TUHH
Hamburg
University of
Technology

Module Manual

Master of Science (M.Sc.)

Computer Science in Engineering
Dual study program

Cohort: Winter Term 2023

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Program description

Content

The master's program in Computer Science in Engineering consistently continues the focus on cyber-physical systems, i.e. networked computing systems in their physical environment, from the bachelor's program. This is done through in-depth computer science education related to engineering disciplines, especially electrical engineering. Students acquire in-depth competencies up to the latest research in computer science, such as on machine learning or data science, with the goal of successfully applying them in engineering applications.

The master's program in Computer Science in Engineering builds on the three pillars of mathematics, computer science, and engineering. Corresponding elective catalogs guarantee that in-depth knowledge is acquired in these three specializations. In engineering, the focus is on electrical engineering. In addition, the curriculum offers a great deal of freedom to choose courses from the TUHH's other technical offerings. In this way, students set their own accents in order to build interdisciplinary bridges in specific engineering fields. Likewise, advanced knowledge in business administration and management as well as in non-technical subjects is acquired in order to form the competencies for the implementation of extensive IT projects. This includes, in particular, the ability to independently acquire complex areas of knowledge and to work independently on complex technical issues.

The study plans for (N) networked embedded systems, (D) reliable and secure systems, (A) algorithms for data engineering, and (M) medical technology show exemplary orientations of high practical relevance.

In addition to the foundational curriculum taught at TUHH, seminars on developing personal skills are integrated into the dual study programme, in the context of transfer between theory and practice. These seminars correspond to the modern professional requirements expected of an engineer, as well as promoting the link between the two places of learning.

The intensive dual courses at TUHH integrating practical experience consist of an academic-oriented and a practice-oriented element, which are completed at two places of learning. The academic-oriented element comprises study at TUHH. The practice-oriented element is coordinated with the study programme in terms of content and time, and consists of practical modules and phases spent in an affiliate company during periods when there are no lectures.

Career prospects

Graduates can take up scientific activities at universities and research institutes, in particular with the aim of obtaining a doctorate, or decide to enter industry directly. They possess a wide range of methodological and interface knowledge that enables them to work across disciplines.

In addition, students acquire basic professional and personal skills as part of the dual study programme that enable them to enter professional practice at an early stage and to go on to further study. Students also gain practical work experience through the integrated practical modules. Graduates of the dual course have broad foundational knowledge, fundamental skills for academic work and relevant personal competences.

Learning target

The learning objectives of the program are based on the objectives listed above. All of the learning objectives listed represent competencies that are required in both corporate and research environments. In distinction to the Bachelor's program in Computer Science in Engineering, the competencies listed here refer to complex problems, to the consideration of uncertainty and to working under given boundary conditions from application fields. In the following, the learning objectives are divided into the categories of knowledge, skills, social competence and independence.

Knowledge

- Engineering Sciences: Graduates have an in-depth understanding of mathematical, scientific, and systems engineering contexts with a focus in electrical engineering. This knowledge is underpinned by a broad theoretical and methodological foundation.
- Computer Science: Graduates have an in-depth knowledge of methods and procedures for model building and problem solving in theoretical, practical and technical computer science.
- Mathematics: Graduates have in-depth knowledge of mathematical methods for optimization, image processing, randomized algorithms, or neural networks.
- Economics: Graduates know the basics of business and management and related subjects such as patents and their relationship to their subject.
- Bridging the gap between computer science and engineering: Graduates have in-depth knowledge of methods and procedures to describe interfaces between engineering applications on the one hand and computer science models on the other hand. Graduates are familiar with the latest information and communication technology systems that interact with the real world - so-called cyber-physical systems.

Skills

- Engineering: Graduates are able to apply their engineering judgment to work with, recognize contradictions in, and deal with complex, potentially incomplete information.
- Computer Science: Graduates are able to develop instances of comprehensive formal models of computer science using advanced modeling approaches, determine their computability and complexity, and implement them in a technical framework using appropriate programming tools. Graduates will be able to design and implement software solutions. This includes complex software systems in which distributed realization, reliability or correctness play a special role.
- Mathematics: Graduates can solve optimization problems, apply mathematical methods of image processing or randomized algorithms.
- Bridging computer science and engineering: Graduates can scientifically analyze and solve engineering problems, develop a suitable formalization for information technology treatment, and implement a software solution. Graduates can realize cyber-physical systems that are distributed and networked.

Social competence

- Graduates are able to present the scientific approach and the results of their work in a written and oral way.
- Graduates are able to communicate about scientific contents and problems of computer science with experts from engineering fields and laymen. They can respond appropriately to inquiries, additions and comments.

Independence

- Graduates are able to obtain necessary information and place it in the context of their knowledge.
- Graduates can realistically assess their existing competencies, compensate for deficits independently and acquire additional competencies independently.
- Graduates are able to develop research areas in a self-organized and self-motivated manner and to find and define new problems (lifelong research).

By continually switching places of learnings throughout the dual study programme, it is possible for theory and practice to be interlinked. Students reflect theoretically on their individual professional practical experience, and apply the results of their reflection to new forms of practice. They also test theoretical elements of the course in a practical setting, and use their findings as a stimulus for theoretical debate.

Program structure

The curriculum of the master's degree program in Computer Science in Engineering is structured as follows. A minimum number of credits must be earned in each of the three core areas of computer science, engineering and mathematics:

1. Computer Science: 18 credits
2. Engineering sciences: 12 credit points
3. Mathematics: 12 credit points

To deepen their studies, students can choose lectures from a catalogue of technical courses offered by TUHH. A total of 24 credit points must be achieved. Practical knowledge and skills are taught in a research project (12 credit points). A further 12 credit points must be earned in the courses Operation & Management and a non-technical supplementary course. The master thesis is assessed with 30 credit points. This results in a total effort of 150 credit points. The curriculum contains a mobility window in such a way that students can spend the third semester abroad.

The following four study plans describe special characteristics of the master's programme in Computer Science and Engineering.

N. Networked Embedded Systems

1. Core subjects computer science

- Software security

- Design of Dependable Systems

- Communication networks

2. Core subjects engineering sciences

- Digital communications

- Information theory and coding

3. Core subjects mathematics

- Linear and nonlinear optimization

- Randomized algorithms and random graphs

4. Supplementary technical courses

- Software for embedded systems

- Simulation of communication networks

- Wirless sensor networks

- Operating system construction

D. Dependable and Secure Systems

1. Core subjects computer science

- Software security

- Software verification

- Design of Dependable Systems

2. Core subjects engineering sciences

- Digital signal processing and filters

- Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids

3. Core subjects mathematics

- Linear and non-linear optimization

- Numerical mathematics II

4. Supplementary technical courses

- Robotics & navigation in medicine

- Data science for cyber security

- Security of cyber physical systems

- Industrial process automation

A. Algorithms for Data Engineering

1. Core subjects computer science

- Software verification

- Algorithmic game theory

- Advanced internet computing

2. Core subjects engineering sciences

- Information theory and coding

- Machine learning in electrical engineering and information technology

3. Core subjects mathematics

- Mathematical image processing

- Mathematics of neuronal networks

4. Supplementary technical courses

- Massively Parallel Systems: Architecture and Programming

- Numerical mathematics II

- Approximation and stability

- Hierarchical algorithms

M. Medical technology

1. Core subjects computer science

- Software verification

- Medical imaging

- Security of cyber physical systems

2. Core subjects engineering sciences

- Intelligent systems project

- Digital signal processing and filters

3. Core subjects mathematics

- Mathematical image processing

- Numerical mathematics II

4. Supplementary technical courses

- Probability theory

- Intelligent systems in medicine

- Robotics & navigation in medicine

- Feedback Control in Medical Technology

The structural model of the dual study programme follows a module-differentiating approach. Given the practice-oriented element, the curriculum of the dual study programme is different compared to a standard Bachelor’s course. Five practical modules are completed at the dual students’ partner company as part of corresponding practical terms during lecture-free periods.

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 M1759: Linking theory and practice (dual study program, Master's degree)

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical modules as part of the dual Bachelor's course • Module "interlinking theory and practice as part of the dual Master's course"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... ... can describe and classify selected classic and current theories, concepts and methods • related to project management and • change and transformation management ... and apply them to specific situations, processes and plans in a personal, professional context.
Skills	Dual students ... • ... anticipate typical difficulties, positive and negative effects, as well as success and failure factors in the engineering sector, evaluate them and consider promising strategies and courses of action. • ... develop specialised technical and conceptual skills to solve complex tasks and problems in their professional field of activity/work.
Personal Competence	
Social Competence	Dual students ... • ... can responsibly lead interdisciplinary teams within the framework of complex tasks and problems. • ... engage in sector-specific and cross-sectoral discussions with experts, stakeholders and staff, representing their approaches, points of view and work results.
Autonomy	Dual students ... • ... define, reflect and evaluate goals and measures for complex application-oriented projects and change processes. • ... shape their professional area of responsibility independently and sustainably. • ... take responsibility for their actions and for the results of their work.
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	Studienbegleitende und semesterübergreifende Dokumentation: Die Leistungspunkte für das Modul werden durch die Anfertigung eines digitalen Lern- und Entwicklungsberichtes (E-Portfolio) erworben. Dabei handelt es sich um eine fortlaufende Dokumentation und Reflexion der Lernerfahrungen und der Kompetenzentwicklung im Bereich der Personalen Kompetenz.

Course L2890: Responsible Project Management in Engineering (for Dual Study Program)

Typ	Seminar
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Henning Haschke, Heiko Sieben
Language	DE
Cycle	WiSe/SoSe
Content	• Theories and methods of project management • Innovation management • Agile project management • Fundamentals of classic and agile methods • Hybrid use of classic and agile methods • Roles, perspectives and stakeholders throughout the project • Initiating and coordinating complex engineering projects • Principles of moderation, team management, team leadership, conflict management • Communication structures: in-house, cross-company • Public information policy • Promoting commitment and empowerment • Sharing experience with specialists and managers from the engineering sector • Documenting and reflecting on learning experiences
Literature	Seminarapparat

Course L2891: Responsible Change and Transformation Management in Engineering (for Dual Study Program)	
Typ	Seminar
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Henning Haschke, Heiko Sieben
Language	DE
Cycle	WiSe/SoSe
Content	• Basic concepts, opportunities and limits of organisational change • Models and methods of organisational design and development • Strategic orientation and change, and their short-, medium- and long-term consequences for individuals, organisations and society as a whole • Roles, perspectives and stakeholders in change processes • Initiating and coordinating change measures in engineering • Phase models of organisational change (Lewin, Kotter, etc.) • Change-oriented information policy and dealing with resistance and uncertainty • Promoting commitment and empowerment • Successfully handling change and transformation: personally, as an employee, as a manager (personal, professional, organisational) • Company-level and globally (systemic) • Sharing experience with specialists and managers from the engineering sector • Documenting and reflecting on learning experiences
Literature	Seminarapparat

Module M1756: Practical module 1 (dual study program, Master's degree)

Courses

Title	Typ	Hrs/wk	CP
Practical term 1 (dual study program, Master's degree) (L2887)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of a compatible dual B.Sc. at TU Hamburg or comparable practical work experience and competences in the area of interlinking theory and practice • Course D from the module on interlinking theory and practice as part of the dual Master’s course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering. • ... have a critical understanding of the practical applications of their engineering subject.
Skills	Dual students ... • ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university’s application recommendations with regard to their current tasks. • ... develop solutions as well as procedures and approaches in their field of activity and area of responsibility.
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in project teams within their working area and proactively deal with problems within their team. • ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders.
Autonomy	Dual students ... • ... define goals for their own learning and working processes as engineers. • ... reflect on learning and work processes in their area of responsibility. • ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university’s application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Aeronautics: Core Qualification: Compulsory Materials Science and Engineering: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory Naval Architecture and Ocean Engineering: Core Qualification: Compulsory

	Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Core Qualification: Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L2887: Practical term 1 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work • Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.) • Working independently in a team and on selected projects - across departments and, if applicable, across companies • Scheduling the current practical module with a clear correlation to work structures • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions • Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity • Systemic skills • Implementing the university’s application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • Creating an e-portfolio • Importance of course contents (M.Sc.) when working as an engineer • Importance of development and innovation when working as an engineer
Literature	• Studierendenhandbuch • Betriebliche Dokumente • Hochschulseitige Handlungsempfehlungen zum Theorie-Praxis-Transfer

Module M1757: Practical module 2 (dual study program, Master's degree)

Courses

Title	Typ	Hrs/wk	CP
Practical term 2 (dual study program, Master's degree) (L2888)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical module 1 as part of the dual Master's course • course D from the module on interlinking theory and practice as part of the dual Master's course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering. • ... have a critical understanding of the practical applications of their engineering subject.
Skills	Dual students ... • ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university's application recommendations with regard to their current tasks. • ... develop (new) solutions as well as procedures and approaches in their field of activity and area of responsibility - including in the case of frequently changing requirements (systemic skills).
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team. • ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together.
Autonomy	Dual students ... • ... define goals for their own learning and working processes as engineers. • ... reflect on learning and work processes in their area of responsibility. • ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Aeronautics: Core Qualification: Compulsory Materials Science and Engineering: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory

	Naval Architecture and Ocean Engineering: Core Qualification: Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Core Qualification: Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L2888: Practical term 2 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work • Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.) • Taking personal responsibility within a team and on selected projects - across departments and, if applicable, across companies • Scheduling the current practical module with a clear correlation to work structures • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions • Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity • Systemic skills • Implementing the university's application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • Updating their e-portfolio • Importance of course contents (M.Sc.) when working as an engineer • Importance of development and innovation when working as an engineer
Literature	• Studierendenhandbuch • Betriebliche Dokumente • Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer

Module M1421: Research Project

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Research Project IIW (L2042)	Projection Course	8	12

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge and techniques in the chosen field of specialization.
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 specific field of Computer Science or a closely related subject.
Skills	Students are able to work self-dependent in a field of Computer Science or a closely related field.
Personal Competence	
Social Competence	
Autonomy	
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	Presentation of a current research topic (25-30 min and 5 min discussion).
Assignment for the Following Curricula	Computer Science in Engineering: Core Qualification: Compulsory

Course L2042: Research Project IIW

Typ	Projection Course
Hrs/wk	8
CP	12
Workload in Hours	Independent Study Time 248, Study Time in Lecture 112
Lecturer	Prof. Volker Turau (sgwe)
Language	DE/EN
Cycle	WiSe/SoSe
Content	Current research topics of the chosen specialization.
Literature	Aktuelle Literatur zu Forschungsthemen aus der gewählten Vertiefungsrichtung. / Current literature on research topics of the chosen specialization.

Module M1758: Practical module 3 (dual study program, Master's degree)

Courses

Title	Typ	Hrs/wk	CP
Practical term 3 (dual study program, Master's degree) (L2889)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical module 2 as part of the dual Master’s course • course E from the module on interlinking theory and practice as part of the dual Master’s course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their comprehensive and specialised engineering knowledge acquired from previous study contents with the strategy-oriented practical knowledge gained from their current field of work and area of responsibility. • ... have a critical understanding of the practical applications of their engineering subject, as well as related fields when implementing innovations.
Skills	Dual students ... • ... apply specialised and conceptual skills to solve complex, sometimes interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university’s application recommendations with regard to their current tasks. • ... develop new solutions as well as procedures and approaches to implement operational projects and assignments - even when facing frequently changing requirements and unpredictable changes (systemic skills). • ... can use academic methods to develop new ideas and procedures for operational problems and issues, and to assess these with regard to their usability.
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team. • ... can promote the professional development of others in a targeted manner. • ... represent complex and interdisciplinary engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together.
Autonomy	Dual students ... • ... reflect on learning and work processes in their area of responsibility. • ... define goals for new application-oriented tasks, projects and innovation plans while reflecting on potential effects on the company and the public. • ... reflect on the relevance of areas of specialisation and research for work as an engineer, and also implement the university’s application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Aeronautics: Core Qualification: Compulsory Materials Science and Engineering: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory

	Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory Naval Architecture and Ocean Engineering: Core Qualification: Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Core Qualification: Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L2889: Practical term 3 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a future professional field of activity as an engineer (M.Sc.) and associated fields of work • Extending responsibilities and authorisation of the dual student within the company up to the intended first assignment after completing their studies • Working responsibly in a team; project responsibility within own area - as well as across divisions and companies if necessary • Scheduling the final practical module with a clear correlation to work structures • Internal agreement on a potential topic or innovation project for the Master's dissertation • Planning the Master's dissertation within the company in cooperation with TU Hamburg • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: dealing with change, project and team development, responsibility as an engineer in their future field of work (M.Sc.), dealing with complex contexts, frequent and unpredictable changes, developing and implementing innovative solutions • Specialising in one field of work (final dissertation) • Systemic skills • Implementing the university's application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • E-portfolio • Relevance of study content and personal specialisation when working as an engineer • Relevance of research and innovation when working as an engineer
Literature	• Studierendenhandbuch • betriebliche Dokumente • Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer

Specialization I. Computer Science

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 M0942: Software Security

Courses

Title	Typ	Hrs/wk	CP
Software Security (L1103)	Lecture	2	3
Software Security (L1104)	Recitation Section (small)	2	3

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with C/C++, web programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can • name the main causes for security vulnerabilities in software • explain current methods for identifying and avoiding security vulnerabilities • explain the fundamental concepts of code-based access control
Skills	Students are capable of • performing a software vulnerability analysis • developing secure code
Personal Competence	
Social Competence	None
Autonomy	Students are capable of acquiring knowledge independently from professional publications, technical standards, and other sources, and are capable of applying newly acquired knowledge to new problems.
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 minutes
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L1103: Software Security	
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	WiSe
Content	• Reliabilty and Software Security • Attacks exploiting character and integer representations • Buffer overruns • Vulnerabilities in memory managemet: double free attacks • Race conditions • SQL injection • Cross-site scripting and cross-site request forgery • Testing for security; taint analysis • Type safe languages • Development proceses for secure software • Code-based access control
Literature	M. Howard, D. LeBlanc: Writing Secure Code, 2nd edition, Microsoft Press (2002) G. Hoglund, G. McGraw: Exploiting Software, Addison-Wesley (2004) L. Gong, G. Ellison, M. Dageforde: Inside Java 2 Platform Security, 2nd edition, Addison-Wesley (2003) B. LaMacchia, S. Lange, M. Lyons, R. Martin, K. T. Price: .NET Framework Security, Addison-Wesley Professional (2002) D. Gollmann: Computer Security, 3rd edition (2011)

Course L1104: Software Security	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	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 M1427: Algorithmic Game Theory

Courses

Title	Typ	Hrs/wk	CP
Algorithmic game theory (L2060)	Lecture	2	4
Algorithmic game theory (L2061)	Recitation Section (large)	2	2

Module Responsible	Prof. Matthias Mnich
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics I • Mathematics II • Algorithms and Data Structures
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can name the basic concepts in algorithmic game theory and mechanism design. 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 game and mechanism design strategies and can reproduce them.
Skills	• Students can model strategic interaction systems of agents with the help of the concepts studied in this course. Moreover, they are capable of analyzing their efficiency and equilibria, 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 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** No / 20 % / Subject theoretical and practical work /
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory

Course L2060: Algorithmic game theory	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	SoSe
Content	Algorithmic game theory is a topic at the intersection of economics and computation. It deals with analyzing the behavior and interactions of strategic agents, who often try to maximize their incentives. The environment in which those agents interact is referred to as a game. We wish to understand if the agents can reach an "equilibrium", or steady state of the game, in which agents have no incentive to deviate from their chosen strategies. The algorithmic part is to design efficient methods to find equilibria in games, and to make recommendations to the agents so that they can quickly reach a state of personal satisfaction. We will also study mechanism design. In mechanism design, we wish to design markets and auctions and give strategic options to agents, so that they have an incentive to act rationally. We also wish to design the markets and auctions so that they are efficient, in the sense that all goods are cleared and agents do not overpay for the goods which they acquire. Topics: • basic equilibrium concepts (Nash equilibria, correlated equilibria, ...) • strategic actions (best-response dynamics, no-regret dynamics, ...) • auction design (revenue-maximizing auctions, Vickrey auctions) • stable matching theory (preference aggregations, kidney exchanges, ...) • price of anarchy and selfish routing (Braess' paradox, congestion games, ...)
Literature	• T. Roughgarden: Twenty Lectures on Algorithmic Game Theory, Cambridge University Press, 2016. • N. Nisan, T. Roughgarden, E. Tardos, V. Vazirani. Algorithmic Game Theory. Cambridge University Press, 2007.

Course L2061: Algorithmic game theory	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Matthias Mnich
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1400: Design of Dependable Systems

Courses

Title	Typ	Hrs/wk	CP
Designing Dependable Systems (L2000)	Lecture	2	3
Designing Dependable Systems (L2001)	Recitation Section (small)	2	3

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge about data structures and algorithms
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	In the following "dependable" summarizes the concepts Reliability, Availability, Maintainability, Safety and Security. Knowledge about approaches for designing dependable systems, e.g., • Structural solutions like modular redundancy • Algorithmic solutions like handling byzantine faults or checkpointing Knowledge about methods for the analysis of dependable systems
Skills	Ability to implement dependable systems using the above approaches. Ability to analyzs the dependability of systems using the above methods for analysis.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • present their solutions orally.
Autonomy	Using accompanying material students independently learn in-depth relations between concepts explained in the lecture and additional solution strategies.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work / Die Lösung einer Aufgabe ist Zulassungsvoraussetzung für die Prüfung. Die Aufgabe wird in Vorlesung und Übung definiert.
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: 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

Course L2000: Designing Dependable Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	Description The term dependability comprises various aspects of a system. These are typically: • Reliability • Availability • Maintainability • Safety • Security This makes dependability a core aspect that has to be considered early in system design, no matter whether software, embedded systems or full scale cyber-physical systems are considered. Contents The module introduces the basic concepts for the design and the analysis of dependable systems. Design examples for getting practical hands-on-experience in dependable design techniques. The module focuses towards embedded systems. The following topics are covered: • Modelling • Fault Tolerance • Design Concepts • Analysis Techniques
Literature	

Course L2001: Designing Dependable Systems	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
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	Will be discussed 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	Will be discussed in the lecture.

Module M1812: Constraint Satisfaction Problems

Courses

Title	Typ	Hrs/wk	CP
Constraint Satisfaction Problems (L3002)	Lecture	2	3
Constraint Satisfaction Problems (L3003)	Recitation Section (large)	2	3

Module Responsible	Prof. Antoine Mottet
Admission Requirements	None
Recommended Previous Knowledge	The students should have followed the courses Complexity Theory, Discrete Algebraic Structures, Linear Algebra.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can describe basic concepts from the theory of constraint satisfaction such as primitive positive formulas, interpretations, polymorphisms, clones • Students can discuss the connections between these concepts • Students know proofs strategies and can reproduce them
Skills	• Students can use CSPs to model problems from complexity theory and decide their complexity using methods from the course.
Personal Competence	
Social Competence	
Autonomy	
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 I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Technomathematics: Specialisation II. Informatics: Elective Compulsory

Course L3002: Constraint Satisfaction Problems

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Antoine Mottet
Language	EN
Cycle	SoSe
Content	This course gives an introduction to the topic of constraint satisfaction problems and their complexity. A constraint satisfaction problem (CSP) is a computational problem of the form "Given variables and constraints on the variables, does there exist an assignment of the variables to some concrete domain that satisfies all the constraints?" The framework of CSPs is very general, and in fact every computational problem is equivalent to a CSP. The study of CSPs has been very prolific in the past, both in practice (e.g., with SAT solvers) and in complexity theory, a prominent field of theoretical computer science. In this course, we will review the theoretical aspects of CSPs. The course will cover the basics of the theory such as the universal-algebraic approach to constraint satisfaction and several classical algorithms such as local consistency checking and the Bulatov-Dalmau algorithm. Basic knowledge in predicate logic and an affinity to abstract mathematical thinking are highly recommended in order to follow this course.
Literature	

Course L3003: Constraint Satisfaction Problems	
Typ	Recitation Section (large)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Antoine Mottet
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0836: Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Selected Topics of Communication Networks (L0899)	Project-/problem-based Learning	2	2
Communication Networks (L0897)	Lecture	2	2
Communication Networks Excercise (L0898)	Project-/problem-based Learning	1	2

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamental stochastics • Basic understanding of computer networks and/or communication technologies is beneficial
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe the principles and structures of communication networks in detail. They can explain the formal description methods of communication networks and their protocols. They are able to explain how current and complex communication networks work and describe the current research in these examples.
Skills	Students are able to evaluate the performance of communication networks using the learned methods. They are able to work out problems themselves and apply the learned methods. They can apply what they have learned autonomously on further and new communication networks.
Personal Competence	
Social Competence	Students are able to define tasks themselves in small teams and solve these problems together using the learned methods. They can present the obtained results. They are able to discuss and critically analyse the solutions.
Autonomy	Students are able to obtain the necessary expert knowledge for understanding the functionality and performance capabilities of new communication networks independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	1.5 hours colloquium with three students, therefore about 30 min per student. Topics of the colloquium are the posters from the previous poster session and the topics of the module.
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective 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 Aeronautics: Core Qualification: 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 L0899: Selected Topics of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr.-Ing. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Example networks selected by the students will be researched on in a PBL course by the students in groups and will be presented in a poster session at the end of the term.
Literature	• see lecture

Course L0897: Communication Networks	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr.-Ing. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	
Literature	• Skript des Instituts für Kommunikationsnetze • Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr.-Ing. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Part of the content of the lecture Communication Networks are reflected in computing tasks in groups, others are motivated and addressed in the form of a PBL exercise.
Literature	• announced during lecture

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 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

Specialization II. Engineering Science

Module M1250: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids

Courses

Title	Typ	Hrs/wk	CP
Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids (L1696)	Lecture	3	4
Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids (L1697)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering, Electrical Power Systems I, Mathematics I, II, III
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain in detail and critically evaluate technologies and information systems for operational management of conventional and modern electric power systems as well as methods and algorithms for steady-state network calculation, failure calculation, power system operation and optimization. They are additonally able to apply these methods to real electric power systems.
Skills	With completion of this module the students are able to apply the acquired skills for planning and analysis of real electric power systems and to critically evaluate the results.
Personal Competence	
Social Competence	The students can participate in specialized and interdisciplinary discussions, advance ideas and represent their own work results in front of others.
Autonomy	Students can independently tap knowledge of the emphasis of the lectures and apply it within further research activities.
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	45 min
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory Energy Systems: Specialisation Energy Systems: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory

Course L1696: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Becker
Language	DE
Cycle	WiSe

Content	• steaedy-state modelling of electric power systems
	  ∘ conventional components
	  ∘ Flexible AC Transmission Systems (FACTS) and HVDC
	  ∘ grid modelling
	• grid operation
	  ∘ electric power supply processes
	  ∘ grid and power system management
	  ∘ grid provision
	• grid control systems
	  ∘ information and communication systems for power system management
	  ∘ IT architectures of bay-, substation and network control level
	  ∘ IT integration (energy market / supply shortfall management / asset management)
	  ∘ future trends of process control technology
	  ∘ smart grids
	• functions and steady-state computations for power system operation and plannung
	  ∘ load-flow calculations
	  ∘ sensitivity analysis and power flow control
	  ∘ power system optimization
	  ∘ short-circuit calculation
	  ∘ asymmetric failure calculation
	    ▪ symmetric components
	    ▪ calculation of asymmetric failures
	  ∘ state estimation

Literature	E. Handschin: Elektrische Energieübertragungssysteme, Hüthig Verlag B. R. Oswald: Berechnung von Drehstromnetzen, Springer-Vieweg Verlag V. Crastan: Elektrische Energieversorgung Bd. 1 & 3, Springer Verlag E.-G. Tietze: Netzleittechnik Bd. 1 & 2, VDE-Verlag

Course L1697: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Christian Becker
Language	DE
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 M0548: Bioelectromagnetics: Principles and Applications

Courses

Title	Typ	Hrs/wk	CP
Bioelectromagnetics: Principles and Applications (L0371)	Lecture	3	5
Bioelectromagnetics: Principles and Applications (L0373)	Recitation Section (small)	2	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of physics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the basic principles, relationships, and methods of bioelectromagnetics, i.e. the quantification and application of electromagnetic fields in biological tissue. They can define and exemplify the most important physical phenomena and order them corresponding to wavelength and frequency of the fields. They can give an overview over measurement and numerical techniques for characterization of electromagnetic fields in practical applications . They can give examples for therapeutic and diagnostic utilization of electromagnetic fields in medical technology.
Skills	Students know how to apply various methods to characterize the behavior of electromagnetic fields in biological tissue. In order to do this they can relate to and make use of the elementary solutions of Maxwell's Equations. They are able to assess the most important effects that these models predict for biological tissue, they can order the effects corresponding to wavelength and frequency, respectively, and they can analyze them in a quantitative way. They are able to develop validation strategies for their predictions. They are able to evaluate the effects of electromagnetic fields for therapeutic and diagnostic applications and make an appropriate choice.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English (e.g. during small group exercises).
Autonomy	Students are capable to gather information from subject related, professional publications and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. theory of electromagnetic fields, fundamentals of electrical engineering / physics). They can communicate problems and effects in the field of bioelectromagnetics in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: None; **Form**: Presentation; **Description**:
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0371: Bioelectromagnetics: Principles and Applications	
Typ	Lecture
Hrs/wk	3
CP	5
Workload in Hours	Independent Study Time 108, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- Fundamental properties of electromagnetic fields (phenomena) - Mathematical description of electromagnetic fields (Maxwell’s Equations) - Electromagnetic properties of biological tissue - Principles of energy absorption in biological tissue, dosimetry - Numerical methods for the computation of electromagnetic fields (especially FDTD) - Measurement techniques for characterization of electromagnetic fields - Behavior of electromagnetic fields of low frequency in biological tissue - Behavior of electromagnetic fields of medium frequency in biological tissue - Behavior of electromagnetic fields of high frequency in biological tissue - Behavior of electromagnetic fields of very high frequency in biological tissue - Diagnostic applications of electromagnetic fields in medical technology - Therapeutic applications of electromagnetic fields in medical technology - The human body as a generator of electromagnetic fields
Literature	- C. Furse, D. Christensen, C. Durney, "Basic Introduction to Bioelectromagnetics", CRC (2009) - A. Vorst, A. Rosen, Y. Kotsuka, "RF/Microwave Interaction with Biological Tissues", Wiley (2006) - S. Grimnes, O. Martinsen, "Bioelectricity and Bioimpedance Basics", Academic Press (2008) - F. Barnes, B. Greenebaum, "Bioengineering and Biophysical Aspects of Electromagnetic Fields", CRC (2006)

Course L0373: Bioelectromagnetics: Principles and Applications	
Typ	Recitation Section (small)
Hrs/wk	2
CP	1
Workload in Hours	Independent Study Time 2, Study Time in Lecture 28
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
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 M1666: Intelligent Systems Lab

Courses

Title	Typ	Hrs/wk	CP
Intelligent Systems Lab (L2709)	Project-/problem-based Learning	6	6

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	Very good programming skills Good knowledge in mathematics Prior knowledge in machine learning is very helpful Prior knowledge in image processing / computer vision is helpful Prior knowledge in robotics is very helpful Prior knowledge in microprocessor programming is helpful
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students will be able to explain aspects of intelligent systems (e.g. autonomy, sensing the environment, interacting with the environment) and provide links to ai / robotics / machine learning / computer vision.
Skills	Students can analyze a complex application scenario and use artificial intelligence methods (particularly from robotics, machine learning, computer vision) to implement an intelligent system. Furthermore, students will be able to define criteria to assess the function of the system and evaluate the system.
Personal Competence	
Social Competence	The students can define project aims and scope and organize the project as team work. They can present their results in an appropriate manner.
Autonomy	The students take responsibility for their tasks and coordinate their individual work with other group members. They deliver their work on time. They independently acquire additional knowledge by doing a specific literature research.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Group discussion; **Description**
Examination	Written elaboration
Examination duration and scale	approx. 8 pages, time frame: over the course of the semester
Assignment for the Following Curricula	Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2709: Intelligent Systems Lab

Typ	Project-/problem-based Learning
Hrs/wk	6
CP	6
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Lecturer	Prof. Alexander Schlaefer
Language	DE/EN
Cycle	SoSe
Content	The actual project topic will be defined as part of the project.
Literature	Wird in der Veranstaltung bekannt gegeben.

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	

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	

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	

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	

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	

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 % / 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 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 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 M0677: Digital Signal Processing and Digital Filters

Courses

Title	Typ	Hrs/wk	CP
Digital Signal Processing and Digital Filters (L0446)	Lecture	3	4
Digital Signal Processing and Digital Filters (L0447)	Recitation Section (large)	2	2

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of signal and system theory as well as random processes. • Fundamentals of spectral transforms (Fourier series, Fourier transform, Laplace transform)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know and understand basic algorithms of digital signal processing. They are familiar with the spectral transforms of discrete-time signals and are able to describe and analyse signals and systems in time and image domain. They know basic structures of digital filters and can identify and assess important properties including stability. They are aware of the effects caused by quantization of filter coefficients and signals. They are familiar with the basics of adaptive filters. They can perform traditional and parametric methods of spectrum estimation, also taking a limited observation window into account. 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 apply methods of digital signal processing to new problems. They can choose and parameterize suitable filter striuctures. In particular, the can design adaptive filters according to the minimum mean squared error (MMSE) criterion and develop an efficient implementation, e.g. based on the LMS or RLS algorithm. Furthermore, the students are able to apply methods of spectrum estimation and to take the effects of a limited observation window into account.
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	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: 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 L0446: Digital Signal Processing and Digital Filters	
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	WiSe
Content	• Transforms of discrete-time signals: ◦ Discrete-time Fourier Transform (DTFT) ◦ Discrete Fourier-Transform (DFT), Fast Fourier Transform (FFT) ◦ Z-Transform • Correspondence of continuous-time and discrete-time signals, sampling, sampling theorem • Fast convolution, Overlap-Add-Method, Overlap-Save-Method • Fundamental structures and basic types of digital filters • Characterization of digital filters using pole-zero plots, important properties of digital filters • Quantization effects • Design of linear-phase filters • Fundamentals of stochastic signal processing and adaptive filters ◦ MMSE criterion ◦ Wiener Filter ◦ LMS- and RLS-algorithm • Traditional and parametric methods of spectrum estimation
Literature	K.-D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung. Vieweg Teubner. V. Oppenheim, R. W. Schafer, J. R. Buck: Zeitdiskrete Signalverarbeitung. Pearson StudiumA. V. W. Hess: Digitale Filter. Teubner. Oppenheim, R. W. Schafer: Digital signal processing. Prentice Hall. S. Haykin: Adaptive flter theory. L. B. Jackson: Digital filters and signal processing. Kluwer. T.W. Parks, C.S. Burrus: Digital filter design. Wiley.

Course L0447: Digital Signal Processing and Digital Filters	
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

Specialization III. Mathematics

Module M0881: Mathematical Image Processing

Courses

Title	Typ	Hrs/wk	CP
Mathematical Image Processing (L0991)	Lecture	3	4
Mathematical Image Processing (L0992)	Recitation Section (small)	1	2

Module Responsible	Prof. Marko Lindner
Admission Requirements	None
Recommended Previous Knowledge	• Analysis: partial derivatives, gradient, directional derivative • Linear Algebra: eigenvalues, least squares solution of a linear system
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • characterize and compare diffusion equations • explain elementary methods of image processing • explain methods of image segmentation and registration • sketch and interrelate basic concepts of functional analysis
Skills	Students are able to • implement and apply elementary methods of image processing • explain and apply modern methods of image processing
Personal Competence	
Social Competence	Students are able to work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge) and to explain theoretical foundations.
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	20 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Computer Science: Specialisation III. Mathematics: Elective Compulsory Computer Science in Engineering: Specialisation III. Mathematics: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: 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 Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0991: Mathematical Image Processing	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Marko Lindner
Language	DE/EN
Cycle	WiSe
Content	• basic methods of image processing • smoothing filters • the diffusion / heat equation • variational formulations in image processing • edge detection • de-convolution • inpainting • image segmentation • image registration
Literature	Bredies/Lorenz: Mathematische Bildverarbeitung

Course L0992: Mathematical Image Processing	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Marko Lindner
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 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 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 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	Oral exam
Examination duration and scale	25 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

Specialization IV. Subject Specific Focus

Module M1434: Technical Complementary Course I for Computational Science and Engineering

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Prof. Görschwin Fey
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	Depends on choice of courses
Credit points	12
Assignment for the Following Curricula	Computer Science in Engineering: Specialisation IV. Subject Specific Focus: Elective Compulsory

Module M1435: Technical Complementary Course II for Computational Science and Engineering

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Prof. Görschwin Fey
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	Depends on choice of courses
Credit points	12
Assignment for the Following Curricula	Computer Science in Engineering: Specialisation IV. Subject Specific Focus: Elective Compulsory

Thesis

Module M1801: Master thesis (dual study program)

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Professoren der TUHH
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... use the specialised knowledge (facts, theories and methods) from their field of study and the acquired professional knowledge confidently to deal with technical and practical professional issues. • ... can explain the relevant approaches and terminologies in depth in one or more of their subject's specialist areas, describe current developments and take a critical stance. • ... formulate their own research assignment to tackle a professional problem and contextualise it within their subject area. They ascertain the current state of research and critically assess it.
Skills	Dual students ... • ... can select suitable methods for the respective subject-related professional problem, apply them and develop them further as required. • ... assess knowledge and methods acquired during their studies (including practical phases) and apply their expertise to complex and/or incompletely defined problems in a solution- and application-oriented manner. • ... acquire new academic knowledge in their subject area and critically evaluate it.
Personal Competence	
Social Competence	Dual students ... • ... can present a professional problem in the form of an academic question in a structured, comprehensible and factually correct manner, both in writing and orally, for a specialist audience and for professional stakeholders. • ... answer questions as part of a professional discussion in an expert, appropriate manner. They represent their own points of view and assessments convincingly.
Autonomy	Dual students ... • ... can structure their own project into work packages, work through them at an academic level and reflect on them with regard to feasible courses of action for professional practice. • ... work in-depth in a partially unknown area within the discipline and acquire the information required to do so. • ... apply the techniques of academic work comprehensively in their own research work when dealing with an operational problem and question.
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 Computer Science in Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory International Management and Engineering: 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 Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory