TUHH

Hamburg University of Technology

Module Manual

Master of Science (M.Sc.)

Information and Communication Systems

Cohort: Winter Term 2019

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Program description

Content

Among the industries with the greatest growth rates is the communications industry which, over the years, has achieved in its products the synergy of the classical disciplines of computer science and networking. The International Master Program Information and Communication Systems addresses this rapidly evolving area by laying in-depth foundations for the design and implementation of networking infrastructures, networked Cyber Physical Systems and the applications and services running on them.

The program is organized as a two-year course (four semesters) which starts on 1st of October each year. It includes around two semesters of lectures and practical courses and almost two semesters devoted to work in a research team (project work) and to the preparation of a master's thesis. The "Master of Science" degree will be awarded. Language of the program is English.

Graduates of the program are provided with the basics and knowledge that are required for a successful engineering activity in the information and communication technology in an international environment. They acquire extensive knowledge in the mathematical, engineering and scientific basic principles of this discipline based on a solid theoretical foundation including all the essential application-oriented aspects. Graduates are qualified to independently resolve problems in the information and communications technology and related disciplines.

The graduates are able to apply methods and procedures required to work on technical issues, as well as critically examine new insights to further develop and incorporate in their work. In this way, they are qualified to carry out their duties for society responsibly.

Career prospects

The study of Information and Communication Systems provides the in-depth training in the areas of Information and Communication Technology, Software Systems, IT Security and Signal Processing. This enables excellent career prospects both in the industrial as well as on the academic job market. The Master's degree qualifies graduates for doctoral studies.

Learning target

Knowledge

The students gain common knowledge from the core qualification and more specific knowledge depending on the selected specialisation. All students are able to describe information theory and coding basics.

Specialisation Communication Systems:

Students can

- show their profound knowledge in digital communications,
- describe their specialized knowledge in communication networks,
- explain software development principles,
- explain signal processing fundamentals.

Specialisation Secure and Dependable IT Systems:

Students can

- give an overview of software verification,
- describe security principles for information and communication systems,

- explain their specialized knowledge in communication networks,
- describe software development and signal processing principles.

Skills

The ability to apply knowledge in order to perform tasks and solve problems will be supported in this course. Information and Communication Systems graduates are capable to

- solve problems in information and communication systems by applying and adapting techniques, procedures and methods that are required for a successful professional activity and by using engineering systematics,
- organize the planning of theoretical and experimental studies in order to develop optimal solutions for complex applications in information and communication technology and evaluate the solutions analyse problems using scientific systematics and solve them most effectively to develop economically viable approaches for products and systematically reflect non-technical implications of engineering activity to responsibly involve them in their actions,
- evaluate reliability of developed systems, prepare and review results of practical applications so that they can be used for systems optimization
- Investigate, evaluate and integrate new technologies, systems, architecture, services and applications for information and communication systems.

Social skills

The ability of target-oriented work in collaboration with others, communication, and understanding their interests and social situations are goals of this course. The students can

- present and argue the results of their work in written and oral form in an comprehensible way,
- communicate and collaborate with international professionals, also of other disciplines,
- collaborate in challenging projects of information and communications technology in a responsible position,
- develop ideas and solutions in team work.

Autonomy

The course helps to improve ability and readiness to act independently and responsibly, reflect own actions and the actions of others, and to develop the own functioning. Information and Communication Systems students are capable to

- identify knowledge gaps and propose solutions to overcome these gaps,
- expand and deepen their knowledge and skills independently, taking into account ecological and economic demands responsibly,
- familiarize themselves with complex tasks, define new tasks and develop the necessary knowledge for solving it and to systematically apply appropriate means.

Program structure

The four-semester program is designed modularly and is based on the university-wide standardized course structure with uniform module sizes (multiples of six credit points (CP)).

Core qualification: 48 CP

Specialization: 42 CP

Master thesis: 30 CP

Total: 120 CP

The core qualification consists of the module Information Theory and Coding (6 CP), technical complementary courses (12 CP), Business & Management (6 CP), nontechnical complementary courses (6 CP) and research

project with seminar (18 CP). The research project with seminar consists of a scientific thesis with documentation and accompanying presentations in a seminar among fellow students.

The students choose between two specialisations (42 CP each):

- Communication Systems

Containing: Communications, software, and signal processing

- Secure and Dependable IT Systems

Containing: IT security, networks, software and signal processing

Students write a master thesis (30 CP).

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 M0524: Nontechnical Elective Complementary Courses for Master

Module Responsible	Dagmar Richter
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**The Nontechnical Academic Programms (NTA)** imparts skills that, in view of the TUHH's training profile, professional engineering studies require but are not able to cover fully. Self-reliance, self-management, collaboration and professional and personnel management competences. The department implements these training objectives in its **teaching architecture**, in its **teaching and learning arrangements**, in **teaching areas** and by means of teaching offerings in which students can qualify by opting for **specific competences** and a **competence level** at the Bachelor's or Master's level. The teaching offerings are pooled in two different catalogues for nontechnical complementary courses. **The Learning Architecture** consists of a cross-disciplinarily study offering. The centrally designed teaching offering ensures that courses in the nontechnical academic programms follow the specific profiling of TUHH degree courses. The learning architecture demands and trains independent educational planning as regards the individual development of competences. It also provides orientation knowledge in the form of "profiles". The subjects that can be studied in parallel throughout the student's entire study program - if need be, it can be studied in one to two semesters. In view of the adaptation problems that individuals commonly face in their first semesters after making the transition from school to university and in order to encourage individually planned semesters abroad, there is no obligation to study these subjects in one or two specific semesters during the course of studies. **Teaching and Learning Arrangements** provide for students, separated into B.Sc. and M.Sc., to learn with and from each other across semesters. The challenge of dealing with interdisciplinarity and a variety of stages of learning in courses are part of the learning architecture and are deliberately encouraged in specific courses. **Fields of Teaching** are based on research findings from the academic disciplines cultural studies, social studies, arts, historical studies, communication studies, migration studies and sustainability research, and from engineering didactics. In addition, from the winter semester 2014/15 students on all Bachelor's courses will have the opportunity to learn about business management and start-ups in a goal-oriented way. The fields of teaching are augmented by soft skills offers and a foreign language offer. Here, the focus is on encouraging goal-oriented communication skills, e.g. the skills required by outgoing engineers in international and intercultural situations. **The Competence Level**

	of the courses offered in this area is different as regards the basic training objective in the Bachelor's and Master's fields. These differences are reflected in the practical examples used, in content topics that refer to different professional application contexts, and in the higher scientific and theoretical level of abstraction in the B.Sc. This is also reflected in the different quality of soft skills, which relate to the different team positions and different group leadership functions of Bachelor's and Master's graduates in their future working life. **Specialized Competence (Knowledge)** Students can • explain specialized areas in context of the relevant non-technical disciplines, • outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the learning area, • different specialist disciplines relate to their own discipline and differentiate it as well as make connections, • sketch the basic outlines of how scientific disciplines, paradigms, models, instruments, methods and forms of representation in the specialized sciences are subject to individual and socio-cultural interpretation and historicity, • Can communicate in a foreign language in a manner appropriate to the subject.
Skills	**Professional Competence (Skills)** In selected sub-areas students can • apply basic and specific methods of the said scientific disciplines, • aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline, • to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner, • justify their decisions on forms of organization and application in practical questions in contexts that go beyond the technical relationship to the subject.
Personal Competence	
Social Competence	**Personal Competences (Social Skills)** Students will be able • to learn to collaborate in different manner, • to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees, • to express themselves competently, in a culturally appropriate and gender-sensitive manner in the language of the country (as far as this study-focus would be chosen), • to explain nontechnical items to auditorium with technical background knowledge.
	Personal Competences (Self-reliance) Students are able in selected areas • to reflect on their own profession and professionalism in the context of real-life fields of

Autonomy	application • to organize themselves and their own learning processes • to reflect and decide questions in front of a broad education background • to communicate a nontechnical item in a competent way in writen form or verbaly • to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
Workload in Hours	Depends on choice of courses
Credit points	6

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

Module M1246: Technical Complementary Course for IMPICS (according to Subject Specific Regulations)

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

Module Responsible	Prof. Andreas Timm-Giel
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	Information and Communication Systems: Core qualification: Compulsory

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)	1	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.
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 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 Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computational Science and 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	DE/EN
Cycle	SoSe

Content	• Fundamentals of information theory
	  ◦ Self information, entropy, mutual information
	  ◦ Source coding theorem, channel coding theorem
	  ◦ Channel capacity of various channels
	• Fundamental source coding algorithms:
	  ◦ Huffman Code, Lempel Ziv Algorithm
	• Fundamentals of channel coding
	  ◦ Basic parameters of channel coding and respective bounds
	  ◦ Decoding principles: Maximum-A-Posteriori Decoding, Maximum-Likelihood Decoding, Hard-Decision-Decoding and Soft-Decision-Decoding
	  ◦ Error probability
	• Block codes
	• Low Density Parity Check (LDPC) Codes and iterative Ddecoding
	• Convolutional codes and Viterbi-Decoding
	• Turbo Codes and iterative decoding
	• 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	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0804: Research Project and Seminar

Courses

Title	Typ	Hrs/wk	CP
Project Work (L1761)	Projection Course	10	15
Seminar (L0817)	Seminar	2	3

Module Responsible	Prof. Karl-Heinz Zimmermann
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 372, Study Time in Lecture 168
Credit points	18
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: Core qualification: Compulsory Computational Science and Engineering: Core qualification: Compulsory Information and Communication Systems: Core qualification: Compulsory

Course L1761: Project Work

Typ	Projection Course
Hrs/wk	10
CP	15
Workload in Hours	Independent Study Time 310, Study Time in Lecture 140
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe
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.

Course L0817: Seminar	
Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe
Content	• Seminar presentations by enrolled students about the research work carried out by the students • Active participation in discussions
Literature	Wird vom Veranstalter bekanntgegeben.

Specialization Communication Systems

Graduates of the Communication Systems specialisation are qualified to independently resolve problems in communication networks and digital communications. They also have profound knowledge in software development principles and signal processing. Graduates are qualified to independently resolve problems in communication systems technology and related disciplines.

The Communication Systems specialisation is recommended for students who already bring along a good mathematical foundation, basic knowledge in computer science and/or electrical engineering with focus on information and communication technology.

Module M0676: Digital Communications

Courses

Title	Typ	Hrs/wk	CP
Digital Communications (L0444)	Lecture	2	3
Digital Communications (L0445)	Recitation Section (large)	1	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.
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 124, Study Time in Lecture 56
Credit points	6

Course achievement	**Compulsory**	**Bonus**	**Form**	**Description**
	Yes	None	Written elaboration	
Examination	Written exam			
Examination duration and scale	90 min			
Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Core qualification: Compulsory Computational Science and 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			

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	DE/EN
Cycle	WiSe
Content	• Digital modulation methods • Coherent and non-coherent detection • Channel estimation and equalization • Single-Carrier- and multi carrier transmission schemes, multiple access schemes (TDMA, FDMA, CDMA, OFDM)
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	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/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 M0710: Microwave Engineering

Courses

Title	Typ	Hrs/wk	CP
Microwave Engineering (L0573)	Lecture	2	3
Microwave Engineering (L0574)	Recitation Section (large)	2	2
Microwave Engineering (L0575)	Practical Course	1	1

Module Responsible	Prof. Arne Jacob
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of communication engineering, semiconductor devices and circuits. Basics of Wave propagation from transmission line theory and theoretical electrical engineering.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the propagation of electromagnetic waves and related phenomena. They can describe transmission systems and components. They can name different types of antennas and describe the main characteristics of antennas. They can explain noise in linear circuits, compare different circuits using characteristic numbers and select the best one for specific scenarios.
Skills	Students are able to calculate the propagation of electromagnetic waves. They can analyze complete transmission systems und configure simple receiver circuits. They can calculate the characteristic of simple antennas and arrays based on the geometry. They can calculate the noise of receivers and the signal-to-noise-ratio of transmission systems. They can apply their theoretical knowledge to the practical courses.
Personal Competence	
Social Competence	Students work together in small groups during the practical courses. Together they document, evaluate and discuss their results.
Autonomy	Students are able to relate the knowledge gained in the course to contents of previous lectures. With given instructions they can extract data needed to solve specific problems from external sources. They are able to apply their knowledge to the laboratory courses using the given instructions.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Subject theoretical and practical work; **Description**
Examination	Written exam
Examination duration and scale	90 min

Assignment for the Following Curricula	Electrical Engineering: Core qualification: Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0573: Microwave Engineering	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Arne Jacob
Language	DE/EN
Cycle	WiSe
Content	- Antennas: Analysis - Characteristics - Realizations - Radio Wave Propagation - Transmitter: Power Generation with Vacuum Tubes and Transistors - Receiver: Preamplifier - Heterodyning - Noise - Selected System Applications
Literature	H.-G. Unger, „Elektromagnetische Theorie für die Hochfrequenztechnik, Teil I“, Hüthig, Heidelberg, 1988 H.-G. Unger, „Hochfrequenztechnik in Funk und Radar“, Teubner, Stuttgart, 1994 E. Voges, „Hochfrequenztechnik - Teil II: Leistungsröhren, Antennen und Funkübertragung, Funk- und Radartechnik“, Hüthig, Heidelberg, 1991 E. Voges, „Hochfrequenztechnik“, Hüthig, Bonn, 2004 C.A. Balanis, “Antenna Theory”, John Wiley and Sons, 1982 R. E. Collin, “Foundations for Microwave Engineering”, McGraw-Hill, 1992 D. M. Pozar, “Microwave and RF Design of Wireless Systems”, John Wiley and Sons, 2001 D. M. Pozar, “Microwave Engineerin”, John Wiley and Sons, 2005

Course L0574: Microwave Engineering	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Arne Jacob
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0575: Microwave Engineering	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Arne Jacob
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0836: Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Analysis and Structure of Communication Networks (L0897)	Lecture	2	2
Selected Topics of Communication Networks (L0899)	Project-/problem-based Learning	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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Specialisation Avionic and Embedded Systems: Elective Compulsory Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory

	Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0897: Analysis and Structure of Communication Networks	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel
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 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	Prof. Andreas Timm-Giel
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 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	Prof. Andreas Timm-Giel
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 M0638: Modern Wireless Systems

Courses

Title	Typ	Hrs/wk	CP
Selected Topics of Modern Wireless Systems (L1982)	Project-/problem-based Learning	2	3
Modern Wireless Systems (L0296)	Lecture	2	3

Module Responsible	Dr. Rainer Grünheid
Admission Requirements	None
Recommended Previous Knowledge	• Lecture "Digital Communications" • Lecture "Advanced Concepts of Wireless Communications"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students have an overview of a variety of contemporary wireless systems of different size and complexity. They understand the technical solutions from the perspective of the physical and data link layer. They have developed a system view and are aware of the technical arguments, considering the respective applications and associated constraints. For several examples (e.g., Long Term Evolution, LTE), students are able to explain different concepts in a very deep technical detail.
Skills	Students have developed a system view. They can transfer their knowledge to evaluate other systems, not discussed in the lecture, and to understand the respective technical solutions. Given specific contraints and technical requirements, students are in a position to make proposals for certain design aspects by an appropriate assessment and the consideration of alternatives.
Personal Competence	
Social Competence	Students can jointly elaborate tasks in small groups and present their results in an adequate fashion.
Autonomy	Students are able to extract necessary information from given literature sources and put it into the perspective of the lecture. They can continuously check their level of expertise with the help of accompanying measures (such as online tests, clicker questions, exercise tasks) and, based on that, to steer their learning process accordingly. They can relate their acquired knowledge to topics of other lectures, e.g., "Digital Communications" and "Advanced Topics of Wireless Communications".
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	PBL-Kurs mit Posterpräsentation

Examination	Oral exam
Examination duration and scale	40 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory

Course L1982: Selected Topics of Modern Wireless Systems	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	WiSe
Content	In this course, selected "hot" topics of modern wireless systems will be covererd. For that purpose, students work in groups to elaborate a given subject. The results will be presented in a poster session towards the end of the semester. Possible topics can include various system concepts and related technical principles, such as: • 5G systems • Millimeter wave communication • Visible light communication • Cooperative Multipoint • Massive MIMO • Massive machine-type communication • Interference cancellation • Non-orthogonal multiple access • Heterogeneous networks • ...
Literature	will be provided, depending on the given topics

Course L0296: Modern Wireless Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	WiSe
Content	The lecture gives an overview of contemporary wireless communication concepts and related techniques from a system point of view. For that purpose, different systems, ranging from Wireless Personal to Wide Area Networks, are covered, mainly discussing the physical and data link layer. Systems under consideration include: - ZigBee / IEEE 802.15.4 - Bluetooth - IEEE 802.11 family - Long Term Evolution (LTE) and LTE Advanced - WiMAX A special focus is placed on 4th generation networks; in particular, an in-depth view into the technical principles of the Long Term Evolution (LTE / LTE Advanced) standard is given, with an emphasis on multiple antenna techniques.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011 Jeffrey G. Andrews, Arunabha Ghosh, Rias Muhamed: Fundamentals of WiMAX. Prentice Hall, 2007

Module M0837: Simulation of Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Simulation of Communication Networks (L0887)	Project-/problem-based Learning	5	6

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Knowledge of computer and communication networks • Basic programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the necessary stochastics, the discrete event simulation technology and modelling of networks for performance evaluation.
Skills	Students are able to apply the method of simulation for performance evaluation to different, also not practiced, problems of communication networks. The students can analyse the obtained results and explain the effects observed in the network. They are able to question their own results.
Personal Competence	
Social Competence	Students are able to acquire expert knowledge in groups, present the results, and discuss solution approaches and results. They are able to work out solutions for new problems in small teams.
Autonomy	Students are able to transfer independently and in discussion with others the acquired method and expert knowledge to new problems. They can identify missing knowledge and acquire this knowledge independently.
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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Specialisation Avionic and Embedded Systems: 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

Course L0887: Simulation of Communication Networks	
Typ	Project-/problem-based Learning
Hrs/wk	5
CP	6
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	SoSe
Content	In the course necessary basic stochastics and the discrete event simulation are introduced. Also simulation models for communication networks, for example, traffic models, mobility models and radio channel models are presented in the lecture. Students work with a simulation tool, where they can directly try out the acquired skills, algorithms and models. At the end of the course increasingly complex networks and protocols are considered and their performance is determined by simulation.
Literature	• Skript des Instituts für Kommunikationsnetze Further literature is announced at the beginning of the lecture.

Module M0637: Advanced Concepts of Wireless Communications

Courses

Title	Typ	Hrs/wk	CP
Advanced Concepts of Wireless Communications (L0297)	Lecture	3	4
Advanced Concepts of Wireless Communications (L0298)	Recitation Section (large)	1	2

Module Responsible	Dr. Rainer Grünheid
Admission Requirements	None
Recommended Previous Knowledge	• Lecture "Signals and Systems" • Lecture "Fundamentals of Telecommunications and Stochastic Processes" • Lecture "Digital Communications"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the general as well as advanced principles and techniques that are applied to wireless communications. They understand the properties of wireless channels and the corresponding mathematical description. Furthermore, students are able to explain the physical layer of wireless transmission systems. In this context, they are proficient in the concepts of multicarrier transmission (OFDM), modulation, error control coding, channel estimation and multi-antenna techniques (MIMO). Students can also explain methods of multiple access. On the example of contemporary communication systems (UMTS, LTE) they can put the learnt content into a larger context.
Skills	Using the acquired knowledge, students are able to understand the design of current and future wireless systems. Moreover, given certain constraints, they can choose appropriate parameter settings of communication systems. Students are also able to assess the suitability of technical concepts for a given application.
Personal Competence	
Social Competence	Students can jointly elaborate tasks in small groups and present their results in an adequate fashion.
Autonomy	Students are able to extract necessary information from given literature sources and put it into the perspective of the lecture. They can continuously check their level of expertise with the help of accompanying measures (such as online tests, clicker questions, exercise tasks) and, based on that, to steer their learning process accordingly. They can relate their acquired knowledge to topics of other lectures, e.g., "Fundamentals of Communications and Stochastic Processes" and "Digital Communications".
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 minutes; scope: content of lecture and exercise
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0297: Advanced Concepts of Wireless Communications	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	SoSe
Content	The lecture deals with technical principles and related concepts of mobile communications. In this context, the main focus is put on the physical and data link layer of the ISO-OSI stack. In the lecture, the transmission medium, i.e., the mobile radio channel, serves as the starting point of all considerations. The characteristics and the mathematical descriptions of the radio channel are discussed in detail. Subsequently, various physical layer aspects of wireless transmission are covered, such as channel coding, modulation/demodulation, channel estimation, synchronization, and equalization. Moreover, the different uses of multiple antennas at the transmitter and receiver, known as MIMO techniques, are described. Besides these physical layer topics, concepts of multiple access schemes in a cellular network are outlined. In order to illustrate the above-mentioned technical solutions, the lecture will also provide a system view, highlighting the basics of some contemporary wireless systems, including UMTS/HSPA, LTE, LTE Advanced, and WiMAX.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 David Tse, Pramod Viswanath: Fundamentals of Wireless Communication. Cambridge, 2005 Bernard Sklar: Digital Communications: Fundamentals and Applications. 2nd Edition, Pearson, 2013 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011

Course L0298: Advanced Concepts of Wireless Communications	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Focus Signal Processing

Module M0550: Digital Image Analysis

Courses

Title	Typ	Hrs/wk	CP
Digital Image Analysis (L0126)	Lecture	4	6

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	System theory of one-dimensional signals (convolution and correlation, sampling theory, interpolation and decimation, Fourier transform, linear time-invariant systems), linear algebra (Eigenvalue decomposition, SVD), basic stochastics and statistics (expectation values, influence of sample size, correlation and covariance, normal distribution and its parameters), basics of Matlab, basics in optics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can • Describe imaging processes • Depict the physics of sensorics • Explain linear and non-linear filtering of signals • Establish interdisciplinary connections in the subject area and arrange them in their context • Interpret effects of the most important classes of imaging sensors and displays using mathematical methods and physical models.
Skills	Students are able to • Use highly sophisticated methods and procedures of the subject area • Identify problems and develop and implement creative solutions. Students can solve simple arithmetical problems relating to the specification and design of image processing and image analysis systems. Students are able to assess different solution approaches in multidimensional decision-making areas. Students can undertake a prototypical analysis of processes in Matlab.
Personal Competence	
Social Competence	k.A.
Autonomy	Students can solve image analysis tasks independently using the relevant literature.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56

Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP
Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory

Course L0126: Digital Image Analysis	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	• Image representation, definition of images and volume data sets, illumination, radiometry, multispectral imaging, reflectivities, shape from shading • Perception of luminance and color, color spaces and transforms, color matching functions, human visual system, color appearance models • imaging sensors (CMOS, CCD, HDR, X-ray, IR), sensor characterization(EMVA1288), lenses and optics • spatio-temporal sampling (interpolation, decimation, aliasing, leakage, moiré, flicker, apertures) • features (filters, edge detection, morphology, invariance, statistical features, texture) • optical flow (variational methods, quadratic optimization, Euler-Lagrange equations) • segmentation (distance, region growing, cluster analysis, active contours, level sets, energy minimization and graph cuts) • registration (distance and similarity, variational calculus, iterative closest points)
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Wedel/Cremers, Stereo Scene Flow for 3D Motion Analysis, Springer 2011 Handels, Medizinische Bildverarbeitung, Vieweg, 2000 Pratt, Digital Image Processing, Wiley, 2001 Jain, Fundamentals of Digital Image Processing, Prentice Hall, 1989

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)	1	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.
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 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computational Science and Engineering: Specialisation II. Engineering Science: Elective Compulsory

Assignment for the Following Curricula	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 Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: 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	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0738: Digital Audio Signal Processing

Courses

Title	Typ	Hrs/wk	CP
Digital Audio Signal Processing (L0650)	Lecture	3	4
Digital Audio Signal Processing (L0651)	Recitation Section (large)	1	2

Module Responsible	Prof. Udo Zölzer
Admission Requirements	None
Recommended Previous Knowledge	Signals and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Die Studierenden können die grundlegenden Verfahren und Methoden der digitalen Audiosignalverarbeitung erklären. Sie können die wesentlichen physikalischen Effekte bei der Sprach- und Audiosignalverarbeitung erläutern und in Kategorien einordnen. Sie können einen Überblick der numerischen Methoden und messtechnischen Charakterisierung von Algorithmen zur Audiosignalverarbeitung geben. Sie können die erarbeiteten Algorithmen auf weitere Anwendungen im Bereich der Informationstechnik und Informatik abstrahieren.
Skills	The students will be able to apply methods and techniques from audio signal processing in the fields of mobile and internet communication. They can rely on elementary algorithms of audio signal processing in form of Matlab code and interactive JAVA applets. They can study parameter modifications and evaluate the influence on human perception and technical applications in a variety of applications beyond audio signal processing. Students can perform measurements in time and frequency domain in order to give objective and subjective quality measures with respect to the methods and applications.
Personal Competence	
Social Competence	The students can work in small groups to study special tasks and problems and will be enforced to present their results with adequate methods during the exercise.
Autonomy	The students will be able to retrieve information out of the relevant literature in the field and putt hem into the context of the lecture. They can relate their gathered knowledge and relate them to other lectures (signals and systems, digital communication systems, image and video processing, and pattern recognition). They will be prepared to understand and communicate problems and effects in the field audio signal processing.
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	45 min
Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computational Science and Engineering: Specialisation Systems Engineering and Robotics: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

	Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0650: Digital Audio Signal Processing	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	• Introduction (Studio Technology, Digital Transmission Systems, Storage Media, Audio Components at Home) • Quantization (Signal Quantization, Dither, Noise Shaping, Number Representation) • AD/DA Conversion (Methods, AD Converters, DA Converters, Audio Processing Systems, Digital Signal Processors, Digital Audio Interfaces, Single-Processor Systems, Multiprocessor Systems) • Equalizers (Recursive Audio Filters, Nonrecursive Audio Filters, Multi-Complementary Filter Bank) • Room Simulation (Early Reflections, Subsequent Reverberation, Approximation of Room Impulse Responses) • Dynamic Range Control (Static Curve, Dynamic Behavior, Implementation, Realization Aspects) • Sampling Rate Conversion (Synchronous Conversion, Asynchronous Conversion, Interpolation Methods) • Data Compression (Lossless Data Compression, Lossy Data Compression, Psychoacoustics, ISO-MPEG1 Audio Coding)
Literature	- U. Zölzer, Digitale Audiosignalverarbeitung, 3. Aufl., B.G. Teubner, 2005. - U. Zölzer, Digitale Audio Signal Processing, 2nd Edition, J. Wiley & Sons, 2005. - U. Zölzer (Ed), Digital Audio Effects, 2nd Edition, J. Wiley & Sons, 2011.

Course L0651: Digital Audio Signal Processing	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0556: Computer Graphics

Courses

Title	Typ	Hrs/wk	CP
Computer Graphics (L0145)	Lecture	2	3
Computer Graphics (L0768)	Recitation Section (small)	2	3

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Students are expected to have a solid knowledge of object-oriented programming as well as of linear algebra and geometry.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students have acquired a theoretical basis in computer graphics and have a clear understanding of the process of computer animation.
Skills	Students have acquired • solid skills in modelling and shading, • solid skills in computer animation techniques, and • a thorough command of Maya, a first-class animation system.
Personal Competence	
Social Competence	Students are trained in communicating abstract ideas and are familiar with planning and conducting projects within a small team.
Autonomy	Students are able to direct complex computer animation projects.
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 Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L0145: Computer Graphics	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	EN
Cycle	SoSe
Content	Computer graphics and animation are leading to an unprecedented visual revolution. The course deals with its technological foundations: • Object-oriented Computer Graphics • Projections and Transformations • Polygonal and Parametric Modelling • Illuminating, Shading, Rendering • Computer Animation Techniques • Kinematics and Dynamics Effects Students will be be working on a series of mini-projects which will eventually evolve into a final project. Learning computer graphics and animation resembles learning a musical instrument. Therefore, doing your projects well and in time is essential for performing well on this course.
Literature	Alan H. Watt: 3D Computer Graphics. Harlow: Pearson (3rd ed., repr., 2009). Dariush Derakhshani: Introducing Autodesk Maya 2014. New York, NY : Wiley (2013).

Course L0768: Computer Graphics	
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	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0551: Pattern Recognition and Data Compression

Courses

Title	Typ	Hrs/wk	CP
Pattern Recognition and Data Compression (L0128)	Lecture	4	6

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	Linear algebra (including PCA, unitary transforms), stochastics and statistics, binary arithmetics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can name the basic concepts of pattern recognition and data compression. Students are able to discuss logical connections between the concepts covered in the course and to explain them by means of examples.
Skills	Students can apply statistical methods to classification problems in pattern recognition and to prediction in data compression. On a sound theoretical and methodical basis they can analyze characteristic value assignments and classifications and describe data compression and video signal coding. They are able to use highly sophisticated methods and processes of the subject area. Students are capable of assessing different solution approaches in multidimensional decision-making areas.
Personal Competence	
Social Competence	k.A.
Autonomy	Students are capable of identifying problems independently and of solving them scientifically, using the methods they have learnt.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP
Assignment for the	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology:

Following Curricula	Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory

Course L0128: Pattern Recognition and Data Compression	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	SoSe
Content	Structure of a pattern recognition system, statistical decision theory, classification based on statistical models, polynomial regression, dimension reduction, multilayer perceptron regression, radial basis functions, support vector machines, unsupervised learning and clustering, algorithm-independent machine learning, mixture models and EM, adaptive basis function models and boosting, Markov random fields Information, entropy, redundancy, mutual information, Markov processes, basic coding schemes (code length, run length coding, prefix-free codes), entropy coding (Huffman, arithmetic coding), dictionary coding (LZ77/Deflate/LZMA2, LZ78/LZW), prediction, DPCM, CALIC, quantization (scalar and vector quantization), transform coding, prediction, decorrelation (DPCM, DCT, hybrid DCT, JPEG, JPEG-LS), motion estimation, subband coding, wavelets, HEVC (H.265,MPEG-H)
Literature	Schürmann: Pattern Classification, Wiley 1996 Murphy, Machine Learning, MIT Press, 2012 Barber, Bayesian Reasoning and Machine Learning, Cambridge, 2012 Duda, Hart, Stork: Pattern Classification, Wiley, 2001 Bishop: Pattern Recognition and Machine Learning, Springer 2006 Salomon, Data Compression, the Complete Reference, Springer, 2000 Sayood, Introduction to Data Compression, Morgan Kaufmann, 2006 Ohm, Multimedia Communication Technology, Springer, 2004 Solari, Digital video and audio compression, McGraw-Hill, 1997 Tekalp, Digital Video Processing, Prentice Hall, 1995

Module M1318: Wireless Sensor Networks

Courses

Title	Typ	Hrs/wk	CP
Wireless Sensor Networks (L1815)	Lecture	2	2
Wireless Sensor Networks (L1816)	Recitation Section (small)	1	1
Wireless Sensor Networks: Project (L1819)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L1815: Wireless Sensor Networks

Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	EN
Cycle	SoSe
Content	
Literature	

Course L1816: Wireless Sensor Networks	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Bernd-Christian Renner
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Course L1819: Wireless Sensor Networks: Project	
Typ	Project-/problem-based Learning
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	The PrBL course part will be performed in small groups of students. Topics are from the field of wireless sensor networks and are loosely related to the lecture contents. Project descriptions and goals are provided but have to be solved by the students as follow: 1. Group meeting, creation of working plan and milestones 2. kick-off presentation (during lecture) 3. free working 4. poster creation and presentation Throughout the semester, there will be meetings with the supervisor on a regular basis (weekly or biweekly). Details about the topics and course organization will be provided in the first lecture. Please note that the number of participants is limited due to the available capacity (rooms, equipment, supervisors).
Literature	Will be provided individually

Module M0552: 3D Computer Vision

Courses

Title	Typ	Hrs/wk	CP
3D Computer Vision (L0129)	Lecture	2	3
3D Computer Vision (L0130)	Recitation Section (small)	2	3

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	• Knowlege of the modules Digital Image Analysis and Pattern Recognition and Data Compression are used in the practical task • Linear Algebra (including PCA, SVD), nonlinear optimization (Levenberg-Marquardt), basics of stochastics and basics of Matlab are required and cannot be explained in detail during the lecture.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain and describe the field of projective geometry.
Skills	Students are capable of • Implementing an exemplary 3D or volumetric analysis task • Using highly sophisticated methods and procedures of the subject area • Identifying problems and • Developing and implementing creative solution suggestions. With assistance from the teacher students are able to link the contents of the three subject areas (modules) • Digital Image Analysis • Pattern Recognition and Data Compression and • 3D Computer Vision in practical assignments.
Personal Competence	
Social Competence	Students can collaborate in a small team on the practical realization and testing of a system to reconstruct a three-dimensional scene or to evaluate volume data sets.
Autonomy	Students are able to solve simple tasks independently with reference to the contents of the lectures and the exercise sets. Students are able to solve detailed problems independently with the aid of the tutorial's programming task.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP

Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Computational Science and Engineering: Specialisation Systems Engineering and Robotics: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory

Course L0129: 3D Computer Vision	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	• Projective Geometry and Transformations in 2D und 3D in homogeneous coordinates • Projection matrix, calibration • Epipolar Geometry, fundamental and essential matrices, weak calibration, 5 point algorithm • Homographies 2D and 3D • Trifocal Tensor • Correspondence search
Literature	• **Skriptum Grigat/Wenzel** • Hartley, Zisserman: Multiple View Geometry in Computer Vision. Cambridge 2003.

Course L0130: 3D Computer Vision	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Focus Software

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 Computer and Software Engineering: Elective Compulsory Computational Science and 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: 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	• Syntax and semantics of logic-based systems
	• Deductive verification
	  ◦ Specification
	  ◦ Proof obligations
	  ◦ Program properties
	  ◦ Automated vs. interactive theorem proving
	• Model checking
	  ◦ Foundations
	  ◦ Property languages
	  ◦ Tool support
	• Timed automata
	• 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 M0733: Software Analysis

Courses

Title	Typ	Hrs/wk	CP
Software Analysis (L0631)	Lecture	2	3
Software Analysis (L0632)	Recitation Section (small)	2	3

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of software-engineering activities • Discrete algebraic structures • Object-oriented programming, algorithms, and data structures • Functional programming or Procedural programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major approaches to data-flow analysis, control-flow analysis, and type-based analysis, along with their classification schemes, and employ abstract interpretation. They explain the standard forms of internal representations and models, including their mathematical structure and properties, and evaluate their suitability for a particular analysis. They explain and categorize the major analysis algorithms. They distinguish precise solutions from approximative approaches, and show termination and soundness properties.
Skills	Presented with an analytical task for a software artifact, students select appropriate approaches from software analysis, and justify their choice. They design suitable representations by modifying standard representations. They develop customized analyses and devise them as safe overapproximations. They formulate analyses in a formal way and construct arguments for their correctness, behavior, and precision.
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 analysis. 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	None
Examination	Subject theoretical and practical work
Examination duration and scale	software artifacts/mathematical write-ups; short presentation
	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Computational Science and Engineering: Specialisation Information and Communication Technology: Elective Compulsory

Assignment for the Following Curricula	Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0631: Software Analysis	
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	• Modeling: Control-Flow Modeling, Data Dependences, Intermediate Languages) • Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward) • Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation) • Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm) • Non-Classical Data-Flow Analyses • Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques) • Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification) • Recent Developments of Analysis Techniques and Applications
Literature	• Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005. • Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009. • Benjamin Pierce, Types and Programming Languages, MIT Press. • Selected research papers

Course L0632: Software Analysis	
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 M0758: Application Security

Courses

Title	Typ	Hrs/wk	CP
Application Security (L0726)	Lecture	3	3
Application Security (L0729)	Recitation Section (small)	2	3

Module Responsible	Prof. Dieter Gollmann
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with Information security, fundamentals of cryptography, Web protocols and the architecture of the Web
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can name current approaches for securing selected applications, in particular of web applications
Skills	Students are capable of • performing a security analysis • developing security solutions for distributed applications • recognizing the limitations of existing standard solutions
Personal Competence	
Social Competence	Students are capable of appreciating the impact of security problems on those affected and of the potential responsibilities for their resolution.
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0726: Application Security	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Dieter Gollmann
Language	EN
Cycle	SoSe
Content	• Email security • Web Services security • Security in Web applications • Access control • Trust Management • Trusted Computing • Digital Rights Management • Security Solutions for selected applications
Literature	Webseiten der OMG, W3C, OASIS, WS-Security, OECD, TCG D. Gollmann: Computer Security, 3rd edition, Wiley (2011) R. Anderson: Security Engineering, 2nd edition, Wiley (2008) U. Lang: CORBA Security, Artech House, 2002

Course L0729: Application Security	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Dieter Gollmann
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1301: Software Testing

Courses

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

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Software Engineering • Higher Programming Languages • Object-Oriented Programming • Algorithms and Data Structures • Experience with (Small) Software Projects • Statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students explain the different phases of testing, describe fundamental techniques of different types of testing, and paraphrase the basic principles of the corresponding test process. They give examples of software development scenarios and the corresponding test type and technique. They explain algorithms used for particular testing techniques and describe possible advantages and limitations.
Skills	Students identify the appropriate testing type and technique for a given problem. They adapt and execute respective algorithms to execute a concrete test technique properly. They interpret testing results and execute corresponding steps for proper re-test scenarios. They write and analyze test specifications. They apply bug finding techniques for non-trivial problems.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Students can assess their level of knowledge continuously and adjust it appropriately, based on feedback and on self-guided studies. Within limits, they can 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 testing. 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	None
Examination	Subject theoretical and practical work
Examination duration and scale	Software

Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

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

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

Module M0924: Software for Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Software for Embdedded Systems (L1069)	Lecture	2	3
Software for Embdedded Systems (L1070)	Recitation Section (small)	3	3

Module Responsible	Prof. Volker Turau
Admission Requirements	None
Recommended Previous Knowledge	• Good knowledge and experience in programming language C • Basis knowledge in software engineering • Basic understanding of assembly language
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know the basic principles and procedures of software engineering for embedded systems. They are able to describe the usage and pros of event based programming using interrupts. They know the components and functions of a concrete microcontroller. The participants explain requirements of real time systems. They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	Students build interrupt-based programs for a concrete microcontroller. They build and use a preemptive scheduler. They use peripheral components (timer, ADC, EEPROM) to realize complex tasks for embedded systems. To interface with external components they utilize serial protocols.
Personal Competence	
Social Competence	
Autonomy	
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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory

Course L1069: Software for Embdedded Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Volker Turau
Language	DE/EN
Cycle	SoSe
Content	• General-Purpose Processors • Programming the Atmel AVR • Interrupts • C for Embedded Systems • Standard Single Purpose Processors: Peripherals • Finite-State Machines • Memory • Operating Systems for Embedded Systems • Real-Time Embedded Systems • Boot loader and Power Management
Literature	1. Embedded System Design, F. Vahid and T. Givargis, John Wiley 2. Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly 3. C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP 4. The Art of Designing Embedded Systems, J. Ganssle, Newnses 5. Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg 6. Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

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

Module M1397: Model Checking - Proof Engines and Algorithms

Courses

Title	Typ	Hrs/wk	CP
Model Checking - Proof Engines and Algorithms (L1979)	Lecture	2	3
Model Checking - Proof Engines and Algorithms (L1980)	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	Students know • algorithms and data structures for model checking, • basics of Boolean reasoning engines and • the impact of specification and modelling on the computational effort for model checking.
Skills	Students can • explain and implement algorithms and data structures for model checking, • decide whether a given problem can be solved using Boolean reasoning or model checking, and • implement the respective algorithms.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • defend 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	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L1979: Model Checking - Proof Engines and Algorithms	
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	Correctness is a major concern in embedded systems. Model checking can fully automatically proof formal properties about digital hardware or software. Such properties are given in temporal logic, e.g., to prove "No two orthogonal traffic lights will ever be green."
	
	And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond?
	
	But what are the limitations of model checking?
	How are the models generated from a given design?
	The lecture will answer these questions. Open source tools will be used to gather a practical experience.
	
	Among other topics, the lecture will consider the following topics:
	• Modelling digital Hardware, Software, and Cyber Physical Systems
	• Data structures, decision procedures and proof engines
	  ◦ Binary Decision Diagrams
	  ◦ And-Inverter-Graphs
	  ◦ Boolean Satisfiability
	  ◦ Satisfiability Modulo Theories
	• Specification Languages
	  ◦ CTL
	  ◦ LTL
	  ◦ System Verilog Assertions
	• Algorithms for
	  ◦ Reachability Analysis
	  ◦ Symbolic CTL Checking
	  ◦ Bounded LTL-Model Checking
	  ◦ Optimizations, e.g., induction, abstraction
	• Quality assurance

Literature	Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA. A. Biere, A. Biere, M. Heule, H. van Maaren, and T. Walsh. 2009. *Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications*. IOS Press, Amsterdam, The Netherlands, The Netherlands. Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms	
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

Specialization Secure and Dependable IT Systems

Graduates of the Secure and Dependable IT Systems specialisation acquire extensive knowledge in software verification and IT security. They also have knowledge in communication networks and signal processing. They are able to apply methods and procedures required to work on secure and dependable IT systems, as well as critically examine new insights to further develop and incorporate in their work.

The Secure and Dependable IT Systems specialisation is recommended for students who already have a good mathematical foundation and basic knowledge in computer science and software development.

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** **Bonus** **Form** **Description** Yes 15 % Excercises
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Computational Science and 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: 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	• Syntax and semantics of logic-based systems
	• Deductive verification
	  ◦ Specification
	  ◦ Proof obligations
	  ◦ Program properties
	  ◦ Automated vs. interactive theorem proving
	• Model checking
	  ◦ Foundations
	  ◦ Property languages
	  ◦ Tool support
	• Timed automata
	• 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. Dieter Gollmann
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	None
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Computational Science and 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. Dieter Gollmann
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. Dieter Gollmann
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0758: Application Security

Courses

Title	Typ	Hrs/wk	CP
Application Security (L0726)	Lecture	3	3
Application Security (L0729)	Recitation Section (small)	2	3

Module Responsible	Prof. Dieter Gollmann
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with Information security, fundamentals of cryptography, Web protocols and the architecture of the Web
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can name current approaches for securing selected applications, in particular of web applications
Skills	Students are capable of • performing a security analysis • developing security solutions for distributed applications • recognizing the limitations of existing standard solutions
Personal Competence	
Social Competence	Students are capable of appreciating the impact of security problems on those affected and of the potential responsibilities for their resolution.
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0726: Application Security	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Dieter Gollmann
Language	EN
Cycle	SoSe
Content	• Email security • Web Services security • Security in Web applications • Access control • Trust Management • Trusted Computing • Digital Rights Management • Security Solutions for selected applications
Literature	Webseiten der OMG, W3C, OASIS, WS-Security, OECD, TCG D. Gollmann: Computer Security, 3rd edition, Wiley (2011) R. Anderson: Security Engineering, 2nd edition, Wiley (2008) U. Lang: CORBA Security, Artech House, 2002

Course L0729: Application Security	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Dieter Gollmann
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1397: Model Checking - Proof Engines and Algorithms

Courses

Title	Typ	Hrs/wk	CP
Model Checking - Proof Engines and Algorithms (L1979)	Lecture	2	3
Model Checking - Proof Engines and Algorithms (L1980)	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	Students know • algorithms and data structures for model checking, • basics of Boolean reasoning engines and • the impact of specification and modelling on the computational effort for model checking.
Skills	Students can • explain and implement algorithms and data structures for model checking, • decide whether a given problem can be solved using Boolean reasoning or model checking, and • implement the respective algorithms.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • defend 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	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L1979: Model Checking - Proof Engines and Algorithms	
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	Correctness is a major concern in embedded systems. Model checking can fully automatically proof formal properties about digital hardware or software. Such properties are given in temporal logic, e.g., to prove "No two orthogonal traffic lights will ever be green."
	
	And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond?
	
	But what are the limitations of model checking?
	How are the models generated from a given design?
	The lecture will answer these questions. Open source tools will be used to gather a practical experience.
	
	Among other topics, the lecture will consider the following topics:
	• Modelling digital Hardware, Software, and Cyber Physical Systems
	• Data structures, decision procedures and proof engines
	  ◦ Binary Decision Diagrams
	  ◦ And-Inverter-Graphs
	  ◦ Boolean Satisfiability
	  ◦ Satisfiability Modulo Theories
	• Specification Languages
	  ◦ CTL
	  ◦ LTL
	  ◦ System Verilog Assertions
	• Algorithms for
	  ◦ Reachability Analysis
	  ◦ Symbolic CTL Checking
	  ◦ Bounded LTL-Model Checking
	  ◦ Optimizations, e.g., induction, abstraction
	• Quality assurance

Literature	Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA. A. Biere, A. Biere, M. Heule, H. van Maaren, and T. Walsh. 2009. *Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications*. IOS Press, Amsterdam, The Netherlands, The Netherlands. Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms	
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 M0943: Network Security

Courses

Title	Typ	Hrs/wk	CP
Network Security (L1105)	Lecture	3	3
Network Security (L1106)	Recitation Section (small)	2	3

Module Responsible	Prof. Dieter Gollmann
Admission Requirements	None
Recommended Previous Knowledge	Discrete Mathematics, Computer Networks (TCP/IP)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can • explain the fundamental security services that can be implemented with the methods of modern cryptography, • describe current standardized network security protocols and mechanisms, • follow current methods for the formal analysis of security protocols.
Skills	Students are capable of • performing an analysis of network security solutions. • identifying suitable security solutions for given requirements. • recognizing the limitations of existing standard solutions, • performing a formal analysis of security protocos.
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 minutes
Assignment for the Following Curricula	Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L1105: Network Security	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Dieter Gollmann
Language	EN
Cycle	SoSe
Content	• Security objectives • Security services and cryptographic mechanisms • Key establishment: Diffie-Hellman, Kerberos • IPsec protocols, mobile IPv6 • SSL/TLS • GSM/UMTS/LTE security protocols • WLAN security • Firewalls and Intrusion Detection Systems • Formal analysis of security protocols
Literature	W. Stallings: Cryptography and Network Security: Principles and Practice, 6th edition (2013) A. Menezes, P. van Oorschot, S. Vanstone: Handbook of Applied Cryptography, CRC Press (1997) D. Gollmann: Computer Security, 3rd edition, Wiley (2011) V. Niemi, K. Nyberg: UMTS Security, Wiley (2003)

Course L1106: Network Security	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Dieter Gollmann
Language	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**
	No	None	Excercises	Praktische Übungsaufgaben zur Anwendung der gelernten Ansätze

Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: 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

Focus Networks

Module M0676: Digital Communications

Courses

Title	Typ	Hrs/wk	CP
Digital Communications (L0444)	Lecture	2	3
Digital Communications (L0445)	Recitation Section (large)	1	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.
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 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description**
Examination	Written exam
Examination duration and scale	90 min
	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Core qualification: Compulsory Computational Science and Engineering: Specialisation II. Engineering Science: Elective

Assignment for the Following Curricula	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

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	DE/EN
Cycle	WiSe
Content	• Digital modulation methods • Coherent and non-coherent detection • Channel estimation and equalization • Single-Carrier- and multi carrier transmission schemes, multiple access schemes (TDMA, FDMA, CDMA, OFDM)
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	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/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 M0836: Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Analysis and Structure of Communication Networks (L0897)	Lecture	2	2
Selected Topics of Communication Networks (L0899)	Project-/problem-based Learning	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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Specialisation Avionic and Embedded Systems: Elective Compulsory Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory

	Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0897: Analysis and Structure of Communication Networks	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel
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 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	Prof. Andreas Timm-Giel
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 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	Prof. Andreas Timm-Giel
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 M0837: Simulation of Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Simulation of Communication Networks (L0887)	Project-/problem-based Learning	5	6

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Knowledge of computer and communication networks • Basic programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the necessary stochastics, the discrete event simulation technology and modelling of networks for performance evaluation.
Skills	Students are able to apply the method of simulation for performance evaluation to different, also not practiced, problems of communication networks. The students can analyse the obtained results and explain the effects observed in the network. They are able to question their own results.
Personal Competence	
Social Competence	Students are able to acquire expert knowledge in groups, present the results, and discuss solution approaches and results. They are able to work out solutions for new problems in small teams.
Autonomy	Students are able to transfer independently and in discussion with others the acquired method and expert knowledge to new problems. They can identify missing knowledge and acquire this knowledge independently.
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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Specialisation Avionic and Embedded Systems: 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

Course L0887: Simulation of Communication Networks	
Typ	Project-/problem-based Learning
Hrs/wk	5
CP	6
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	SoSe
Content	In the course necessary basic stochastics and the discrete event simulation are introduced. Also simulation models for communication networks, for example, traffic models, mobility models and radio channel models are presented in the lecture. Students work with a simulation tool, where they can directly try out the acquired skills, algorithms and models. At the end of the course increasingly complex networks and protocols are considered and their performance is determined by simulation.
Literature	• Skript des Instituts für Kommunikationsnetze Further literature is announced at the beginning of the lecture.

Module M0839: Traffic Engineering

Courses

Title	Typ	Hrs/wk	CP
Seminar Traffic Engineering (L0902)	Seminar	2	2
Traffic Engineering (L0900)	Lecture	2	2
Traffic Engineering Exercises (L0901)	Recitation Section (small)	1	2

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamentals of communication or computer networks • Stochastics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe methods for planning, optimisation and performance evaluation of communication networks.
Skills	Students are able to solve typical planning and optimisation tasks for communication networks. Furthermore they are able to evaluate the network performance using queuing theory. Students are able to apply independently what they have learned to other and new problems. They can present their results in front of experts and discuss them.
Personal Competence	
Social Competence	
Autonomy	Students are able to acquire the necessary expert knowledge to understand the functionality and performance of new communication networks independently.
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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computational Science and Engineering: Specialisation Information and Communication Technology: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory

Course L0902: Seminar Traffic Engineering	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	WiSe
Content	Selected applications of methods for planning, optimization, and performance evaluation of communication networks, which have been introduced in the traffic engineering lecture are prepared by the students and presented in a seminar.
Literature	• U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Vieweg + Teubner • further literature announced in the lecture

Course L0900: Traffic Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	WiSe
Content	Network Planning and Optimization • Linear Programming (LP) • Network planning with LP solvers • Planning of communication networks Queueing Theory for Communication Networks • Stochastic processes • Queueing systems • Switches (circuit- and packet switching) • Network of queues
Literature	Literatur: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer further literature announced in the lecture

Course L0901: Traffic Engineering Exercises	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	WiSe
Content	Accompanying exercise for the traffic engineering course
Literature	Literatur: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer further literature announced in the lecture

Focus Software and Signal Processing

Module M0738: Digital Audio Signal Processing

Courses

Title	Typ	Hrs/wk	CP
Digital Audio Signal Processing (L0650)	Lecture	3	4
Digital Audio Signal Processing (L0651)	Recitation Section (large)	1	2

Module Responsible	Prof. Udo Zölzer
Admission Requirements	None
Recommended Previous Knowledge	Signals and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Die Studierenden können die grundlegenden Verfahren und Methoden der digitalen Audiosignalverarbeitung erklären. Sie können die wesentlichen physikalischen Effekte bei der Sprach- und Audiosignalverarbeitung erläutern und in Kategorien einordnen. Sie können einen Überblick der numerischen Methoden und messtechnischen Charakterisierung von Algorithmen zur Audiosignalverarbeitung geben. Sie können die erarbeiteten Algorithmen auf weitere Anwendungen im Bereich der Informationstechnik und Informatik abstrahieren.
Skills	The students will be able to apply methods and techniques from audio signal processing in the fields of mobile and internet communication. They can rely on elementary algorithms of audio signal processing in form of Matlab code and interactive JAVA applets. They can study parameter modifications and evaluate the influence on human perception and technical applications in a variety of applications beyond audio signal processing. Students can perform measurements in time and frequency domain in order to give objective and subjective quality measures with respect to the methods and applications.
Personal Competence	
Social Competence	The students can work in small groups to study special tasks and problems and will be enforced to present their results with adequate methods during the exercise.
Autonomy	The students will be able to retrieve information out of the relevant literature in the field and putt hem into the context of the lecture. They can relate their gathered knowledge and relate them to other lectures (signals and systems, digital communication systems, image and video processing, and pattern recognition). They will be prepared to understand and communicate problems and effects in the field audio signal processing.
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	45 min
	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computational Science and Engineering: Specialisation Systems Engineering and Robotics:

Assignment for the Following Curricula	Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0650: Digital Audio Signal Processing	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	• Introduction (Studio Technology, Digital Transmission Systems, Storage Media, Audio Components at Home) • Quantization (Signal Quantization, Dither, Noise Shaping, Number Representation) • AD/DA Conversion (Methods, AD Converters, DA Converters, Audio Processing Systems, Digital Signal Processors, Digital Audio Interfaces, Single-Processor Systems, Multiprocessor Systems) • Equalizers (Recursive Audio Filters, Nonrecursive Audio Filters, Multi-Complementary Filter Bank) • Room Simulation (Early Reflections, Subsequent Reverberation, Approximation of Room Impulse Responses) • Dynamic Range Control (Static Curve, Dynamic Behavior, Implementation, Realization Aspects) • Sampling Rate Conversion (Synchronous Conversion, Asynchronous Conversion, Interpolation Methods) • Data Compression (Lossless Data Compression, Lossy Data Compression, Psychoacoustics, ISO-MPEG1 Audio Coding)
Literature	- U. Zölzer, Digitale Audiosignalverarbeitung, 3. Aufl., B.G. Teubner, 2005. - U. Zölzer, Digitale Audio Signal Processing, 2nd Edition, J. Wiley & Sons, 2005. - U. Zölzer (Ed), Digital Audio Effects, 2nd Edition, J. Wiley & Sons, 2011.

Course L0651: Digital Audio Signal Processing	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0733: Software Analysis

Courses

Title	Typ	Hrs/wk	CP
Software Analysis (L0631)	Lecture	2	3
Software Analysis (L0632)	Recitation Section (small)	2	3

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of software-engineering activities • Discrete algebraic structures • Object-oriented programming, algorithms, and data structures • Functional programming or Procedural programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major approaches to data-flow analysis, control-flow analysis, and type-based analysis, along with their classification schemes, and employ abstract interpretation. They explain the standard forms of internal representations and models, including their mathematical structure and properties, and evaluate their suitability for a particular analysis. They explain and categorize the major analysis algorithms. They distinguish precise solutions from approximative approaches, and show termination and soundness properties.
Skills	Presented with an analytical task for a software artifact, students select appropriate approaches from software analysis, and justify their choice. They design suitable representations by modifying standard representations. They develop customized analyses and devise them as safe overapproximations. They formulate analyses in a formal way and construct arguments for their correctness, behavior, and precision.
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 analysis. 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	None
Examination	Subject theoretical and practical work
Examination duration and scale	software artifacts/mathematical write-ups; short presentation
	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Computational Science and Engineering: Specialisation Information and Communication Technology: Elective Compulsory

Assignment for the Following Curricula	Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0631: Software Analysis	
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	• Modeling: Control-Flow Modeling, Data Dependences, Intermediate Languages) • Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward) • Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation) • Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm) • Non-Classical Data-Flow Analyses • Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques) • Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification) • Recent Developments of Analysis Techniques and Applications
Literature	• Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005. • Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009. • Benjamin Pierce, Types and Programming Languages, MIT Press. • Selected research papers

Course L0632: Software Analysis	
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 M0550: Digital Image Analysis

Courses

Title	Typ	Hrs/wk	CP
Digital Image Analysis (L0126)	Lecture	4	6

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	System theory of one-dimensional signals (convolution and correlation, sampling theory, interpolation and decimation, Fourier transform, linear time-invariant systems), linear algebra (Eigenvalue decomposition, SVD), basic stochastics and statistics (expectation values, influence of sample size, correlation and covariance, normal distribution and its parameters), basics of Matlab, basics in optics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can • Describe imaging processes • Depict the physics of sensorics • Explain linear and non-linear filtering of signals • Establish interdisciplinary connections in the subject area and arrange them in their context • Interpret effects of the most important classes of imaging sensors and displays using mathematical methods and physical models.
Skills	Students are able to • Use highly sophisticated methods and procedures of the subject area • Identify problems and develop and implement creative solutions. Students can solve simple arithmetical problems relating to the specification and design of image processing and image analysis systems. Students are able to assess different solution approaches in multidimensional decision-making areas. Students can undertake a prototypical analysis of processes in Matlab.
Personal Competence	
Social Competence	k.A.
Autonomy	Students can solve image analysis tasks independently using the relevant literature.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None

Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP
Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory

Course L0126: Digital Image Analysis	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	• Image representation, definition of images and volume data sets, illumination, radiometry, multispectral imaging, reflectivities, shape from shading • Perception of luminance and color, color spaces and transforms, color matching functions, human visual system, color appearance models • imaging sensors (CMOS, CCD, HDR, X-ray, IR), sensor characterization(EMVA1288), lenses and optics • spatio-temporal sampling (interpolation, decimation, aliasing, leakage, moiré, flicker, apertures) • features (filters, edge detection, morphology, invariance, statistical features, texture) • optical flow (variational methods, quadratic optimization, Euler-Lagrange equations) • segmentation (distance, region growing, cluster analysis, active contours, level sets, energy minimization and graph cuts) • registration (distance and similarity, variational calculus, iterative closest points)
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Wedel/Cremers, Stereo Scene Flow for 3D Motion Analysis, Springer 2011 Handels, Medizinische Bildverarbeitung, Vieweg, 2000 Pratt, Digital Image Processing, Wiley, 2001 Jain, Fundamentals of Digital Image Processing, Prentice Hall, 1989

Module M0924: Software for Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Software for Embdedded Systems (L1069)	Lecture	2	3
Software for Embdedded Systems (L1070)	Recitation Section (small)	3	3

Module Responsible	Prof. Volker Turau
Admission Requirements	None
Recommended Previous Knowledge	• Good knowledge and experience in programming language C • Basis knowledge in software engineering • Basic understanding of assembly language
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know the basic principles and procedures of software engineering for embedded systems. They are able to describe the usage and pros of event based programming using interrupts. They know the components and functions of a concrete microcontroller. The participants explain requirements of real time systems. They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	Students build interrupt-based programs for a concrete microcontroller. They build and use a preemptive scheduler. They use peripheral components (timer, ADC, EEPROM) to realize complex tasks for embedded systems. To interface with external components they utilize serial protocols.
Personal Competence	
Social Competence	
Autonomy	
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	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory

Course L1069: Software for Embdedded Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Volker Turau
Language	DE/EN
Cycle	SoSe
Content	• General-Purpose Processors • Programming the Atmel AVR • Interrupts • C for Embedded Systems • Standard Single Purpose Processors: Peripherals • Finite-State Machines • Memory • Operating Systems for Embedded Systems • Real-Time Embedded Systems • Boot loader and Power Management
Literature	1. Embedded System Design, F. Vahid and T. Givargis, John Wiley 2. Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly 3. C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP 4. The Art of Designing Embedded Systems, J. Ganssle, Newnses 5. Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg 6. Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

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

Module M0556: Computer Graphics

Courses

Title	Typ	Hrs/wk	CP
Computer Graphics (L0145)	Lecture	2	3
Computer Graphics (L0768)	Recitation Section (small)	2	3

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Students are expected to have a solid knowledge of object-oriented programming as well as of linear algebra and geometry.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students have acquired a theoretical basis in computer graphics and have a clear understanding of the process of computer animation.
Skills	Students have acquired • solid skills in modelling and shading, • solid skills in computer animation techniques, and • a thorough command of Maya, a first-class animation system.
Personal Competence	
Social Competence	Students are trained in communicating abstract ideas and are familiar with planning and conducting projects within a small team.
Autonomy	Students are able to direct complex computer animation projects.
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 Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L0145: Computer Graphics	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	EN
Cycle	SoSe
Content	Computer graphics and animation are leading to an unprecedented visual revolution. The course deals with its technological foundations: • Object-oriented Computer Graphics • Projections and Transformations • Polygonal and Parametric Modelling • Illuminating, Shading, Rendering • Computer Animation Techniques • Kinematics and Dynamics Effects Students will be be working on a series of mini-projects which will eventually evolve into a final project. Learning computer graphics and animation resembles learning a musical instrument. Therefore, doing your projects well and in time is essential for performing well on this course.
Literature	Alan H. Watt: 3D Computer Graphics. Harlow: Pearson (3rd ed., repr., 2009). Dariush Derakhshani: Introducing Autodesk Maya 2014. New York, NY : Wiley (2013).

Course L0768: Computer Graphics	
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	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0551: Pattern Recognition and Data Compression

Courses

Title	Typ	Hrs/wk	CP
Pattern Recognition and Data Compression (L0128)	Lecture	4	6

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	Linear algebra (including PCA, unitary transforms), stochastics and statistics, binary arithmetics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can name the basic concepts of pattern recognition and data compression. Students are able to discuss logical connections between the concepts covered in the course and to explain them by means of examples.
Skills	Students can apply statistical methods to classification problems in pattern recognition and to prediction in data compression. On a sound theoretical and methodical basis they can analyze characteristic value assignments and classifications and describe data compression and video signal coding. They are able to use highly sophisticated methods and processes of the subject area. Students are capable of assessing different solution approaches in multidimensional decision-making areas.
Personal Competence	
Social Competence	k.A.
Autonomy	Students are capable of identifying problems independently and of solving them scientifically, using the methods they have learnt.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP
Assignment for the	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology:

Following Curricula	Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory

Course L0128: Pattern Recognition and Data Compression	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	SoSe
Content	Structure of a pattern recognition system, statistical decision theory, classification based on statistical models, polynomial regression, dimension reduction, multilayer perceptron regression, radial basis functions, support vector machines, unsupervised learning and clustering, algorithm-independent machine learning, mixture models and EM, adaptive basis function models and boosting, Markov random fields Information, entropy, redundancy, mutual information, Markov processes, basic coding schemes (code length, run length coding, prefix-free codes), entropy coding (Huffman, arithmetic coding), dictionary coding (LZ77/Deflate/LZMA2, LZ78/LZW), prediction, DPCM, CALIC, quantization (scalar and vector quantization), transform coding, prediction, decorrelation (DPCM, DCT, hybrid DCT, JPEG, JPEG-LS), motion estimation, subband coding, wavelets, HEVC (H.265,MPEG-H)
Literature	Schürmann: Pattern Classification, Wiley 1996 Murphy, Machine Learning, MIT Press, 2012 Barber, Bayesian Reasoning and Machine Learning, Cambridge, 2012 Duda, Hart, Stork: Pattern Classification, Wiley, 2001 Bishop: Pattern Recognition and Machine Learning, Springer 2006 Salomon, Data Compression, the Complete Reference, Springer, 2000 Sayood, Introduction to Data Compression, Morgan Kaufmann, 2006 Ohm, Multimedia Communication Technology, Springer, 2004 Solari, Digital video and audio compression, McGraw-Hill, 1997 Tekalp, Digital Video Processing, Prentice Hall, 1995

Module M1301: Software Testing

Courses

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

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Software Engineering • Higher Programming Languages • Object-Oriented Programming • Algorithms and Data Structures • Experience with (Small) Software Projects • Statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students explain the different phases of testing, describe fundamental techniques of different types of testing, and paraphrase the basic principles of the corresponding test process. They give examples of software development scenarios and the corresponding test type and technique. They explain algorithms used for particular testing techniques and describe possible advantages and limitations.
Skills	Students identify the appropriate testing type and technique for a given problem. They adapt and execute respective algorithms to execute a concrete test technique properly. They interpret testing results and execute corresponding steps for proper re-test scenarios. They write and analyze test specifications. They apply bug finding techniques for non-trivial problems.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Students can assess their level of knowledge continuously and adjust it appropriately, based on feedback and on self-guided studies. Within limits, they can 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 testing. 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	None
Examination	Subject theoretical and practical work
Examination duration and scale	Software

Assignment for the Following Curricula	Computer Science: Specialisation Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

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

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

Module M0552: 3D Computer Vision

Courses

Title	Typ	Hrs/wk	CP
3D Computer Vision (L0129)	Lecture	2	3
3D Computer Vision (L0130)	Recitation Section (small)	2	3

Module Responsible	Prof. Rolf-Rainer Grigat
Admission Requirements	None
Recommended Previous Knowledge	• Knowlege of the modules Digital Image Analysis and Pattern Recognition and Data Compression are used in the practical task • Linear Algebra (including PCA, SVD), nonlinear optimization (Levenberg-Marquardt), basics of stochastics and basics of Matlab are required and cannot be explained in detail during the lecture.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain and describe the field of projective geometry.
Skills	Students are capable of • Implementing an exemplary 3D or volumetric analysis task • Using highly sophisticated methods and procedures of the subject area • Identifying problems and • Developing and implementing creative solution suggestions. With assistance from the teacher students are able to link the contents of the three subject areas (modules) • Digital Image Analysis • Pattern Recognition and Data Compression and • 3D Computer Vision in practical assignments.
Personal Competence	
Social Competence	Students can collaborate in a small team on the practical realization and testing of a system to reconstruct a three-dimensional scene or to evaluate volume data sets.
Autonomy	Students are able to solve simple tasks independently with reference to the contents of the lectures and the exercise sets. Students are able to solve detailed problems independently with the aid of the tutorial's programming task.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 Minutes, Content of Lecture and materials in StudIP

Assignment for the Following Curricula	Computer Science: Specialisation Intelligence Engineering: Elective Compulsory Computational Science and Engineering: Specialisation Systems Engineering and Robotics: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Numerics and Computer Science: Elective Compulsory

Course L0129: 3D Computer Vision	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	• Projective Geometry and Transformations in 2D und 3D in homogeneous coordinates • Projection matrix, calibration • Epipolar Geometry, fundamental and essential matrices, weak calibration, 5 point algorithm • Homographies 2D and 3D • Trifocal Tensor • Correspondence search
Literature	• **Skriptum Grigat/Wenzel** • Hartley, Zisserman: Multiple View Geometry in Computer Vision. Cambridge 2003.

Course L0130: 3D Computer Vision	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Rolf-Rainer Grigat
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Thesis

Module M-002: Master Thesis

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Professoren der TUHH
Admission Requirements	• According to General Regulations §21 (1): At least 60 credit points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• The students can use specialized knowledge (facts, theories, and methods) of their subject competently on specialized issues. • The students can explain in depth the relevant approaches and terminologies in one or more areas of their subject, describing current developments and taking up a critical position on them. • The students can place a research task in their subject area in its context and describe and critically assess the state of research.
Skills	The students are able: • To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question. • To apply knowledge they have acquired and methods they have learnt in the course of their studies to complex and/or incompletely defined problems in a solution-oriented way. • To develop new scientific findings in their subject area and subject them to a critical assessment.
Personal Competence	
Social Competence	Students can • Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured way. • Deal with issues competently in an expert discussion and answer them in a manner that is appropriate to the addressees while upholding their own assessments and viewpoints convincingly.
Autonomy	Students are able: • To structure a project of their own in work packages and to work them off accordingly. • To work their way in depth into a largely unknown subject and to access the information required for them to do so.

	• To apply the techniques of scientific work comprehensively in research of their own.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination	Thesis
Examination duration and scale	According to General Regulations
Assignment for the Following Curricula	Civil Engineering: Thesis: Compulsory Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Computer Science: Thesis: Compulsory Electrical Engineering: Thesis: Compulsory Energy and Environmental Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Global Innovation Management: Thesis: Compulsory Computational Science and Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory International Management and Engineering: Thesis: Compulsory Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory Logistics, Infrastructure and Mobility: Thesis: Compulsory Materials Science: Thesis: Compulsory Mathematical Modelling in Engineering: Theory, Numerics, Applications: Thesis: Compulsory Mechanical Engineering and Management: Thesis: Compulsory Mechatronics: Thesis: Compulsory Biomedical Engineering: Thesis: Compulsory Microelectronics and Microsystems: Thesis: Compulsory Product Development, Materials and Production: Thesis: Compulsory Renewable Energies: Thesis: Compulsory Naval Architecture and Ocean Engineering: Thesis: Compulsory Ship and Offshore Technology: Thesis: Compulsory Teilstudiengang Lehramt Metalltechnik: Thesis: Compulsory Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory