Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science Communications and Multimedia Engineering

(Version of examination regulation: 20232)

for the winter term 2025/2026

Table of contents

1	**Module name** 47800	**Digital Communications** Digital communications	**5 ECTS**
2	Courses / lectures	Vorlesung: Digital Communications (3 SWS) Übung: Tutorial for Digital Communications (1 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Brikena Kaziu	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Alle modernen Kommunikationssysteme basieren auf digitalen Übertragungsverfahren. Diese Vorlesung befasst sich mit den Grundlagen der Analyse und des Entwurfs digitaler Sender und Empfänger. Dabei wird zunächst von einem einfachen Kanalmodell bei dem das Empfangssignal nur durch additives weißes Gaußsches Rauschen gestört wird ausgegangen. Im Verlauf der Vorlesung werden aber auch Kanäle mit unbekannter Phase sowie verzerrende Kanäle betrachtet. Behandelt werden unter anderem digitale Modulationsverfahren (z.B. Pulsamplitudenmodulation (PAM), digitale Frequenzmodulation (FSK), und Kontinuierliche-Phasenmodulation (CPM)), Orthogonalkonstellationen, das Nyquistkriterium in Zeit- und Frequenzbereich, optimale kohärente und inkohärente Detektions- und Decodierungsverfahren, die Signalraumdarstellung digital modulierter Signale, verschiedene Entzerrungsverfahren, und Mehrträger-Übertragungsverfahren. --- Modern communication systems are based on digital transmission methods. This course covers basics of analysis and design of digital transmitters and receivers. Initially, we consider a simple channel model whose received signal is impaired only by additive white Gaussian noise. Then, we extend fundamental concepts to channels with unknown phases and distortion. Additionally, we treat digital modulation techniques, e.g., pulse amplitude modulation (PAM), digital frequency modulation (FSK) and continuous-phase modulation (CPM), and orthogonal constellations. The Nyquist criterion in time and frequency domain, optimal coherent and incoherent detection and decoding methods, signal space representations of digitally modulated signals, various equalization methods, and multicarrier transmission methods are also discussed.
6	**Learning objectives and skills**	Die Studierenden • analysieren und klassifizieren digitale Modulationsverfahren hinsichtlich ihrer Leistungs- und Bandbreiteneffizienz sowie ihres Spitzenwertfaktors, • ermitteln notwendige Kriterien für impulsinterferenzfreie Übertragung, • charakterisieren digitale Modulationsverfahren im Signalraum, • ermitteln informationsverlustfreie Demodulationsverfahren, • entwerfen optimale kohärente und inkohärente Detektions- und Decodierungsverfahren,

		• vergleichen verschiedene Entzerrungsverfahren hinsichtlich deren Leistungsfähigkeit und Komplexität, • entwerfen einfache digitale Übertragungssysteme mit vorgeschriebenen Leistungs- und Bandbreiteneffizienzen sowie Spitzenwertfaktoren. • -- The students • analyze and classify digital modulation techniques in terms of performance and bandwidth efficiency as well as crest factor, • determine necessary criteria to design impulses for interference-free transmission, • characterize digital modulation methods in signal space, • determine information loss-free demodulation methods, • design optimal coherent and incoherent detection and decoding methods, • compare different equalization methods in terms of performance and complexity, • design simple digital transmission systems with prescribed power and bandwidth efficiency and crest factor.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 92325	**Digital Signal Processing** Digital signal processing	**5 ECTS**
2	Courses / lectures	Vorlesung: Digitale Signalverarbeitung (3 SWS) Übung: Übung zu Digitale Signalverarbeitung (1 SWS)	5 ECTS -
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	**Module coordinator**	Dr.-Ing. Heinrich Löllmann

5	**Contents**	• A/D and D/A conversion
		•
		  ◦ Time-domain and z-domain reprenstations
		  ◦ Signal flow graphs
		  ◦ Analytic computation of the frequency response
		  ◦ Special systems (allpass, minimum phase, and linear phase systems)
		• Design of recursive and non-recursive filters
		• Multirate systems and filter banks
		• Frequency-domain signal analysis
		• Effects of finite wordlength

6	**Learning objectives and skills**	The students • analyze discrete-time linear time-invariant systems by determining the describing function and parameters • apply fundamental approaches for the design of discrete-time systems and evaluate their performance • understand the differences between various methods for spectral analysis and apply them to the analysis of given signals • understand methods to represent multirate systems and apply them for the representation of filter banks • know basic methods for the analysis of finite word length effects and apply them to discrete-time linear time-invariant systems.
7	**Prerequisites**	The course assumes knowledge of the basic theory of discrete-time deterministic signals as taught in lectures such as Signals and Systems II.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam of 90 min duration. The following resources are allowed for this exam: a handwritten formulary totalling a two-sided DIN A4 sheet of paper and a non-programmable calculator. Answers can be given either in English or German
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• A.V. Oppenheim and R. W. Schafer: Discrete-Time Signal Processing, Prentice Hall, Third Edition, 1996 • J.G. Proakis and D.G. Manolakis: Digital Signal Processing, Prenctice Hall, Second Edition, 1999

1	**Module name** 96310	**Image and Video Compression** Image and video compression	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	**Multi-Dimensional Sampling** • Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling **Entropy and Lossless Coding** • Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding **Statistical Dependency** • Joint entropy and statistical dependency, run-length coding, fax compression standards **Quantization** • Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization **Predictive Coding** • Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) **Transform Coding** • Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts **Subband Coding** • Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding **Visual Perception and Color** • Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats **Image Coding Standards** • JPEG and JPEG2000 **Interframe Coding** • Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding **Video Coding Standards** • H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	**Learning objectives and skills**	The students • visualize multi-dimensional sampling and the influence of motion within the video signal • differentiate and evaluate different methods for lossless image and video coding

		• understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization) • determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	**Prerequisites**	Lectures on Signal and Systems and Communication Systems strongly recommended
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral (90 minutes) Written exam of 90 min duration
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	J.-R. Ohm: Multimedia Communications Technology, Springer, 2004

1	**Module name** 93602	**Information Theory and Coding /** **Informationstheorie und Codierung** Information theory and coding	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	1. Introduction: binomial distribution, (7,4)-Hamming code, parity-check matrix, generator matrix 2. Probability, entropy, and inference: entropy, conditional probability, Bayes law, likelihood, Jensens inequality 3. Inference: inverse probability, statistical inference 4. The source coding theorem: information content, typical sequences, Chebychev inequality, law of large numbers 5. Symbol codes: unique decidability, expected codeword length, prefix-free codes, Kraft inequality, Huffman coding 6. Stream codes: arithmetic coding, Lempel-Ziv coding, Burrows-Wheeler transform 7. Dependent random variables: mutual information, data processing lemma 8. Communication over a noisy channel: discrete memory-less channel, channel coding theorem, channel capacity 9. The noisy-channel coding theorem: jointly-typical sequences, proof of the channel coding theorem, proof of converse, symmetric channels 10. Error-correcting codes and real channels: AWGN channel, multivariate Gaussian pdf, capacity of AWGN channel 11. Binary codes: minimum distance, perfect codes, why perfect codes are bad, why distance isnt everything 12. Message passing: distributed counting, path counting, low-cost path, min-sum (=Viterbi) algorithm 13. Exact marginalization in graphs: factor graphs, sum-product algorithm 14. Low-density parity-check codes: density evolution, check node degree, regular vs. irregular codes, girth 15. Lossy source coding: transform coding and JPEG compression -- 1. Einleitung: Binomialverteilung, (7,4)-Hamming-Code, Paritätsmatrix, Generatormatrix 2. Wahrscheinlichkeit, Entropie und Inferenz: Entropie, bedingte Wahrscheinlichkeit, Bayessches Gesetz, Likelihood, Jensensche Ungleichung 3. Inferenz: Inverse Wahrscheinlichkeit, statistische Inferenz 4. Das Quellencodierungstheorem: Informationsgehalt, typische Folgen, Tschebyschevsche Ungleichung, Gesetz der großen Zahlen 5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung 6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation

		7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma 8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität 9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanaäle 10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals 11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist 12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus 13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus 14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang 15. Verlustbehaftete Quellencodierung: Transformationscodierung und JPEG-Kompression
6	**Learning objectives and skills**	The students apply Bayesian inference to problems in both communications and everyday's life. The students explain the concept of digital communications by means of source compression and forward-error correction coding. For the design of communication systems, they use the concepts of entropy and channel capacity. They calculate these quantities for memoryless sources and channels. The students proof both the source coding and the channel coding theorem. The students compare various methods of source coding with respect to compression rate and complexity. The students apply source compression methods to measure mutual information. The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables. The students explain the design of error-correcting codes and the role of minimum distance. They decode error-correcting codes by means of maximum-likelihood decoding and message passing. The students apply distributed algorithms to problems in both communications and everydays life. The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution. The students transform source images into the frequency domain to improve lossy compression. -- Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an. Die Studierenden erklären die konzeptuelle Trennung von digitaler Übertragung in Quellen- und Kanalcodierung.

		Kommunikationssysteme entwerfen sie unter Betrachtung von Entropie und Kanalkapazität. Sie berechnen diese Größen für gedächtnislose Quellen und Kanäle. Die Studierenden beweisen sowohl das Quellen- als auch das Kanalcodierungstheorem. Die Studierenden vergleichen verschiedenartige Quellencodierungsverfahren hinsichtlich Komplexität und Kompressionsrate. Die Studierenden verwenden Quellencodierverfahren zur Messung von Transinformation. Die Studierenden faktorisieren Funktionen mehrerer Veränderlicher, stellen diese als Graph dar und marginalisieren sie bezüglich mehrerer Veränderlicher. Die Studierenden erklären den Entwurf von Kanalcodes und den Einfluss der Minimaldistanz. Sie decodieren Kanalcodes gemäß maximaler Likelihood und Nachrichtenaustausch. Die Studierenden wenden verteilte Algorithmen auf Probleme der Nachrichtentechnik und des Alltagslebens an. Die Studierenden verbessern die Eigenschaften von LDPC-Codes durch Erhöhung des Umfangs und/oder durch irreguäre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression iin den Frequenzbereich.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

1	**Module name** 43142	**Mobile Communications** Mobile communications	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	History of mobile communications, cellular systems, sectorization, spectral efficiency, co-channel interference, adjacent-channel interference, near-far effect, cellular network architecture, antenna types and parameters, free space propagation, reflection, attenuation, diffraction, scattering, classification of channel models, ground reflection model, Okumura-Hata model, shadowing, narrow-band fading, time- variant channels, scattering function, delay-Doppler spectrum, diversity principles, combining methods, diversity gain, multiplexing, duplexing, digital modulation, Gaussian filtered minimum shift keying, basics of channel coding, interleaving, global system for mobile communications, physical versus logical channels, frame structure, call set-up, synchronization, channel estimation, hand-off
6	**Learning objectives and skills**	The students explain the cellular structure of mobile communication systems. They students explain the physical mechanics of radio wave propagation in the cm-band. The students explain the GSM cellular communications standard. The students discuss the pros and cons of several multiple-access and duplexing methods. The students discuss the pros and cons of several modulation and coding formats. The students decide which antenna type is suitable for a given morphological structure of the environment. The students predict the amplitude and dynamic of the antenuation between a mobile transmitter and a fixed receiver. The students utilize diversity methods to improve the link quality. The students determine the coverage probability of a given cellular communication system. The students collaborate on solving exercise problems. The students discuss which system solutions fit to which environments.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001. Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001. Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992. Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005.

1	**Module name** 96430	**Statistical Signal Processing** Statistical signal processing	**5 ECTS**
2	Courses / lectures	Übung: Übung zur Statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Baoqi Bai	

4	**Module coordinator**	Prof. Dr.-Ing. Sebastian Schlecht
5	**Contents**	The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are: • Discrete-time stochastic processes in the time and frequency domain: Random variables (RVs), probability distributions and densities, expectations of random variables, transformation of RVs, vectors of normally distributed RVs, time-discrete random processes: probability distribution and densities, expectation, stationarity, cyclostationarity, ergodicity, correlation functions and correlation matrices, spectral representations, principal component analysis (PCA), Karhunen-Loève transform (KLT). • Estimation theory: estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound • Linear signal models: Parametric models (cepstral decomposition, Paley-Wiener theorem, spectral flatness), non-parametric models (all-pole, all-zero and pole-zero models, lattice structures, Yule-Walker equations, PARCOR coefficients, cepstral representation) • Signal estimation: Supervised estimation, problem classes, orthogonality principle, MMSE estimation, linear MMSE estimation for normally distributed random processes, optimum FIR filtering, optimum linear filtering for stationary processes, prediction and smoothing, Kalman filters, optimum multichannel filtering (Wiener filter, LCMV, MVDR, GSC) • Adaptive filtering: Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior
6	**Learning objectives and skills**	The students: • analyze the statistical properties of random variables, random vectors, and stochastic processes by probability density functions and expectations as well as correlation functions and matrices and their frequency-domain representations • know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes • understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation

		• analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems • evaluate adaptive filters for the identification of optimum linear estimators.
7	**Prerequisites**	Courses on signals and systems as well as digital signal processing strongly recommended
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam of 90min duration.
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• A. Papoulis, S. Pillai: Probability, Random Variables and Stochastic Processes; McGraw-Hill, 2002 • D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005

1	**Module name** 1995	**Forschungspraktikum (M.Sc. Communications and Multimedia Engineering 20232)** Research Internship	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker Dr.-Ing. Heinrich Löllmann
5	**Contents**	The aim of the research internship is to provide some hands-on experience in research. The focus of the research work can be experimental, theoretical or constructive. Combinations of different focal points are permitted. It is usually conducted at a university chair. Every chair of the Department Electrical Engineering (EEI) and the chair of Pattern Recognition are eligible to supervise the research internship. It is, however, recommended to choose a chair that is closely associated with the CME study program, e.g. LMS, IDC, AudioLabs or LIKE.
6	**Learning objectives and skills**	**Learning and methodical competence** The students • acquire the ability to pursue a scientific question over a longer period of time. • can develop independent ideas and concepts for the systematic solution of a scientific problem. • are able to assess and review the theories, terminologies, peculiarities, limits and doctrines of the field in a profound and critical manner. • are able to independently apply and further develop suitable scientific methods - also in new and unfamiliar as well as interdisciplinary contexts. • are able to present subject-related content in a scientifically appropriate form in writing and orally in a manner appropriate to the target group. **Self-competence** The students • learn self-critical reflection of their own work. • expand their planning and structuring ability. • acquire the ability to learn and criticize.
7	**Prerequisites**	The research internship (Forschungspraktikum) should ideally be completed in the third semester after having passed all compulsory modules.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement The research internship has a workload of 10 ECTS (300 hours). For completion, a presentation of about 20 minutes has to be given and a

		report of 10 to 15 pages has to be written. The research internship is not graded. It is a pass/fail achievement.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 100 h Independent study: 200 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 1999	**Masterarbeit mit Vortrag (M.Sc. Communications and Multimedia Engineering 20232)** Master thesis	**30 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	A Master's thesis is a piece of original scicentific work conducted under the direction of a faculty advisor. The Master's thesis is intended to demonstrate students' ability to solve scientific problems in the field of communication and multimedia engineering independently. Topics are announced on the chairs' websites or can be requested directly from the professors. Students may also suggest a topic themselves. All full-time university lecturers teaching at the Department of Electrical Engineering (EEI) are entitled to supervise Master's theses. The requirements of the Master's thesis are to be set in such a way that it can be completed within six months with a processing time of approximately 900 hours.
6	**Learning objectives and skills**	The students • acquire the ability to pursue a scientific question over a longer period of time, to work on the corresponding subject area independently and within a given time limit. • develop independent ideas and concepts for solving scientific problems. • deal with theories, terminologies, special features, limitations and doctrines of the subject in an in-depth and critical manner and reflect on them. • are able to apply and further develop suitable scientific methods largely independently - also in new and unfamiliar as well as interdisciplinary contexts - and to present the results in a scientifically appropriate form. • are able to present subject-related content clearly and appropriately to the target group in writing and orally and to represent it argumentatively. • expand their planning and structuring skills in execution of a project.
7	**Prerequisites**	Prerequisite for admission to the Master's thesis is that all compulsory modules have been passed and at least 80 ECTS points have been acquired.
8	**Integration in curriculum**	semester: 4
9	**Module compatibility**	Pflichtmodul Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written (6 Monate) The thesis consists of a written part and an oral part.

		There is no mandatory length for the written part of a thesis. Most Master's theses have between 50 and 80 pages. However, depending on the topic, more or fewer pages may be appropriate. If the written part was graded at least *sufficient*, the author must present the results of their work in an oral presentation of approximately 30 minutes length with subsequent discussion. The date for the final presentation is set by the supervising university lecturer.
11	**Grading procedure**	Written (100%)
12	**Module frequency**	Every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: variable Independent study: 900 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	

Technical courses

1	**Module name** 151664	**Advanced Communication Networks** Advanced communication networks	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Telecommunications have become ubiquitous in daily life and wireless networks play a fundamental role thanks to their capability to support mobility. In a wireless communication, the concept of link does not exist. Users radiate energy and communicate through the superposition of each others transmissions which creates interference. Compared to wireline networks this scenario is extremely challenging but also offers unpredictable opportunities in the development of new technologies (massive MIMO, cognitive radio, etc.) and exploitation of new features, e.g., opportunistic communications and multiuser diversity. The exponentially increasing request of higher and higher throughput is satisfied densifying users and access points per unit area and allowing more and more interference while adopting advanced techniques and innovative resource allocation to mitigate the detrimental effects of interference. Objective of this course is to introduce the student to advanced techniques for coordinated medium access control and radio resource management in cellular systems. Power allocation, rate adaptation and scheduling will be discussed both in centralized and distributed settings. Some mathematical methods play a fundamental role in resource allocation, namely, classical Perron-Frobenius theory for nonnegative matrices, convex and nonconvex constrained optimization, distributed optimization and game theory. The course introduces the student to such methods and exemplifies their application to various resource allocation problems. Additionally, the course addresses relevant aspects of resource allocation in wireless networks such as fairness and cross-layer design. *Technical Content* • Properties and challenges of the wireless medium. • Basic concepts of communication networks: the layered architecture. • Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution. • Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA. • Uplink-downlink duality. • Opportunistic scheduling and multiuser diversity. • Advanced concepts: small cells and heterogeneous networks, relaying and cooperation, network coding, cognitive radio networks. • Basics of resource allocation: power allocation, rate adaptation, and scheduling.

		• Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	**Learning objectives and skills**	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE. • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenious theorem to allocate power in a centralized manner.

		• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility. • Uses the Perron-Frobenious theorem to design a distributed power control scheme. • Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control. • Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality. • Judges the applicability of KKT conditions and duality. • Uses KKT conditions to solve convex optimization problems. • Uses duality to solve convex optimization problems. • Applies convex optimization to resource allocation in wireless communications. • Compares different definitions of fairness and applies them to rate allocation. • Appraises the effect of channel knowledge at the transmitter on different fairness criteria. • Applies KKT conditions for opportunistic user scheduling. • Describes a proportional fair algorithm for opportunistic scheduling. • Applies relaxation to nonconvex quadratic constrained quadratic programming. • Formulates resource allocation problems as constrained optimization programming. • Contrasts various distributed optimization methods. • Applies the concept of best response to determine Nash equilibria. • Argues about existence and uniqueness of Nash equilibria. • Assesses if a given game is a potential game and solves it. • Defends the concept of Pareto optimality in resource allocation. • Contrasts the concepts of pure and mixed strategies in game theory. • Uses coupled constrained concave game to allocate powers in heterogeneous networks.
7	**Prerequisites**	Information Theory and Coding It is advisable that the student is familiar with basic concepts of Mobile Communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes) Oral exam, 30 minutes

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 621649	**Advanced Optical Communication Systems** Advanced optical communication systems	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Optical Communication Systems (2 SWS) Übung: Advanced Optical Communication Systems Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Bernhard Schmauß Benedikt Beck Esther Renner	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats:intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration
6	**Learning objectives and skills**	Students • gain detailed Knowledge on concepts and structure of various optical transmission systems. • are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. • are able to develop and to optimize link designes of optical transmission systems. • are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
7	**Prerequisites**	**Recommended Prerequisites:** • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes)

		Examinbation: oral exam (30 Minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008. Lecture notes.

1	**Module name** 96875	**Ausgewählte Kapitel der Audiodatenreduktion** Advanced topics in perceptual audio coding	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Topics in Perceptual Audio Coding (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Herre	

4	**Module coordinator**	Prof. Dr.-Ing. Jürgen Herre
5	**Contents**	Perceptual audio coding is ubiquitous in modern life (mp3 players, mobile phones, DVD players, computers, ...) Based on related classes (esp. Speech and Audio Processing"), this lecture aims at deepening the understanding of modern algorithms for perceptual source coding of audio. It includes an overview of the most relevant standardized coders, starting with MPEG-1 (incl. mp3) via MPEG-4 all the way to the most recent MPEG Audio standard. The significant algorithms are discussed and new approaches are described. The selected topics include: Efficient coding of several audio channels / parametric multi- channel coding Typical coding artifacts; subjective and objective quality assessment Scalable audio coding Bandwidth extension Semi-parametric audio coding Low-delay audio coding The lecture includes a number of demonstrations and audio examples to illustrate the discussed algorithms.
6	**Learning objectives and skills**	• Wissen - Die Studenten kennen die Hauptkomponenten eines gehörangepassten Audiocodecs, sowie die wichtigsten Algorithmen, Codierstrategien und Bewertungsmethoden. Weiterhin kennen sie die Terminologie und gängige Abkürzungen aus diesem Kontext. • Verstehen - Die Studenten verstehen, wie Designentscheidungen in Audiocodecs die letztendlich erreichte Audioqualität beeinflussen, verstehen die gebräuchlichsten Tools aus dem Bereich der gehörangepasste Audiocodierung und wie verschiedene Anwendungsszenarien das Coderdesign bestimmen. • Anwenden - Die Studenten können übliche mathematische Analysemethoden verwenden, um einfache Coder-Componenten zu beschreiben und gegebenenfalls zu modifizieren. • Analysieren - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge dazu analysieren um die zugrundeliegenden Konzepte und Anforderungen zu erfassen. • Evaluieren (Beurteilen) - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge evaluieren um zu beurteilen, welcher

		Standard bzw. welches Messwerkzeug das passendste ist für einen bestimmten Anwendungsfall. • Synthese - Die Studenten können eine Liste von Anforderungen und Bewertungskriterien für Audiocodecs zusammenstellen für gewünschte Anwendungsfälle. • Lern- bzw. Methodenkompetenz - Die Studenten hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral Prüfung: Mündlich, 30min.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96010	**Architekturen der digitalen Signalverarbeitung** Architectures for digital signal processing	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Inhalt: • Basis-Algorithmen der Signalverarbeitung (FFT, Fensterung, Digitale FIR- und IIR-Filter) • Nichtideale Effekte bei Digitalfiltern (Quantisierung der Filterkoeffizienten, Quantisierte Arithmetik) • CORDIC-Architekturen • Architekturen für Multiratensysteme (Abtastratenumsetzer) • Architekturen digitaler Signalgeneratoren • Maßnahmen zur Leistungssteigerung (Pipelining) • Architekturen digitaler Signalprozessoren • Anwendungen Content: • Basic algorithms of signal processing (FFT, windowing, digital FIR and IIR-filters) • Non-idealities of digital filters (quantization of filter coefficients, fixed-point arthmetic) • CORDIC-architectures • Architectures of systems with multiple sampling rates (conversion between different sampling rates) • Digital signal generation • Measures of performance improvement (pipelining) • Architecture of digital signal processors • Applications
6	**Learning objectives and skills**	Die Studierenden erlangen Grundlagenkenntnisse der Signaltheorie und können zeit- und wertkontinuierliche sowie zeit- und wertdiskrete Signale im Zeit- und Frequenzbereich definieren und erklären Die Studierenden sind in der Lage, ein klassisches Echtzeitsystem zur digitalen Signalverarbeitung konzeptionieren und die Einzelkomponenten nach den Anforderungen zu dimensionieren Die Studierenden erlangen einen Überblick über Vor- und Nachteile analoger sowie digitaler Signalverarbeitung Die Studierenden verstehen die Theorie der Fourier-Transformation und sind in der Lage, die Vorteile der Fast-Fourier-Transformation in der digitalen Signalverarbeitung zu verstehen und anzuwenden Die Studierenden können digitale Filter dimensionieren und beurteilen ===Englisch=== Students

		• can obtain fundamentals of signal theory and can define as well time-comtinous and value-continous as time-discrete and value-discrete signals in time and frequency domain • can construct a realtime digital signal processing system and dimension its components according requirements • can review pros and cons of analogue versus digitzal signal processing • can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing • can dimension digital filters and evaluate their performance
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Electronic examination (60 minutes) Klausur (E-Exam 60 Min.)
11	**Grading procedure**	Electronic examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 947709	**Auditory Models** Auditory models	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Bernd Edler
5	**Contents**	• Main components of the human auditory system • Common models • Mechanical models • Physiological models • Psychoacoustic models • Applications (hearing aids, audio coding, . . .)
6	**Learning objectives and skills**	Goals • Students understand the structure and function of the human auditory system • Students gain deeper insight into psychoacoustic phenomena, such as masking, directional and spatial hearing • Students implement and evaluate perceptual models for various applications • Students collaborate with scientists in the fields of audiology and neuroscience
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 43400	**Entzerrung und adaptive Systeme in der digitalen Übertragung** Equalisation and adaptive systems for digital communications	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Equalization and Adaptive Systems for Digital Communications (2 SWS)	2,5 ECTS
3	Lecturers	apl. Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Bei der digitalen Übertragung spielen Kanalverzerrungen aufgrund ständig steigender Datenraten eine immer grössere Rolle. Bei vielen Anwendungen müssen für eine zuverlässige Übertragung komplexe Entzerrverfahren eingesetzt werden. Dies gilt sowohl für die leitungsgebundene als auch die drahtlose Kommunikation. Z.B. werden in der xDSL-Systemfamilie (Digital Subscriber Lines), die eine schnelle digitale Übertragung über Ortsanschlussleitungen gewährleistet, oft entscheidungsrückgekoppelte Entzerrverfahren oder Vorcodierungsverfahren eingesetzt und beim Mobilfunkstandard GSM und seiner Weiterentwicklung EDGE (Enhanced Data Rates for GSM Evolution) Maximum-Likelihood-Sequenzschätzung bzw. zustandsreduzierte Entzerrung. Eng im Zusammenhang mit der eigentlichen Entzerrung stehen Adaptionsverfahren, mit denen die Parameter des Entzerrers optimal an den Übertragungskanal angepasst werden können. Lernziel: Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen. Content: Channel distortions are playing an increasingly important role in digital transmission due to constantly increasing data rates. In many applications, complex equalization techniques must be used for a reliable transmission. This applies to both wired and wireless communication. For example, decision feedback equalization or precoding techniques are often used in the xDSL (Digital Subscriber Lines) system family, which ensures fast digital transmission over local subscriber loops, and the GSM system and its advanced version EDGE (Enhanced Data Rates for GSM Evolution) employ maximum likelihood sequence estimation and state-reduced equalization. Closely related to the task of equalization are adaptation methods with which the parameters of the equalizer can be optimally adjusted to the transmission channel. Objective: The aim of the lecture is a comprehensive presentation of common equalization and adaptation methods. The participants should acquire an in-depth knowledge of the various procedures which enables them to make meaningful design decisions in practice.

6	**Learning objectives and skills**	Die Studierenden • beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung, • setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten, • vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität, • wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus, • entwerfen neuartige Verfahren für gegebene Anforderungen, • formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal, • ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu. Learning Objectives and Competences: The students - describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation, - realize various approaches in block diagrams and optimize their components, - compare equalization methods in terms of their performance, characterized by the error rate, and complexity, - select suitable methods for various applications such as wired and wireless transmission, - design novel schemes for given requirements, - formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel, - assign suitable adaptation algorithms to equalization schemes.
7	**Prerequisites**	Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Written or oral (100%)

12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung. Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992. Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999. Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995. Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996.

1	**Module name** 96312	**Bild-, Video- und mehrdimensionale Signalverarbeitung** Image, video and multidimensional signal processing	**5 ECTS**
2	Courses / lectures	Vorlesung: Image, Video, and Multidimensional Signal Processing (2 SWS) Übung: Supplements Image, Video, and Multidimensional Signal Processing	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Katja Kossira	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup

5	**Contents**	•
		  ◦ Histogram equalization, gamma correction
		•
		  ◦ Morphological filters, erosion, dilation, opening, closing
		•
		  ◦ Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity
		•
		  ◦ Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering
		•
		  ◦ Bi-linear interpolation, bi-cubic interpolation, spline interpolation
		  ◦ Image feature detection
		• Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix
		•
		  ◦ Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform
		  ◦ Image matching
		• Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm
		•
		  ◦ Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video
		•
		  ◦ Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT

6	**Learning objectives and skills**	The students • understand point operations for image data and gamma correction

		• test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data • segment image data by implementing basic classification and clustering methods • understand the principle of transformations on image data and apply them exemplarily
7	**Prerequisites**	Course on Signals und Systems I and II recommended
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam of 90 min duration
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J.-R. Ohm: |Multimedia Content Analysis|, Springer, 2016 • J. W. Woods: |Multidimensional Signal, Image, and Video Processing and Coding|, Academic Press, second edition, 2012

1	**Module name** 267499	**Linear and non-linear fibre optics**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.
6	**Learning objectives and skills**	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links
7	**Prerequisites**	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester

13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	**Module name** 48440	**Machine Learning in Signal Processing** Machine learning in signal processing	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Maschinelles Lernen in der Signalverarbeitung (2 SWS) Vorlesung: Maschinelles Lernen in der Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Michele De Vita Marc Hölle Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.
6	**Learning objectives and skills**	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232

		Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam of 90min duration
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

1	**Module name** 96300	**MIMO Communication Systems** MIMO communication systems	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	**Learning objectives and skills**	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	**Prerequisites**	Basic course in communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Written or oral (90 minutes) Written exam (Klausur), 90 minutes.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 687141	**Multiuser Information and Communications Theory** Multiuser information and communications theory	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Multiuser Information and Communications Theory (1 SWS) Vorlesung: Multiuser Information and Communications Theory (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Linear vs. nonlinear multiple-access, CDMA as a canoncal framework for any multiple-access schemes, optimum multiuser detection, linear multiuser detection, interference cancellation, rate region, multiuser source coding, time sharing, multiuser channel codes, multiple-access channel (MAC), capacity region, mutual information versus minimum-mean squared error, Gaussian MAC, power region, Gaussian vector MAC, source coding with side information, degraded broadcast channel, Gaussian broadcast-MAC duality, Gaussian vector broadcast channel, dirty-paper coding, physically degraded relay channel, scalar Gaussian relay channel, Gaussian interference channel, cut-set bound, network coding, fading channels, multiuser water filling, block fading, diversity, user diversity, capacity versus outage, near-far gain, dual antenna arrays
6	**Learning objectives and skills**	The students model any multiple access method as a special case of code-division multiple access. The students apply various algorithms for multiuser detection. The students explain various types of multiuser channels and their limits to transport information. The students explain the limits of distributed source coding algorithms. The students apply the cut-set bound. The students explain the method of dirty-paper coding. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: A basic course on information theory (can be taken in parallel)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The examination is a 30-minute oral exam.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• El Gamal, A., Kim, Y.: Network Information Theory, Cambridge University Press, 2011 • Cover, T., Thomas, J.: Elements of Information Theory, 2nd ed., Wiley, Hoboken, 2006 • Verdú, S.: Multiuser Detection, Cambridge Univ. Press, Cambridge, 1998 • Tse, D., Viswanath, P.: Fundamentals of Wireless Communications, Cambridge University Press, 2005.

1	**Module name** 302148	**Musiksignalverarbeitung - Analyse** Music processing - Analysis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Music Processing Analysis (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	Music signals possess specific acoustic and structural characteristics that are not shared by spoken language or audio signals from other domains. In fact, many music analysis tasks only become feasible by exploiting suitable music-specific assumptions. In this course, we study feature design principles that have been applied to music signals to account for the music-specific aspects. In particular, we discuss various musically expressive feature representations that refer to musical dimensions such as harmony, rhythm, timbre, or melody. Furthermore, we highlight the practical and musical relevance of these feature representations in the context of current music analysis and retrieval tasks. Here, our general goal is to show how the development of music-specific signal processing techniques is of fundamental importance for tackling otherwise infeasible music analysis problems.
6	**Learning objectives and skills**	Expertise Understand • The students present central tasks in music processing in their own words and outline possible solutions. • The students understand the properties of different forms of representation of music. Apply • The students apply basic algorithms for the analysis and comparison of music signals. • Students can predict how different musical properties will affect the signal analysis. Analyze • The students observe and discuss the meaning and impact of parameters in music analysis. • The students compare different methods of analyzing periodicities. Evaluate • The students question assumptions that are often implicitly made when using analytical methods. • Students estimate when methods might work when analyzing specific music signals and when they typically fail. Learning and methodological skills • The students prepare for the lecture using selected literature and Jupyter notebooks. • The students question existing approaches regarding their applicability in practice. • The students pay attention to efficiency issues in the algorithms discussed. Self-competence

		• The students question their understanding of what they have learned using exercises. • The students formulate questions and ask them to the lecturer and the audience in the lecture. Social skills • The students independently organize learning groups in which the subject is discussed and deepened. • The students simulate oral exams with their fellow students. Fachkompetenz Verstehen • Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze. • Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik. Anwenden • Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an. • Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken. Analysieren • Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse. • Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber. Evaluieren (Beurteilen) • Die Studierenden hinterfragen Annahmen, die implizit bei der Verwendung von Analysemethoden gemacht werden. • Die Studierenden schätzen ein, wann Methoden bei der Analyse von gewissen Musiksignalen funktionieren könnten und wann sie typischerweise versagen. Lern- bzw. Methodenkompetenz • Die Studierenden bereiten sich auf die Vorlesung anhand ausgewählter Literatur vor. • Die Studierenden hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis. • Die Studierenden beachten Fragen der Effizienz bei den diskutierten Algorithmen. Selbstkompetenz • Die Studierenden hinterfragen ihr Verständnis von dem Gelernten anhand von Übungsaufgaben. • Die Studierenden formulieren Fragen und stellen diese in der Vorlesung an den Dozenten und die Zuhörerschaft. Sozialkompetenz • Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird. • Die Studierenden simulieren mit ihren Kommilitonen mündliche Prüfungen.

7	**Prerequisites**	In this course, we discuss a number of current research problems in music processing or music information retrieval (MIR) covering aspects from information science and digital signal processing. We provide the necessary background information and give numerous motivating examples so that no specialized knowledge is required. However, the students should have a solid mathematical background. The lecture is accompanied by readings from textbooks or the research literature. Furthermore, the students are required to experiment with the presented algorithms using Python.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	http://www.music-processing.de http://www.springer.com/gp/book/9783319219448

1	**Module name** 639119	**Music Processing Analysis - Lecture and Exercise** Music processing analysis - Lecture and exercise	**5 ECTS**
2	Courses / lectures	Übung: Music Processing Analysis - Exercise (2 SWS) Vorlesung: Music Processing Analysis (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	Music signals possess specific acoustic and structural characteristics that are not shared by spoken language or audio signals from other domains. In fact, many music analysis tasks only become feasible by exploiting suitable music-specific assumptions. In this course, we study feature design principles that have been applied to music signals to account for the music-specific aspects. In particular, we discuss various musically expressive feature representations that refer to musical dimensions such as harmony, rhythm, timbre, or melody. Furthermore, we highlight the practical and musical relevance of these feature representations in the context of current music analysis and retrieval tasks. Here, our general goal is to show how the development of music-specific signal processing techniques is of fundamental importance for tackling otherwise infeasible music analysis problems.
6	**Learning objectives and skills**	Fachkompetenz Verstehen • Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze. • Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik. • Die Studierenden interpretieren Signaleigenschaften anhand von Visualisierungen (Exercise). Anwenden • Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an. • Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken. • Die Studierenden implementieren Algorithmen zur Analyse, zum Vergleich und zur inhaltsbasierten Suche von Musiksignalen (Exercise). Analysieren • Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse. • Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber. • Die Studierenden analysieren und erforschen Eigenschaften von Musiksignalen mittels automatisierter Methoden (Exercise). • Die Studierenden klassifieren und strukturieren Musikdaten mittels Lernverfahren (Exercise).

		Evaluieren (Beurteilen)
		• Die Studierenden hinterfragen Annahmen, die implizit bei der Verwendung von Analysemethoden gemacht werden.
		• Die Studierenden schätzen ein, wann Methoden bei der Analyse von gewissen Musiksignalen funktionieren könnten und wann sie typischerweise versagen.
		• Die Studierenden evaluieren automatisierte Methoden mittels geeigneter Evaluationsmaße unter Verwendung von manuell erstellten Annotationen (Exercise).
		Erschaffen
		•
		  ◦ Die Studierenden bereiten sich auf die Vorlesung anhand ausgewählter Literatur vor.
		  ◦ Die Studierenden hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
		  ◦ Die Studierenden beachten Fragen der Effizienz bei den diskutierten Algorithmen.
		  ◦ Die Studierenden entwickeln praktische Lösungswege für Problem in der Musikverarbeitung (Exercise)
		  ◦ Die Studierenden hinterfragen ihr Verständnis von dem Gelernten anhand von Übungsaufgaben.
		  ◦ Die Studierenden formulieren Fragen und stellen diese in der Vorlesung an den Dozenten und die Zuhörerschaft.
		  ◦ Die Studierenden nutzen Verbesserungshinweise des Betreuers und der Tutoren zur Verbesserung ihrer Lernstrategien (Exercise).
		  ◦ Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.
		  ◦ Die Studierenden simulieren mit ihren Kommilitonen mündliche Prüfungen.
		  ◦ Die Studierenden entwickeln und implementieren Software im Team (Exercise).
		  ◦ Die Studierenden geben Kommilitonen im Rahmen ihrer Zusammenarbeit wertschätzendes Feedback (Exercise).

7	**Prerequisites**	In this course, we discuss a number of current research problems in music processing or music information retrieval (MIR) covering aspects from information science and digital signal processing. We provide the necessary background information and give numerous motivating examples so that no specialized knowledge is required. However, the students should have a solid mathematical background. The lecture is accompanied by readings from textbooks or the research literature. Furthermore, the students are required to experiment with the presented algorithms using Python.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Oral (30 minutes) Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Meinard Müller Fundamentals of Music Processing Using Python and Jupyter Notebooks 2nd edition, 495 p., hardcover ISBN: 978-3-030-69807-2 Springer, 2021 http://www.music-processing.de/ https://www.audiolabs-erlangen.de/FMP

1	**Module name** 502007	**Musiksignalverarbeitung - Synthese** Music processing - synthesis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Musikverarbeitung - Synthese (2 SWS)	-
3	Lecturers	Dr.-Ing. Maximilian Schäfer	

4	**Module coordinator**	Dr.-Ing. Maximilian Schäfer
5	**Contents**	• Verarbeitung von Audiosignalen durch parametrische Filter und Effekte • Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese • Klangwiedergabe in echten und virtuellen Räumen • Klangbeispiele und Demonstrationen • Programmiersprachen für Audio-Echtzeit-Verarbeitung *Content*: • a short history of electrical and electronic music • processing of audio signals by parametric filters and effects • digital sound synthesis • sound reproduction in real and in virtual environments • sound examples and demonstrations • programming languages for audio real-time processing
6	**Learning objectives and skills**	Die Studierenden • beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung, • wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an, • gestalten eigene Software-Realisierungen zur Klangsynthese, • entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen. The students • specify the special requirements for audio realtime processing, • apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds, • design their own software realizations for sound synthesis • implement technical systems for digital music.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)

12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Das Vorlesungsskript und weitere Zusatzmaterialien zur Vorlesung werden via StudOn zur Verfügung gestellt.

1	**Module name** 44120	**Pattern Analysis** Pattern analysis	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.-Ing. Christian Riess
5	**Contents**	This lecture is the sequel to the lecture "Pattern Recognition". As such, it covers topics from the chapters 8-14 from the book "Pattern Recognition and Machine Learning" by Christopher Bishop. These topics include various aspects of Bayesian modeling, including (but not limited to) probabilistic graphical models, mixture modeling, variational inference, sampling methods, manifold learning, Markov random fields, hidden Markov models, tree-based methods and ensembling.
6	**Learning objectives and skills**	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Variable (60 minutes) Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten. / The form of examination is a written exam with multiple choice with a duration of 60 minutes.
11	**Grading procedure**	Variable (100%)

12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Begleitende Literatur / Accompanying literature: • C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 • A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013

1	**Module name** 44130	**Pattern Recognition** Pattern recognition	**5 ECTS**
2	Courses / lectures	Übung: PR Exercise (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Linda-Sophie Schneider Dr.-Ing. Siming Bayer Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	**Learning objectives and skills**	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	**Prerequisites**	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english english
16	**Bibliography**	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009 • Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	**Module name** 250058	**Signal Analysis** Signal analysis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Signalanalyse (2 SWS)	-
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	**Module coordinator**	Dr.-Ing. Heinrich Löllmann
5	**Contents**	Es werden im Rahmen dieser Vorlesung unterschiedliche Verfahren zur Analyse digitaler Signale, sowie deren Anwendungsmöglichkeiten behandelt. Die folgenden Konzepte werden dabei insbesondere behandelt: • Fourieranalyse von Signalen • Signalanalyse mittels Zeit-Frequenz-Transformationen • Parametrische und nichtparametrische Signalanalyse • Verfahren zur Frequenzschätzung • Räumliche Signalanalyse • Filterbänke und Wavelets. In this course, different approaches for the analysis of digital signals and their applications are treated, which comprises the following topics: • Fourier analysis of signals • Signal analysis by means of time-frequency transformations • Parametric and non-parametric signal analysis • Frequency estimation • Spatial signal analysis • Filter-banks and wavelets.
6	**Learning objectives and skills**	Die Studierenden • beschreiben, welche Methoden der Signalanalyse für unterschiedlichen Arten von Signalen angewendet werden • beschreiben grundlegende Methoden der spektralen Signalanalyse • erläutern wodurch die spektrale und zeitliche Auflösung bei der Spektralanalyse von Signalen begrenzt wird • beschreiben die Konzepte sowie die Vor- und Nachteile der parametrischen und nichtparametrischen Signalanalyse • erklären unterschiedliche Verfahren der Zeit-Frequenz-Analyse • stellen die Analyse von Signalen mittels Filterbänke und Wavelets dar • können Verfahren zur Frequenzschätzung erläutern • formulieren Verfahren zur Analyse räumlicher Signale. The students • describe which methods for signal analysis can be applied for different types of signals • describe fundamental approaches for spectral signal analysis • explain the limiting factors for the time and frequency resolution for the spectral analysis of signals • describe concepts as well as the pros and cons of parametric and non-parametric signal analysis • explain different approaches for time-frequency analysis

		• describe the analysis of signals by means of filter-banks and wavelets • explain methods for frequency estimation • formulate approaches for spatial signal analysis.
7	**Prerequisites**	Fundierte Kenntnisse in digitaler Signalverarbeitung. Requirements Solid knowledge in digital signal processing
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Mündliche Prüfung mit einer Dauer von 30 min. Oral examination of 30 min duration.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	P. Stoica und R. Moses: "Spectral Analysis of Signals", Pearson Prentice Hall, 2005

1	**Module name** 788996	**Speech Enhancement** Speech enhancement (oral examination)	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Speech Processing (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Emanuël Habets	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	*Course Description* We live in a noisy world! In all applications related to speech, from hands-free communication to human-machine interfaces, a speech signal of interest captured by one or more microphones is contaminated by noise and reverberation. The quality and intelligibility of the signal of interest depend highly on the level of noise and reverberation. Therefore, it is highly desirable, and sometimes even indispensable, to "clean up" the captured signals before storage, transmission, or reproduction. This course discusses both model-driven and data-driven methods to estimate the signal of interest. It aims to provide a strong foundation for researchers, engineers, and graduate students interested in signal and speech enhancement. *Relation to other courses* This course is the most advanced course offered by the university on this topic, and serves as an excellent basis from which to commence research in the area. Various aspects of the course bring students up to date with the very latest developments in the field, as seen in recent international conferences and journals. This course is well complimented by |Selected Topics in Perceptual Audio Coding| (Prof. Herre) and |Auditory Models| (Prof. Edler).
6	**Learning objectives and skills**	Students • Formulate the speech enhancement problem mathematically. • Derive optimal single- and multi-channel filters to reduce noise and reverberation. • Evaluate and compare the performance of single- and multi-channel filters for speech enhancement. • Understand how reference signals and other prior information can be used in a speech enhancement system. • Understand the limitations and challenges of existing speech enhancement systems. • Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids. • Design a microphone array and analyze its performance. • Design a speech enhancement system for a given acoustic scenario. • Evaluate both subjectively and objectively the performance of a speech enhancement system in terms of the speech quality and intelligibility.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral oral examination (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 43420	**Transmission and Detection for Advanced Mobile Communications** Transmission and detection for advanced mobile communications	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	The aim of this lecture is that the students acquire a basic knowledge of advanced transmission and detection techniques which are relevant to practical mobile communications systems. In the first part, it is shown how equalization schemes like decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE) can be applied to the GSM/EDGE (Enhanced Data Rates for GSM Evolution) standard. Also, channel estimation for GSM/EDGE is covered. In GSM/EDGE, disturbance by interfering signals of other users is a further major problem. Therefore, interference cancellation algorithms are discussed in detail. The cases of several receive antennas and one receive antenna (single antenna interference cancellation) are distinguished. Several receive antennas can be also utilized for increasing the robustness against fading, applying diversity combination techniques. In the case of the availability of several transmit antennas only, additional space-time coding has to be used for realization of diversity gains. These aspects are also discussed in depth. Furthermore, an introduction to code-division multiple access (CDMA) transmission is given and it is shown how CDMA is applied in the UMTS system. The lecture is concluded by an introduction to digital transmission in the Long Term Evolution (LTE) system.
6	**Learning objectives and skills**	The students • describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE), • apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system, • formulate channel estimation methods for mobile communication systems, • characterize the interference problem in GSM / EDGE, - design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively, • characterize the performance of mobile communication networks for different reception schemes, • devise receivers for the realization of diversity gains for multiple receive antennas,

		• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, • describe transmission schemes which are based on code-division multiple access (CDMA), • apply reception techniques for CDMA to the UMTS system, • characterize the uplink transmission in the Long Term Evolution (LTE) system, • develop receivers for LTE. Die Studierenden • beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE), • wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an, • formulieren Kanalschätzverfahren für Mobilfunksysteme, • charakterisieren das Interferenzproblem bei GSM/EDGE, • entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen, • bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren, • konzipieren Empfänger zur Realisierung von Diversitätsgewinnnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codierverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität, • beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren, • wenden Empfangsverfahren für CDMA auf das UMTS-System an, • charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE), • entwerfen Empfänger für LTE.
7	**Prerequisites**	Systemtheorie, Nachrichtenübertragung
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral Oral exam, 30 minutes.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Lecture notes

1	**Module name** 498723	**Transformationen in der Signalverarbeitung** Transforms in signal processing	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.-Ing. Jürgen Seiler
5	**Contents**	Das Modul "Transformationen in der Signalverarbeitung" behandelt mehrere verschiedene Transformationen, die im Rahmen der Signalverarbeitung Verwendung finden. Dabei werden zuerst die grundlegenden Konzepte von Transformationen diskutiert und die Vorteile die Transformationen mit sich bringen erläutert. Im Anschluss daran werden die grundlegenden Eigenschaften von Integraltransformationen betrachtet und die Laplace- und die Fourier-Transformation im Detail untersucht. Um auch zeitlich veränderliche Signale gut transformieren zu können werden danach die Kurzzeit-Fourier-Transformation und die Gabor-Transformation eingeführt. Im Anschluss daran erfolgt eine Betrachtung der Auswirkung der Abtastung auf transformierte Signale, bevor die z-Transformation als Transformation für diskrete Signale behandelt wird. Abschließend erfolgt die Betrachtung weiterer Transformationen für diskrete Signale wie der Diskreten Fourier-Transformation oder linearer Block-Transformationen. The module "Transforms in Signal Processing" covers several different transforms which are used in the field of signal processing. For this, first the basic concepts of transforms are discussed and the advantages which are offered by the different transforms are presented. Subsequent to this, fundamental properties of integral transforms are considered and the Laplace- and the Fourier-Transform are examined in detail. To be able to transform time-varying signals, the Short-Time Fourier-Transform and the Gabor-Transform are introduced, afterwards. Subsequent to this, the impact of sampling on transformed signals is analyzed before the z-Transform as a transform for discrete signals is covered. Finally, further transforms for discrete signals like the Discrete Fourier-Transform or Linear-Block Transforms are discussed.
6	**Learning objectives and skills**	Die Studierenden können nach Besuch der Vorlesung • Anwendungsmöglichkeiten von Transformationen bestimmen • Integraltransformationen gegenüberstellen und untersuchen • die Existenz von Transformationen hinterfragen • die Eindeutigkeit von Transformationen überprüfen • Sätze und Eigenschaften von Transformationen entwickeln • zu Transformationen zugehörige inverse Transformationen einschätzen • die Zusammenhänge zwischen verschiedenen Transformationen einschätzen • auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern • Symmetriebeziehungen von Transformationen ausarbeiten

		• Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten Educational Objectives and Competences: After attending the lecture, students will be able to • determine applications of transforms • contrast and examine integral transforms • question the existence of transforms • evaluate the uniqueness of transforms • develop theorems and properties of transforms • evaluate to transforms corresponding inverse transforms • evaluate the relationships between different transforms • asses the relationship between original signal and transformed signals • devise the symmetry properties of transforms • devise the relationship between continuous and discrete signals
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Mündliche Prüfung von 30 min Dauer.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart

1	**Module name** 96270	**Kanalcodierung** Channel coding	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Kanalcodierung (3 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	**Module coordinator**	Dr.-Ing. Clemens Stierstorfer
5	**Contents**	1) Introduction and Motivation 2) Fundamentals of Block Coding 3) Introduction to Finite Fields I 4) Linear Block Codes 5) Linear Cyclic Codes 6) Introduction to Finite Fields II 7) BCH and RS Codes 8) Convolutional Codes 9) Codes with Iterative Decoding
6	**Learning objectives and skills**	Das Modul Kanalcodierung umfasst eine Einführung in die Grundlagen der algebraischen, fehlerkorrigierenden Blockcodes sowie einen Einstieg in die Thematik der Faltungscodes. Iterativ decodierte Codeschemata wie Turbo-Codes und LDPC-Codes werden ebenfalls eingeführt. Im Einzelnen sind die Inhalte oben aufgeführt. Die Studierenden definieren die Problematik der Kanalcodierung, grenzen sie von anderen Codierverfahren (z.B. der Quellencodierung) ab und kennzeichnen die unterschiedlichen Ansätze zur Fehlerkorrektur und -erkennung. Sie nennen Beispiele für Einsatzgebiete von Kanalcodierung und geben einen Überblick über die historische Entwicklung des Fachgebiets. Die Studierenden erstellen Übertragungsszenarien für den Einsatz von Kanalcodierung bestehend aus Sender, Übertragungskanal und Empfänger und beachten dabei die Grundannahmen beim Einsatz von Blockcodes bzw. der Modellierung der Kanäle. Sie formulieren mathematische Beschreibungen der Encodierung sowie der optimalen Decodierung bzw. suboptimaler Varianten. Die Studierenden beherrschen die Grundlagen fehlerkorrigierender linearer Blockcodes, beschreiben diese mathematisch korrekt mittels Vektoren und Matrizen über endlichen Körpern und implementieren und bewerten zugehörige Encoder- und Decoderstrukturen insbesondere Syndromdecoder. Dabei modifizieren sie Generatormatrizen, ermitteln Prüfmatrizen und erstellen Syndromtabellen. Sie schätzen die minimale Hammingdistanz von Codes mittels Schranken ab und können den erzielbaren Codegewinn erläutern. Sie kennen und benutzen beispielhaften Codefamilien (z.B. Hamming-Codes, Simplex-Codes, Reed-Muller-Codes). Die Studierenden erkennen die Vorteile zyklischer linearer Blockcodes und beschreiben diese mit Polynomen über endlichen Körpern. Sie nutzen die Restklassenrechnung bzgl. Polynomen zur Umsetzung systematischer Encoder und zur Realisierung von Syndromdecodern mittels Schieberegisterschaltungen. Sie kennen beispielhafte Codefamilien.

Die Studierenden nutzen Primkörper, Erweiterungskörper, Minimalpolynome und Kreisteilungsklassen sowie die Spektraldarstellung über endlichen Körpern zur Realisierung von BCH- und Reed-Solomon-Codes gemäß der BCH-Schranke. Sie verstehen die Grundlagen der Decodierung von BCH- und Reed-Solomon-Codes. Sie skizzieren und erläutern die Kanalcodierkonzepte von CD und DVD.
Die Studierenden erklären die Unterschiede von Faltungscodes und Blockcodes, skizzieren anhand von tabellierten Generatorpolynomen zugehörige Encoder und erläutern diese. Sie erklären die Funktionsweise des optimalen Decoders (MLSE) und demonstrieren diese beispielhaft.
Die Studierenden verstehen die Grundlagen der iterativen Decodierung, insbesondere wenden sie die Grundlagen des Information Combining zur Kombination von verschiedenen Beobachtungen an. Sie verstehen die Bedeutung von Log-Likelihood-Ratios bei iterativen Decodieruvorgängen und berechnen diese. Sie skizzieren die grundlegenden Encoder- und Decoderstrukturen von Turbo-Codes und die Grundzüge der Codierung mit LDPC-Codes u.a. der Decodierung mittels Belief Propagation.
Die Vorlesung erfolgt wechselweise auf Deutsch oder Englisch (Winter/ Sommer). Die zur Verfügung gestellten Unterlagen sind ausschließlich in Englisch gehalten. Die Studierenden verwenden entweder die englischen Fachtermini sicher oder kennen diese und drücken sich sicher mit den entsprechenden deutschen Fachbegriffen aus.
Die Umsetzung der angegebenen Algorithmen in eine Programmiersprache (C, Matlab usw.) sollten die Studierenden zu diesem Zeitpunkt des Studiums üblicherweise beherrschen. Übungen hierzu bleiben der Eigeninitiative überlassen.

Students define the problems of channel coding, how to distinguish it from other coding methods (such as source coding) and how to describe the various different approaches to error correction and detection. They are able to list example application areas of channel coding and give an overview of the historical development of the field.
Furthermore, they describe and analyze transmission scenarios for the application of channel coding which consist of transmitter, transmission channel and receiver, taking into account the general assumptions for applying block codes or modeling the channels. They formulate mathematical descriptions of encoding, optimal decoding and sub-optimal methods.
Students illustrate the principles of error-correcting linear block codes and describe them mathematically using vectors and matrices over finite fields. They implement and analyze corresponding encoder and decoder structures, in particular syndrome decoders, and modify generator matrices, construct test matrices and create syndrome tables. They estimate the minimum Hamming distance of codes using bounds and are able to explain the coding gain that can be achieved in individual cases. They analyze and use example code families (e.g. Hamming codes, simplex codes, Reed-Muller codes).

		Students explain the advantages of cyclic linear block codes and how to describe them with polynomials over finite fields. They apply polynomial modular arithmetic to implement systematic encoders and realize syndrome decoders using shift register circuits. They know and use exemplary code families. Students use prime fields, extension fields, minimal polynomials and cyclotomic cosets, and spectral representation over finite fields to implement BCH and Reed-Solomon codes using the BCH bound. They understand the foundations of decoding BCH and Reed-Solomon codes and how to sketch and explain the channel coding concepts of CDs and DVDs. Students are able to describe the differences between convolutional codes and block codes, to sketch the respective encoders based on tabulated generator polynomials and to explain them. They are able to explain how optimal decoders (MLSE) work using examples. Students sketch the foundations of iterative decoding. In particular, they apply methods of information combining to combine different observations. They use and calculate log-likelihood ratios in iterative decoding processes, sketch the basic encoding and decoding structures of turbo codes and the basics of coding using LDPC codes (including decoding using belief propagation). Students either are able to use the English technical terms correctly or know them and are able to express themselves using the respective technical terms in German.
7	**Prerequisites**	Es ist hilfreich, wenn die Studierenden die erlernten Algorithmen in eine Programmiersprache (C, Matlab usw.) umsetzen können. It would be very helpful if the participants can implement the specified algorithms into a programming language (C, Matlab, etc.).
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Hilfsblatt, Taschenrechner: Sie können ein einzelnes A4-Blatt (Vorder- und Rückseite oder andere Blätter mit offensichtlich identischer Gesamtfläche) verwenden, um Ihre eigene, handschriftliche Formelsammlung aufzuschreiben. Sie können einen nicht programmierbaren Taschenrechner verwenden. ——————————— The examination is a 90-minute written test. Cheat Sheet, Calculator: A single A4 sheet (front and back, or any other collection of sheets with an obviously identical total area size) can be

		used to write down your own handwritten collection of formulas, etc. You may also bring a non-programmable calculator.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	• J. Huber, R. Fischer, C. Stierstorfer: Folien zur Vorlesung • M. Bossert: Kanalcodierung, Oldenbourg Wissenschaftsverlag, 3. Auflage, 2013 • M. Bossert: Channel Coding for Telecommunications, John Wiley & Sons, 1999 • B. Friedrichs: Kanalcodierung, Springer Verlag, 1996 • S.B. Wicker: Error Control Systems for Digital Communications and Storage, Prentice-Hall, 1995

Lab courses

1	**Module name** 894349	**Audio Processing Laboratory** Audio processing laboratory	**2,5 ECTS**
2	Courses / lectures	Praktikum: Audio Processing Laboratory (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller Prof. Dr. Emanuël Habets Prof. Dr.-Ing. Jürgen Herre Prof. Dr.-Ing. Bernd Edler	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	This lab course offers a general introduction to Python and possibly also to other languages (MATLAB, R, ...). In particular, functions, transforms, and algorithms that are important for analyzing and processing audio signals are covered. After a general part, the lab course will allow the participants to delve into a more specific application within audio and acoustic signal processing.
6	**Learning objectives and skills**	The goal of this lab course is to acquire a deeper understanding of audio processing techniques by experimenting with, modifying and extending existing code. Furthermore, programming skills in Python and possibly also in other languages (MATLAB, R, ...) are acquired. The students understand and implement computer programs for specific experiments described in the script accompanying the lab. They test and evaluate their programs by conducting a series of experiments within the field of audio signal processing. They understand the requirements of practical realizations, synthesize a solution for a given problem, and apply advanced disciplinary knowledge and skills in signal processing. The students evaluate and interpret results by applying various visualization techniques and statistical methods. They collaborate with fellows students, discuss their solutions, give feedback to each other, and reflect upon the underlying theory as well as implementation issues.
7	**Prerequisites**	This lab course requires a good understanding of basic principles in signal processing and some basic programming skills. Furthermore, it is beneficial to have some background in one of the more specific topics offered by the International Audio Laboratories Erlangen.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement The lab course consists of four lab units. Each unit is presented for 15 minutes per participant, and is graded with up to three points. In order to pass the lab course, a total of at least 6 points must be achieved, with at least 1 point in each individual unit.
11	**Grading procedure**	Practical achievement (pass/fail)

12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 92356	**Praktikum Communications Systems Design** Laboratory course: Communications systems design	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Communications Systems Design	2,5 ECTS
3	Lecturers	Torsten Reißland	

4	**Module coordinator**	Arslan Ali Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi
5	**Contents**	The lab course is based on the GNU Radio software platform. It includes a general introduction into GNU Radio, Python programming and Software Defined Radios (SDRs), as well as a more thorough introduction into USRPs. The students learn how to set up pure simulations of communication systems in Gnu Radio, how to use it in conjunction with Software Defined Radios and how to develop and test custom modules in Python. Regarding Gnu Radio the usage of different data types, variables, structures (e.g. vectors and streams), hierarchical development and flow control are part of the course. The course is structured into 8 exercises which first cover different modulation schemes like AM, PAM, and OFDM. In the later part of the course topics of practical relevance like synchronization (time, frequencye, phase, frame) and equalization are covered. One synchronization scheme for OFDM is to be implemented by the students in Python. Most exercises have the goal to transmit audio data, first in a simulation, then in a loopback with one device and later between several devices. Setups to evaluate metrics like eye diagrams and EVM are introduced in a practical manner. Passing an introduction test is prerequisite for the participation in the lab course.
6	**Learning objectives and skills**	Students can • bridge the gap between communications theory, analog/digital baseband, and RF design • develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions • determine the design parameters and assess the interaction between various analog and digital parts • create efficient Tx/Rx programs and signal processing algorithms in GNU Radio • implement channel estimation and equalization algorithms in TDD and FDD systems • demonstrate OFDM based systems • quantify and evaluate system performance using EVM and impairments analysis
7	**Prerequisites**	Prerequisite for this course is proper knowledge in the fundamentals of digital communications and digital signal processing.
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement At the begin of the lab course, the prerequisites are tested with a short (15 min) written test. Passing this test is required to participate in the experiments. The lab course itself consists of six experiments. At the end of every experiment the students have to present their respective final result. The understanding of the theoretical concepts will be check orally.
11	**Grading procedure**	Practical achievement (100%)
12	**Module frequency**	Every semester The lab course takes place as a block course (1 week) in each semester.
13	**Workload in clock hours**	Contact hours: 40 h Independent study: 35 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 93511	**Praktikum Digitale Übertragung** Digital communication Lab	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Digitale Übertragung (3 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	• 1 Digital Transmission of Data 1.1 Introduction, Background, Motivation 1.2 Purpose 1.3 Lab Environment 1.3.1 Transmitter 1.3.2 Receiver 1.4 Lab Exercises 1.4.1 Signal Generation at the Transmitter 1.4.2 (Coherent) Receivers for Pulse Amplitude Modulation 1.4.3 Transmission over the AWGN Channel • 2 Implementation of Transmitter and Receiver in Matlab 2.1 Introduction, Background, Motivation 2.2 Purpose 2.3 Lab Environment 2.3.1 Oversampling factor 2.3.2 Transmitter 2.3.3 Channel 2.3.4 Receiver 2.4 Lab Exercises 2.4.1 Transmitter 2.4.2 Channel 2.4.3 Receiver 2.4.4 BER calculation • 3 Variants of PAM-Transmission Schemes 3.1 Introduction, Background, Motivation 3.2 Purpose 3.3 Lab Environment 3.4 Lab Exercises 3.4.1 Basic Pulse Shape 3.4.2 Offset-QAM 3.4.3 Gaussian Minimum Shift-Keying 3.4.4 "Carrierless Amplitude and Phase Modulation • 4 OFDM 4.1 Introduction, Background, Motivation 4.1.1 Orthogonal Frequency-Division Multiplexing 4.1.2 Bit Loading 4.2 Purpose 4.3 Lab Environment 4.4 Lab Exercises 4.4.1 OFDM Transmitter 4.4.2 OFDM Receiver 4.4.3 Bit Loading • 5 Signal Space Representation 5.1 Introduction, Background, Motivation 5.2 Purpose 5.3 Lab Environment 5.4 Signal Space Representation 5.4.1 Orthogonality 5.4.2 Orthogonalization 5.5 Lab Exercises 5.5.1 Transmission with signal elements 5.5.2 Gram-Schmidt Procedure 5.5.3 Frequency Shift Keying • 6 Signal Processing in MIMO Systems 6.1 Introduction, Background, Motivation 6.2 Lab Environment 6.3 Lab Exercises 6.3.1 System Model 6.3.2 SISO 6.3.3 SIMO 6.3.4 MIMO
6	**Learning objectives and skills**	Die Studierenden vertiefen und erweitern ihre Kenntnisse der digitalen Nachrichtenübertragungsverfahren und der zugehörigen mathematischen Grundlagen anhand von Laborversuchen. Sie analysieren die Eigenschaften digitaler Pulsamplitudenmodulation und Varianten digitaler PAM. Dazu erzeugen sie im Labor mit der zur Verfügung gestellten Ausrüstung Sendesignale, die sie mit Hilfe üblicher Messgeräte (Oszilloskop, Effektivwertmesser) analysieren. Sie bauen Übertragunsstrecken für diese PAM-Verfahren auf und untersuchen die Effekte auf Empfängerseite. Sie bestimmen Störabstände, Fehlerraten usw. Des weiteren setzen die Studierenden ihre Kenntnisse der PAM-Übertragungsverfahren in selbst erstellte MATLAB-Routinen um, die die Simulation einer kompletten PAM-Übertragung mit Sender, Kanal

und Empfänger am Rechner modellieren. In einem weiteren Versuch ergänzen die Studierenden dieses Modell um eine OFDM-Übertragung und analysieren die Funktionsweisen von OFDM-Sendern und -empfängern. Sie untersuchen die Arbeitsweise von Ladealgorithmen bei OFDM-Systemen und implementieren diese in MATLAB.
Die Studierenden verdeutlichen sich das Konzept der Signalraumdarstellung in der digitalen Übertragung und implementieren ein beispielhaftes System in MATLAB. Sie erstellen Routinen zur Gram-Schmidt-Orthogonalisierung und zur FSK-Übertragung in MATLAB.
Die Studierenden analysieren einfache MIMO-Szenarien und implementieren entsprechende Empfängeralgorithemen.
Die Studierenden bereiten die Bearbeitung der Versuche im Labor anhand der ausgegeben Unterlagen und den Unterlagen zum Modul "Digitale Übertragung selbständig vor. Sie sind in der Lage, die für den jeweiligen Versuch notwendigen theoretischen Kenntnisse vor und während des Versuchs zu erklären und zur Lösung der Laboraufgaben und vorbereitenden Hausaufgaben einzusetzen. Sie dokumentieren die durchgeführten Versuche selbständig in ihren Unterlagen, so dass die Nachvollziehbarkeit der Arbeiten jederzeit gegeben ist. Die Arbeit im Labor organisieren sie in Kleingruppen (2-3 Personen) selbst.
Sie erkennen die Notwendigkeit gewissenhafter Vorbereitung der Lerninhalte und disziplinierter Arbeitsweise im Labor.
Die Unterrichtssprache ist wahlweise Deutsch oder Englisch. Unterlagen werden ausschließlich auf Englisch zur Verfügung gestellt, weswegen die Studierenden die englischen Fachtermini kennen und nutzen.

Students deepen and extend their knowledge of digital message transmission methods and the associated mathematical principles by means of laboratory experiments. They analyze the properties of digital pulse amplitude modulation and variants of digital PAM. To this end, they generate transmit signals in the laboratory using the equipment provided and analyze them with the aid of standard measuring instruments (oscilloscope, rms meter). They build transmission links for these PAM methods and investigate the effects on the receiver side. They determine signal-to-noise ratios, error rates, etc.
Furthermore, the students implement their knowledge of the PAM transmission methods in self-created MATLAB routines, which model the simulation of a complete PAM transmission with transmitter, channel and receiver on the computer. In another experiment, students add an OFDM transmission to this model and analyze the operation of OFDM transmitters and receivers. They investigate the operation of loading algorithms in OFDM systems and implement them in MATLAB.
Students clarify the concept of signal space representation in digital transmission and implement an example system in MATLAB. They create routines for Gram-Schmidt orthogonalization and FSK transmission in MATLAB. Students analyze simple MIMO scenarios and implement corresponding receiver algorithms.
The students independently prepare the experiments in the laboratory using the issued documents and the documents for the module "Digital

		Transmission". They are able to explain the theoretical knowledge required for the respective experiment before and during the experiment and use it to solve the laboratory tasks and preparatory homework. They independently document the experiments carried out in their records so that the supervisors can trace the work at any time. They organize the work in the laboratory themselves in small groups (2-3 persons). They recognize the necessity of certain preparation of the learning content and disciplined working methods in the laboratory. The language of instruction is either German or English. Documents are provided exclusively in English, which is why the students know and use the English technical terms.
7	**Prerequisites**	Das Praktikum richtet sich ausschließlich an Studierende, die das Moduls "Digitale Übertragung bereits absolviert haben oder es parallel zum Praktikum belegen. Die Inhalte dieses Moduls sind unabdingbare Grundlage und werden von den Studierenden beherrscht, d.h., sie können die entsprechenden Zusammenhänge erklären, Problemstellungen mathematisch formulieren und benötigte Größen berechnen. Grundlegende Kenntnisse der Software MATLAB sind notwendig (bspw. aus "Software für die Mathematik" oder "Simulationstools"). The lab course is aimed exclusively at students who have already completed the "Digital Transmission" module or who are taking it in parallel with the lab course. The contents of this module are an indispensable basis and are mastered by the students, i.e. they can explain the corresponding relationships, formulate problems mathematically and calculate required quantities. Basic mastery of the MATLAB software is necessary
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement • There are 5 experiments to complete as well as an online test on Matlab knowledge and basic knowledge of digital communications. The details are described in the course materials. • Each experiment must be prepared in writing at home. The preparation will be checked and evaluated at the beginning of each experiment (sufficient/insufficient). • The results of each experiment must be recorded on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/insufficient). The measured results must be documented in writing. • To pass the course, 5 sufficient experiment preparations, 5 sufficient experiment executions and the passed asynchronous online test are required.

		• Es sind 5 Experimente zu absolvieren sowie vorab ein Online-Test zu Matlab-Kenntnissen und Grundkenntnissen in digitaler Kommunikation. Die Einzelheiten sind in den Kursunterlagen beschrieben. • Jedes Experiment muss zu Hause schriftlich vorbereitet werden. Die Vorbereitung wird zu Beginn eines jeden Experiments überprüft und bewertet (ausreichend/nicht ausreichend). • Die Ergebnisse jedes Experiments sind während der Durchführung des Experiments auf den Versuchsrechnern festzuhalten (Programmieraufgaben) und werden am Ende des Experiments kontrolliert (ausreichend/nicht ausreichend). Die gemessenen Ergebnisse sind schriftlich zu dokumentieren. • Zum Bestehen des Kurses sind 5 ausreichende Versuchsvorbereitungen, 5 ausreichende Versuchsdurchführungen sowie der bestandene asynchrone Online-Test erforderlich.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german english
16	**Bibliography**	• Skriptum zum Praktikum • Skriptum zur Vorlesung Digitale Übertragung bzw. Digital Communications • übliche Standardlehrwerke zur Thematik (Proakis, Haykin usw.)

1	**Module name** 97520	**Laborpraktikum Digitale Signalverarbeitung**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Digital Signal Processing (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Heinrich Löllmann Prof. Dr.-Ing. Sebastian Schlecht	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
5	**Contents**	In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters. The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing. The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required. The course requires previous experience in Python programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises is strongly recommended.
6	**Learning objectives and skills**	The students • create functional Python programs for the individual pre-drawn experiments and apply the knowledge acquired in the lecture and exercise • analyze and evaluate the algorithm they have implemented • understand the requirements of practical implementations of digital signal processing algorithms • reflect on their own learning process during the lab course.
7	**Prerequisites**	Strongly recommended are courses on signals and systems
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement Students must successfully complete 5 experiments and then work on a scientific project in groups of two, about which a 3 to 4-page documentation must be prepared. At the beginning of each experiment, the status of the preparation and the experimental results of the previous session are checked in a written test. To pass the lab course, a minimum number of points from the tests and the group project is required.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in winter semester

13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	The script for this lab course will be handed out at the introductory meeting. Moreover, the following books are recommended • J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007. • A.V. Oppenheim, R.V. Schafer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975. • K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012

1	**Module name** 97525	**Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen** Laboratory course: Image and video signal processing on embedded platforms	**2,5 ECTS**
2	Courses / lectures	Praktikum: Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen (3 SWS)	2,5 ECTS
3	Lecturers	Alexander Kopte PD Dr.-Ing. Jürgen Seiler	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	Today, many image and video signal processing applications are running on embedded systems. However, the computational power and the energy storage is a limiting demand for embedded systems. Nevertheless, daily mobile devices like smartphone and tablet are able to perform signal processing tasks for image and video signals, for example coding of images and videos, the creation of a panorama or the calculation of images with high dynamic range. The image and video signal processing on embedded systems lab course should show the challenges that occur while handling with such mobile devices and the implementation of such algorithm on an embedded system. Therefore, Raspberry Pis as embedded systems and Python as coding language is used in the laboratory. The experiments include the setup of the Raspberry Pi, an introduction to Python and an introduction to image and video signal processing. In addition, a camera will be connected, signal processing will be done with the camera and digital filters are implemented. Moreover, the laboratory includes different computer vision applications like the creation of a panorama.
6	**Learning objectives and skills**	The students • understand the challenges of the embedded system • make use of the coding language Python for image and video signal processing algorithms • implement functional programs with Python • evaluate the blocks of computer vision algorithms • evaluate the self-implemented programs by subjective and objective comparison • reflect the learning process in the laboratory.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement The laboratory is based on nine experiments, which are described in the laboratory script. Every experiment has to be prepared at home and will be checked before every experiment. The results of the prepared tasks in the laboratory will be checked at the end

		of the experiment. For this, the participants have to explain their developed results to the supervisors. The laboratory is passed if all nine experiments are successfully completed.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session.

1	**Module name** 97651	**Laborpraktikum Image and Video Compression** Laborpraktikum Multimediakommunikation	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr. Christian Herglotz
5	**Contents**	**Content** • Introduction to MATLAB • Implementation of the single video codec processing blocks • Integration into the video codec pipeline, tests, and extensions • Participation in a subjective video test of selected implementations • Presentation and discussion of the achieved results
6	**Learning objectives and skills**	The students • create a fully functional program using the programming environment MATLAB, • evaluate the processing blocks of a typical video codec, • design their own video codec and enhance it by extensions of their choice, • evaluate their implemented video codecs in a subjective comparison, • reflect upon the methods conveyed during the laboratory.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement The lab course comprises ten sessions of four hours plus two sessions of two hours, which include 7 work packages, a subjective test, and a final presentation. Each work package requires a preparation in written form and will be checked and reviewed (pass/fail) before the start of each session. During each of the ten mandatory lab sessions, the students are required to work on programming tasks, which will be reviewed at the end of each session (pass/fail). After these ten programming sessions, a working video codec has to be handed in. Besides, the students have to participate a subjective test, where the codec results are evaluated. In the last session, each video codec has to be presented by the students. A certificate confirming the successful participation in the laboratory is received if all work packages have been sufficiently prepared and implemented, if the results of all work packages have been combined into a functional and running video codec which is suitable for subjective testing, if

		the subjective video test has been participated in, and if the final video codec has been presented during the final presentation.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 30 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	The lab course notes will be distributed during the introductory meeting.

1	**Module name** 878210	**Praktikum Machine Learning in der Signalverarbeitung** Lab course machine learning in signal processing	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	This is an advanced level lab course in machine learning. Imagine a car driving on an autobahn in an automatic mode. Among other things, the car needs to steer itself to keep driving in it's own lane. To accomplish this, the central problem is to detect the road-lane markings. These are the white solid or dashed lines that are drawn on each side of the lane. The standard modern approach to solve this type of problems is to take a large dataset of labeled examples and train a deep neural network model to accomplish the task. This is how car and pedestrian detection algorithms are developed. The difficulty with the road-lane markings is that there is no labeled dataset of them and creating such dataset would cost millions of dollars. In this lab course we will solve this problem using transfer learning and mathematical modeling: • Create cartoon-like artificial images of a road with known locations for the lane markings. • Train deep neural network on these artificial images with heavy data augmentations that mimic real-world images. • Create a dataset of unlabeled real-life videos by downloading and organizing examples from youtube. • Create a machine learning pipeline for working with these videos efficiently. • Apply the neural network that has been trained on artificial data to the real world videos. • Analyze the quality of results produced by the network. • Use mathematical modeling to correct the outputs of the network. • Retrain the network on the dataset composed of the corrected outputs. • Measure and analyze the quality of the results. The software will be written in Python using JupyterLab development framework. Access to modern GPU server will be provided. The best students will have the opportunity to contribute to the creation of state-of-the-art lane detection system for self-driving cars during or after the corse.
6	**Learning objectives and skills**	Students are able to: • Independently design machine learning pipelines to solve complex problems in artificial intelligence. • Choose appropriate algorithms for the problem at hand.

		• Use standard packages for machine learning in Python: numpy, cvxpy, scikit-learn, pywavelets, pytorch. • Debug and calibrate machine learning algorithms. Develop modification to the standard algorithms as appropriate to the problem at hand. • Explain the theoretical aspects of deep learning.
7	**Prerequisites**	Knowledge of Python programming language is required. Basic theoretical knowledge in machine learning is assumed: consider taking the Machine Learning in Signal Processing (MLSIP) course in the same semester.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement To pass the lab course, the programming tasks of each of the 5 session must be successfully completed.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 47574	**Praktikum Machine Learning and Systems** Lab Course Machine Learning and Systems	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Maschine Learning and Systems (4 SWS) It is mandatory to attend all sessions of the lab course.	2,5 ECTS
3	Lecturers	Michele De Vita Prof. Dr. Vasileios Belagiannis Amir El-Ghoussani	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will learn to develop machine learning algorithms for systems. Lab projects will focus on efficient model training and inference, hardware-aware algorithms, interpretability, and robustness of machine learning systems. Deep neural networks will be the main approach for development. The assignments will include tasks such as: • Neural network compression. • Machine learning algorithms on embedded devices. • Automated driving applications. • Generative models. • Model interpretability. Benchmarking.
6	**Learning objectives and skills**	The students will learn to: • Develop hardware-aware machine learning algorithms. • Implement neural network architectures for robotic perception. • Train and fine-tune deep neural network models. • Deploy and benchmark machine learning algorithms.
7	**Prerequisites**	Knowledge in Machine Learning
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement The credit points will be awarded once the practical work has been passed. In particular: There is a lab course assignment almost every other week, conducted in Python. Details of each assignment are provided in the course material that has been distributed. Each assignment is prepared during the lab course session and at home. The tasks set for these assignments are normally programming-related and the deliverable is usually Python code.

		There is a deadline for submitting each assignment. Each assignment is then assessed. In order to pass the lab course, all assignments must be submitted and passed.
11	**Grading procedure**	Practical achievement (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

1	**Module name** 97640	**Laborpraktikum Mobilkommunikation** Laboratory course: Mobile communication	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker

5	**Contents**	Experiments
		•
		  ◦ Characteristics of real mobile radio channels such as distortions and time variability
		  ◦ models for mobile radio channels
		  ◦ effects on the performance of a mobile radio system
		•
		  ◦ Principles of different equalization methods
		  ◦ equalizer design for GSM / EDGE
		  ◦ simulation of trellis-based equalizers and visualization of the results
		•
		  ◦ Principle of OFDM
		  ◦ implementation-relevant aspects such as nonlinearities and peak-to-average-power ratio
		  ◦ synchronization and equalization
		• MIMO Transmission (2 experiments)
		Versuche
		•
		  ◦ Eigenschaften realer Mobilfunkkanäle wie Verzerrungen und Zeitvarianz,
		  ◦ Modelle für Mobilfunkkanäle
		  ◦ Auswirkungen auf die Leistungsfähigkeit eines Mobilfunksystems
		•
		  ◦ Prinzipien verschiedener Entzerrverfahren
		  ◦ Entzerrerdesign für GSM/EDGE
		  ◦ Simulation von trellisbasierten Entzerrern und Visualisierung der Ergebnisse
		•
		  ◦ Prinzip von OFDM
		  ◦ implementierungsrelevante Aspekte wie Nichtlinearitäten und Spitzenwertfaktor
		  ◦ Synchronisation und Entzerrung
		• MIMO Übertragung (2 Versuche)

6	**Learning objectives and skills**	The students • describe the characteristics of real mobile radio channels, • explain the principles of OFDM and MIMO transmission systems,

		• implement equalization and adaptation procedures in Matlab, • perform radio network simulations, • learn to develop program code, • work together in a small team. --- Die Studierenden • charakterisieren die Eigenschaften realer Mobilfunkkanäle, • erklären die Funktionsweise von OFDM- und MIMO-Übertragungssystemen, • implementieren Entzerrungs- und Adaptionsverfahren in Matlab, • führen Funknetzsimulationen durch, • erlernen Programmcode eingeständig zu entwickeln, • arbeiten zielorientiert in einem kleinen Team zusammen.
7	**Prerequisites**	Vorkenntnisse aus Vorlesungen zu Nachrichtenübertragung (Communications) und Systemtheorie (Signals and Systems); Inhalte des Moduls "Mobile Communications" sind erforderliche Voraussetzung für eine sinnvolle Teilnahme;
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Praktika Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Practical achievement • There are 8 experiments to be completed as well as an introduction to Matlab. These are described in the course materials. • Each experiment is to be prepared in writing at home. The preparation is checked and evaluated (sufficient/not sufficient) at the beginning of each experiment. • The results of each experiment are to be kept on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/not sufficient). Measurement results are to be documented in writing. • To pass the course, 8 sufficient experiment preparations and 8 sufficient experiment executions are required. --- • Es sind 8 Versuche sowie eine Einführung in Matlab zu absolvieren. Diese sind in den Kursunterlagen beschrieben. • Jeder Versuch ist zu Hause schriftlich vorzubereiten. Die Vorbereitung wird zu Beginn eines jeden Versuchs überprüft und bewertet (ausreichend/nicht ausreichend). • Die Ergebnisse eines jeden Versuchs sind während der Versuchsdurchführung auf den Versuchsrechnern vorzuhalten (Programmieraufgaben) und werden zum Abschluss des Versuchs überprüft (ausreichend/nicht ausreichend). Messergebnisse sind schriftlich zu dokumentieren.

		• Zum Bestehen des Praktikums sind 8 ausreichende Versuchsvorbereitungen und 8 ausreichende Versuchsdurchführungen notwendig.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 40 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german english
16	**Bibliography**	Skriptum zum Praktikum Mobilkommunikation

Seminar

1	**Module name** 330542	**Audio Processing Seminar** Audio processing seminar	**2,5 ECTS**
2	Courses / lectures	Seminar: Audio Processing Seminar (2 SWS)	-
3	Lecturers	Prof. Dr. Emanuël Habets Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	The audio processing seminar trains students to prepare, summarize and present a recent scientific paper from the field of audio processing. The students work on a recent cutting-edge paper from one of the following fields: • Speech and Audio Coding • Audio Signal Analysis • Audio Signal Processing with the Internet of Things • Spatial Audio Signal Processing • Semantic Audio Processing • Audio in Virtual Reality During the seminar, each participant prepares a paper, creates a written report (2 pages) and presents it in the form of a talk (20 min.) to the other participants. Thereby, the students are guided by their own supervisors. General skills are taught in joint classes. Paper specific aspects are discussed individually between the students and their supervisor. The seminar ends with the presentation of all topics over the course of one or two days. Participation in these presentations and the following discussions are mandatory for all participants. The seminar not only gives a broad overview of the field of audio processing, but conveys fundamental scientific working and communication skills.
6	**Learning objectives and skills**	Learning objectives and skills Students will gain the following skills: • How to analyze a scientific paper and understand its key principles and field of application. • How to perform a thorough literature survey and evaluate relevant literature for the focus of key points in the paper. • How to acquire a broad knowledge and deeper understanding of the specific scientific area. • How to prepare the subject, identify its most important topics, their dependencies, didactic reduction. • How to compile a written summary of a paper, scientific writing, correct citations. • How to create an appealing visual presentation, review and successively optimize it. • How to present the topic in front of other students, how to train presentation skills. • How to analyze presentations of other students, deriving questions, learn to participate in a scientific discussion.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 3

9	**Module compatibility**	Seminar Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Seminar achievement - Attendance is required for 2 introductory sessions of 2h each and 3h final presentation. Self-study and preparations account to 68h. - The final presentation (20 min + 10 min Q&A) accounts to 75% of the final grade and the written report (at least 2 pages) to the remaining 25%.
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 775681	**Seminar Ausgewählte Kapitel der Nachrichtentechnik** Selected areas in communications	**2,5 ECTS**
2	Courses / lectures	Hauptseminar: IDC - Hauptseminar/Seminar -- "Molecular Communications: From Nature to Next Generation Healthcare and Environmental Applications" (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Robert Schober Dr.-Ing. Maximilian Schäfer Prof. Dr. Laura Cottatellucci apl. Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci apl. Prof. Dr. Wolfgang Gerstacker Prof. Dr.-Ing. Ralf Müller Prof. Dr.-Ing. Robert Schober
5	**Contents**	Inhalt / Contents In diesem Seminar werden aktuelle Themen innerhalb eines wechselnden Schwerpunkts im Bereich der Nachrichtentechnik bzw. drahtlosen Kommunikation bearbeitet und präsentiert. _____ In this seminar, current topics in the field of telecommunications and wireless communication are presented by students.
6	**Learning objectives and skills**	Die Studierenden • erlernen grundlegende Techniken der Recherche, Themenaufbereitung und Präsentation technischer Inhalte und wenden diese an • analysieren und evaluieren gegebene Literatur im Hinblick auf die Schwerpunkte ihres Vortrags zu einem technischen Thema • wenden ihr bisher im Studium erworbenes Wissen an, um davon ausgehend eigenständig einen technischen Schwerpunkt zu vertiefen • wenden ihr bisheriges Wissen an, um als Zuhörer sinnvolle Fragen zu einem Vortragsthema zu formulieren und das Präsentierte zu diskutieren • analysieren und evaluieren die Präsentationen der anderen Seminarteilnehmer. _____ The students • learn basic techniques of research, topic preparation and presentation of technical content and apply them • analyze and evaluate given literature with regard to the focus of a talk on a technical topic • apply the knowledge they have acquired during their studies to independently deepen their technical focus

		• apply their previous knowledge to formulate meaningful questions as a listener on a talk and to discuss what is presented • analyze and evaluate the presentations of the other seminar participants.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Seminar Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Seminar achievement • Die Themen werden unter Anleitung eines/r Betreuers/in eigenständig im Hinblick auf eine Präsentation in Vortragsform erarbeitet. • Studierende haben die Möglichkeit sich aktiv an der Formulierung des Vortragsthemas zu beteiligen. • Themen werden bei einer Vorbesprechung zu Beginn des Semesters vergeben. • Eine kurze Präsentation der Struktur und erster Ergebnisse erfolgt etwa 5 Wochen nach der Vorbesprechung. Gegen Ende des Vorlesungszeitraums hält jede/r Studierende einen ca. 30-minütigen Vortrag mit anschließender 15-minütiger Diskussion. • Vor den Beiträgen der Studierenden erfolgt eine Einführung zur Vortragstechnik durch Mitarbeiter des Lehrstuhls. • Es wird eine ca. 10-15-seitige Ausarbeitung erstellt. --- • The topics are independently worked out under the guidance of a supervisor. • Students have the opportunity to actively participate in the formulation of their individual topic. • Topics are assigned at a preliminary meeting at the beginning of the semester. • A brief presentation of the structure and initial results will be given about 5 weeks after the preliminary discussion. • Towards the end of the lecture period, each student gives a talk of approximately 30 minutes followed by a 15-minute discussion. • Students will be introduced into lecture techniques. • An approx. 10-15-page paper has to be written.
11	**Grading procedure**	Seminar achievement (100%) • ca. halbstündiger Vortrag (60%) • Ausarbeitung im Umfang von 10-15 Seiten (vergleichbar IEEE Paper zweispaltig, 30%) • aktive Teilnahme an der Diskussion anderer Vorträge (10%) --- • approx. half-hour presentation (60%) • paper of 10-15 pages (comparable to IEEE paper in two columns, 30%)

		• active participation in the discussion of other presentations (10%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 15 h Independent study: 60 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Unterlagen zu den Modulen Digitale Übertragung, MIMO Communication Systems, Convex Optimization in Communications and Signal Processing • Informationen zur Literatursuche und zu Präsentationstechniken • Vorlagen für Ausarbeitungen und Präsentationsfolien werden zur Verfügung gestellt • Technische Literatur im Themengebiet _____ • Lecture notes of the modules Digital Transmission, MIMO Communication Systems, Convex Optimization in Communications and Signal Processing • Information on literature search and presentation techniques • Templates for papers and presentation slides will be provided • Technical literature in the subject area

1	**Module name** 92374	**Seminar on Selected Topics in Machine Learning**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar on Selected Topics in Machine Learning The participants must be present at all in-person events.	2,5 ECTS
3	Lecturers	Michele De Vita Prof. Dr. Vasileios Belagiannis Marc Hölle	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will study, understand, and present scientific publications from the literature on machine learning and deep learning. At the end of the seminar, the student will be able to summarise and present a publication. The seminar covers a wide range of research topics in the field of machine learning and deep learning, including generative and foundation models, different types of learning and applications machine learning.
6	**Learning objectives and skills**	The students will learn to: • Conduct literature reviews. • Present and analyse a scientific topic. • Write a report on a specific problem. • Discuss and communicate research findings.
7	**Prerequisites**	Basic knowledge in Machine Learning and Deep Learning beneficial
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Seminar Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Seminar achievement The assigned topic must be presented at the end of the seminar in a talk (15 to 45 minutes) and presented in a written report (5 to 15 pages).
11	**Grading procedure**	Seminar achievement (100%) For the final grade, the presentation is weighted at 80% and the submitted report at 20%.
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Literature research is one of the learning objectives of the seminar. In the event that more in-depth literature is required, this will be made available during the seminar.

1	**Module name** 914949	**Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung** Seminar on selected topics of multimedia communications and signal processing	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung (2 SWS) Participation at each session of the seminar is mandatory.	2,5 ECTS
3	Lecturers	Marc Hölle Michele De Vita Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	The Seminar on Selected Topics of Multimedia Communications and Signal Processing deals with current research topics in the area of multimedia communications and signal processing. In an introductory meeting, the course of the seminar is outlined and each participant selects one of the offered topics. The participant should become familiar with the assigned research topic and present it by a report and a talk at the end of the seminar with the support of a supervisor. In an intermediate meeting about 5 weeks after the introductory meeting, the participants give a brief presentation about their topics and show first results. In addition, hints for the preparation of the final talk are provided at this meeting.
6	**Learning objectives and skills**	The students • acquire and apply fundamental techniques to conduct a literature survey, and to prepare and present a technical topic • analyze and evaluate provided literature regarding the focus of their technical presentation • apply the knowledge acquired during their studies to deepen by themselves their technical focus • apply acquired knowledge to ask a presenter questions and to discuss the presentation • analyze and evaluate the presentations of other seminar participants.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Seminar Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Seminar achievement At the end of the semester, a final one-day meeting takes place where each participant presents his topic in a talk of 30 minutes followed by a discussion and questions from the audience. In addition, each participant has to submit a report of about 10 pages about his topic a few days before the final meeting.

11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 92735	**Hauptseminar Lokalisierungssysteme** Advanced seminar Localization systems	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Lokalisierungssysteme	-
3	Lecturers	Prof. Dr.-Ing. Jörg Robert	

4	**Module coordinator**	Prof. Dr.-Ing. Jörg Robert
5	**Contents**	Das Seminar behandelt die Funklokalisierung, beispielsweise in Satellitensystemen oder im Internet der Dinge (IoT). Beim ersten Seminartermin werden den Studierenden Betreuer und Themen zugewiesen, die sich im jeweiligen Forschungsbereich des Betreuers befinden. Mit Unterstützung des Betreuers erarbeiten die Teilnehmenden einen 30-minütigen Vortrag, der im Verlauf des Seminars präsentiert wird. Zusätzlich ist eine wissenschaftliche Ausarbeitung im Umfang von sechs Seiten anzufertigen. Ein fünfminütiger Probevortrag ermöglicht es, vorab Feedback zum Vortragsstil zu erhalten und die Zielsetzung des Seminars besser zu verstehen.
6	**Learning objectives and skills**	1. Sie sollen lernen, sich ein wissenschaftliches Thema selbständig zu erarbeiten und eine didaktisch durchdachte Präsentation vorzubereiten. 2. Sie sollen lernen unter Einhaltung von Zeitvorgaben, Ihre Erkenntnisse publikumsangepasst zu vermitteln. 3. Sie sollen Ihre verbale sowie nonverbale Kommunikation weiterentwickeln. 4. Sie sollen ansatzweise lernen, wie eine wissenschaftliche Veröffentlichung aussehen sollte. Selbstkompetenz: Fähigkeit und Bereitschaft, sich weiterzuentwickeln und das eigene Leben eigenständig und verantwortlich im jeweiligen sozialen, kulturellen bzw. beruflichen Kontext zu gestalten, Selbstkritische Einschätzung des Kompetenzniveaus bei der Vor- und Nachbereitung von Lehrveranstaltungen. Selbstkritische Bewertung der Studienleistungen. Sozialkompetenz: Der Absolvent ist in der Lage, zielorientiert mit seinen Kommilitonen sowie externen Fachleuten und fachfremden Dritten zusammenzuarbeiten. Hierbei ist er in der Lage, fachliche und soziale Situationen zu erfassen, sich mit ihnen rational und verantwortungsbewusst auseinanderzusetzen sowie dadurch seine Arbeits- und Lebenswelt mitzugestalten.
7	**Prerequisites**	None

8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Seminar Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Only in summer semester SS: GNSS-Lokalisierung WS: IoT-Lokalisierung
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	Wird je nach Schwerpunktwahl des Seminars neu festgelegt.

Technical Electives

1	**Module name** 44466	**Advanced C++ Programming** Advanced C++ programming	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Harald Köstler
5	**Contents**	VHB-Kurs! Der Kurs vermittelt neuere Sprachkonstrukte der C++ Programmiersprache (C++11 Standard und später). Konkret werden folgende Themenbereiche behandelt: Type deduction and initialization syntax, Lambda expressions, extended object-oriented features, smart pointer, extended standard library, templates, C++20 standard.
6	**Learning objectives and skills**	Fachkompetenz Wissen Die Studierenden sollen grundlegende Begriffe der C++ Programmiersprache definieren können. Verstehen Die Studierenden sollen verschiedene neuere Sprachkonstrukte wiedergeben können. Anwenden Die Studierenden sollen mit Hilfe von neueren Sprachkonstrukten Aufgaben lösen. Evaluieren (Beurteilen) Die Studierenden sollen selbständig anhand des C++ Sprachstandards und Codebeispielen neuere Sprachkonstrukte verstehen und beurteilen können.
7	**Prerequisites**	Voraussetzung sind die Inhalte des VHB-Kurses Programmierung in C++.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 5 h Independent study: 70 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german english
16	**Bibliography**	

1	**Module name** 151664	**Advanced Communication Networks** Advanced communication networks	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Telecommunications have become ubiquitous in daily life and wireless networks play a fundamental role thanks to their capability to support mobility. In a wireless communication, the concept of link does not exist. Users radiate energy and communicate through the superposition of each others transmissions which creates interference. Compared to wireline networks this scenario is extremely challenging but also offers unpredictable opportunities in the development of new technologies (massive MIMO, cognitive radio, etc.) and exploitation of new features, e.g., opportunistic communications and multiuser diversity. The exponentially increasing request of higher and higher throughput is satisfied densifying users and access points per unit area and allowing more and more interference while adopting advanced techniques and innovative resource allocation to mitigate the detrimental effects of interference. Objective of this course is to introduce the student to advanced techniques for coordinated medium access control and radio resource management in cellular systems. Power allocation, rate adaptation and scheduling will be discussed both in centralized and distributed settings. Some mathematical methods play a fundamental role in resource allocation, namely, classical Perron-Frobenius theory for nonnegative matrices, convex and nonconvex constrained optimization, distributed optimization and game theory. The course introduces the student to such methods and exemplifies their application to various resource allocation problems. Additionally, the course addresses relevant aspects of resource allocation in wireless networks such as fairness and cross-layer design. *Technical Content* • Properties and challenges of the wireless medium. • Basic concepts of communication networks: the layered architecture. • Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution. • Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA. • Uplink-downlink duality. • Opportunistic scheduling and multiuser diversity. • Advanced concepts: small cells and heterogeneous networks, relaying and cooperation, network coding, cognitive radio networks. • Basics of resource allocation: power allocation, rate adaptation, and scheduling.

		• Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	**Learning objectives and skills**	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE. • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenious theorem to allocate power in a centralized manner.

		• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility. • Uses the Perron-Frobenious theorem to design a distributed power control scheme. • Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control. • Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality. • Judges the applicability of KKT conditions and duality. • Uses KKT conditions to solve convex optimization problems. • Uses duality to solve convex optimization problems. • Applies convex optimization to resource allocation in wireless communications. • Compares different definitions of fairness and applies them to rate allocation. • Appraises the effect of channel knowledge at the transmitter on different fairness criteria. • Applies KKT conditions for opportunistic user scheduling. • Describes a proportional fair algorithm for opportunistic scheduling. • Applies relaxation to nonconvex quadratic constrained quadratic programming. • Formulates resource allocation problems as constrained optimization programming. • Contrasts various distributed optimization methods. • Applies the concept of best response to determine Nash equilibria. • Argues about existence and uniqueness of Nash equilibria. • Assesses if a given game is a potential game and solves it. • Defends the concept of Pareto optimality in resource allocation. • Contrasts the concepts of pure and mixed strategies in game theory. • Uses coupled constrained concave game to allocate powers in heterogeneous networks.
7	**Prerequisites**	Information Theory and Coding It is advisable that the student is familiar with basic concepts of Mobile Communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes) Oral exam, 30 minutes

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 621649	**Advanced Optical Communication Systems** Advanced optical communication systems	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Optical Communication Systems (2 SWS) Übung: Advanced Optical Communication Systems Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Bernhard Schmauß Benedikt Beck Esther Renner	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats:intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration
6	**Learning objectives and skills**	Students • gain detailed Knowledge on concepts and structure of various optical transmission systems. • are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. • are able to develop and to optimize link designes of optical transmission systems. • are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
7	**Prerequisites**	**Recommended Prerequisites:** • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes)

		Examinbation: oral exam (30 Minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008. Lecture notes.

1	**Module name** 869547	**Advanced Networking LEx** Advanced networking LEx	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Networking (2 SWS) Übung: Advanced Networking Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Kai-Steffen Hielscher Dr.-Ing. Peter Bazan	

4	**Module coordinator**	Dr.-Ing. Kai-Steffen Hielscher
5	**Contents**	Due to the demands of big data, cloud computing, Internet-of-Things (IoT) and mobile devices, new architectures for computer networks have evolved: Software Defined Networking (SDN) decouples the data plane (packet forwarding, on commodity hardware) from the control plane (control functions, on high performance servers) and offers open programming interfaces. Network Functions Virtualization (NFV) extends existing concepts for server and network virtualization. This allows network functions (like, e.g., routing) that have traditionally been executed on proprietary hardware to be virtualized and executed on commercial off-the-shelf hardware. This lecture offers an introduction to these new technologies, concepts and standards and provides insight into their application in data centers, for fog and cloud computing and for IoT applications.
6	**Learning objectives and skills**	Understanding The students learn to understand the basic concepts of • Software Defined Networking • Network Function Virtualization • Internet of Things • Cloud Computing Application The students learn to apply the knowledge in assignments in labs. Creating The students create own configurations in the lab for • Software Defined Networking • Internet of Things Furthermore, the students create an IoT application according to their own ideas.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Portfolio Prüfungsleistung, mehrteilige Prüfung, Dauer (in Minuten): 30, benotet Anteil an der Berechnung der Modulnote: 100.0 % weitere Erläuterungen: Die Modulprüfung besteht aus: • Bearbeitung (zwei)wöchentlicher Aufgabenblätter in Gruppenarbeit. Für diese unbenotete Studienleistung sind alle Aufgabenblätter korrekt zu lösen und abzugeben.

		• mündliche Prüfung (Dauer: 30 Minuten)
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	William Stallings: Foundations of Modern Networking - SDN, QoE, IoT, and Cloud; Pearson

1	**Module name** 96875	**Ausgewählte Kapitel der Audiodatenreduktion** Advanced topics in perceptual audio coding	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Topics in Perceptual Audio Coding (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Herre	

4	**Module coordinator**	Prof. Dr.-Ing. Jürgen Herre
5	**Contents**	Perceptual audio coding is ubiquitous in modern life (mp3 players, mobile phones, DVD players, computers, ...) Based on related classes (esp. Speech and Audio Processing"), this lecture aims at deepening the understanding of modern algorithms for perceptual source coding of audio. It includes an overview of the most relevant standardized coders, starting with MPEG-1 (incl. mp3) via MPEG-4 all the way to the most recent MPEG Audio standard. The significant algorithms are discussed and new approaches are described. The selected topics include: Efficient coding of several audio channels / parametric multi- channel coding Typical coding artifacts; subjective and objective quality assessment Scalable audio coding Bandwidth extension Semi-parametric audio coding Low-delay audio coding The lecture includes a number of demonstrations and audio examples to illustrate the discussed algorithms.
6	**Learning objectives and skills**	• Wissen - Die Studenten kennen die Hauptkomponenten eines gehörangepassten Audiocodecs, sowie die wichtigsten Algorithmen, Codierstrategien und Bewertungsmethoden. Weiterhin kennen sie die Terminologie und gängige Abkürzungen aus diesem Kontext. • Verstehen - Die Studenten verstehen, wie Designentscheidungen in Audiocodecs die letztendlich erreichte Audioqualität beeinflussen, verstehen die gebräuchlichsten Tools aus dem Bereich der gehörangepasste Audiocodierung und wie verschiedene Anwendungsszenarien das Coderdesign bestimmen. • Anwenden - Die Studenten können übliche mathematische Analysemethoden verwenden, um einfache Coder-Componenten zu beschreiben und gegebenenfalls zu modifizieren. • Analysieren - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge dazu analysieren um die zugrundeliegenden Konzepte und Anforderungen zu erfassen. • Evaluieren (Beurteilen) - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge evaluieren um zu beurteilen, welcher

		Standard bzw. welches Messwerkzeug das passendste ist für einen bestimmten Anwendungsfall. • Synthese - Die Studenten können eine Liste von Anforderungen und Bewertungskriterien für Audiocodecs zusammenstellen für gewünschte Anwendungsfälle. • Lern- bzw. Methodenkompetenz - Die Studenten hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral Prüfung: Mündlich, 30min.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 42800	**Advanced Topics in Deep Learning** Advanced topics in deep learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will learn advanced deep learning topics, including recent network architectures, generative models, self-supervision, interpretability and explainability. In the exercises, the students will implement advanced models and techniques for classification or regression tasks. The lecture topics include: • Geometric deep learning • Attention and transformers • Unsupervised and self-supervised learning • Generative models • Interpretability • Explainability • Efficient Inference • Uncertainty estimation • Transfer learning and domain adaptation • Few-shot learning
6	**Learning objectives and skills**	The students will learn: • State-of-the-art topics in Deep Learning • Recent Neural network architectures • Generative modelling • Lifelong learning approaches • Robustness and reliability in Deep Learning.
7	**Prerequisites**	Basic knowledge of machine learning, deep learning, and programming.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam of 90 min duration Schriftliche Prüfung von 90 min Dauer
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Deisenroth, M. P., Faisal, A. A., & Ong, C. S. (2020). Mathematics for machine learning. Cambridge University Press. • Molnar, C. (2020). Interpretable machine learning. Lulu. com.

1	**Module name** 96010	**Architekturen der digitalen Signalverarbeitung** Architectures for digital signal processing	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Inhalt: • Basis-Algorithmen der Signalverarbeitung (FFT, Fensterung, Digitale FIR- und IIR-Filter) • Nichtideale Effekte bei Digitalfiltern (Quantisierung der Filterkoeffizienten, Quantisierte Arithmetik) • CORDIC-Architekturen • Architekturen für Multiratensysteme (Abtastratenumsetzer) • Architekturen digitaler Signalgeneratoren • Maßnahmen zur Leistungssteigerung (Pipelining) • Architekturen digitaler Signalprozessoren • Anwendungen Content: • Basic algorithms of signal processing (FFT, windowing, digital FIR and IIR-filters) • Non-idealities of digital filters (quantization of filter coefficients, fixed-point arthmetic) • CORDIC-architectures • Architectures of systems with multiple sampling rates (conversion between different sampling rates) • Digital signal generation • Measures of performance improvement (pipelining) • Architecture of digital signal processors • Applications
6	**Learning objectives and skills**	Die Studierenden erlangen Grundlagenkenntnisse der Signaltheorie und können zeit- und wertkontinuierliche sowie zeit- und wertdiskrete Signale im Zeit- und Frequenzbereich definieren und erklären Die Studierenden sind in der Lage, ein klassisches Echtzeitsystem zur digitalen Signalverarbeitung konzeptionieren und die Einzelkomponenten nach den Anforderungen zu dimensionieren Die Studierenden erlangen einen Überblick über Vor- und Nachteile analoger sowie digitaler Signalverarbeitung Die Studierenden verstehen die Theorie der Fourier-Transformation und sind in der Lage, die Vorteile der Fast-Fourier-Transformation in der digitalen Signalverarbeitung zu verstehen und anzuwenden Die Studierenden können digitale Filter dimensionieren und beurteilen ===Englisch=== Students

		• can obtain fundamentals of signal theory and can define as well time-comtinous and value-continous as time-discrete and value-discrete signals in time and frequency domain • can construct a realtime digital signal processing system and dimension its components according requirements • can review pros and cons of analogue versus digitzal signal processing • can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing • can dimension digital filters and evaluate their performance
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Electronic examination (60 minutes) Klausur (E-Exam 60 Min.)
11	**Grading procedure**	Electronic examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 44522	**Audio Processing for the Internet of Things** Audio processing for the Internet of Things	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Nils Peters
5	**Contents**	The course focuses on audio and speech processing algorithms within the context of the Internet of Things (IoT). • Foundation (history, components, current challenges) • Overview of relevant wireless protocols (bandwidth, range, latency, spectrum) • Audio device synchronization (NTP, PTP, device orchestration, acoustic wireless sensor networks, asynchronous and event-driven audio sampling) • Acoustic Sensing for Voice User Interfaces (keyword spotting, speech recognition, speaker verification, anti-spoofing) • Acoustic Scene Detection (event detection, scene classification, anomaly detection, sound tagging, blind reverb estimation) • Sound Creation (text-to-speech, sound generative networks) • Data-over-sound (sound-beacon, watermarking, acoustic fingerprint) • Privacy in IoT (edge vs. cloud processing, secure signal processing, federated learning, differential privacy, audio encryption)
6	**Learning objectives and skills**	The students will be able to • understand the principles, key components, and current in IoT • know the differences between various wireless transmission protocols and can give recommendations based on the IoT use case • understand the differences of edge- and cloud-based audio signal processing • understand algorithmic strategies to enhance privacy in IoT use cases • understand the algorithmic components in a voice user interface • understand state-of-the art methods for detection and classification of acoustic scenes and events • learn and apply algorithms to transmit data via acoustic signals • quantify the impact of latency in audio networks and apply strategies for acoustic device synchronization
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Recommendations for each topic are given during the lectures

1	**Module name** 947709	**Auditory Models** Auditory models	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Bernd Edler
5	**Contents**	• Main components of the human auditory system • Common models • Mechanical models • Physiological models • Psychoacoustic models • Applications (hearing aids, audio coding, . . .)
6	**Learning objectives and skills**	Goals • Students understand the structure and function of the human auditory system • Students gain deeper insight into psychoacoustic phenomena, such as masking, directional and spatial hearing • Students implement and evaluate perceptual models for various applications • Students collaborate with scientists in the fields of audiology and neuroscience
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 816185	**Body Area Communications** Body area communications	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Body Area Communications (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Contents: The Lecture and exercise deals with the following topics: • Introduction to Body Area Communications • Electromagnetic Characteristics of Human Body • Electromagnetic Analysis Methods • Body Area Channel Modeling • Modulation/Demodulation • Body Area Communication Performance • Electromagnetic Compatibility Consideration
6	**Learning objectives and skills**	Learning objectives • Students understand the challenges in designing Body Area Communication (BAC) systems • Students can conduct basic design decisions with BAC systems, like frequency and modulation selection • Students understand electromagnetic wave propagation in bodies • Students understand the frequency dependent loss and propagation behavior of electromagnetic waves • Students can analyze the communication performance of a BAC system • Students can evaluate Electromagnetic Compatibility of a BAC system • Students can assess the field strength inside body and relate it to regulatory limits like SAR (Specific Absorption rate), frequency dependent maximum electrical and magnetic field strength • Students can sketch block diagrams of BAC systems • Students can derive channel models for BAC
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96270	**Kanalcodierung** Channel coding	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Kanalcodierung (3 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	**Module coordinator**	Dr.-Ing. Clemens Stierstorfer
5	**Contents**	1) Introduction and Motivation 2) Fundamentals of Block Coding 3) Introduction to Finite Fields I 4) Linear Block Codes 5) Linear Cyclic Codes 6) Introduction to Finite Fields II 7) BCH and RS Codes 8) Convolutional Codes 9) Codes with Iterative Decoding
6	**Learning objectives and skills**	Das Modul Kanalcodierung umfasst eine Einführung in die Grundlagen der algebraischen, fehlerkorrigierenden Blockcodes sowie einen Einstieg in die Thematik der Faltungscodes. Iterativ decodierte Codeschemata wie Turbo-Codes und LDPC-Codes werden ebenfalls eingeführt. Im Einzelnen sind die Inhalte oben aufgeführt. Die Studierenden definieren die Problematik der Kanalcodierung, grenzen sie von anderen Codierverfahren (z.B. der Quellencodierung) ab und kennzeichnen die unterschiedlichen Ansätze zur Fehlerkorrektur und -erkennung. Sie nennen Beispiele für Einsatzgebiete von Kanalcodierung und geben einen Überblick über die historische Entwicklung des Fachgebiets. Die Studierenden erstellen Übertragungsszenarien für den Einsatz von Kanalcodierung bestehend aus Sender, Übertragungskanal und Empfänger und beachten dabei die Grundannahmen beim Einsatz von Blockcodes bzw. der Modellierung der Kanäle. Sie formulieren mathematische Beschreibungen der Encodierung sowie der optimalen Decodierung bzw. suboptimaler Varianten. Die Studierenden beherrschen die Grundlagen fehlerkorrigierender linearer Blockcodes, beschreiben diese mathematisch korrekt mittels Vektoren und Matrizen über endlichen Körpern und implementieren und bewerten zugehörige Encoder- und Decoderstrukturen insbesondere Syndromdecoder. Dabei modifizieren sie Generatormatrizen, ermitteln Prüfmatrizen und erstellen Syndromtabellen. Sie schätzen die minimale Hammingdistanz von Codes mittels Schranken ab und können den erzielbaren Codegewinn erläutern. Sie kennen und benutzen beispielhaften Codefamilien (z.B. Hamming-Codes, Simplex-Codes, Reed-Muller-Codes). Die Studierenden erkennen die Vorteile zyklischer linearer Blockcodes und beschreiben diese mit Polynomen über endlichen Körpern. Sie nutzen die Restklassenrechnung bzgl. Polynomen zur Umsetzung systematischer Encoder und zur Realisierung von Syndromdecodern mittels Schieberegisterschaltungen. Sie kennen beispielhafte Codefamilien.

Die Studierenden nutzen Primkörper, Erweiterungskörper, Minimalpolynome und Kreisteilungsklassen sowie die Spektraldarstellung über endlichen Körpern zur Realisierung von BCH- und Reed-Solomon-Codes gemäß der BCH-Schranke. Sie verstehen die Grundlagen der Decodierung von BCH- und Reed-Solomon-Codes. Sie skizzieren und erläutern die Kanalcodierkonzepte von CD und DVD.
Die Studierenden erklären die Unterschiede von Faltungscodes und Blockcodes, skizzieren anhand von tabellierten Generatorpolynomen zugehörige Encoder und erläutern diese. Sie erklären die Funktionsweise des optimalen Decoders (MLSE) und demonstrieren diese beispielhaft.
Die Studierenden verstehen die Grundlagen der iterativen Decodierung, insbesondere wenden sie die Grundlagen des Information Combining zur Kombination von verschiedenen Beobachtungen an. Sie verstehen die Bedeutung von Log-Likelihood-Ratios bei iterativen Decodieruvorgängen und berechnen diese. Sie skizzieren die grundlegenden Encoder- und Decoderstrukturen von Turbo-Codes und die Grundzüge der Codierung mit LDPC-Codes u.a. der Decodierung mittels Belief Propagation.
Die Vorlesung erfolgt wechselweise auf Deutsch oder Englisch (Winter/ Sommer). Die zur Verfügung gestellten Unterlagen sind ausschließlich in Englisch gehalten. Die Studierenden verwenden entweder die englischen Fachtermini sicher oder kennen diese und drücken sich sicher mit den entsprechenden deutschen Fachbegriffen aus.
Die Umsetzung der angegebenen Algorithmen in eine Programmiersprache (C, Matlab usw.) sollten die Studierenden zu diesem Zeitpunkt des Studiums üblicherweise beherrschen. Übungen hierzu bleiben der Eigeninitiative überlassen.

Students define the problems of channel coding, how to distinguish it from other coding methods (such as source coding) and how to describe the various different approaches to error correction and detection. They are able to list example application areas of channel coding and give an overview of the historical development of the field.
Furthermore, they describe and analyze transmission scenarios for the application of channel coding which consist of transmitter, transmission channel and receiver, taking into account the general assumptions for applying block codes or modeling the channels. They formulate mathematical descriptions of encoding, optimal decoding and sub-optimal methods.
Students illustrate the principles of error-correcting linear block codes and describe them mathematically using vectors and matrices over finite fields. They implement and analyze corresponding encoder and decoder structures, in particular syndrome decoders, and modify generator matrices, construct test matrices and create syndrome tables. They estimate the minimum Hamming distance of codes using bounds and are able to explain the coding gain that can be achieved in individual cases. They analyze and use example code families (e.g. Hamming codes, simplex codes, Reed-Muller codes).

		Students explain the advantages of cyclic linear block codes and how to describe them with polynomials over finite fields. They apply polynomial modular arithmetic to implement systematic encoders and realize syndrome decoders using shift register circuits. They know and use exemplary code families. Students use prime fields, extension fields, minimal polynomials and cyclotomic cosets, and spectral representation over finite fields to implement BCH and Reed-Solomon codes using the BCH bound. They understand the foundations of decoding BCH and Reed-Solomon codes and how to sketch and explain the channel coding concepts of CDs and DVDs. Students are able to describe the differences between convolutional codes and block codes, to sketch the respective encoders based on tabulated generator polynomials and to explain them. They are able to explain how optimal decoders (MLSE) work using examples. Students sketch the foundations of iterative decoding. In particular, they apply methods of information combining to combine different observations. They use and calculate log-likelihood ratios in iterative decoding processes, sketch the basic encoding and decoding structures of turbo codes and the basics of coding using LDPC codes (including decoding using belief propagation). Students either are able to use the English technical terms correctly or know them and are able to express themselves using the respective technical terms in German.
7	**Prerequisites**	Es ist hilfreich, wenn die Studierenden die erlernten Algorithmen in eine Programmiersprache (C, Matlab usw.) umsetzen können. It would be very helpful if the participants can implement the specified algorithms into a programming language (C, Matlab, etc.).
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Hilfsblatt, Taschenrechner: Sie können ein einzelnes A4-Blatt (Vorder- und Rückseite oder andere Blätter mit offensichtlich identischer Gesamtfläche) verwenden, um Ihre eigene, handschriftliche Formelsammlung aufzuschreiben. Sie können einen nicht programmierbaren Taschenrechner verwenden. ——————————— The examination is a 90-minute written test. Cheat Sheet, Calculator: A single A4 sheet (front and back, or any other collection of sheets with an obviously identical total area size) can be

		used to write down your own handwritten collection of formulas, etc. You may also bring a non-programmable calculator.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	• J. Huber, R. Fischer, C. Stierstorfer: Folien zur Vorlesung • M. Bossert: Kanalcodierung, Oldenbourg Wissenschaftsverlag, 3. Auflage, 2013 • M. Bossert: Channel Coding for Telecommunications, John Wiley & Sons, 1999 • B. Friedrichs: Kanalcodierung, Springer Verlag, 1996 • S.B. Wicker: Error Control Systems for Digital Communications and Storage, Prentice-Hall, 1995

1	**Module name** 412023	**Channel Coding on Graphs** Channel coding on graphs	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	*Description* In today's communications world, channel coding underlies the physical layer of all major communication systems. For example: algebraic block coding (Reed-Solomon codes) are used in the CD and DVD standards; trellis coded modulation is used in line modems; low-density parity check codes (LDPC) are used in satellite communications (DVB-S2 standard), LAN (10GBase-T Ethernet) and wireless LAN (Wi-Fi 802.11); turbo codes are implemented in 3G/4G mobile communications (e.g. in UMTS and LTE) and in (deep space) satellite communications. Recently, polar codes have been adopted for the eMBB (Enhanced Mobile Broadband) control channels for the 5G NR (5th Generation New Radio) interface. Objective of this course is to provide an introductory but thorough background on codes over graphs and covers both classical convolutional codes and the modern theory of random-like codes with iterative decoding. Namely, LDPCs (Low Density Parity Check Codes, Turbo Codes, and Polar Codes. Students will acquire the fundamental knowledge to design and analyze performance of channel codes on graphs, as well as implement the corresponding encoders and decoders. *Technical Content* • Role of channel coding in a communication system. • Idealized channel models : the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel. • Some preliminary basic concepts from linear block codes: Parity Check, Hamming distance, weight enumerating functions, performance evaluations, and performance bounds. • Factor graphs and belief propagation. • Binary random-like codes: LDPC codes and message-passing decoding, threshold behaviour of message passing decoding: density evolution analysis. Design of LDPC ensembles. • Polar Codes: Polarization, polar channel coding, performance, encoding and decoding. • Binary convolutional codes : the algebraic structure, the dynamic structure, Viterbi decoding, performance analysis via weight enumerating function, the forward-backward algorithm. • Other random-like codes: the Turbo Codes. Efficient decoding of Turbo Codes via forward-backward algorithm and interpretation via factor graphs. Performance analysis and exit charts.

6	**Learning objectives and skills**	The student Uses idealized channel models (the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel) to compute their capacities Contrasts soft output decoders with disjoint detection and decoding, maximum likelihood and maximum a posteriori decoders Relates the concepts of Parity Check, Hamming distance, weight enumerating functions to the performance analysis of codes on graphs Devises factor graphs of proposed communication systems Assesses and justifies the applicability of belief propagation to given factor graphs Assesses and justifies the applicability of message passing to codebooks defined in terms of Tanner graph or parity check matrix Applies message passing to codebooks defined in terms of Tanner graph or parity check matrix Analyses the performance of LDPC code decoding via density evolution Computes exit charts for LDPC codes for the equations of the density evolution Designs LDPC ensemble for a given channel to maximize the code rate Justifies the design of LDPC codes via design of LDPC ensembles Interprets convolutional codes as linear block codes Compares algebraic and dynamic representations of convolutional codes Computes steps of the Viterbi algorithm Summarizes and justifies the fundamental structure of the Viterbi algorithm Computes steps of the BCJR algorithm Summarizes and justifies the fundamental structure of BCJR algorithm Compares Viterbi and BCJR algorithms Justifies low complexity and/or practical implementations of the Viterbi and the BCJR algorithm Attaches a direct graph to a convolutional code and computes its transfer function Assesses the performance of the Viterbi decoder via (bit) weight enumerating function based on the transfer function method Interprets a BCJR algorithm as message passing over a factor graph Combines encoders of convolutional codes to generate parallel concatenated codes with interleaver (turbo codes) of given rate Combines encoders of convolutional codes to generate serial concatenated codes with interleaver (turbo codes) Compares the key features of parallel concatenated codes with interleaver (turbo codes) to serial concatenated codes with interleaver (turbo codes) Designs decoders for turbo codes utilizing coupled BCJR-based decoders for convolutional codes Interprets turbo decoders as factor graphs and justifies their implementation via message passing Assesses the performance of turbo codes using exit charts

		Formulates the concept of source polarization and relates it to polar channel coding Interprets polar channel coding as factor graphs Designs polar channel codes Argues about capacity achievability of polar channel codes
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes) Oral exam, 30 minutes
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96410	**Schaltungen und Systeme der Übertragungstechnik** Circuits and Systems of Transmission Techniques	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Norman Franchi
5	**Contents**	Im Rahmen dieses Modules werden die Grundlagen und technische Ausführung Übertragungstechniken vermittelt. Fokus liegt dabei auf dem Automotivebereich. Elektrofahrzeuge werden nicht nur die heute bereits in der Oberklasse verfügbaren Fahrassistenzsysteme nutzen sondern weitere E-Mobility spezifische Anwendung insbesondere zur Energie- und Reichweitoptimierung. Drahtlose Kommunikation zwischen Fahrzeug und Ladeeinrichtungen, zwischen Fahrzeugen untereinander, genaue Ortung und Streckenprognose sowie autonomes energiesparendes Fahren mit Radar-Abstandsreglung spielen hier eine wichtige Rolle. In diesem Modul werden diese modernen Entwicklungen adressiert und die dafür notwendigen Grundlagen erarbeitet. Grundlagen: • Funkkanaleigenschaften • Modellierung • Modulation, Codierung, Vielfachzugriff Fahrzeugkommunikationssysteme: • Übertragungssysteme für die Fahrassistenz • Car-to-Car und Car-to-X-Kommunikation • Breitbandige In-Car-Datenübertragung Fahrzeugsensorik: • Fahrzeugortung (lokal und global) • Automobilradar und Umfeldüberwachung • Sensorische Erfassung von Bioparametern im Fahrzeug
6	**Learning objectives and skills**	Die Studierenden sind nach der erfolgreichen Teilnahme am Modul in der Lage: Funkkanaleigenschaften und Modelle für spezifische Anwendungs- und Betriebsszenarien anzuwenden Modulationstechniken zu erläutern und zu analysieren Moderne Codierungs- und Vielfachzugriffstechniken zu erläutern Architekturen und Anwendungen von Fahrzeugkommunikationssystemen zu erläutern und zu analysieren Architekturen und Anwendungen von Fahrzeugsensoriksystemen zu erläutern und zu analysieren
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral

		• Sommersemester: schriftliche Klausur (90 min); • Wintersemester: mündliche Prüfung (30 min).
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	

1	**Module name** 92355	**Communications systems design**	**2,5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer
5	**Contents**	• Introduction • Analogue-Digital Balance • Software Defined Radio • ADC/DAC Converter Performance Metrics and their evolution over time • Signal Distortion mechanisms and metrics (IP3, EVM, ACPR, Spectral mask, wideband noise, reverse intermod) • Impairment modelling • System Complexity Analysis for Mixed Signal Systems • Transceiver architectures, design and analysis • Chained Noise figures and IP3 figures • Dynamic Range in RX and TX, Automatic Gain Control in RX and power control in TX • Synchronous versus asynchronous Architectures (RF DAC, PLM) • Challenges by Duplex operation, FDD, TDD, same frequency, TX-RX isolation, transmitter leakage cancelation • Simulation techniques (HB, Transient, Circuit Envelope) • Power Amplifier Systems, Amplifier architectures, Vector quantised PA, Class-S, DSM, PWM • Amplifier linearization, digital predistortion • MIMO Architectures • Implementation of Active Antenna Arrays, calibration • Spectrum Engineering • Physical Layer definition in light of implementation challenges The exercise will be conducted based on PC and USRP Software Defined Radios. National Instruments Labview Comsuite Toolbox will be used for designing and studying Communication Systems.
6	**Learning objectives and skills**	Students • can compare key performance indicators of alternative transceiver architectures • can construct the line up with TX and RX • can formulate requirements for transceivers • can gauge isolation between TX and RX • can choose a power amplifier class based on requirements • can rate physical layer properties • can assess complexity in analogue and digital domain

		• can plan a simulation strategy for analysing transceivers - can categorise transceiver architectures for single or multiple antennas • Can develop a predistorion system for power amplifiers
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 30 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Ralf Rudersdorfer, Radio Receiver Technology: Principles, Architectures and Applications, Wiley, 2014 Frank Ellinger, Radio Frequency Integrated Circuits and Technologies, Springer, 2008 Abbas Mohammadi und Fadhel M. Ghannouchi, RF Transceiver Design for MIMO Wireless Communications, Springer, 2012

1	**Module name** 43822	**Computer Graphics** Computer graphics	**5 ECTS**
2	Courses / lectures	Vorlesung: Computer Graphics (3 SWS) Übung: CGTut (1 SWS)	3,75 ECTS 1,25 ECTS
3	Lecturers	Prof. Dr. Marc Stamminger Nikolai Hofmann Linus Franke Laura Fink	

4	**Module coordinator**	Prof. Dr. Marc Stamminger
5	**Contents**	Die Vorlesung gibt eine Einführung in die Computergraphik: • Graphik Pipeline • Clipping • 3D Transformationen • Hierarchische Display Strukturen • Perspektive und Projektionen • Visibilitätsbetrachtungen • Rastergraphik und Scankonvertierung • Farbmodelle • Lokale und globale Beleuchtungsmodelle • Schattierungsverfahren • Ray Tracing und Radiosity • Schatten und Texturen Contents: This lecture covers the following aspects of Computer Graphics: • graphics pipeline • clipping • 3D transformations • hierarchical display structures • perspective transformations and projections • visibility determination • raster graphics and scan conversion • color models • local and global illumination models • shading models • ray tracing and radiosity • shadows and textures
6	**Learning objectives and skills**	Die Studierenden • geben die unterschiedlichen Schritte der Graphik Pipeline wieder • erklären die Funktionsweise der Clippingalgorithmen für Linien und Polygone • beschreiben, charakterisieren und berechnen affine und perspektivische Transformationen in 3D und veranschaulichen die allgemeine Form der Transformationsmatrix in homogener Koordinaten • skizzieren die Verfahren zur Tiefe- und Visibilitätsberechnung

		• vergleichen die unterschiedlichen Farbmodelle der Computergraphik • illustrieren und untersuchen die Datenstrukturen zur Beschreibung virtueller 3D Modelle und komplexer Szenen • erläutern die Funktionsweise der Rasterisierung und Scankonvertierung in der Graphikpipeline • lösen Aufgaben zu Beleuchtung und Texturierung von 3D virtuellen Modellen • klassifizieren Schattierungsverfahren • bestimmen den Unterschied zwischen lokaler und globaler Beleuchtung und formulieren Algorithmen für Ray Tracing und Radiocity *Educational objectives and skills:* Students should be able to • describe the processing steps in the graphics pipeline • explain clipping algorithms for lines and polygons • explain, characterize and compute affine and perspective transformations in 2D and 3D, and provide an intuitive description of the general form of corresponding transformation matrices in homogeneous coordinates • depict techniques to compute depth, occlusion and visibility • compare the different color models • describe data structures to represent 3D virtual models and complex scenes • explain the algorithms for rasterization and scan conversion • solve problems with shading and texturing of 3D virtual models • classify different shadowing techniques • explain the difference between local and global illumination techniques and formulate algorithms for ray tracing and radiosity
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Tutorial achievement Written examination (60 minutes) Die Übungen ("Computer Graphics Basic Tutorials") bestehen aus insgesamt 10 wöchentlichen Aufgabenblättern mit kleinen Programmieraufgaben. The exercises ("Computer Graphics Basic Tutorials") consist of weekly worksheets (10 worksheets in total) with small programming tasks.
11	**Grading procedure**	Tutorial achievement (pass/fail) Written examination (100%) Zum Bestehen des Moduls müssen 50% der Punkte in den Übungen erreicht und die Abschlussprüfung bestanden werden. Die Modulnote ergibt sich zu 100% aus der Prüfung.

		The module is passed when 50% of the points in the exercises are reached and when the final exam is passed. The grade of the module is entirely determined by the grade in the final exam.
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german english
16	**Bibliography**	• P. Shirley: Fundamentals of Computer Graphics. AK Peters Ltd., 2002 • Hearn, M. P. Baker: Computer Graphics with OpenGLD. Pearson • Foley, van Dam, Feiner, Hughes: Computer Graphics - Principles and Practice • Rauber: Algorithmen der Computergraphik • Bungartz, Griebel, Zenger: Einführung in die Computergraphik • Encarnação, Strasser, Klein: Computer Graphics

1	**Module name** 713618	**Computer vision**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Tim Weyrich
5	**Contents**	This lecture discusses important algorithms from the field of computer vision. The emphasis lies on 3-D vision algorithms, covering the geometric foundations of computer vision, and central algorithms such as stereo vision, structure from motion, optical flow, and 3-D multiview reconstruction. Participants of this advanced course are expected to bring experience from prior lectures either from the field of pattern recognition or from the field of computer graphics.
6	**Learning objectives and skills**	Die Vorlesung stellt eine Auswahl von Methoden aus dem Gebiet der Computer Vision vor, die in dem Feld eine zentrale Stellung einnehmen. In den Übungen implementieren und evaluieren die Studierenden selbständig diese Methoden. Die Studierenden arbeiten die ganze Zeit über an populären Computer Vision-Methoden wie zum Beispiel Stereosehen, optischer Fluss und 3D-Rekonstruktion aus mehreren Ansichten. Für diese Probleme • beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen, • erklären die Studierenden die behandelten Methoden, • diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen, • implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code, • entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme, • erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation, • diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen, • diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens. The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants • describe perspective projection, rotations, and related geometric foundations, • explain the presented methods, • discuss the advantages and disadvantages of different modalities for acquiring 3-D information,

		• implement individually and in small groups code, • discover best practices in data acquisition, • explore and rank different choices for evaluation, • discuss and present in groups the advantages and disadvantages of their implementations, • discuss and reflect the social impact of applications of computer vision algorithms.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Variable (90 minutes) Dieses Modul wird mit einer Klausur (90 Minuten) geprüft. The form of examination is a written exam of 90 minutes.
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.

1	**Module name** 96850	**Convex Optimization in Communications and Signal Processing** Convex optimization in communications and signal processing	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Convex Optimization in Communications and Signal Processing (1 SWS) Vorlesung: Convex Optimization in Communications and Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Yifei Wu apl. Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Convex optimization problems are a special class of mathematical problems which arise in a variety of practical applications. In this course we focus on the theory of convex optimization, corresponding algorithms, and applications in communications and signal processing (e.g. statistical estimation, allocation of resources in communications networks, and filter design). Special attention is paid to recognizing and formulating convex optimization problems and their efficient solution. The course is based on the textbook "Convex Optimization" by Boyd and Vandenberghe and includes a tutorial in which many examples and exercises are discussed.
6	**Learning objectives and skills**	Students • characterize convex sets and functions, • recognize, describe and classify convex optimization problems, • determine the solution of convex optimization problems via the dual function and the KKT conditions, • apply numerical algorithms in order to solve convex optimization problems, • apply methods of convex optimization to different problems in communications and signal processing
7	**Prerequisites**	Signals and Systems, Communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Prüfungssprache ist Englisch. The examination is a 90-minute written test. The examination language is English.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Boyd, Steven ; Vandenberghe, Lieven: Convex Optimization. Cambridge, UK : Cambridge University Press, 2004

1	**Module name** 901895	**Deep Learning** Deep learning	**5 ECTS**
2	Courses / lectures	Vorlesung: Deep Learning (2 SWS) Übung: DL Exercise (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Tomas Arias Vergara Dr.-Ing. Dr. Soroosh Tayebi Arasteh Prof. Dr.-Ing. Andreas Maier Zijin Yang	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Deep Learning (DL) has attracted much interest in a wide range of applications such as image recognition, speech recognition and artificial intelligence, both from academia and industry. This lecture introduces the core elements of neural networks and deep learning, it comprises: • (multilayer) perceptron, backpropagation, fully connected neural networks • loss functions and optimization strategies • convolutional neural networks (CNNs) • activation functions • regularization strategies • common practices for training and evaluating neural networks • visualization of networks and results • common architectures, such as LeNet, Alexnet, VGG, GoogleNet • recurrent neural networks (RNN, TBPTT, LSTM, GRU) • deep reinforcement learning • unsupervised learning (autoencoder, RBM, DBM, VAE) • generative adversarial networks (GANs) • weakly supervised learning • applications of deep learning (segmentation, object detection, speech recognition, ...) The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.
6	**Learning objectives and skills**	The students • explain the different neural network components, • compare and analyze methods for optimization and regularization of neural networks, • compare and analyze different CNN architectures, • explain deep learning techniques for unsupervised / semi-supervised and weakly supervised learning, • explain deep reinforcement learning, • explain different deep learning applications, • implement the presented methods in Python, • autonomously design deep learning techniques and prototypically implement them, • effectively investigate raw data, intermediate results and results of Deep Learning techniques on a computer,

		• autonomously supplement the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of deep learning applications.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written exam, 90 min.
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Ian Goodfellow, Yoshua Bengio, Aaron Courville: Deep Learning. MIT Press, 2016. • Christopher Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • Yann LeCun, Yoshua Bengio, Geoffrey Hinton: Deep learning. Nature 521, 436444 (28 May 2015)

1	**Module name** 43400	**Entzerrung und adaptive Systeme in der digitalen Übertragung** Equalisation and adaptive systems for digital communications	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Equalization and Adaptive Systems for Digital Communications (2 SWS)	2,5 ECTS
3	Lecturers	apl. Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Bei der digitalen Übertragung spielen Kanalverzerrungen aufgrund ständig steigender Datenraten eine immer grössere Rolle. Bei vielen Anwendungen müssen für eine zuverlässige Übertragung komplexe Entzerrverfahren eingesetzt werden. Dies gilt sowohl für die leitungsgebundene als auch die drahtlose Kommunikation. Z.B. werden in der xDSL-Systemfamilie (Digital Subscriber Lines), die eine schnelle digitale Übertragung über Ortsanschlussleitungen gewährleistet, oft entscheidungsrückgekoppelte Entzerrverfahren oder Vorcodierungsverfahren eingesetzt und beim Mobilfunkstandard GSM und seiner Weiterentwicklung EDGE (Enhanced Data Rates for GSM Evolution) Maximum-Likelihood-Sequenzschätzung bzw. zustandsreduzierte Entzerrung. Eng im Zusammenhang mit der eigentlichen Entzerrung stehen Adaptionsverfahren, mit denen die Parameter des Entzerrers optimal an den Übertragungskanal angepasst werden können. Lernziel: Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen. Content: Channel distortions are playing an increasingly important role in digital transmission due to constantly increasing data rates. In many applications, complex equalization techniques must be used for a reliable transmission. This applies to both wired and wireless communication. For example, decision feedback equalization or precoding techniques are often used in the xDSL (Digital Subscriber Lines) system family, which ensures fast digital transmission over local subscriber loops, and the GSM system and its advanced version EDGE (Enhanced Data Rates for GSM Evolution) employ maximum likelihood sequence estimation and state-reduced equalization. Closely related to the task of equalization are adaptation methods with which the parameters of the equalizer can be optimally adjusted to the transmission channel. Objective: The aim of the lecture is a comprehensive presentation of common equalization and adaptation methods. The participants should acquire an in-depth knowledge of the various procedures which enables them to make meaningful design decisions in practice.

6	**Learning objectives and skills**	Die Studierenden • beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung, • setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten, • vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität, • wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus, • entwerfen neuartige Verfahren für gegebene Anforderungen, • formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal, • ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu. Learning Objectives and Competences: The students - describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation, - realize various approaches in block diagrams and optimize their components, - compare equalization methods in terms of their performance, characterized by the error rate, and complexity, - select suitable methods for various applications such as wired and wireless transmission, - design novel schemes for given requirements, - formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel, - assign suitable adaptation algorithms to equalization schemes.
7	**Prerequisites**	Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Written or oral (100%)

12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung. Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992. Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999. Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995. Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996.

1	**Module name** 44973	**Generative Models for Signal Processing** Generative models for signal processing	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Generative Models for Signal Processing	-
3	Lecturers	Prof. Dr. Meinard Müller Prof. Dr. Emanuël Habets	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	In this course, the students will learn the foundations of generative AI. The students will acquire knowledge on techniques for generating different types of data with some emphasis on natural signals (audio, images, video). In (non-mandatory) pen-and-paper exercises and programming tasks, the students can deepen their understanding and try out the learned principles in practice. The topics of the lecture include: • Recap of mathematical preliminaries • Learning-based representations of the data distribution • Autoregressive models • Normalizing flows • Variational autoencoders • Energy-based models • Generative adversarial networks • Conditional flow matching models and diffusion models • Neural audio coding
6	**Learning objectives and skills**	• Understanding of state of the art in generative AI by a comprehensive introduction to the theory of generative modeling • Ability to build new models based on the acquired theoretical background • Paper reading ability by discussion of popular models and applications • Ability to realize projects by (non-mandatory) coding and pen-and-paper exercises
7	**Prerequisites**	• Basic mathematics (linear algebra, probability theory, calculus) as acquired in undergraduate studies or in other machine learning courses • Some prior machine learning courses, e.g., in deep learning or in statistical machine learning, are recommended but not mandatory
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral • Oral examination (30 mins)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester

13	**Workload in clock hours**	Contact hours: 25 h Independent study: 50 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Tomczak: Deep Generative Modeling, 2nd ed., Springer, 2024 • Prince: Understanding Deep Learning, MIT Press, 2024 • Murphy: Probabilistic Machine Learning: Advanced Topics, MIT Press, 2023 • Bishop: Deep Learning, Springer 2024

1	**Module name** 645618	**Human Computer Interaction** Human computer interaction	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Björn Eskofier Madeleine Flaucher
5	**Contents**	Das Modul vermittelt Konzepte, Prinzipien, Modelle, Methoden und Techniken für die effektive Entwicklung von benutzerfreundlichen Mensch-Computer-Schnittstellen. Das Thema moderner Benutzungsschnittstellen wird dabei für klassische Computer aber auch für mobile Geräte, eingebettete Systeme, Automobile und intelligente Umgebungen betrachtet. Die folgenden Themen werden im Modul behandelt: • Einführung in die Grundlagen der Mensch-Computer-Interaktion, historische Entwicklung • Entwurfsprinzipien und Modelle für moderne Benutzungsschnittstellen und interaktive Systeme • Informationsverarbeitung des Menschen, Wahrnehmung, Motorik, Eigenschaften und Fähigkeiten des Benutzers • Interaktionskonzepte und -stile, Metaphern, Normen, Regeln und Style Guides • Ein- und Ausgabegeräte, Entwurfsraum für interaktive Systeme • Analyse-, Entwurfs- und Entwicklungsmethoden und -werkzeuge für Benutzungsschnittstellen • Prototypische Realisierung und Implementierung von interaktiven Systemen, Werkzeuge • Architekturen für interaktive Systeme, User Interface Toolkits und Komponenten • Akzeptanz, Evaluationsmethoden und Qualitätssicherung Contents: The module aims to teach basic knowledge of concepts, principles, models, methods and techniques for developing highly user-friendly Human-Computer Interfaces. Beyond traditional computer systems, modern user interfaces are also discussed in the context of automobile and intelligent environments, mobile devices and embedded systems. This module addresses the following topics: • Introduction to the basics of Human-Computer Interaction • Design principles and models for modern user interfaces and interactive systems • Information processing of humans, perception, motor skills, properties and skills of the users • Interaction concepts, metaphors, standards, norms and style guides

		• In- and output devices, design space for interactive systems • Analysis-, design- and development of methodologies and tools for easy-to-use user interfaces • Prototypic implementation of interactive systems • Architectures for interactive systems, User Interface Toolkits and components • Acceptance, evaluation methods and quality assurance
6	**Learning objectives and skills**	• Studierende entwickeln ein Verständnis für Modelle, Methoden und Konzepte der Mensch-Computer-Interaktion. • Sie lernen verschiedene Ansätze für den Entwurf, die Entwicklung und Bewertung von Benutzungsschnittstellen kennen und verstehen deren Vor- und Nachteile. • Die Teilnahme an der Veranstaltung versetzt Studierende in die Lage, einen Entwicklungsprozess in der Mensch-Computer-Interaktion zu verstehen und umzusetzen. • Sie werden weiterhin in die Lage versetzt, dies vor dem Hintergrund der Informationsverarbeitungsfähigkeit, Wahrnehmung und Motorik des Benutzers zu gestalten. • Passende Methoden der Evaluation sowie Akzeptanz- und Qualitätssicherung werden erlernt. Learning Objectives and Competences: • Students develop an understanding of models, methods and concepts in the field of Human-Computer Interaction. • They learn different approaches for designing, developing and evaluating User Interfaces and their advantages and disadvantages. • Joining the course enables students to understand and execute a development process in Human-Computer Interaction. • Students will be able to do a UI evaluation by learning the basics of information processing, perception and motoric skills of the user. • Appropriate evaluation methods, as well as acceptance and quality assurance aspects, will be learned.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Electronic examination Electronic exam (in presence), 90min
11	**Grading procedure**	Electronic examination (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96312	**Bild-, Video- und mehrdimensionale Signalverarbeitung** Image, video and multidimensional signal processing	**5 ECTS**
2	Courses / lectures	Vorlesung: Image, Video, and Multidimensional Signal Processing (2 SWS) Übung: Supplements Image, Video, and Multidimensional Signal Processing	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Katja Kossira	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup

5	**Contents**	•
		  ◦ Histogram equalization, gamma correction
		•
		  ◦ Morphological filters, erosion, dilation, opening, closing
		•
		  ◦ Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity
		•
		  ◦ Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering
		•
		  ◦ Bi-linear interpolation, bi-cubic interpolation, spline interpolation
		  ◦ Image feature detection
		• Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix
		•
		  ◦ Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform
		  ◦ Image matching
		• Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm
		•
		  ◦ Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video
		•
		  ◦ Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT

6	**Learning objectives and skills**	The students • understand point operations for image data and gamma correction

		• test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data • segment image data by implementing basic classification and clustering methods • understand the principle of transformations on image data and apply them exemplarily
7	**Prerequisites**	Course on Signals und Systems I and II recommended
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Schriftliche Prüfung von 90 min Dauer
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• J.-R. Ohm: |Multimedia Content Analysis|, Springer, 2016 • J. W. Woods: |Multidimensional Signal, Image, and Video Processing and Coding|, Academic Press, second edition, 2012

1	**Module name** 43405	**Introduction to Deep Learning** Introduction to deep learning	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Introduction to Deep Learning (2 SWS) Übung: Supplements for Introduction to Deep Learning (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Marc Hölle	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will learn the basics in deep learning, including classical neural network models and recent architectures. The students will acquire knowledge on processing different types of data with deep neural networks. In the exercises, the students will implement some of the standard models for classification or regression tasks and acquire knowledge on machine learning applications. The lecture topics include: • Learning from data, machine learning and deep learning • Machine learning principles • Artificial neural networks • Convolutional neural networks • Back-propagation • Network optimization • Initialisation, regularisation • Deep network architectures • Generative models • Auto-encoders • Sequential models • Deep learning applications
6	**Learning objectives and skills**	The students will learn: • Machine learning theory • Artificial neural networks • Deep neural networks • Modern architectures • Model and parameter learning
7	**Prerequisites**	Basic knowledge of higher mathematics and programming
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Schriftliche Prüfung von 90min Dauer
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Rojas, R. (2013). Neural networks: a systematic introduction. • Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.

1	**Module name** 267499	**Linear and non-linear fibre optics**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.
6	**Learning objectives and skills**	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links
7	**Prerequisites**	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester

13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	**Module name** 668129	**Machine Learning in Communications** Machine learning in communications	**5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning in Communications (4 SWS) Übung: Tutorial for Machine Learning in Communications (0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Christian Forsch	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Recently, in many areas of wireless communications such as wireless sensor networks (WSNs), heterogeneous networks and complex ad hoc networks, distributed graph algorithms and machine learning on graphs are gaining relevance as fundamental tools in network analysis and information processing. This motivates to deliver a general introduction to fundamentals of machine learning such as detection of clusters on graphs. The introduction is followed by the application of machine learning to the design of physical and data layer techniques in wireless communications and in the optimization of mobile networks.
6	**Learning objectives and skills**	The students • know and explain the fundamentals of machine learning with special attention to machine learning over graphs. • apply these principles in the design and optimisation of wireless communications systems and mobile networks.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 48440	**Machine Learning in Signal Processing** Machine learning in signal processing	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Maschinelles Lernen in der Signalverarbeitung (2 SWS) Vorlesung: Maschinelles Lernen in der Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Michele De Vita Marc Hölle Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.
6	**Learning objectives and skills**	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232

		Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Schriftliche Prüfung von 90min Dauer
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

1	**Module name** 48400	**Mathematical Optimization in Communications and Signal Processing** Mathematical optimization in communications and signal processing	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Content: The focus of this module is on methods for modeling and solving optimization problems as they occur in the field communication and signal processing. Starting from practical applications, different classes of optimization problems are introduced that include linear, mixed-integer linear, continuous non-linear as well as mixed-integer non-linear optimization problems. Advantages and disadvantages of different modeling techniques will be outlined and different reformulations will be presented in order to achieve efficient solution approaches. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications in communications and signal processing.
6	**Learning objectives and skills**	The students a)have an overview over mathematical optimization in practice b)apply mathematical optimization modeling and solution techniques c)decide which solution approaches are suitable for which class of models d)know available software and how to use it
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 454183	**Molecular Communications** Molecular communications	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Molecular Communications (0 SWS) Vorlesung: Molecular Communications (4 SWS)	- 5 ECTS
3	Lecturers	Teena tom Dieck Prof. Dr.-Ing. Robert Schober	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Conventional communication systems employ electromagnetic waves for information transmission. This approach is suitable for typical macroscopic applications such as mobile communication. However, newly emerging applications in biology, nanotechnology, and medicine require communication between so-called nano-machines (e.g. nano-robots and nano-sensors) with sizes on the order of nano- and micro-meter. For such device sizes electromagnetic waves cannot be used for efficient information transmission. Instead Molecular Communication, an approach that is also widely used in natural biological systems, has to be applied. In Molecular Communication, transmitter and receiver communicate by exchanging information-carrying molecules. The design of molecular communication systems requires a basic understanding of relevant biological processes and systems as well as their communication-theoretical modelling and analysis. The course is structured as follows: 1) Introduction to Molecular Communication; 2) Biological Nano-Machines; 3) Molecular Communication in Biological Systems; 4) Synthetic Molecular Communication Systems; 5) Mathematical Modelling and Simulation; 6) Communication and Information Theory for Molecular Communication; 7) Design of Molecular Communication Systems; 8) Applications for Molecular Communication Systems.
6	**Learning objectives and skills**	The students are able to design synthetic molecular communication systems. They can explain natural communication processes in biological systems and how to harness these natural processes for the construction of man-made molecular communication systems. The students can also analyse, model, and simulate molecular communication systems.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 687141	**Multiuser Information and Communications Theory** Multiuser information and communications theory	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Multiuser Information and Communications Theory (1 SWS) Vorlesung: Multiuser Information and Communications Theory (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Linear vs. nonlinear multiple-access, CDMA as a canoncal framework for any multiple-access schemes, optimum multiuser detection, linear multiuser detection, interference cancellation, rate region, multiuser source coding, time sharing, multiuser channel codes, multiple-access channel (MAC), capacity region, mutual information versus minimum-mean squared error, Gaussian MAC, power region, Gaussian vector MAC, source coding with side information, degraded broadcast channel, Gaussian broadcast-MAC duality, Gaussian vector broadcast channel, dirty-paper coding, physically degraded relay channel, scalar Gaussian relay channel, Gaussian interference channel, cut-set bound, network coding, fading channels, multiuser water filling, block fading, diversity, user diversity, capacity versus outage, near-far gain, dual antenna arrays
6	**Learning objectives and skills**	The students model any multiple access method as a special case of code-division multiple access. The students apply various algorithms for multiuser detection. The students explain various types of multiuser channels and their limits to transport information. The students explain the limits of distributed source coding algorithms. The students apply the cut-set bound. The students explain the method of dirty-paper coding. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: A basic course on information theory (can be taken in parallel)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The examination is a 30-minute oral exam.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• El Gamal, A., Kim, Y.: Network Information Theory, Cambridge University Press, 2011 • Cover, T., Thomas, J.: Elements of Information Theory, 2nd ed., Wiley, Hoboken, 2006 • Verdú, S.: Multiuser Detection, Cambridge Univ. Press, Cambridge, 1998 • Tse, D., Viswanath, P.: Fundamentals of Wireless Communications, Cambridge University Press, 2005.

1	**Module name** 302148	**Musiksignalverarbeitung - Analyse** Music processing - Analysis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Music Processing Analysis (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	Music signals possess specific acoustic and structural characteristics that are not shared by spoken language or audio signals from other domains. In fact, many music analysis tasks only become feasible by exploiting suitable music-specific assumptions. In this course, we study feature design principles that have been applied to music signals to account for the music-specific aspects. In particular, we discuss various musically expressive feature representations that refer to musical dimensions such as harmony, rhythm, timbre, or melody. Furthermore, we highlight the practical and musical relevance of these feature representations in the context of current music analysis and retrieval tasks. Here, our general goal is to show how the development of music-specific signal processing techniques is of fundamental importance for tackling otherwise infeasible music analysis problems.
6	**Learning objectives and skills**	Expertise Understand • The students present central tasks in music processing in their own words and outline possible solutions. • The students understand the properties of different forms of representation of music. Apply • The students apply basic algorithms for the analysis and comparison of music signals. • Students can predict how different musical properties will affect the signal analysis. Analyze • The students observe and discuss the meaning and impact of parameters in music analysis. • The students compare different methods of analyzing periodicities. Evaluate • The students question assumptions that are often implicitly made when using analytical methods. • Students estimate when methods might work when analyzing specific music signals and when they typically fail. Learning and methodological skills • The students prepare for the lecture using selected literature and Jupyter notebooks. • The students question existing approaches regarding their applicability in practice. • The students pay attention to efficiency issues in the algorithms discussed. Self-competence

- The students question their understanding of what they have learned using exercises.
- The students formulate questions and ask them to the lecturer and the audience in the lecture.

Social skills

- The students independently organize learning groups in which the subject is discussed and deepened.
- The students simulate oral exams with their fellow students.

Fachkompetenz

Verstehen

- Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze.
- Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik.

Anwenden

- Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an.
- Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken.

Analysieren

- Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse.
- Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber.

Evaluieren (Beurteilen)

- Die Studierenden hinterfragen Annahmen, die implizit bei der Verwendung von Analysemethoden gemacht werden.
- Die Studierenden schätzen ein, wann Methoden bei der Analyse von gewissen Musiksignalen funktionieren könnten und wann sie typischerweise versagen.

Lern- bzw. Methodenkompetenz

- Die Studierenden bereiten sich auf die Vorlesung anhand ausgewählter Literatur vor.
- Die Studierenden hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
- Die Studierenden beachten Fragen der Effizienz bei den diskutierten Algorithmen.

Selbstkompetenz

- Die Studierenden hinterfragen ihr Verständnis von dem Gelernten anhand von Übungsaufgaben.
- Die Studierenden formulieren Fragen und stellen diese in der Vorlesung an den Dozenten und die Zuhörerschaft.

Sozialkompetenz

- Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.
- Die Studierenden simulieren mit ihren Kommilitonen mündliche Prüfungen.

7	**Prerequisites**	In this course, we discuss a number of current research problems in music processing or music information retrieval (MIR) covering aspects from information science and digital signal processing. We provide the necessary background information and give numerous motivating examples so that no specialized knowledge is required. However, the students should have a solid mathematical background. The lecture is accompanied by readings from textbooks or the research literature. Furthermore, the students are required to experiment with the presented algorithms using Python.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	http://www.music-processing.de http://www.springer.com/gp/book/9783319219448

1	**Module name** 639119	**Music Processing Analysis - Lecture and Exercise** Music processing analysis - Lecture and exercise	**5 ECTS**
2	Courses / lectures	Übung: Music Processing Analysis - Exercise (2 SWS) Vorlesung: Music Processing Analysis (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	Music signals possess specific acoustic and structural characteristics that are not shared by spoken language or audio signals from other domains. In fact, many music analysis tasks only become feasible by exploiting suitable music-specific assumptions. In this course, we study feature design principles that have been applied to music signals to account for the music-specific aspects. In particular, we discuss various musically expressive feature representations that refer to musical dimensions such as harmony, rhythm, timbre, or melody. Furthermore, we highlight the practical and musical relevance of these feature representations in the context of current music analysis and retrieval tasks. Here, our general goal is to show how the development of music-specific signal processing techniques is of fundamental importance for tackling otherwise infeasible music analysis problems.
6	**Learning objectives and skills**	Fachkompetenz Verstehen • Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze. • Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik. • Die Studierenden interpretieren Signaleigenschaften anhand von Visualisierungen (Exercise). Anwenden • Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an. • Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken. • Die Studierenden implementieren Algorithmen zur Analyse, zum Vergleich und zur inhaltsbasierten Suche von Musiksignalen (Exercise). Analysieren • Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse. • Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber. • Die Studierenden analysieren und erforschen Eigenschaften von Musiksignalen mittels automatisierter Methoden (Exercise). • Die Studierenden klassifieren und strukturieren Musikdaten mittels Lernverfahren (Exercise).

		Evaluieren (Beurteilen)
		• Die Studierenden hinterfragen Annahmen, die implizit bei der Verwendung von Analysemethoden gemacht werden.
		• Die Studierenden schätzen ein, wann Methoden bei der Analyse von gewissen Musiksignalen funktionieren könnten und wann sie typischerweise versagen.
		• Die Studierenden evaluieren automatisierte Methoden mittels geeigneter Evaluationsmaße unter Verwendung von manuell erstellten Annotationen (Exercise).
		Erschaffen
		•
		  ◦ Die Studierenden bereiten sich auf die Vorlesung anhand ausgewählter Literatur vor.
		  ◦ Die Studierenden hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
		  ◦ Die Studierenden beachten Fragen der Effizienz bei den diskutierten Algorithmen.
		  ◦ Die Studierenden entwickeln praktische Lösungswege für Problem in der Musikverarbeitung (Exercise)
		  ◦ Die Studierenden hinterfragen ihr Verständnis von dem Gelernten anhand von Übungsaufgaben.
		  ◦ Die Studierenden formulieren Fragen und stellen diese in der Vorlesung an den Dozenten und die Zuhörerschaft.
		  ◦ Die Studierenden nutzen Verbesserungshinweise des Betreuers und der Tutoren zur Verbesserung ihrer Lernstrategien (Exercise).
		  ◦ Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.
		  ◦ Die Studierenden simulieren mit ihren Kommilitonen mündliche Prüfungen.
		  ◦ Die Studierenden entwickeln und implementieren Software im Team (Exercise).
		  ◦ Die Studierenden geben Kommilitonen im Rahmen ihrer Zusammenarbeit wertschätzendes Feedback (Exercise).

7	**Prerequisites**	In this course, we discuss a number of current research problems in music processing or music information retrieval (MIR) covering aspects from information science and digital signal processing. We provide the necessary background information and give numerous motivating examples so that no specialized knowledge is required. However, the students should have a solid mathematical background. The lecture is accompanied by readings from textbooks or the research literature. Furthermore, the students are required to experiment with the presented algorithms using Python.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Oral (30 minutes) Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Meinard Müller Fundamentals of Music Processing Using Python and Jupyter Notebooks 2nd edition, 495 p., hardcover ISBN: 978-3-030-69807-2 Springer, 2021 http://www.music-processing.de/ https://www.audiolabs-erlangen.de/FMP

1	**Module name** 502007	**Musiksignalverarbeitung - Synthese** Music processing - synthesis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Musikverarbeitung - Synthese (2 SWS)	-
3	Lecturers	Dr.-Ing. Maximilian Schäfer	

4	**Module coordinator**	Dr.-Ing. Maximilian Schäfer
5	**Contents**	• Verarbeitung von Audiosignalen durch parametrische Filter und Effekte • Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese • Klangwiedergabe in echten und virtuellen Räumen • Klangbeispiele und Demonstrationen • Programmiersprachen für Audio-Echtzeit-Verarbeitung *Content*: • a short history of electrical and electronic music • processing of audio signals by parametric filters and effects • digital sound synthesis • sound reproduction in real and in virtual environments • sound examples and demonstrations • programming languages for audio real-time processing
6	**Learning objectives and skills**	Die Studierenden • beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung, • wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an, • gestalten eigene Software-Realisierungen zur Klangsynthese, • entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen. The students • specify the special requirements for audio realtime processing, • apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds, • design their own software realizations for sound synthesis • implement technical systems for digital music.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Die Prüfung ist eine mündliche Prüfung mit einer Dauer von 30 Minuten. / The form of examination is an oral exam of 30 minutes.
11	**Grading procedure**	Oral (100%)

12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Das Vorlesungsskript und weitere Zusatzmaterialien zur Vorlesung werden via StudOn zur Verfügung gestellt.

1	**Module name** 96300	**MIMO Communication Systems** MIMO communication systems	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	**Learning objectives and skills**	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	**Prerequisites**	Basic course in communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Written or oral (90 minutes) Written exam (Klausur), 90 minutes.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96065	**Next Generation Mobile Communication Systems: 5G-Advanced and 6G**	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr. Stefan Brück apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Mobile communication plays a significant role in our daily life. Over the last three decades the mobile applications have been tremendously enhanced from voice only over mobile broadband to applications for the mobile internet. Currently, the next generation of cellular systems, the so-called 5th Generation (5G) is developed and first commercial 5G networks are expected to be deployed around mid of 2019. 5G will play an outstanding role for the Internet of Things and will redefine a wide range of industries by enabling new use cases. This lecture will provide the technical foundation of 4G (LTE) and 5G mobile communication systems with a focus on the radio access network and the PHY & MAC layer concepts.
6	**Learning objectives and skills**	The students • learn the technical history of mobile communications from 2nd (GSM), 3rd (UMTS), 4th (LTE) to the 5th (5G New Radio) Generation • understand the system and radio access network architecture of modern cellular communications systems and their enhancements towards 5G • compare the physical layer design of LTE and 5G New Radio • discuss how 5G networks are designed to address a wide range of diverse services and devices • analyze enhanced radio resource management concepts for use cases like cellular V2X (Vehicle-to-Everything) and NB-IoT (Narrowband Internet of Things) Die Studierenden • erfahren die technische Geschichte der Mobilkommunikation von der 2. (GSM), 3. (UMTS), 4. (LTE) bis zur 5. Generation (5G New Radio) • verstehen die System- und Funkzugangsnetzarchitektur moderner zellularer Kommunikationssysteme und ihre Verbesserungen bei 5G • vergleichen das Design der physikalischen Übertragungsschicht von LTE und 5G New Radio • diskutieren, wie 5G-Netze für eine breite Palette unterschiedlicher Dienste und Geräte konzipiert sind • analysieren verbesserte Funkressourcenverwaltungskonzepte für Anwendungsfälle wie zellulare V2X (Vehicle-to-Everything)

		Kommunikation und das NB-IoT (Schmalband-Internet der Dinge)
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Lecture Notes 4G/5G Mobile Communication Systems

1	**Module name** 44120	**Pattern Analysis** Pattern analysis	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.-Ing. Christian Riess
5	**Contents**	This lecture is the sequel to the lecture "Pattern Recognition". As such, it covers topics from the chapters 8-14 from the book "Pattern Recognition and Machine Learning" by Christopher Bishop. These topics include various aspects of Bayesian modeling, including (but not limited to) probabilistic graphical models, mixture modeling, variational inference, sampling methods, manifold learning, Markov random fields, hidden Markov models, tree-based methods and ensembling.
6	**Learning objectives and skills**	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Variable (60 minutes) Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten. / The form of examination is a written exam with multiple choice with a duration of 60 minutes.
11	**Grading procedure**	Variable (100%)

12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Begleitende Literatur / Accompanying literature: • C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 • A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013

1	**Module name** 44130	**Pattern Recognition** Pattern recognition	**5 ECTS**
2	Courses / lectures	Übung: PR Exercise (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Linda-Sophie Schneider Dr.-Ing. Siming Bayer Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	**Learning objectives and skills**	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	**Prerequisites**	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english english
16	**Bibliography**	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009 • Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	**Module name** 42801	**Perception in Robotics** Perception in robotics	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will learn robotic perception topics, including camera models, filtering, transformations, low-level features, point-cloud processing, recognition, pose estimation, localization, mapping, depth, and motion estimation. In the exercises, the students will implement techniques for different perception modules. The lecture topics include: • Sensor models • Camera calibration • Feature detection and matching. • Edges, lines, circles. • Transformations. • Multiple views. • Recognition. • Pose estimation. • Localization and mapping. • Depth estimation. • Point-cloud processing.
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	Basic knowledge of image and signal processing
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written examination (90 minutes) Written examination of 90 min duration *Schriftliche Prüfung von 90 min Dauer.*
11	**Grading procedure**	Written examination (100%) A grade bonus of 0.3 is awarded for regular participation in the exercise assignments. The grade bonus can only be counted towards the overall grade only if the examination is passed. A grade improvement from 5.0 to 4.0 is not possible.
12	**Module frequency**	Only in summer semester

13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Szeliski, Richard. Computer vision: algorithms and applications. Springer Nature, 2022. • Thrun, Sebastian, Wolfram Burgard, and Dieter Fox. "Probalistic robotics.", MIT Press. • Hartley, Richard, and Andrew Zisserman. Multiple view geometry in computer vision. Cambridge University Press, 2003

1	**Module name** 96316	**Radar, RFID and Wireless Sensor Systems (RWS)** Radar, RFID and wireless sensor systems (RWS)	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Martin Vossiek
5	**Contents**	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonoumous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems. The module "Radar, RFID and Wireless Sensors" is an introduction into functional principles, building blocks, hardware and signal processing concepts and applications of modern radar, RFID, wireless sensor and real time locating systems. Covered applications include automotive radar, road and air traffic control systems, as well as robotics, industrial automation and medical technology. RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR.
6	**Learning objectives and skills**	The students • learn about the setup, function and application of wireless sensors, Radar and RFID-systems • can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases • can determine the underlying physical limitations and sources of errors • are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems • can create and define independently applications and system designs of RWSs
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written (90 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009 Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999 Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008 "RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009. RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.

1	**Module name** 44400	**Radar Signal Processing** Radar signal processing	**5 ECTS**
2	Courses / lectures	Vorlesung: Radar Signal Processing (2 SWS) Übung: Radar Signal Processing Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Gerhard Krieger	

4	**Module coordinator**	Prof. Dr.-Ing. Gerhard Krieger
5	**Contents**	Radar is a key technology for a growing number of sensing tasks that range from the detection, location and tracking of moving objects to high-resolution imaging of surfaces, sub-surfaces and 3-D volumes. While the traditional radar applications focused on aerospace security, weather services and traffic surveillance, radar is now becoming a central contactless sensor technology for the automotive sector, medical diagnostics, gesture control, civil engineering, as well as large scale environmental and climate change monitoring, to name only a few. Associated with the new applications is an increasing demand for advanced signal processing techniques to extract the relevant information from the microwave echoes acquired by single- and multi-aperture radar systems in complex environments. This lecture will give an overview of a variety of one-, two-, and three-dimensional radar signal and image processing algorithms and their application for different sensing tasks. The theoretical derivations are complemented by computer examples and simulations that form an integral part of both the lecture and the exercises. The lecture covers the following topics: • Introduction (radar principles & applications, signal & noise models, interference, Doppler shift) • Basics of Signal Processing with Python (Jupyter Notebooks) • Data Acquisition (I/Q demodulation, complex signal representation, sampling, quantization) • Range Processing (radar waveforms, pulse compression, ambiguity function, sidelobe reduction) • Doppler Processing (MTI, clutter suppression, range-Doppler ambiguities, spectral estimation) • Detection Theory (target models, Neyman-Pearson criterion, CFAR detector, CRBs) • Multi-Channel Processing (spatial filtering, interference suppression, adaptive beamforming) • Synthetic Aperture Radar (basics of coherent imaging, SAR data model, time-domain processing) • SAR Focusing Algorithms (range-Doppler, chirp scaling, motion compensation, autofocus) • SAR Image Analysis (image statistics, speckle filtering, segmentation, classification) • Radar Polarimetry (wave representations, scattering models, polarimetric decomposition) • Interferometry (interferometric processing chain, statistical performance models, applications)

		• Tomography (principles of 3-D imaging, tomographic processing, remote sensing applications) • Space-Time Adaptive Processing (GMTI, optimum processor, pre- & post-Doppler STAP) • Advanced Topics (bi- & multistatic radar, MIMO radar, compressive sensing)
6	**Learning objectives and skills**	**Fachkompetenz** Verstehen • understand the basic principles and applications of radar systems • understand the statistical properties of SAR images and their combinations • understand current developments associated with bi- and multistatic SAR, MIMO radar, etc. Anwenden • implement signal processing algorithms for radar detection and parameter estimation • use performance metrics for the evaluation of radar systems and signal processing algorithms • focus coherent radar raw data into high-resolution SAR images • apply space-time adaptive processing techniques for ground moving target indication Analysieren • select and apply spectral processing techniques for clutter and interference suppression • simulate the performance of radar systems in complex environments Erschaffen • combine multiple complex-valued SAR images into higher-level information products
7	**Prerequisites**	Keine formalen Voraussetzungen, aber grundlegende Kenntnisse erforderlich in • Signal- und Systemtheorie, • Wahrscheinlichkeitstheorie • Lineare Algebra. Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete: • statistische Signalverarbeitung • Hochfrequenztechnik • Radarsysteme • Nachrichtentechnische Systeme.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Prüfungsform: mündlich (30 Minuten)

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	• The handouts distributed at the beginning of each lecture cover the entire material and are fully sufficient for exam preparation.
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		  ◦ M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014
		  ◦ I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004
		  ◦ J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991
		  ◦ F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014
		  ◦ C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004
		  ◦ H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002
		  ◦ J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015
		  ◦ R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001
		  ◦ J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008

1	**Module name** 451971	**Random Matrices in Communications and Signal Processing** Random matrices in communications and signal processing	**5 ECTS**
2	Courses / lectures	Vorlesung: Random Matrices in Communications and Signal Processing (2 SWS) Übung: Tutorial for Random Matrices in Communications and Signal Processing (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Dual antenna arrays, compressive sensing, Wishart distribution, factor iid model, Kronecker model, convergence of random variables, semi-circle law, quarter circle law, full circle law, Haar distribution, Marchenko-Pastur distribution, Stieltjes transform, Girkos law, unitary invariance, freeness, free convolution, R-transform, free central limit theorem, free Poisson limit theorem, subordination, S-transform, R-diagonal random matrices, R-diagonal free convolution, Haagerup-Larsen law, operator-valued freeness, linearization of noncommutative polynomials, free Fourier transform, self-averaging properties, microscopic vs. macroscopic random variables, quenched random variable, a statistical physics point of view of digital systems, spin glasses, frozen disorder, replica method, replica continuity, replica symmetry, replica symmetry breaking, approximate message passing, classification of np-complete problems
6	**Learning objectives and skills**	The students find the limiting eigenvalue distributions of various types of random matrices. The students explain Stieltjes, R- and S-transforms. The students explain the limits of various types of fading channels. The students design coding and decoding methods for a given type of multiuser channel. The students perform additive and multiplicative free convolution. The students calculate the asymptotic eigenvalues distributions of given random matrix ensembles. The students construct random matrix ensembles with a given eigenvalue distribution. The students linearize matrix polynomials. The students derive the Boltzmann distribution. The students utilize saddle point integration. The students perform replica calculations. The students explain the meaning of replica symmetry breaking. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: Good skills in linear algebra, probability theory and complex analysis
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232

10	**Method of examination**	Oral The examination is a 30-minute oral exam.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Mingo, J., Speicher, R.: Free Probability and Random Matrices, Springer, 2017 • Couillet, R., Debbah, M.: Random Matrix Methods for Wireless Communications, Cambridge Univ. Press, Cambridge, 2011. • Mezard, M., Montanari, A.: Information, Physics, and Computation, Oxford Graduate Texts, 2009.

1	**Module name** 93185	**Reinforcement Learning** Reinforcement learning	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Christopher Mutschler
5	**Contents**	The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics: • Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes) • Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration) • Model-Free Prediction • Model-Free Control • Value Function Approximation (Linear VFA and DQNs) • Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO) • Model-based RL • Offline RL • Explainable RL • Exploration-Exploitation • Simulation to Reality Transfer • Research frontiers & hot topics, Sim2Real & Real-World Applications
6	**Learning objectives and skills**	The students will learn to • understand the basic principle behind sequestration decision making problems and how to translate them into a formal model • compare and analyze methods different agents to search for policies • implement the presented methods in PyTorch, • discuss the social impact of applications that automate decision making
7	**Prerequisites**	
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Variable (90 minutes) • The examiniation will include a written exam of 90 minutes at the end of the semester • The exam will cover the content of the lecture as well as that of the exercises (the exam will hence contain a mixture of theoretical questions and practical coding tasks) Please note that the exam will only take place in summer terms.
11	**Grading procedure**	Variable (100%)

		Written Exam (100 %)
12	**Module frequency**	Only in summer semester The lecture and exam will only be able during summer terms.
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	• Richard S. Sutton and Andrew G. Barto. 2018. Reinforcement Learning: An Introduction. A Bradford Book, Cambridge, MA, USA. • Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5. • Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers. • Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley. • Maxim Lapan. 2020. Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more, 2nd Edition. Packt Publishing. • Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific. • Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning. • Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics.

1	**Module name** 250058	**Signal Analysis** Signal analysis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Signalanalyse (2 SWS)	-
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	**Module coordinator**	Dr.-Ing. Heinrich Löllmann
5	**Contents**	Es werden im Rahmen dieser Vorlesung unterschiedliche Verfahren zur Analyse digitaler Signale, sowie deren Anwendungsmöglichkeiten behandelt. Die folgenden Konzepte werden dabei insbesondere behandelt: • Fourieranalyse von Signalen • Signalanalyse mittels Zeit-Frequenz-Transformationen • Parametrische und nichtparametrische Signalanalyse • Verfahren zur Frequenzschätzung • Räumliche Signalanalyse • Filterbänke und Wavelets. In this course, different approaches for the analysis of digital signals and their applications are treated, which comprises the following topics: • Fourier analysis of signals • Signal analysis by means of time-frequency transformations • Parametric and non-parametric signal analysis • Frequency estimation • Spatial signal analysis • Filter-banks and wavelets.
6	**Learning objectives and skills**	Die Studierenden • beschreiben, welche Methoden der Signalanalyse für unterschiedlichen Arten von Signalen angewendet werden • beschreiben grundlegende Methoden der spektralen Signalanalyse • erläutern wodurch die spektrale und zeitliche Auflösung bei der Spektralanalyse von Signalen begrenzt wird • beschreiben die Konzepte sowie die Vor- und Nachteile der parametrischen und nichtparametrischen Signalanalyse • erklären unterschiedliche Verfahren der Zeit-Frequenz-Analyse • stellen die Analyse von Signalen mittels Filterbänke und Wavelets dar • können Verfahren zur Frequenzschätzung erläutern • formulieren Verfahren zur Analyse räumlicher Signale. The students • describe which methods for signal analysis can be applied for different types of signals • describe fundamental approaches for spectral signal analysis • explain the limiting factors for the time and frequency resolution for the spectral analysis of signals • describe concepts as well as the pros and cons of parametric and non-parametric signal analysis • explain different approaches for time-frequency analysis

		• describe the analysis of signals by means of filter-banks and wavelets • explain methods for frequency estimation • formulate approaches for spatial signal analysis.
7	**Prerequisites**	Fundierte Kenntnisse in digitaler Signalverarbeitung. Requirements Solid knowledge in digital signal processing
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Mündliche Prüfung mit einer Dauer von 30 min. Oral examination of 30 min duration.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	P. Stoica und R. Moses: "Spectral Analysis of Signals", Pearson Prentice Hall, 2005

1	**Module name** 788996	**Speech Enhancement** Speech enhancement (oral examination)	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Speech Processing (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Emanuël Habets	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	*Course Description* We live in a noisy world! In all applications related to speech, from hands-free communication to human-machine interfaces, a speech signal of interest captured by one or more microphones is contaminated by noise and reverberation. The quality and intelligibility of the signal of interest depend highly on the level of noise and reverberation. Therefore, it is highly desirable, and sometimes even indispensable, to "clean up" the captured signals before storage, transmission, or reproduction. This course discusses both model-driven and data-driven methods to estimate the signal of interest. It aims to provide a strong foundation for researchers, engineers, and graduate students interested in signal and speech enhancement. *Relation to other courses* This course is the most advanced course offered by the university on this topic, and serves as an excellent basis from which to commence research in the area. Various aspects of the course bring students up to date with the very latest developments in the field, as seen in recent international conferences and journals. This course is well complimented by |Selected Topics in Perceptual Audio Coding| (Prof. Herre) and |Auditory Models| (Prof. Edler).
6	**Learning objectives and skills**	Students • Formulate the speech enhancement problem mathematically. • Derive optimal single- and multi-channel filters to reduce noise and reverberation. • Evaluate and compare the performance of single- and multi-channel filters for speech enhancement. • Understand how reference signals and other prior information can be used in a speech enhancement system. • Understand the limitations and challenges of existing speech enhancement systems. • Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids. • Design a microphone array and analyze its performance. • Design a speech enhancement system for a given acoustic scenario. • Evaluate both subjectively and objectively the performance of a speech enhancement system in terms of the speech quality and intelligibility.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral oral examination (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 498723	**Transformationen in der Signalverarbeitung** Transforms in signal processing	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.-Ing. Jürgen Seiler
5	**Contents**	Das Modul "Transformationen in der Signalverarbeitung" behandelt mehrere verschiedene Transformationen, die im Rahmen der Signalverarbeitung Verwendung finden. Dabei werden zuerst die grundlegenden Konzepte von Transformationen diskutiert und die Vorteile die Transformationen mit sich bringen erläutert. Im Anschluss daran werden die grundlegenden Eigenschaften von Integraltransformationen betrachtet und die Laplace- und die Fourier-Transformation im Detail untersucht. Um auch zeitlich veränderliche Signale gut transformieren zu können werden danach die Kurzzeit-Fourier-Transformation und die Gabor-Transformation eingeführt. Im Anschluss daran erfolgt eine Betrachtung der Auswirkung der Abtastung auf transformierte Signale, bevor die z-Transformation als Transformation für diskrete Signale behandelt wird. Abschließend erfolgt die Betrachtung weiterer Transformationen für diskrete Signale wie der Diskreten Fourier-Transformation oder linearer Block-Transformationen. The module "Transforms in Signal Processing" covers several different transforms which are used in the field of signal processing. For this, first the basic concepts of transforms are discussed and the advantages which are offered by the different transforms are presented. Subsequent to this, fundamental properties of integral transforms are considered and the Laplace- and the Fourier-Transform are examined in detail. To be able to transform time-varying signals, the Short-Time Fourier-Transform and the Gabor-Transform are introduced, afterwards. Subsequent to this, the impact of sampling on transformed signals is analyzed before the z-Transform as a transform for discrete signals is covered. Finally, further transforms for discrete signals like the Discrete Fourier-Transform or Linear-Block Transforms are discussed.
6	**Learning objectives and skills**	Die Studierenden können nach Besuch der Vorlesung • Anwendungsmöglichkeiten von Transformationen bestimmen • Integraltransformationen gegenüberstellen und untersuchen • die Existenz von Transformationen hinterfragen • die Eindeutigkeit von Transformationen überprüfen • Sätze und Eigenschaften von Transformationen entwickeln • zu Transformationen zugehörige inverse Transformationen einschätzen • die Zusammenhänge zwischen verschiedenen Transformationen einschätzen • auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern • Symmetriebeziehungen von Transformationen ausarbeiten

		• Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten Educational Objectives and Competences: After attending the lecture, students will be able to • determine applications of transforms • contrast and examine integral transforms • question the existence of transforms • evaluate the uniqueness of transforms • develop theorems and properties of transforms • evaluate to transforms corresponding inverse transforms • evaluate the relationships between different transforms • asses the relationship between original signal and transformed signals • devise the symmetry properties of transforms • devise the relationship between continuous and discrete signals
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral Mündliche Prüfung von 30 min Dauer.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart

1	**Module name** 43420	**Transmission and Detection for Advanced Mobile Communications** Transmission and detection for advanced mobile communications	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Wolfgang Gerstacker
5	**Contents**	The aim of this lecture is that the students acquire a basic knowledge of advanced transmission and detection techniques which are relevant to practical mobile communications systems. In the first part, it is shown how equalization schemes like decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE) can be applied to the GSM/EDGE (Enhanced Data Rates for GSM Evolution) standard. Also, channel estimation for GSM/EDGE is covered. In GSM/EDGE, disturbance by interfering signals of other users is a further major problem. Therefore, interference cancellation algorithms are discussed in detail. The cases of several receive antennas and one receive antenna (single antenna interference cancellation) are distinguished. Several receive antennas can be also utilized for increasing the robustness against fading, applying diversity combination techniques. In the case of the availability of several transmit antennas only, additional space-time coding has to be used for realization of diversity gains. These aspects are also discussed in depth. Furthermore, an introduction to code-division multiple access (CDMA) transmission is given and it is shown how CDMA is applied in the UMTS system. The lecture is concluded by an introduction to digital transmission in the Long Term Evolution (LTE) system.
6	**Learning objectives and skills**	The students • describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE), • apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system, • formulate channel estimation methods for mobile communication systems, • characterize the interference problem in GSM / EDGE, - design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively, • characterize the performance of mobile communication networks for different reception schemes, • devise receivers for the realization of diversity gains for multiple receive antennas,

		• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, • describe transmission schemes which are based on code-division multiple access (CDMA), • apply reception techniques for CDMA to the UMTS system, • characterize the uplink transmission in the Long Term Evolution (LTE) system, • develop receivers for LTE. Die Studierenden • beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE), • wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an, • formulieren Kanalschätzverfahren für Mobilfunksysteme, • charakterisieren das Interferenzproblem bei GSM/EDGE, • entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen, • bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren, • konzipieren Empfänger zur Realisierung von Diversitätsgewinnnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codierverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität, • beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren, • wenden Empfangsverfahren für CDMA auf das UMTS-System an, • charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE), • entwerfen Empfänger für LTE.
7	**Prerequisites**	Systemtheorie, Nachrichtenübertragung
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral Oral exam, 30 minutes.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Lecture notes

1	**Module name** 96895	**Music Processing - Synthesis** Music processing - synthesis	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Musikverarbeitung - Synthese (2 SWS)	-
3	Lecturers	Dr.-Ing. Maximilian Schäfer	

4	**Module coordinator**	Dr.-Ing. Maximilian Schäfer
5	**Contents**	• Verarbeitung von Audiosignalen durch parametrische Filter und Effekte • Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese • Klangwiedergabe in echten und virtuellen Räumen • Klangbeispiele und Demonstrationen • Programmiersprachen für Audio-Echtzeit-Verarbeitung *Content*: • a short history of electrical and electronic music • processing of audio signals by parametric filters and effects • digital sound synthesis • sound reproduction in real and in virtual environments • sound examples and demonstrations • programming languages for audio real-time processing
6	**Learning objectives and skills**	Die Studierenden • beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung, • wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an, • gestalten eigene Software-Realisierungen zur Klangsynthese, • entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen. The students • specify the special requirements for audio realtime processing, • apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds, • design their own software realizations for sound synthesis • implement technical systems for digital music.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Written or oral The examination is a 30-minute oral exam. The examination language is English.
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in winter semester

13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Das Vorlesungsskript und weitere Zusatzmaterialien zur Vorlesung werden via StudOn zur Verfügung gestellt.

1	**Module name** 700506	**Communications Systems Design** Commmunications systems design	**5 ECTS**
2	Courses / lectures	Vorlesung: Communications Systems Design (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi Torsten Reißland Torsten Reißland
5	**Contents**	Learning based on LabVIEW communications and NI USRP: Introduction to USRP including hardware blocks of Tx/Rx chains Getting familiar with LabVIEW communications environment and controlling VIs (Panel, diagram, etc.) and fundamentals of LabVIEW programming: data types, arrays, flow control (for/while loop), clusters, case structures, signal sources, sinks, signal processing tools, filters, time/ frequency domain analysis, etc. Transmission and reception of analog modulation schemes: AM/DSB-SC and FM Implementation of digital modulation schemes: ASK, FSK, BPSK, QPSK, 16-QAM, etc. Digital Tx/Rx: symbol mapping, upsampling/downsampling, pulse shaping (rectangular, Gaussian, RRC), matched filtering, pulse alignment, synchronization, and detection Phase synchronization, FDM and image rejection algorithm Eye diagram analysis: ISI, clock jitter, optimal sampling time, detection threshold Power control for over-the-air transmission in sub-6 GHz ISM bands and analysis on fading and multipath propagation effects Channel estimation, equalization (decision directed, linear LS, adaptive LMS), modelling: coherence bandwidth and propagation delay Learning based on MATLAB and USRPs (Communications toolbox and SDR support packages): OFDM Tx/Rx with frequency domain equalization (FDE) and synchronization (training sequence and frame detection) LTE downlink transmission (MIMO) including system information blocks (SIB) and spectrum analysis including estimation/calibration of carrier frequency offset (CFO) Impairments/distortion analysis: ACPR, EVM tool: IQ offset errors, phase noise, PA nonlinearity, etc. Learning based on GNU Radio and RTL-SDR: Introduction to GNU Radio with RF prototyping demonstration Spectrum analyzer implementation: RBW, VBW, sweep time, and phase noise Small Project/assignment for students
6	**Learning objectives and skills**	Students Can bridge the gap between communications theory, analog/digital baseband, and RF design

		Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions Can determine the design parameters and assess the interaction between various analog and digital parts Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate MIMO and OFDM based systems like LTE and beyond Can quantify and evaluate system performance using EVM and impairments analysis
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 30 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 92736	**Localization Systems for IoT**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Jörg Robert
5	**Contents**	Overview of localisation systems for the IoT sector • RSSI-based localisation methods • AoA-based localisation methods • TDoA/ToA-based localisation methods • Implementation in current transmission standards • Algorithms for data evaluation
6	**Learning objectives and skills**	1) The students understand the functioning of localisation methods in the field of IoT 2) The students analyse the performance and limitations of various localisation methods
7	**Prerequisites**	Vorlesung Nachrichtentechnische Systeme, Kommunikationselektronik (empfohlen)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232
10	**Method of examination**	Oral (30 minutes) Tutorial achievement
11	**Grading procedure**	Oral (100%) Tutorial achievement (pass/fail)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	Vorlesungsunterlagen