# Module Manual

Master of Science (M.Sc.)

# Information and Communication Systems

Cohort: Winter Term 2021

Updated: 31st May 2021

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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.<br>• Students are able to explain basic theories, categories, and models in selected special areas of business management.<br>• Students are able to interrelate technical and management knowledge. |
| *Skills* | • Students are able to apply basic methods in selected areas of business management.<br>• 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 |
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| **Information regarding lectures and courses can be found in the corresponding module handbook published separately.** |

## Module M0524: Non-technical Courses for Master

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|---|---|
| **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)**<br><br>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.<br><br>**The Learning Architecture**<br><br>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.<br><br>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".<br><br>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.<br><br>**Teaching and Learning Arrangements**<br><br>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.<br><br>**Fields of Teaching**<br><br>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.<br><br>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.<br><br>**The Competence Level**<br><br>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.<br><br>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.<br><br>**Specialized Competence (Knowledge)**<br><br>Students can<br><br>• explain specialized areas in context of the relevant non-technical disciplines,<br>• outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the learning area,<br>• different specialist disciplines relate to their own discipline and differentiate it as well as make connections,<br>• 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,<br>• Can communicate in a foreign language in a manner appropriate to the subject. |
| *Skills* | **Professional Competence (Skills)**<br><br>In selected sub-areas students can<br><br>• apply basic and specific methods of the said scientific disciplines,<br>• aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline,<br>• to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner,<br>• 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)** |

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|---|---|
| | Students will be able<br>• to learn to collaborate in different manner,<br>• to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees,<br>• 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),<br>• to explain nontechnical items to auditorium with technical background knowledge. |
| *Autonomy* | **Personal Competences (Self-reliance)**<br>Students are able in selected areas<br>• to reflect on their own profession and professionalism in the context of real-life fields of application<br>• to organize themselves and their own learning processes<br>• to reflect and decide questions in front of a broad education background<br>• to communicate a nontechnical item in a competent way in writen form or verbaly<br>• 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 |
|---|---|---|---|

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|---|---|
| **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**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*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) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Mathematics 1-3<br>• Probability theory and random processes<br>• 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 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Computational Science and Engineering: Specialisation II. Engineering Science: Elective Compulsory<br>Information and Communication Systems: Core qualification: Compulsory<br>International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory<br>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<br>  ◦ Self information, entropy, mutual information<br>  ◦ Source coding theorem, channel coding theorem<br>  ◦ Channel capacity of various channels<br>• Fundamental source coding algorithms:<br>  ◦ Huffman Code, Lempel Ziv Algorithm<br>• Fundamentals of channel coding<br>  ◦ Basic parameters of channel coding and respective bounds<br>  ◦ Decoding principles: Maximum-A-Posteriori Decoding, Maximum-Likelihood Decoding, Hard-Decision-Decoding and Soft-Decision-Decoding<br>  ◦ Error probability<br>• Block codes<br>• Low Density Parity Check (LDPC) Codes and iterative Ddecoding<br>• Convolutional codes and Viterbi-Decoding<br>• Turbo Codes and iterative decoding<br>• Coded Modulation |
| **Literature** | Bossert, M.: Kanalcodierung. Oldenbourg.<br>Friedrichs, B.: Kanalcodierung. Springer.<br>Lin, S., Costello, D.: Error Control Coding. Prentice Hall.<br>Roth, R.: Introduction to Coding Theory.<br>Johnson, S.: Iterative Error Correction. Cambridge.<br>Richardson, T., Urbanke, R.: Modern Coding Theory. Cambridge University Press.<br>Gallager, R. G.: Information theory and reliable communication. Whiley-VCH<br>Cover, T., Thomas, J.: Elements of information theory. Wiley. |

| Course L0438: Information Theory and Coding | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | 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 |

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|---|---|
| **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** | 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.<br>/<br>Current literature on research topics of the chosen specialization. |

### Course L0817: Seminar

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|---|---|
| **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<br>• 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) | 2 | 2 |
| Laboratory Digital Communications (L0646) | Practical Course | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Mathematics 1-3<br>• Signals and Systems<br>• 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 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | Compulsory: Yes; Bonus: None; Form: Written elaboration; Description: |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Core qualification: Compulsory<br>Computational Science and Engineering: Specialisation II. Engineering Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems: Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory<br>Microelectronics and Microsystems: Core qualification: Elective Compulsory |

| Course L0444: Digital Communications | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | • Digital modulation methods<br>• Coherent and non-coherent detection<br>• Channel estimation and equalization<br>• Single-Carrier- and multi carrier transmission schemes, multiple access schemes (TDMA, FDMA, CDMA, OFDM) |
| **Literature** | K. Kammeyer: Nachrichtenübertragung, Teubner<br>P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.<br>J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.<br>S. Haykin: Communication Systems. Wiley<br>R.G. Gallager: Principles of Digital Communication. Cambridge<br>A. Goldsmith: Wireless Communication. Cambridge.<br>D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge. |

| Course L0445: Digital Communications | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | 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<br>- Random processes<br>- Digital data transmission |
| **Literature** | K. Kammeyer: Nachrichtenübertragung, Teubner<br>P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.<br>J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.<br>S. Haykin: Communication Systems. Wiley<br>R.G. Gallager: Principles of Digital Communication. Cambridge<br>A. Goldsmith: Wireless Communication. Cambridge.<br>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 |

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|---|---|
| **Module Responsible** | Prof. Alexander Kölpin |
| **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** / **Bonus** / **Form** / **Description**: Yes / None / Subject theoretical and practical work |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Core qualification: Compulsory<br>Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory<br>International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory<br>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. Alexander Kölpin |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | - Antennas: Analysis - Characteristics - Realizations<br>- Radio Wave Propagation<br>- Transmitter: Power Generation with Vacuum Tubes and Transistors<br>- Receiver: Preamplifier - Heterodyning - Noise<br>- Selected System Applications |
| **Literature** | H.-G. Unger, „Elektromagnetische Theorie für die Hochfrequenztechnik, Teil I“, Hüthig, Heidelberg, 1988<br>H.-G. Unger, „Hochfrequenztechnik in Funk und Radar“, Teubner, Stuttgart, 1994<br>E. Voges, „Hochfrequenztechnik - Teil II: Leistungsröhren, Antennen und Funkübertragung, Funk- und Radartechnik“, Hüthig, Heidelberg, 1991<br>E. Voges, „Hochfrequenztechnik“, Hüthig, Bonn, 2004<br>C.A. Balanis, “Antenna Theory”, John Wiley and Sons, 1982<br>R. E. Collin, “Foundations for Microwave Engineering”, McGraw-Hill, 1992<br>D. M. Pozar, “Microwave and RF Design of Wireless Systems”, John Wiley and Sons, 2001<br>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. Alexander Kölpin |
| **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. Alexander Kölpin |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M0836: Communication Networks

**Courses**

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

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

### Course L0899: Selected Topics of Communication Networks

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

| Course L0898: Communication Networks Excercise | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | 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 | 3 | 3 |

| | |
|---|---|
| **Module Responsible** | Dr. Rainer Grünheid |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Lecture "Digital Communications"<br>• 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 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | Compulsory: Yes; Bonus: None; Form: Subject theoretical and practical work; Description: 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<br>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:<br>• 5G systems<br>• Millimeter wave communication<br>• Visible light communication<br>• Cooperative Multipoint<br>• Massive MIMO<br>• Massive machine-type communication<br>• Interference cancellation<br>• Non-orthogonal multiple access<br>• Heterogeneous networks<br>• ... |
| **Literature** | will be provided, depending on the given topics |

| Course L0296: Modern Wireless Systems | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **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.<br><br>Systems under consideration include:<br>- ZigBee / IEEE 802.15.4<br>- Bluetooth<br>- IEEE 802.11 family<br>- Long Term Evolution (LTE) and LTE Advanced<br>- WiMAX<br><br>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<br><br>Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011<br><br>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<br>• 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** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Aircraft Systems Engineering: Core qualification: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: 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<br><br>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) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Dr. Rainer Grünheid |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Lecture "Signals and Systems"<br>• Lecture "Fundamentals of Telecommunications and Stochastic Processes"<br>• 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 110, Study Time in Lecture 70 |
| **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<br>Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory<br>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.<br><br>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.<br><br>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<br><br>David Tse, Pramod Viswanath: Fundamentals of Wireless Communication. Cambridge, 2005<br><br>Bernard Sklar: Digital Communications: Fundamentals and Applications. 2nd Edition, Pearson, 2013<br><br>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** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **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<br>• Describe imaging processes<br>• Depict the physics of sensorics<br>• Explain linear and non-linear filtering of signals<br>• Establish interdisciplinary connections in the subject area and arrange them in their context<br>• Interpret effects of the most important classes of imaging sensors and displays using mathematical methods and physical models. |
| *Skills* | Students are able to<br>• Use highly sophisticated methods and procedures of the subject area<br>• Identify problems and develop and implement creative solutions.<br>Students can solve simple arithmetical problems relating to the specification and design of image processing and image analysis systems.<br>Students are able to assess different solution approaches in multidimensional decision-making areas.<br>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 II: Intelligence Engineering: Elective Compulsory<br>Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Electrical Engineering: Specialisation Medical Technology: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Robotics 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<br>• Perception of luminance and color, color spaces and transforms, color matching functions, human visual system, color appearance models<br>• imaging sensors (CMOS, CCD, HDR, X-ray, IR), sensor characterization(EMVA1288), lenses and optics<br>• spatio-temporal sampling (interpolation, decimation, aliasing, leakage, moiré, flicker, apertures)<br>• features (filters, edge detection, morphology, invariance, statistical features, texture)<br>• optical flow ( variational methods, quadratic optimization, Euler-Lagrange equations)<br>• segmentation (distance, region growing, cluster analysis, active contours, level sets, energy minimization and graph cuts)<br>• registration (distance and similarity, variational calculus, iterative closest points) |
| **Literature** | Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011<br>Wedel/Cremers, Stereo Scene Flow for 3D Motion Analysis, Springer 2011<br>Handels, Medizinische Bildverarbeitung, Vieweg, 2000<br>Pratt, Digital Image Processing, Wiley, 2001<br>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) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Mathematics 1-3<br>• Signals and Systems<br>• Fundamentals of signal and system theory as well as random processes.<br>• 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 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory<br>Computational Science and Engineering: Specialisation II. Engineering Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory<br>Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory<br>Theoretical Mechanical Engineering: Technical Complementary Course: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory |

| Course L0446: Digital Signal Processing and Digital Filters | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | • Transforms of discrete-time signals:<br>  ◦ Discrete-time Fourier Transform (DTFT)<br>  ◦ Discrete Fourier-Transform (DFT), Fast Fourier Transform (FFT)<br>  ◦ Z-Transform<br>• Correspondence of continuous-time and discrete-time signals, sampling, sampling theorem<br>• Fast convolution, Overlap-Add-Method, Overlap-Save-Method<br>• Fundamental structures and basic types of digital filters<br>• Characterization of digital filters using pole-zero plots, important properties of digital filters<br>• Quantization effects<br>• Design of linear-phase filters<br>• Fundamentals of stochastic signal processing and adaptive filters<br>  ◦ MMSE criterion<br>  ◦ Wiener Filter<br>  ◦ LMS- and RLS-algorithm<br>• Traditional and parametric methods of spectrum estimation |
| **Literature** | K.-D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung. Vieweg Teubner.<br>V. Oppenheim, R. W. Schafer, J. R. Buck: Zeitdiskrete Signalverarbeitung. Pearson StudiumA. V.<br>W. Hess: Digitale Filter. Teubner.<br>Oppenheim, R. W. Schafer: Digital signal processing. Prentice Hall.<br>S. Haykin:  Adaptive filter theory.<br>L. B. Jackson: Digital filters and signal processing.  Kluwer.<br>T.W. Parks, C.S. Burrus: Digital filter design. Wiley. |

| Course L0447: Digital Signal Processing and Digital Filters | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## 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** | 60 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>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)<br>• Quantization (Signal Quantization, Dither, Noise Shaping, Number Representation)<br>• AD/DA Conversion (Methods, AD Converters, DA Converters, Audio Processing Systems, Digital Signal Processors, Digital Audio Interfaces, Single-Processor Systems, Multiprocessor Systems)<br>• Equalizers (Recursive Audio Filters, Nonrecursive Audio Filters, Multi-Complementary Filter Bank)<br>• Room Simulation (Early Reflections, Subsequent Reverberation, Approximation of Room Impulse Responses)<br>• Dynamic Range Control (Static Curve, Dynamic Behavior, Implementation, Realization Aspects)<br>• Sampling Rate Conversion (Synchronous Conversion, Asynchronous Conversion, Interpolation Methods)<br>• Data Compression (Lossless Data Compression, Lossy Data Compression, Psychoacoustics, ISO-MPEG1 Audio Coding) |
| **Literature** | - U. Zölzer, Digitale Audiosignalverarbeitung, 3. Aufl., B.G. Teubner, 2005 .<br>- U. Zölzer, Digitale Audio Signal Processing, 2nd Edition, J. Wiley & Sons, 2005.<br>- 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** | • Linear Algebra (in particular matrix/vector computation)<br>• Basic programming skills in C/C++ |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain and describe basic algorithms in 3D computer graphics. |
| *Skills* | Students are capable of<br>• implementing a basic 3D rendering pipeline. This consists of projecting simple 3D structures (e.g. cube, spheres) onto a 2D surface using a virtual camera.<br>• apply geometric transformations (e.g. rotation, scaling) in 2D and 3D computer graphics.<br>• using well-known 2D/3D APIs (OpenGL, Cairo) for solving a given problem statement. |
| **Personal Competence** | |
| *Social Competence* | Students can collaborate in a small team on the realization and validation of a 3D computer graphics pipeline. |
| *Autonomy* | • Students are able to solve simple tasks independently with reference to the contents of the lectures and the exercise sets.<br>• 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** | 90 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: 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:<br>• Object-oriented Computer Graphics<br>• Projections and Transformations<br>• Polygonal and Parametric Modelling<br>• Illuminating, Shading, Rendering<br>• Computer Animation Techniques<br>• Kinematics and Dynamics Effects<br>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:<br>3D Computer Graphics.<br>Harlow: Pearson (3rd ed., repr., 2009).<br><br>Dariush Derakhshani:<br>Introducing Autodesk Maya 2014.<br>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 M1700: Satellite Communications and Navigation

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Radio-Based Positioning and Navigation (L2711) | Lecture | 2 | 3 |
| Satellite Communications (L2710) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*Autonomy* | |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory |

### Course L2711: Radio-Based Positioning and Navigation

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch, Dr. Ing. Rico Mendrzik |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

### Course L2710: Satellite Communications

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## Module M1702: Process Imaging

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Process Imaging (L2723) | Lecture | 2 | 3 |
| Process Imaging (L2724) | Project-/problem-based Learning | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Alexander Penn |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*Autonomy* | |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory<br>Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory<br>Process Engineering: Specialisation Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory<br>Water and Environmental Engineering: Specialisation Environment: Elective Compulsory<br>Water and Environmental Engineering: Specialisation Environment: Elective Compulsory<br>Water and Environmental Engineering: Specialisation Water: Elective Compulsory<br>Water and Environmental Engineering: Specialisation Water: Elective Compulsory |

### Course L2723: Process Imaging

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Alexander Penn |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

| Course L2724: Process Imaging | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Alexander Penn |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## Module M1598: Image Processing

**Courses**

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

| | |
|---|---|
| **Module Responsible** | Prof. Tobias Knopp |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Signal and Systems |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students know about<br>• visual perception<br>• multidimensional signal processing<br>• sampling and sampling theorem<br>• filtering<br>• image enhancement<br>• edge detection<br>• multi-resolution procedures: Gauss and Laplace pyramid, wavelets<br>• image compression<br>• image segmentation<br>• morphological image processing |
| *Skills* | The students can<br>• analyze, process, and improve multidimensional image data<br>• implement simple compression algorithms<br>• design custom filters for specific applications |
| **Personal Competence** | |
| *Social Competence* | Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem. |
| *Autonomy* | Students are able to independently investigate a complex problem and assess which competencies are required to solve it. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Data Science: Core qualification: Elective Compulsory<br>Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Electrical Engineering: Specialisation Medical Technology: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory |

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

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

## 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<br>• Computational logic<br>• Object-oriented programming, algorithms, and data structures<br>• Functional programming or procedural programming<br>• 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 I. Computer and Software Engineering: Elective Compulsory<br>Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Compulsory<br>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<br>• Deductive verification<br>  ◦ Specification<br>  ◦ Proof obligations<br>  ◦ Program properties<br>  ◦ Automated vs. interactive theorem proving<br>• Model checking<br>  ◦ Foundations<br>  ◦ Property languages<br>  ◦ Tool support<br>• Timed automata<br>• Recent developments of verification techniques and applications |
| **Literature** | • C. Baier and J-P. Katoen, Principles of Model Checking, MIT Press 2007.<br>• M. Huth and M. Bryan, Logic in Computer Science. Modelling and Reasoning about Systems, 2nd Edition, 2004.<br>• 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<br>• Discrete algebraic structures<br>• Object-oriented programming, algorithms, and data structures<br>• 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 |
| **Assignment for the Following Curricula** | Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>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)<br>• Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward)<br>• Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation)<br>• Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm)<br>• Non-Classical Data-Flow Analyses<br>• Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques)<br>• Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification)<br>• Recent Developments of Analysis Techniques and Applications |
| **Literature** | • Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005.<br>• Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009.<br>• Benjamin Pierce, Types and Programming Languages, MIT Press.<br>• 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 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<br>• Higher Programming Languages<br>• Object-Oriented Programming<br>• Algorithms and Data Structures<br>• Experience with (Small) Software Projects<br>• 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.<br>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 s own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of s testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. T devise plans to arrive at new solutions or assess existing ones |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Subject theoretical and practical work |
| **Examination duration and scale** | Software |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>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<br>• Model-based testing<br>• Test automation<br>• Criteria-based testing |
| **Literature** | • M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008.<br>• P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2016.<br>• 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<br>• Model-based testing<br>• Test automation<br>• Criteria-based testing |
| **Literature** | • M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008.<br>• P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2015. |

## Module M1682: Secure Software Engineering

**Courses**

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

| | |
|---|---|
| **Module Responsible** | Prof. Riccardo Scandariato |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*Autonomy* | |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory |

### Course L2667: Secure Software Engineering

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

### Course L2668: Secure Software Engineering

| | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## 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<br>• algorithms and data structures for model checking,<br>• basics of Boolean reasoning engines and<br>• the impact of specification and modelling on the computational effort for model checking. |
| *Skills* | Students can<br>• explain and implement algorithms and data structures for model checking,<br>• decide whether a given problem can be solved using Boolean reasoning or model checking, and<br>• implement the respective algorithms. |
| **Personal Competence** | |
| *Social Competence* | Students<br>• discuss relevant topics in class and<br>• 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** | **Compulsory** / **Bonus** / **Form** / **Description**<br>Yes / None / Subject theoretical and practical work / Die Aufgabe wird im Rahmen von Volresung und Prüfung definiert. Die Lösung der Aufgabe ist Zulassungsvoraussetzung für die Prüfung. |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: 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."<br><br>And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond?<br><br>But what are the limitations of model checking?<br>How are the models generated from a given design?<br>The lecture will answer these questions. Open source tools will be used to gather a practical experience.<br><br>Among other topics, the lecture will consider the following topics:<br>• Modelling digital Hardware, Software, and Cyber Physical Systems<br>• Data structures, decision procedures and proof engines<br>◦ Binary Decision Diagrams<br>◦ And-Inverter-Graphs<br>◦ Boolean Satisfiability<br>◦ Satisfiability Modulo Theories<br>• Specification Languages<br>◦ CTL<br>◦ LTL<br>◦ System Verilog Assertions<br>• Algorithms for<br>◦ Reachability Analysis<br>◦ Symbolic CTL Checking<br>◦ Bounded LTL-Model Checking<br>◦ Optimizations, e.g., induction, abstraction<br>• Quality assurance |
| **Literature** | Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA.<br><br>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.<br><br>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<br>• Computational logic<br>• Object-oriented programming, algorithms, and data structures<br>• Functional programming or procedural programming<br>• Concurrency |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students apply the major verification techniques in model checking and deductive verification. They explain in formal terms syntax and semantics of the underlying logics, and assess the expressivity of different logics as well as their limitations. They classify formal properties of software systems. They find flaws in formal arguments, arising from modeling artifacts or underspecification. |
| *Skills* | Students formulate provable properties of a software system in a formal language. They develop logic-based models that properly abstract from the software under verification and, where necessary, adapt model or property. They construct proofs and property checks by hand or using tools for model checking or deductive verification, and reflect on the scope of the results. Presented with a verification problem in natural language, they select the appropriate verification technique and justify their choice. |
| **Personal Competence** | |
| *Social Competence* | Students discuss relevant topics in class. They defend their solutions orally. They communicate in English. |
| *Autonomy* | Using accompanying on-line material for self study, students can assess their level of knowledge continuously and adjust it appropriately. Working on exercise problems, they receive additional feedback. Within limits, they can set their own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of software verification. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. They can devise plans to arrive at new solutions or assess existing ones. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | **Compulsory** Yes; **Bonus** 15 %; **Form** Excercises; **Description** |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Compulsory<br>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<br>• Deductive verification<br>  ◦ Specification<br>  ◦ Proof obligations<br>  ◦ Program properties<br>  ◦ Automated vs. interactive theorem proving<br>• Model checking<br>  ◦ Foundations<br>  ◦ Property languages<br>  ◦ Tool support<br>• Timed automata<br>• Recent developments of verification techniques and applications |
| **Literature** | • C. Baier and J-P. Katoen, Principles of Model Checking, MIT Press 2007.<br>• M. Huth and M. Bryan, Logic in Computer Science. Modelling and Reasoning about Systems, 2nd Edition, 2004.<br>• Selected Research Papers |

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

## Module M0942: Software Security

**Courses**

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

| | |
|---|---|
| **Module Responsible** | Prof. Riccardo Scandariato |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Familiarity with C/C++, web programming |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can<br>• name the main causes for security vulnerabilities in software<br>• explain current methods for identifying and avoiding security vulnerabilities<br>• explain the fundamental concepts of code-based access control |
| *Skills* | Students are capable of<br>• performing a software vulnerability analysis<br>• 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 I. Computer and Software Engineering: Elective Compulsory<br>Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory |

### Course L1103: Software Security

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | • Reliabilty and Software Security<br>• Attacks exploiting character and integer representations<br>• Buffer overruns<br>• Vulnerabilities in memory managemet: double free attacks<br>• Race conditions<br>• SQL injection<br>• Cross-site scripting and cross-site request forgery<br>• Testing for security; taint analysis<br>• Type safe languages<br>• Development proceses for secure software<br>• Code-based access control |
| **Literature** | M. Howard, D. LeBlanc: Writing Secure Code, 2nd edition, Microsoft Press (2002)<br>G. Hoglund, G. McGraw: Exploiting Software, Addison-Wesley (2004)<br>L. Gong, G. Ellison, M. Dageforde: Inside Java 2 Platform Security, 2nd edition, Addison-Wesley (2003)<br>B. LaMacchia, S. Lange, M. Lyons, R. Martin, K. T. Price: .NET Framework Security, Addison-Wesley Professional (2002)<br>D. Gollmann: Computer Security, 3rd edition (2011) |

| Course L1104: Software Security | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module 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<br>• algorithms and data structures for model checking,<br>• basics of Boolean reasoning engines and<br>• the impact of specification and modelling on the computational effort for model checking. |
| *Skills* | Students can<br>• explain and implement algorithms and data structures for model checking,<br>• decide whether a given problem can be solved using Boolean reasoning or model checking, and<br>• implement the respective algorithms. |
| **Personal Competence** | |
| *Social Competence* | Students<br>• discuss relevant topics in class and<br>• 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** | **Compulsory** / **Bonus** / **Form** / **Description**<br>Yes / None / Subject theoretical and practical work / Die Aufgabe wird im Rahmen von Volresung und Prüfung definiert. Die Lösung der Aufgabe ist Zulassungsvoraussetzung für die Prüfung. |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: 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."<br><br>And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond?<br><br>But what are the limitations of model checking?<br>How are the models generated from a given design?<br>The lecture will answer these questions. Open source tools will be used to gather a practical experience.<br><br>Among other topics, the lecture will consider the following topics:<br>• Modelling digital Hardware, Software, and Cyber Physical Systems<br>• Data structures, decision procedures and proof engines<br>◦ Binary Decision Diagrams<br>◦ And-Inverter-Graphs<br>◦ Boolean Satisfiability<br>◦ Satisfiability Modulo Theories<br>• Specification Languages<br>◦ CTL<br>◦ LTL<br>◦ System Verilog Assertions<br>• Algorithms for<br>◦ Reachability Analysis<br>◦ Symbolic CTL Checking<br>◦ Bounded LTL-Model Checking<br>◦ Optimizations, e.g., induction, abstraction<br>• Quality assurance |
| **Literature** | Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA.<br><br>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.<br><br>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 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.<br>Knowledge about approaches for designing dependable systems, e.g.,<br>• Structural solutions like modular redundancy<br>• Algorithmic solutions like handling byzantine faults or checkpointing<br>Knowledge about methods for the analysis of dependable systems |
| *Skills* | Ability to implement dependable systems using the above approaches.<br>Ability to analyzs the dependability of systems using the above methods for analysis. |
| **Personal Competence** | |
| *Social Competence* | Students<br>• discuss relevant topics in class and<br>• 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: Yes; Bonus: None; Form: Subject theoretical and practical work; Description: Die Lösung einer Aufgabe ist Zuslassungsvoraussetzung für die Prüfung. Die Aufgabe wird in Vorlesung und Übung definiert. |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Computational Science and Engineering: Specialisation I. Computer Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory<br>Mechatronics: Specialisation System Design: Elective Compulsory<br>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<br><br>The term dependability comprises various aspects of a system. These are typically:<br><br>• Reliability<br>• Availability<br>• Maintainability<br>• Safety<br>• Security<br><br>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.<br>Contents<br><br>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:<br><br>• Modelling<br>• Fault Tolerance<br>• Design Concepts<br>• 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) | 2 | 2 |
| Laboratory Digital Communications (L0646) | Practical Course | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Mathematics 1-3<br>• Signals and Systems<br>• 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 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | Compulsory: Yes; Bonus: None; Form: Written elaboration; Description: |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Core qualification: Compulsory<br>Computational Science and Engineering: Specialisation II. Engineering Science: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems: Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory<br>Microelectronics and Microsystems: Core qualification: Elective Compulsory |

| Course L0444: Digital Communications | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | • Digital modulation methods<br>• Coherent and non-coherent detection<br>• Channel estimation and equalization<br>• Single-Carrier- and multi carrier transmission schemes, multiple access schemes (TDMA, FDMA, CDMA, OFDM) |
| **Literature** | K. Kammeyer: Nachrichtenübertragung, Teubner<br>P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.<br>J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.<br>S. Haykin: Communication Systems. Wiley<br>R.G. Gallager: Principles of Digital Communication. Cambridge<br>A. Goldsmith: Wireless Communication. Cambridge.<br>D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge. |

| Course L0445: Digital Communications | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | 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<br>- Random processes<br>- Digital data transmission |
| **Literature** | K. Kammeyer: Nachrichtenübertragung, Teubner<br>P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner.<br>J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.<br>S. Haykin: Communication Systems. Wiley<br>R.G. Gallager: Principles of Digital Communication. Cambridge<br>A. Goldsmith: Wireless Communication. Cambridge.<br>D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge. |

## Module M0836: Communication Networks

**Courses**

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

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

### Course L0899: Selected Topics of Communication Networks

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

| Course L0898: Communication Networks Excercise | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | 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<br>• 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** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Aircraft Systems Engineering: Core qualification: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: 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<br><br>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<br>• 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.<br>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 I. Computer and Software Engineering: Elective Compulsory<br>Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: 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, Dr. Phuong Nga Tran |
| **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<br>• 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, Dr. Phuong Nga Tran |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | Network Planning and Optimization<br>• Linear Programming (LP)<br>• Network planning with LP solvers<br>• Planning of communication networks<br>Queueing Theory for Communication Networks<br>• Stochastic processes<br>• Queueing systems<br>• Switches (circuit- and packet switching)<br>• Network of queues |
| **Literature** | Literatur:<br>U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer<br>Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben<br>/<br>Literature:<br>U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer<br>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:<br>U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer<br>Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature:<br>U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer<br>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** | 60 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>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)<br>• Quantization (Signal Quantization, Dither, Noise Shaping, Number Representation)<br>• AD/DA Conversion (Methods, AD Converters, DA Converters, Audio Processing Systems, Digital Signal Processors, Digital Audio Interfaces, Single-Processor Systems, Multiprocessor Systems)<br>• Equalizers (Recursive Audio Filters, Nonrecursive Audio Filters, Multi-Complementary Filter Bank)<br>• Room Simulation (Early Reflections, Subsequent Reverberation, Approximation of Room Impulse Responses)<br>• Dynamic Range Control (Static Curve, Dynamic Behavior, Implementation, Realization Aspects)<br>• Sampling Rate Conversion (Synchronous Conversion, Asynchronous Conversion, Interpolation Methods)<br>• Data Compression (Lossless Data Compression, Lossy Data Compression, Psychoacoustics, ISO-MPEG1 Audio Coding) |
| **Literature** | - U. Zölzer, Digitale Audiosignalverarbeitung, 3. Aufl., B.G. Teubner, 2005 .<br>- U. Zölzer, Digitale Audio Signal Processing, 2nd Edition, J. Wiley & Sons, 2005.<br>- 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<br>• Discrete algebraic structures<br>• Object-oriented programming, algorithms, and data structures<br>• 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 |
| **Assignment for the Following Curricula** | Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>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)<br>• Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward)<br>• Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation)<br>• Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm)<br>• Non-Classical Data-Flow Analyses<br>• Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques)<br>• Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification)<br>• Recent Developments of Analysis Techniques and Applications |
| **Literature** | • Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005.<br>• Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009.<br>• Benjamin Pierce, Types and Programming Languages, MIT Press.<br>• 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<br>• Describe imaging processes<br>• Depict the physics of sensorics<br>• Explain linear and non-linear filtering of signals<br>• Establish interdisciplinary connections in the subject area and arrange them in their context<br>• Interpret effects of the most important classes of imaging sensors and displays using mathematical methods and physical models. |
| *Skills* | Students are able to<br>• Use highly sophisticated methods and procedures of the subject area<br>• Identify problems and develop and implement creative solutions.<br>Students can solve simple arithmetical problems relating to the specification and design of image processing and image analysis systems.<br>Students are able to assess different solution approaches in multidimensional decision-making areas.<br>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 II: Intelligence Engineering: Elective Compulsory<br>Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Electrical Engineering: Specialisation Medical Technology: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Robotics 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<br>• Perception of luminance and color, color spaces and transforms, color matching functions, human visual system, color appearance models<br>• imaging sensors (CMOS, CCD, HDR, X-ray, IR), sensor characterization(EMVA1288), lenses and optics<br>• spatio-temporal sampling (interpolation, decimation, aliasing, leakage, moiré, flicker, apertures)<br>• features (filters, edge detection, morphology, invariance, statistical features, texture)<br>• optical flow ( variational methods, quadratic optimization, Euler-Lagrange equations)<br>• segmentation (distance, region growing, cluster analysis, active contours, level sets, energy minimization and graph cuts)<br>• registration (distance and similarity, variational calculus, iterative closest points) |
| **Literature** | Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011<br>Wedel/Cremers, Stereo Scene Flow for 3D Motion Analysis, Springer 2011<br>Handels, Medizinische Bildverarbeitung, Vieweg, 2000<br>Pratt, Digital Image Processing, Wiley, 2001<br>Jain, Fundamentals of Digital Image Processing, Prentice Hall, 1989 |

## 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<br>• Higher Programming Languages<br>• Object-Oriented Programming<br>• Algorithms and Data Structures<br>• Experience with (Small) Software Projects<br>• 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.<br>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 s own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of s testing. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. T devise plans to arrive at new solutions or assess existing ones |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Subject theoretical and practical work |
| **Examination duration and scale** | Software |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory<br>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<br>• Model-based testing<br>• Test automation<br>• Criteria-based testing |
| **Literature** | • M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008.<br>• P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2016.<br>• 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<br>• Model-based testing<br>• Test automation<br>• Criteria-based testing |
| **Literature** | • M. Pezze and M. Young, Software Testing and Analysis, John Wiley 2008.<br>• P. Ammann and J. Offutt, "Introduction to Software Testing", 2nd edition 2015. |

## Module M1682: Secure Software Engineering

**Courses**

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

| | |
|---|---|
| **Module Responsible** | Prof. Riccardo Scandariato |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*Autonomy* | |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory |

### Course L2667: Secure Software Engineering

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

### Course L2668: Secure Software Engineering

| | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Riccardo Scandariato |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## Module M1700: Satellite Communications and Navigation

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Radio-Based Positioning and Navigation (L2711) | Lecture | 2 | 3 |
| Satellite Communications (L2710) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Gerhard Bauch |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence**<br>*Knowledge*<br>*Skills*<br>**Personal Competence**<br>*Social Competence*<br>*Autonomy* | |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory |

### Course L2711: Radio-Based Positioning and Navigation

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch, Dr. Ing. Rico Mendrzik |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

### Course L2710: Satellite Communications

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Gerhard Bauch |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## 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** | • Linear Algebra (in particular matrix/vector computation)<br>• Basic programming skills in C/C++ |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain and describe basic algorithms in 3D computer graphics. |
| *Skills* | Students are capable of<br>• implementing a basic 3D rendering pipeline. This consists of projecting simple 3D structures (e.g. cube, spheres) onto a 2D surface using a virtual camera.<br>• apply geometric transformations (e.g. rotation, scaling) in 2D and 3D computer graphics.<br>• using well-known 2D/3D APIs (OpenGL, Cairo) for solving a given problem statement. |
| **Personal Competence** | |
| *Social Competence* | Students can collaborate in a small team on the realization and validation of a 3D computer graphics pipeline. |
| *Autonomy* | • Students are able to solve simple tasks independently with reference to the contents of the lectures and the exercise sets.<br>• 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** | 90 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: 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:<br>• Object-oriented Computer Graphics<br>• Projections and Transformations<br>• Polygonal and Parametric Modelling<br>• Illuminating, Shading, Rendering<br>• Computer Animation Techniques<br>• Kinematics and Dynamics Effects<br>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:<br>3D Computer Graphics.<br>Harlow: Pearson (3rd ed., repr., 2009).<br><br>Dariush Derakhshani:<br>Introducing Autodesk Maya 2014.<br>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 M1598: Image Processing

**Courses**

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

| | |
|---|---|
| **Module Responsible** | Prof. Tobias Knopp |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Signal and Systems |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students know about<br>• visual perception<br>• multidimensional signal processing<br>• sampling and sampling theorem<br>• filtering<br>• image enhancement<br>• edge detection<br>• multi-resolution procedures: Gauss and Laplace pyramid, wavelets<br>• image compression<br>• image segmentation<br>• morphological image processing |
| *Skills* | The students can<br>• analyze, process, and improve multidimensional image data<br>• implement simple compression algorithms<br>• design custom filters for specific applications |
| **Personal Competence** | |
| *Social Competence* | Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem. |
| *Autonomy* | Students are able to independently investigate a complex problem and assess which competencies are required to solve it. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Data Science: Core qualification: Elective Compulsory<br>Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory<br>Electrical Engineering: Specialisation Medical Technology: Elective Compulsory<br>Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory<br>International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory |

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

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

## Module M1694: Security of Cyber-Physical Systems

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Security of Cyber-Physical Systems (L2691) | Lecture | 2 | 3 |
| Security of Cyber-Physical Systems (L2692) | Recitation Section (small) | 2 | 3 |

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|---|---|
| **Module Responsible** | Prof. Sibylle Fröschle |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | IT security, programming skills, statistics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students know and can explain<br>- the threats posed by cyber attacks to cyber-physical systems (CPS)<br>- concrete attacks at a technical level, e.g. on bus systems<br>- security solutions specific to CPS with their capabilities and limitations<br>- examples of security architectures for CPS and the requirements they guarantee<br>- standard security engineering processes for CPS |
| *Skills* | The students are able to<br>- identify security threats and assess the risks for a given CPS<br>- apply attack toolkits to analyse a networked control system, and detect attacks beyond those taught in class<br>- identify and apply security solutions suitable to the requirements<br>- follow security engineering processes to develop a security architecture for a given CPS<br>- recognize challenges and limitations, e.g. posed by novel types of attack |
| **Personal Competence** | |
| *Social Competence* | The students are able to<br>- expertly discuss security risks and incidents of CPS and their mitigation in a solution-oriented fashion with experts and non-experts<br>- foster a security culture with respect to CPS and the corresponding critical infrastructures |
| *Autonomy* | The students are able to<br>- follow up and critically assess current developments in the security of CPS including relevant security incidents<br>- master a new topic within the area by self-study and self-initiated interaction with experts and peers. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory<br>Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory |

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

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

# 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):<br>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.<br>• 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.<br>• 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:<br>• To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question.<br>• 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.<br>• To develop new scientific findings in their subject area and subject them to a critical assessment. |
| **Personal Competence** | |
| *Social Competence* | Students can<br>• Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured way.<br>• 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:<br>• To structure a project of their own in work packages and to work them off accordingly.<br>• To work their way in depth into a largely unknown subject and to access the information required for them to do so.<br>• 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<br>Bioprocess Engineering: Thesis: Compulsory<br>Chemical and Bioprocess Engineering: Thesis: Compulsory<br>Computer Science: Thesis: Compulsory<br>Electrical Engineering: Thesis: Compulsory<br>Energy and Environmental Engineering: Thesis: Compulsory<br>Energy Systems: Thesis: Compulsory<br>Environmental Engineering: Thesis: Compulsory<br>Aircraft Systems Engineering: Thesis: Compulsory<br>Global Innovation Management: Thesis: Compulsory<br>Computational Science and Engineering: Thesis: Compulsory<br>Information and Communication Systems: Thesis: Compulsory<br>Interdisciplinary Mathematics: Thesis: Compulsory<br>International Management and Engineering: Thesis: Compulsory<br>Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory<br>Logistics, Infrastructure and Mobility: Thesis: Compulsory<br>Materials Science: Thesis: Compulsory<br>Mechanical Engineering and Management: Thesis: Compulsory<br>Mechatronics: Thesis: Compulsory<br>Biomedical Engineering: Thesis: Compulsory<br>Microelectronics and Microsystems: Thesis: Compulsory<br>Product Development, Materials and Production: Thesis: Compulsory<br>Renewable Energies: Thesis: Compulsory |

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|---|---|
| | Naval Architecture and Ocean Engineering: Thesis: Compulsory<br>Ship and Offshore Technology: Thesis: Compulsory<br>Teilstudiengang Lehramt Metalltechnik: Thesis: Compulsory<br>Theoretical Mechanical Engineering: Thesis: Compulsory<br>Process Engineering: Thesis: Compulsory<br>Water and Environmental Engineering: Thesis: Compulsory<br>Certification in Engineering & Advisory in Aviation: Thesis: Compulsory |