulsory

Course L2987: Machine Learning for Physical Systems

Typ	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

Typ	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: Medical Imaging

Courses

Title	Typ	Hrs/wk	CP
Medical Imaging (L1694)	Lecture	2	3
Medical Imaging (L1695)	Recitation Section (small)	2	3

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in linear algebra, numerics, and signal processing
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module, students are able to describe reconstruction methods for different tomographic imaging modalities such as computed tomography and magnetic resonance imaging. They know the necessary basics from the fields of signal processing and inverse problems and are familiar with both analytical and iterative image reconstruction methods. The students have a deepened knowledge of the imaging operators of computed tomography and magnetic resonance imaging.
Skills	The students are able to implement reconstruction methods and test them using tomographic measurement data. They can visualize the reconstructed images and evaluate the quality of their data and results. In addition, students can estimate the temporal complexity of imaging algorithms.
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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Technomathematics: Specialisation II. Informatics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L1694: Medical Imaging

Typ	Lecture
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	• 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**; Z.-P. Liang and P. C. Lauterbur; IEEE Press, New York, 1999

Course L1695: Medical Imaging	
Typ	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: Operational Aspekts in Aviation

Courses

Title	Typ	Hrs/wk	CP
Airline Operations (L1310)	Lecture	3	3
Flight Guidance I (Introduction) (L0848)	Lecture	2	2
Flight Guidance I (Introduction) (L0854)	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 Knowledge	Air Transportation Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Analysis and description of the interaction between people and aircraft in operation
Skills	Understanding and application of design and calculation methods Understanding of interdisciplinary and integrative interdependencies Evaluation of operational issues in aviation and development 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 solutions structured task analysis and definition of solutions
Workload in Hours	Depends on choice of courses
Credit points	6
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory International Management and Engineering: Specialisation II. Aviation Systems: Elective Compulsory International Management and Engineering: Specialisation II. Logistics: Elective Compulsory Logistics, Infrastructure and Mobility: Specialisation Production and Logistics: Elective Compulsory Logistics, Infrastructure and Mobility: Specialisation Infrastructure and Mobility: Elective Compulsory

Course L1310: Airline Operations

Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Klausur
Examination duration and scale	90 min
Lecturer	Prof. Volker Gollnick, Dr. Karl Echtermeyer
Language	DE
Cycle	SoSe
Content	1. Introdution and overview 2. Airline business models 3. Interdependencies in flight planning (network management, slot management, netzwork structures, aircraft circulation) 4. Operative flight preparation (weight & balance, payload/range, etc.) 5. fleet policy 6. Aircraft assessment and fleet planning 7. Airline organisation 8. 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)	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
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 aircraft attitude (magnetic field- and inertial 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)	
Typ	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 scale	60 min
Lecturer	Prof. Volker Gollnick
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L1276: Airport Operations	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Klausur
Examination duration and scale	90 min
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	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Prof. Volker Gollnick, Dr. Ulrich Häp
Language	DE
Cycle	WiSe
Content	1. Introduction, definitions, overviewg 2. Runway systems 3. Air space strucutres around airports 4. Airfield lightings, marking and information 5. 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	
Typ	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 scale	60 min
Lecturer	Prof. Volker Gollnick, Dr. Ulrich Häp
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L2376: Aviation and Environment	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Klausur
Examination duration and scale	90 min
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 flying ◦ Atmospheric influences on flight performance ◦ Flight 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 flight planning ◦ Environmental policy measures, e.g. EU-ETS, CORSIA ◦ 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. Brüning, X. Hafer, G. Sachs: Flugleistungen, Springer, 1993

Module M1884: Data-Driven Innovation

Courses

Title	Typ	Hrs/wk	CP
Data-Driven Innovation (L3114)	Lecture	3	3
Data-Driven Innovation Seminar (L3115)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Moritz Göldner
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 20 %; **Form** Excercises; **Description** Erfolgreiche Teilnahme PBL-Übung
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	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

Typ	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

Typ	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: Robotics and Navigation in Medicine

Courses

Title	Typ	Hrs/wk	CP
Robotics and Navigation in Medicine (L0335)	Lecture	2	3
Robotics and Navigation in Medicine (L0338)	Project Seminar	2	2
Robotics and Navigation in Medicine (L0336)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of programming, e.g., in Java or C++ • solid R or Matlab skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can explain kinematics and tracking systems in clinical contexts and illustrate systems and their components in detail. Systems can be evaluated with respect to collision detection and safety and regulations. Students can assess typical systems regarding design and limitations.
Skills	The students are able to design and evaluate navigation systems and robotic systems for medical applications.
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 software management tools. The students can critically reflect on the results of other groups, make constructive suggestions for improvement, and also incorporate them into their own work.
Autonomy	The students can assess their level of knowledge and independently control their learning processes on this basis as well as 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 Time in Lecture 70
Credit points	6
Course achievement	**Compulsory / Bonus / Form / Description** Yes / 10 % / Written elaboration Yes / 10 % / Presentation
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0335: Robotics and Navigation in Medicine	
Typ	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	
Typ	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	
Typ	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	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

Title	Typ	Hrs/wk	CP
General Introduction Machine Learning (L3004)	Lecture	1	2
Machine Learning Applications in Electric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnetic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequency Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Communications (L3005)	Lecture	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know basic machine learning concepts and learning strategies. They are aware of specific opportunities, challenges and approaches of machine learning in various fields of electrical engineering. They know exemplary applications of machine learning in electrical engineering. The students are familiar with the contents of the module courses. They can explain and apply them to new problems.
Skills	The students are able to apply methods from machine learning to problems in electrical engineering. They are able to determine, dimension and implement suitable approaches such as types of deep learning networks and learning strategies for specific engineering problems. In particular, they are able to include domain knowledge in machine learning architectures and learning strategies. They are able to critically assess the learning results based on domain knowledge.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period e.g. by solving tutorial problems or using software tools.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	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
	  ◦ 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	
Typ	Lecture
Hrs/wk	1
CP	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	
Typ	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.

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	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	
Typ	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: Causal Data Science for Business Analytics

Courses

Title	Typ	Hrs/wk	CP
Business Analytics with Causal Data 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 Knowledge	- Linear Algebra - 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 “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 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 confounding factors. - programming in relevant programming languages. - selection of the appropriate method depending on the problem.
Personal Competence	
Social Competence	Students can work on the problems both individually and in groups during the exercise times and also ask questions and contribute to the solution of other people's problems outside the exercise times in a dedicated forum for the course (Mattermost). 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 them to new learning content. To obtain information and solve problems, especially those related to programming errors, they learn 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 scale	Solutions to coding problem sets after each class session
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L3096: Business Analytics with Causal Data Science	
Typ	Project-/problem-based Learning
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
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 Science	
Typ	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
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.

Module M1880: Deep Learning for Social Analytics

Courses

Title	Typ	Hrs/wk	CP
Deep Learning for Text and Graphs (L3097)	Lecture	2	3
Social Analytics with Deep Learning (L3098)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Christoph Ihl
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of Python • Familiarity with probability theory, linear algebra and statistics
Educational Objectives	After taking part successfully, students have reached 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	
Social Competence	• Collaboration on projects and assignments • Communication regarding computational, algorithmic and modeling challenges
Autonomy	• Maneuver in the field of deep learning including scientific literature and models • Solve computational, algorithmic, and modeling challenges related to deep learning models • Critical thinking skills • Self-sufficient problem-solving regarding coding issues
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 scale	Solutions to coding problem sets after each class session
Assignment for the Following Curricula	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L3097: Deep Learning for Text and Graphs	
Typ	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	WiSe
Content	Today, 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: 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 Analytics with Deep Learning	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Christoph Ihl
Language	EN
Cycle	WiSe
Content	Today, 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: 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: Machine Learning for Physical Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Machine Learning for Physical Systems (L2987)	Lecture	2	3
Machine Learning for Physical Systems (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 scale	60 min
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Advanced Materials: Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Engineering Science: Specialisation Advanced Materials: Compulsory Engineering Science: Specialisation Advanced Materials: Elective Compulsory Mechatronics: Specialisation Dynamic Systems and AI: Elective Compulsory Mechatronics: Specialisation Robot- and Machine-Systems: Elective Compulsory

Course L2987: Machine Learning for Physical Systems

Typ	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

Typ	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: Medical Imaging

Courses

Title	Typ	Hrs/wk	CP
Medical Imaging (L1694)	Lecture	2	3
Medical Imaging (L1695)	Recitation Section (small)	2	3

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in linear algebra, numerics, and signal processing
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module, students are able to describe reconstruction methods for different tomographic imaging modalities such as computed tomography and magnetic resonance imaging. They know the necessary basics from the fields of signal processing and inverse problems and are familiar with both analytical and iterative image reconstruction methods. The students have a deepened knowledge of the imaging operators of computed tomography and magnetic resonance imaging.
Skills	The students are able to implement reconstruction methods and test them using tomographic measurement data. They can visualize the reconstructed images and evaluate the quality of their data and results. In addition, students can estimate the temporal complexity of imaging algorithms.
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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Technomathematics: Specialisation II. Informatics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L1694: Medical Imaging

Typ	Lecture
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	• 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**; Z.-P. Liang and P. C. Lauterbur; IEEE Press, New York, 1999

Course L1695: Medical Imaging	
Typ	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: Applied Humanoid Robotics

Courses

Title	Typ	Hrs/wk	CP
Applied Humanoid Robotics (L1794)	Project-/problem-based Learning	6	6

Module Responsible	Patrick Göttsch
Admission Requirements	None
Recommended Previous Knowledge	• Object oriented programming; algorithms and data structures • Introduction to control systems • Control systems theory and design • Mechanics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain humanoid robots. • Students can explain the basic concepts, relationships and methods of forward- and inverse kinematics • Students learn to apply basic control concepts for different tasks in humanoid robotics.
Skills	• Students can implement models for humanoid robotic systems in Matlab and C++, and use these models for robot motion or other tasks. • They are capable of using models in Matlab for simulation and testing these models if necessary 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 teams and present these. • They can provide appropriate feedback to others, and constructively handle feedback on their own results
Autonomy	• Students are able to obtain required information from provided literature sources, and to put in into the context of the lecture. • They can independently define tasks and apply the appropriate means to solve them.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	5-10 pages
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1794: Applied Humanoid Robotics

Typ	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 M1668: Probability Theory

Courses

Title	Typ	Hrs/wk	CP
Probability Theory (L2643)	Lecture	3	4
Probability Theory (L2644)	Recitation Section (small)	1	2

Module Responsible	Prof. Matthias Schulte
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with the basic concepts of probability
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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students can put their knowledge in relation to the contents of other lectures. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard 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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory

Course L2643: Probability Theory	
Typ	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	
Typ	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 M1301: Software Testing

Courses

Title	Typ	Hrs/wk	CP
Software Testing (L1791)	Lecture	2	3
Software Testing (L1792)	Project-/problem-based Learning	2	3

Module Responsible
Prof. Sibylle Schupp

Admission Requirements
None

Recommended Previous Knowledge

- Software Engineering
- Higher Programming Languages
- Object-Oriented Programming
- Algorithms and Data Structures
- Experience with (Small) Software Projects
- Statistics

Educational Objectives
After taking part successfully, students have reached the following learning results

Professional Competence

Knowledge

Students explain the different phases of testing, describe fundamental techniques of different types of testing, and paraphrase the basic principles 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 Competence
Students discuss relevant topics in class. They defend their solutions orally.
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, they can own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. T devise plans to arrive at new solutions or assess existing ones

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 scale
Software

Assignment for the Following Curricula
Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory
Data Science: Specialisation II. Computer Science: Elective Compulsory
Data Science: Specialisation IV. Special Focus Area: Elective Compulsory
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 Compulsory

Course L1791: Software Testing	
Typ	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	
Typ	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
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.

Module M1884: Data-Driven Innovation

Courses

Title	Typ	Hrs/wk	CP
Data-Driven Innovation (L3114)	Lecture	3	3
Data-Driven Innovation Seminar (L3115)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Moritz Göldner
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 20 %; **Form** Excercises; **Description** Erfolgreiche Teilnahme PBL-Übung
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	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

Typ	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

Typ	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	**Typ**	**Hrs/wk**	**CP**
GPU Architectures and Programming (L3039)	Lecture	2	3
GPU Architectures and Programming (L3040)	Project-/problem-based Learning	4	3

Module Responsible	Prof. Sohan Lal
Admission Requirements	None
Recommended Previous Knowledge	An introductory module on computer engineering or computer architecture, and good programming skills in C/C++.
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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L3039: GPU Architectures and Programming

Typ	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	
Typ	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 M1794: Applied Cryptography

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Applied Cryptography (L2954)	Lecture	3	4
Applied Cryptography (L2955)	Recitation Section (small)	1	2

Module Responsible	Prof. Sibylle Fröschle
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	**Compulsory** No; **Bonus** 10 %; **Form** Excercises; **Description** Die Übungsaufgaben finden semesterbegleitend statt
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2954: Applied Cryptography

Typ	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

Typ	Recitation Section (small)
Hrs/wk	1
CP	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: Autonomous Cyber-Physical Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Autonomous Cyber-Physical Systems (L3000)	Lecture	2	3
Autonomous Cyber-Physical Systems (L3001)	Recitation Section (small)	2	3

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	• Very good knowledge and practical experience in programming in the C/C++ language (e.g., module: Procedural Programming for Computer Scientists) • Basic knowledge in software engineering • Basic knowledge in wired and wireless communication protocols • Principal understanding of simple electronic 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 methods for monitoring the environment, infrastructure, etc. Essential aspects in the implementation of such systems are their networking, especially based on wireless technologies, and their autonomous operation, especially on the basis of regenerative energy sources. After successfully attending this event, the students are able to • to present the special features of cyber-physical systems and the associated challenges and concepts, • describe and evaluate wired and wireless communication on different layers of the ISO/OSI model, • explain and compare methods of regenerative energy production, • discuss and evaluate procedures for the autonomous and self-sufficient operation of such systems.
Skills	Students will be able to • to implement programs for cyber-physical systems in high-level languages and using existing libraries, • to assess which communication and networking protocols can be used most sensibly in which application and to use them in real scenarios, • select and implement suitable methods for adapting the tasks based on the energy consumption and the future expected energy yield, • plan and evaluate scientific experiments.
Personal Competence	
Social Competence	After completing the module, the students are able to work on similar tasks alone or in a group and to present the results in a suitable way.
Autonomy	After completing the module, the students are able to independently work on sub-areas of the subject using specialist literature, to summarize and present the knowledge they have acquired and to link it to the content of other courses.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 10 % · **Form** Attestation · **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory

Course L3000: Autonomous Cyber-Physical Systems

Typ	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	
Typ	Recitation Section (small)
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	See interlocking course
Literature	See interlocking course

Module M1773: Cybersecurity Data Science

Courses

Title	Typ	Hrs/wk	CP
Cybersecurity Data Science (L2914)	Lecture	2	3
Exercise Cybersecurity Data Science (L2915)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of probabilities and statistics. Familiarity with object oriented programming.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Apply data science methods to the resolution of complex cybersecurity problems. • Use of data science methods to quantify risks and optimize cybersecurity operations. • Identify strengths and limitations of state-of-the-art methods • Select the performance indicators of data-oriented cybersecurity solutions. • 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
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 independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 5 % · **Form** Subject theoretical and practical work · **Description** Gruppenarbeit mit aktuellen Technologien aus dem Bereich Sicherheit
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L2914: Cybersecurity Data Science	
Typ	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., 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] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). 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 Cybersecurity Data Science	
Typ	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 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] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). 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.

Module M0924: Software for Embedded Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
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 Knowledge	• Very Good knowledge and practical experience in programming in the C language and its compilation process • Basic knowledge in software engineering • Basic understanding of assembly language • Basic knowledge of electrical engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students know the basic principles and procedures of software engineering for embedded systems. • They are able to describe the usage and advantages of event-based programming using interrupts. • They know the components and functions of a concrete microcontroller. • The participants explain requirements of real time systems. • They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	• Students design and write hardware-oriented software modules for an embedded system based on a specific microcontroller. • They learn to interact with peripherals (timer, ADC, EEPROM), including interrupt-based processing and program flow. • They build and use a (preemptive) scheduler 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. • They learn and broaden their teamwork abilities. • They learn to define and split tasks within the team.
Autonomy	Students are able • 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 description. • to read and understand data sheets and manuals of electronic components (such as micro-controllers and sensors)
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No · **Bonus** 10 % · **Form** Attestation · **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1069: Software for Embdedded Systems	
Typ	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	1. Embedded System Design, F. Vahid and T. Givargis, John Wiley 2. Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly 3. C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP 4. The Art of Designing Embedded Systems, J. Ganssle, Newnses 5. Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg 6. Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

Course L1070: Software for Embdedded Systems	
Typ	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: Secure Software Engineering

Courses

Title	Typ	Hrs/wk	CP
Secure Software Engineering (L2667)	Lecture	2	3
Secure Software Engineering (L2668)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with basic software engineering concepts (e.g., requirements, design) and basic security concepts (e.g., confidentiality, integrity, availability)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Elicit security requirements in a software project • Model and document security measures in a software design • Use threat and risk analysis techniques • Understand how security code reviews are performed • Understand the core definitions of concepts related to privacy • Understand privacy enhancing technologies
Skills	Select appropriate security assurance techniques to be used in a security assurance program
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 independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 5 % / Subject theoretical and practical work / Gruppenarbeit mit aktuellen Technologien aus dem Bereich Sicherheit
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory 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 Compulsory

Course L2667: Secure Software Engineering	
Typ	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	• 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	
Typ	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: Robotics and Navigation in Medicine

Courses

Title	Typ	Hrs/wk	CP
Robotics and Navigation in Medicine (L0335)	Lecture	2	3
Robotics and Navigation in Medicine (L0338)	Project Seminar	2	2
Robotics and Navigation in Medicine (L0336)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of programming, e.g., in Java or C++ • solid R or Matlab skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can explain kinematics and tracking systems in clinical contexts and illustrate systems and their components in detail. Systems can be evaluated with respect to collision detection and safety and regulations. Students can assess typical systems regarding design and limitations.
Skills	The students are able to design and evaluate navigation systems and robotic systems for medical applications.
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 software management tools. The students can critically reflect on the results of other groups, make constructive suggestions for improvement, and also incorporate them into their own work.
Autonomy	The students can assess their level of knowledge and independently control their learning processes on this basis as well as 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 Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 10 % / Written elaboration Yes / 10 % / Presentation
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0335: Robotics and Navigation in Medicine	
Typ	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	
Typ	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	
Typ	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	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1921: Technical Complementary Course for DSMS (according to Subject Specific Regulations)

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	See selected module according to Subject Specific Regulations
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 Following Curricula	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory

Module M1879: Causal Data Science for Business Analytics

Courses

Title	Typ	Hrs/wk	CP
Business Analytics with Causal Data 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 Knowledge	- Linear Algebra - 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 “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 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 confounding factors. - programming in relevant programming languages. - selection of the appropriate method depending on the problem.
Personal Competence	
Social Competence	Students can work on the problems both individually and in groups during the exercise times and also ask questions and contribute to the solution of other people's problems outside the exercise times in a dedicated forum for the course (Mattermost). 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 them to new learning content. To obtain information and solve problems, especially those related to programming errors, they learn 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 scale	Solutions to coding problem sets after each class session
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L3096: Business Analytics with Causal Data Science	
Typ	Project-/problem-based Learning
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
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 Science	
Typ	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
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.

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

Title	Typ	Hrs/wk	CP
General Introduction Machine Learning (L3004)	Lecture	1	2
Machine Learning Applications in Electric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnetic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequency Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Communications (L3005)	Lecture	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know basic machine learning concepts and learning strategies. They are aware of specific opportunities, challenges and approaches of machine learning in various fields of electrical engineering. They know exemplary applications of machine learning in electrical engineering. The students are familiar with the contents of the module courses. They can explain and apply them to new problems.
Skills	The students are able to apply methods from machine learning to problems in electrical engineering. They are able to determine, dimension and implement suitable approaches such as types of deep learning networks and learning strategies for specific engineering problems. In particular, they are able to include domain knowledge in machine learning architectures and learning strategies. They are able to critically assess the learning results based on domain knowledge.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period e.g. by solving tutorial problems or using software tools.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	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 ◦ 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	
Typ	Lecture
Hrs/wk	1
CP	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	
Typ	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.

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	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	
Typ	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 M1405: Randomised Algorithms and Random Graphs

Courses

Title	Typ	Hrs/wk	CP
Randomised Algorithms and Random Graphs (L2010)	Lecture	2	3
Randomised Algorithms and Random Graphs (L2011)	Recitation Section (large)	2	3

Module Responsible	Prof. Anusch Taraz
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can describe basic concepts in the area of Randomized Algorithms and Random Graphs such as random walks, tail bounds, fingerprinting and algebraic techniques, first and second moment methods, and various random graph models. 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 apply them.
Skills	• Students can model problems 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 in teams. They are capable to establish a common language. • 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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard 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 scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory

Course L2010: Randomised Algorithms and Random Graphs	
Typ	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	
Typ	Recitation Section (large)
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	See interlocking course
Literature	See interlocking course

Module M0711: Numerical Mathematics II

Courses

Title	Typ	Hrs/wk	CP
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 reached the following learning results
Professional Competence	
Knowledge	Students are able to • name advanced numerical methods for interpolation, approximation, integration, eigenvalue problems, eigenvalue problems, nonlinear root finding problems and explain their core ideas, • repeat convergence statements for the numerical methods, sketch convergence proofs, • explain practical aspects of numerical methods concerning runtime and storage needs • explain aspects regarding the practical implementation of numerical methods with respect to computational and storage complexity.
Skills	Students are able to • implement, apply and compare advanced numerical methods in Python, • justify the convergence behaviour of numerical methods with respect to the problem and solution algorithm and to transfer it to related problems, • for a given problem, develop a suitable solution approach, if necessary through composition of several algorithms, to execute this approach and to critically evaluate the results
Personal Competence	
Social Competence	Students are able to • work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the supporting theoretical and practical excercises are better solved individually or in a team, • to assess their individual progess and, if necessary, 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	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L0568: Numerical Mathematics II	
Typ	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	1. Error and stability: Notions and estimates 2. Rational interpolation and approximation 3. Multidimensional interpolation (RBF) and approximation (neural nets) 4. Quadrature: Gaussian quadrature, orthogonal polynomials 5. Linear systems: Perturbation theory of decompositions, structured matrices 6. Eigenvalue problems: LR-, QD-, QR-Algorithmus 7. Nonlinear systems of equations: Newton and Quasi-Newton methods, line search (optional) 8. Krylov space methods: Arnoldi-, Lanczos methods (optional)
Literature	• Skript • Stoer/Bulirsch: Numerische Mathematik 1, Springer • Dahmen, Reusken: Numerik für Ingenieure und Naturwissenschaftler, Springer

Course L0569: Numerical Mathematics II	
Typ	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: Advanced Internet Computing

Courses

Title	Typ	Hrs/wk	CP
Advanced Internet Computing (L2916)	Lecture	2	3
Advanced Internet Computing (L2917)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Stefan Schulte
Admission Requirements	None
Recommended Previous Knowledge	Good programming skills are necessary. Previous knowledge in the field of distributed systems is helpful.
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 basic concepts of Cloud Computing, the Internet of Things (IoT), and blockchain technologies • Discuss and assess critical aspects of Cloud Computing, the IoT, and blockchain 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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	Group project incl. presentation (50 %), written exam (60 min, 50 %)
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2916: Advanced Internet Computing

Typ	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 Internet Computing	
Typ	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: Numerical Methods for Ordinary Differential Equations

Courses

Title	Typ	Hrs/wk	CP
Numerical Treatment of Ordinary Differential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary Differential Equations (L0582)	Recitation Section (small)	2	3

Module Responsible	Prof. Daniel Ruprecht
Admission Requirements	None
Recommended Previous Knowledge	• Mathematik I, II, III for Engineers (German or English) or Analysis & Linear Algebra I + II plus Analysis III for Technomathematiker. • Basic knowledge of MATLAB, Python or a similar 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 ordinary differential equations and explain their core ideas, • formulate convergence statements for the taught numerical methods (including the necessary assumptions about the solved problem), • explain aspects regarding the practical realisation of a method, • select the appropriate numerical method for specific problems, implement the numerical algorithms efficiently and interpret the numerical results.
Skills	Students are able to • implement, apply and compare numerical methods for the solution of ordinary differential equations, • explain the convergence behaviour of numerical methods, taking into consideration the solved problem and selected algorithm, • develop a suitable solution approach for a given problem, if necessary by combining multiple algorithms, 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 programs and with different background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the provided theoretical and practical excercises are better solved individually or in a team and • to assess their individual progress and, if necessary, 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 scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0576: Numerical Treatment of Ordinary Differential Equations	
Typ	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 Treatment of Ordinary Differential Equations	
Typ	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: Information Theory and Coding

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Information Theory and Coding (L0436)	Lecture	3	4
Information Theory and Coding (L0438)	Recitation Section (large)	2	2

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Probability theory and random processes • Basic knowledge of communications engineering (e.g. from lecture "Fundamentals of Communications 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 quantification of information in the sense of information theory. They know Shannon's source coding theorem and channel coding theorem and are able to determine theoretical limits of data compression and error-free data transmission over noisy channels. They understand the principles of source coding as well as error-detecting and error-correcting channel coding. They are familiar with the principles of decoding, in particular 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 and tutorials. They can explain and apply 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 capabilities, decoding delay, decoding complexity and to decide for a suitable method. They are capable of implementing basic 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 information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory

Course L0436: Information Theory and Coding

Typ	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

  - 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), non-orthogonal 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 ▪ Trellis coded modulation (TCM) ▪ Set partitioning ▪ Ungerböck 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. 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	
Typ	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	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1881: Digital Health

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Digital Health (L3099)	Lecture	3	3
Digital Health Seminar (L3100)	Project-/problem-based Learning	3	3

Module Responsible	Prof. Moritz Göldner
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 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes / **Bonus** 20 % / **Form** Excercises / **Description** Erfolgreiche Teilnahme PBL-Übung
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory

Course L3099: Digital Health

Typ	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

Typ	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: Matrix Algorithms

Courses

Title	Typ	Hrs/wk	CP
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 Knowledge	• Mathematics I - III • Numerical Mathematics 1/ Numerics • Basic knowledge of the programming languages Matlab and C
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to 1. name, state and classify state-of-the-art Krylov subspace methods for the solution of the core problems of the engineering sciences, namely, eigenvalue problems, solution of linear systems, and model reduction; 2. state approaches for the solution of matrix equations (Sylvester, Lyapunov, Riccati).
Skills	Students are capable to 1. implement and assess basic Krylov subspace methods for the solution of eigenvalue problems, linear systems, and model reduction; 2. assess methods used in modern software with respect to computing time, stability, and domain of applicability; 3. adapt the approaches learned to new, unknown types of problem.
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 necessary, 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	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory

Course L0984: Matrix Algorithms	
Typ	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: 1. Saad, Yousef. Numerical methods for large eigenvalue problems: revised edition. Society for Industrial and Applied Mathematics, 2011. 2. Saad, Yousef. Iterative methods for sparse linear systems. Society for Industrial and Applied Mathematics, 2003. 3. Van der Vorst, Henk A. Iterative Krylov methods for large linear systems. No. 13. Cambridge University Press, 2003. 4. Liesen, Jörg, and Zdenek Strakos. Krylov subspace methods: principles and analysis. Oxford University Press, 2013.

Course L0985: Matrix Algorithms	
Typ	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 Processing

Courses

Title	Typ	Hrs/wk	CP
Image Processing (L2443)	Lecture	2	4
Image Processing (L2444)	Recitation Section (small)	2	2

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Signal and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about • visual perception • multidimensional signal processing • sampling and sampling theorem • filtering • image enhancement • edge detection • multi-resolution procedures: Gauss and Laplace pyramid, wavelets • image compression • image segmentation • morphological image processing
Skills	The students can • analyze, process, and improve multidimensional image data • implement simple compression algorithms • design custom filters for specific applications
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	Students are able to independently investigate a complex problem and assess which competencies are required 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 scale	90 min
Assignment for the Following Curricula	Data Science: Core Qualification: Elective Compulsory Data Science: Specialisation I. Mathematics/Computer Science: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2443: Image Processing	
Typ	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	
Typ	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

Module M1694: Security of Cyber-Physical Systems

Courses			
Title	**Typ**	**Hrs/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 Knowledge	IT security, programming skills, statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
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 guarantee - standard security engineering processes for CPS
Skills	The students are able to - identify security threats and assess the risks for a given CPS - apply attack toolkits to analyse a networked control system, and detect attacks beyond those taught in class - identify and apply security solutions suitable 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 incidents of CPS and their mitigation in a solution-oriented fashion with experts and non-experts - foster a security culture with respect to CPS and the corresponding critical infrastructures
Autonomy	The students are able to - follow up and critically assess current developments in the security of CPS including relevant security incidents - master a new topic within the area by self-study and self-initiated interaction with experts and peers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 10 % / Excercises / Die Übungsaufgaben finden semesterbegleitend statt.
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L2691: Security of Cyber-Physical Systems	
Typ	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	
Typ	Recitation Section (small)
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	See interlocking course
Literature	See interlocking course

Module M1880: Deep Learning for Social Analytics

Courses

Title	Typ	Hrs/wk	CP
Deep Learning for Text and Graphs (L3097)	Lecture	2	3
Social Analytics with Deep Learning (L3098)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Christoph Ihl
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of Python • Familiarity with probability theory, linear algebra and statistics
Educational Objectives	After taking part successfully, students have reached 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	
Social Competence	• Collaboration on projects and assignments • Communication regarding computational, algorithmic and modeling challenges
Autonomy	• Maneuver in the field of deep learning including scientific literature and models • Solve computational, algorithmic, and modeling challenges related to deep learning models • Critical thinking skills • Self-sufficient problem-solving regarding coding issues
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 scale	Solutions to coding problem sets after each class session
Assignment for the Following Curricula	Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L3097: Deep Learning for Text and Graphs	
Typ	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	WiSe
Content	Today, 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: 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 Analytics with Deep Learning	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Christoph Ihl
Language	EN
Cycle	WiSe
Content	Today, 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: 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.

Module M0753: Software Verification

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Software Verification (L0629)	Lecture	2	3
Software Verification (L0630)	Recitation Section (small)	2	3

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Automata theory and formal languages • Computational logic • Object-oriented programming, algorithms, and data structures • Functional programming or procedural programming • Concurrency
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major verification techniques in model checking and deductive verification. They explain in formal terms syntax and semantics of the underlying logics, and assess the expressivity of different logics as well as their limitations. They classify formal properties of software systems. They find flaws in formal arguments, arising from modeling artifacts or underspecification.
Skills	Students formulate provable properties of a software system in a formal language. They develop logic-based models that properly abstract from the software under verification and, where necessary, adapt model or property. They construct proofs and property checks by hand or using tools for model checking or deductive verification, and reflect on the scope of the results. Presented with a verification problem in natural language, they select the appropriate verification technique and justify their choice.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Using accompanying on-line material for self study, students can assess their level of knowledge continuously and adjust it appropriately. Working on exercise problems, they receive additional feedback. Within limits, they can set their own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of software verification. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. They can devise plans to arrive at new solutions or assess existing ones.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 15 %; **Form** Excercises; **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0629: Software Verification

Typ	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	
Typ	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 M1780: Massively Parallel Systems: Architecture and Programming

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Massively Parallel Systems: Architecture and Programming (L2936)	Lecture	2	3
Massively Parallel Systems: Architecture and Programming (L2937)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Sohan Lal
Admission Requirements	None
Recommended Previous Knowledge	An introductory module on computer Engineering or computer architecture, good programming skills in C/C++.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The course starts with parallel computers classification, multithreading, and covers the architecture of centralized and distributed shared-memory parallel systems, multiprocessor cache coherence, snooping / directory-based cache coherence protocols, implementation, and limitations. Next, students study interconnection networks and routing in parallel systems. To ensure the correctness of shared-memory multithreaded programs, independent of the speed of execution of their individual threads, the important topics of memory consistency and synchronization will be covered in detail. As a case study, the architecture of a few accelerators such as GPUs will also be discussed in detail. Besides understanding the architecture and organization of parallel systems, programming them is also very challenging. The course will also cover how to program massively parallel systems using API/libraries such as CUDA/OpenCL/MPI/OpenMP.
Skills	After completing this course, students will be able to understand the architecture and organization of parallel systems. They will be able to evaluate different design choices and make decisions while designing a parallel system. In addition, they will be able to program parallel systems (ranging from an embedded system to a supercomputer) using CUDA/OpenCL/MPI/OpenMP.
Personal Competence	
Social Competence	The course will encourage students to work in small groups to solve complex problems, thus, inculcating the importance of teamwork.
Autonomy	Today, parallel computers are present everywhere. Students will be able to not only program parallel computers independently, but also understand their underlying organization and architecture. This will further help to understand the performance issues of parallel applications and provide insights to improve them.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 20 % / Subject theoretical and practical work /
Examination	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2936: Massively Parallel Systems: Architecture and Programming

Typ	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 Parallel Systems: Architecture and Programming	
Typ	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: Linear and Nonlinear Optimization

Courses

Title	Typ	Hrs/wk	CP
Linear and Nonlinear Optimization (L2062)	Lecture	4	4
Linear and Nonlinear Optimization (L2063)	Recitation Section (large)	1	2

Module Responsible	Prof. Matthias Mnich
Admission Requirements	None
Recommended Previous Knowledge	• Discrete Algebraic Structures • Mathematics I • Graph Theory and Optimization
Educational Objectives	After taking part successfully, students have reached the following 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.
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	• Students are able to work together in teams. They are capable to use mathematics as a common language. • 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 understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard problems.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 20 % / Excercises /
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory

Course L2062: Linear and Nonlinear Optimization	
Typ	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	
Typ	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 M0623: Intelligent Systems in Medicine

Courses

Title	Typ	Hrs/wk	CP
Intelligent Systems in Medicine (L0331)	Lecture	2	3
Intelligent Systems in Medicine (L0334)	Project Seminar	2	2
Intelligent Systems in Medicine (L0333)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of stochastics • principles of programming, Java/C++ and R/Matlab • advanced programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to analyze and solve clinical treatment planning and decision support problems using methods for search, optimization, and planning. They are able to explain methods for classification and their respective advantages and disadvantages in clinical contexts. The students can compare different methods for representing medical knowledge. They can evaluate methods in the context of clinical data and explain challenges due to the clinical nature of the data and its acquisition and due to privacy and safety requirements.
Skills	The students can give reasons for selecting and adapting methods for classification, regression, and prediction. They can assess the methods based on actual patient data and evaluate the implemented methods.
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 can critically reflect on the results of other groups, make constructive suggestions for improvement and also incorporate them into their own work.
Autonomy	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 Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 10 % / Presentation Yes / 10 % / Written elaboration
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective 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	
Typ	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	
Typ	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	
Typ	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

Module M0716: Hierarchical Algorithms

Courses

Title	Typ	Hrs/wk	CP
Hierarchical Algorithms (L0585)	Lecture	2	3
Hierarchical Algorithms (L0586)	Recitation Section (small)	2	3

Module Responsible	Prof. Sabine Le Borne
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics I, II, III for Engineering students (german or english) or Analysis & Linear Algebra I + II as well as Analysis III for Technomathematicians • Programming experience in C
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • name representatives of hierarchical algorithms and list their characteristics, • explain construction techniques for hierarchical algorithms, • discuss aspects regarding the efficient implementation of hierarchical algorithms.
Skills	Students are able to • implement the hierarchical algorithms discussed 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 variants.
Personal Competence	
Social Competence	Students are able to • work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the supporting theoretical and practical excercises are better solved individually or in a team, • to work on complex problems over an extended period of time, • to assess their individual progess and, if necessary, 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	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Computer Science: Specialisation III. Mathematics: Elective Compulsory Data Science: Specialisation I. Mathematics: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory

Course L0585: Hierarchical Algorithms

Typ	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	
Typ	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: Digital Communications

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
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 Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of Communications and Random Processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and design modern digital information transmission schemes. They are familiar with the properties of linear and non-linear digital modulation methods. They can describe distortions caused by transmission channels and design and evaluate detectors including channel estimation and equalization. They know the principles of single carrier transmission and multi-carrier transmission as well as the fundamentals of basic multiple access schemes. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to design and analyse a digital information transmission scheme including multiple access. They are able to choose a digital modulation scheme taking into account transmission rate, required bandwidth, error probability, and further signal properties. They can design an appropriate detector including channel estimation and equalization taking into account performance and complexity properties of suboptimum solutions. They are able to set parameters of a single carrier or multi carrier transmission scheme and trade the properties of both approaches against each other.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Core Qualification: Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0444: Digital Communications

Typ	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	• Repetition: Baseband Transmission ◦ Pulse shaping: Non-return to zero (NRZ) 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
  - 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

	- 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	
Typ	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	
Typ	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: Master Thesis

Courses			
Title	Typ	Hrs/wk	CP

Module Responsible	Professoren der TUHH
Admission Requirements	• According to General Regulations §21 (1): At least 60 credit points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
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 or 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.
Skills	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.
Personal Competence	
Social Competence	Students can • Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured way. • 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	Thesis
Examination duration and scale	According to General Regulations
Assignment for the Following Curricula	Civil Engineering: Thesis: Compulsory Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Computer Science: Thesis: Compulsory Data Science: Thesis: Compulsory Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Global Innovation Management: 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 Mechanical Engineering and Management: 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