

Module Manual

Master of Science (M.Sc.)

Information and Communication Systems

Cohort: Winter Term 2022 Updated: 7th June 2024

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Program description

Content

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

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

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

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

Career prospects

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

Learning target

Knowledge

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

Specialisation Communication Systems

Students can

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

Specialisation Secure and Dependable IT Systems:

Students can

- give an overview of software verification,
- describe security principles for information and communication systems,
- explain their specialized knowledge in communication networks,
- · describe software development and signal processing principles.

Skills

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

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

Social skills

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

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

Autonomy

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

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

Program structure

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

Core qualification: 48 CP

Specialization: 42 CP Master thesis: 30 CP

Total: 120 CP

The core qualification consists of the module Information Theory and Coding (6 CP), technical complementary courses (12 CP), Business & Management (6 CP), nontechnical complementary courses (6 CP) and research project with seminar (18 CP). The research project with seminar consists of a scientific thesis with documentation and accompanying presentations in a seminar among fellow students.

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

Communication Systems

Containing: Communications, software, and signal processing

Secure and Dependable IT Systems

Containing: IT security, networks, software and signal processing

Students write a master thesis (30 CP).

Core Qualification

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

Courses

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

Madula Daaraa ikia	Preserve Disktor
Module Responsible	Dagmar Richter
Admission Requirements	None
Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	······································
Knowledge	The Nontechnical Academic Programms (NTA)
	imparts skills that in view of the THHH's training profile, professional engineering studies require but are not able to cover fully.
	Self-reliance, self-management, collaboration and professional and personnel management competences. The department
	implements these training objectives in its teaching architecture, in its teaching and learning arrangements, in teaching
	areas and by means of teaching offerings in which students can qualify by opting for specific competences and a competence
	level at the Bachelor's or Master's level. The teaching offerings are pooled in two different catalogues for nontechnical
	complementary courses.
	The Learning Architecture
	consists of a cross-disciplinarily study offering. The centrally designed teaching offering ensures that courses in the nontechnical
	academic programms follow the specific profiling of TUHH degree courses.
	The learning architecture demands and trains independent educational planning as regards the individual development of
	competences. It also provides orientation knowledge in the form of "profiles".
	The subjects that can be studied in parallel throughout the student's entire study program - if need be, it can be studied in one to
	two semesters. In view of the adaptation problems that individuals commonly face in their first semesters after making the transition from school to university and in order to encourage individually planned semesters abroad, there is no obligation to
	study these subjects in one or two specific semesters during the course of studies.
	Teaching and Learning Arrangements
	provide for students, separated into B.Sc. and M.Sc., to learn with and from each other across semesters. The challenge of dealing
	with interdisciplinarity and a variety of stages of learning in courses are part of the learning architecture and are deliberately
	encouraged in specific courses.
	Fields of Teaching
	are based on research findings from the academic disciplines cultural studies, social studies, arts, historical studies,
	communication studies, migration studies and sustainability research, and from engineering didactics. In addition, from the winter
	in a goal-oriented way.
	I ne fields of teaching are augmented by soft skills offers and a foreign language offer. Here, the focus is on encouraging goal- oriented communication skills, e.g. the skills required by outgoing engineers in international and intercultural situations.
	The Competence Level
	of the courses offered in this area is different as regards the basic training objective in the Bachelor's and Master's fields. These
	differences are reflected in the practical examples used, in content topics that refer to different professional application contexts,
	This is also reflected in the different quality of soft skills, which relate to the different team positions and different group leadership
	functions of Bachelor's and Master's graduates in their future working life.
	Specialized Competence (Knowledge)
	Students can
	 explain specialized areas in context of the relevant non-technical disciplines,
	• outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the
	learning area,
	 different specialist disciplines relate to their own discipline and differentiate it as well as make connections, alstab the basis authors of here as isotific disciplines restations models instruments mathed and forms of connectations.
	 sketch the basic outlines of now sciencific disciplines, paradigms, models, instruments, methods and forms of representation in the specialized sciences are subject to individual and socio-cultural interpretation and historicity.
	 Can communicate in a foreign language in a manner appropriate to the subject.
Skills	Professional Competence (Skills)
	In colorted sub-proper students ran
	 apply basic and specific methods of the said scientific disciplines, accustion a creatific technical phonomena. medale theories from the view slot of smaller technical phonomena.
	 aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline.
	 to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner,
	• justify their decisions on forms of organization and application in practical questions in contexts that go beyond the
	technical relationship to the subject.

Personal Competence

Social Competence Personal Competences (Social Skills)

	 Students will be able to learn to collaborate in different manner, to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees, to express themselves competently, in a culturally appropriate and gender-sensitive manner in the language of the country (as far as this study-focus would be chosen), to explain nontechnical items to auditorium with technical background knowledge.
Autonomy	Personal Competences (Self-reliance)
	Students are able in selected areas
	 to reflect on their own profession and professionalism in the context of real-life fields of application to organize themselves and their own learning processes to reflect and decide questions in front of a broad education background to communicate a nontechnical item in a competent way in writen form or verbaly to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
Workload in Hours	Depends on choice of courses
Credit points	6

Courses

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

Module M1246: Tech	nical 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	Information and Communication Systems: Core Qualification: Compulsory
Following Curricula	

Module M0673: Inform	mation Theory and Coding			
Courses				
Title	436)	Typ Lecture	Hrs/wk	CP 4
Information Theory and Coding (L0	438)	Recitation Section (large)	2	2
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	· Mathematica 1.2			
Knowledge	Mathematics 1-3 Probability theory and random processes			
	Basic knowledge of communications engineering (e.g. Processes")	g. from lecture "Fundamentals o	of Communica	tions and Random
Educational Objectives	After taking part successfully, students have reached the follow	ving 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 tutor	ials. They can explain and apply t	hem to new pr	oblems.
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 knowledge during the lecture period by solving tutorial problem	n appropriate literature sources. ns, software tools, clicker system.	They can co	ntrol their level of
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70			
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale	Electrical Englishering Constaliantics Information and Commun	institut Contanta Election Commu		
Assignment for the	Electrical Engineering: Specialisation Information and Commun	Ication Systems: Elective Compuls	ory	
Following Curricula	Information and Communication Systems: Core Qualification: C	ompulsory		
	International Management and Engineering: Specialisation II. E	lectrical Engineering: Elective Con	npulsorv	
	Mechatronics: Technical Complementary Course: Elective Comp	pulsory		
		,		

Course L0436: Information Theory and Coding Typ Lecture Hrs/wk 3 СР 4 Workload in Hours Independent Study Time 78, Study Time in Lecture 42 Lecturer Prof. Gerhard Bauch Language ΕN 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 $\circ~$ 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), nonorthogonal 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

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	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 R - Kanalcodierung Springer			
	Freurens, B., Kunacoulerung, apringer.			
	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		
Тур	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 M1776: Resea	arch Project ICS			
Courses				
Title		Тур	Hrs/wk	СР
Research Project ICS (L2919)		Projection Course	8	12
Module Responsible	Prof. Riccardo Scandariato			
Admission Requirements	None			
Recommended Previous	Basic knowledge and techniques in the chosen fie	ld of specialization.		
Knowledge				
Educational Objectives	After taking part successfully, students have reach	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 of	or a closely related s	ubject.
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 Lectu	re 112		
Credit points	12			
Course achievement	None			
Examination	Study work			
Examination duration and	Presentation of a current research topic (25-30 mi	n and 5 min discussion)		
scale				
Assignment for the	Information and Communication Systems: Core Qu	ualification: Compulsory		
Following Curricula				

Course L2919: Research Proj	iect ICS
Тур	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.

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.

Courses						
Title Digital Communications (L0444) Digital Communications (L0445) Laboratory Digital Communications ((L0646)			Typ Lecture Recitation Section (large) Practical Course	Hrs/wk 2 2 1	CP 3 2 1
Module Responsible	Prof. Gerhard Bauch					
Admission Requirements	None					
Recommended Previous Knowledge	 Mathematics 1- Signals and Sys Fundamentals of 	3 tems f Communications ar	nd Random Processes			
Educational Objectives	After taking part succe	ssfully, students hav	e reached the followi	ng learning results		
Professional Competence						
Knowledge Skills Personal Competence Social Competence Autonomy	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. 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. The students can jointly solve specific problems.					
	knowledge during the	lecture period by som	ving tutorial problems	s, software tools, clicker syst	.em.	
Workload in Hours	Independent Study Tir	ne 110, Study Time i	n Lecture 70			
Credit points	6 Compulsory Bonus	Form	Description			
course achievement	Yes None	Written elaboration				
Examination	Written exam					
Examination duration and	90 min					
Assignment for the	Electrical Engineering	Core Qualification: C	`ompulsory			
Following Curricula	Computer Science in E	ngineering: Specialis	ation II. Engineering S	Science: Elective Compulsor	v	
	Information and Comn Information and Comn International Manager International Manager Microelectronics and N	nunication Systems: S nunication Systems: S nent and Engineering nent and Engineering licrosystems: Core Q	Specialisation Commu Specialisation Secure I: Specialisation II. Info I: Specialisation II. Ele ualification: Elective (inication Systems: Computer and Dependable IT Systems ormation Technology: Electiv cerrical Engineering: Elective Compulsory	ory , Focus Networks: ve Compulsory Compulsory	Elective Compulsory

Course L0444: Digital Comm	unications		
Тур	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)
 - Cvclic 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.	
I	J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill.	
1	S. Haykin: Communication Systems. Wiley	
1	R.G. Gallager: Principles of Digital Communication. Cambridge	
1	A. Goldsmith: Wireless Communication. Cambridge.	
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.	

Course L0445: Digital Communications		
Тур	Recitation Section (large)	
Hrs/wk	2	
СР	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		
Тур	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		
	A. Goldsmith: Wireless Communication. Cambridge.	
	D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.	

Module M0836: Comn	nunication Networks			
Courses				
Title Selected Topics of Communication Networks (L0899) Communication Networks (L0897)		Typ Project-/problem-based Learning Lecture	Hrs/wk 2 2	CP 2 2
Communication Networks Excercise	e (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 	unication technologies is beneficia	al	
Educational Objectives	After taking part successfully, students have reached the follow	ing 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 c	ritically analyse the solutions.		
Autonomy	Students are able to obtain the necessary expert knowledge for new communication networks independently.	or understanding the functionalit	y and perforn	nance capabilities of
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70			
Credit points	6			
Course achievement	None			
Examination	Presentation			
Examination duration and	1.5 hours colloquium with three students, therefore about 30 n	nin per student. Topics of the col	loquium are t	the posters from the
scale	previous poster session and the topics of the module.			
Assignment for the	Electrical Engineering: Specialisation Information and Communic	cation Systems: Elective Compuls	ory	
Following Curricula	Electrical Engineering: Specialisation Control and Power System:	s Engineering: Elective Compulso	ry	
	Aircraft Systems Engineering: Core Qualification: Elective Comp	ulsory		
	Computer Science in Engineering: Specialisation I. Computer Sci	ience: Elective Compulsory		
	Information and Communication Systems: Specialisation Commu	unication Systems: Elective Comp	ulsory	
	Information and Communication Systems: Specialisation Secure	and Dependable II Systems, Foc	us Networks:	Elective Compulsory
	Mechatronics: Technical Complementary Course: Elective Comp	ulsory	mpulsory	
	Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory			
	Theoretical Mechanical Engineering: Specialisation Robotics and	Computer Science: Elective Com	pulsory	

Course L0899: Selected Topics of Communication Networks		
Тур	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		
Тур	Lecture	
Hrs/wk	2	
CP	2	
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28	
Lecturer	Prof. Andreas Timm-Giel, Dr. Koojana Kuladinithi	
Language	EN	
Cycle	WiSe	
Content		
Literature	 Skript des Instituts f ür Kommunikationsnetze Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture. 	

Course L0898: Communication Networks Excercise		
Тур	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: Micro	wave Engineering			
-				
Courses				
Title		Тур	Hrs/wk	СР
Microwave Engineering (L0573)		Recitation Section (large)	2	2
Microwave Engineering (L0575)		Practical Course	1	1
Module Responsible	Prof. Alexander Kölpin			
Admission Requirements	None			
Recommended Previous	Fundamentals of communication engineering, semicon	ductor devices and circuits. Basics of \	Nave propagatio	on from transmission
Knowledge	line theory and theoretical electrical engineering.			
Educational Objectives	After taking part successfully, students have reached t	ne 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 elec configure simple receiver circuits. They can calculate They can calculate the noise of receivers and the sign knowledge to the practical courses.	tromagnetic waves. They can analyze the characteristic of simple antennas nal-to-noise-ratio of transmission syste	complete trans and arrays bas ms. They can a	mission systems und ed on the geometry. pply their theoretical
Personal Competence Social Competence	Students work together in small groups during the prac	tical courses. Together they document,	evaluate and d	iscuss 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	1		
Credit points	6			
Course achievement	Compulsory Bonus Form Desi Yes None Subject theoretical and practical work	ription		
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Electrical Engineering: Core Qualification: Compulsory			
Following Curricula	Information and Communication Systems: Specialisation	n Communication Systems: Elective Co	mpulsory	
	International Management and Engineering: Specialisat	ion II. Electrical Engineering: Elective C	ompulsory	
	Microelectronics and Microsystems: Specialisation Com	munication and Signal Processing: Elec	tive Compulsory	1

Course L0573: Microwave Engineering		
Тур	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	HG. Unger, "Elektromagnetische Theorie für die Hochfrequenztechnik, Teil I", Hüthig, Heidelberg, 1988	
	HG. 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	
Тур	Recitation Section (large)
Hrs/wk	2
СР	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		
Тур	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: Adva	nced Concepts of Wireless Communio	ations		
Courses				
Title Advanced Concepts of Wireless Communications (L0297) Advanced Concepts of Wireless Communications (L0298)		Typ Lecture Recitation Section (large)	Hrs/wk 3 2	CP 4 2
Module Responsible	Dr. Rainer Grünheid			
Admission Requirements	None			
Recommended Previous Knowledge	 Lecture "Signals and Systems" Lecture "Fundamentals of Telecommunications Lecture "Digital Communications" 	and Stochastic Processes"		
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 app	ly them to new p	roblems.
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 a	nd present their results in an adequate t	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	0		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and scale	90 minutes; scope: content of lecture and exercise			
Assignment for the	Electrical Engineering: Specialisation Information and	Communication Systems: Elective Com	oulsory	
Following Curricula	Information and Communication Systems: Specialisat Microelectronics and Microsystems: Specialisation Co	on Communication Systems: Elective Co nmunication and Signal Processing: Elec	ompulsory ctive Compulsory	·

Course L0297: Advanced Con	cepts of Wireless Communications
Тур	Lecture
Hrs/wk	3
СР	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	
Тур	Recitation Section (large)
Hrs/wk	2
СР	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: Simu	lation of Communication Networks			
Courses				
Title		Тур	Hrs/wk	СР
Simulation of Communication Netw	vorks (L0887)	Project-/problem-based Learning	5	6
Module Responsible	Prof. Andreas Timm-Giel			
Admission Requirements	None			
Recommended Previous	Knowledge of computer and communication networks			
Knowledge	Basic programming skills			
Educational Objectives	After taking part successfully, students have reached the foll	owing learning results		
Professional Competence				
Knowledge	Students are able to explain the necessary stochastics, the performance evaluation.	discrete event simulation technolo	gy and mode	lling of networks for
Skills	Students are able to apply the method of simulation for p	performance evaluation to different	, also not pra	acticed, problems of
	communication networks. The students can analyse the obta	ined results and explain the effects	observed in th	e network. They are
	able to question their own results.			
Personal Competence				
Social Competence	Students are able to acquire expert knowledge in groups, p	resent the results, and discuss solut	ion approach	es and results. They
	are able to work out solutions for new problems in small tear	ns.		
Διιτοροπγ	Students are able to transfer independently and in discuss	sion with others the acquired meth	nd and experi	t knowledge to new
Autonomy	problems. They can identify missing knowledge and acquire	this knowledge independently.		t knowledge to new
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70			
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information and Commit	unication Systems: Elective Compuls	ory	
Following Curricula	Ancran Systems Engineering: Core Quantication: Elective Co	mpulsory ure and Dependable IT Systems, Foc	us Networks	Elective Compulsory
	Information and Communication Systems: Specialisation Sec	nmunication Systems: Elective Com	ulsorv	Liective Compulsoly
	International Management and Engineering: Specialisation II.	Information Technology: Elective Co	ompulsory	
	Theoretical Mechanical Engineering: Specialisation Simulatio	n Technology: Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisation Simulatio	n Technology: Elective Compulsory		

Course L0887: Simulation of	Communication Networks
Тур	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: Adva	nced Seminars Computer Science and	d Communication Tech	nology	
Courses				
Title Advanced Seminar Computer Scien	nce and Communication Technology I (L2352)	Typ Seminar Seminar	Hrs/wk	CP 3
Module Responsible	Dozenten des SD E	Seminar	L	5
Admission Requirements	None			
Recommended Previous	Basic knowledge of Computer Science and Mathemati	ics at the Master's level.		
Knowledge				
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 Comput describe complex issues, present different views and evaluate in a critication 	er Science, al way.		
Skills	The students are able to			
	 familiarize in a specific topic of Computer Scier realize a literature survey on the specific topic elaborate a presentation and give a lecture to a sum up the presentation in 10-15 lines, answer questions in the final discussion. 	nce in limited time, and cite in a correct way, a selected audience,		
Personal Competence				
Social Competence	 The students are able to elaborate and introduce a topic for a certain au discuss the topic, content and structure of the discuss certain aspects with the audience, and as the lecturer listen and respond to questions 	udience, presentation with the instructor, from the audience.		
Autonomy	The students are able to define the task in question in an autonomous w develop the necessary knowledge, use appropriate work equipment, and 	vay,		
	 guided by an instructor critically check the wor 	king status.		
Mauldand In Harris	Index and ext Church Times 104. Church Times in Leaders 1	50		
workload in Hours	independent Study Time 124, Study Time in Lecture 5	00		
Course achievement	None			
Evamination	Precentation			
Examination duration and scale	X			
Assignment for the Following Curricula	Computer Science: Specialisation IV. Subject Specific Information and Communication Systems: Specialisat Information and Communication Systems: Specialisat	Focus: Elective Compulsory ion Communication Systems: Elect ion Secure and Dependable IT Syst	ive Compulsory tems: Elective Compuls	Sory

Course L2352: Advanced Seminar Computer Science and Communication Technology I		
Тур	Seminar	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Dozenten des SD E	
Language	EN	
Cycle	WiSe/SoSe	
Content	- Seminar presentations by enrolled students about selected topics of computer science and communication technology	
	- Active participation in discussions	
Literature	Wird vom Veranstalter bekanntgegeben.	

Course L2429: Introductory Seminar Computer Science and Communication Technology II	
Тур	Seminar
Hrs/wk	2
СР	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: Mode	rn Wireless Sys	tems				
Courses						
Title				Тур	Hrs/wk	СР
Selected Topics of Modern Wireless	s 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	Lecture "Digital	Communications"				
Knowledge	Lecture "Advance"	ed Concepts of Wirele	ss Communications			
Educational Objectives	After taking part succe	cefully students have	reached the followi	na learning results		
Professional Competence	Arter taking part succe	ssiuny, students nuve		ing learning results		
Knowledge	Students have an over	rview of a variety of co	ontemporary wirele	ess systems of different size and	complexity. T	hev understand the
	technical solutions from	n the perspective of th	ne physical and dat	a link layer. They have developed	d a system vie	ew and are aware of
	the technical argumen	ts, considering the res	spective application	ns and associated constraints. Fo	r several exar	mples (e.g., 5G New
	Radio), students are al	ole to explain different	concepts in a very	deep technical detail.		
	The students are famil	iar with the contents of	f lecture and PBL co	ourse. They can explain and apply	, them to new	problems.
					,	p
Skills	Students have develo	ped a system view. T	hey can transfer t	heir knowledge to evaluate oth	er systems, n	ot discussed in the
	lecture, and to underst	and the respective tec	hnical solutions. Gi	ven specific contraints and techn	ical requireme	ents, students are in
Demonstration of the second second	a position to make pro	posals for certain desig	in aspects by an ap	propriate assessment and the co	nsideration of	alternatives.
Personal Competence	Chudanta con isinthu al	herete teelre in eneell .	wayna and avacant	khoir reculto in en edecueto fech	ion	
Social Competence	Students can jointly el	aborate tasks in small g	groups and present	their results in an adequate fash	ion.	
Autonomy	Students are able to ex	tract necessary inform	nation from given li	terature sources and put it into the	ne perspective	of the lecture. They
	can continuously chec	k their level of experti	se with the help of	f accompanying measures (such	as online test	s, clicker questions,
	exercise tasks) and, ba	ased on that, to steer t	heir learning proce	ss accordingly. They can relate t	heir acquired	knowledge to topics
	of other lectures, e.g.,	"Digital Communicatio	ns" and "Advanced	Topics of Wireless Communication	ons".	
Workload in Hours	Independent Study Tin	ne 110, Study Time in I	_ecture 70			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description			
	Yes None	Subject theoretical	andPBL-Kurs mit	Posterpräsentation		
		practical work				
Examination	Oral exam					
Examination duration and	40 min					
scale	Fleetrical Engine arises	Creation Informa	tion and Community	akian Cuatanan Flashiya Commu		
Assignment for the	Electrical Engineering:	specialisation Informa	cion and Communic	ation Systems: Elective Compuls	ulcon	
Following Curricula	information and Comm	iunication Systems: Sp	ecialisation Commu	unication Systems: Elective Comp	uisory	

Course L1982: Selected Topi	cs of Modern Wireless Systems
Тур	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 machine-type communication • Interference cancellation • Non-orthogonal multiple access • Heterogeneous networks •
Literature	will be provided, depending on the given topics

Course L0296: Modern Wirel	ess Systems
Тур	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 SG 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: Digita	al Audio Signal Processing			
Courses				
Title		Тур	Hrs/wk	СР
Digital Audio Signal Processing (L06	650)	Lecture	3	4
Digital Audio Signal Processing (L06	651)	Recitation Section (large)	1	2
Module Responsible	Prof. Udo Zölzer			
Admission Requirements	None			
Recommended Previous	Signals and Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the fe	ollowing learning results		
Professional Competence				
Knowledge	Die Studierenden können die grundlegenden Verfahren un	d Methoden der digitalen Audiosigi	nalverarbeitung	erklären. Sie können
	die wesentlichen physikalischen Effekte bei der Sprach- u	nd Audiosignalverarbeitung erläute	ern und in Kateg	jorien einordnen. Sie
	können einen Überblick der numerischen Methoder	n und messtechnischen Charal	cterisierung vo	n Algorithmen zur
	Audiosignalverarbeitung geben. Sie können die erar	beiteten Algorithmen auf weiter	e Anwendunge	en im Bereich der
	Informationstechnik und Informatik abstrahieren.			
Skills	The students will be able to apply methods and techniq	ues 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 eval	uate the influence on human perce	ption and techr	nical applications in a
	variety of applications beyond audio signal processing. S	tudents can perform measuremen	ts in time and	frequency domain in
	order to give objective and subjective quality measures wit	h respect to the methods and appli	cations.	
Personal Competence				
Social Competence	The students can work in small groups to study special	tasks and problems and will be e	nforced to prese	ent their results with
,	adequate methods during the exercise.	·		
Autonomy	The students will be able to retrieve information out of the	ne relevant literature in the field a	nd putt hem inf	the context of the
	lecture. They can relate their gathered knowledge and rel	ate them to other lectures (signals	and systems, d	Igital communication
	systems, image and video processing, and pattern recogn	ition). They will be prepared to und		mmunicate problems
	and effects in the field addio 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	60 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information and Com	munication Systems: Elective Comp	ulsory	
Following Curricula	Information and Communication Systems: Specialisation Co	ommunication Systems, Focus Sign	al Processing: El	ective Compulsory
	Information and Communication Systems: Specialisation	n Secure and Dependable IT Sy	stems, Focus S	Software and Signal
	Processing: Elective Compulsory			
	Microelectronics and Microsystems: Specialisation Commun	nication and Signal Processing: Elec	tive Compulsory	r

Course L0650: Digital Audio	Signal Processing
Тур	Lecture
Hrs/wk	3
СР	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	
Тур	Recitation Section (large)
Hrs/wk	1
СР	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: Digita	al Signal Processing and Digi	tal Filters			
Courses					
Title Digital Signal Processing and Digita Digital Signal Processing and Digita	al Filters (L0446) al Filters (L0447)		Typ Lecture Recitation Section (large)	Hrs/wk 3 2	CP 4 2
Module Responsible	Prof. Gerhard Bauch				
Admission Requirements	None				
Recommended Previous Knowledge	 Mathematics 1-3 Signals and Systems Fundamentals of signal and system Fundamentals of spectral transform 	n theory as well as rand ns (Fourier series, Fouri	om processes. er transform, Laplace transf	orm)	
Educational Objectives	After taking part successfully, students ha	ave reached the followi	ng learning results		
Professional Competence Knowledge Skills Personal Competence Social Competence Autonomy	The students know and understand basic discrete-time signals and are able to de structures of digital filters and can id effects caused by quantization of filter of perform traditional and parametric metho The students are familiar with the content The students are able to apply methods of filter striuctures. In particular, the can des develop an efficient implementation, e.g methods of spectrum estimation and to ta The students can jointly solve specific pro The students are able to acquire relev	algorithms of digital s ascribe and analyse sid lentify and assess in coefficients and signals ds of spectrum estimal ts of lecture and tutoria of digital signal process usign adaptive filters ac g. based on the LMS ake the effects of a limit oblems.	ignal processing. They are f gnals and systems in time portant properties includir s. They are familiar with th tion, also taking a limited ob als. They can explain and app sing to new problems. They cording to the minimum me or RLS algorithm. Furtherr ted observation window into appropriate literature sour	amiliar with the s and image doma og stability. They e basics of adapt servation window oly them to new p can choose and p can choose and p nan squared error nore, the studen account.	pectral transforms of in. They know basic are aware of the ive filters. They can into account. roblems. warameterize suitable (MMSE) criterion and ts are able to apply ontrol their level of
	knowledge during the lecture period by so	owing totonal problems	, software tools, clicker syst	em.	
Workload in Hours	Independent Study Time 110, Study Time	e in Lecture 70			
Credit points	6 None				
Course achievement	Written even				
Examination	90 min				
scale					
Assignment for the	Electrical Engineering: Specialisation Cont	trol and Power Systems	Engineering: Elective Comp	oulsory	
Following Curricula	Computer Science in Engineering: Special	lisation II. Engineering	Science: Elective Compulsor	y j	
	Information and Communication Systems: Mechanical Engineering and Management Mechatronics: Specialisation Intelligent Sy Microelectronics and Microsystems: Specia	: Specialisation Commu t: Specialisation Mechai ystems and Robotics: E ialisation Communication	nication Systems, Focus Sig cronics: Elective Compulsory lective Compulsory on and Signal Processing: Ele	nal Processing: El	ective Compulsory
	I neoretical Mechanical Engineering: Spec	cialisation Robotics and	Computer Science: Elective	Compulsory	

Course L0446: Digital Signal	Processing and Digital Filters
Тур	Lecture
Hrs/wk	3
СР	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Cycle	UNSP Se State Stat
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	KD. Kammeyer, K. Kroschel: Digitale Signalverarbeitung. Vieweg Teubner.
	V. Oppenheim, R. W. Schafer, J. R. Buck: Zeitdiskrete Signalverarbeitung. Pearson StudiumA. V.
	W. Hess: Digitale Filter. Teubner.
	Oppenheim, R. W. Schafer: Digital signal processing. Prentice Hall.
	S. Haykin: Adaptive flter theory.
	L. B. Jackson: Digital filters and signal processing. Kluwer.
	T.W. Parks, C.S. Burrus: Digital filter design. Wiley.

Course L0447: Digital Signal Processing and Digital Filters	
Тур	Recitation Section (large)
Hrs/wk	2
СР	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: Comp	outer Graphics			
Courses				
Title Computer Graphics (L0145)		Тур Lecture	Hrs/wk 2	СР 3
Computer Graphics (L0768)		Recitation Section (small)	2	3
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Linear Algebra (in particular matrix/vector computation	an)		
Knowledge	 Basic programming skills in C/C++ 			
Educational Objectives	After taking part successfully, students have reached the fol	lowing learning results		
Professional Competence				
Knowledge	Students can explain and describe basic algorithms in 3D co	mputer graphics.		
Skills	Students are capable of			
	 implementing a basic 3D rendering pipeline. This corr 	sists of projecting simple 3D struc	tures (e.a. cubi	e spheres) onto a 2D
	surface using a virtual camera.	sists of projecting simple 3D struc	cures (e.g. cube	s, spheres, once a 20
	 apply geometric transformations (e.g. rotation, scalin 	g) in 2D and 3D computer graphic	s.	
	 using well-known 2D/3D APIs (OpenGL, Cairo) for solv 	ring a given problem statement.		
Demonstration of the second second				
Personal Competence	Chudanta can callabarata in a small team on the realization o	and validation of a 2D commuter or	anhias ninalina	
Social Competence	Students can collaborate in a small team on the realization a	ind validation of a 3D computer gr	apnics pipeline.	
Autonomy	 Students are able to solve simple tacks independently 	with reference to the contents of	f the lectures ar	d the exercise sets
	 Students are able to solve detailed problems independent. 	dently 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	90 min			
scale	Conservation Colonies - Conservation - L.C. Conservation - L.C. Conservation	Fundation Flating Comp.		
Assignment for the	Computer Science: Specialisation I. Computer and Software	Engineering: Elective Compulsory	stome Facure (Coffwara and Cine-I
Following Curricula	Processing: Elective Compulsory	Secure and Dependable IT Sys	scenns, FOCUS S	Joitware and Signal
	Information and Communication Systems: Specialisation Cor	nmunication Systems, Focus Signa	al Processing: Fl	ective Compulsory
	International Management and Engineering: Specialisation II	. Information Technology: Elective	Compulsorv	compaisory
Social Competence Social Competence Autonomy Workload in Hours Credit points Course achievement Examination Examination duration and scale Assignment for the Following Curricula	 Students can collaborate in a small team on the realization a Students are able to solve simple tasks independent! Students are able to solve detailed problems independent Study Time 124, Study Time in Lecture 56 Independent Study Time 124, Study Time in Lecture 56 None Written exam 90 min Computer Science: Specialisation I. Computer and Software I Information and Communication Systems: Specialisation Processing: Elective Compulsory Information and Communication Systems: Specialisation Cor International Management and Engineering: Specialisation II 	Ind validation of a 3D computer gr y with reference to the contents of idently with the aid of the tutorial's Engineering: Elective Compulsory Secure and Dependable IT Sys nmunication Systems, Focus Signa , Information Technology: Elective	aphics pipeline. [†] the lectures an s programming stems, Focus S al Processing: El Compulsory	Id the exercise sets. task. Software and Signal lective Compulsory

Course L0145: Computer Graphics		
Тур	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	
Тур	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: Satel	lite Communications and Navigation			
Courses				
Title		Typ	Hrs/wk	CP
Radio-Based Positioning and Navig	ation (L2711)	Lecture	2	3
Satellite Communications (L2710)		Lecture	3	3
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	The module is designed for a diverse audience, i.e.	students with different backgrou	nd. Basic knowledge	of communications
Knowledge	engineering and signal processing are of advantage	e but not required. The cours	e intends to provid	e the chapters on
	communications techniques such that on the one hand	students with a communications	engineering backgro	und learn additional
	concepts and examples (e.g. modulation and coding so	hemes or signal processing conce	epts) which have not	or in a different way
	been treated in our other bachelor and master courses	On the other hand, students with	h other background sh	hall be able to grasp
	the ideas but may not be able to understand in the s	ame depth. The individual backo	pround of the student	s will be taken into
	consideration in the oral exam.			
Educational Objectives	After taking part successfully, students have reached th	e following learning results		
Professional Competence				
Knowledge	The students are able to understand, compare and	analyse digital satellite commu	inications system as	well as navigation
	techniques. They are familiar with principal ideas of the	e respective communications, sig	gnal processing and p	ositioning methods.
	They can describe distortions and resulting limitation	s caused by transmission channe	els and hardware con	nponents. They can
	describe how fundamental communications and naviga	ion techniques are applied in sele	ected practical system	s.
	The students are familiar with the contents of lecture a	d tutorials. They can explain and	apply them to new pr	oblems.
Skills	The students are able to describe and analyse digital s	atellite communications systems	and navigation system	ms. They are able to
	analyse transmission chains including link budget calcu	lations. They are able to choose a	ippropriate transmissi	on 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 fr	om 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	30 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information and C	ommunication Systems: Elective O	Compulsory	
Following Curricula	Information and Communication Systems: Specialisa	tion Secure and Dependable I	T Systems, Focus Se	oftware and Signal
	Processing: Elective Compulsory			
	Information and Communication Systems: Specialisation	Communication Systems, Focus	Signal Processing: Ele	ective Compulsory
	Microelectronics and Microsystems: Specialisation Com	nunication and Signal Processing:	Elective Compulsory	

Course L2711: Radio-Based Positioning and Navigation		
Тур	Lecture	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Gerhard Bauch, Dr. Rico Mendrzik	
Language	EN	
Cycle	SoSe	
Content	Information overaction from communication cignals	
	Ime-or-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 Gram for Backbarrier differences of a minute and the set of a minut
 Cramer-Rao lower bound for synchronized time-of-arrival positioning Core study. Synchronized time of arrival positioning
Case study: synchronized time-or-arrival positioning Cremér Des lawer bound for uncurative privat times of arrival positioning
Cramer-National bound for unsynchronized time-or-arrival positioning
Case study. Onsynchronized time-or-arrival positioning
 Angle of arrival positioning principle
 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 Coursian case
State transition in the linear Gaussian case Dreaf of predicted pectagion distribution of the Kelmen filter
From or predicted posterior distribution of the Kalman litter State undate in the linear Gaussian case
 State update in the initial Gaussian case Broof of marginal postorior 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	

Type Lecture Workload in Heurs Independent Study Time 48. Study Time in Lecture 42. Workload in Heurs Independent Study Time 48. Study Time in Lecture 42. Lenguage IM Occurre Prif. Gerhard Bauch Overview or Study. IN Content Introduction to satellite communications Overview or Study. Study. The Belt, components of a satellite Social Study.	Course L2710: Satellite Communications		
Hybrid 3 Workload in Hours Independent Study Time 48, Study Time in Lecture 42 Interface Lecture Prof. Gertard Bauch Sola Control Sola Control Sola Control Introduction to stabilite communications • What is a stabilite • Overview orbits, Van Allen Belt, components of a stabilite • Stabilite services • International Telecommunications unlon (TU) • International Telecommunications Unlon (TU) • International Telecommunications Unlon (TU) • Internation Stabilite communications System • Components of a stabilite communications • International Telecommunications Unlon (TU) • Internation Instabilite communications System • Communication Instabilite communications System • Communication Instabilite communications System • Communication Instabilite communications • Uniternative Instabilite Communications System • Communication Instabilite communications • Element Coverage • Element Coverage (ERP) • Control segment • Communication Insta • Uniterstabilite Instabilite Communications • Element Coverage • Element Coverage • Element Coverage of LEO and GEO satellites (Iridium, Viasat) • Transparent vs. repercative appload • Orbits • Corubati Corbits	Тур	Lecture	
Or p 3 Workload in Hours Independent Study Time 48, Study Time in Lecture 42 Lecture Prof. Central Bauch Lequage Sister Content Content Content Content Image: Sister Content Image: Sister Content Content Content Image: Sister Content Image: Sister Content Content Image: Sister Content I	Hrs/wk	3	
Workload in Houry Integratemt Study Time 48, Study Time in Lecture 42 Language FN Content 5% Content 5% Content • Introduction to satellite communications • What is a satellite • Overview othts, Van Allen Belt, components of a satellite • Statilite services • Prequency bands for satellite services • Interaction Telecommunications Union (TU) • Influence of atmospheric impairments • Milestones in satellite communications system • Graudo Segment • Graudo Segment • Graudo Segment • Graudo Segment • Graudo Segment • Components of a satellite communications system • Graudo Segment • Graudo Segment • Graudo Segment • Graudo Segment • Graudo Segment • Other Segment • Graudo Segment • Econtrol LECO Normalications system • Graudo Segment • Signal to noise power ratio vs. carrier to noise ratio • Signal to noise power ratio vs. carrier to noise ratio • Singla to noise power ratio vs. carrier to noise ratio • Signal to noise power ratio vs. carrier to noise ratio • Singla to noise power ratio vs. carrier to noise ratio • Orbis <t< th=""><th>СР</th><th>3</th></t<>	СР	3	
Letture Ford Genhard Bauch Cycle Sobe Content • Introduction to satellite communications • What is a satellite communications • What is a satellite services • Overview orbits, Van Allen Belt, components of a satellite • Satellite services • International Telecommunications Union (TU) • International Telecommunications Union (TU) • Influence of atmospheric impairments • Influence of atmospheric impairments • Communication Is satellite communications • Overview of attribute communications • Communication Inks • Communication Inks • Communication Inks • Uplink, downlink • Space segment • Space segment • Communication Inks • Uplink, downlink • International relecommunications system • Effective isotropic radiated power (EIRP), antenne gain, figure of meril, G/T, carrier to noise ratio • Single board and multibeen sectifies • Bear overage • Examples for baam coverage of LEO and GEO satellites (Indium, Viasat) • Transparent vs. regenerative payload • Orbits • Circular MEO Orbits (Intermediate Circular Orbits (ICO)) • Examples for baam coverage of LEO and GEO satellites • Examples for baam coverage of LEO and GEO satellites • Orbits<	Workload in Hours	Independent Study Time 48, Study Time in Lecture 42	
Language EV Content Introduction to satellite communications • What is a statilite • What is a statilite • Overview obtaits, Van Allen Belt, components of a statellite • Statellite services • Interactional Telecommunications Union (TU) • Inference of atmospheric impairments • Mistions and Telecommunications system • Ground segment • Space aggment • Space aggment • Space aggment • Space aggment • Outroit signent • Uplink, downlink • Forward ink, reverse link • Interaction costs • Muttione crossents • Space aggment • Space aggment • Space aggment • Sigipal to noise power ratio x carrier to noise ratio	Lecturer	Prof. Gerhard Bauch	
Cycle Sese Content introduction to satellite communications what is a satellite Overview orbits, Van Allen Belt, components of a satellite Subratius arrives Frequency bands for satellite services international Telecommunications Union (ITU) influence of atmospheric impairments ellistion earlies components of a satellite communications components of a satellite communications components of a satellite communications commonication insis influence of atmospheric impairments ellistion earlies or control segment control segment control segment communication insis bulpink, downlink e frective torongic radiated power (ERP), antenna gain, figure of meril, G/T, carrier to noise ratio is topic segment control segment control segment control segment control segment control is a topic provide radiated power (ERP), antenna gain, figure of meril, G/T, carrier to noise ratio single beam and multibeam satellites verifies for beam coverage of LEO and GEO satellites (tridium, Viasat) Transparent vs. regenerative payload orbits via earch orbot (LEO), medium earth orbit (MEO), geosynchroneous and geostationary orbits (CEO), highly elliptical orbits via equational orbits, geostationary orbits (CEO) viacurate orbits circular MEO orbits (MEO and GEO satellites viacurate orbits circular EO orbits (MEO and GEO satellites viacurate orbits circular EO orbits (MEO and GEO satellites viacurates orbits circular MEO orbits (MEO and GEO satellites viacurat	Language	EN	
Content Introduction to satellite communications What is a stellite Overview whits, Van Allen Belt, components of a satellite Setellite services International Telecommunications Union (ITU) Influence of atmospheric impairments Mileatone in satellite communications Components of a satellite communications Communication links Oplink, downlink Forward link, reverse link Intersatellite links Intersatellite links Intersatellite links Intersatellite links Beam coverage Effective isotropic radiated power (ERP), antenna gain, figure of merit, G/T, carrier to noise ratio Single beam and multibeam satellites Beam coverage Examples for beam coverage of LEO and GEO satellites (indium, Vlasat) Transparent vs. regenerative payload Orbits Low earth orbit (LEO), medium earth orbit (MEO), geosynchroneous and geostationary orbits (GEO), highly elliptical orbits Low earth orbits Elicival-EU orbits Elicival-EU orbits Circular EU orbits Circular EU orbits Circular EU orbits Elicival-EU orbits Elicival-EU orbits Elicival-EU orbits Foreit saves of planetary motion Gravitata	Cycle	SoSe	
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 What is a statilite Overview works, Van Allen Belt, components of a satellite Satellite services International Telecommunications Union (ITU) International Telecommunications Union (ITU) International Telecommunications Union (ITU) International Telecommunications Union (ITU) International Telecommunications Section Satellite communications Components of a satellite communications Components of a satellite communications Components of a satellite communications Communication links Ground Segment Communication links Intersatellite links Intersatellite links Intersatellite links Beam Coverage Performance measures Performance measures Performance measures Single beam and multiboam satellites Beam Coverage Examples for beam coverage of LEO and GEO satellites (irdium, 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: Intervative payload Circular EO orbits Circular EO orbits (Interweite Circular Orbits (ICO)) Equativital orbits (GEO) Important aspects of LEO, MEO and GEO satellites Circular EO orbits Intervative and indire date disculate Circular Orbits (ICO)) Equativital arbits, gestationary orbits (ICO) Important aspects of LEO, MEO and GEO satellites Kepler's laws of planetary motion Gravitational force Pranneters of ellipses and elliptical orbits		Introduction to satellite communications	
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- Block codes and convolutional codes
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- Low density parity check (LDPC) codes, principle of message passing decoding, bit error rate performance
- Cyclic block codes
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 - Generator matrix, generator polynomials
 - Systematic encoding and syndrome determination with shift registers
 - Cyclic redundancy check (CRC) codes
- Automatic repeat request (ARQ)
 - Principle of ARQ
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 - Selective-repeat ARO
- Transmission gains and losses

- - - Single errors vs. block errors, cyclic block codes for burst errors

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 snace loss free snace loss for generationary satellites
Atmospheric loss
 Losses in transmit and receive equipment
Eostes in durante de le celere equipitente Feader locs
Polarization mismatch loss
Combined effect of lesses
Mille hoise
Additive white Gaussian poice (AWGN) channel model
Farth hrightness temperature
Signal to noise ratios
Atmosphere distributions Atmosphere of the earth: Transcribere, stratesphere, mesosphere, thermosphere, executions
Attrosphere of the earth. Troposphere, suadosphere, mesosphere, thermosphere, exosphere
Scintillation
Earaday officet
 Multinath contributions
GEO clear sky unlink and downlink
GEO uplink and downlink under rain conditions
Link availability improvement through site diversity and adaptive transmission
Transparent vs. regenerative payload
Non-linear amplifiers
Saleh 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
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: Proce	ss Imaging			
Courses				
Title		Тур	Hrs/wk	СР
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	No special prerequisites needed			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the f	ollowing learning results		
Professional Competence				
Knowledge	Content: The module focuses primarily on discussing est (b) magnetic resonance imaging, (c) X-ray imaging and to recent imaging modalities. The students will learn:	ablished imaging techniques including mography, and (d) ultrasound imagin) (a) optical a g but also cov	and infrared imagin vers a range of mo
	 what these imaging techniques can measure (su composition, temperature), 	ch as sample density or concentrat	ion, material	transport, chemi
	 how the measurements work (physical measurements) how to determine the most suited imaging methods 	it principles, hardware requirements, i for a given problem.	mage reconst	ruction), and
	Learning goals: After the successful completion of the co	urse, the students shall:		
	 understand the physical principles and practical asp be able to assess the pros and cons of these met temporal resolution, and based on this assessment be able to identify the most suited imaging moda bioprocess engineering. 	ects of the most common imaging me hods with regard to cost, complexity lity for any specific engineering chall	thods, r, expected c enge in the f	ontrasts, spatial a ïeld of chemical a
Skills Personal Competence				
Social Competence	In the problem-based interactive course, students work in	n small teams and set up two proces	s imaging sy	stems and use the
	systems to measure relevant process parameters in difference	ent chemical and bioprocess engineeri	ng applicatior	ns. The teamwork
	foster interpersonal communication skills.			
Autonomy	Students are guided to work in self-motivation due to the	challenge-based character of this mod	ule. A final pr	resentation improv
	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	120 min			
scale				
Assignment for the	Bioprocess Engineering: Specialisation A - General Bioproce	ess Engineering: Elective Compulsory		
Following Curricula	Bioprocess Engineering: Specialisation B - Industrial Biopro	cess Engineering: Elective Compulsory	/ d Pieprocoss	Tachnology, Electi
	Compulsory	rocess Engineering, Focus Energy and	J Bioprocess	lechnology: Electi
	Chemical and Bioprocess Engineering: Specialisation Gene	ral Process Engineering: Elective Com	nulsory	
	Chemical and Bioprocess Engineering: Specialisation Gene	ocess Engineering: Elective Compulso	rv	
	Chemical and Bioprocess Engineering: Specialisation Chem	nical Process Engineering: Elective Con	npulsorv	
	Computer Science: Specialisation II: Intelligence Engineerin	ng: Elective Compulsory	ipulsory	
	Information and Communication Systems: Specialisation Content in the system of the sys	ommunication Systems, Focus Signal F II. Process Engineering and Biotechno	Processing: El logy: Elective	ective Compulsory Compulsory
	Theoretical Mechanical Engineering: Specialisation Robotic	s and Computer Science: Elective Com	ipulsory	
	Theoretical Mechanical Engineering: Specialisation Robotic	s and Computer Science: Elective Com	ipulsory	
	Process Engineering: Specialisation Process Engineering: E	lective Compulsory		
	Process Engineering: Specialisation Chemical Process Engineering: Specialisation Environmental Process	Engineering: Elective Compulsory		
	Water and Environmental Engineering: Specialisation Environmental	conment: Elective Compulsory		
	Water and Environmental Engineering: Specialisation Water	er: Elective Compulsory		
		· · · · · · · · · · · · · · · · · · ·		

Course L2723: Process Imaging		
Тур	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 Imagi	ng
Тур	Project-/problem-based Learning
Hrs/wk	3
СР	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:
	 what these imaging techniques can measure (such as sample density or concentration, material transport, chemical composition, temperature),
	 now the measurements work (physical measurement principles, hardware requirements, image reconstruction), and 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,
	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
	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	e Processing			
Courses				
Title		Тур	Hrs/wk	СР
Image Processing (L2443)		Lecture	2	4
Image Processing (L2444)		Recitation Section (small)	2	2
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Signal and Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowieage	The students know about			
	visual perception			
	 multidimensional signal processing 			
	 sampling and sampling theorem 			
	filtering			
	image enhancement			
	edge detection			
	multi-resolution procedures: Gauss and Laplace image compression	e pyramid, wavelets		
	image segmentation			
	morphological image processing			
Skills	The students can			
	 analyze, process, and improve multidimensional 	al image data		
	implement simple compression algorithms			
	design custom filters for specific applications			
Borsonal Competence				
Social Competence	Students can work on complex problems both indepen	dently and in teams. They can exchange	o idoac with oac	a other and use their
Social Competence	individual strengths to solve the problem	identity and in teams. They can exchang		i other and use their
Autonomy	Students are able to independently investigate a com	plex problem and assess which compete	ncies are require	ed to solve it.
Workload in Hours	Independent Study Time 124 Study Time in Lecture 5	6		
Credit points	6			
Course achievement	None			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Data Science: Core Qualification: Elective Compulsory			
Following Curricula	Data Science: Specialisation I. Mathematics/Computer	Science: Elective Compulsory		
	Data Science: Specialisation II. Computer Science: Ele	ctive Compulsory		
	Data Science: Specialisation IV. Special Focus Area: E	ective Compulsory		
	Electrical Engineering: Specialisation Information and	Communication Systems: Elective Comp	oulsory	
	Electrical Engineering: Specialisation Medical Technol	ogy: Elective Compulsory		
	Information and Communication Systems: Specialisat	on Communication Systems, Focus Sign	al Processing: Ele	ective Compulsory
	Information and Communication Systems: Speciali	sation Secure and Dependable IT Sy	stems, Focus S	oftware and Signal
	Processing: Elective Compulsory	ation II. Information Tachnology, Elective	Compulsory	
	Mechatronics: Specialisation Intelligent Systems and I	action II. Information Technology: Elective	compulsory	
	Mechatronics: Specialisation System Design: Elective	Compulsory		
	Mechatronics: Core Qualification: Elective Compulsory			
	Microelectronics and Microsystems: Specialisation Con	nmunication and Signal Processing: Elec	tive Compulsory	
	Theoretical Mechanical Engineering: Specialisation Ro	botics and Computer Science: Elective C	Compulsory	

Course L2443: Image Proces	sing
Тур	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 Jahne: Digitale Bildverarbeitung - Springer, Berlin 2005

Course L2444: Image Processing		
Тур	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: Softw	are Verification						
Courses							
Title Software Verification (L0629)					Typ Lecture	Hrs/wk	CP 3
Modulo Posponsible	Prof Sibullo Schupp				Recitation Section (Smail)	Z	5
Admission Requirements	None						
Recommended Previous Knowledge	Automata theory Computational lo Object-oriented Functional progr Concurrency	and formal la ogic programming, amming or pro	anguages algorithms, ocedural pro	, and data struc	tures		
Educational Objectives	After taking part succes	ssfully, studen	its have rea	ched the follow	ing learning results		
Professional Competence Knowledge Skills Personal Competence Social Competence Autonomy	Students apply the maj and semantics of the of formal properties of sol Students formulate pro abstract from the softw checks by hand or usin verification problem in Students discuss releva Using accompanying of appropriately. Working goals. Upon successful the field of software ver	or verification underlying log itware systems vable properti vare under ver g tools for moo natural langua ant topics in cla on-line materia g on exercise completion, st erification. Wit	techniques ics, and as s. They find ies of a soft rification an del checking age, they se ass. They de ass. They de al for self s problems, s tudents can thin this fiel	in model check sess the expres flaws in formal ware system in d, where neces g or deductive v lect the approp efend their solu study, students they receive ac identify and pr d, they can con	sing and deductive verificat solution of different logics a arguments, arising from r a formal language. They sary, adapt model or prop verification, and reflect on riate verification techniqu tions orally. They commune can assess their level of diditional feedback. Within recisely formulate new pro-	ation. They explain i as well as their lim modeling artifacts o develop logic-based perty. They construct the scope of the re e and justify their c hicate in English. of knowledge conti h limits, they can s oblems in academic s to acquire the ne	n formal terms synta itations. They classif r underspecification. I models that proper sults. Presented with hoice. nuously and adjust et their own learnin or applied research i cessary competencie
	and compile their findir	ngs in academi	ic reports. T	hey can devise	plans to arrive at new sol	utions or assess exi	isting ones.
Workload in Hours	Independent Study Tim	e 124, Study 1	Time in Lect	ture 56			
Credit points	6						
Course achievement	Compulsory Bonus	Form Excercises		Description			
Examination	Written exam	Excelences					
Examination duration and	90 min						
scale							
Assignment for the Following Curricula	Computer Science: Spe Computer Science in Er Information and Comm Information and Comm International Managem	cialisation I. Congineering: Spo unication System unication System unication System	computer an ecialisation eems: Specia eems: Specia eering: Spe	d Software Eng I. Computer Sc alisation Secure alisation Comm cialisation II. Inf	ineering: Elective Compul- ience: Elective Compulsor and Dependable IT Syste unication Systems, Focus formation Technology: Elect	sory y ms: Compulsory Software: Elective C ctive Compulsory	Compulsory
	61 h1						

Course L0629: Software Veri	fication
Тур	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		
Тур	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: Softw	vare Analysis			
Courses				
Title Software Analysis (L0631) Software Analysis (L0632)		Typ Lecture Recitation Section (small)	Hrs/wk 2 2	CP 3 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 Functional programming or Procedural programmir 	a structures g		
Educational Objectives	After taking part successfully, students have reached the	following learning results		
Professional Competence				
Knowledge	Students apply the major approaches to data-flow and classification schemes, and employ abstract interpretai models, including their mathematical structure and prope and categorize the major analysis algorithms. They di termination and soundness properties.	alysis, control-flow analysis, and t tion. They explain the standard f erties, and evaluate their suitability stinguish precise solutions from a	:ype-based analy: orms of internal for a particular a approximative ap	sis, along with their representations and nalysis. They explain proaches, and show
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 the	ir solutions orally. They communica	ate in English.	
Autonomy	Using accompanying on-line material for self study, stu appropriately. Working on exercise problems, they rece goals. Upon successful completion, students can identify the field of software analysis. Within this field, they can a compile their findings in academic reports. They can devise	udents can assess their level of l eive additional feedback. Within lin and precisely formulate new proble conduct independent studies to acc se plans to arrive at new solutions of	cnowledge contin nits, they can se ems in academic of quire the necessa or assess existing	uously and adjust it t their own learning or applied research in ry competencies and 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	software artifacts/mathematical write-ups; short presenta	tion		
scale				
Assignment for the	Information and Communication Systems: Specialisation	on Secure and Dependable IT S	ystems, Focus S	software and Signal
Following Curricula	Information and Communication Systems: Specialisation (International Management and Engineering: Specialisation	Communication Systems, Focus Sof n II. Information Technology: Electiv	tware: Elective Co ve Compulsory	ompulsory

Course L0631: Software Ana	lysis
Тур	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	
Literature	 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				
Тур	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: Mode	l Checking - Pro	oof Engines and .	Algorithms			
Courses						
Title Model Checking - Proof Engines and Model Checking - Proof Engines and	d Algorithms (L1979) d Algorithms (L1980)			Typ Lecture Recitation Section (small)	Hrs/wk 2 2	CP 3 3
Module Responsible	Prof. Görschwin Fey					
Admission Requirements	None					
Recommended Previous Knowledge	Basic knowledge abou	ut data structures and al	gorithms			
Educational Objectives	After taking part succ	essfully, students have r	eached the followi	ng learning results		
Professional Competence Knowledge	Students know algorithms and basics of Boole the impact of s 	data structures for mod an reasoning engines an	el checking, d	tional 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	Yes None	Form Subject theoretical practical work	andDie Aufgabe der Aufgabe	wird im Rahmen von Volresung ist Zulassungsvoraussetzung fü	g und Prüfung c ir die Prüfung.	lefiniert. Die Lösung
Examination	Oral exam					
Examination duration and scale	30 min					
Assignment for the Following Curricula	Computer Science: Sp Information and Comp Information and Comp	pecialisation I. Computer munication Systems: Spe munication Systems: Spe	and Software Engi ecialisation Commu ecialisation Secure	neering: Elective Compulsory inication Systems, Focus Softwa and Dependable IT Systems: El	are: Elective Co lective Compuls	mpulsory ory

Course L1979: Model Checkin	ng - Proof Engines and Algorithms
Тур	Lecture
Hrs/wk	2
СР	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 areen."
	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. <i>Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications.</i> IOS Press, Amsterdam, The Netherlands, The Netherlands.
	Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms				
Тур	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			

Courses uncluin y Hericket Markate Hericket Markate Hericket Markate Hericket Markate Status Status <t< th=""><th>Module M1</th><th>1301: Software Testing</th><th></th></t<>	Module M1	1301: Software Testing					
The instrume Typ Heavier CP Software Tetring (1179) Isome Tetring (1179) Project-growteen-based Learning 2 3 Module profile Project-growteen-based Learning 2 3 Module profile Software Tetring (1179) Project-growteen-based Learning 2 3 Admission Name Project-growteen-based Learning 2 3 Software Tetring UTSP Software Tetring UTSP Software Tetring UTSP 3 Admission Software Tetring UTSP	Courses						
betware tenting (1173) Lentum 2 3 Module Responsible	Title	Typ Hrs/wk CP					
Software Testing (11.72) Project-problem based Learning 2 3 Media Andinasion Andinasion Andinasion Andinasion Recommended None Software Engineering International Software Projects Inte	Software Testing ((L1791) Lecture 2 3					
Media Pot. Stype Schupp Responsible Feedback Regurationed Software Engineering Recomments Software Engineering Network Engineering Software Engineering Software Engineering Software Engineering Higher Programming Languages Software Engineering Software Engineering Software Engineering Konvertedge Software Engineering Software Engineering Software Engineering Recomments Software Engineering Software Engineering Software Engineering Recomments Software Engineering Software Engineering Software Engin Software Engineering <	Software Testing ((L1792) Project-/problem-based Learning 2 3					
Respuestor Image: Second	Module	Prof. Sibylle Schupp					
Admission None Requirements Software Engineering Recommented Frevious Software Engineering Automation Object-Oriented Programming Augustumes and Data Structures Educational After taking part successfully, students have reached the following learning results Object-Oriented Programming Competence Substructures Educational After taking part successfully, students have reached the following learning results Object-Oriented Programming Freidesional Competence Knowledge Students explain the different phases of testing, describe fundamental techniques of different types of testing, and paraphrase the basic professional Students development scenarios and the corresponding test type and techniques and describe possible advantages and limitations. Studiets Students identify the appropriate testing type and technique for a given problem. They adapt and execute respective algorithms to execute a concrete test technique property. They interpret testing results and execute corresponding steps for proper rest scenarios. They write and analyze test specifications. They apply bug finding techniques for non-trivial problems. Competence Students dictures relevent topics in class. They defend their solutions orally. Competence Students dictures relevent topics in class. They defend their solutions orally. Competence Students dictures relevent topics	Responsible	9					
Requirements Instruments Recommende Provisions - Software Engineering - Nigher Programming Languages - Object-Contents Programming - Augenthms and Bac Structures - Experience with (Small Software Projects - Experience with (Small Software Projects) Educational Knowledge After taking part successfully, students have reached the following learning results Objectives Fortessional Educational Rechniques of different types of testing, describe fundamental techniques of different types of testing, and paraphrase the basic principles of the corresponding test process. They give examples of techniques of different types of testing and paraphrase the basic principles of the corresponding test process. They give examples of techniques and describe possible davinatoges and limitations. Solations Students identify the appropriate testing type and technique and describe possible davinatoges and limitations. Solations Students identify the appropriate testing type and technique for a given problem. They adapt and execute respective algorithms to execute a concrete test theringue property. They interpret testing results and execute corresponding step for proper re-test scenarios. They write and analyze test specifications. They apply bug finding techniques for non-trivial problem. Competence Numers distant discus relevant tapics in class. They defend ther solutions orally. Competence Independent Study Time 124. Study T	Admission	n None					
Recommended software Engineering Previous Software Engineering Knowledge Object-Oriented Horgmanning Object-Oriented Horgmanning Auguithms and bats Siturtures Statistics Statistics Educational After taking part successfully, students have reached the following learning results Object-Oriented Statistics Educational After taking part successfully, students have reached the following learning results Competence Statistics Statistics Statistics Statistics <th>Requirements</th> <th>5</th> <th></th>	Requirements	5					
Provides Knowledge • Figher Programming Languages • Diglet-Oriented Programming • Agentima and Data Structures • Experience with (Smail) Software Projects • Statistics Educational Objectives Providesional Competence Knowledge After taking part successfully, students have reached the following learning results Educational Competence Knowledge After taking part successfully, students have reached the following learning results Knowledge After taking part successfully, students have reached the following learning results Knowledge After taking part successfully, students have reached the following learning results Knowledge Sutdents explain the different types of testing, and paraphrase the basic principles of the corresponding test process. They give examples of Software developments scenarios and the corresponding test type and techniques and describe possible advantages and limitations. Students licutes and describe possible advantages and limitations. Sudents datus relevant tapics in class. They apply bug finding techniques for non-trivial problems. They adplat and execute respective algorithms to execute a concrete test technique properite. They defend their solutions orally. Competence Romeater and secure proper results in class. They defend their solutions orally. Sudents data sust tries solutons or asases a	Recommended	d Saftwara Engineering					
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Agarithms and Data Structures Experience with (Small) Software Projects Statistic Education After taking part successfully, students have reached the following learning results Objectives Forfessional Knowledge Students explain the different pases 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 process. They give examples of software development scenarios and the corresponding test process. Software development scenarios cancel testing techniques and describe possible advantages and limitations. Software development scenarios cancel testing techniques and describe possible advantages and limitations. Software development scenarios cancel agriculture testing results and concrete test technique properiv. They interpret testing results and analyze test specifications. They apply bug finding techniques for non-trivial problems. Software development scenarios cancel advantage continuously and adjust it appropriately, based on feedback and on self-guided studes. Within limits, they can interming pais. Sudents discuss relevant topics in dass. They defend their solutions orally. They communicate in English. Automory Students during the appropriate testing continuously and adjust it appropriately, based on feedback and on self-guided studes. Within limits, they can interming pais. Undent discuss The solutions or assess existing ones for the infinitions in academic reports testing above there solutions or assess existing ones for the infinitions and communication systems: Specialisation Communication Systems:	Knowledge	Object-Oriented Programming					
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Course L1791: Software Testing				
Тур	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				
Тур	Project-/problem-based Learning			
Hrs/wk	2			
СР	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: Secur	re Software Engineering					
Courses						
Title		Тур	Hrs/wk	СР		
Secure Software Engineering (L266	57)	Lecture	2	3		
Secure Software Engineering (L266	58)	Project-/problem-based Learning	2	3		
Module Responsible	Prof. Riccardo Scandariato					
Admission Requirements	None					
Recommended Previous	Familiarity with basic software engineering concepts (e.	g., requirements, design) and basic secu	rity concepts	(e.g., confidentiality,		
Knowledge	integrity, availability)					
Educational Objectives	After taking part successfully, students have reached th	e following learning results				
Professional Competence						
Knowledge	Students can:					
	 Elicit security requirements in a software project 					
	 Model and document security measures in a software project 	ware decign				
	Use threat and risk analysis techniques	vare design				
	Understand how security code reviews are performed					
	Understand the core definitions of concepts relate	ed to privacy				
	 Understand privacy enhancing technologies 	stand 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 fro	m academic publications, techical standa	ards, and whi	te papers.		
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56					
Credit points	6					
Course achievement	None					
Examination	1 Written exam					
Examination duration and	120 min					
scale	3					
Assignment for the	Computer Science: Specialisation I. Computer and Softw	are Engineering: Elective Compulsory				
Following Curricula	Information and Communication Systems: Specialisation	Communication Systems, Focus Softwar	e: Elective C	ompulsory		
	Information and Communication Systems: Specialisa	tion Secure and Dependable IT Syste	ems, Focus	Software and Signal		
	Processing: Elective Compulsory					

Course L2667: Secure Software Engineering						
Тур	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					
Тур	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: Appli	ed Cryp	tograp	hy				
Courses							
Title					Тур	Hrs/wk	СР
Applied Cryptography (L2954)					Lecture	3	4
Applied Cryptography (L2955)					Recitation Section (small)	1	2
Module Responsible	Prof. Sibyll	e Fröschle	e				
Admission Requirements	None						
Recommended Previous							
Knowledge							
Educational Objectives	After takin	g part suc	ccessfully, students	have reached the follow	ving learning results		
Professional Competence							
Knowledge							
Skills							
Personal Competence							
Social Competence							
Autonomy							
Workload in Hours	Independe	nt Study -	Time 124, Study Tin	ne in Lecture 56			
Credit points	6						
Course achievement	Compulsory	Bonus	Form	Description			
	No	10 %	Excercises	Die Übungsa	aufgaben finden semesterbeg	leitend statt	
Examination	Written ex	am					
Examination duration and	120 min						
scale							
Assignment for the	Computer	Science: S	Specialisation I. Con	nputer and Software Eng	gineering: Elective Compulsor	у	
Following Curricula	Information	n and Cor	nmunication Systen	ns: Specialisation Comm	unication Systems, Focus Sof	tware: Elective Co	ompulsory

Course L2954: Applied Cryptography					
Тур	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	
Тур	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	Тур		Hrs/wk	СР
Advanced Internet Computing (L29	16) Lecture		2	3
Advanced Internet Computing (L29	17) Project-/problem-based Lea	rning	2	3
Module Responsible	Prof. Stefan Schulte			
Admission Requirements	None			
Recommended Previous	Good programming skills are necessary. Previous knowledge in the field of distributed systemeters and the second statement of the systemeters of the systemeters and the systemeters are specified as a second statement of the systeme	ems is	helpful.	
Knowledge				
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 block	hain t	echnologies	
	Discuss and assess critical aspects of Cloud Computing, the IoT, and blockchain tech	inologi	es	
	 Select and apply cloud and IoT technologies for particular application areas 			
	Design and develop practical solutions for the integration of smart objects in IoT, Clo	oud, an	nd 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 excha	ange ic	leas with eac	h other and use their
	individual strengths to solve the problem.			
Autonomy	Chudente ere chie te independently investigate a compley problem and second which comp	otonoi		al to polyo it
Autonomy	Students are able to independently investigate a complex problem and assess which comp	etenci	es are require	ed to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56			
Credit points	6			
Course achievement	None			
Examination	Subject theoretical and practical work			
Examination duration and	Group project incl. presentation (50 %), written exam (60 min, 50 %)			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulse	ory		
Following Curricula	Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory			
	Information and Communication Systems: Specialisation Communication Systems, Focus S	oftwar	e: Elective Co	ompulsory
	Information and Communication Systems: Specialisation Secure and Dependable IT System	ns, Foc	us Networks:	Elective Compulsory

Course L2916: Advanced Internet Computing		
Тур	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		
Тур	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: Softw	vare for Embedded Systems			
Courses				
Title		Τγρ	Hrs/wk	СР
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 practice	al experience in programming in the C language		
	Basic knowledge in software engin	ieering		
	Basic understanding of assembly I	anguage		
Educational Objectives	After taking part successfully, students h	ave reached the following learning results		
Professional Competence				
Knowledge	Students know the basic principles and p	procedures of software engineering for embedded	systems. They are	e able to describe the
	usage and pros of event based prog	ramming using interrupts. They know the com	ponents and fund	ctions of a concrete
	microcontroller. The participants explain	requirements of real time systems. They know a	t least three sche	duling algorithms for
	real time operating systems including the	eir pros and cons.		
Skills Students build interrupt-based programs for a concrete microcontroller. They build and use a preemptive sc		scheduler. They use		
	peripheral components (timer, ADC, E	EPROM) to realize complex tasks for embedded	systems. To inte	erface with external
	components they utilize serial protocols.			
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 110, Study Time	e in Lecture 70		
Credit points	6			
Course achievement	Compulsory Bonus Form	Description		
	No 10 % Attestation			
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation I. Comp	outer and Software Engineering: Elective Compulso	ry	
Following Curricula	Electrical Engineering: Specialisation Info	prmation and Communication Systems: Elective Con	npulsory	
	Information and Communication Systems	s: Specialisation Communication Systems, Focus Sc	ftware: Elective Co	ompulsory
	Mechatronics: Technical Complementary	Course: Elective Compulsory		
	Mechatronics: Specialisation Intelligent S	ystems and Robotics: Elective Compulsory		
	Mechatronics: Specialisation System Des	ign: Elective Compulsory		
1	Microelectronics and Microsystems: Spec	ialisation Embedded Systems: Elective Compulsory	1	

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

Course L1070: Software for Embdedded Systems	
Тур	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: Mach	ine Learning in Electrical Engineer	ing and Information Tec	hnology	
Courses				
Title		Тур	Hrs/wk	СР
General Introduction Machine Learning (L3004)		Lecture	1	2
Machine Learning Applications in E	lectric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagne	tic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequence	cy Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Com	munications (L3005)	Lecture	1	1
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	The module is designed for a diverse audience, i.e	e. students with different backgrour	nd. It shall be suitable fo	or both students with
Knowledge	deeper knowledge in machine learning methods	but less knowledge in electrical e	engineering, e.g. math	or computer science
l	students, and students with deeper knowledge in	n electrical engineering but less kr	nowledge in machine le	arning methods, e.g.
	electrical engineering students. Machine learning	methods will be explained on a rel	atively high level indica	ting mainly principle
	ideas. The focus is on specific applications in elect	rical engineering and information te	chnology.	
	The chapters of the course will be understandable	e in different depth depending on th	ne individual backgroun	d of the student. The
	individual background of the students will be taken	n into consideration in the oral exam	1.	
Educational Objectives	After taking part successfully, students have reach	ed the following learning results		
Professional Competence				
Knowledge				
Skills				
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 110, Study Time in Lectu	re 70		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information a	and Communication Systems: Electiv	e Compulsory	
Following Curricula	Electrical Engineering: Specialisation Microwave En	ngineering, Optics, and Electromagn	etic Compatibility: Elect	ive Compulsory
	Electrical Engineering: Specialisation Control and F	Power Systems Engineering: Elective	e Compulsory	
	Computer Science in Engineering: Specialisation II	Engineering Science: Elective Com	pulsory	
	Information and Communication Systems: Speciali	sation Communication Systems, Foo	us Software: Elective Co	ompulsory

Γ

ourse L3004: General Introduction Machine Learning		
Тур	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 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 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	
Тур	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		
Тур	Lecture	
Hrs/wk	1	
СР	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	
Тур	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 Lear	ning in Wireless Communications
Тур	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
	Recan time-varying channel models
	Recurrent neural networks for temporal prediction
	e Hands-on session
Literature	

Module M1780: Massi	vely Parallel Sy	stems: Architec	ture and Pro	gramming		
Courses						
Title				Тур	Hrs/wk	СР
Massively Parallel Systems: Archite	cture and Programming (L	L2936)		Lecture	2	3
Massively Parallel Systems: Archite	cture and Programming (L	_2937)		Project-/problem-based Learning	2	3
Module Responsible	Prof. Sohan Lal					
Admission Requirements	None					
Recommended Previous	An introductory module	e on computer Engineer	ing or computer a	rchitecture, good programming	skills in C/C++.	
Knowledge						
Educational Objectives	After taking part succe	essfully, students have r	eached the followi	ng learning results		
Professional Competence						
Knowledge	The course starts with	parallel computers clas	sification, multith	reading, and covers the archited	cture of central	ized and distributed
	shared-memory parall	lel systems, multiproc	essor cache cohe	erence, snooping / directory-b	ased cache co	oherence protocols
	implementation, and I	imitations. Next, stude	nts study intercon	nection networks and routing i	in parallel syst	ems. To ensure the
	correctness of shared-	-memory multithreaded	programs, indep	endent of the speed of executi	on of their ind	ividual threads, the
	important topics of me	emory consistency and	synchronization w	ill be covered in detail. As a ca	se study, the a	rchitecture of a fev
	accelerators such as (GPUs will also be discu	ssed in detail. Be	sides understanding the archite	ecture and orga	anization of paralle
	systems, programming	them is also very chal	lenging. The cours	e will also cover how to prograr	n massively pa	rallel systems using
	API/IIbraries such as CU	JDA/OpenCL/MPI/OpenM	IP.			
Skills	After completing this c	ourse, students will be	able to understand	the architecture and organizati	on of parallel s	ystems. They will be
	able to evaluate differ	ent design choices and	make decisions v	vhile designing a parallel syster	m. In addition,	they will be able to
	program parallel system	ms (ranging from an em	bedded system to	a supercomputer) using CUDA/	OpenCL/MPI/Op	enMP.
Demonstration of the second						
Personal Competence	The second will second			to active according and the set		
Social Competence	The course will encou	irage students to work	in small groups	to solve complex problems, th	ius, incuicating	the importance o
4	Tedan work.			Chudanta will be able to	ant ant	
Autonomy	loday, parallel con	nputers are present	everywnere.	students will be able to	not only	program parallel
	the performance issue	s of parallol application	a their underlying	bts to improve them	inis wiii iurther	
	the performance issue.	s of parallel application.	and provide maig	nts to improve them.		
Workload in Hours	Independent Study Tim	ne 124, Study Time in L	ecture 56			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description			
	Yes 20 %	Subject theoretical	and			
		practical work				
Examination	Oral exam					
Examination duration and	25 min					
scale						
Assignment for the	Computer Science: Spe	ecialisation I. Computer	and Software Engi	neering: Elective Compulsory		
Following Curricula	Data Science: Specialis	sation II. Computer Scie	nce: Elective Comp	oulsory		
	Data Science: Specialis	sation IV. Special Focus	Area: Elective Con	npulsory		
	Computer Science in E	ngineering: Specialisati	on I. Computer Sci	ence: Elective Compulsory		
	Information and Comm	nunication Systems: Spe	cialisation Commu	inication Systems, Focus Softwa	re: Elective Cor	npulsory
	Microelectronics and M	licrosystems: Specialisa	tion Embedded Sy	stems: Elective Compulsory		

Course L2936: Massively Parallel Systems: Architecture and Programming			
Тур	Lecture		
Hrs/wk	2		
CP	3		
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28		
Lecturer	Prof. Sohan Lal		
Language	EN		
Cycle	WiSe		
Content	Brief outline:		
	 Parallel computers and their classification Centralized and distributed shared-memory architectures: snooping vs directory-based cache coherence protocols, implementation, and limitations Chip multiprocessors: software-based, block (coarse-grain), interleaved (fine-grain), simultaneous multithreading Synchronization: high-level primitives and implementation, memory consistency models: sequential and weaker memory consistency models Interconnection networks: topologies (direct and indirect networks) and routing techniques Graphics Processing Units (GPUs) architecture and programming using CUDA/OpenCL Parallel programming with message passing interface (MPI), OpenMP 		
Literature	 Michel Dubois, Murali Annavaram, and Per Stenström, Parallel Computer Organization and Design (Book) David A Patterson and John L. Hennessy, Computer Architecture: A Quantitative Approach, Elsevier (Book) David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book) 		

Course L2937: Massively Par	allel Systems: Architecture and Programming
Тур	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Sohan Lal
Language	EN
Cycle	WiSe
Content	 There will be 3-4 assignments for project-based learning consisting of the following: Implement and compare different cache coherence protocols using a simulator or a high-level, event-driven simulation interface such as SystemC Programming massively parallel systems to solve computationally intensive problems such as password cracking using CUDA/OpenCL/MPI/OpenMP
Literature	 The following literature will be useful for project-based learning. The further required resources will be discussed during the course. David B. Kirk, Wen-mei W. Hwu, Programming Massivley Parallel Processors, Elsevier (Book) MPI Forum, https://www.mpi-forum.org/ SystemC, https://www.accellera.org/community/systemc

Specialization 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: Softw	vare Verificatio	n				
Courses						
Title Software Verification (L0629) Software Verification (L0630)				Typ Lecture Recitation Section (small)	Hrs/wk 2 2	CP 3 3
Module Responsible	Prof. Sibylle Schupp					-
Admission Requirements	None					
Recommended Previous Knowledge	 Automata theo Computational Object-oriente Functional pro Concurrency 	ory and formal lang logic d programming, al gramming or proce	guages Igorithms, and data stru edural programming	ictures		
Educational Objectives	After taking part succ	essfully, students	have reached the follow	wing learning results		
Professional Competence Knowledge Skills Personal Competence Social Competence Autonomy	Students apply the m and semantics of the formal properties of s Students formulate p abstract from the sof checks by hand or us verification problem i Students discuss rele Using accompanying appropriately. Worki goals. Upon successf the field of software and compile their find	ajor verification te e underlying logics software systems. rovable properties tware under verifi ing tools for mode n natural languag vant topics in clas on-line material ng on exercise pr ul completion, stu- verification. Withi dings in academic	echniques in model cher s, and assess the expr They find flaws in forma s of a software system i cation and, where nece d checking or deductive e, they select the appro s. They defend their sol for self study, studen roblems, they receive a dents can identify and p n this field, they can cor reports. They can devis	cking and deductive verifications essivity of different logics as al arguments, arising from mo n a formal language. They de essary, adapt model or proper verification, and reflect on the priate verification technique a lutions orally. They communic ts can assess their level of additional feedback. Within lip precisely formulate new problo onduct independent studies to se plans to arrive at new solut	on. They explain ir well as their limit odeling artifacts or velop logic-based rty. They construct ie scope of the res and justify their ch ate in English. knowledge contin mits, they can se ems in academic o to acquire the nec- ions or assess exist	a formal terms syntax rations. They classify underspecification. models that properly proofs and property ults. Presented with a oice. uously and adjust if t their own learning or applied research ir essary competencies ting ones.
Workload in Hours	Independent Study T	ime 124. Study Tir	me in Lecture 56			
Credit points	6	, <u>, , , , , , , , , , , , , , , , , , </u>				
Course achievement	CompulsoryBonusYes15 %	Form Excercises	Description			
Examination	Written exam					
Examination duration and	90 min					
scale						
Assignment for the	Computer Science: S	pecialisation I. Cor	nputer and Software En	gineering: Elective Compulso	ry	
Following Curricula	Computer Science in Information and Com Information and Com International Manage	Engineering: Spec munication Syster munication Syster ment and Enginee	nalisation I. Computer S ns: Specialisation Secur ns: Specialisation Comr ering: Specialisation II. II	cience: Elective Compulsory re and Dependable IT Systems nunication Systems, Focus So nformation Technology: Electi	s: Compulsory ftware: Elective Co ve Compulsory	ompulsory

Course L0629: Software Veri	fication
Тур	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 Veri	ourse L0630: Software Verification		
Тур	Recitation Section (small)		
Hrs/wk	2		
СР	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: Softw	vare Security			
Courses				
Title		Тур	Hrs/wk	СР
Software Security (L1103)		Lecture	2	3
Software Security (L1104)		Recitation Section (small)	2	3
Module Responsible	Prof. Riccardo Scandariato			
Admission Requirements	None			
Recommended Previous	Familiarity with C/C++, web programming			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the follo	wing learning results		
Professional Competence				
Knowledge	Students can			
	name the main causes for security vulnerabilities in sof	tware		
	explain current methods for identifying and avoiding set	explain current methods for identifying and avoiding security vulnerabilities		
	 explain the fundamental concepts of code-based acces 	S 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 independent	ly from professional publication	ns, technical	standards, and other
	sources, and are capable of applying newly acquired knowled	ge 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	120 minutes			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software En	ngineering: Elective Compulsory		
Following Curricula	Computer Science in Engineering: Specialisation I. Computer S	Science: Elective Compulsory		
	Information and Communication Systems: Specialisation Secu	re and Dependable IT Systems:	Elective Compu	lsory

Course L1103: Software Seco	ırity
Тур	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	 Reliability 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 processes 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		
Тур	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: Mode	el Checking - Pro	oof Engines and	Algorithms			
Courses						
Title Model Checking - Proof Engines and Model Checking - Proof Engines and	d Algorithms (L1979) d Algorithms (L1980)			Typ Lecture Recitation Section (small)	Hrs/wk 2 2	СР 3 3
Module Responsible	Prof. Görschwin Fey					
Admission Requirements	None					
Recommended Previous Knowledge	Basic knowledge abo	ut data structures and al	gorithms			
Educational Objectives	After taking part succ	essfully, students have i	reached the followi	ng learning results		
Professional Competence						
Knowledge	Students know					
<i>Skills</i> Personal Competence <i>Social Competence</i>	 algorithms and basics of Boole the impact of s Students can explain and im decide whethe implement the Students discuss relevant 	l data structures for moc an reasoning engines ar specification and modelli plement algorithms and r a given problem can be respective algorithms.	lel checking, ng on the computa data structures for a solved using Bool	tional effort for model checkin model checking, ean reasoning or model check	g. ing, and	
Autonomy	defend their so Using accompanying additional solution str	olutions orally. material students inde rategies.	pendently learn ir	-depth relations between cor	ncepts explained	in the lecture and
Workload in Hours	Independent Study Ti	me 124, Study Time in L	ecture 56			
Credit points	6					
Course achievement	Yes None	Form Subject theoretical practical work	Description andDie Aufgabe der Aufgabe	wird im Rahmen von Volresur ist Zulassungsvoraussetzung f	ng und Prüfung o ür die Prüfung.	definiert. Die Lösung
Examination	Oral exam					
Examination duration and scale	30 min					
Assignment for the	Computer Science: S	pecialisation I. Computer	and Software Engi	neering: Elective Compulsory		
Following Curricula	Information and Com Information and Com	munication Systems: Spe munication Systems: Spe	ecialisation Commu ecialisation Secure	inication Systems, Focus Softward and Dependable IT Systems: E	vare: Elective Co Elective Compuls	mpulsory ory

Course L1979: Model Checki	ng - Proof Engines and Algorithms
Тур	Lecture
Hrs/wk	2
СР	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 are
	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. <i>Handbook of Satisfiability: Volume 185 Frontiers in Artificial Intelligence and Applications.</i> IOS Press, Amsterdam, The Netherlands, The Netherlands.
	Selected research papers

Course L1980: Model Checking - Proof Engines and Algorithms		
Тур	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: Cybei	security Data Science			
Courses				
Title		Тур	Hrs/wk	СР
Cybersecurity Data Science (L2914)	Lecture	2	3
Exercise Cybersecurity Data Science	e (L2915)	Project-/problem-based Learning	2	3
Module Responsible	Prof. Riccardo Scandariato			
Admission Requirements	None			
Recommended Previous	Basic knowledge of probabilities and statistics. Familiarity with object oriented programming.			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the for	ollowing learning results		
Professional Competence				
Knowledge	Students can:			
	 Apply data science methods to the resolution of com 	play cybersecurity problems		
	Ise of data science methods to quantify risks and or	primize cybersecurity operations		
	 Identify strengths and limitations of state-of-the-art 	methods		
	 Select the performance indicators of data-oriented c 	vbersecurity solutions.		
	 Understand cybersecurity threats in data science me 	ethods.		
	· · · · · · · · · · · · · · · · · · ·			
Skills	Implement and evaluate data-driven models for the identifi	ication, treatment, and mitigation of c	ybersecurity r	isks
Personal Competence				
Social Competence	None			
Autonomy	Students can apply the knowledge acquired throughout the	e course to the resolution of industrial	case studies.	Students should also
	be capable to acquire new knowledge independently from a	academic publications, techical standa	ards, and whit	e 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	120 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software	e Engineering: Elective Compulsory		
Following Curricula	Information and Communication Systems: Specialisation Se	ecure and Dependable IT Systems: Ele	ctive Compuls	sory

Course L2914: Cybersecurity Data Science		
Тур	Lecture	
Hrs/wk	2	
СР	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 Cybe	ersecurity Data Science
Тур	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: Desig	n of Dependab	le Systems				
Courses						
Title				Түр	Hrs/wk	СР
Designing Dependable Systems (L2	2000)			Lecture	2	3
Designing Dependable Systems (L2	2001)			Recitation Section (small)	2	3
Module Responsible	Prof. Görschwin Fey					
Admission Requirements	None					
Recommended Previous	Basic knowledge abou	ut data structures and al	gorithms			
Knowledge						
Educational Objectives	After taking part succ	essfully, students have r	eached the followi	ng learning results		
Professional Competence						
Knowledge	In the following "depe	ndable" summarizes the	concepts Reliabili	ty, Availability, Maintainability	y, Safety and Secu	urity.
	Knowledge about app	roaches for designing de	ependable systems	, e.g.,		
	Structural solut	tions like modular redund	dancy			
	Algorithmic sol	utions like handling byza	ntine faults or che	ckpointing		
	Knowledge about met	hods for the analysis of	dependable syster	ns		
Skills	Ability to implement o	lependable systems usin	g the above appro	aches.		
	Ability to analyze the	dependability of systems	using the above	methods for analysis		
	Ability to analyzs the	dependability of system.	s using the above i	nethous for analysis.		
Personal Competence						
Social Competence	Students					
	 discuss relevant 	t topics in class and				
	 present their set 	olutions orally.				
Autonomy	Using accompanying	material students indep	pendently learn ir	n-depth relations between co	oncepts explained	I in the lecture and
	additional solution str	ategies.				
Workload in Hours	Independent Study Ti	me 124, Study Time in L	ecture 56			
Credit points	6 Compulsony Bonus	Eorm	Description			
Course achievement	Yes None	Subject theoretical	andDie Lösung (einer Aufgabe ist Zuslassung	isvoraussetzung f	für die Prüfung Die
	i i i i i i i i i i i i i i i i i i i	practical work	Aufgabe wird	l in Vorlesung und Übung defi	niert.	are tratarig. Die
Examination	Oral exam					
Examination duration and	30 min					
scale						
Assignment for the	Computer Science: Sp	ecialisation I. Computer	and Software Eng	ineering: Elective Compulsory	1	
Following Curricula	Computer Science in	Engineering: Specialisati	on I. Computer Sci	ence: Elective Compulsory		
	Information and Com	munication Systems: Spe	cialisation Secure	and Dependable IT Systems:	Elective Compuls	ory
	Mechatronics: Special	isation System Design: E	lective Compulsor	У		
	Microelectronics and I	Microsystems: Specialisa	tion Embedded Sy	stems: Elective Compulsory		

Course L2000: Designing Dependable Systems		
Тур	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				
Тур	Recitation Section (small)			
Hrs/wk	2			
СР	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: Advar	nced Seminars Computer Science an	d Communication Tech	nology	
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Courses				
Title Advanced Seminar Computer Scien	nce and Communication Technology I (L2352)	Typ Seminar Seminar	Hrs/wk 2	CP 3
Module Responsible	Dozenten des SD E	Seminar	L	5
Admission Requirements	None			
Recommended Previous	Basic knowledge of Computer Science and Mathemat	ics at the Master's level		
Knowledge				
Educational Objectives	After taking part successfully, students have reached	the following learning results		
Professional Competence				
Knowledge	The students are able to			
Skills	 explicate a specific topic in the field of Comput describe complex issues, present different views and evaluate in a critic The students are able to	er Science, al way.		
	 familiarize in a specific topic of Computer Scier realize a literature survey on the specific topic elaborate a presentation and give a lecture to sum up the presentation in 10-15 lines, answer questions in the final discussion. 	nce in limited time, and cite in a correct way, a selected audience,		
Personal Competence				
Social Competence	The students are able to			
Autonomy	 elaborate and introduce a topic for a certain au discuss the topic, content and structure of the discuss certain aspects with the audience, and as the lecturer listen and respond to questions The students are able to define the task in question in an autonomous v develop the necessary knowledge, use appropriate work equipment, and guided by an instructor critically check the work 	udience, presentation with the instructor, from the audience. vay, :king 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 Information and Communication Systems: Specialisat Information and Communication Systems: Specialisat	Focus: Elective Compulsory ion Communication Systems: Elect ion Secure and Dependable IT Syst	ive Compulsory ems: Elective Compuls	sory

Course L2352: Advanced Seminar Computer Science and Communication Technology I		
Тур	Seminar	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Dozenten des SD E	
Language	EN	
Cycle	WiSe/SoSe	
Content	- Seminar presentations by enrolled students about selected topics of computer science and communication technology	
	- Active participation in discussions	
Literature	Wird vom Veranstalter bekanntgegeben.	

Course L2429: Introductory Seminar Computer Science and Communication Technology II	
Тур	Seminar
Hrs/wk	2
СР	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: Comn	nunication Networks			
Courses				
Title		Тур	Hrs/wk	СР
Selected Topics of Communication	Networks (L0899)	Project-/problem-based Learning	2	2
Communication Networks (L0897)	o (1.0909)	Lecture	2	2
Communication Networks Excercise	Puef Andreas Times Cicl	Project-/problem-based Learning	1	Ζ
Module Responsible	Prof. Andreas Timm-Giel			
Admission Requirements	None			
Recommended Previous	Fundamental stochastics			
Knowledge	Basic understanding of computer networks and/or com	munication technologies is benefici	al	
Educational Objectives	After taking part successfully, students have reached the foll-	owing learning results		
Professional Competence				
Knowledge	Students are able to describe the principles and structures	s of communication networks in de	tail. They ca	n explain the formal
	description methods of communication networks and the	er protocols. They are able to ex	kplain how c	urrent and complex
	communication networks work and describe the current rese	arch in these examples.		
Skills	Students are able to evaluate the performance of communic	ation networks using the learned m	ethods. They	are able to work out
	problems themselves and apply the learned methods. They	can apply what they have learned	autonomousl	y 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 lea	arned methods. They
	can present the obtained results. They are able to discuss an	d critically analyse the solutions.		
Autonomy	Students are able to obtain the necessary expert knowledge	e for understanding the functionalit	y and perform	mance 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	1.5 hours colloquium with three students, therefore about 3	0 min per student. Topics of the co	lloquium are	the posters from the
scale	previous poster session and the topics of the module.			
Assignment for the	Electrical Engineering: Specialisation Information and Commu	unication Systems: Elective Compuls	ory	
Following Curricula	Electrical Engineering: Specialisation Control and Power Syste	ems Engineering: Elective Compulso	iry	
_	Aircraft Systems Engineering: Core Qualification: Elective Cor	npulsory		
	Computer Science in Engineering: Specialisation I. Computer	Science: Elective Compulsory		
	Information and Communication Systems: Specialisation Com	nmunication Systems: Elective Comp	oulsory	
	Information and Communication Systems: Specialisation Sector	ure and Dependable IT Systems, Foo	us Networks:	Elective Compulsory
	International Management and Engineering: Specialisation II.	Information Technology: Elective Co	ompulsory	
	Mechatronics: Technical Complementary Course: Elective Con	mpulsory		
	Microelectronics and Microsystems: Specialisation Communic	ation and Signal Processing: Electiv	e Compulsory	(
	Theoretical Mechanical Engineering: Specialisation Robotics a	and Computer Science: Elective Com	npulsory	

Course L0899: Selected Topics of Communication Networks		
Тур	Project-/problem-based Learning	
Hrs/wk	2	
СР	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	
Тур	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel, Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	
Literature	 Skript des Instituts f ür Kommunikationsnetze Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Тур	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: Digita	al Communicatio	ons				
Courses						
Title				Тур	Hrs/wk	СР
Digital Communications (L0444)				Lecture	2	3
Digital Communications (L0445)				Recitation Section (large)	2	2
Laboratory Digital Communications	s (L0646)			Practical Course	1	1
Module Responsible	Prof. Gerhard Bauch					
Admission Requirements	None					
Recommended Previous	 Mathematics 1 	2				
Knowledge	Mathematics 1-	-5 				
	 Signals and Sys Eurodementals 	olems				
	 Fundamentais of 	of Communications and F	Candom Processes			
Educational Objectives	After taking part succe	essfully, students have re	eached the followi	ng learning results		
Professional Competence						
Knowledge	The students are able	to understand, compare	and design mode	rn digital information transm	ission schemes. T	hey are familiar with
	the properties of linea	ar and non-linear digital r	nodulation metho	ds. They can describe distort	ions caused by tr	ansmission channels
	and design and evalu	uate detectors including	channel estimat	ion and equalization. They	know the princip	oles of single carrier
	transmission and mult	ti-carrier transmission as	well as the funda	mentals of basic multiple acc	ess schemes.	
	The students are fami	liar with the contents of	lecture and tutoria	als. They can explain and app	ly them to new p	roblems.
Skille	The students are able	to design and analyse a	digital informatio	n transmission scheme inclu	ding multiple acc	ess. They are able to
Skiiis	choose a digital modulation scheme taking into account transmission rate, required bandwidth, error probability, and further signal					
	properties They can	, design an appropriat	e detector inclu	ding channel estimation ar	d equalization	taking into account
	performance and com	nlexity properties of sub	ontimum solution	They are able to set param	eters of a single (arrier or multi carrie
	transmission scheme	and trade the properties	of both approach	es against each other.	eters of a single (
Personal Competence						
Social Competence	The students can joint	tly solve specific problem	15.			
	,	.,				
Autonomy	The students are ab	le to acquire relevant	information from	appropriate literature sour	ces. They can c	ontrol their level of
	knowledge during the	lecture period by solving	tutorial problems	s, software tools, clicker syste	em.	
Workload in Hours	Independent Study Tir	me 110, Study Time in Le	ecture 70			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description			
	Yes None	Written elaboration				
Examination	Written exam					
Examination duration and	90 min					
scale						
Assignment for the	Electrical Engineering	: Core Qualification: Com	pulsory			
Following Curricula	Computer Science in E	Engineering: Specialisatio	on II. Engineering	Science: Elective Compulsory		
	Information and Comm	nunication Systems: Spe	cialisation Commu	inication Systems: Compulso	ry	
	Information and Comm	nunication Systems: Spe	cialisation Secure	and Dependable IT Systems,	Focus Networks:	Elective Compulsory
	International Manager	ment and Engineering: Sr	pecialisation II. Inf	ormation Technology: Electiv	e Compulsory	
	International Manager	ment and Engineering: Sr	pecialisation II. Ele	ectrical Engineering: Elective	Compulsory	
	Microelectronics and M	Microsystems: Core Quali	fication: Elective	Compulsory		

Course L0444: Digital Communications		
Тур	Lecture	
Hrs/wk	2	
СР	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Gerhard Bauch	
Language	EN	
Cycle	WiSe	
Content	Renetition: Reschand Transmission	
	Pulse shaning: Non-return to zero (NRZ) rectangular pulses, raised-cosine pulses, square-root raised-cosine pulses	
	 Date sneptral density (nst) of baseband simplify paises, raised cosine paises, square root raised cosine paises Dover spectral density (nst) of baseband simplify 	
	Intersymbol interference (ISI)	
	First and second Noulist 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

Systems	
	 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	
Тур	Recitation Section (large)
Hrs/wk	2
СР	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		
Тур	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: Simul	lation of Communication Networks			
Courses				
Title		Тур	Hrs/wk	СР
Simulation of Communication Netw	vorks (L0887)	Project-/problem-based Learning	5	6
Module Responsible	Prof. Andreas Timm-Giel			
Admission Requirements	None			
Recommended Previous	 Knowledge of computer and communication networks 			
Knowledge	Basic programming skills			
Educational Objectives	After taking part successfully, students have reached the followi	ng learning results		
Professional Competence				
Knowledge	Students are able to explain the necessary stochastics, the dis performance evaluation.	screte event simulation technolo	gy and modelli	ng of networks for
Skills	Students are able to apply the method of simulation for perf	ormance evaluation to different	, also not prac	ticed, problems of
	communication networks. The students can analyse the obtaine	d results and explain the effects of	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, pres	ent the results, and discuss solut	ion approaches	s 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 metho	nd 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			
Course achievement	Nono			
Course achievement				
Examination				
scale				
Assignment for the	Electrical Engineering: Specialisation Information and Communic	cation Systems: Elective Compuls	orv	
Following Curricula	Aircraft Systems Engineering: Core Qualification: Elective Compo	ulsory		
-	Information and Communication Systems: Specialisation Secure	and Dependable IT Systems, Foc	us Networks: El	lective Compulsory
	Information and Communication Systems: Specialisation Commu	unication Systems: Elective Comp	ulsory	
	International Management and Engineering: Specialisation II. Inf	ormation Technology: Elective Co	mpulsory	
	Theoretical Mechanical Engineering: Specialisation Simulation Te	echnology: Elective Compulsory		
	Theoretical Mechanical Engineering: Specialisation Simulation Te	echnology: Elective Compulsory		

Course L0887: Simulation of	Communication Networks
Тур	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	
Elterature	Skript des Instituts für Kommunikationsnetze
	Further literature is announced at the beginning of the lecture.

Module M1774: Advanced Internet Computing				
Courses				
Title	Тур		Hrs/wk	СР
Advanced Internet Computing (L29	16) Lecture		2	3
Advanced Internet Computing (L29	17) Project-/problem-based Le	arning	2	3
Module Responsible	Prof. Stefan Schulte			
Admission Requirements	None			
Recommended Previous	Good programming skills are necessary. Previous knowledge in the field of distributed sys	tems is	helpful.	
Knowledge				
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 block Discuss and assess critical aspects of Cloud Computing the IoT and blockchain tee 	chain t	echnologies	
	 Select and apply cloud and IoT technologies for particular application areas 	molog	63	
	 Design and develop practical solutions for the integration of smart objects in IoT. Cl 	oud. ar	nd blockchain	software
	Implement IoT services	,		
Skills	The students acquire the ability to model Internet-based distributed systems and to w especially the ability to select and utilize fitting technologies for different application a critically assess the chosen technologies.	vork wit nreas. F	th these syst	ems. This comprises students are able to
Personal Competence				
Social Competence	Students can work on complex problems both independently and in teams. They can exch individual strengths to solve the problem.	iange io	leas with eac	h other and use their
Autonomy	Students are able to independently investigate a complex problem and assess which com	petenci	es are require	ed to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56			
Credit points	6			
Course achievement	None			
Examination	Subject theoretical and practical work			
Examination duration and	Group project incl. presentation (50 %), written exam (60 min, 50 %)			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software Engineering: Elective Computer	sory		
Following Curricula	Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsor	y		
	Information and Communication Systems: Specialisation Communication Systems, Focus	Softwar _	e: Elective Co	mpulsory
	Information and Communication Systems: Specialisation Secure and Dependable IT System	ms, Foc	us Networks:	Elective Compulsory

Course L2916: Advanced Internet Computing		
Тур	Lecture	
Hrs/wk	2	
СР	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		
Тур	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, Cioud-based redundant data storages, and Cloud-based Onion Routing.	
Literature	Will be discussed in the lecture.	

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Module M0839: Traffi	ic Engineering			
Courses				
Title		Тур	Hrs/wk	СР
Seminar Traffic Engineering (L0902	2)	Seminar	2	2
Traffic Engineering (L0900)		Lecture	2	2
Traffic Engineering Exercises (L090	01)	Recitation Section (small)	1	2
Module Responsible	Prof. Andreas Timm-Giel			
Admission Requirements	None			
Recommended Previous	- Fundamentals of communication or			
Knowledge	Fundamentals of communication of	computer networks		
	• Stochastics			
Educational Objectives	After taking part successfully, students have	ve reached the following learning results		
Professional Competence				
Knowledge	Students are able to describe methods for	planning, optimisation and performance evaluation	of communicati	on networks.
Skills	Students are able to solve typical planning	ng and optimisation tasks for communication net	works. Furtherm	ore they are able to
	evaluate the network performance using g	ueuing theory.		,
		5		
	Students are able to apply independently	what they have learned to other and new proble	ms. They can pr	esent their results in
	front of experts and discuss them.			
Personal Competence				
Social Competence				
Autonomy	Students are able to acquire the nece	ssary expert knowledge to understand the fun	ctionality and p	performance of new
	communication networks independently.			
Workload in Hours	Independent Study Time 110, Study Time i	n Lecture 70		
Credit points	6			
Course achievement	None			
Examination	Oral exam			
Examination duration and	30 min			
scale				
Assignment for the	Computer Science: Specialisation I. Compu	ter and Software Engineering: Elective Compulsory		
Following Curricula	Electrical Engineering: Specialisation Inform	nation and Communication Systems: Elective Comp	oulsory	
	Information and Communication Systems:	Specialisation Secure and Dependable IT Systems,	Focus Networks:	Elective Compulsory

Course L0902: Seminar Traff	ic Engineering
Тур	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	
Тур	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	
Recitation Section (small)	
1	
2	
Independent Study Time 46, Study Time in Lecture 14	
Prof. Andreas Timm-Giel	
EN	
WiSe	
Accompanying exercise for the traffic engineering course	
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		Тур	Hrs/wk	СР
Digital Audio Signal Processing (L0	650)	Lecture	3	4
Digital Audio Signal Processing (L0	651)	Recitation Section (large)	1	2
Module Responsible	Prof. Udo Zölzer			
Admission Requirements	None			
Recommended Previous	Signals and Systems			
Knowledge				
Educational Objectives	After taking part successfully, students have reached the	e following learning results		
Professional Competence				
Knowledge	Die Studierenden können die grundlegenden Verfahren	und Methoden der digitalen Audios	ignalverarbeitung	erklären. Sie können
	die wesentlichen physikalischen Effekte bei der Sprach	n- und Audiosignalverarbeitung erlä	utern und in Kateo	gorien einordnen. Sie
	können einen Überblick der numerischen Metho	oden und messtechnischen Chai	akterisierung vo	n Algorithmen zur
	Audiosignalverarbeitung geben. Sie können die e	rarbeiteten Algorithmen auf wei	tere Anwendunge	en im Bereich der
	Informationstechnik und Informatik abstrahieren.			
Skills	The students will be able to apply methods and tech	niques from audio signal processin	a in the fields of	mobile and internet
	communication. They can rely on elementary algorithm	ns of audio signal processing in for	m of Matlab code	and interactive JAVA
	applets. They can study parameter modifications and e	evaluate the influence on human per	rception and techr	nical applications in a
	variety of applications beyond audio signal processing	g. Students can perform measurem	ents in time and	frequency domain in
	order to give objective and subjective quality measures	with respect to the methods and ap	plications.	
Personal Competence				
Social Competence	The students can work in small groups to study spec	ial tasks and problems and will be	enforced to prese	ent their results with
overal competence	adequate methods during the exercise.		chiefeed to press	
Autonomy	The students will be able to retrieve information out o	of the relevant literature in the field	and putt hem int	to the context of the
	lecture. They can relate their gathered knowledge and	relate them to other lectures (signa	ils and systems, d	igital communication
	systems, image and video processing, and pattern reco	ognition). They will be prepared to u	nderstand and co	mmunicate problems
	and effects in the field addio 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	60 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information and C	ommunication Systems: Elective Cor	npulsory	
Following Curricula	Information and Communication Systems: Specialisation	n Communication Systems, Focus Sig	anal Processing: El	ective Compulsory
	Information and Communication Systems: Specialisa	tion Secure and Dependable IT	Systems, Focus S	Software and Signal
	Processing: Elective Compulsory			
	Microelectronics and Microsystems: Specialisation Com	munication and Signal Processing: El	ective Compulsory	,

Course L0650: Digital Audio	Signal Processing
Тур	Lecture
Hrs/wk	3
СР	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	
Тур	Recitation Section (large)
Hrs/wk	1
СР	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: Softw	vare Analysis			
Courses				
Title Software Analysis (L0631) Software Analysis (L0632)		Typ Lecture Recitation Section (small)	Hrs/wk 2 2	CP 3 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 Functional programming or Procedural programmir 	ı structures g		
Educational Objectives	After taking part successfully, students have reached the	following learning results		
Professional Competence				
Knowledge	Students apply the major approaches to data-flow and classification schemes, and employ abstract interpretai models, including their mathematical structure and prope and categorize the major analysis algorithms. They di termination and soundness properties.	lysis, control-flow analysis, and t ion. They explain the standard for rties, and evaluate their suitability stinguish precise solutions from a	ype-based analy orms of internal for a particular a opproximative ap	sis, along with their representations and analysis. They explain aproaches, and show
Skills	Presented with an analytical task for a software artifact, s their choice. They design suitable representations by mo devise them as safe overapproximations. They formulate behavior, and precision.	udents select appropriate approac lifying standard representations. T analyses in a formal way and cons	nes from software hey develop cust truct arguments	e analysis, and justify comized analyses and for their correctness,
Personal Competence				
Social Competence	Students discuss relevant topics in class. They defend the	ir solutions orally. They communica	te in English.	
Autonomy	Using accompanying on-line material for self study, stu appropriately. Working on exercise problems, they rece goals. Upon successful completion, students can identify the field of software analysis. Within this field, they can a compile their findings in academic reports. They can devise	idents can assess their level of k ive additional feedback. Within lin and precisely formulate new proble conduct independent studies to acc se plans to arrive at new solutions o	nowledge contin nits, they can se ms in academic o juire the necessa or assess existing	uously and adjust it at their own learning or applied research in ary competencies and pones.
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	software artifacts/mathematical write-ups; short presenta	tion		
scale				
Assignment for the	Information and Communication Systems: Specialisation	on Secure and Dependable IT S	ystems, Focus 9	Software and Signal
Following Curricula	Processing: Elective Compulsory		-	
	Information and Communication Systems: Specialisation (International Management and Engineering: Specialisation	ommunication Systems, Focus Sofi II. Information Technology: Electiv	ware: Elective Co e Compulsory	ompulsory

Course L0631: Software Ana	lysis
Тур	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	
Literature	 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
	 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	
Тур	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: Comp	outer Graphics			
Courses				
Title Computer Graphics (L0145)		Typ Lecture	Hrs/wk 2	СР 3
Computer Graphics (L0768)		Recitation Section (small)	2	3
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Linear Algebra (in particular matrix/vector computatio	n)		
Knowledge	 Basic programming skills in C/C++ 			
Educational Objectives	After taking part successfully, students have reached the follo	owing learning results		
Professional Competence				
Knowledge	Students can explain and describe basic algorithms in 3D cor	nputer graphics.		
Skills	Students are capable of			
	• implementing a basic 3D rendering pipeline. This con-	sists of projecting simple 3D struc	tures (e.g. cube	e, spheres) onto a 2D
	surface using a virtual camera.			
	apply geometric transformations (e.g. rotation, scaling) in 2D and 3D computer graphics	5.	
	 using well-known 2D/3D APIs (OpenGL, Cairo) for solvi 	ng a given problem statement.		
Personal Competence				
Social Competence	Students can collaborate in a small team on the realization a	nd validation of a 3D computer gra	aphics pipeline.	
			P P P	
Autonomy	• Students are able to solve simple tasks independently	with reference to the contents of	the lectures an	nd the exercise sets.
	Students are able to solve detailed problems independ	lently 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	90 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software E	ngineering: Elective Compulsory		
Following Curricula	Information and Communication Systems: Specialisation	Secure and Dependable IT Sys	tems, Focus S	Software and Signal
	Processing: Elective Compulsory			
	Information and Communication Systems: Specialisation Com	munication Systems, Focus Signa	I Processing: El	ective Compulsory
	International Management and Engineering: Specialisation II.	Information Technology: Elective	Compulsory	

Course L0145: Computer Gra	phics
Тур	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	
Тур	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: Secur	re Software Engineering			
Courses				
Title		Тур	Hrs/wk	СР
Secure Software Engineering (L266	57)	Lecture	2	3
Secure Software Engineering (L266	58)	Project-/problem-based Learning	2	3
Module Responsible	Prof. Riccardo Scandariato			
Admission Requirements	None			
Recommended Previous	Familiarity with basic software engineering concepts (e.	g., requirements, design) and basic secu	rity concepts	(e.g., confidentiality,
Knowledge	integrity, availability)			
Educational Objectives	After taking part successfully, students have reached the	e following learning results		
Professional Competence				
Knowledge	Students can:			
	 Elicit cocurity requirements in a software project. 			
	 Elicit security requirements in a software project Model and document socurity measures in a software 	ware decign		
	House and document security measures in a solut	Vare design		
	Understand how security code reviews are perform	med		
	Understand the core definitions of concents relate	ed to privacy		
	Understand the core demindons of concepts relate			
	onderstand privacy enhancing cermologies			
Skills	Select appropriate security assurance techniques to be u	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 fro	m academic publications, techical standa	ards, and whi	te 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	120 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Softw	are Engineering: Elective Compulsory		
Following Curricula	Information and Communication Systems: Specialisation	Communication Systems, Focus Softwar	e: Elective Co	ompulsory
	Information and Communication Systems: Specialisa	tion Secure and Dependable IT Syste	ems, Focus	Software and Signal
	Processing: Elective Compulsory			

Course L2667: Secure Softwa	are Engineering
Тур	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.
	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 Softwa	are Engineering
Тур	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 M1700: Satel	lite Communications and Navigation			
Courses				
Title		Тур	Hrs/wk	СР
Radio-Based Positioning and Navig	ation (L2711)	Lecture	2	3
Satellite Communications (L2710)		Lecture	3	3
Module Responsible	Prof. Gerhard Bauch			
Admission Requirements	None			
Recommended Previous	The module is designed for a diverse audience, i.e.	students with different background. Ba	sic knowledge	of communications
Knowledge	engineering and signal processing are of advantage	e but not required. The course inte	nds to provide	e the chapters on
	communications techniques such that on the one hand	students with a communications engine	ering backgrou	und learn additional
	concepts and examples (e.g. modulation and coding so	hemes or signal processing concepts) w	hich have not c	or in a different way
	been treated in our other bachelor and master courses	On the other hand, students with other	background sh	nall be able to grasp
	the ideas but may not be able to understand in the s	ame depth. The individual background	of the students	s will be taken into
	consideration in the oral exam.			
Educational Objectives	After taking part successfully, students have reached th	e following learning results		
Professional Competence				
Knowledge	The students are able to understand, compare and	analyse digital satellite communicatio	ns system as	well as navigation
	techniques. They are familiar with principal ideas of the	e respective communications, signal pro	ocessing and p	ositioning methods.
	They can describe distortions and resulting limitation	s caused by transmission channels and	hardware com	nponents. They can
	describe how fundamental communications and naviga	ion techniques are applied in selected pr	actical systems	s.
	The students are familiar with the contents of lecture a	nd tutorials. They can explain and apply t	hem to new pro	oblems
Skills	The students are able to describe and analyse digital s	atellite communications systems and na	vigation system	ns. They are able to
	analyse transmission chains including link budget calcu	lations. They are able to choose appropr	iate transmissio	on 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 fr	om 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	30 min			
scale				
Assignment for the	Electrical Engineering: Specialisation Information and C	ommunication Systems: Elective Compute	sory	
Following Curricula	Information and Communication Systems: Specialisa	tion Secure and Dependable IT Syste	ems, Focus So	oftware and Signal
	Processing: Elective Compulsory			
	Information and Communication Systems: Specialisation	Communication Systems, Focus Signal	Processing: Ele	ctive Compulsory
	Microelectronics and Microsystems: Specialisation Com	nunication and Signal Processing: Electiv	e Compulsory	

Course L2711: Radio-Based I	Positioning and Navigation
Тур	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch, Dr. Rico Mendrzik
Language	EN
Cycle	SoSe
Content	Information overaction from communication cignals
	Ime-or-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
 Lime-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 Cramer-Rao lower bound
 Fisher information in the AWGN case
 Multi-variate Fisher information
 Cramer-Rao lower bound for synchronized time-of-arrival positioning
 Case study: Synchronized time-of-arrival positioning Case for base laws a feature to a site of a minute a min
 Cramer-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 point an angle of arrival positioning
 Effect of horse on angle-of-arrival positioning Least encode angle of arrival positioning with known exiantation
Least squares angle-of-arrival positioning with known orientation
Effect of orientation uncertainty
Effect of offentation uncertainty Angle difference of envired positioning
Angle-difference-of-arrival positioning Connectric interpretation angle difference of arrival positioning
Geometric interpretation angle difference of arrival locus
 Proof of angle-uniterence-of-arrivatiocus Inscribed angle lomma
Case study: Angle-difference-of-arrival-nocitioning
Performance limits of angle-based nocitioning
 Cramér-Bao 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 Com	munications
Тур	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
	Committee Contraction Contraction
	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
	a Orbita
	 Units Low earth orbit (LEO) medium earth orbit (MEO) geosynchronoous and geostationary orbits (CEO) highly elliptical
	 Low earth obde (LEO), medium earth orbit (MEO), geosynchroneous and geostationally orbits (GEO), mgmy empirical orbits (HEO)
	o Dista (i Leo
	- introductor object.
	Circular Lo arbit
	Circular AEO Orbits Circular Orbits (Intermediate Circular Orbits (ICO))
	Foundarial 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

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	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
	 IEO menaconstellations: SpaceX Starlink, Kuiner, OneWeb
	Snare debris
	• The German Heinrich Hertz mission

Literature

Module M1842: GPU	Architectures			
Courses				
Title		Тур	Hrs/wk	СР
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	An introductory module on computer			
Knowledge	engineering or computer architecture, and good programming	skills in C/C++.		
Educational Objectives	After taking part successfully, students have reached the follow	wing 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	30 min			
scale				
Assignment for the	Computer Science: Specialisation I. Computer and Software Er	gineering: Elective Compulsory		
Following Curricula	Information and Communication Systems: Specialisation S	ecure and Dependable IT Syste	ems, Focus	Software and Signal
	Processing: Elective Compulsory			
	Microelectronics and Microsystems: Specialisation Embedded	Systems: Elective Compulsory		

Course L3039: GPU Architecture	
Тур	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,
	nigh-power consumption/energy efficiency, GPU security
	- Application case study - deep learning
	The learning in the lectures will be augmented by a semester-long
	nrohlem-hased project
Literature	

Course L3040: GPU Architecture	
Тур	Project-/problem-based Learning
Hrs/wk	1
СР	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 M1	L301: Software Testing			
Courses				
Title		Тур	Hrs/wk	СР
Software Testing (I	(L1791)	Lecture	2	3
Software Testing (I	(L1792)	Project-/problem-based Learning	2	3
Module	e Prof. Sibylle Schupp			
Responsible	e			
Admission	n None			
Requirements	s			
Recommended	d			
Previous	• Software Engineering S			
Knowledge	Object-Oriented Programming			
	Algorithms and Data Structures			
	Experience with (Small) Software Projects			
	Statistics			
Educational	After taking part successfully, students have reached the following learning result	lts		
Objectives	s			
Professional	4			
Competence	e			
Knowledge	e Students explain the different phases of testing, describe fundar	nental		
	techniques of different types of testing, and paraphrase the basi	c		
	principles of the corresponding test process. They give examples	sof		
	software development scenarios and the corresponding test type	e and		
	technique. They explain algorithms used for particular testing			
	techniques and describe possible advantages and limitations.			
Skills	5 Students identify the enprendiate testing type and technique for	a diyon		
	Students identity the appropriate testing type and technique for a given			
	concrete test technique properly. They interpret testing results a	and		
	execute corresponding steps for proper re-test scenarios. They we	concrete test technique property. They interpret testing results and		
	analyze test specifications. They apply bug finding techniques for	r		
	non-trivial problems.			
Personal	4			
Competence	e			
Social	Social Students discuss relevant topics in class. They defend their solutions orally.			
Competence	e They communicate in English.			
Autonomy			studies Within limits they ca	
Autonomy	own learning goals. Upon successful completion, students can identify and preci-	selv formulate new problems in	academic or	applied research in the field of
	testing. Within this field, they can conduct independent studies to acquire the	necessary competencies and	compile their	findings in academic reports
	devise plans to arrive at new solutions or assess existing ones			
	······································			
Workload in	n Independent Study Time 124, Study Time in Lecture 56			
Hours	s			
Credit points	s 6			
Course	e None			
achievement	t			
Examination	n Subject theoretical and practical work			
Examination	n Software			
duration and	d			
scale	e			
Assignment	t Computer Science: Specialisation I. Computer and Software Engineering: Elective	e Compulsory		
for the	e Information and Communication Systems: Specialisation Communication System	is, Focus Software: Elective Con	npulsory	
Following	g Information and Communication Systems: Specialisation Secure and Dependable	e IT Systems, Focus Software ar	d Signal Proce	essing: Elective Compulsory
Curricula	a			

Course L1791: Software Testing	
Тур	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		
Тур	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: Autor	nomous Cyber-Physical System	15		
Courses				
Title		Тур	Hrs/wk	СР
Autonomous Cyber-Physical System	ns (L3000)	Lecture	2	3
Autonomous Cyber-Physical System	ns (L3001)	Recitation Section (small)	2	3
Module Responsible	Prof. Bernd-Christian Renner			
Admission Requirements	None			
Recommended Previous Knowledge	 Very Good knowledge and practical e Basic knowledge in software enginee Basic knowledge in wired and wireles Principal understanding of simple ele 	experience in programming in the C language (Mo ring is communication protocols ctronic circuits	dule: Procedural	Programming)
Educational Objectives	After taking part successfully, students have	e reached the following learning results		
Professional Competence				
Knowledge				
Skills				
Personal Competence				
Social Competence				
Autonomy				
Workload in Hours	Independent Study Time 124, Study Time in	1 Lecture 56		
Credit points	6			
Course achievement	CompulsoryBonusFormNo10 %Attestation	Description		
Examination	Written exam			
Examination duration and	90 min			
scale				
Assignment for the	Computer Science: Specialisation I. Comput	er and Software Engineering: Elective Compulsor	y	
Following Curricula	Computer Science in Engineering: Specialisa	ation I. Computer Science: Elective Compulsory		
	Information and Communication Systems	: Specialisation Secure and Dependable IT S	ystems, Focus S	Software and Signal
	Processing: Elective Compulsory			

Course L3000: Autonomous	Course L3000: Autonomous Cyber-Physical Systems	
Тур	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	
Тур	Recitation Section (small)
Hrs/wk	2
СР	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 M1694: Secur	ity of Cyber-Ph	ysical Systen	ns			
Courses						
Title Security of Cyber-Physical Systems	(L2691)			Typ Lecture	Hrs/wk	CP 3
Module Responsible	Prof. Sibyllo Fröschlo			Recitation Section (smail)	2	2
Admission Requirements	None					
Recommended Previous	IT security, programm	ning skills, statistics				
Knowledge		-				
Educational Objectives	After taking part succ	essfully, students h	ave reached the followi	ng learning results		
Professional Competence						
Knowledge	The students know ar	nd can explain				
	- the threats posed by	/ cyber attacks to cy	yber-physical systems (CPS)		
	- concrete attacks at	a technical level, e.	g. on bus systems			
	- security solutions sp	ecific to CPS with th	neir capabilities and lim	itations		
	- examples of security	/ architectures for C	CPS and the requiremen	ts they guarantee		
	- standard security er	igineering processe	s for CPS			
Skills	The students are able	e to				
	- identify security thr	eats and assess the	e risks for a given CPS			
	- apply attack toolkits	s to analyse a netwo	orked control system, a	nd detect attacks beyond the	ose taught in class	
	 identify and apply s 	ecurity solutions su	itable to the requireme	nts		
	- follow security engi	neering processes t	o develop a security ar	chitecture for a given CPS		
	- recognize challenge	es and limitations, e	.g. posed by novel type	s of attack		
Borconal Competence						
Social Competence	The students are able	e to				
	- expertly discuss se experts	curity risks and inc	idents of CPS and the	ir mitigation in a solution-or	iented fashion wi	th experts and non-
	- foster a security cult	ture with respect to	CPS and the correspon	ding critical infrastructures		
Autonomy	The students are able	e to				
	- follow up and critica	lly assess current d	evelopments in the sec	urity of CPS including relevar	nt security inciden	ts
	- master a new topic	within the area by s	elf-study and self-initia	ted interaction with experts a	and peers.	
Workload in Hours	Independent Study Ti	me 124, Study Time	e in Lecture 56			
Credit points	6					
Course achievement	Compulsory Bonus	Form	Description	ufashan findan comostarhaa	loitond statt	
Examination	Written exam	Exectedee	Die oburigsu	arguben maen semesterbeg		
Examination duration and	120 min					
scale						
Assignment for the	Computer Science: Sp	pecialisation I. Comp	outer and Software Eng	ineering: Elective Compulsor	у	
Following Curricula	Data Science: Special	isation II. Computer	Science: Elective Com	pulsory		
	Computer Science in	sation IV. Special F	lisation L Computer Sci	ence: Elective Compulsory		
	Information and Cor	nmunication Syste	ms: Specialisation Se	cure and Dependable IT S	ystems, Focus S	oftware and Signal
	Processing: Elective C	Compulsory		·		5 .

Course L2691: Security of Cy	/ber-Physical Systems
Тур	Lecture
Hrs/wk	2
СР	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		
Тур	Recitation Section (small)	
Hrs/wk	2	
CP	3	
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28	
Lecturer	Prof. Sibylle Fröschle	
Language	EN	
Cycle	WiSe	
Content	See interlocking course	
Literature	See interlocking course	

Module M1598: Image	e Processing			
Courses				
Title		Тур	Hrs/wk	СР
Image Processing (L2443)		Lecture	2	4
Image Processing (L2444)		Recitation Section (small)	2	2
Module Responsible	Prof. Tobias Knopp			
Admission Requirements	None			
Recommended Previous	Signal and Systems			
Knowledge				
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	e pyramid, wavelets		
	image compression			
	image segmentation			
	 morphological image processing 			
Skills	The students can			
	 analyze process and improve multidimension. 	al image data		
	 implement simple compression algorithms 			
	 design custom filters for specific applications 			
	5 1 11			
Personal Competence				
Social Competence	Students can work on complex problems both indepe	ndently and in teams. They can exchang	e ideas with eacl	n other and use their
	individual strengths to solve the problem.			
Autonomy	Students are able to independently investigate a com	plex problem and assess which compete	ncies are require	ed 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	90 min			
scale				
Assignment for the	Data Science: Core Qualification: Elective Compulsory	1		
Following Curricula	Data Science: Specialisation I. Mathematics/Compute	r Science: Elective Compulsory		
	Data Science: Specialisation II. Computer Science: Ele	ective Compulsory		
	Data Science: Specialisation IV. Special Focus Area: E	lective Compulsory		
	Electrical Engineering: Specialisation Information and	Communication Systems: Elective Comp	oulsory	
	Electrical Engineering: Specialisation Medical Technol	ogy: Elective Compulsory		
	Information and Communication Systems: Specialisat	ion Communication Systems, Focus Sign	al Processing: Ele	ective Compulsory
	Information and Communication Systems: Special	isation Secure and Dependable IT Sy	stems, Focus S	oftware and Signal
	Processing: Elective Compulsory			
	International Management and Engineering: Specialis	ation II. Information Technology: Elective	e Compulsory	
	Mechatronics: Specialisation Intelligent Systems and	Robotics: Elective Compulsory		
	Mechatronics: Specialisation System Design: Elective	Compulsory		
	Mechatronics: Core Qualification: Elective Compulsory	/		
	Microelectronics and Microsystems: Specialisation Co	mmunication and Signal Processing: Elec	tive Compulsory	
	Theoretical Mechanical Engineering: Specialisation Ro	obotics and Computer Science: Elective C	ompulsory	

Course L2443: Image Processing			
Тур	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		
Тур	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	

	Thesis
Medule M 002: Maste	x Thoric
Module M-002: Maste	ir mesis
Courses	
Title	Typ Hrs/wk CP
Module Responsible	Professoren der TUHH
Admission Requirements	A According to Canaval Degulations \$21 (1):
	• According to deheral Regulations 921 (1).
	At least 60 credit points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous	
Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• The students can use specialized knowledge (facts, theories, and methods) of their subject competently on specialized
	issues.
	 The students can explain in depth the relevant approaches and terminologies in one or more areas of their subject, describing current developments and taking up a critical position on them
	 The students can place a research task in their subject area in its context and describe and critically assess the state of
	research.
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Skills	The students are able:
	• To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question.
	• To apply knowledge they have acquired and methods they have learnt in the course of their studies to complex and/or
	Incompletely defined problems in a solution-oriented way. To develop new scientific findings in their subject area and subject them to a critical assessment
	• To develop new sciencine informs in their subject area and subject them to a childran assessment.
Personal Competence	
Social Competence	Students can
	• Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured
	way.
	 Deal with issues competently in an expert discussion and answer them in a manner that is appropriate to the addressees while unholding their own assessments and viewpoints convincingly.
	while apholang cicle own assessments and viewpoints convincingly.
Autonomy	Students are able:
	 To structure a project of their own in work packages and to work them off accordingly.
	• To work their way in depth into a largely unknown subject and to access the information required for them to do so.
	 To apply the techniques of scientific work comprehensively in research of their own.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination	Thesis
Examination duration and	According to General Regulations
Scale Assignment for the	Civil Engineering: Thecis: Compulsory
Following Curricula	Bioprocess Engineering: Thesis: Compulsory
, , , , , , , , , , , , , , , , , , ,	Chemical and Bioprocess Engineering: Thesis: Compulsory
	Computer Science: Thesis: Compulsory
	Data Science: Thesis: Compulsory
	Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory
	Environmental Engineering: Thesis: Compulsory
	Aircraft Systems Engineering: Thesis: Compulsory
	Global Innovation Management: Thesis: Compulsory
	Computer Science in Engineering: Thesis: Compulsory
	Interdisciplinary Mathematics: Thesis: Compulsory
	International Production Management: Thesis: Compulsory
	International Management and Engineering: Thesis: Compulsory
	Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory
	Logistics, Intrastructure and Mobility: Thesis: Compulsory Aeronautics: Thesis: Compulsory
	Materials Science and Engineering: Thesis: Compulsory
	Materials Science: Thesis: Compulsory
	Mechanical Engineering and Management: Thesis: Compulsory
	Mechatronics: Thesis: Compulsory
I	biomedical Engineering: Thesis: Compulsory
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Module Manual M. Systems"	Sc. "Information and Communication
	Microelectronics and Microsystems: Thesis: Compulsory
	Product Development, Materials and Production: Thesis: Compulsory
	Renewable Energies: Thesis: Compulsory
	Naval Architecture and Ocean Engineering: Thesis: Compulsory
	Ship and Offshore Technology: Thesis: Compulsory
	Teilstudiengang Lehramt Metalltechnik: Thesis: Compulsory
	Theoretical Mechanical Engineering: Thesis: Compulsory
	Process Engineering: Thesis: Compulsory
	Water and Environmental Engineering: Thesis: Compulsory
	Certification in Engineering & Advisory in Aviation: Thesis: Compulsory