TUHH
Hamburg
University of
Technology

Module Manual

Master of Science (M.Sc.)

Information and Communication Systems
Dual study program

Cohort: Winter Term 2022

Updated: 27th January 2023

Table of Contents

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.

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

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

Career prospects

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.

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

Learning target

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.

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

Program structure

The 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: 78 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).

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

Core Qualification

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

Course L3065: Current Issues in Digital Economics B&M	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	30 Minuten
Lecturer	Dr. Christina Strobel
Language	DE
Cycle	WiSe
Content	Digital economics is the targeted approach to meeting human needs in the face of scarcity based on the use of digital information and communication technologies. The goal of the seminar is to discuss current issues in digital economics and their underlying economic theory. To do so, students will read a current popular science book (in German or English) as well as the relevant scientific literature (in English) prior to the seminar. During the seminar, individual topics will be presented by the students and critically discussed.
Literature	

Course L2993: Current issues in behavioral economics	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	30 Minuten
Lecturer	Prof. Timo Heinrich
Language	EN
Cycle	WiSe/SoSe
Content	The goal of the seminar is to discuss current issues in behavioral and to shed light on their relationship to economic theory and our own behavior. Students will first read a current popular science book (in English) as well as the relevant scientific literature. Then the individual topics will be presented and critically discussed during the seminar. Furthermore, students will develop individual research questions.
Literature	Wird noch bekanntgegeben.

Course L2860: Behavioral Online Experiments	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	5-seitige Ausarbeitung & 20-minütige Teampräsentation
Lecturer	Dr. Christina Strobel
Language	EN
Cycle	SoSe
Content	The course offers an introduction to the methods and techniques of online experiments used in experimental Economics, Psychology, and Business Administration. The course is targeted at participants with no or limited experience. It pursues the agenda of providing the practical, theoretical and tool knowledge to find a research question, deduce hypotheses and design and run an experiment. Hence, the focus will be on general methodological, design and process issues. The course is not surveying the existing experimental evidence but rather pinpoints towards selected well knowns experiments. We will follow a learning-by-doing approach. We will have a short introduction to data evaluation using non-parametric statistics as well as to relevant software tools (oTree). At the end of this course you will have gained not only the know-how needed to develop and implement an experimental research design online but you have also gained the basic skills required to gather, analyze and interpret experimental data.
Literature	Webster, M., & Sell, J. (Eds.). (2014). Laboratory experiments in the social sciences. Elsevier.

Course L2546: Building Business Data Products	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	folgt
Lecturer	Prof. Christoph Ihl, Joschka Schwarz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L2544: Business Data Science Basics	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	folgt
Lecturer	Prof. Christoph Ihl, Joschka Schwarz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L2545: Business Decisions with Machine Learning	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	folgt
Lecturer	Prof. Christoph Ihl, Joschka Schwarz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L2722: Digitalization and the impact on people	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28

Examination Form	Schriftliche Ausarbeitung (laut FPrO)
Examination duration and scale	Ausarbeitung, 5 Seiten
Lecturer	Robert Damköhler, Laura Noack
Language	DE
Cycle	SoSe
Content	**Digital:** In this module we provide you with a practical overview of digital tools & methods, new business models & strategies, technological trends and legal aspects in 3 intensive phases - the conception, implementation and establishment of projects. The whole thing is consolidated with practical exercises, so that you already develop your own business model in the course of the seminar and test it on the market with the right techniques. **Human Factors:** With practical exercises, you will learn about methodical user-centredness through the user-centred design process and learn in which project phases, which UCD methods are useful to apply. In addition, you will get to know the subject area of "Human Factors" and understand why we also talk about socio-technical systems in digitalisation, why these represent an important success factor and which phases have to be gone through to integrate the principles into the organisational structure of a company. **New Leadership:** In the New Leadership module, you will learn about a new leadership approach that supports you in mastering the challenges of digitalisation. With the help of agile methodology and interactive exercises, you will learn how to anchor the principles of the new leadership approach and increase the empowerment and self-organisation of the team in order to create the framework for innovative work.
Literature	**Digital:** • Eine kurze Geschichte der Menschheit, Yuval Noah Harari • 21 Lektionen für das 21. Jahrhundert, Yuval Noah Harari • Eine kurze Geschichte der Digitalisierung, Martin Burckhardt • Digitale Fabrik, Uwe Bracht, Dieter Geckler und Gigrid Wenzel • Human Computer Interaction, R. Dix, Verlag: Pearson/Prentice Hall • The Mom Test: How to Talk to Customers & Learn if Your Business is a Good Idea When Everyone is Lying to You, Rob Fitzpatrick • Digitalisierungsstrategie entwickeln und umsetzen: Ein Praxisratgeber zur Entwicklung und Umsetzung der Digitalisierungsstrategie für die digitale Transformation, David Theil **Human Factors:** • Ergonomie der Mensch-System-Interaktion, DIN EN ISO 9241, Deutsches Institut für Normung • Methoden der Usability Evalution: Wissenschaftliche Grundlagen und praktische Anwendung von Florian Sarodnic , Henning Brau, Verlag: Hogrefe AG • Introduction to Human Factors Engineering von Christopher D. Wicken, Verlag: Pearson • Sketching User Experiences von Bill Buxton, Verlag:mitp • Rapid Contextual Design von Karen Holtzblatt, Verlag: Elsevier Science & Technology • Wie User Testing in der Praxis wirklich funktioniert von M. Pirker, S. Rössler, M. Placho, A. Riedmüller, Verlag: Independently published (05.06.2019) • Wie User Experience in der Praxis wirklich funktioniert von M. Pirker, S. Rössler, M. Placho, A. Riedmüller, Verlag: Independently published (27.02.2018) • Schreckensberger, P., Schilbach, B., & Saier, T. (2015). Design Management: Zwischen Marken- & Produktsystemen (1. Aufl; P. Schreckensberger, Hrsg.). Norderstedt: Books on Demand. • Goodwin, K. (2009). Designing for the digital age: How to create human-centered products and services. Wiley Pub. • Haskins, B., Stecklein, J., Dick, B., Moroney, G., Lovell, R., & Dabney, J. (2014). Error Cost Escalation Through the Project Life Cycle. INCOSE International Symposium **New Leadership** • Pink, D. H. (2011). Drive: The surprising truth about what motivates us. Penguin. • Sinek, S. (2009). Start with why: How great leaders inspire everyone to take action. Penguin. • Doerr, J. (2018). Measure what matters: OKRs: The simple idea that drives 10x growth. Penguin UK. • Darrell, K. R., Sutherland, J., & Takeuchi, H. (2016). Embracing agile. Harvard Business Review, 94(5), 41-50. • Sutherland, J. (2015). Die Scrum-Revolution: Management mit der bahnbrechenden Methode der erfolgreichsten Unternehmen. Campus Verlag. • Schwaber, K., & Sutherland, J. (2011). The scrum guide. Scrum Alliance, 21(1). • Beck, K., Beedle, M., Van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., ... & Thomas, D. (2009). Agile manifesto, 2001. URL http://www. agilemanifesto. org. • Takeuchi, H., & Nonaka, I. (1986). The new new product development game. Harvard business review, 64(1), 137-146. • Medinilla, Á. (2012). Agile management: Leadership in an agile environment. Springer Science & Business Media. • Edmondson, A. C. (1999). Psychological safety and learning behavior in work teams. Administrative Science Quarterly, 44(2), 350−383. • Edmondson, A. C. (2003). Managing the risk of learning: Psychological safety in work teams. In M. West, D. Tjosvold, & K.G. Smith (Eds.), International handbook of organizational teamwork and cooperative working (pp. 255−276). John Wiley & Sons. • Harteis, C., Bauer, J., & Gruber, H. (2008). The culture of learning from mistakes: How employees handle mistakes in everyday work. International Journal of Educational Research, 47(4), 223−231.

Course L1703: Emotional Design / User Centered Product Development	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	Teamarbeit und abschließender Vortrag
Lecturer	Jörg Heuser
Language	DE
Cycle	SoSe
Content	Lecture • Objective and subjective perception for the evaluation of product characteristics • Effects of material, color, shape and structure to the acceptance of a product • Aesthetic function of a product • Case studies, lack of acceptance of a product and possible reason Seminar • Identification of non-technical product functions • Identification of subjective influences for the product development Project Work • Topics will be developed in cooperation with the students. Project works will be presented in teams, presented and evaluated Exemplary Project: Holistic product evaluation, product optimization
Literature	Wird in der Veranstaltung angegeben

Course L2348: Drivers of Success for Projects	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	0
Lecturer	Dr. Alexander Kuhlicke, Stephan Meier
Language	DE
Cycle	WiSe
Content	
Literature	

Course L3123: Organizational Design for Innovation and Collaboration	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Prof. Tim Schweisfurth
Language	EN
Cycle	WiSe
Content	
Literature	

Course L2600: Green Economy - Entrepreneurship, Innovation & Technology Management	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	Ausarbeitung und Gruppenpräsentation
Lecturer	Prof. Michael Prange
Language	EN
Cycle	WiSe/SoSe
Content	Topics: • Green Economy • Business models • Business strategy • Green Technologies • Green Innovation • Business planning • Business development • Green Entrepreneurship Based on examples and case studies primarily in the field of Green Economy, students learn the basics of Entrepreneurship, Innovation and Technology Management and will be able to develop business models, to evaluate start-up projects and to describe strategic innovation processes.
Literature	Präsentationsfolien, Beispiele und Fallstudien aus der Lehrveranstaltung. Presentation slides, examples, and case studies from the lecture.

Course L2347: Human resource management for engineers	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	0
Lecturer	Helge Kochskämper
Language	DE
Cycle	WiSe
Content	
Literature	

Course L1711: Innovation Debates	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	3 Präsentationen der schriftlichen Ausarbeitung à 20 Minutes
Lecturer	Prof. Daniel Heiner Ehls
Language	EN
Cycle	WiSe
Content	Scientific knowledge grows continuously but also experiences certain alignments over time. For example, early cultures had the believe of a flat earth while latest research has a spherical earth model. Also in social science and business management, from time to time certain concepts that have even been the predominant paradigm are challenged by new observations and models. Consequently, certain controversies emerge and build the base for advancing theory and managerial practice. With this lecture, we put ourselves in the middle of heated debates for informed academics and practitioners of the day after tomorrow. The lecture targets several controversies in the domain of technology strategy and innovation management. By the classical academic method and the novel problem based learning format of a structured discussion, a given controversy is scrutinized. On selected topics, students will discuss a dispute and gain a thorough understanding. Specifically, based on a brief introduction of a motion, a affirmative constructive as well as a negative constructive is presented by two different student groups. Each presentation is followed by a response of the other group and questions from the class. Topics range from latest theories and concepts for value capture, to the importance of operating within a global marketplace, to cutting edge approaches for innovation stimulation and technology management. Consequently, this lecture deepens the knowledge in technology strategy and innovation management (TIM), enables a critical thinking and thought leadership.
Literature	1. Course notes and materials provided before the lecture 2. Leiblein/ Ziedonis (2011): Technology Strategy and innovation management. Edward Elgar Publishing Ltd (optional)

Course L0940: Innovation Management	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	
Lecturer	Prof. Cornelius Herstatt
Language	DE/EN
Cycle	SoSe
Content	Innovation is key to corporate growth and sustainibility. In this lecture Prof. Herstatt presents a systematic way from generating ideas to the successful implementation of innovations. **The lecture is presented in German language only**
Literature	• Goffin, K., Herstatt, C. and Mitchell, R. (2009): Innovationsmanagement: Strategie und effektive Umsetzung von Innovationsprozessen mit dem Pentathlon-Prinzip, München: Finanzbuch Verlag **Weiterführende Literatur** • Innovationsmanagement Juergen Hauschildt • F + E Management Specht, G. / Beckmann, Chr. • Management der frühen Innovationsphasen Cornelius Herstatt, Birgit Verworn (im TUHH-Intranet auch als E-Book verfügbar) • Bringing Technology and Innovation Into the Boardroom • weitere Literaturempfehlungen auf Anfrage

Course L3093: Innovation Management (EN)	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	NN
Lecturer	Dr. Vytaute Dlugoborskyte
Language	EN
Cycle	SoSe
Content	The course aims to provide students with an understanding of key issues in the management of innovation and development of the relevant skills needed to manage innovation at both strategic and operational levels. It provides evidence of different approaches based on leading research, real world examples and experiences of firms and organizations from around the world. The management of innovation is one of the most important and challenging aspects of modern organization. Innovation is a fundamental driver of competitiveness and it plays a large part in improving quality of life. Innovation, and particularly technological innovation, is inherently difficult, uncertain and risky, and most new technologies fail to be translated into successful products and services. Given this, it is essential that students understand the strategies, tools and techniques for managing innovation, which often requires a different set of management knowledge and skills from those employed in everyday business administration. The course itself draws upon research activities of the Innovation Management Group within TUHH, the Institute for Technology and Innovation Management (TIM, W-7, www.tuhh.de/tim) **Knowledge Objectives:** 1. Understand definitions and concepts of innovation, 2. Explore major models and theories of innovation, 3. Use and apply tools for innovation management. **Skill Objectives:** 1. Diagnostic and analytical skills, 2. Enhance verbal skills through class and syndicate discussions, 3. Build up critical and interpretation skills, 4. Learn how to evaluate different options, 5. Formulate and develop strategy, 6. Assess and resolve managerial challenges. **Learning Outcomes** At the end of the course students will be able to demonstrate understanding, and make critical assessments of the following: 1. Assess and interpret innovation processes, 2. Develop and formulate managerial strategies to shape innovative performance, 3. Utilize tools of innovation management to map and measure innovative activities, 4. Diagnose different innovation challenges and make recommendations for resolving them. **Course Outline - Lecture Topics:** 1. The Management of (Technological) Innovation, 2. Strategy and Organization for Innovation, 3. Innovation of Products, Services and Business Models, 4. Managing the Innovation Process, 5. Networks, Communities of Innovators and Lead User-Innovation, 6. Innovation in the Age of Circular Economy (C2C), 7. Market-Research for Innovation and Design-thinking, 8. Capturing value from R&D, Open Innovation and IP, 9. Creativity and mindfulness in Innovation, 10. Conclusions and Future Challenges.
Literature	Wir werden wichtige Themen auf der Grundlage wichtiger Forschungsarbeiten im Bereich des Innovationsmanagements diskutieren (wird den Studierenden über StudIP zur Verfügung gestellt). Darüber hinaus umfasst die Grundlagenliteratur die folgenden Themen: 1. Dodgson, M. Gann, D. and Salter A. The management of technological innovation: strategy and practice. Oxford University Press, 2008. 2. Tidd, J., Bessant, J. and Pavitt, K.: Managing Innovation: Integrating technological, market and organizational change. 5th ed., John Wiley and Sons, 2013. 3. Goffin, K., Mitchell, R.: Innovation Management: Effective strategy and implementation. 3rd ed., Macmillan Education, 2016.

Course L0161: Internationalization Strategies	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	20-30 Minuten Referat einschl. Diskussionsleitung plus schriftliche Ausarbeitung (ca. 10 Seiten)
Lecturer	Prof. Thomas Wrona
Language	EN
Cycle	SoSe
Content	• Introduction • Internationalization of markets • Measuring internationalization of firms • Target market strategies • Market entry strategies • Timing strategies • Allocation strategies • Working in small teams on close-to-reality problems based on presented theories • Paper writing on developed solution to the given problem/project e.g. market attractiveness analysis; development of market entry strategy for a hypothetical product in a given region
Literature	• Bartlett/Ghoshal (2002): Managing Across Borders, The Transnational Solution, 2nd edition, Boston • Buckley, P.J./Ghauri, P.N. (1998), The Internationalization of the Firm, 2nd edition • Czinkota, Ronkainen, Moffett, Marinova, Marinov (2009), International Business, Hoboken • Dunning, J.H. (1993), The Globalization of Business: The Challenge of the 1990s, London • Ghoshal, S. (1987), Global Strategy: An Organizing Framework, Strategic Management Journal, p. 425-440 • Praveen Parboteeah, K.,Cullen, J.B. (2011) , Strategic International Management, International 5th Edition • Rugman, A.M./Collinson, S. (2012): International Business, 6th Edition, Essex 2012

Course L3060: Causal Data Science for Business Analytics	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	Mehrere schriftliche Ausarbeitungen über das Semester hinweg verteilt
Lecturer	Oliver Mork
Language	EN
Cycle	WiSe
Content	Most managerial decision problems require answers to questions such as “what happens to Y if we do X?”, or “was it X that caused Y to change?” In other words, practical business decision-making requires knowledge about cause-and-effect. While most data science and machine learning approaches are designed to efficiently detect patterns in high-dimensional data, they are not able to distinguish causal relationships from simple correlations. That means, commonly used approaches to business analytics often fall short to provide decision makers with important causal knowledge. Therefore, many leading companies currently try to develop specific causal data science capabilities. This module will provide an introduction into the topic of causal inference with the help of modern data science and machine learning approaches and with a focus on applications to practical business problems from various management areas. Based on an overarching framework for causal data science, the course will guide students to detect sources of confounding influence factors, understand the problem of selective measurement in data collection, and extrapolate causal knowledge across different business contexts. We also cover several tools for causal inference, such as A/B testing and experiments, difference-in-differences, instrumental variables, matching, regression discontinuity designs, etc. A variety of hands-on examples will be discussed that allow students to apply their newly obtained knowledge and carry out state-of-the-art causal analyses by themselves.
Literature	

Course L0863: Marketing	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	
Lecturer	Prof. Christian Lüthje
Language	EN
Cycle	WiSe
Content	**Contents** Basics of Marketing

	The philosophy and fundamental aims of marketing. Contrasting different marketing fields (e.g. business-to-consumer versus business-to-business marketing). The process of marketing planning, implementation and controlling Strategic Marketing Planning How to find profit opportunities? How to develop cooperation, internationalization, timing, differentiation and cost leadership strategies? Market-oriented Design of products and services How can companies get valuable customer input on product design and development? What is a service? How can companies design innovative services supporting the products? Pricing What are the underlying determinants of pricing decision? Which pricing strategies should companies choose over the life cycle of products? What are special forms of pricing on business-to-business markets (e.g. competitive bidding, auctions)? Marketing Communication What is the role of communication and advertising in business-to-business markets? Why advertise? How can companies manage communication over advertisement, exhibitions and public relations? Sales and Distribution How to build customer relationship? What are the major requirements of industrial selling? What is a distribution channel? How to design and manage a channel strategy on business-to-business markets? **Knowledge** Students will gain an introduction and good overview of • Specific challenges in the marketing of innovative goods and services • Key strategic areas in strategic marketing planning (cooperation, internationalization, timing) • Tools for information gathering about future customer needs and requirements • Fundamental pricing theories and pricing methods • Main communication instruments • Marketing channels and main organizational issues in sales management • Basic approaches for managing customer relationship **Skills** Based on the acquired knowledge students will be able to: • Design market timing decisions • Make decisions for marketing-related cooperation and internationalization activities • Manage the challenges of market-oriented development of new products and services • Translate customer needs into concepts, prototypes and marketable offers • Determine the perceived quality of an existing product or service using advanced elicitation and measurement techniques that fit the given situation • Analyze the pricing alternatives for products and services • Make strategic sales decisions for products and services (i.e. selection of sales channels) • Analyze the value of customers and apply customer relationship management tools **Social Competence** The students will be able to • have fruitful discussions and exchange arguments • present results in a clear and concise way • carry out respectful team work **Self-reliance** The students will be able to • Acquire knowledge independently in the specific context and to map this knowledge on other new complex problem fields. • Consider proposed business actions in the field of marketing and reflect on them.
Literature	Homburg, C., Kuester, S., Krohmer, H. (2009). Marketing Management, McGraw-Hill Education, Berkshire, extracts p. 31-32, p. 38-53, 406-414, 427-431 Bingham, F. G., Gomes, R., Knowles, P. A. (2005). Business Marketing, McGraw-Hill Higher Education, 3rd edition, 2004, p. 106-110 Besanke, D., Dranove, D., Shanley, M., Schaefer, S. (2007), Economics of strategy, Wiley, 3rd edition, 2007, p. 149-155 Hutt, M. D., Speh, T.W. (2010), Business Marketing Management, 10th edition, South Western, Lengage Learning, p. 112-116

Course L3140: Sustainable corporate governance in practice	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	60 Minuten
Lecturer	Stefan Klebert
Language	DE
Cycle	SoSe
Content	
Literature	

Course L3125: Open and Collaborative Innovation	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Prof. Tim Schweisfurth
Language	EN
Cycle	SoSe
Content	
Literature	

Course L2350: Operational Leadership	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Dr. Thomas Kosin
Language	DE
Cycle	WiSe
Content	• Leadership & its Environment - Führung & Führungsumfeld • Motivation • Lead Yourself - Selbstführung • Leadership Theories & Styles - Führungstheorien und -stile • Team Leadership - Team & Führung • Lead Change - Wandel herbeiführen • Operational Change - Veränderung im Unternehmen umsetzen • Develop Leadership - Führungsworkshop
Literature	Czikszentmihalyi, Mihalyi (2014): Flow im Beruf oder Das Geheimnis des Glücks am Arbeitsplatz, Klett-Cotta, 1. Auflage Drucker, Peter F. (1999): Manage Oneself, Harvard Business School, On Managing Yourself, S.13-32 Dweck, Carol (2017): Selbstbild - Wie unser Denken Erfolge oder Niederlagen bewirkt, Piper-Verlag (engl. Original: Mindset - The new psychology of success) Goleman, Daniel (2000): Leadership that gets results, Harvard Business School, On Managing People, S.1-14 Laloux, Frederic (2015): Reinventing Organizations, Verlag Franz Vahlen McKee, Annie (2014): A focus on leaders, Pearson Education Ltd., 2. Auflage Northouse, Peter G. (2019): Leadership - Theory & Practise, Sage Publications, 8. Auflage Robbins, Stephen P., Coulter, Mary, Fischer, Ingo (2014): Management - Grundlagen der Unternehmensführung, , Pearson Deutschland GmbH, 12. Auflage (engl. Original: Management, 2007, Pearson Prentice Hall, 9. Auflage)

Course L0709: Project Management	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	
Lecturer	Prof. Carlos Jahn
Language	EN
Cycle	WiSe
Content	The lecture “project management” aims at characterizing typical phases of projects. Important contents are: possible tasks, organization, techniques and tools for initiation, definition, planning, management and finalization of projects. This will also be deepened by exercises within the framework of the event. The following topics will be covered in the lecture: • SMART, Work Breakdown Structure, Operationalization, Goals relation matrix • Metra-Potential Method (MPM), Critical-Path Method (CPM), Program evaluation and review technique (PERT) • Milestone Analysis, Earned Value Analyis (EVA) • Progress reporting, Tracing of project goals, deadlines and costs, Project Management Control Loop, Maturity Level Assurance (MLA) • Risk Management, Failure Mode and Effects Analysis (FMEA), Risk Matrix
Literature	Project Management Institute (2017): A Guide to the Project Management Body of Knowledge (PMBOK® Guide) 6. Aufl. Newtown Square, PA, USA: Project Management Institute. DeMarco, Tom (1997). The Deadline: A Novel About Project Management. DIN Deutsches Institut für Normung e.V. (2009). Projektmanagement - Projektmanagementsysteme - Teil 5: Begriffe. (DIN 69901-5) Frigenti, Enzo and Comninos, Dennis (2002). The Practice of Project Management. Haberfellner, Reinhard (2015). Systems Engineering: Grundlagen und Anwendung Harrison, Frederick and Lock, Dennis (2004). Advanced Project Management: A Structured Approach. Heyworth, Frank (2002). A Guide to Project Management. ISO - International Organization for Standardization (2012). Guidance on Project Management. (21500:2012(E)) Kerzner, Harold (2013). Project Management: A Systems Approach to Planning, Scheduling, and Controlling. Lock, Dennis (2018). Project Management. Martinelli, Russ J. and Miloševic, Dragan (2016). Project Management Toolbox: Tools and Techniques for the Practicing Project Manager. Murch, Richard (2011). Project Management: Best Practices for IT Professionals. Patzak, Gerold and Rattay, Günter (2009). Projektmanagement: Leitfaden zum Management von Projekten, Projektportfolios, Programmen und projektorientierten Unternehmen.

Course L1385: Project Management in Industrial Practice	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Schriftliche Ausarbeitung
Examination duration and scale	Gruppenarbeit: Erstellung eines Poster sowie eines Aufgabenblatts (inkl. Lösungen)
Lecturer	Dipl.-Ing. Wilhelm Radomsky
Language	DE
Cycle	WiSe
Content	The event will cover current knowledge and trends in project management: Basics of project management (competences, methods, tools) are practised, e.g. EVA, MTA, KTA, FMEA, PDCA, MPM Project management culture with lessons learned, optimisation of theory and process Project management theory mirrored by experiences from project management practice Development, implementation and operation of a PM system in small and large companies, e.g. Siemens **The aim is to inform about current challenges in PM.** Modern agile project management in dynamic markets Meeting challenges in turbulent times, project management in VUCA and BANI environments Managing change and transformation Securing the future through professional action Ensuring health and results in job and project **With the main topics** Project management in industry, SMEs, studies and private life Project life cycle, process and organisation, agile or 'agile' Integration, content and scope management, environment and stakeholder management Contract, risk and change management Schedule, cost and personnel management Quality management, success factors in the project environment The human factor, corporate culture Communication management, team development, leadership theories Project management is presented as a proven means of solving tasks and problems in private and professional environments. Project management is increasingly used as an agile goal-oriented leadership concept in companies and businesses. The participants are presented with competences and solutions to better cope with their tasks. The application of project management can already lead to an improvement of structure, communication and results during studies and prepare for the start of a career. The lecture serves as a basis for project management certification with the corresponding certification bodies such as GPM or PMI. The project management process is presented according to the basic international project management standards of IPMA and PMI and the Siemens project management system adapted for practical use.
Literature	• PMI - PMBOK-Guide 7th Edition (A Guide to the Project Management Body of Knowledge) 2021 • GPM - Kompetenzbasiertes Projektmanagement (PM4) 2019 • Bea/Scheurer/Hesselmann - Projektmanagement 2019 • Kerzner, Harold - Projektmanagement 2022

Course L1897: Project Management and Agile Methods	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	Ausarbeitung eines Projektplans in Kleingruppen (ca. 5-10 Seiten)
Lecturer	Christian Bussler
Language	DE
Cycle	SoSe
Content	The Seminar teaches the basics of project management, which constitutes the foundations for technical as well as for business projects. It also includes a sideline about process management. The participants will work on the following questions: • What is a project and what challenges does it imply? • What methods have been developed to meet those challenges? • How have this methods evolved over time? What is “state of the art” today? • What basic skills should project members have? • What is the difference between project and process? How can the latter be analyzed? The approaches are not just taught theoretically, but put to use in group work. Through this approach, participants are enabled to work successfully on actual projects - and manage projects later on. As project work is increasingly important in work life, project management is a key skill for job applicants. Main topics of the seminar include: • The “magic triangle” of project objectives • Typical project phases • Key instruments and methods (project structure plan, RACI, Gantt chart) • Project organization and steering • Team communication and collaboration • The agile approach of Scrum • Process levels and cascading • Process improvement With the knowledge and experience from the seminar, participants should be able to acquire a basic certificate in project management with relatively little additional effort. The certification is available through institutions like GPM. Participants already start working on their homework paper in the group work. It comprises 5 to 10 pages and a structure plan for the chosen project, which can be done in Excel for example. Ideally, the members of the work groups write their homework paper together. The expected scale of the paper would increase in this case, yet not proportionally with the number of group members (4 participants would be expected to hand in a paper of 15-20 pages).
Literature	Hans-D. Litke, Ilonka Kunow; Projektmanagement. 3. Auflage 2015 Georg Patzak, Günter Rattay; Projektmanagement: Projekte, Projektpotfolios, Programme und projektorientierte Unternehmen. 6. Auflage 2014 G P M Deutsche Gesellschaft für Projektmanagement; Kompetenzbasiertes Projektmanagement (PM3): Handbuch für die Projektarbeit, Qualifizierung und Zertifizierung auf Basis der IPMA Competence Baseline Version 3.0. 6. Auflage, 2014 Tom DeMarco; Der Termin: Ein Roman über Projektmanagement. 2007 Jeff Sutherland, Ken Schwaber; Der Scrum Guide. Der gültige Leitfaden für Scrum: Die Spielregeln. Ständig aktualisiert, kostenloser Download auf http://www.scrumguides.org/ Jurgen Appello; Management 3.0: Leading Agile Developers, Developing Agile Leaders. 2010

Course L2349: Accounting and Financial Statements	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	60 min
Lecturer	Prof. Matthias Meyer
Language	DE
Cycle	WiSe/SoSe
Content	
Literature	

Course L1133: Law for Engineers	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	90 Minuten
Lecturer	Markus A. Meyer-Chory
Language	DE
Cycle	WiSe
Content	• Refreshment: Basics of Law • Legal relevance of Engineers cases and actions: Contract Law, Liabilities - also for products, labor law, patent law, companies law
Literature	**Notwendiger Gesetzestext (in Klausur erlaubt):** **Bürgerliches Gesetzbuch 72. Auflage , 2013 , dtv Beck-Texte 5001, ISBN 978-3-406-65707-8** **Empfohlene Gesetzestexte:Arbeitsgesetze 83. Auflage, 2013 dtv Beck-Texte 5006 ISBN 978-3-406-65689-7** **Handelsgesetzbuch 54. Auflage, 2013** dtv Beck Texte 5002 ISBN 978-3-406-65083-3 **Gesellschaftsrecht, 13. Auflage , 2013** dtv Beck Texte 5585 ISBN 978-3-406-64502-0 **Wettbewerbsrecht, Markenrecht und Kartellrecht , 33. Auflage, 2013** dtv Beck Texte ISBN 978-3-406-65212-7 **Empfohlene Literatur:** **Vock, Willi,** Recht der Ingenieure, 1. Auflage 2012, Boorberg Verlag , ISBN-10:3-415-04535-8 --- EAN:9783415045354 **Meurer** Rechtshandbuch für Architekten und Ingenieure 1...Auflage -- erscheint Anfg 2014 Werner Verlag ISBN 978-3-8041-4342-5 **Eisenberg / Gildeggen / Reuter / Willburger** Produkthaftung 2. Auflage - erscheint Anfg 2014 Oldenbourg Verlag - ISBN 978-3-486-71324-4 **ENDERS/HETGER,** Grundzüge der betrieblichen Rechtsfragen, 4. Auflage, 2008 Richard Boorberg Verlag - ISBN 978-3-415-04005-2 **Müssig, Peter,** Wirtschaftsprivatrecht, 15. Auflage, 2012 , C.F. Müller UTB - ISBN 978-3-81149476-3 **Schade, Friedrich,** Wirtschaftsprivatrecht, 2. Auflage 2009, Kohlhammer - ISBN 978-3-17-021087-5

Course L1389: Key Aspects of Patent Law	
Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	
Lecturer	Prof. Christian Rohnke
Language	DE
Cycle	SoSe
Content	Mayor Issues in Patent Law: The seminar covers five mayor issues in german patent law, namely patentatbility, prosecution, ownership and employee inventions, infringement and licensing and other commercila uses. The lecturer will give an introduction to each issue which will be followed by in-depth inquiry by the participants through group work, presentation of results and moderated discussion.
Literature	wird noch bekannt gegeben

Course L2982: Startup Engineering	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	30 Minuten
Lecturer	Prof. Christoph Ihl, Dr. Hannes Lampe
Language	EN
Cycle	WiSe
Content	
Literature	

Course L2409: Strategic Shared-Value Management	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	30 Minuten
Lecturer	Dr. Jill Küberling-Jost
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2295: Strategic Planning with Simulation Games	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Referat
Examination duration and scale	
Lecturer	Dr. Jan Spitzner
Language	DE
Cycle	SoSe
Content	
Literature	

Course L1351: Management Consulting	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	
Lecturer	Gerald Schwetje
Language	DE
Cycle	SoSe
Content	The Management Consulting lecture teaches students knowledge that is complementary to their technical and business administration studies. They learn the basics of consulting and agent-principal theory and are given an overview of the consulting market. They are also shown how management consulting works and which methodical building blocks (processes) are needed to deal with a client's concerns and to undertake a consulting process. By means of practical examples students gain an insight into the extensive range of management consultancy services and of functional consulting.
Literature	Bamberger, Ingolf (Hrsg.): Strategische Unternehmensberatung: Konzeptionen - Prozesse - Methoden, Gabler Verlag, Wiesbaden 2008 Bansbach, Schübel, Brötzel & Partner (Hrsg.): Consulting: Analyse - Konzepte - Gestaltung, Stollfuß Verlag, Bonn 2008 Fink, Dietmar (Hrsg.): Strategische Unternehmensberatung, Vahlens Handbücher, München, Verlag Vahlen, 2009 Heuermann, R./Herrmann, F.: Unternehmensberatung: Anatomie und Perspektiven einer Dienstleistungselite, Fakten und Meinungen für Kunden, Berater und Beobachter der Branche, Verlag Vahlen, München 2003 Kubr, Milan: Management consulting: A guide to the profession, 3. Auflage, Geneva, International Labour Office, 1992 Küting, Karlheinz (Hrsg.): Saarbrücker Handbuch der Betriebswirtschaftlichen Beratung; 4. Aufl., NWB Verlag, Herne 2008 Nagel, Kurt: 200 Strategien, Prinzipien und Systeme für den persönlichen und unternehmerischen Erfolg, 4. Aufl., Landsberg/Lech, mi-Verlag, 1991 Niedereichholz, Christel: Unternehmensberatung: Beratungsmarketing und Auftragsakquisition, Band 1, 2. Aufl., Oldenburg Verlag, 1996 Niedereichholz; Christel: Unternehmensberatung: Auftragsdurchführung und Qualitätssicherung, Band 2, Oldenburg Verlag, 1997 Quiring, Andreas: Rechtshandbuch für Unternehmensberater: Eine praxisorientierte Darstellung der typischen Risiken und der zweckmäßigen Strategien zum Risikomanagement mit Checklisten und Musterverträgen, Vahlen Verlag, München 2005 Schwetje, Gerald: Ihr Weg zur effizienten Unternehmensberatung: Beratungserfolg durch eine qualifizierte Beratungsmethode, NWB Verlag, Herne 2013 Schwetje, Gerald: Wer seine Nachfolge nicht regelt, vermindert seinen Unternehmenswert, in: NWB, Betriebswirtschaftliche Beratung, 03/2011 und: Sparkassen Firmenberatung aktuell, 05/2011 Schwetje, Gerald: Strategie-Assessment mit Hilfe von Arbeitshilfen der NWB-Datenbank - Pragmatischer Beratungsansatz speziell für KMU: NWB, Betriebswirtschaftliche Beratung, 10/2011 Schwetje, Gerald: Strategie-Werkzeugkasten für kleine Unternehmen, Fachbeiträge, Excel-Berechnungsprogramme, Checklisten/Muster und Mandanten-Merkblatt: NWB, Downloadprodukte, 11/2011 Schwetje, Gerald: Die Unternehmensberatung als komplementäres Leistungsangebot der Steuerberatung - Zusätzliches Honorar bei bestehenden Klienten: NWB, Betriebswirtschaftliche Beratung, 02/2012 Schwetje, Gerald: Die Mandanten-Berater-Beziehung: Erfolgsfaktor Beziehungsmanagement, in: NWB Betriebswirtschaftliche Beratung, 08/2012 Schwetje, Gerald: Die Mandanten-Berater-Beziehung: Erfolgsfaktor Vertrauen, in: NWB Betriebswirtschaftliche Beratung, 09/2012 Wohlgemuth, Andre C.: Unternehmensberatung (Management Consulting): Dokumentation zur Vorlesung „Unternehmensberatung", vdf Hochschulverlag, Zürich 2010

Course L2669: Negotiation Management	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Examination Form	Fachtheoretisch-fachpraktische Arbeit
Examination duration and scale	Vorbereitung, Durchführung und Selbstreflektion zu einer simulierten Verhandlungssituation. Die fiktive Verhandlung hat einen Umfang von 4 ½ Präsenzstunden und erfordert ausführliche Vor- und Nachbereitung im Umfang von ca. 3 x 2 Stunden. Zum Abschluss ist ein Reflektionsbericht einzureichen. Weitere Prüfungsleistungen werden im Rahmen von Lernfortschrittsabfragen entlang der Vorlesung erbracht.
Lecturer	Prof. Christian Lüthje
Language	EN
Cycle	WiSe
Content	**General description of course content and course goals**

We negotiaate everday in privat and professional contexts. Leading negotiations successfully has a significant impact on future careers. Yet, we tend to have limited knowledge about the theory and empirical evidence regarding successful negotiating. Many people approach negotiations in a rather intuitive and unplanned way which often results in sub-optimal negotiation outcomes.

The purpose of this interactive and problem-based course is to theortically understand the strategies and process of negotiation as practiced in a variety of business-related settings (e.g. negotiations about working conditions, negotiations with customers and suppliers). The course will highlight the components of an effective negotiation (strategy, perparation, execution, evaluation) and offer the students the opportunity to analyze their own behavior in negotiations in order to improve.

The course structure is experiential and problem-based, combining lectures, class discussion, mini-cases and small erxercises, and more comprehensive negotiation practices in longer sessions. Through participation in negotiation exercises, students will have the opportunity to practice their communication and persuasion skills and to experiment with a variety of negotiating strategies and tactics. Students will apply the lessons learned to ongoing, real-world negotiations.

Content:

The students will find answers to the following fundamental questions of negotiation strategies in theory and practice:

- How do negotiations influence everyday life and business processes?
- What are key features of negotiations?
- What are different forms of negotiations? What kinds of negotiation can be distinguished?
- Which theoretical approaches to a theory of negotiation can be distinguished?
- How can game theory be applied to negotiation?
- What makes an effective negotiator?
- Which factors should be considered when planning negotiations?
- What steps must be followed to reach a deal?
- Are there specific negotiation tactics?
- What are the typical barriers to an agreement and how to deal with them?
- What are possible cognitive (mental) errors and how to correct them?

Knowledge

Students know...

- the theory basics of negotiations (e.g. game theory, behavioral theories)
- the types and the pros and cons of diffrent negotiation strategies
- the process of negotiation, inlcuding goal formulation, preparation/planning, execution and evaluation
- about some key issues impacting negotiations (e.g. team building and roles, barriers to reaching a deal, cognitive biases, multi-phase negotiations)

Skills

Students are capable of...

- simultaneously considering multiple factors in negotiation situations and taking reasoned actions when preparing and conducting negotiations.
- Analyzing and handling the key challenges of uncertainty, risk, intercultural differences, and time pressure in realistic negotiation situations.
- assessing the typical barriers to an agreement (e.g. lack of trust), dealing with hardball tactics (e.g. good cop, bad cop; lowball, highball; intimidation), and avoiding cognitive traps (e.g. unchecked emotions, overconfidence).
- reflecting on their decision-making in uncertain negotiation situations and derive actions for future decisions.

Social Competence

Students can...

- provide appropriate feedback and handle feedback on their own performance constructively.
- constructively interact with their team members in role playing in negotiations sessions
- develop joint solutions in mixed teams and present them to others in real-world negotiation situatio

  Self-Reliance

  Students are able to...

  - assess possible consequences of their own negotiation behavior
  - define own positions and tasks in the negotiation preparation process.
  - justify and make elaborated decisions in authentic negotiation situations.

Literature

R.J. Lewicki / B. Barry / D.M. Saunders: Negotiation. Sixth Edition, McGraw-Hill, Boston, 2010.

H. Raiffa: Negotiation analysis. Belknap Press of Harvard Univ. Press, Cambridge, Mass, 2007.

R. Fisher / W. Ury: Getting to yes. Third edition. Penguin, New York, 2011.

M. Voeth / U. Herbst: Verhandlungsmanagement: Planung, Steuerung und Analyse. Schäffer-Poeschel, Stuttgart, 2009.

Course L1132: Civil- & Business Law	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	90 Minuten
Lecturer	Markus A. Meyer-Chory
Language	DE
Cycle	SoSe
Content	- Basics of German Law System - Basic concepts and Systematics of Civil-, Commercial-, Companies- and Labor Law by specific bullet points, i.e. Insurance law, etc.
Literature	folgt im Seminar

Course L1381: Public and Constitutional Law	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Examination Form	Klausur
Examination duration and scale	2 Stunden
Lecturer	Klaus-Ulrich Tempke
Language	DE
Cycle	WiSe/SoSe
Content	Different areas of public law; proceedings, jurisdiction of administrative courts with stages of appeal, members of the courts; Court levels, organization and legal capacity; Introduction to and structure of fundamental rights; Human dignity: the guiding principle of the constitution; General right of privacy and freedom of action.
Literature	

Module M1759: Linking theory and practice (dual study program, Master's degree)	
Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical modules as part of the dual Bachelor’s course • Module "interlinking theory and practice as part of the dual Master’s course"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... ... can describe and classify selected classic and current theories, concepts and methods • related to project management and • change and transformation management ... and apply them to specific situations, processes and plans in a personal, professional context.
Skills	Dual students ... • ... anticipate typical difficulties, positive and negative effects, as well as success and failure factors in the engineering sector, evaluate them and consider promising strategies and courses of action. • ... develop specialised technical and conceptual skills to solve complex tasks and problems in their professional field of activity/work.
Personal Competence	
Social Competence	Dual students ... • ... can responsibly lead interdisciplinary teams within the framework of complex tasks and problems. • ... engage in sector-specific and cross-sectoral discussions with experts, stakeholders and staff, representing their approaches, points of view and work results.
Autonomy	Dual students ... • ... define, reflect and evaluate goals and measures for complex application-oriented projects and change processes. • ... shape their professional area of responsibility independently and sustainably. • ... take responsibility for their actions and for the results of their work.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Studienbegleitende und semesterübergreifende Dokumentation: Die Leistungspunkte für das Modul werden durch die Anfertigung eines digitalen Lern- und Entwicklungsberichtes (E-Portfolio) erworben. Dabei handelt es sich um eine fortlaufende Dokumentation und Reflexion der Lernerfahrungen und der Kompetenzentwicklung im Bereich der Personalen Kompetenz.

Course L2890: Responsible Project Management in Engineering (for Dual Study Program)	
Typ	Seminar
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Henning Haschke, Heiko Sieben
Language	DE
Cycle	WiSe/SoSe
Content	• Theories and methods of project management • Innovation management • Agile project management • Fundamentals of classic and agile methods • Hybrid use of classic and agile methods • Roles, perspectives and stakeholders throughout the project • Initiating and coordinating complex engineering projects • Principles of moderation, team management, team leadership, conflict management • Communication structures: in-house, cross-company • Public information policy • Promoting commitment and empowerment • Sharing experience with specialists and managers from the engineering sector • Documenting and reflecting on learning experiences
Literature	Seminarapparat

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

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

Courses

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

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

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

Module M0673: Information Theory and Coding

Courses

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

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Probability theory and random processes • Basic knowledge of communications engineering (e.g. from lecture "Fundamentals of Communications and Random Processes")
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know the basic definitions for quantification of information in the sense of information theory. They know Shannon's source coding theorem and channel coding theorem and are able to determine theoretical limits of data compression and error-free data transmission over noisy channels. They understand the principles of source coding as well as error-detecting and error-correcting channel coding. They are familiar with the principles of decoding, in particular with modern methods of iterative decoding. They know fundamental coding schemes, their properties and decoding algorithms. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to determine the limits of data compression as well as of data transmission through noisy channels and based on those limits to design basic parameters of a transmission scheme. They can estimate the parameters of an error-detecting or error-correcting channel coding scheme for achieving certain performance targets. They are able to compare the properties of basic channel coding and decoding schemes regarding error correction capabilities, decoding delay, decoding complexity and to decide for a suitable method. They are capable of implementing basic coding and decoding schemes in software.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory

Course L0436: Information Theory and Coding

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe

Content	• Introduction to information theory and coding
	• Definitions of information: Self information, entropy
	• Binary entropy function
	• Source coding theorem
	• Entropy of continuous random variables: Differential entropy, differential entropy of uniformly and Gaussian distributed random variables
	• Source coding
	  ◦ Principles of lossless source coding
	  ◦ Optimal source codes
	  ◦ Prefix codes, prefix-free codes, instantaneous codes
	  ◦ Morse code
	  ◦ Huffman code
	  ◦ Shannon code
	  ◦ Bounds on the average codeword length
	  ◦ Relative entropy, Kullback-Leibler distance, Kullback-Leibler divergence
	  ◦ Cross entropy
	  ◦ Lempel-Ziv algorithm
	  ◦ Lempel-Ziv-Welch (LZW) algorithm

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

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

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

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

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence *Knowledge* *Skills* **Personal Competence** *Social Competence* *Autonomy*	
Workload in Hours	Depends on choice of courses
Credit points	12
Assignment for the Following Curricula	Information and Communication Systems: Core Qualification: Compulsory

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

Courses

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

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

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

Module M1776: Research Project ICS

Courses

Title	Typ	Hrs/wk	CP
Research Project ICS (L2919)	Projection Course	8	12

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge and techniques in the chosen field of specialization.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to acquire advanced knowledge in a specific field of Computer Science or a closely related subject.
Skills	Students are able to work self-dependent in a field of Computer Science or a closely related field.
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 248, Study Time in Lecture 112
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	Presentation of a current research topic (25-30 min and 5 min discussion)
Assignment for the Following Curricula	Information and Communication Systems: Core Qualification: Compulsory

Course L2919: Research Project ICS

Typ	Projection Course
Hrs/wk	8
CP	12
Workload in Hours	Independent Study Time 248, Study Time in Lecture 112
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe
Content	Current research topics of the chosen specialization.
Literature	Aktuelle Literatur zu Forschungsthemen aus der gewählten Vertiefungsrichtung. / Current literature on research topics of the chosen specialization.

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

Courses

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

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

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

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

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

Course L0444: Digital Communications

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe

Content	• Repetition: Baseband Transmission
	  ◦ Pulse shaping: Non-return to zero (NRZ) rectangular pulses, raised-cosine pulses, square-root raised-cosine pulses
	  ◦ Power spectral density (psd) of baseband signals
	  ◦ Intersymbol interference (ISI)
	  ◦ First and second Nyquist criterion
	  ◦ AWGN channel
	  ◦ Matched filter
	  ◦ Matched-filter receiver and correlation receiver
	  ◦ Noise whitening matched filter

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

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

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

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

Module M0836: Communication Networks

Courses

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

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

Course L0899: Selected Topics of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	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 • Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	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 M0710: Microwave Engineering

Courses

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

Module Responsible	Prof. 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 Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

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

Course L0574: Microwave Engineering	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. 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 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" • Lecture "Fundamentals of Telecommunications and Stochastic Processes" • Lecture "Digital Communications"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the general as well as advanced principles and techniques that are applied to wireless communications. They understand the properties of wireless channels and the corresponding mathematical description. Furthermore, students are able to explain the physical layer of wireless transmission systems. In this context, they are proficient in the concepts of multicarrier transmission (OFDM), modulation, error control coding, channel estimation and multi-antenna techniques (MIMO). Students can also explain methods of multiple access. On the example of contemporary communication systems (LTE, 5G) they can put the learnt content into a larger context. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
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 Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0297: Advanced Concepts of Wireless Communications

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	SoSe
Content	The lecture deals with technical principles and related concepts of mobile communications. In this context, the main focus is put on the physical and data link layer of the ISO-OSI stack. In the lecture, the transmission medium, i.e., the mobile radio channel, serves as the starting point of all considerations. The characteristics and the mathematical descriptions of the radio channel are discussed in detail. Subsequently, various physical layer aspects of wireless transmission are covered, such as channel coding, modulation/demodulation, channel estimation, synchronization, and equalization. Moreover, the different uses of multiple antennas at the transmitter and receiver, known as MIMO techniques, are described. Besides these physical layer topics, concepts of multiple access schemes in a cellular network are outlined. In order to illustrate the above-mentioned technical solutions, the lecture will also provide a system view, highlighting the basics of some contemporary wireless systems, including LTE, LTE Advanced, and 5G New Radio.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 David Tse, Pramod Viswanath: Fundamentals of Wireless Communication. Cambridge, 2005 Bernard Sklar: Digital Communications: Fundamentals and Applications. Second Edition, Pearson, 2013 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011 Erik Dahlman, Stefan Parkvall, Johan Sköld: 5G NR - The Next Generation Wireless Access Technology. Second Edition, Academic Press, 2021

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

Module M0837: Simulation of Communication Networks

Courses

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

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Knowledge of computer and communication networks • Basic programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the necessary stochastics, the discrete event simulation technology and modelling of networks for performance evaluation.
Skills	Students are able to apply the method of simulation for performance evaluation to different, also not practiced, problems of communication networks. The students can analyse the obtained results and explain the effects observed in the network. They are able to question their own results.
Personal Competence	
Social Competence	Students are able to acquire expert knowledge in groups, present the results, and discuss solution approaches and results. They are able to work out solutions for new problems in small teams.
Autonomy	Students are able to transfer independently and in discussion with others the acquired method and expert knowledge to new problems. They can identify missing knowledge and acquire this knowledge independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation 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 Further literature is announced at the beginning of the lecture.

Module M1564: Advanced Seminars Computer Science and Communication Technology

Courses

Title	Typ	Hrs/wk	CP
Advanced Seminar Computer Science and Communication Technology I (L2352)	Seminar	2	3
Introductory Seminar Computer Science and Communication Technology II (L2429)	Seminar	2	3

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of Computer Science and Mathematics at the Master's level.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to • explicate a specific topic in the field of Computer Science, • describe complex issues, • present different views and evaluate in a critical way.
Skills	The students are able to • familiarize in a specific topic of Computer Science in limited time, • realize a literature survey on the specific topic and cite in a correct way, • elaborate a presentation and give a lecture to a selected audience, • sum up the presentation in 10-15 lines, • answer questions in the final discussion.
Personal Competence	
Social Competence	The students are able to • elaborate and introduce a topic for a certain audience, • discuss the topic, content and structure of the presentation with the instructor, • discuss certain aspects with the audience, and • as the lecturer listen and respond to questions from the audience.
Autonomy	The students are able to • define the task in question in an autonomous way, • develop the necessary knowledge, • use appropriate work equipment, and • guided by an instructor critically check the working status.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	x
Assignment for the Following Curricula	Computer Science: Specialisation IV. Subject Specific Focus: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L2352: Advanced Seminar Computer Science and Communication Technology I

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

Course L2429: Introductory Seminar Computer Science and Communication Technology II

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/SoSe
Content	
Literature	

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" • 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., 5G New Radio), students are able to explain different concepts in a very deep technical detail. The students are familiar with the contents of lecture and PBL course. They can explain and apply them to new problems.
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 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 small groups to elaborate a given subject, including a quantitative analysis with provided simulation tools. The results will be presented in a poster session or a talk towards the end of the semester. Possible topics can include various system concepts and related technical principles, such as: • WLAN sytems • 5G systems • Millimeter wave communication • Visible light communication • Cooperative Multipoint • Massive MIMO • Massive machine-type communication • Interference cancellation • Non-orthogonal multiple access • Heterogeneous networks • ...
Literature	will be provided, depending on the given topics

Course L0296: Modern Wireless Systems	
Typ	Lecture
Hrs/wk	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. Systems under consideration include: - Near Field Communication (NFC) - ZigBee / IEEE 802.15.4 - Bluetooth - IEEE 802.11 family - L-band Digital Aeronautical Communication System (LDACS) - Long Term Evolution (LTE) and LTE Advanced - 5G New Radio A special focus is placed on 4th and 5th generation networks; in particular, an in-depth view into the technical principles of the 5G New Radio standard is given.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011 Erik Dahlman, Stefan Parkvall, Johan Sköld: 5G NR - The Next Generation Wireless Access Technology. Second Edition, Academic Press, 2021

Focus 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 Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

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

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

Module M0677: Digital Signal Processing and Digital Filters

Courses

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

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of signal and system theory as well as random processes. • Fundamentals of spectral transforms (Fourier series, Fourier transform, Laplace transform)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know and understand basic algorithms of digital signal processing. They are familiar with the spectral transforms of discrete-time signals and are able to describe and analyse signals and systems in time and image domain. They know basic structures of digital filters and can identify and assess important properties including stability. They are aware of the effects caused by quantization of filter coefficients and signals. They are familiar with the basics of adaptive filters. They can perform traditional and parametric methods of spectrum estimation, also taking a limited observation window into account. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to apply methods of digital signal processing to new problems. They can choose and parameterize suitable filter striuctures. In particular, the can design adaptive filters according to the minimum mean squared error (MMSE) criterion and develop an efficient implementation, e.g. based on the LMS or RLS algorithm. Furthermore, the students are able to apply methods of spectrum estimation and to take the effects of a limited observation window into account.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0446: Digital Signal Processing and Digital Filters	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe

Content	• Transforms of discrete-time signals:
	  ◦ Discrete-time Fourier Transform (DTFT)
	  ◦ Discrete Fourier-Transform (DFT), Fast Fourier Transform (FFT)
	  ◦ Z-Transform
	• Correspondence of continuous-time and discrete-time signals, sampling, sampling theorem
	• Fast convolution, Overlap-Add-Method, Overlap-Save-Method
	• Fundamental structures and basic types of digital filters
	• Characterization of digital filters using pole-zero plots, important properties of digital filters
	• Quantization effects
	• Design of linear-phase filters
	• Fundamentals of stochastic signal processing and adaptive filters
	  ◦ MMSE criterion
	  ◦ Wiener Filter
	  ◦ LMS- and RLS-algorithm
	• Traditional and parametric methods of spectrum estimation

Literature	K.-D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung. Vieweg Teubner. V. Oppenheim, R. W. Schafer, J. R. Buck: Zeitdiskrete Signalverarbeitung. Pearson StudiumA. V. W. Hess: Digitale Filter. Teubner. Oppenheim, R. W. Schafer: Digital signal processing. Prentice Hall. S. Haykin: Adaptive filter theory. L. B. Jackson: Digital filters and signal processing. Kluwer. T.W. Parks, C.S. Burrus: Digital filter design. Wiley.

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

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) • 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 • 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. • apply geometric transformations (e.g. rotation, scaling) in 2D and 3D computer graphics. • 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. • 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 Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory 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: • Object-oriented Computer Graphics • Projections and Transformations • Polygonal and Parametric Modelling • Illuminating, Shading, Rendering • Computer Animation Techniques • Kinematics and Dynamics Effects Students will be be working on a series of mini-projects which will eventually evolve into a final project. Learning computer graphics and animation resembles learning a musical instrument. Therefore, doing your projects well and in time is essential for performing well on this course.
Literature	Alan H. Watt: 3D Computer Graphics. Harlow: Pearson (3rd ed., repr., 2009). Dariush Derakhshani: Introducing Autodesk Maya 2014. New York, NY : Wiley (2013).

Course L0768: Computer Graphics	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1700: Satellite Communications and Navigation

Courses

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

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. Basic knowledge of communications engineering and signal processing are of advantage but not required. The course intends to provide the chapters on communications techniques such that on the one hand students with a communications engineering background learn additional concepts and examples (e.g. modulation and coding schemes or signal processing concepts) which have not or in a different way been treated in our other bachelor and master courses. On the other hand, students with other background shall be able to grasp the ideas but may not be able to understand in the same depth. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and analyse digital satellite communications system as well as navigation techniques. They are familiar with principal ideas of the respective communications, signal processing and positioning methods. They can describe distortions and resulting limitations caused by transmission channels and hardware components. They can describe how fundamental communications and navigation techniques are applied in selected practical systems. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to describe and analyse digital satellite communications systems and navigation systems. They are able to analyse transmission chains including link budget calculations. They are able to choose appropriate transmission technologies and system parameters for given scenarios.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources.
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 Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course 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	• Information extraction from communication signals
	  ◦ Time-of-arrival principle
	  ▪ Ranging in additive white Gaussian noise (AWGN) channel
	  ▪ Correlation-based range estimation
	  ▪ Effect of multipath propagation on time-of-arrival principle
	  ▪ Zero-forcing range estimation in the presence of multipath
	  ▪ Optimum range estimation in the presence of multipath
	  ▪ Zero-forcing in presence of noise
	  ◦ Angle-of-arrival principle
	  ▪ Angle-of-arrival estimation in AWGN channel
	  ▪ Delay-and-sum estimator
	  ▪ Multiple Signal Classifier (MUSIC)
	  ▪ MUSIC-based angle-of-arrival estimation
	  ▪ Case study: Comparison of estimators in AWGN channels
	  ▪ Effect of multipath propagation on angle-of-arrival principle
	  ▪ Case study: Comparison of estimators in multipath channels

- Information fusion of extracted signals
  - Distance-based positioning
    - Principle of time-of-arrival positioning
    - Geometric interpretation
    - Positioning in the absence of noise
    - Linearization of the positioning problem
    - Positioning in the presence of noise
    - Optimality criteria
    - Least squares time-of-arrival positioning
    - Maximum likelihood time-of-arrival positioning
    - Interactive Matlab demo
    - Excursion: gradient descent solvers for nonlinear programs
    - Real-life positioning with embedded development board (Arduino)
    - Linearized least squares time-of-arrival positioning
    - Effect of clock offsets on distance-based positioning
    - Time-difference-of-arrival principle
    - Least squares time-difference-of-arrival positioning
    - Clock offset mitigation via two-way ranging
  - Performance limits of distance-based positioning
    - Fisher information and the Cramér-Rao lower bound
    - Fisher information in the AWGN case
    - Multi-variate Fisher information
    - Cramér-Rao lower bound for synchronized time-of-arrival positioning
    - Case study: Synchronized time-of-arrival positioning
    - Cramér-Rao lower bound for unsynchronized time-of-arrival positioning
    - Case study: Unsynchronized time-of-arrival positioning
  - Angle-based Positioning
    - Angle-of-arrival positioning principle
    - Geometric interpretation angle-of-arrival positioning principle
    - Noise-free angle-of-arrival positioning with known orientation
    - Effect of noise on angle-of-arrival positioning
    - Least squares angle-of-arrival positioning with known orientation
    - Linear least squares angle-of-arrival positioning
    - Effect of orientation uncertainty
    - Angle-difference-of-arrival positioning
    - Geometric interpretation angle difference of arrival positioning
    - Proof of angle-difference-of-arrival locus
    - Inscribed angle lemma
    - Case study: Angle-difference-of-arrival-positioning
  - Performance limits of angle-based positioning
    - Cramér-Rao lower bound for angle-of-arrival positioning with known orientation
    - Case study: Angle-of-arrival positioning with known orientation
- Information Filtering
  - Bayesian filtering
    - Principle of Bayesian filtering
    - General Problem Formulation
    - Solution to the linear Gaussian case
    - State transition in the linear Gaussian case
    - Proof of predicted posterior distribution of the Kalman filter
    - State update in the linear Gaussian case
    - Proof of marginal posterior distribution of the Kalman filter
    - Working with Gaussian random variables
      - Proof: Affine transformation
      - Proof: Marginalization
      - Proof: Conditioning
    - Kalman filter: Optimum Inference in the linear Gaussian case
    - Modeling of process noise
    - Modeling of measurement noise
    - Case study: Kalman filtering in the linear Gaussian case
    - Interactive Kalman filtering in Matlab
    - Dealing with nonlinearities in Bayesian filtering
    - Nonlinear Gaussian case
    - Extended Kalman filter
    - Proof of predicted posterior distribution of the extended Kalman filter
    - Proof of marginal posterior distribution of the extended Kalman filter
    - Example: Nonlinear state transition
    - Case study: Extended Kalman filtering
    - Practical considerations for filter design
- Satellite Navigation
  - Overview from positioning perspective
    - Earth-centered earth-fixed (ECEF) coordinate system
    - World geodetic system (WGS)
    - Satellite navigation systems
    - System-receiver clock offsets and pseudo-ranges

	▪ Unsynchronized time-of-arrival positioning revisited ◦ GPS legacy signals and ranging ▪ Signal overview ▪ Time-of-arrival principle revisited ▪ Direct sequence spread spectrum principle ▪ Short and long codes ▪ Satellite signal generation ▪ Carriers and codes ▪ Correlation properties of codes ▪ Code division multiple access in flat fading channels ▪ Navigation message ◦ Velocity estimation ◦ Hands-on case study: Design of an extended Kalman filter for satellite navigation based on recorded data • Robust navigation ◦ Multipath-assisted positioning in millimeter wave multiple antenna systems ◦ Multi-sensor fusion
Literature	

Course L2710: Satellite Communications	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	• Introduction to satellite communications ◦ What is a satellite ◦ Overview orbits, Van Allen Belt, components of a satellite ◦ Satellite services ◦ Frequency bands for satellite services ◦ International Telecommunications Union (ITU) ◦ Influence of atmospheric impairments ◦ Milestones in satellite communications • Components of a satellite communications system ◦ Ground segment ◦ Space segment ◦ Control segment • Communication links ◦ Uplink, downlink ◦ Forward link, reverse link ◦ Intersatellite links ◦ Multiple access ◦ Performance measures ▪ Effective isotropic radiated power (EIRP), antenna gain, figure of merit, G/T, carrier to noise ratio ▪ Signal to noise power ratio vs. carrier to noise ratio • Single beam and multibeam satellites ◦ Beam coverage ◦ Examples for beam coverage of LEO and GEO satellites (Iridium, Viasat) • Transparent vs. regenerative payload • Orbits ◦ Low earth orbot (LEO), medium earth orbit (MEO), geosynchroneous and geostationary orbits (GEO), highly elliptical orbits (HEO ◦ Favourable orbits: ▪ HEO orbits with 63-64^{o} inclination, Molnya and Tundra orbits ▪ Circular LEO orbits ▪ Circular MEO Orbits (Intermediate Circular Orbits (ICO)) ▪ Equatorial orbits, geostationary orbit (GEO) ◦ Important aspects of LEO, MEO and GEO satellites • Kepler’s laws of planetary motion • Gravitational force • Parameters of ellipses and elliptical orbits ◦ Major and minor half axis ◦ Foci ◦ Eccentricity ◦ Eccentric anomaly, mean anomaly, true anomaly ◦ Area ◦ Orbit period ◦ Perigee, apogee ◦ Distance of satellite from center of earth ◦ Construction of ellipses according to de La Hire ◦ Orbital plane in space, inclination, right ascension (longitude) of ascending node, Vernal equinox

- Newton’s laws of motion
- Newton’s universal law of gravitation

- Energy of satellites: Potential energy, kinetic energy, total energy
- Instantaneous speed of a satellite
- Kepler’s equation
- Satellite visibility, elevation
- Required number of LEO, MEO or GEO satellites for continuous earth coverage
- Satellite altitude and distance from a point on earth

- Choice of orbits
  - LEO, HEO, GEO
  - Elliptical orbits with non-zero inclination, Molnya orbits, Tundra orbits
  - Geosynchronous orbits
    - Parameters of geosynchronous orbits
    - Circular geosynchronous orbits
    - Inclined geosynchronous orbits
    - Quasi-zenith satellite systems (QZSS)
    - Syb-synchronous circular equatorial orbits
    - Geostationary orbit
      - Parameters of the geostationary orbit
      - Visibility
      - Propagation delay
      - Applications and system examples

- Perturbations of orbits
  - Station keeping
    - Station keeping box
    - Estimation of orbit parameters

- Fundamentals of digital communications techniques
  - Components of a digital communications system
  - Principles of encryption
  - Scrambling
  - Scrambling vs. interleaving for randomization of data sequences
  - Interleaving: Block interleaver, convolutional interleaver, random interleaver
  - Digital modulation methods
    - Linear and non-linear digital modulation methods
    - Linear digital modulation methods
      - QAM modulator and demodulator
      - Pulse shaping, square-root raised-cosine pulses
      - Average power spectral density
      - Signal space constellation
      - Examples: M-ary phase shift keying (M-PSK), M-ary quadrature amplitude shift keying (M-QAM)
      - M-PSK in noisy channels
      - Bit error probabilities of M-PSK and M-QAM
      - M-PSK vs. M-QAM
      - M-ary amplitude and phase shift keying (M-APSK)
      - M-APSK vs. M-QAM
      - Differential phase shift keying (DPSK)

Error control coding (channel coding)

- Error detecting and forward error correcting (FEC) codes
- Principle of channel coding
- Data rate, code rate, Baud rate, spectral efficiency of modulation and coding schemes
- Bandwidth-power trade-off, bandwidth-limited vs. power-limited transmission
- Coding and modulation for transparent vs. regenerative payload
- Block codes and convolutional codes
- Concatenated codes
- Bit-interleaved coded modulation
- Convolutional codes
- Low density parity check (LDPC) codes, principle of message passing decoding, bit error rate performance
- Cyclic block codes
  - Examples for cyclic block codes
  - Single errors vs. block errors, cyclic block codes for burst errors
  - Generator matrix, generator polynomials
  - Systematic encoding and syndrome determination with shift registers
  - Cyclic redundancy check (CRC) codes

- Automatic repeat request (ARQ)
  - Principle of ARQ
  - Stop-and-wait ARQ
  - Go-back-N ARQ
  - Selective-repeat ARQ
- Transmission gains and losses

	◦ Antenna gain ▪ Antenna radiation pattern ▪ Maximum antenna gain, 3dB beamwidth ▪ Maximum antenna gain of circular aperture ▪ Maximum antenna gain of a geostationary satellite with global coverage ◦ Effective isotropic radiated power (EIRP) ◦ Power flux density ◦ Path loss ▪ Free space loss, free space loss for geostationary satellites ▪ Atmospheric loss ▪ Received power ◦ Losses in transmit and receive equipment ▪ Feeder loss ▪ Depointing loss ▪ Polarization mismatch loss ◦ Combined effect of losses • Noise ◦ Origins of noise ◦ White noise ◦ Noise power spectral density and noise power ◦ Additive white Gaussian noise (AWGN) channel model ◦ Antenna noise temperature ◦ Earth brightness temperature ◦ Signal to noise ratios • Atmospheric distortions ◦ Atmosphere of the earth: Troposphere, stratosphere, mesosphere, thermosphere, exosphere ◦ Attenuation and depolarization due to rain, fog, rain and ice clouds, sandstorms ◦ Scintillation ◦ Faraday effect ◦ Multipath contributions • Link budget calculations ◦ GEO clear sky uplink and downlink ◦ GEO uplink and downlink under rain conditions ◦ Transparent vs. regenerative payload • Link availability improvement through site diversity and adaptive transmission ◦ Transparent vs. regenerative payload ▪ Non-linear amplifiers ▪ Saleh model, Rapp model ▪ Input and output back-off factor ▪ Single carrier and multicarrier operation ▪ Dimensioning of transmission parameters ▪ Sources of noise: Thermal noise, interference, intermodulation products ▪ Signal to noise ratio and bit error probability ▪ Robustness against interference and non-linear channels • Satellite networks ◦ Satellite network reference architectures ◦ Network topologies ◦ Network connectivity ▪ Types of network connectivity ▪ On-board connectivity ▪ Inter-satellite links ◦ Broadcast networks ◦ Satellite-based internet • Satellite communications systems and standards examples ◦ The role of standards in satellite communications ◦ The Digital Video Broadcast Satellite Standard: DVB-S, DVB-S2, DVB-S2X ◦ Satellites in 3GPP mobile communications networks ◦ LEO megaconstellations: SpaceX Starlink, Kuiper, OneWeb ◦ Space debris ◦ The German Heinrich Hertz mission
Literature	

Module M1702: Process Imaging

Courses

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

Module Responsible	Prof. Alexander Penn
Admission Requirements	None
Recommended Previous Knowledge	No special prerequisites needed
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**Content:** The module focuses primarily on discussing established imaging techniques including (a) optical and infrared imaging, (b) magnetic resonance imaging, (c) X-ray imaging and tomography, and (d) ultrasound imaging but also covers a range of more recent imaging modalities. The students will learn: 1. what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature), 2. how the measurements work (physical measurement principles, hardware requirements, image reconstruction), and 3. how to determine the most suited imaging methods for a given problem. **Learning goals:** After the successful completion of the course, the students shall: 1. understand the physical principles and practical aspects of the most common imaging methods, 2. be able to assess the pros and cons of these methods with regard to cost, complexity, expected contrasts, spatial and temporal resolution, and based on this assessment 3. be able to identify the most suited imaging modality for any specific engineering challenge in the field of chemical and bioprocess engineering.
Skills	
Personal Competence	
Social Competence	In the problem-based interactive course, students work in small teams and set up two process imaging systems and use these systems to measure relevant process parameters in different chemical and bioprocess engineering applications. The teamwork will foster interpersonal communication skills.
Autonomy	Students are guided to work in self-motivation due to the challenge-based character of this module. A final presentation improves presentation skills.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
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 Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory Water and Environmental Engineering: Specialisation Environment: Elective Compulsory Water and Environmental Engineering: Specialisation Water: Elective Compulsory

Course L2723: Process Imaging	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Alexander Penn
Language	EN
Cycle	SoSe
Content	
Literature	Wang, M. (2015). Industrial Tomography. Cambridge, UK: Woodhead Publishing. Available as e-book in the library of TUHH: https://katalog.tub.tuhh.de/Record/823579395

Course L2724: Process Imaging	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Alexander Penn, Dr. Stefan Benders
Language	EN
Cycle	SoSe
Content	**Content:** The module focuses primarily on discussing established imaging techniques including (a) optical and infrared imaging, (b) magnetic resonance imaging, (c) X-ray imaging and tomography, and (d) ultrasound imaging and also covers a range of more recent imaging modalities. The students will learn: 1. what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature), 2. how the measurements work (physical measurement principles, hardware requirements, image reconstruction), and 3. how to determine the most suited imaging methods for a given problem. **Learning goals:** After the successful completion of the course, the students shall: 1. understand the physical principles and practical aspects of the most common imaging methods, 2. be able to assess the pros and cons of these methods with regard to cost, complexity, expected contrasts, spatial and temporal resolution, and based on this assessment 3. be able to identify the most suited imaging modality for any specific engineering challenge in the field of chemical and bioprocess engineering.
Literature	Wang, M. (2015). Industrial Tomography. Cambridge, UK: Woodhead Publishing. Available as e-book in the library of TUHH: https://katalog.tub.tuhh.de/Record/823579395

Module M1598: Image Processing

Courses

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

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

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

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

Focus Software

Module M0753: Software Verification

Courses

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

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

Course L0629: Software Verification

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

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

Module M0733: Software Analysis

Courses

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

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of software-engineering activities • Discrete algebraic structures • Object-oriented programming, algorithms, and data structures • Functional programming or Procedural programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major approaches to data-flow analysis, control-flow analysis, and type-based analysis, along with their classification schemes, and employ abstract interpretation. They explain the standard forms of internal representations and models, including their mathematical structure and properties, and evaluate their suitability for a particular analysis. They explain and categorize the major analysis algorithms. They distinguish precise solutions from approximative approaches, and show termination and soundness properties.
Skills	Presented with an analytical task for a software artifact, students select appropriate approaches from software analysis, and justify their choice. They design suitable representations by modifying standard representations. They develop customized analyses and devise them as safe overapproximations. They formulate analyses in a formal way and construct arguments for their correctness, behavior, and precision.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Using accompanying on-line material for self study, students can assess their level of knowledge continuously and adjust it appropriately. Working on exercise problems, they receive additional feedback. Within limits, they can set their own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of software analysis. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. They can devise plans to arrive at new solutions or assess existing ones.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	software artifacts/mathematical write-ups; short presentation
Assignment for the Following Curricula	Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0631: Software Analysis

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	• Modeling: Control-Flow Modeling, Data Dependences, Intermediate Languages) • Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward) • Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation) • Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm) • Non-Classical Data-Flow Analyses • Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques) • Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification) • Recent Developments of Analysis Techniques and Applications
Literature	• Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005. • Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009. • Benjamin Pierce, Types and Programming Languages, MIT Press. • Selected research papers

Course L0632: Software Analysis	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1397: Model Checking - Proof Engines and Algorithms

Courses

Title	Typ	Hrs/wk	CP
Model Checking - Proof Engines and Algorithms (L1979)	Lecture	2	3
Model Checking - Proof Engines and Algorithms (L1980)	Recitation Section (small)	2	3

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge about data structures and algorithms
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know • algorithms and data structures for model checking, • basics of Boolean reasoning engines and • the impact of specification and modelling on the computational effort for model checking.
Skills	Students can • explain and implement algorithms and data structures for model checking, • decide whether a given problem can be solved using Boolean reasoning or model checking, and • implement the respective algorithms.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • defend their solutions orally.
Autonomy	Using accompanying material students independently learn in-depth relations between concepts explained in the lecture and additional solution strategies.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** 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 Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory 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." And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond? But what are the limitations of model checking? How are the models generated from a given design? The lecture will answer these questions. Open source tools will be used to gather a practical experience. Among other topics, the lecture will consider the following topics: • Modelling digital Hardware, Software, and Cyber Physical Systems • Data structures, decision procedures and proof engines ◦ Binary Decision Diagrams ◦ And-Inverter-Graphs ◦ Boolean Satisfiability ◦ Satisfiability Modulo Theories • Specification Languages ◦ CTL ◦ LTL ◦ System Verilog Assertions • Algorithms for ◦ Reachability Analysis ◦ Symbolic CTL Checking ◦ Bounded LTL-Model Checking ◦ Optimizations, e.g., induction, abstraction • Quality assurance
Literature	Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA. A. Biere, A. Biere, M. Heule, H. van Maaren, and T. Walsh. 2009. *Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications*. IOS Press, Amsterdam, The Netherlands, The Netherlands. Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1301: Software Testing

Courses

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

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

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

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

Module M1682: Secure Software Engineering

Courses

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

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with basic software engineering concepts (e.g., requirements, design) and basic security concepts (e.g., confidentiality, integrity, availability)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Elicit security requirements in a software project • Model and document security measures in a software design • Use threat and risk analysis techniques • Understand how security code reviews are performed • Understand the core definitions of concepts related to privacy • Understand privacy enhancing technologies
Skills	Select appropriate security assurance techniques to be used in a security assurance program
Personal Competence	
Social Competence	None
Autonomy	Students can apply the knowledge acquired throughout the course to the resolution of industrial case studies. Students should also be capable to acquire new knowledge independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	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 Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L2667: Secure Software Engineering

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

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

Module M1794: Applied Cryptography

Courses

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

Module Responsible	Prof. Sibylle Fröschle
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: No; Bonus: 10 %; Form: Excercises; Description: Die Übungsaufgaben finden semesterbegleitend statt
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L2954: Applied Cryptography

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

Course L2955: Applied Cryptography

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

Module M1774: Advanced Internet Computing

Courses

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

Module Responsible	Prof. Stefan Schulte
Admission Requirements	None
Recommended Previous Knowledge	Good programming skills are necessary. Previous knowledge in the field of distributed systems is helpful.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the course, students are able to: • Describe basic concepts of Cloud Computing, the Internet of Things (IoT), and blockchain technologies • Discuss and assess critical aspects of Cloud Computing, the IoT, and blockchain technologies • Select and apply cloud and IoT technologies for particular application areas • Design and develop practical solutions for the integration of smart objects in IoT, Cloud, and blockchain software • Implement IoT services
Skills	The students acquire the ability to model Internet-based distributed systems and to work with these systems. This comprises especially the ability to select and utilize fitting technologies for different application areas. Furthermore, students are able to critically assess the chosen technologies.
Personal Competence	
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: Yes; Bonus: 20 %; Form: Subject theoretical and practical work; Description: Gruppenarbeit mit aktuellen Technologien aus dem Bereich Internet of Things
Examination	Subject theoretical and practical work
Examination duration and scale	0
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2916: Advanced Internet Computing

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

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

Module M0924: Software for Embedded Systems

Courses

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

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	• Very Good knowledge and practical experience in programming in the C language • Basic knowledge in software engineering • Basic understanding of assembly language
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know the basic principles and procedures of software engineering for embedded systems. They are able to describe the usage and pros of event based programming using interrupts. They know the components and functions of a concrete microcontroller. The participants explain requirements of real time systems. They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	Students build interrupt-based programs for a concrete microcontroller. They build and use a preemptive scheduler. They use peripheral components (timer, ADC, EEPROM) to realize complex tasks for embedded systems. To interface with external components they utilize serial protocols.
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	Compulsory: No; Bonus: 10 %; Form: Attestation; Description:
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L1069: Software for Embdedded Systems

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

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

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

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

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence *Knowledge* *Skills* **Personal Competence** *Social Competence* *Autonomy*	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	Lecture
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe

Content	• From Rule-Based Systems to Machine Learning
	  ◦ Brief overview recent advances in ML in various domain
	  ◦ Outline and expected learning outcomes
	  ◦ Basics statistical inference and statistics
	  ◦ Basics of information theory
	• The Notions of Learning in Machine Learning
	  ◦ Unsupervised and supervised machine learning
	  ◦ Model-based and data-driven machine learning
	  ◦ Hybrid modelling
	  ◦ Online/offline/meta/transfer learning
	  ◦ General loss functions
	• Introduction to Deep Learning
	  ◦ Variants of neural networks
	  ◦ MLP
	  ◦ Conv. neural networks
	  ◦ Recurrent neural networks
	  ◦ Training neural networks
	  ◦ (Stochastic) Gradient Descent
	• Regression vs. Classification
	  ◦ Classification as supervised learning problem
	  ◦ Hands-On Session
	• Representation Learning and Generative Models
	  ◦ AutoEncoders
	  ◦ Directed Generative Models
	  ◦ Undirected Generative Models
	  ◦ Generative Adversarial Neural Networks
	• Probabilistic Graphical Models
	  ◦ Bayesian Networks
	  ◦ Variational inference (variational autoencoder)

Literature	

Course L3008: Machine Learning Applications in Electric Power Systems	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application. Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to expand todays physcis-based approaches in EMC Engineering.
Literature	

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3005: Machine Learning in Wireless Communications	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe

Content	• Supervised Learning Application - Channel Coding
	  ◦ Recap channel coding and block codes
	  ◦ Block codes as trainable neural networks
	  ◦ Tanner graph with trainable weights
	  ◦ Hands-on session
	• Supervised Learning Application - Modulation Detection
	  ◦ Recap wireless modulation schemes
	  ◦ Convolutional neuronal networks for blind detection of modulation schemes
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping I
	  ◦ Recap channel capacity and constellation shaping,
	  ◦ Capacity achieving machine learning systems
	  ◦ Information theoretical explanation of the autoencoder training
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping II
	  ◦ Training without a channel model
	  ◦ Mutual information neural estimator
	  ◦ Hands-on session
	• Generative Adversarial Network Application - Channel Modelling
	  ◦ Recap realistic channels with non-linear hardware impairments
	  ◦ Training a digital twin of a realistic channel with insufficient training data
	  ◦ Hands-on session
	• Recurrent Neural Network Application - Channel prediction
	  ◦ Recap time-varying channel models
	  ◦ Recurrent neural networks for temporal prediction
	  ◦ Hands-on session

Literature	

Specialization Secure and Dependable IT Systems

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

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

Module M0753: Software Verification

Courses

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

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

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

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

Module M0942: Software Security

Courses

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

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with C/C++, web programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can • name the main causes for security vulnerabilities in software • explain current methods for identifying and avoiding security vulnerabilities • explain the fundamental concepts of code-based access control
Skills	Students are capable of • performing a software vulnerability analysis • developing secure code
Personal Competence	
Social Competence	None
Autonomy	Students are capable of acquiring knowledge independently from professional publications, technical standards, and other sources, and are capable of applying newly acquired knowledge to new problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	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 Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L1103: Software Security

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

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

Module M1397: Model Checking - Proof Engines and Algorithms

Courses

Title	Typ	Hrs/wk	CP
Model Checking - Proof Engines and Algorithms (L1979)	Lecture	2	3
Model Checking - Proof Engines and Algorithms (L1980)	Recitation Section (small)	2	3

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge about data structures and algorithms
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know • algorithms and data structures for model checking, • basics of Boolean reasoning engines and • the impact of specification and modelling on the computational effort for model checking.
Skills	Students can • explain and implement algorithms and data structures for model checking, • decide whether a given problem can be solved using Boolean reasoning or model checking, and • implement the respective algorithms.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • defend their solutions orally.
Autonomy	Using accompanying material students independently learn in-depth relations between concepts explained in the lecture and additional solution strategies.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** 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 Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory 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." And how do the underlying reasoning algorithms work so effectively in practice despite a computational complexity of NP hardness and beyond? But what are the limitations of model checking? How are the models generated from a given design? The lecture will answer these questions. Open source tools will be used to gather a practical experience. Among other topics, the lecture will consider the following topics: • Modelling digital Hardware, Software, and Cyber Physical Systems • Data structures, decision procedures and proof engines ◦ Binary Decision Diagrams ◦ And-Inverter-Graphs ◦ Boolean Satisfiability ◦ Satisfiability Modulo Theories • Specification Languages ◦ CTL ◦ LTL ◦ System Verilog Assertions • Algorithms for ◦ Reachability Analysis ◦ Symbolic CTL Checking ◦ Bounded LTL-Model Checking ◦ Optimizations, e.g., induction, abstraction • Quality assurance
Literature	Edmund M. Clarke, Jr., Orna Grumberg, and Doron A. Peled. 1999. *Model Checking*. MIT Press, Cambridge, MA, USA. A. Biere, A. Biere, M. Heule, H. van Maaren, and T. Walsh. 2009. *Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications*. IOS Press, Amsterdam, The Netherlands, The Netherlands. Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1773: Cybersecurity Data Science

Courses

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

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of probabilities and statistics. Familiarity with object oriented programming.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Apply data science methods to the resolution of complex cybersecurity problems. • Use of data science methods to quantify risks and optimize cybersecurity operations. • Identify strengths and limitations of state-of-the-art methods • Select the performance indicators of data-oriented cybersecurity solutions. • Understand cybersecurity threats in data science methods.
Skills	Implement and evaluate data-driven models for the identification, treatment, and mitigation of cybersecurity risks
Personal Competence	
Social Competence	None
Autonomy	Students can apply the knowledge acquired throughout the course to the resolution of industrial case studies. Students should also be capable to acquire new knowledge independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	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 Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L2914: Cybersecurity Data Science

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations: • Introduction to data science • Supervised and unsupervised learning • Data science methods (e.g., clustering, decision trees, artificial neural networks) • Performance metrics Cybersecutrity Applications: • Spam detection • Phishing detection • Intrusion detection • Access-control prediction • Denial of Service (DoS) prediction • Vulnerability/malware prediction • Adversarial machine learning
Literature	[1] Sarker, I.H., Kayes, A.S.M., Badsha, S., Alqahtani, H., Watters, P. and Ng, A., 2020. Cybersecurity data science: an overview from machine learning perspective. Journal of Big data, 7(1), pp.1-29. [2] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). Springer, Singapore. [3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press. [4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of Machine Learning in Computer Security. [5] Torres, J.M., Comesaña, C.I. and Garcia-Nieto, P.J., 2019. Machine learning techniques applied to cybersecurity. International Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836. [6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

Course L2915: Exercise Cybersecurity Data Science	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Riccardo Scandariato
Language	EN
Cycle	SoSe
Content	Theoretical Foundations: • Introduction to data science • Supervised and unsupervised learning • Data science methods (e.g., clustering, decision trees, artificial neural networks) • Performance metrics Cybersecutrity Applications: • Spam detection • Phishing detection • Intrusion detection • Access-control prediction • Denial of Service (DoS) prediction • Vulnerability/malware prediction • Adversarial machine learning
Literature	[1] Sarker, I.H., Kayes, A.S.M., Badsha, S., Alqahtani, H., Watters, P. and Ng, A., 2020. Cybersecurity data science: an overview from machine learning perspective. Journal of Big data, 7(1), pp.1-29. [2] Truong, T.C., Zelinka, I., Plucar, J., Čandík, M. and Šulc, V., 2020. Artificial intelligence and cybersecurity: Past, presence, and future. In Artificial intelligence and evolutionary computations in engineering systems (pp. 351-363). Springer, Singapore. [3] Dua, S. and Du, X., 2016. Data mining and machine learning in cybersecurity. CRC press. [4] Arp, D., Quiring, E., Pendlebury, F., Warnecke, A., Pierazzi, F., Wressnegger, C., Cavallaro, L. and Rieck, K., Dos and Don'ts of Machine Learning in Computer Security. [5] Torres, J.M., Comesaña, C.I. and Garcia-Nieto, P.J., 2019. Machine learning techniques applied to cybersecurity. International Journal of Machine Learning and Cybernetics, 10(10), pp.2823-2836. [6] Russell, S. and Norvig, P., 2010. Artificial Intelligence: A Modern Approach, Prentice Hall.

Module M1400: Design of Dependable Systems

Courses

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

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge about data structures and algorithms
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	In the following "dependable" summarizes the concepts Reliability, Availability, Maintainability, Safety and Security. Knowledge about approaches for designing dependable systems, e.g., • Structural solutions like modular redundancy • Algorithmic solutions like handling byzantine faults or checkpointing Knowledge about methods for the analysis of dependable systems
Skills	Ability to implement dependable systems using the above approaches. Ability to analyzs the dependability of systems using the above methods for analysis.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • present their solutions orally.
Autonomy	Using accompanying material students independently learn in-depth relations between concepts explained in the lecture and additional solution strategies.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: 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 Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

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

Course L2001: Designing Dependable Systems	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1564: Advanced Seminars Computer Science and Communication Technology

Courses

Title	Typ	Hrs/wk	CP
Advanced Seminar Computer Science and Communication Technology I (L2352)	Seminar	2	3
Introductory Seminar Computer Science and Communication Technology II (L2429)	Seminar	2	3

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of Computer Science and Mathematics at the Master's level.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to • explicate a specific topic in the field of Computer Science, • describe complex issues, • present different views and evaluate in a critical way.
Skills	The students are able to • familiarize in a specific topic of Computer Science in limited time, • realize a literature survey on the specific topic and cite in a correct way, • elaborate a presentation and give a lecture to a selected audience, • sum up the presentation in 10-15 lines, • answer questions in the final discussion.
Personal Competence	
Social Competence	The students are able to • elaborate and introduce a topic for a certain audience, • discuss the topic, content and structure of the presentation with the instructor, • discuss certain aspects with the audience, and • as the lecturer listen and respond to questions from the audience.
Autonomy	The students are able to • define the task in question in an autonomous way, • develop the necessary knowledge, • use appropriate work equipment, and • guided by an instructor critically check the working status.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	x
Assignment for the Following Curricula	Computer Science: Specialisation IV. Subject Specific Focus: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory

Course L2352: Advanced Seminar Computer Science and Communication Technology I

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

Course L2429: Introductory Seminar Computer Science and Communication Technology II

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/SoSe
Content	
Literature	

Focus Networks

Module M0836: Communication Networks

Courses

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

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

Course L0899: Selected Topics of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	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 • Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	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 M0676: Digital Communications

Courses

Title	Typ	Hrs/wk	CP
Digital Communications (L0444)	Lecture	2	3
Digital Communications (L0445)	Recitation Section (large)	2	2
Laboratory Digital Communications (L0646)	Practical Course	1	1

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

Course L0444: Digital Communications

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe

Content	• Repetition: Baseband Transmission
	  ◦ Pulse shaping: Non-return to zero (NRZ) rectangular pulses, raised-cosine pulses, square-root raised-cosine pulses
	  ◦ Power spectral density (psd) of baseband signals
	  ◦ Intersymbol interference (ISI)
	  ◦ First and second Nyquist criterion
	  ◦ AWGN channel
	  ◦ Matched filter
	  ◦ Matched-filter receiver and correlation receiver
	  ◦ Noise whitening matched filter
	  ◦ Discrete-time AWGN channel model
	• Representation of bandpass signals and systems in the equivalent baseband
	  ◦ Quadrature amplitude modulation (QAM)
	  ◦ Equivalent baseband signal and system
	  ◦ Analytical signal
	  ◦ Equivalent baseband random process, equivalent baseband white Gaussian noise process
	  ◦ Equivalent baseband AWGN channel
	  ◦ Equivalent baseband channel model with frequency-offset and phase noise

- Equivalent baseband Rayleigh fading and Rice fading channel models
- Equivalent baseband frequency-selective channel model
- Discrete memoryless channels (DMC)

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

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

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

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

Module M0837: Simulation of Communication Networks

Courses

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

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Knowledge of computer and communication networks • Basic programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the necessary stochastics, the discrete event simulation technology and modelling of networks for performance evaluation.
Skills	Students are able to apply the method of simulation for performance evaluation to different, also not practiced, problems of communication networks. The students can analyse the obtained results and explain the effects observed in the network. They are able to question their own results.
Personal Competence	
Social Competence	Students are able to acquire expert knowledge in groups, present the results, and discuss solution approaches and results. They are able to work out solutions for new problems in small teams.
Autonomy	Students are able to transfer independently and in discussion with others the acquired method and expert knowledge to new problems. They can identify missing knowledge and acquire this knowledge independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation 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 Further literature is announced at the beginning of the lecture.

Module M1774: Advanced Internet Computing

Courses

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

Module Responsible	Prof. Stefan Schulte
Admission Requirements	None
Recommended Previous Knowledge	Good programming skills are necessary. Previous knowledge in the field of distributed systems is helpful.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the course, students are able to: • Describe basic concepts of Cloud Computing, the Internet of Things (IoT), and blockchain technologies • Discuss and assess critical aspects of Cloud Computing, the IoT, and blockchain technologies • Select and apply cloud and IoT technologies for particular application areas • Design and develop practical solutions for the integration of smart objects in IoT, Cloud, and blockchain software • Implement IoT services
Skills	The students acquire the ability to model Internet-based distributed systems and to work with these systems. This comprises especially the ability to select and utilize fitting technologies for different application areas. Furthermore, students are able to critically assess the chosen technologies.
Personal Competence	
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: Yes; Bonus: 20 %; Form: Subject theoretical and practical work; Description: Gruppenarbeit mit aktuellen Technologien aus dem Bereich Internet of Things
Examination	Subject theoretical and practical work
Examination duration and scale	0
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L2916: Advanced Internet Computing

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

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

Module M0839: Traffic Engineering

Courses

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

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamentals of communication or computer networks • Stochastics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe methods for planning, optimisation and performance evaluation of communication networks.
Skills	Students are able to solve typical planning and optimisation tasks for communication networks. Furthermore they are able to evaluate the network performance using queuing theory. Students are able to apply independently what they have learned to other and new problems. They can present their results in front of experts and discuss them.
Personal Competence	
Social Competence	
Autonomy	Students are able to acquire the necessary expert knowledge to understand the functionality and performance of new communication networks independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory 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 • 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 • Linear Programming (LP) • Network planning with LP solvers • Planning of communication networks Queueing Theory for Communication Networks • Stochastic processes • Queueing systems • Switches (circuit- and packet switching) • Network of queues
Literature	Literatur: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer further literature announced in the lecture

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

Focus Software and Signal Processing

Module M0738: Digital Audio Signal Processing

Courses

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

Module Responsible	Prof. Udo Zölzer
Admission Requirements	None
Recommended Previous Knowledge	Signals and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Die Studierenden können die grundlegenden Verfahren und Methoden der digitalen Audiosignalverarbeitung erklären. Sie können die wesentlichen physikalischen Effekte bei der Sprach- und Audiosignalverarbeitung erläutern und in Kategorien einordnen. Sie können einen Überblick der numerischen Methoden und messtechnischen Charakterisierung von Algorithmen zur Audiosignalverarbeitung geben. Sie können die erarbeiteten Algorithmen auf weitere Anwendungen im Bereich der Informationstechnik und Informatik abstrahieren.
Skills	The students will be able to apply methods and techniques from audio signal processing in the fields of mobile and internet communication. They can rely on elementary algorithms of audio signal processing in form of Matlab code and interactive JAVA applets. They can study parameter modifications and evaluate the influence on human perception and technical applications in a variety of applications beyond audio signal processing. Students can perform measurements in time and frequency domain in order to give objective and subjective quality measures with respect to the methods and applications.
Personal Competence	
Social Competence	The students can work in small groups to study special tasks and problems and will be enforced to present their results with adequate methods during the exercise.
Autonomy	The students will be able to retrieve information out of the relevant literature in the field and putt hem into the context of the lecture. They can relate their gathered knowledge and relate them to other lectures (signals and systems, digital communication systems, image and video processing, and pattern recognition). They will be prepared to understand and communicate problems and effects in the field audio signal processing.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	60 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

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

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

Module M0733: Software Analysis

Courses

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

Module Responsible	Prof. Sibylle Schupp
Admission Requirements	None
Recommended Previous Knowledge	• Basic knowledge of software-engineering activities • Discrete algebraic structures • Object-oriented programming, algorithms, and data structures • Functional programming or Procedural programming
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students apply the major approaches to data-flow analysis, control-flow analysis, and type-based analysis, along with their classification schemes, and employ abstract interpretation. They explain the standard forms of internal representations and models, including their mathematical structure and properties, and evaluate their suitability for a particular analysis. They explain and categorize the major analysis algorithms. They distinguish precise solutions from approximative approaches, and show termination and soundness properties.
Skills	Presented with an analytical task for a software artifact, students select appropriate approaches from software analysis, and justify their choice. They design suitable representations by modifying standard representations. They develop customized analyses and devise them as safe overapproximations. They formulate analyses in a formal way and construct arguments for their correctness, behavior, and precision.
Personal Competence	
Social Competence	Students discuss relevant topics in class. They defend their solutions orally. They communicate in English.
Autonomy	Using accompanying on-line material for self study, students can assess their level of knowledge continuously and adjust it appropriately. Working on exercise problems, they receive additional feedback. Within limits, they can set their own learning goals. Upon successful completion, students can identify and precisely formulate new problems in academic or applied research in the field of software analysis. Within this field, they can conduct independent studies to acquire the necessary competencies and compile their findings in academic reports. They can devise plans to arrive at new solutions or assess existing ones.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	software artifacts/mathematical write-ups; short presentation
Assignment for the Following Curricula	Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory

Course L0631: Software Analysis

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	• Modeling: Control-Flow Modeling, Data Dependences, Intermediate Languages) • Classical Bit-Vector Analyses (Reaching Definition, Very Busy Expressions, Liveness, Available Expressions, May/Must, Forward/Backward) • Monotone Frameworks (Lattices, Transfer Functions, Ascending Chain Condition, Distributivity, Constant Propagation) • Theory of Data-Flow Analysis (Tarski's Fixed Point Theorem, Data-Flow Equations, MFP Solution, MOP Solution, Worklist Algorithm) • Non-Classical Data-Flow Analyses • Abstract Interpretation (Galois Connections, Approximating Fixed Points, Construction Techniques) • Type Systems (Type Derivation, Inference Trees, Algorithm W, Unification) • Recent Developments of Analysis Techniques and Applications
Literature	• Flemming Nielsen, Hanne Nielsen, and Chris Hankin. Principles of Program Analysis. Springer, 2nd. ed. 2005. • Uday Khedker, Amitabha Sanyal, and Bageshri Karkara. Data Flow Analysis: Theory and Practice. CRC Press, 2009. • Benjamin Pierce, Types and Programming Languages, MIT Press. • Selected research papers

Course L0632: Software Analysis	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sibylle Schupp
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module 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) • 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 • 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. • apply geometric transformations (e.g. rotation, scaling) in 2D and 3D computer graphics. • 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. • 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 Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory 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: • Object-oriented Computer Graphics • Projections and Transformations • Polygonal and Parametric Modelling • Illuminating, Shading, Rendering • Computer Animation Techniques • Kinematics and Dynamics Effects Students will be be working on a series of mini-projects which will eventually evolve into a final project. Learning computer graphics and animation resembles learning a musical instrument. Therefore, doing your projects well and in time is essential for performing well on this course.
Literature	Alan H. Watt: 3D Computer Graphics. Harlow: Pearson (3rd ed., repr., 2009). Dariush Derakhshani: Introducing Autodesk Maya 2014. New York, NY : Wiley (2013).

Course L0768: Computer Graphics	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1682: Secure Software Engineering

Courses

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

Module Responsible	Prof. Riccardo Scandariato
Admission Requirements	None
Recommended Previous Knowledge	Familiarity with basic software engineering concepts (e.g., requirements, design) and basic security concepts (e.g., confidentiality, integrity, availability)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Elicit security requirements in a software project • Model and document security measures in a software design • Use threat and risk analysis techniques • Understand how security code reviews are performed • Understand the core definitions of concepts related to privacy • Understand privacy enhancing technologies
Skills	Select appropriate security assurance techniques to be used in a security assurance program
Personal Competence	
Social Competence	None
Autonomy	Students can apply the knowledge acquired throughout the course to the resolution of industrial case studies. Students should also be capable to acquire new knowledge independently from academic publications, techical standards, and white papers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	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 Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L2667: Secure Software Engineering

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

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

Module M1842: GPU Architectures

Courses

Title	Typ	Hrs/wk	CP
GPU Architecture (L3039)	Lecture	3	4
GPU Architecture (L3040)	Project-/problem-based Learning	1	2

Module Responsible	Prof. Sohan Lal
Admission Requirements	None
Recommended Previous Knowledge	An introductory module on computer engineering or computer architecture, and good programming skills in C/C++.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence *Knowledge* *Skills* **Personal Competence** *Social Competence* *Autonomy*	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L3039: GPU Architecture

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	SoSe
Content	- Review of computer architecture basics - measuring performance, benchmarks, five-stage RISC pipeline, caches - GPU basics - evolution of GPU computing, a high-level overview of a GPU architecture - GPU programming with CUDA - program structure, CUDA threads organization, warp/thread-block scheduling - GPU (micro) architecture - streaming multiprocessors, single instruction multiple threads (SIMT) core design, tensor/RT cores, mixed-precision support - GPU memory hierarchy - banked register file and operand collectors, shared memory, GPU caches (differences w.r.t. CPU caches), global memory - Branch and memory divergence - branch handling, stack-based reconvergence, memory coalescing, coalescer design - Barriers and synchronization - Temporal and spatial locality exploitation challenges in GPU caches - Global memory- high throughput requirements, GDDR/HBM, memory bandwidth optimization techniques - GPU research issues - performance bottlenecks, GPU power modeling, high-power consumption/energy efficiency, GPU security - Application case study - deep learning - Cycle accurate simulators for GPUs The learning in the lectures will be augmented by a semester-long problem-based project.
Literature	

Course L3040: GPU Architecture	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Sohan Lal
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	3	3

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. Basic knowledge of communications engineering and signal processing are of advantage but not required. The course intends to provide the chapters on communications techniques such that on the one hand students with a communications engineering background learn additional concepts and examples (e.g. modulation and coding schemes or signal processing concepts) which have not or in a different way been treated in our other bachelor and master courses. On the other hand, students with other background shall be able to grasp the ideas but may not be able to understand in the same depth. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and analyse digital satellite communications system as well as navigation techniques. They are familiar with principal ideas of the respective communications, signal processing and positioning methods. They can describe distortions and resulting limitations caused by transmission channels and hardware components. They can describe how fundamental communications and navigation techniques are applied in selected practical systems. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to describe and analyse digital satellite communications systems and navigation systems. They are able to analyse transmission chains including link budget calculations. They are able to choose appropriate transmission technologies and system parameters for given scenarios.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources.
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 Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course 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	• Information extraction from communication signals
	  ◦ Time-of-arrival principle
	  ▪ Ranging in additive white Gaussian noise (AWGN) channel
	  ▪ Correlation-based range estimation
	  ▪ Effect of multipath propagation on time-of-arrival principle
	  ▪ Zero-forcing range estimation in the presence of multipath
	  ▪ Optimum range estimation in the presence of multipath
	  ▪ Zero-forcing in presence of noise
	  ◦ Angle-of-arrival principle
	  ▪ Angle-of-arrival estimation in AWGN channel
	  ▪ Delay-and-sum estimator
	  ▪ Multiple Signal Classifier (MUSIC)
	  ▪ MUSIC-based angle-of-arrival estimation
	  ▪ Case study: Comparison of estimators in AWGN channels
	  ▪ Effect of multipath propagation on angle-of-arrival principle
	  ▪ Case study: Comparison of estimators in multipath channels

- Information fusion of extracted signals
  - Distance-based positioning
    - Principle of time-of-arrival positioning
    - Geometric interpretation
    - Positioning in the absence of noise
    - Linearization of the positioning problem
    - Positioning in the presence of noise
    - Optimality criteria
    - Least squares time-of-arrival positioning
    - Maximum likelihood time-of-arrival positioning
    - Interactive Matlab demo
    - Excursion: gradient descent solvers for nonlinear programs
    - Real-life positioning with embedded development board (Arduino)
    - Linearized least squares time-of-arrival positioning
    - Effect of clock offsets on distance-based positioning
    - Time-difference-of-arrival principle
    - Least squares time-difference-of-arrival positioning
    - Clock offset mitigation via two-way ranging
  - Performance limits of distance-based positioning
    - Fisher information and the Cramér-Rao lower bound
    - Fisher information in the AWGN case
    - Multi-variate Fisher information
    - Cramér-Rao lower bound for synchronized time-of-arrival positioning
    - Case study: Synchronized time-of-arrival positioning
    - Cramér-Rao lower bound for unsynchronized time-of-arrival positioning
    - Case study: Unsynchronized time-of-arrival positioning
  - Angle-based Positioning
    - Angle-of-arrival positioning principle
    - Geometric interpretation angle-of-arrival positioning principle
    - Noise-free angle-of-arrival positioning with known orientation
    - Effect of noise on angle-of-arrival positioning
    - Least squares angle-of-arrival positioning with known orientation
    - Linear least squares angle-of-arrival positioning
    - Effect of orientation uncertainty
    - Angle-difference-of-arrival positioning
    - Geometric interpretation angle difference of arrival positioning
    - Proof of angle-difference-of-arrival locus
    - Inscribed angle lemma
    - Case study: Angle-difference-of-arrival-positioning
  - Performance limits of angle-based positioning
    - Cramér-Rao lower bound for angle-of-arrival positioning with known orientation
    - Case study: Angle-of-arrival positioning with known orientation
- Information Filtering
  - Bayesian filtering
    - Principle of Bayesian filtering
    - General Problem Formulation
    - Solution to the linear Gaussian case
    - State transition in the linear Gaussian case
    - Proof of predicted posterior distribution of the Kalman filter
    - State update in the linear Gaussian case
    - Proof of marginal posterior distribution of the Kalman filter
    - Working with Gaussian random variables
      - Proof: Affine transformation
      - Proof: Marginalization
      - Proof: Conditioning
    - Kalman filter: Optimum Inference in the linear Gaussian case
    - Modeling of process noise
    - Modeling of measurement noise
    - Case study: Kalman filtering in the linear Gaussian case
    - Interactive Kalman filtering in Matlab
    - Dealing with nonlinearities in Bayesian filtering
    - Nonlinear Gaussian case
    - Extended Kalman filter
    - Proof of predicted posterior distribution of the extended Kalman filter
    - Proof of marginal posterior distribution of the extended Kalman filter
    - Example: Nonlinear state transition
    - Case study: Extended Kalman filtering
    - Practical considerations for filter design
- Satellite Navigation
  - Overview from positioning perspective
    - Earth-centered earth-fixed (ECEF) coordinate system
    - World geodetic system (WGS)
    - Satellite navigation systems
    - System-receiver clock offsets and pseudo-ranges

	▪ Unsynchronized time-of-arrival positioning revisited ◦ GPS legacy signals and ranging ▪ Signal overview ▪ Time-of-arrival principle revisited ▪ Direct sequence spread spectrum principle ▪ Short and long codes ▪ Satellite signal generation ▪ Carriers and codes ▪ Correlation properties of codes ▪ Code division multiple access in flat fading channels ▪ Navigation message ◦ Velocity estimation ◦ Hands-on case study: Design of an extended Kalman filter for satellite navigation based on recorded data • Robust navigation ◦ Multipath-assisted positioning in millimeter wave multiple antenna systems ◦ Multi-sensor fusion
Literature	

Course L2710: Satellite Communications	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	• Introduction to satellite communications ◦ What is a satellite ◦ Overview orbits, Van Allen Belt, components of a satellite ◦ Satellite services ◦ Frequency bands for satellite services ◦ International Telecommunications Union (ITU) ◦ Influence of atmospheric impairments ◦ Milestones in satellite communications • Components of a satellite communications system ◦ Ground segment ◦ Space segment ◦ Control segment • Communication links ◦ Uplink, downlink ◦ Forward link, reverse link ◦ Intersatellite links ◦ Multiple access ◦ Performance measures ▪ Effective isotropic radiated power (EIRP), antenna gain, figure of merit, G/T, carrier to noise ratio ▪ Signal to noise power ratio vs. carrier to noise ratio • Single beam and multibeam satellites ◦ Beam coverage ◦ Examples for beam coverage of LEO and GEO satellites (Iridium, Viasat) • Transparent vs. regenerative payload • Orbits ◦ Low earth orbot (LEO), medium earth orbit (MEO), geosynchroneous and geostationary orbits (GEO), highly elliptical orbits (HEO ◦ Favourable orbits: ▪ HEO orbits with 63-64^{o} inclination, Molnya and Tundra orbits ▪ Circular LEO orbits ▪ Circular MEO Orbits (Intermediate Circular Orbits (ICO)) ▪ Equatorial orbits, geostationary orbit (GEO) ◦ Important aspects of LEO, MEO and GEO satellites • Kepler’s laws of planetary motion • Gravitational force • Parameters of ellipses and elliptical orbits ◦ Major and minor half axis ◦ Foci ◦ Eccentricity ◦ Eccentric anomaly, mean anomaly, true anomaly ◦ Area ◦ Orbit period ◦ Perigee, apogee ◦ Distance of satellite from center of earth ◦ Construction of ellipses according to de La Hire ◦ Orbital plane in space, inclination, right ascension (longitude) of ascending node, Vernal equinox

- Newton’s laws of motion
- Newton’s universal law of gravitation

- Energy of satellites: Potential energy, kinetic energy, total energy
- Instantaneous speed of a satellite
- Kepler’s equation
- Satellite visibility, elevation
- Required number of LEO, MEO or GEO satellites for continuous earth coverage
- Satellite altitude and distance from a point on earth

- Choice of orbits
  - LEO, HEO, GEO
  - Elliptical orbits with non-zero inclination, Molnya orbits, Tundra orbits
  - Geosynchronous orbits
    - Parameters of geosynchronous orbits
    - Circular geosynchronous orbits
    - Inclined geosynchronous orbits
    - Quasi-zenith satellite systems (QZSS)
    - Syb-synchronous circular equatorial orbits
    - Geostationary orbit
      - Parameters of the geostationary orbit
      - Visibility
      - Propagation delay
      - Applications and system examples

- Perturbations of orbits
  - Station keeping
    - Station keeping box
    - Estimation of orbit parameters

- Fundamentals of digital communications techniques
  - Components of a digital communications system
  - Principles of encryption
  - Scrambling
  - Scrambling vs. interleaving for randomization of data sequences
  - Interleaving: Block interleaver, convolutional interleaver, random interleaver
  - Digital modulation methods
    - Linear and non-linear digital modulation methods
    - Linear digital modulation methods
      - QAM modulator and demodulator
      - Pulse shaping, square-root raised-cosine pulses
      - Average power spectral density
      - Signal space constellation
      - Examples: M-ary phase shift keying (M-PSK), M-ary quadrature amplitude shift keying (M-QAM)
      - M-PSK in noisy channels
      - Bit error probabilities of M-PSK and M-QAM
      - M-PSK vs. M-QAM
      - M-ary amplitude and phase shift keying (M-APSK)
      - M-APSK vs. M-QAM
      - Differential phase shift keying (DPSK)

Error control coding (channel coding)

- Error detecting and forward error correcting (FEC) codes
- Principle of channel coding
- Data rate, code rate, Baud rate, spectral efficiency of modulation and coding schemes
- Bandwidth-power trade-off, bandwidth-limited vs. power-limited transmission
- Coding and modulation for transparent vs. regenerative payload
- Block codes and convolutional codes
- Concatenated codes
- Bit-interleaved coded modulation
- Convolutional codes
- Low density parity check (LDPC) codes, principle of message passing decoding, bit error rate performance
- Cyclic block codes
  - Examples for cyclic block codes
  - Single errors vs. block errors, cyclic block codes for burst errors
  - Generator matrix, generator polynomials
  - Systematic encoding and syndrome determination with shift registers
  - Cyclic redundancy check (CRC) codes

- Automatic repeat request (ARQ)
  - Principle of ARQ
  - Stop-and-wait ARQ
  - Go-back-N ARQ
  - Selective-repeat ARQ
- Transmission gains and losses

	◦ Antenna gain ▪ Antenna radiation pattern ▪ Maximum antenna gain, 3dB beamwidth ▪ Maximum antenna gain of circular aperture ▪ Maximum antenna gain of a geostationary satellite with global coverage ◦ Effective isotropic radiated power (EIRP) ◦ Power flux density ◦ Path loss ▪ Free space loss, free space loss for geostationary satellites ▪ Atmospheric loss ▪ Received power ◦ Losses in transmit and receive equipment ▪ Feeder loss ▪ Depointing loss ▪ Polarization mismatch loss ◦ Combined effect of losses • Noise ◦ Origins of noise ◦ White noise ◦ Noise power spectral density and noise power ◦ Additive white Gaussian noise (AWGN) channel model ◦ Antenna noise temperature ◦ Earth brightness temperature ◦ Signal to noise ratios • Atmospheric distortions ◦ Atmosphere of the earth: Troposphere, stratosphere, mesosphere, thermosphere, exosphere ◦ Attenuation and depolarization due to rain, fog, rain and ice clouds, sandstorms ◦ Scintillation ◦ Faraday effect ◦ Multipath contributions • Link budget calculations ◦ GEO clear sky uplink and downlink ◦ GEO uplink and downlink under rain conditions ◦ Transparent vs. regenerative payload • Link availability improvement through site diversity and adaptive transmission ◦ Transparent vs. regenerative payload ▪ Non-linear amplifiers ▪ Saleh model, Rapp model ▪ Input and output back-off factor ▪ Single carrier and multicarrier operation ▪ Dimensioning of transmission parameters ▪ Sources of noise: Thermal noise, interference, intermodulation products ▪ Signal to noise ratio and bit error probability ▪ Robustness against interference and non-linear channels • Satellite networks ◦ Satellite network reference architectures ◦ Network topologies ◦ Network connectivity ▪ Types of network connectivity ▪ On-board connectivity ▪ Inter-satellite links ◦ Broadcast networks ◦ Satellite-based internet • Satellite communications systems and standards examples ◦ The role of standards in satellite communications ◦ The Digital Video Broadcast Satellite Standard: DVB-S, DVB-S2, DVB-S2X ◦ Satellites in 3GPP mobile communications networks ◦ LEO megaconstellations: SpaceX Starlink, Kuiper, OneWeb ◦ Space debris ◦ The German Heinrich Hertz mission
Literature	

Module M1301: Software Testing

Courses

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

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

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

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

Module M1810: Autonomous Cyber-Physical Systems

Courses

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

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	• Very Good knowledge and practical experience in programming in the C language (Module: Procedural Programming) • Basic knowledge in software engineering • Basic knowledge in wired and wireless communication protocols • Principal understanding of simple electronic circuits
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence *Knowledge* *Skills* **Personal Competence** *Social Competence* *Autonomy*	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: No; Bonus: 10 %; Form: Attestation; Description:
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

Course L3000: Autonomous Cyber-Physical Systems

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3001: Autonomous Cyber-Physical Systems

Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1598: Image Processing

Courses

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

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

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

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

Module M1694: Security of Cyber-Physical Systems

Courses

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

Module Responsible	Prof. Sibylle Fröschle
Admission Requirements	None
Recommended Previous Knowledge	IT security, programming skills, statistics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know and can explain - the threats posed by cyber attacks to cyber-physical systems (CPS) - concrete attacks at a technical level, e.g. on bus systems - security solutions specific to CPS with their capabilities and limitations - examples of security architectures for CPS and the requirements they guarantee - standard security engineering processes for CPS
Skills	The students are able to - identify security threats and assess the risks for a given CPS - apply attack toolkits to analyse a networked control system, and detect attacks beyond those taught in class - identify and apply security solutions suitable to the requirements - follow security engineering processes to develop a security architecture for a given CPS - recognize challenges and limitations, e.g. posed by novel types of attack
Personal Competence	
Social Competence	The students are able to - expertly discuss security risks and incidents of CPS and their mitigation in a solution-oriented fashion with experts and non-experts - foster a security culture with respect to CPS and the corresponding critical infrastructures
Autonomy	The students are able to - follow up and critically assess current developments in the security of CPS including relevant security incidents - master a new topic within the area by self-study and self-initiated interaction with experts and peers.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	Compulsory: No; Bonus: 10 %; Form: Excercises; Description: Die Übungsaufgaben finden semesterbegleitend statt.
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory

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

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

Thesis

Module M1801: Master thesis (dual study program)

Courses

Title	Typ	Hrs/wk	CP

Module Responsible	Professoren der TUHH
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... use the specialised knowledge (facts, theories and methods) from their field of study and the acquired professional knowledge confidently to deal with technical and practical professional issues. • ... can explain the relevant approaches and terminologies in depth in one or more of their subject's specialist areas, describe current developments and take a critical stance. • ... formulate their own research assignment to tackle a professional problem and contextualise it within their subject area. They ascertain the current state of research and critically assess it.
Skills	Dual students ... • ... can select suitable methods for the respective subject-related professional problem, apply them and develop them further as required. • ... assess knowledge and methods acquired during their studies (including practical phases) and apply their expertise to complex and/or incompletely defined problems in a solution- and application-oriented manner. • ... acquire new academic knowledge in their subject area and critically evaluate it.
Personal Competence	
Social Competence	Dual students ... • ... can present a professional problem in the form of an academic question in a structured, comprehensible and factually correct manner, both in writing and orally, for a specialist audience and for professional stakeholders. • ... answer questions as part of a professional discussion in an expert, appropriate manner. They represent their own points of view and assessments convincingly.
Autonomy	Dual students ... • ... can structure their own project into work packages, work through them at an academic level and reflect on them with regard to feasible courses of action for professional practice. • ... work in-depth in a partially unknown area within the discipline and acquire the information required to do so. • ... apply the techniques of academic work comprehensively in their own research work when dealing with an operational problem and question.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination	Thesis
Examination duration and scale	According to General Regulations
Assignment for the Following Curricula	Civil Engineering: Thesis: Compulsory Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Computer Science: Thesis: Compulsory Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Computer Science in Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory International Management and Engineering: Thesis: Compulsory Logistics, Infrastructure and Mobility: Thesis: Compulsory Materials Science: Thesis: Compulsory Mechanical Engineering and Management: Thesis: Compulsory Mechatronics: Thesis: Compulsory Biomedical Engineering: Thesis: Compulsory Microelectronics and Microsystems: Thesis: Compulsory Product Development, Materials and Production: Thesis: Compulsory Renewable Energies: Thesis: Compulsory Naval Architecture and Ocean Engineering: Thesis: Compulsory Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory