Friedrich-Alexander-Universität
Erlangen-Nürnberg

# Module description

for the degree programme

## Master of Science Communications and Multimedia Engineering

(Version of examination regulation: 2011)

# Table of contents

Technical elective modules

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| 1 | **Module name**<br>47800 | **Digital Communications**<br>Digital communications | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr. Laura Cottatellucci |
| 5 | **Contents** | Alle modernen Kommunikationssysteme basieren auf digitalen Übertragungsverfahren.<br>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.<br>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.<br>---<br>Modern communication systems are based on digital transmission methods.<br>This course covers basics of analysis and design of digital transmitters and receivers.<br>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<br>• analysieren und klassifizieren digitale Modulationsverfahren hinsichtlich ihrer Leistungs- und Bandbreiteneffizienz sowie ihres Spitzenwertfaktors,<br>• ermitteln notwendige Kriterien für impulsinterferenzfreie Übertragung,<br>• charakterisieren digitale Modulationsverfahren im Signalraum,<br>• ermitteln informationsverlustfreie Demodulationsverfahren,<br>• entwerfen optimale kohärente und inkohärente Detektions- und Decodierungsverfahren, |

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| | | • vergleichen verschiedene Entzerrungsverfahren hinsichtlich deren Leistungsfähigkeit und Komplexität,<br>• entwerfen einfache digitale Übertragungssysteme mit vorgeschriebenen Leistungs- und Bandbreiteneffizienzen sowie Spitzenwertfaktoren.<br>• --<br>The students<br>• analyze and classify digital modulation techniques in terms of performance and bandwidth efficiency as well as crest factor,<br>• determine necessary criteria to design impulses for interference-free transmission,<br>• characterize digital modulation methods in signal space,<br>• determine information loss-free demodulation methods,<br>• design optimal coherent and incoherent detection and decoding methods,<br>• compare different equalization methods in terms of performance and complexity,<br>• 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** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>93500 | **Digitale Signalverarbeitung**<br>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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | The course assumes familiarity with basic theory of discrete-time deterministic signals and linear systems and extends this by a discussion of the properties of idealized and causal, realizable systems (e.g., lowpass, Hilbert transformer) and corresponding representations in the time domain, frequency domain, and z-domain. Thereupon, design methods for recursive and nonrecursive digital filters are discussed. Recursive systems with prescribed frequency-domain properties are obtained by using design methods for Butterworth filters, Chebyshev filters, and elliptic filters borrowed from analog filter design. Impulse-invariant transform and the Prony-method are representatives of the considered designs with prescribed time-domain behaviour.For nonrecursive systems, we consider the Fourier approximation in its original and its modified form introducing a broad selection of windowing functions. Moreover, the equiripple approximation is introduced based on the Remez-exchange algorithm.<br>Another section is dedicated to the Discrete Fourier Transform (DFT) and the algorithms for its fast realizations ('Fast Fourier Transform').<br>As related transforms we introduce cosine and sine transforms. This is followed by a section on nonparametric spectrum estimation. Multirate systems and their efficient realization as polyphase structures form the basis for describing analysis/synthesis filter banks and discussing their applications.<br>The last section is dedicated to investigating effects of finite wordlength as they are unavoidable in any realization of digital signal processing systems.<br>A corresponding lab course on DSP will be offered in the winter term. |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• analysieren zeitdiskrete lineare zeitinvariante Systeme durch Ermittlung der beschreibenden Funktionen und Parameter<br>• wenden grundlegende Verfahren zum Entwurf zeitdiskreter Systeme an und evaluieren deren Leistungsfähigkeit<br>• verstehen die Unterschiede verschiedener Methoden zur Spektralanalyse und können damit vorgegebene Signale analysieren<br>• verstehen die Beschreibungsmethoden von Multiratensystemen und wenden diese zur Beschreibung von Filterbänken an<br>• kennen elementare Methoden zur Analyse von Effekten endlicher Wortlängen und wenden diese auf zeitdiskrete lineare zeitinvariante Systeme an |

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| | | The students<br>• analyze discrete-time linear time-invariant systems by determining the describing function and parameters<br>• apply fundamental approaches for the design of discrete-time systems and evaluate their performance<br>• understand the differences between various methods for spectral analysis and apply them to the analysis of given signals<br>• understand methods to represent multirate systems and apply them for the representation of filter banks<br>• know basic methods for the analysis of finite word length effects and apply them to discrete-time linear time-invariant systems. |
| 7 | **Prerequisites** | Vorlesung Signale und Systeme I & II |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | *Empfohlene Literatur/ Recommended Reading:*<br><br>*1.* J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007.<br><br>*2.* A.V. Oppenheim, R.V. Schafer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975.<br><br>*3.* K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012 |

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| 1 | **Module name**<br>96310 | **Image and Video Compression**<br>Image and video compression | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Image and Video Compression (IVC)<br>Übung: Übung zu Image and Video Compression | -<br>- |
| 3 | Lecturers | Prof. Dr.-Ing. Andre Kaup<br>Anna Meyer | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | *Multi-Dimensional Sampling*<br>Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling<br>*Entropy and Lossless Coding*<br>Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding<br>*Statistical Dependency*<br>Joint entropy and statistical dependency, run-length coding, fax compression standards<br>*Quantization*<br>Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization<br>*Predictive Coding*<br>Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM)<br>*Transform Coding*<br>Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts<br>*Subband Coding*<br>Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding<br>*Visual Perception and Color*<br>Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats<br>*Image Coding Standards*<br>JPEG and JPEG2000<br>*Interframe Coding*<br>Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding<br>*Video Coding Standards*<br>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** | Die Studierenden<br>• veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal<br>• unterscheiden und bewerten verschiedene Verfahren zur verlustfreien Codierung von Bild- und Videodaten |

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| | | • verstehen und analysieren Verbundentropie und statistische Abhängigkeiten in Bild- und Videodaten<br>• berechnen skalare und vektorielle Quantisierer nach unterschiedlichen Optimierungsvorgaben (minimaler mittlerer quadratischer Fehler, entropiecodiert, eingebetteter Quantisierer)<br>• bestimmen und evaluieren optimale ein- und zwei-dimensionale lineare Prädiktoren<br>• wenden Prädiktion und Quantisierung sinnvoll in einem gemeinsamen DPCM-System an<br>• verstehen das Prinzip und die Effekte von Transformations- und Teilbandcodierung für Bilddaten einschließlich optimaler Bitzuteilungen<br>• beschreiben die Grundzüge der menschlichen visuellen Wahrnehmung für Helligkeit und Farbe<br>• analysieren Blockschaltbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale<br>• kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression.<br>The students<br>• visualize multi-dimensional sampling and the influence of motion within the video signal<br>• differentiate and evaluate different methods for lossless image and video coding<br>• understand and analyze mutual entropy and statistical dependencies in image and video data<br>• determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization)<br>• determine and evaluate optimal one-dimensional and two-dimensional linear predictor<br>• apply prediction and quantization for a common DPCM system<br>• understand the principle and effects of transform and subband coding for image data including optimal bit allocation<br>• describe the principles of the human visual system for brightness and color<br>• analyze block diagrams and the functioning of hybrid coders and decoders for video signals<br>• know the prevailing international standards of ITU and MPEG for image and video compression. |
| 7 | **Prerequisites** | Modul Signale und Systeme II" und das Modul Nachrichtentechnische Systeme" |
| 8 | **Integration in curriculum** | semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |

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| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | J.-R. Ohm, Multimedia Communications Technology", Berlin: Springer-Verlag, 2004 |

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|---|---|---|---|
| 1 | **Module name**<br>93601 | **Information Theory and Coding /<br>Informationstheorie und Codierung**<br>Information theory and coding | **5 ECTS** |
| 2 | Courses / lectures | Übung: Informationstheorie und Codierung - Übungen (1.0 SWS)<br>Vorlesung: Informationstheorie und Codierung (3.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Ralf Müller<br>Kenneth Mayer | |

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

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| | | 5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung<br>6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation<br>7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma<br>8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität<br>9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanaäle<br>10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals<br>11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist<br>12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus<br>13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus<br>14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang<br>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.<br>The students explain the concept of digital communications by means of source compression and forward-error correction coding.<br>For the design of communication systems, they use the concepts of entropy and channel capacity.<br>They calculate these quantities for memoryless sources and channels.<br>The students proof both the source coding and the channel coding theorem.<br>The students compare various methods of source coding with respect to compression rate and complexity.<br>The students apply source compression methods to measure mutual information.<br>The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables.<br>The students explain the design of error-correcting codes and the role of minimum distance.<br>They decode error-correcting codes by means of maximum-likelihood decoding and message passing.<br>The students apply distributed algorithms to problems in both communications and everydays life.<br>The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution.<br>The students transform source images into the frequency domain to improve lossy compression.<br>-- |

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| | | Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an.<br>Die Studierenden erklären die konzeptuelle Trennung von digitaler Übertragung in Quellen- und Kanalcodierung.<br>Kommunikationssysteme entwerfen sie unter Betrachtung von Entropie und Kanalkapazität.<br>Sie berechnen diese Größen für gedächtnislose Quellen und Kanäle.<br>Die Studierenden beweisen sowohl das Quellen- als auch das Kanalcodierungstheorem.<br>Die Studierenden vergleichen verschiedenartige Quellencodierungsverfahren hinsichtlich Komplexität und Kompressionsrate.<br>Die Studierenden verwenden Quellencodierverfahren zur Messung von Transinformation.<br>Die Studierenden faktorisieren Funktionen mehrerer Veränderlicher, stellen diese als Graph dar und marginalisieren sie bezüglich mehrerer Veränderlicher.<br>Die Studierenden erklären den Entwurf von Kanalcodes und den Einfluss der Minimaldistanz.<br>Sie decodieren Kanalcodes gemäß maximaler Likelihood und Nachrichtenaustausch.<br>Die Studierenden wenden verteilte Algorithmen auf Probleme der Nachrichtentechnik und des Alltagslebens an.<br>Die Studierenden verbessern die Eigenschaften von LDPC-Codes durch Erhöhung des Umfangs und/oder durch irreguäre Knotenordnungsverteilungen.<br>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** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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. |

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|---|---|---|---|
| 1 | **Module name**<br>1999 | **Masterarbeit mit Vortrag (M.Sc. Communications and Multimedia Engineering 2011)**<br>Master's 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! | |

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| 4 | **Module coordinator** | Prof. Dr. Wolfgang Gerstacker |
| 5 | **Contents** | The Master’s thesis is intended to demonstrate students’ ability to solve scientific problems in the field of communication and multimedia engineering independently. All full-time university lecturers teaching at the Department of Electrical Engineering 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.The Master's thesis includes a presentation with subsequent discussion of the results of the Master's thesis. The date for the final presentation is set by the supervising university lecturer. |
| 6 | **Learning objectives and skills** | The students<br>•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<br>•develop independent ideas and concepts for solving scientific problems<br>•deal with theories, terminologies, special features, limitations and doctrines of the subject in an in-depth and critical manner and reflect on them<br>•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<br>•are able to present subject-related content clearly and appropriately to the target group in writing and orally and to represent it argumentatively<br>•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** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 2011 |
| 10 | **Method of examination** | schriftlich (6 Monate)<br>Type and scope of the examination (EA) and course achievements (CA): Written Master's thesis (EA; graded) + presentation (CA; pass/fail)<br>Duration: 6 months<br>Grades with thirds (4,3) |
| 11 | **Grading procedure** | schriftlich (100%)<br>Proportion in the calculation of the module grade: 100.0 % |
| 12 | **Module frequency** | every semester |

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| 13 | **Resit examinations** | The exams of this moduls can only be resit once. |
| 14 | **Workload in clock hours** | Contact hours: variable<br>Independent study: 900 h |
| 15 | **Module duration** | Six months starting from the registration at the Examination Office semester |
| 16 | **Teaching and examination language** | english |
| 17 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>43141 | **Mobile Communications**<br>Mobile communications | **5 ECTS** |
| 2 | Courses / lectures | Übung: Mobile Communications - Tutorial (1.0 SWS)<br>Vorlesung: Mobile Communications (3.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Bastian Eisele<br>Prof. Dr.-Ing. Ralf Müller<br>Hans Rosenberger | |

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| 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.<br>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.<br>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** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |

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| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001.<br><br>Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001.<br><br>Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992.<br><br>Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005. |

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| 1 | **Module name**<br>1995 | **Research Internship (M.Sc. Communications and Multimedia Engineering 2011)**<br>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! | |

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| 4 | **Module coordinator** | Prof. Dr. Wolfgang Gerstacker<br>Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | The research internship teaches the practice of scientific work in research at a chair of the Department Electrical Engineering (EEI). The focus of the research work can be experimental, theoretical or constructive. Combinations of different focal points are permitted. |
| 6 | **Learning objectives and skills** | Learning and methodical competence:<br>The students<br>• acquire the ability to pursue a scientific question over a longer period of time.<br>• can develop independent ideas and concepts for the systematic solution of a scientific problem.<br>• are able to assess and review the theories, terminologies, peculiarities, limits and doctrines of the field in a profound and critical manner.<br>• are able to independently apply and further develop suitable scientific methods - also in new and unfamiliar as well as interdisciplinary contexts.<br>• are able to present and present subject-related content in a scientifically appropriate form in writing and orally in a manner appropriate to the target group.<br>Self-competence:<br>The students<br>• learn self-critical reflection of their own work<br>• expand your own planning and structuring ability<br>• acquire the ability to learn and criticize. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 3 |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 2011 |
| 10 | **Method of examination** | Praktikumsleistung<br>Type and scope of the examination (EA) and course achievements (CA): laboratory course/internship achievement (pass/fail) |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 270 h<br>Independent study: 30 h |
| 14 | **Module duration** | 1 semester |

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

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|---|---|---|---|
| 1 | **Module name**<br>96460 | **Speech and Audio Signal Processing**<br>Speech and audio 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | It concentrates on algorithms for speech and audio signal processing with applications in telecommunications and multimedia, especially<br>• physiology and models for human speech production and hearing: source-filter model, filterbank model of the cochlea, masking effects,<br>• representation of speech and audio signals: estimation and representation of short-term and long-term statistics in the time and frequency domain as well as the cepstral domain; typical examples and visualizations<br>• source coding for speech and audio signals: criteria, scalar and vector quantization, linear prediction, prediction of the pitch frequency; waveform coding, parametric coding, hybrid coding, codec standards (ITU, GSM, ISO-MPEG)<br>• basic concepts of automatic speech recognition (ASR): feature extraction, dynamic time warping, Hidden Markov Models (HMMs)<br>• basic concepts of speech synthesis: text-to-speech systems, model-based and data-driven synthesis, PSOLA synthesis system<br>• signal enhancement for acquisition and reproduction: noise reduction, acoustic echo cancellation, dereverberation using single-channel and multichannel algorithms.<br>Es werden Grundlagen und Algorithmen der Verarbeitung von Sprach- und Audiosignalen mit Anwendungen in Telekommunikation und Multimedia behandelt, insbesondere:<br>• Physiologie und Modelle der Spracherzeugung und des Hörens: Quelle-Filter-Modell, Filterbank-Modell der Cochlea; Maskierungseffekte;<br>• Darstellung von Sprach- und Audiosignalen: Schätzung und Darstellung der Kurzzeit- und Langzeitstatistik in Zeit-, Frequenz- und Cepstralbereich; typische Beispiele, Visualisierungen;<br>• Quellencodierung für Sprache und Audiosignale: Kriterien; skalare und vektorielle Codierung; lineare Prädiktion; Pitchprädiktion; Wellenform-/Parameter-/Hybrid-Codierung; Standards (ITU, GSM, ISO-MPEG)<br>• Spracherkennung: Merkmalextraktion, Dynamic Time Warping, Hidden Markov Models<br>• Grundprinzipien der Sprachsynthese: Text-to-Speech Systeme, modellbasierte und datenbasierte Synthese, PSOLA-Synthese |

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| | | • Signalverbesserung bei Signalaufnahme und wiedergabe: Geräuschbefreiung, Echokompensation, Enthallung mittels ein- und mehrkanaliger Verfahren; |
| 6 | **Learning objectives and skills** | The students<br>• understand basic physiological mechanisms of human speech production and hearing and can apply them for the analysis of speech and audio signals<br>• apply basic methods for the estimation and representation of the short-term and long-term statistics of speech and audio signals and can analyze such signals by means of these methods<br>• understand current methods for source coding of speech and audio signals and can analyze current coding standards<br>• verstehen die Grundbausteine von Spracherkennungssystemen und können deren Funktion mittels Rechnersimulation analysieren<br>• understand the basic principle of text-to-speech systems and can apply fundamental methods for speech synthesis<br>• can apply basic algorithms for speech enhancement and understand their functionality for real-world data.<br>Die Studierenden<br>• verstehen die grundlegenden physiologischen Mechanismen der Spracherzeugung und des Hörens beim Menschen und können diese zur Analyse von Sprach- und Audiosignalen anwenden<br>• wenden die grundlegenden Methoden zur Schätzung und Darstellung der Kurzzeit- und Langzeitstatistik von Sprach- und Audiosignalen an und können diese damit analysieren<br>• verstehen die aktuellen Methoden zur Quellencodierung von Sprache-und Audiosignalen und können aktuelle Codierstandards analysieren<br>• verstehen die Grundbausteine von Spracherkennungssystemen und können deren Funktion mittels Rechnersimulation analysieren<br>• verstehen die Grundprinzipien von Text-to-Speech Systemen und können elementare Algorithmen zur Sprachsynthese anwenden<br>• können elementare Algorithmen zur Signalverbesserung anwenden und für reale Daten analysieren |
| 7 | **Prerequisites** | Vorlesung Signale und Systeme I & II |
| 8 | **Integration in curriculum** | semester: 2 |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 2011 |
| 10 | **Method of examination** | schriftlich oder mündlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |

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| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Gemäß themenbezogenen Angaben in der Lehrveranstaltung |

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| 1 | **Module name**<br>96430 | **Statistical Signal Processing**<br>Statistical 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are:<br>*Discrete-time stochastic processes in the time and frequency domain*<br>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).<br>*Estimation theory*<br>estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound<br>*Linear signal models*<br>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)<br>*Signal estimation*<br>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)<br>*Adaptive filtering*<br>Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior<br>*Zeitdiskrete Zufallsprozesse im Zeit- und Frequenzbereich*<br>Zufallsvariablen (ZVn), Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte; Transformation von ZVn; Vektoren normalverteilter ZVn; zeitdiskrete Zufallsprozesse (ZPe): Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte, Stationarität, Zyklostationarität, Ergodizität, Korrelationsfunktionen und -matrizen, Spektraldarstellungen; Principal Component Analysis, Karhunen-Loeve Transformation;<br>*Schätztheorie*<br>Schätzkriterien; Prädiktion; klassische und Bayessche Parameterschätzung (inkl. MMSE, Maximum Likelihood, Maximum A Posteriori); Cramer-Rao-Schranke<br>*Lineare Signalmodelle* |

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| | | Parametrische Modelle (Cepstrale Zerlegung, Paley-Wiener Theorem, Spektrale Glattheit); Nichtparametrische Modelle: Allpole-/Allzero-/ Pole-zero-(AR/MA/ARMA) Modelle; Lattice-Strukturen, Yule-Walker Gleichungen, PARCOR-Koeffizienten, Cepstraldarstellungen;<br>*Signalschätzung*<br>Überwachte Signalschätzung, Problemklassen; Orthogonalitätsprinzip, MMSE-Schätzung, lineare MMSE-Schätzung für Gaußprozesse; Optimale FIR-Filter; Lineare Optimalfilter für stationäre Prozesse; Prädiktion und Glättung; Kalman-Filter; optimale Multikanalfilterung (Wiener-Filter, LCMV, MVDR, GSC);<br>*Adaptive Filterung*<br>Gradientenverfahren; LMS-, NLMS-, APA- und RLS-Algorithmus und Ihr Konvergenzverhalten. |
| 6 | **Learning objectives and skills** | The students:<br>• 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<br>• know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes<br>• understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation<br>• analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems<br>• evaluate adaptive filters for the identification of optimum linear estimators.<br>Die Studierenden<br>• analysieren die statistischen Eigenschaften von Zufallsvariablen, -vektoren und stochastischen Prozessen mittels Wahrscheinlichkeitsdichten und Erwartungswerten, bzw. Korrelationsfunktionen, Korrelationsmatrizen und deren Frequenzbereichsdarstellungen<br>• kennen die spezielle Rolle der Gaußverteilung und ihre Auswirkungen auf die Eigenschaften von Zufallsvariablen, -vektoren und Prozessen<br>• verstehen die Unterschiede klassischer und Bayesscher Schätzung, entwerfen und analysieren MMSE- und ML-Schätzer für spezielle Schätzprobleme, insbesondere zur Signalschätzung<br>• analysieren und evaluieren lineare MMSE-optimale Schätzer (ein- und vielkanalige Wiener-Filter und Kalman-Filter) für direkte und inverse überwachte Schätzprobleme;<br>• evaluieren adaptive Filter zur Identifikation optimaler linearer Signalschätzer |
| 7 | **Prerequisites** | Module Signale und Systeme I und Signale und Systeme II, Digitale Signalverarbeitung oder gleichwertige |

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| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Pflichtmodul Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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 (englisch)<br><br>D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005 (englisch) |

# Lab Courses

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|---|---|---|---|
| 1 | **Module name**<br>894349 | **Audio Processing Laboratory**<br>Audio processing laboratory | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Audio Processing Laboratory (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Jürgen Herre<br>Prof. Dr. Nils Peters<br>Prof. Dr.-Ing. Bernd Edler<br>Prof. Dr. Emanuël Habets<br>Prof. Dr. Meinard Müller | |

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| 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<br>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.<br>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<br>processing and some basic programming skills. Furthermore, it<br>is beneficial to<br>have some background in one of the more specific topics offered by the International Audio Laboratories Erlangen. |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |

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| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german<br>english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>93511 | **Praktikum Digitale Übertragung**<br>Digital communication Lab | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Praktikum Digitale Übertragung / Lab Course Digital Communications - Morning Group (3.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Dr.-Ing. Clemens Stierstorfer | |

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| 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<br>• 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<br>• 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<br>• 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<br>• 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<br>• 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.
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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

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| | | transmission in MATLAB. Students analyze simple MIMO scenarios and implement corresponding receiver algorithms.<br>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.<br>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.<br>Grundlegende Kenntnisse der Software MATLAB sind notwendig (bspw. aus "Software für die Mathematik" oder "Simulationstools").<br>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.<br>Basic mastery of the MATLAB software is necessary |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 35 h<br>Independent study: 40 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german<br>english |
| 16 | **Bibliography** | • Skriptum zum Praktikum<br>• Skriptum zur Vorlesung Digitale Übertragung bzw. Digital Communications |

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| | | • übliche Standardlehrwerke zur Thematik (Proakis, Haykin usw.) |

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| 1 | **Module name**<br>194239 | **Praktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen**<br>Lab course image and video processing on embedded platforms | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | Betrachtet man Anwendungen der Bild- und Videosignalverarbeitung stellt man fest, dass viele davon auf mobilen Plattformen ablaufen.<br>Die dort verwendeten Systeme haben aber häufig nur eine reduzierte Leistungsfähigkeit und müssen besonders auf den Energieverbrauch achten. Nichtsdestotrotz sind aber auch einfache, mobile Systeme wie Smartphones oder Tablets in der Lage, anspruchsvolle Signalverarbeitungsaufgaben für Bild- und Videosignale durchzuführen. Dies umfasst zum Beispiel die Codierung von Bildern und Videos, aber auch die Erzeugung von Panoramen oder die Berechnung von Bildern mit hohem Dynamikumfang.<br>Das Praktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen" soll die Herausforderung, die mit einer Verarbeitung dieser Signale auf eingebetteten Plattformen einhergehen genauer vermitteln und es wird aufgezeigt, wie man selbst auf Plattformen mit eingeschränkter Leistungsfähigkeit entsprechende Algorithmen umsetzen kann. Hierzu werden in dem Praktikum  Raspberry Pis als Plattform verwendet und die Programmierung erfolgt in Python.<br>Die Versuche umfassen den Aufbau und die Inbetriebnahme der eingebetteten Plattform, eine Einführung in Python und in die grundlegenden Prozesse der Bild- und Videosignalverarbeitung. Weitere Versuchsinhalte sind die Anbindung einer Kamera, Bildsignalverarbeitungsprozesse mit der Kamera und die Implementierung verschiedener digitaler Filter. Das Praktikum beinhaltet außerdem verschiedene Anwendungen computergestützten Sehens (Computer Vision). Die Detektion von Merkmalen und Objekten in Bildern und Videos werden einführend behandelt und aktuelle Computer Vision Anwendungen, wie die Erstellung eines Panoramas werden betrachtet.<br>*Content*:<br>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.<br>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 |

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| | | 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** | Die Studierenden<br>• verstehen die Herausforderungen von eingebetteten Plattformen<br>• wenden die Programmiersprache Python für Bild- und Videosignalverarbeitunsalgorithmen an<br>• erzeugen funktionsfähige Programme mit der Programmiersprache Python<br>• beurteilen die Funktionsblöcke von Computer Vision-Algorithmen<br>• bewerten die von ihnen erstellten Programme durch subjektive und objektive Vergleiche<br>• reflektieren den Lernprozess während des Praktikums.<br>The students<br>• understand the challenges of the embedded system<br>• make use of the coding language Python for image and video signal processing algorithms<br>• implement functional programs with Python<br>• evaluate the blocks of computer vision algorithms<br>• evaluate the self-implemented programs by subjective and objective comparison<br>• reflect the learning process in the laboratory. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 15 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Das Skript zum Praktikum Image and video signal processing on embedded platforms" wird in der Einführungsveranstaltung ausgegeben. |

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| | | The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session. |

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| 1 | **Module name**<br>878210 | **Praktikum Machine Learning in der Signalverarbeitung**<br>Lab course machine learning in signal processing | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Lab Course Machine Learning in Signal Processing (4.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Amir El-Ghoussani<br>Michele De Vita<br>Prof. Dr. Vasileios Belagiannis | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 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,<br>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.<br>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.<br>In this lab course we will solve this problem using transfer learning and mathematical modeling:<br>• Create cartoon-like artificial images of a road with known locations for the lane markings.<br>• Train deep neural network on these artificial images with heavy data augmentations that mimic real-world images.<br>• Create a dataset of unlabeled real-life videos by downloading and organizing examples from youtube.<br>• Create a machine learning pipeline for working with these videos efficiently.<br>• Apply the neural network that has been trained on artificial data to the real world videos.<br>• Analyze the quality of results produced by the network.<br>• Use mathematical modeling to correct the outputs of the network.<br>• Retrain the network on the dataset composed of the corrected outputs.<br>• Measure and analyze the quality of the results.<br>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:<br>• Independently design machine learning pipelines to solve complex problems in artificial intelligence. |

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| | | • Choose appropriate algorithms for the problem at hand.<br>• Use standard packages for machine learning in Python: numpy, cvxpy, scikit-learn, pywavelets, pytorch.<br>• Debug and calibrate machine learning algorithms. Develop modification to the standard algorithms as appropriate to the problem at hand.<br>• 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** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 15 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | <ol><br><li>Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning.</li><br><li>Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.</li><br><li>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.</li><br></ol><br><ol><br><li>Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning.</li> |

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| | | <li>Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.</li><br><li>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.</li><br></ol><br><ol><br><li>Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning.</li><br><li>Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.</li><br><li>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.</li><br></ol> |

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| 1 | **Module name**<br>92356 | **Praktikum Communications Systems Design**<br>Laboratory course: Communications systems design | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Praktikum Communications Systems Design | - |
| 3 | Lecturers | Arslan Ali<br>Christof Pfannenmüller<br>Torsten Reißland | |

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

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| | | Can bridge the gap between communications theory, analog/digital baseband, and RF design<br>Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions<br>Can determine the design parameters and assess the interaction between various analog and digital parts<br>Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio<br>Can implement channel estimation and equalization algorithms in TDD and FDD systems<br>Can demonstrate MIMO and OFDM based systems like LTE and beyond<br>Can quantify and evaluate system performance using EVM and impairments analysis |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 45 h<br>Independent study: 30 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>97525 | **Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen**<br>Laboratory course: Image and video signal processing on embedded platforms | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | Betrachtet man Anwendungen der Bild- und Videosignalverarbeitung stellt man fest, dass viele davon auf mobilen Plattformen ablaufen.<br>Die dort verwendeten Systeme haben aber häufig nur eine reduzierte Leistungsfähigkeit und müssen besonders auf den Energieverbrauch achten. Nichtsdestotrotz sind aber auch einfache, mobile Systeme wie Smartphones oder Tablets in der Lage, anspruchsvolle Signalverarbeitungsaufgaben für Bild- und Videosignale durchzuführen. Dies umfasst zum Beispiel die Codierung von Bildern und Videos, aber auch die Erzeugung von Panoramen oder die Berechnung von Bildern mit hohem Dynamikumfang.<br>Das Praktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen" soll die Herausforderung, die mit einer Verarbeitung dieser Signale auf eingebetteten Plattformen einhergehen genauer vermitteln und es wird aufgezeigt, wie man selbst auf Plattformen mit eingeschränkter Leistungsfähigkeit entsprechende Algorithmen umsetzen kann. Hierzu werden in dem Praktikum Raspberry Pis als Plattform verwendet und die Programmierung erfolgt in Python.<br>Die Versuche umfassen den Aufbau und die Inbetriebnahme der eingebetteten Plattform, eine Einführung in Python und in die grundlegenden Prozesse der Bild- und Videosignalverarbeitung. Weitere Versuchsinhalte sind die Anbindung einer Kamera, Bildsignalverarbeitungsprozesse mit der Kamera und die Implementierung verschiedener digitaler Filter. Das Praktikum beinhaltet außerdem verschiedene Anwendungen computergestützten Sehens (Computer Vision). Die Detektion von Merkmalen und Objekten in Bildern und Videos werden einführend behandelt und aktuelle Computer Vision Anwendungen, wie die Erstellung eines Panoramas werden betrachtet.<br>*Content*:<br>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.<br>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 |

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| | | 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** | Die Studierenden<br>• verstehen die Herausforderungen von eingebetteten Plattformen<br>• wenden die Programmiersprache Python für Bild- und Videosignalverarbeitunsalgorithmen an<br>• erzeugen funktionsfähige Programme mit der Programmiersprache Python<br>• beurteilen die Funktionsblöcke von Computer Vision-Algorithmen<br>• bewerten die von ihnen erstellten Programme durch subjektive und objektive Vergleiche<br>• reflektieren den Lernprozess während des Praktikums.<br>The students<br>• understand the challenges of the embedded system<br>• make use of the coding language Python for image and video signal processing algorithms<br>• implement functional programs with Python<br>• evaluate the blocks of computer vision algorithms<br>• evaluate the self-implemented programs by subjective and objective comparison<br>• reflect the learning process in the laboratory. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 15 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Das Skript zum Praktikum Image and video signal processing on embedded platforms" wird in der Einführungsveranstaltung ausgegeben. |

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| | | The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session. |

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| 1 | **Module name**<br>97640 | **Laborpraktikum Mobilkommunikation**<br>Laboratory course: Mobile communication | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Praktikum Mobilkommunikation / Lab Course Mobile Communications - Group 2 (3.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Wolfgang Gerstacker | |

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| 4 | **Module coordinator** | Prof. Dr. Wolfgang Gerstacker |
| 5 | **Contents** | # Experiments<br>• <br>  ◦ Characteristics of real mobile radio channels such as distortions and time variability<br>  ◦ models for mobile radio channels<br>  ◦ effects on the performance of a mobile radio system<br>• <br>  ◦ Principles of different equalization methods<br>  ◦ equalizer design for GSM / EDGE<br>  ◦ simulation of trellis-based equalizers and visualization of the results<br>• <br>  ◦ Principle of OFDM<br>  ◦ implementation-relevant aspects such as nonlinearities and peak-to-average-power ratio<br>  ◦ synchronization and equalization<br>• MIMO Transmission (2 experiments)<br># Versuche<br>• <br>  ◦ Eigenschaften realer Mobilfunkkanäle wie Verzerrungen und Zeitvarianz,<br>  ◦ Modelle für Mobilfunkkanäle<br>  ◦ Auswirkungen auf die Leistungsfähigkeit eines Mobilfunksystems<br>• <br>  ◦ Prinzipien verschiedener Entzerrverfahren<br>  ◦ Entzerrerdesign für GSM/EDGE<br>  ◦ Simulation von trellisbasierten Entzerrern und Visualisierung der Ergebnisse<br>• <br>  ◦ Prinzip von OFDM<br>  ◦ implementierungsrelevante Aspekte wie Nichtlinearitäten und Spitzenwertfaktor<br>  ◦ Synchronisation und Entzerrung<br>• MIMO Übertragung (2 Versuche) |
| 6 | **Learning objectives and skills** | # The students<br>• describe the characteristics of real mobile radio channels,<br>• explain the principles of OFDM and MIMO transmission systems,<br>• implement equalization and adaptation procedures in Matlab, |

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| | | • perform radio network simulations,<br>• learn to develop program code,<br>• work together in a small team.<br><br>Die Studierenden<br>• charakterisieren die Eigenschaften realer Mobilfunkkanäle,<br>• erklären die Funktionsweise von OFDM- und MIMO-Übertragungssystemen,<br>• implementieren Entzerrungs- und Adaptionsverfahren in Matlab,<br>• führen Funknetzsimulationen durch,<br>• erlernen Programmcode eingeständig zu entwickeln,<br>• 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** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung<br>• There are 8 experiments to be completed as well as an introduction to Matlab. These are described in the course materials.<br>• 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.<br>• 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.<br>• To pass the course, 8 sufficient experiment preparations and 8 sufficient experiment executions are required.<br><br>• Es sind 8 Versuche sowie eine Einführung in Matlab zu absolvieren. Diese sind in den Kursunterlagen beschrieben.<br>• Jeder Versuch ist zu Hause schriftlich vorzubereiten. Die Vorbereitung wird zu Beginn eines jeden Versuchs überprüft und bewertet (ausreichend/nicht ausreichend).<br>• 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. |

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| | | • Zum Bestehen des Praktikums sind 8 ausreichende Versuchsvorbereitungen und 8 ausreichende Versuchsdurchführungen notwendig. |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 35 h<br>Independent study: 40 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german<br>english |
| 16 | **Bibliography** | Skriptum zum Praktikum Mobilkommunikation |

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| 1 | **Module name**<br>97535 | **Laborpraktikum Statistische Signalverarbeitung**<br>Laboratory course: Statistical 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | After an introduction to scientific programming with Python, experiments and exercises related to the following topics are carried out during the laboratory course:<br>Fundamental properties of random variables and stochastic processes<br>Properties of correlations matrices, Principal Component Analysis (PCA), KLT<br>Parametric and non-parametric linear signal models<br>MMSE signal estimation<br>Kalman filtering with applications to source tracking<br>Optimum multichannel filtering<br>Introduction to adaptive filtering.<br>In the second phase of the lab course, the students will work in small project teams on relevant research problems.<br>Nach einer Einführung in den Gebrauch der Programmiersprache Python werden Experimente und<br>Übungen zu folgenden Themen der Statistischen Signalverarbeitung durchgeführt:<br>• Grundlegende Eigenschaften von Zufallsvariablen und stochastischer Prozesse<br>• Eigenschaften von Korrelationsmatrizen, Hauptachsentransformation, KLT<br>• Parametrische und nicht-parametrische lineare Signalmodelle<br>• MMSE-Signalschätzung<br>• Kalman-Filterung mit Anwendungen zur Signalquellenverfolgung<br>• Optimale Mehrkanalfilterung,<br>• Einführung in die adaptive Filterung.<br>In der zweiten Phase des Praktikums werden die Studenten in kleinen Projektgruppen (max. 3 Studenten) selbstständig eine forschungsrelevante Problemstellung analysieren und mögliche Lösungssansätze erarbeiten, implementieren und evaluieren. |
| 6 | **Learning objectives and skills** | The students<br>implement Python codes to solve described problems and apply their collected knowledge,<br>analyze, evaluate and discuss the implemented algorithms,<br>familiarize themselves with the necessary steps to implement theoretical models,<br>reflect their learning progress during the laboratory.<br>Die Studenten |

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| | | • verfassen Python-Programme zu den einzelnen vorgezeichneten Experimenten und wenden damit das in Vorlesung und Übung erworbene Wissen an,<br>• analysieren und evaluieren implementierte Algorithmen,<br>• erlernen die notwendigen Schritte zur praktischen Umsetzung von theoretischen Modellen,<br>• reflektieren ihren eigenen Lernprozess während des Praktikums. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 45 h<br>Independent study: 30 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>97520 | **Laborpraktikum Digitale Signalverarbeitung** | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | In diesem Laborpraktikum wird die Theorie aus der Vorlesung Digitale Signalverarbeitung in der Praxis angewandt, unter Verwendung der Programmierumgebung MATLAB. Die behandelten Themen umfassen Quantisierung, Spektralanalyse, FIR- und IIR-Filterentwurf, Filterbänke, sowie adaptive Filter.<br>Das Praktikum besteht aus 5 Versuchsterminen, an denen die Teilnehmer in Zweiergruppen Programmieraufgaben lösen, und einem 5-tägigen Block, in dem jede Gruppe ein individuelles Projekt aus dem Bereich der Digitalen Signalverarbeitung bearbeitet.<br>Das Praktikum erfordert vorhandene MATLAB-Programmierkenntnisse. Es ist möglich, das Praktikum parallel zur Vorlesung Digitale Signalverarbeitung zu besuchen, allerdings ist es dazu notwendig, die jeweiligen Vorlesungsinhalte vor dem Praktikumstermin zu wiederholen, und an Übung und Tutorium teilzunehmen.<br>*Contents*<br>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.<br>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.<br>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.<br>The course requires previous experience in MATLAB 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 and tutorials is required. |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• erzeugen funktionsfähige MATLAB-Programme zu den einzelnen vorgezeichneten Experimenten und wenden damit das in Vorlesung und Übung erworbene Wissen an<br>• analysieren und evaluieren den von ihnen implementierten Algorithmus<br>• verstehen die Anforderungen praktischer Realisierungen von Algorithmen zur Digitalen Signalverarbeitung |

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| | | • reflektieren ihren eigenen Lernprozess während des Praktikums. |
| 7 | **Prerequisites** | Vorlesung Signale und Systeme I & II |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>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<br>• J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007.<br>• A.V. Oppenheim, R.V. Schafer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975.<br>• K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012 |

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| 1 | **Module name**<br>97651 | **Laborpraktikum Image and Video Compression**<br>Laborpraktikum Multimediakommunikation | **2,5 ECTS** |
| 2 | Courses / lectures | Praktikum: Lab Course Image and Video Compression (3.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Geetha Ramasubbu | |

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| 4 | **Module coordinator** | Dr.-Ing. Christian Herglotz |
| 5 | **Contents** | • Einführung in die Programmierumgebung MATLAB<br>• Realisierung der Verarbeitungsblöcke von Videocodern<br>• Aufbau eines Videocodecs und optionale Erweiterungen<br>• Durchführung eines subjektiven Vergleichs verschiedener Videocodecs<br>• Präsentation und kritische Beurteilung der Ergebnisse<br>*Content*<br>• Introduction to MATLAB<br>• Implementation of the single video codec processing blocks<br>• Integration into the video codec pipeline, tests, and extensions<br>• Participation in a subjective video test of selected implementations<br>• Presentation and discussion of the achieved results. |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• erzeugen ein funktionsfähiges Programmsystem mit der Programmierumgebung MATLAB,<br>• beurteilen die Funktionsblöcke von Video-Codern,<br>• gestalten ihren eigenen Videocodec und entwickeln dazu von ihnen selbst gewählte optionale Erweiterungen,<br>• bewerten die von ihnen realisierten Videocodecs durch einen subjektiven Vergleich,<br>• reflektieren den Lernprozess während des Praktikums.<br>* Learning Targets and Skills:*<br>The students<br>• create a fully functional program using the programming environment MATLAB,<br>• evaluate the processing blocks of a typical video codec,<br>• design their own video codec and enhance it by extensions of their choice,<br>• evaluate their implemented video codecs in a subjective comparison,<br>• reflect upon the methods conveyed during the laboratory. |
| 7 | **Prerequisites** | Das Praktikum Image and Video Compression wendet sich an Studierende aus den Studiengängen EEI, IuK und CE, die die Vorlesung Bild- und Videocodierung (Image and Video Coding) im gleichen Semester hören oder bereits gehört haben.<br>The lab course Image and Video Compression is suited for students from the field of study in EEI, IuK, WIng, ASC, CME, and CE, who participate in the lecture Image and Video Compression in the current summer semester or who have already attended the lecture. |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |

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| 9 | **Module compatibility** | Praktika Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Praktikumsleistung |
| 11 | **Grading procedure** | Praktikumsleistung (0%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 45 h<br>Independent study: 30 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Das Skriptum Praktikum Image and Video Compression wird in der Einführungsveranstaltung ausgegeben.<br><br>The lab course notes will be distributed during the introductory meeting. |

# Seminar

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| 1 | **Module name**<br>330542 | **Audio Processing Seminar**<br>Audio processing seminar | **2,5 ECTS** |
| 2 | Courses / lectures | Seminar: Audio Processing Seminar (2.0 SWS) | - |
| 3 | Lecturers | Prof. Dr.-Ing. Bernd Edler<br>Dr.-Ing. Stefan Turowski<br>Prof. Dr. Nils Peters<br>Prof. Dr. Meinard Müller<br>Prof. Dr. Emanuël Habets<br>Prof. Dr.-Ing. Jürgen Herre | |

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| 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:<br>• Speech and Audio Coding<br>• Audio Signal Analysis<br>• Audio Signal Processing with the Internet of Things<br>• Spatial Audio Signal Processing<br>• Semantic Audio Processing<br>• Audio in Virtual Reality<br>During the seminar, each participant prepares a paper, creates a written report (3-7 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<br>Students will gain the following skills:<br>• How to analyze a scientific paper and understand its key principles and field of application.<br>• How to perform a thorough literature survey and evaluate relevant literature for the focus of key points in the paper.<br>• How to acquire a broad knowledge and deeper understanding of the specific scientific area.<br>• How to prepare the subject, identify its most important topics, their dependencies, didactic reduction.<br>• How to compile a written summary of a paper, scientific writing, correct citations.<br>• How to create an appealing visual presentation, review and successively optimize it.<br>• How to present the topic in front of other students, how to train presentation skills. |

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| | | • How to analyze presentations of other students, deriving questions, learn to participate in a scientific discussion. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Seminar Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Seminarleistung |
| 11 | **Grading procedure** | Seminarleistung (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>775681 | **Seminar Ausgewählte Kapitel der Nachrichtentechnik**<br>Selected areas in 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.<br>Ja | |
| 3 | Lecturers | - | |

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

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| | | • analyze and evaluate the presentations of the other seminar participants. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Seminar Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Seminarleistung<br>• Die Themen werden unter Anleitung eines/r Betreuers/in eigenständig im Hinblick auf eine Präsentation in Vortragsform erarbeitet.<br>• Studierende haben die Möglichkeit sich aktiv an der Formulierung des Vortragsthemas zu beteiligen.<br>• Themen werden bei einer Vorbesprechung zu Beginn des Semesters vergeben.<br>• 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.<br>• Vor den Beiträgen der Studierenden erfolgt eine Einführung zur Vortragstechnik durch Mitarbeiter des Lehrstuhls.<br>• Es wird eine ca. 10-15-seitige Ausarbeitung erstellt.<br>═══<br>• The topics are independently worked out under the guidance of a supervisor.<br>• Students have the opportunity to actively participate in the formulation of their individual topic.<br>• Topics are assigned at a preliminary meeting at the beginning of the semester.<br>• A brief presentation of the structure and initial results will be given about 5 weeks after the preliminary discussion.<br>• Towards the end of the lecture period, each student gives a talk of approximately 30 minutes followed by a 15-minute discussion.<br>• Students will be introduced into lecture techniques.<br>• An approx. 10-15-page paper has to be written. |
| 11 | **Grading procedure** | Seminarleistung (100%)<br>• ca. halbstündiger Vortrag (60%)<br>• Ausarbeitung im Umfang von 10-15 Seiten (vergleichbar IEEE Paper zweispaltig, 30%)<br>• aktive Teilnahme an der Diskussion anderer Vorträge (10%)<br>═══<br>• approx. half-hour presentation (60%)<br>• paper of 10-15 pages (comparable to IEEE paper in two columns, 30%)<br>• active participation in the discussion of other presentations (10%) |
| 12 | **Module frequency** | only in winter semester |

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| 13 | **Workload in clock hours** | Contact hours: 15 h<br>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<br>• Informationen zur Literatursuche und zu Präsentationstechniken<br>• Vorlagen für Ausarbeitungen und Präsentationsfolien werden zur Verfügung gestellt<br>• Technische Literatur im Themengebiet<br>_____<br>• Lecture notes of the modules Digital Transmission, MIMO Communication Systems, Convex Optimization in Communications and Signal Processing<br>• Information on literature search and presentation techniques<br>• Templates for papers and presentation slides will be provided<br>• Technical literature in the subject area |

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| 1 | **Module name**<br>914949 | **Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung**<br>Seminar on selected topics of multimedia communications and signal processing | **2,5 ECTS** |
| 2 | Courses / lectures | Seminar: Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Vasileios Belagiannis<br>Michele De Vita<br>Amir El-Ghoussani | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup<br>Prof. Dr.-Ing. Walter Kellermann |
| 5 | **Contents** | Im Seminar Multimediakommunikation und Signalverarbeitung werden aktuelle Themen aus dem Bereich der Multimediakommunikation und Signalverarbeitung bearbeitet. Nach einer gemeinsamen Vorbesprechung und Themenauswahl werden die einzelnen Themen unter Anleitung eines Betreuers oder einer Betreuerin eigenständig im Hinblick auf eine Präsentation in Vortragsform erarbeitet. Eine kurze Präsentation der Struktur und erster Ergebnisse erfolgt etwa 5 Wochen nach der Vorbesprechung. Gegen Ende des Vorlesungszeitraums hält jeder Teilnehmer einen ca. 30-minütigen Vortrag mit anschließender Diskussion im Rahmen eines ganztägigen Workshops. Als Begleitmaterial zum Vortrag wird auch eine ca. 10-seitige Ausarbeitung erstellt. Für die Vortragsveranstaltungen besteht Anwesenheitspflicht.<br>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. 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.<br>In addition, each participant has to submit a report of about 10 pages about his topic a few days before the final meeting. |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• erlernen grundlegende Techniken der Recherche, Themenaufbereitung und Präsentation technischer Inhalte und wenden diese an<br>• analysieren und evaluieren gegebene Literatur im Hinblick auf die Schwerpunkte ihres Vortrags zu einem technischen Thema |

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| | | • wenden ihr bisher im Studium erworbenes Wissen an, um davon ausgehend eigenständig einen technischen Schwerpunkt zu vertiefen<br>• wenden ihr bisheriges Wissen an, um als Zuhörer sinnvolle Fragen zu einem Vortragsthema zu formulieren und das Präsentierte zu diskutieren<br>• analysieren und evaluieren die Präsentationen der anderen Seminarteilnehmer.<br>The students<br>• acquire and apply fundamental techniques to conduct a literature survey, and to prepare and present a technical topic<br>• analyze and evaluate provided literature regarding the focus of their technical presentation<br>• apply the knowledge acquired during their studies to deepen by themselves their technical focus<br>• apply acquired knowledge to ask a presenter questions and to discuss the presentation<br>• analyze and evaluate the presentations of other seminar participants. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Seminar Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Seminarleistung |
| 11 | **Grading procedure** | Seminarleistung (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

# Technical courses

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|---|---|---|---|
| 1 | **Module name**<br>151664 | **Advanced Communication Networks**<br>Advanced communication networks | **5 ECTS** |
| 2 | Courses / lectures | Übung: Advanced Communication Networks - Tutorial (0.5 SWS)<br>Vorlesung: Advanced Communication Networks (3.5 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Prof. Dr. Laura Cottatellucci<br>Christian Forsch | |

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| 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.<br>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.<br>*Technical Content*<br>• Properties and challenges of the wireless medium.<br>• Basic concepts of communication networks: the layered architecture.<br>• Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution.<br>• Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA.<br>• Uplink-downlink duality.<br>• Opportunistic scheduling and multiuser diversity. |

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

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| | | • Analyses performance of relaying schemes.<br>• Argues on possible improvements of relaying schemes via network coding and physical layer network coding.<br>• Uses the Perron-Frobenious theorem to allocate power in a centralized manner.<br>• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility.<br>• Uses the Perron-Frobenious theorem to design a distributed power control scheme.<br>• Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control.<br>• Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality.<br>• Judges the applicability of KKT conditions and duality.<br>• Uses KKT conditions to solve convex optimization problems.<br>• Uses duality to solve convex optimization problems.<br>• Applies convex optimization to resource allocation in wireless communications.<br>• Compares different definitions of fairness and applies them to rate allocation.<br>• Appraises the effect of channel knowledge at the transmitter on different fairness criteria.<br>• Applies KKT conditions for opportunistic user scheduling.<br>• Describes a proportional fair algorithm for opportunistic scheduling.<br>• Applies relaxation to nonconvex quadratic constrained quadratic programming.<br>• Formulates resource allocation problems as constrained optimization programming.<br>• Contrasts various distributed optimization methods.<br>• Applies the concept of best response to determine Nash equilibria.<br>• Argues about existence and uniqueness of Nash equilibria.<br>• Assesses if a given game is a potential game and solves it.<br>• Defends the concept of Pareto optimality in resource allocation.<br>• Contrasts the concepts of pure and mixed strategies in game theory.<br>• Uses coupled constrained concave game to allocate powers in heterogeneous networks. |
| 7 | **Prerequisites** | Information Theory and Coding<br><br>It is advisable that the student is familiar with basic concepts of Mobile Communications |
| 8 | **Integration in curriculum** | semester: 1 |

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| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>621649 | **Advanced Optical Communication Systems**<br>Advanced optical 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Bernhard Schmauß |
| 5 | **Contents** | Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing<br>• Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems<br>• Noise and Power Management: power budget, OSNR management, OSNR calculation<br>• Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons<br>• Spectral Efficiency: definition, increase of spectral efficiency<br>• Modulation Formats:intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission<br>• Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration |
| 6 | **Learning objectives and skills** | Students<br>• gain detailed Knowledge on concepts and structure of various optical transmission systems.<br>• are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts.<br>• are able to develop and to optimize link designes of optical transmission systems.<br>• are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results. |
| 7 | **Prerequisites** | **Prerequisites:**<br>• Fundamentals in signals and systems.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h |

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| | | 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<br><br>Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001.<br><br>Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002.<br><br>Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008.<br><br>Lecture notes. |

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| 1 | **Module name**<br>96875 | **Ausgewählte Kapitel der Audiodatenreduktion**<br>Advanced topics in perceptual audio coding | **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 | - | |

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| 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.<br>The selected topics include:<br>Efficient coding of several audio channels / parametric multi- channel coding<br>Typical coding artifacts; subjective and objective quality assessment<br>Scalable audio coding<br>Bandwidth extension<br>Semi-parametric audio coding<br>Low-delay audio coding<br>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.<br>• 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.<br>• Anwenden - Die Studenten können übliche mathematische Analysemethoden verwenden, um einfache Coder-Componenten zu beschreiben und gegebenenfalls zu modifizieren.<br>• Analysieren - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge dazu analysieren um die zugrundeliegenden Konzepte und Anforderungen zu erfassen.<br>• Evaluieren (Beurteilen) - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge evaluieren um zu beurteilen, welcher |

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| | | Standard bzw. welches Messwerkzeug das passendste ist für einen bestimmten Anwendungsfall.<br>• Synthese - Die Studenten können eine Liste von Anforderungen und Bewertungskriterien für Audiocodecs zusammenstellen für gewünschte Anwendungsfälle.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>96010 | **Architekturen der digitalen Signalverarbeitung**<br>Architectures for digital signal processing | **5 ECTS** |
| 2 | Courses / lectures | Übung: Übungen zu Architekturen der Digitalen Signalverarbeitung (2.0 SWS)<br>Vorlesung: Architekturen der Digitalen Signalverarbeitung (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Sebastian Peters<br>Timo Maiwald | |

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

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| | | • 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<br>• can construct a realtime digital signal processing system and dimension its components according requirements<br>• can review pros and cons of analogue versus digitzal signal processing<br>• can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>947709 | **Auditory Models**<br>Auditory models | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Auditory Models (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Bernd Edler | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Bernd Edler |
| 5 | **Contents** | • Main components of the human auditory system<br>• Common models<br>• Mechanical models<br>• Physiological models<br>• Psychoacoustic models<br>• Applications (hearing aids, audio coding, . . . ) |
| 6 | **Learning objectives and skills** | Goals<br>• Students understand the structure and function of the human auditory system<br>• Students gain deeper insight into psychoacoustic phenomena, such as masking, directional and spatial hearing<br>• Students implement and evaluate perceptual models for various applications<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>43400 | **Entzerrung und adaptive Systeme in der digitalen Übertragung**<br>Equalisation and adaptive systems for digital 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 | - | |

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| 4 | **Module coordinator** | 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),<br>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.<br>Lernziel:<br>Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt<br>werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen.<br>Content:<br>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.<br>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. |

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| 6 | **Learning objectives and skills** | Die Studierenden<br>• beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung,<br>• setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten,<br>• vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität,<br>• wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus,<br>• entwerfen neuartige Verfahren für gegebene Anforderungen,<br>• formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal,<br>• ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu.<br>Learning Objectives and Competences:<br>The students<br>- describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation,<br>- realize various approaches in block diagrams and optimize their components,<br>- compare equalization methods in terms of their performance, characterized by the error rate, and complexity,<br>- select suitable methods for various applications such as wired and wireless transmission,<br>- design novel schemes for given requirements,<br>- formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel,<br>- assign suitable adaptation algorithms to equalization schemes. |
| 7 | **Prerequisites** | Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h |

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| | | 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.<br><br>Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992.<br><br>Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999.<br><br>Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995.<br><br>Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996. |

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| 1 | **Module name**<br>447324 | **Image, Video, and Multidimensional Signal Processing**<br>Image, video and multidimensional signal processing | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Image, Video, and Multidimensional Signal Processing (2.0 SWS, )<br>Übung: Supplements for Image, Video, and Multidimensional Signal Processing () | 5 ECTS<br>- |
| 3 | Lecturers | Prof. Dr.-Ing. Andre Kaup | |

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| 4 | **Module coordinator** | |
| 5 | **Contents** | no content description available! |
| 6 | **Learning objectives and skills** | no learning objectives and skills description available! |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | no Module frequency information available! |
| 13 | **Workload in clock hours** | Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt)<br>Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt) |
| 14 | **Module duration** | ?? semester (no information for Module duration available) |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>96312 | **Bild-, Video- und mehrdimensionale Signalverarbeitung**<br>Image, video and multidimensional 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | *Punktoperationen*<br>Histogrammausgleich, Gamma-Korrektur<br>*Binäroperationen*<br>Morphologische Filter, Erosion, Dilatation, Opening, Closing<br>*Farbräume*<br>Trichromat, RGB- Farbraum, HSV-Farbraum<br>*Mehrdimensionale Signale und Systeme*<br>Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter<br>*Interpolation von Bildsignalen*<br>Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation<br>*Merkmalsdetektion in Bildern*<br>Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix<br>*Skalierungsraumdarstellung*<br>LoG, DoG, SIFT, SURF<br>*Bildabgleich*<br>Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC<br>*Bildsegmentierung*<br>Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos<br>*Bildverarbeitung im Transformationsbereich*<br>Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT<br>*Content:*<br>*Point operations*<br>Histogram equalization, gamma correction<br>*Binary operations*<br>Morphological filters, erosion, dilation, opening, closing<br>*Color spaces*<br>Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity<br>*Multidimensional signals and systems*<br>Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering<br>*Interpolation of image signals*<br>Bi-linear interpolation, bi-cubic interpolation, spline interpolation |

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| | | *Image feature detection*<br>Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix<br>*Scale space representation*<br>Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform<br>*Image matching*<br>Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm<br>*Image segmentation*<br>Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video<br>*Transform domain image processing*<br>Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• verstehen Punktoperationen an Bilddaten und Gamma-Korrektur<br>• testen die Wirkung von Rangordnungs- und Medianfiltern an Bilddaten<br>• unterscheiden und bewerten verschiedene Farbräume für Bilddaten<br>• erklären das Prinzip der zwei-dimensionalen linearen Filterung für Bildsignale<br>• berechnen und bewerten die zweidimensionale diskrete Fourier-Transformierte eines Bildsignales<br>• bestimmen vergrößerte diskrete Bildsignale mit Methoden der bilinearen und Spline-Interpolation<br>• überprüfen Bilddaten auf ausgewählte Textur-, Kanten- und Bewegungsmerkmale<br>• analysieren Bild- und Videodaten auf Merkmale in unterschiedlichen Scale-Spaces<br>• erläutern und beurteilen Methoden für das Matching von Bilddaten<br>• segmentieren Bilddaten durch Programmierung von einfachen Klassifikations- oder Clustering-Verfahren<br>• verstehen das Prinzip von Transformation auf Bilddaten und können diese an Beispielen anwenden.<br>The students<br>• understand point operations for image data and gamma correction<br>• test the effects of rank order and median filters for image data<br>• evaluate and differentiate between different color spaces for image data<br>• explain the principle of two-dimensional linear filtering for image signals<br>• calculate and evaluate the two-dimensional discrete Fourier transform of an image signal |

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| | | • determine enlarged discrete image signals by bi-linear and spline interpolation<br>• verify image data for selected texture, edge and motion features<br>• analyze image and video data for features in different scale spaces<br>• explain and evaluate methods for the matching of image data<br>• segment image data by implementing basic classification and clustering methods<br>• understand the principle of transformations on image data and apply them exemplarily |
| 7 | **Prerequisites** | Vorlesung Signale und Systeme I und II |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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<br><br>J. W. Woods: \|Multidimensional Signal, Image, and Video Processing and Coding\|, Academic Press, 2^nd^ edition, 2012 |

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| 1 | **Module name**<br>267499 | **Linear and non-linear fibre optics** | **5 ECTS** |
| 2 | Courses / lectures | Übung: Linear and non-linear fibre optics: Exercise (2.0 SWS)<br>Vorlesung: Linear and non-linear fibre optics (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Andreas Rittler | |

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| 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<br>• Understand structure and operation of components of optical communication systems<br>• Rate the optical properties of components and evaluate the influence of operational parameters on system performance<br>• Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance<br>• Can make use of system simulation tools to engineer optical links |
| 7 | **Prerequisites** | Recommended prior knowledge:<br>• Semiconductor physics<br>• Ray optics<br>• Photonics |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |

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| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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<br><br>Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002<br><br>Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008 |

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|---|---|---|---|
| 1 | **Module name**<br>48440 | **Machine Learning in Signal Processing**<br>Machine learning in 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 | - | |

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| 4 | **Module coordinator** | Jürgen Seiler |
| 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.<br>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<br>• understand regression and classification problems<br>• apply PDF estimation algorithms<br>• understand Gaussian mixture models and expectation-maximization<br>• apply principal component analysis and independent component analysis<br>• assess different estimation algorithms<br>• explain the application of machine learning to system identification<br>• apply hidden Markov models<br>• understand different artificial neural network architectures<br>• explain deep learning principles<br>• apply artificial neural networks<br>• devise learning strategies for deep neural networks<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |

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| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Literature:<br>• C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML<br>• S. Theodoridis and K. Koutroumbas: Pattern Recognition<br>• M. Nielsen: Neural Networks and Deep Learning. |

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| 1 | **Module name**<br>96300 | **MIMO Communication Systems**<br>MIMO communication systems | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: MIMO Communication Systems (3.0 SWS)<br>Übung: MIMO Communication Systems - Tutorial (1.0 SWS) | 5 ECTS<br>- |
| 3 | Lecturers | Hedieh Ajam<br>Prof. Dr.-Ing. Robert Schober | |

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| 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<br>• learn about different MIMO channel models,<br>• analyze MIMO communication systems with respect to their channel capacity and reliability,<br>• determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain,<br>• compare and evaluate different MIMO receiver designs,<br>• characterize the rate region of multiuser systems,<br>• analyze massive MIMO systems,<br>• discuss the advantages and disadvantages of different relay network architectures.<br>Die Studierenden<br>• lernen verschiedene MIMO-Kanalmodelle kennen,<br>• analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit,<br>• ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn,<br>• vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien,<br>• charakterisieren die Ratenregion von Mehrteilnehmersystemen,<br>• analysieren Massive-MIMO-Systeme,<br>• 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 |

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| | | Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>687141 | **Multiuser Information and Communications Theory**<br>Multiuser information and communications theory | **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 | - | |

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| 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.<br>The students apply various algorithms for multiuser detection.<br>The students explain various types of multiuser channels and their limits to transport information.<br>The students explain the limits of distributed source coding algorithms.<br>The students apply the cut-set bound.<br>The students explain the method of dirty-paper coding.<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |

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

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| 1 | **Module name**<br>302148 | **Musiksignalverarbeitung - Analyse**<br>Music processing - Analysis | **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 | - | |

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| 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<br>Understand<br>• The students present central tasks in music processing in their own words and outline possible solutions.<br>• The students understand the properties of different forms of representation of music.<br>Apply<br>• The students apply basic algorithms for the analysis and comparison of music signals.<br>• Students can predict how different musical properties will affect the signal analysis.<br>Analyze<br>• The students observe and discuss the meaning and impact of parameters in music analysis.<br>• The students compare different methods of analyzing periodicities.<br>Evaluate<br>• The students question assumptions that are often implicitly made when using analytical methods.<br>• Students estimate when methods might work when analyzing specific music signals and when they typically fail.<br>Learning and methodological skills<br>• The students prepare for the lecture using selected literature and Jupyter notebooks.<br>• 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

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| | | • Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>639119 | **Music Processing Analysis - Lecture and Exercise**<br>Music processing analysis - Lecture and exercise | **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 | - | |

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| 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<br>Verstehen<br>• Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze.<br>• Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik.<br>• Die Studierenden interpretieren Signaleigenschaften anhand von Visualisierungen (Exercise).<br>Anwenden<br>• Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an.<br>• Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken.<br>• Die Studierenden implementieren Algorithmen zur Analyse, zum Vergleich und zur inhaltsbasierten Suche von Musiksignalen (Exercise).<br>Analysieren<br>• Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse.<br>• Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber.<br>• Die Studierenden analysieren und erforschen Eigenschaften von Musiksignalen mittels automatisierter Methoden (Exercise). |

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

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| | | Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Portfolio |
| 11 | **Grading procedure** | Portfolio (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Meinard Müller<br><br>Fundamentals of Music Processing<br><br>Using Python and Jupyter Notebooks<br><br>2nd edition, 495 p., hardcover<br><br>ISBN: 978-3-030-69807-2<br><br>Springer, 2021<br><br>http://www.music-processing.de/<br><br>https://www.audiolabs-erlangen.de/FMP |

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| 1 | **Module name**<br>502007 | **Musiksignalverarbeitung - Synthese**<br>Music processing - synthesis | **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 | - | |

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| 4 | **Module coordinator** | Maximilian Schäfer |
| 5 | **Contents** | • Verarbeitung von Audiosignalen durch parametrische Filter und Effekte<br>• Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese<br>• Klangwiedergabe in echten und virtuellen Räumen<br>• Klangbeispiele und Demonstrationen<br>• Programmiersprachen für Audio-Echtzeit-Verarbeitung<br>*Content*:<br>• a short history of electrical and electronic music<br>• processing of audio signals by parametric filters and effects<br>• digital sound synthesis<br>• sound reproduction in real and in virtual environments<br>• sound examples and demonstrations<br>• programming languages for audio real-time processing |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung,<br>• wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an,<br>• gestalten eigene Software-Realisierungen zur Klangsynthese,<br>• entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen.<br>The students<br>• specify the special requirements for audio realtime processing,<br>• apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds,<br>• design their own software realizations for sound synthesis<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |

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

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|---|---|---|---|
| 1 | **Module name**<br>43000 | **Optische Kommunikationsnetze**<br>Optical communication networks | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr. Herbert Haunstein |
| 5 | **Contents** | Global communication between billions of subscribers utilizing a multitude of devices is accomplished over a trans-continental fiber-optic transport network. End users worldwide access this network over copper cable (xDSL, HFC), by wireless technologies like WLAN, GSM, UMTS, LTE and also via GPON, EPON and WDM-PON (PON: Passive Optical Network). After a short distance ("the last mile") data streams from many users are aggregated (e.g. by IP routers) into higher data rate transport streams, which are then carried over cost-efficient and highly reliable optical connections.<br><br>Rapid increase of data traffic has quickly evolved from Gigabit Ethernet (1GbE) to 10GbE and 100GbE data rates.<br>To operate optical networks on a global scale, standards like OTN (Optical Transport Network) have been developed to provide high capacity links by use of many wavelengths together with operations and maintenance (OAM) functions. Automated protection and restauration schemes provide a high level of availabilty and can guarantee carrier-grade Quality of Service (QoS). Future data rate increase will be driven by video streaming as well as the introduction of 5G wireless technology and the Internet of Things (IoT).<br><br>The course shall provide a fundamental understanding of modern fiber optic networks from fixed and mobile access through metropolitan area to core networks.<br>1) Introduction – Evolution of optical networks<br>2) Network layers - Internet Protocol – TCP/IP<br>3) Label switching – MPLS – MPLS-TP<br>4) Quality of Service - traffic classification – resource allocation<br>5) Ethernet - switching and physical transport<br>6) Optical Transport Network - OTN<br>7) Optical fiber properties – optical amplification<br>8) Optical transmitter – laser – modulator<br>9) Optical receiver – photo detection – Clock&Data recovery – Bit Error Ratio calculation<br>10) Modulation formats – transmission - margin allocation<br>11) Coherent detection – optical signal processing<br>12) Optical networks – optical switching<br>13) Network control & automation |

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| 6 | **Learning objectives and skills** | Students ...<br>• explain the functional building blocks of optical networks<br>• can eloborate on the different tasks provided by the logical/ control plane (routing), the physical layer and transmission/ data plane of optical networks<br>• refer which standardisation organisation contributes to the different function of optical networks<br>• explain the purpose of different protocols that interact along an end-to-end communication channel<br>• describe technologies for E/O and O/E conversion and optical switches<br>• express the design challenges of future optical systems for fixed and mobile access, data center interconnects,<br>• metro-regional, core, ultra-long-haul and submarine networks |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | 1) R. Ramaswami and K.N. Sivarajan: “Optical Networks”, Morgan Kaufman Publishers, 1998<br>2) U. Black: “Optical Networks - Third generation transport systems”, Prentice Hall, 2002<br>3) P. Tomsu and Chr. Schmutzer: “Next generation optical networks”, Prentice Hall, 2002<br>4) M. Bossert, M. Breitbach: “Digitale Netze”, Teubner Verlag, 1997<br>5) I. Kaminow and T. Li (eds.): “Optical fiber telecommunications IVA+B”, Academic Press, 2002<br>6) D.E. Comer, „Computernetworks and Internets, Pearson“, 2009<br>7) G.P. Agrawal, “Fiber optic communication systems”, Wiley, 1992, (new 1997)<br>8) G.P. Agrawal, “Nonlinear fiber optics”, Academic Press, 1995<br>9) K. Petermann: “Laser Diode Modulation and Noise”, Kluver, 1991<br>10) I. Kazovsky et al., „Optical Fiber Communication Systems“, Artech House, 1996 |

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| | | 11) K.-P. Ho, „Phase-Modulated Optical Communication Systems“, Springer 2005<br>12) H. Haunstein, Presentation material (slides) of the lectures (in English)<br>13) |

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| 1 | **Module name**<br>849203 | **Optische Kommunikationsnetze**<br>Optical communication networks | **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! | |

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|---|---|---|
| 4 | **Module coordinator** | Prof. Dr. Herbert Haunstein |
| 5 | **Contents** | Global communication between billions of subscribers utilizing a multitude of devices is accomplished over a trans-continental fiber-optic transport network. End users worldwide access this network over copper cable (xDSL, HFC), by wireless technologies like WLAN, GSM, UMTS, LTE and also via GPON, EPON and WDM-PON (PON: Passive Optical Network). After a short distance ("the last mile") data streams from many users are aggregated (e.g. by IP routers) into higher data rate transport streams, which are then carried over cost-efficient and highly reliable optical connections.<br><br>Rapid increase of data traffic has quickly evolved from Gigabit Ethernet (1GbE) to 10GbE and 100GbE data rates.<br>To operate optical networks on a global scale, standards like OTN (Optical Transport Network) have been developed to provide high capacity links by use of many wavelengths together with operations and maintenance (OAM) functions. Automated protection and restauration schemes provide a high level of availabilty and can guarantee carrier-grade Quality of Service (QoS). Future data rate increase will be driven by video streaming as well as the introduction of 5G wireless technology and the Internet of Things (IoT).<br><br>The course shall provide a fundamental understanding of modern fiber optic networks from fixed and mobile access through metropolitan area to core networks.<br>1) Introduction – Evolution of optical networks<br>2) Network layers - Internet Protocol – TCP/IP<br>3) Label switching – MPLS – MPLS-TP<br>4) Quality of Service - traffic classification – resource allocation<br>5) Ethernet - switching and physical transport<br>6) Optical Transport Network - OTN<br>7) Optical fiber properties – optical amplification<br>8) Optical transmitter – laser – modulator<br>9) Optical receiver – photo detection – Clock&Data recovery – Bit Error Ratio calculation<br>10) Modulation formats – transmission - margin allocation<br>11) Coherent detection – optical signal processing<br>12) Optical networks – optical switching<br>13) Network control & automation |
| 6 | **Learning objectives and skills** | Students ...<br>• explain the functional building blocks of optical networks |

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| | | • can eloborate on the different tasks provided by the logical/ control plane (routing), the physical layer and transmission/ data plane of optical networks<br>• refer which standardisation organisation contributes to the different function of optical networks<br>• explain the purpose of different protocols that interact along an end-to-end communication channel<br>• describe technologies for E/O and O/E conversion and optical switches<br>• express the design challenges of future optical systems for fixed and mobile access, data center interconnects,<br>• metro-regional, core, ultra-long-haul and submarine networks |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | 1) R. Ramaswami and K.N. Sivarajan: “Optical Networks”, Morgan Kaufman Publishers, 1998<br>2) U. Black: “Optical Networks - Third generation transport systems”, Prentice Hall, 2002<br>3) P. Tomsu and Chr. Schmutzer: “Next generation optical networks”, Prentice Hall, 2002<br>4) M. Bossert, M. Breitbach: “Digitale Netze”, Teubner Verlag, 1997<br>5) I. Kaminow and T. Li (eds.): “Optical fiber telecommunications IVA+B”, Academic Press, 2002<br>6) D.E. Comer, „Computernetworks and Internets, Pearson“, 2009<br>7) G.P. Agrawal, “Fiber optic communication systems”, Wiley, 1992, (new 1997)<br>8) G.P. Agrawal, “Nonlinear fiber optics”, Academic Press, 1995<br>9) K. Petermann: “Laser Diode Modulation and Noise”, Kluver, 1991<br>10) L. Kazovsky et al., „Optical Fiber Communication Systems“, Artech House, 1996<br>11) K.-P. Ho, „Phase-Modulated Optical Communication Systems“, Springer 2005 |

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| | | 12) H. Haunstein, Presentation material (slides) of the lectures (in English) |

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| 1 | **Module name**<br>44120 | **Pattern Analysis**<br>Pattern analysis | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Pattern Analysis (3.0 SWS)<br>Übung: PA-Prog (1.0 SWS) | 3,75 ECTS<br>1,25 ECTS |
| 3 | Lecturers | Christian Riess<br>Dalia Rodriguez Salas | |

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| 4 | **Module coordinator** | Christian Riess |
| 5 | **Contents** | This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods.<br>The topics comprise:<br>• clustering methods: soft and hard clustering<br>• classification and regression trees and forests<br>• parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees<br>• mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking<br>• linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps<br>• Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling<br>• Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts<br>Das Modul führt in das Design von Musteranalysesystemen sowie die zugrundeliegenden mathematischen Methoden ein.<br>Die Vorlesung umfasst im Einzelnen:<br>• Clustering-Methoden: Soft- und Hard-Clustering<br>• Klassifikations- und Regressionsbäume/-wälder<br>• parametrische und nicht-parametrische Dichteschätzung: Verfahren sind ML- und MAP-Schätzung, Histogramme, Parzenschätzung, Zusammenhang gefaltete Histogramme und Parzenschätzung, adaptives Binning mit Regressionsbäumen.<br>• 'Mean Shift'-Algorithmus: lokale Maximierung durch Gradientenaufstieg bei nicht-parametrischen Dichtefunktionen, Anwendungen des 'Mean Shift'-Algorithmus zum Clustering, Farbquantisierung und Objektverfolgung<br>• Linear and Non-Linear Manifold Learning: Curse of Dimensionality, Verschiedene Methode zur |

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| | | Dimensionsreduktion: Principal Component Analysis (PCA), Multidimensionsional Scaling (MDS), Isomap, Laplacian Eigenmaps<br>• Gaußsche Mischverteilungsmodelle (GMM) und Hidden-Markov-Modelle (HMM): 'Expectation Maximization'-Algorithmus, Parameterschätzung, Bestimmung der optimalen Zustandsfolge/Viterbi-Algorithmus, Vorwärts-Rückwärts-Algorithmus, Skalierung<br>• Markov-Zufallsfelder: Definition, Wahrscheinlichkeiten auf ungerichteten Graphen, Cliquen-Potenziale, Hammersley-Clifford-Theorem, Inferenz mit Gibbs-Sampling und Graph Cuts |
| 6 | **Learning objectives and skills** | The students<br>• explain the discussed methods for classification, prediction, and analysis of patterns,<br>• compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem,<br>• compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem,<br>• apply non-parametric probability density estimation to pattern analysis problems,<br>• apply dimensionality reduction techniques to high-dimensional feature spaces,<br>• explain statistic modeling of feature sets and sequences of features,<br>• explain statistic modeling of statistical dependencies,<br>• implement presented methods in Python,<br>• supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature,<br>• discuss the social impact of applications of pattern analysis solutions.<br>Die Studierenden<br>• erläutern die behandelten Methoden zur Klassifikation, Vorhersage und Analyse von Mustern,<br>• vergleichen und analysieren Methoden des Manifold Learning und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus,<br>• vergleichen und analysieren Methoden zur Dichteschätzung und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus,<br>• wenden nicht-parametrische Dichteschätzung auf Probleme der Musteranalyse an,<br>• wenden Dimensionsreduktion bei hochdimensionalen Merkmalsräumen an,<br>• erläutern statistische Modellierung von Merkmalsmengen und Merkmalsfolgen,<br>• erklären statistische Modellierung abhängiger Größen, |

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| | | • implementieren vorgestellte Verfahren in Python.<br>• ergänzen eigenständig mathematische Grundlagen der präsentierten Methoden durch selbstbestimmtes Studium der Literatur<br>• diskutieren die gesellschaftlichen Auswirkungen von Anwendungen der Musteranalyse |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Variabel (60 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Begleitende Literatur / Accompanying literature:<br>• C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006<br>• T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009<br>• A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013 |

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|---|---|---|---|
| 1 | **Module name**<br>44130 | **Pattern Recognition**<br>Pattern recognition | **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 | - | |

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

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| | | • beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung<br>• verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren<br>Students<br>• understand the structure of machine learning systems for simple patterns<br>• explain the mathematical foundations of selected machine learning techniques<br>• apply classification techniques in order to solve given classification tasks<br>• evaluate various classifiers with respect to their suitability to solve the given problem<br>• 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<br>• The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful.<br>• Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english<br>english |
| 16 | **Bibliography** | • Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001<br>• Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009<br>• Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006 |

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|---|---|---|---|
| 1 | **Module name**<br>250058 | **Signalanalyse**<br>Signal analysis | **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 | - | |

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

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| | | • explain different approaches for time-frequency analysis<br>• describe the analysis of signals by means of filter-banks and wavelets<br>• explain methods for frequency estimation<br>• formulate approaches for spatial signal analysis. |
| 7 | **Prerequisites** | Fundierte Kenntnisse in digitaler Signalverarbeitung.<br>Requirements<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich<br>Mündliche Prüfung mit einer Dauer von 30 min.<br><br>Oral examination of 30 min duration. |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>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 |

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|---|---|---|---|
| 1 | **Module name**<br>788996 | **Speech Enhancement**<br>Speech enhancement (oral examination) | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr. Emanuël Habets |
| 5 | **Contents** | *Course Description*<br>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.<br>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.<br>*Relation to other courses*<br>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<br>• Formulate the speech enhancement problem mathematically.<br>• Derive optimal single- and multi-channel filters to reduce noise and reverberation.<br>• Evaluate and compare the performance of single- and multi-channel filters for speech enhancement.<br>• Understand how reference signals and other prior information can be used in a speech enhancement system.<br>• Understand the limitations and challenges of existing speech enhancement systems.<br>• Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids.<br>• Design a microphone array and analyze its performance.<br>• Design a speech enhancement system for a given acoustic scenario.<br>• Evaluate both subjectively and objectively the performance of a speech enhancement system in terms of the speech quality and intelligibility. |

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| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>498723 | **Transformationen in der Signalverarbeitung**<br>Transforms in signal processing | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Transformationen in der Signalverarbeitung (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Jürgen Seiler | |

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| 4 | **Module coordinator** | 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.<br>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.<br>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<br>• Anwendungsmöglichkeiten von Transformationen bestimmen<br>• Integraltransformationen gegenüberstellen und untersuchen<br>• die Existenz von Transformationen hinterfragen<br>• die Eindeutigkeit von Transformationen überprüfen<br>• Sätze und Eigenschaften von Transformationen entwickeln<br>• zu Transformationen zugehörige inverse Transformationen einschätzen<br>• die Zusammenhänge zwischen verschiedenen Transformationen einschätzen<br>• auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern<br>• Symmetriebeziehungen von Transformationen ausarbeiten |

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| | | • Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten<br>Educational Objectives and Competences:<br>After attending the lecture, students will be able to<br>• determine applications of transforms<br>• contrast and examine integral transforms<br>• question the existence of transforms<br>• evaluate the uniqueness of transforms<br>• develop theorems and properties of transforms<br>• evaluate to transforms corresponding inverse transforms<br>• evaluate the relationships between different transforms<br>• asses the relationship between original signal and transformed signals<br>• devise the symmetry properties of transforms<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig<br><br>B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart |

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| 1 | **Module name**<br>43420 | **Transmission and Detection for Advanced Mobile Communications**<br>Transmission and detection for advanced mobile communications | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Transmission and Detection for Advanced Mobile Communications (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Wolfgang Gerstacker | |

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| 4 | **Module coordinator** | 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<br>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<br>• describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE),<br>• apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system,<br>• formulate channel estimation methods for mobile communication systems,<br>• characterize the interference problem in GSM / EDGE,<br>- design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively,<br>• characterize the performance of mobile communication networks for different reception schemes,<br>• devise receivers for the realization of diversity gains for multiple receive antennas,<br>• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, |

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| | | • describe transmission schemes which are based on code-division multiple access (CDMA),<br>• apply reception techniques for CDMA to the UMTS system,<br>• characterize the uplink transmission in the Long Term Evolution (LTE) system,<br>• develop receivers for LTE.<br>Die Studierenden<br>• beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE),<br>• wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an,<br>• formulieren Kanalschätzverfahren für Mobilfunksysteme,<br>• charakterisieren das Interferenzproblem bei GSM/EDGE,<br>• entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen,<br>• bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren,<br>• konzipieren Empfänger zur Realisierung von Diversitätsgewinnnen bei empfangsseitiger Antennendiversität<br>• entwerfen Space-Time-Codierverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität,<br>• beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren,<br>• wenden Empfangsverfahren für CDMA auf das UMTS-System an,<br>• charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE),<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |

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| 16 | **Bibliography** | Lecture notes |

# Technical elective modules

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| 1 | **Module name**<br>151664 | **Advanced Communication Networks**<br>Advanced communication networks | **5 ECTS** |
| 2 | Courses / lectures | Übung: Advanced Communication Networks - Tutorial (0.5 SWS)<br>Vorlesung: Advanced Communication Networks (3.5 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Prof. Dr. Laura Cottatellucci<br>Christian Forsch | |

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| 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.<br>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.<br>*Technical Content*<br>• Properties and challenges of the wireless medium.<br>• Basic concepts of communication networks: the layered architecture.<br>• Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution.<br>• Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA.<br>• Uplink-downlink duality.<br>• Opportunistic scheduling and multiuser diversity. |

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

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| | | • Analyses performance of relaying schemes.<br>• Argues on possible improvements of relaying schemes via network coding and physical layer network coding.<br>• Uses the Perron-Frobenious theorem to allocate power in a centralized manner.<br>• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility.<br>• Uses the Perron-Frobenious theorem to design a distributed power control scheme.<br>• Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control.<br>• Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality.<br>• Judges the applicability of KKT conditions and duality.<br>• Uses KKT conditions to solve convex optimization problems.<br>• Uses duality to solve convex optimization problems.<br>• Applies convex optimization to resource allocation in wireless communications.<br>• Compares different definitions of fairness and applies them to rate allocation.<br>• Appraises the effect of channel knowledge at the transmitter on different fairness criteria.<br>• Applies KKT conditions for opportunistic user scheduling.<br>• Describes a proportional fair algorithm for opportunistic scheduling.<br>• Applies relaxation to nonconvex quadratic constrained quadratic programming.<br>• Formulates resource allocation problems as constrained optimization programming.<br>• Contrasts various distributed optimization methods.<br>• Applies the concept of best response to determine Nash equilibria.<br>• Argues about existence and uniqueness of Nash equilibria.<br>• Assesses if a given game is a potential game and solves it.<br>• Defends the concept of Pareto optimality in resource allocation.<br>• Contrasts the concepts of pure and mixed strategies in game theory.<br>• Uses coupled constrained concave game to allocate powers in heterogeneous networks. |
| 7 | **Prerequisites** | Information Theory and Coding<br><br>It is advisable that the student is familiar with basic concepts of Mobile Communications |
| 8 | **Integration in curriculum** | semester: 1 |

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| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>44466 | **Advanced C++ Programming**<br>Advanced C++ programming | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Advanced C++ Programming (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Harald Köstler | |

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| 4 | **Module coordinator** | |
| 5 | **Contents** | 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<br>Wissen<br>Die Studierenden sollen grundlegende Begriffe der C++ Programmiersprache definieren können.<br>Verstehen<br>Die Studierenden sollen verschiedene neuere Sprachkonstrukte wiedergeben können.<br>Anwenden<br>Die Studierenden sollen mit Hilfe von neueren Sprachkonstrukten Aufgaben lösen.<br>Evaluieren (Beurteilen)<br>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** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (60 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 0 h<br>Independent study: 75 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german<br>english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>869547 | **Advanced Networking LEx**<br>Advanced networking LEx | **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 | - | |

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| 4 | **Module coordinator** | Dr.-Ing. Kai-Steffen Hielscher |
| 5 | **Contents** | Für die durch Big Data, Cloud Computing, Internet-of-Things (IoT) und mobile Endgeräte hervorgerufenen Herausforderungen sind neue Architekturen für Rechnernetze entstanden: Software-Defined-Networking (SDN) entkoppelt die Data Plane (Weiterleitung von Paketen, auf handelsüblicher Hardware) und die Control Plane (Steuerung, auf leistungsfähigen Plattformen) und bietet offene Programmierschnittstellen; Network Functions Virtualization (NFV) erweitert Konzepte zur Server- und Netzwerkvirtualisierung, so dass bisher auf proprietärer Hardware ausgeführte Netzwerkfunktionen (wie z.B. Routing) ebenfalls virtualisiert und auf handelsüblicher Hardware ausgeführt werden können. Die Vorlesung stellt hinter diesen Technologien stehende Konzepte und Standards vor und zeigt, wie sie für Rechenzentren, für Cloud- und Fog-Computing und für IoT-Anwendungen eingesetzt werden können.<br><br>Content: New architectures for computer networks have emerged to meet the challenges posed by Big Data, Cloud Computing, Internet-of-Things (IoT) and mobile devices: Software-Defined-Networking (SDN) decouples the data plane (forwarding of packets, on commercially available hardware) and the control plane (control, on powerful platforms) and offers open programming interfaces; Network Functions Virtualization (NFV) extends concepts for server and network virtualisation, so that network functions (such as routing) previously executed on proprietary hardware can also be virtualised and executed on commercially available hardware. The lecture introduces concepts and standards behind these technologies and shows how they can be used for data centres, for cloud and fog computing and for IoT applications. |
| 6 | **Learning objectives and skills** | Fachkompetenz<br>Verstehen<br>Die Studierenden erlangen Verständnis der grundlegenden Konzepte von<br>• Software Defined Networking<br>• Network Function Virtualization<br>• Internet of Things<br>• Cloud Computing.<br>Anwenden<br>Die Studierenden wenden die Erkenntisse in Übungsaufgaben an.<br>Erschaffen |

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| | | Die Studierenden erstellen eigene Laborkofigurationen zu<br>• Software Defined Networking<br>• Internet of Things.<br>Competences:<br>Professional competence<br>Understanding<br>Students will gain an understanding of the basic concepts of<br>• Software Defined Networking<br>• Network Function Virtualization<br>• Internet of Things<br>• Cloud Computing.<br>Apply<br>Students apply the knowledge gained in exercises.<br>Create<br>The students create their own laboratory configurations on<br>• Software Defined Networking<br>• Internet of Things. |
| 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** | Portfolio<br>Prüfungsleistung, mehrteilige Prüfung, Dauer (in Minuten): 30, benotet Anteil an der Berechnung der Modulnote: 100.0 % weitere Erläuterungen:<br>Die Modulprüfung besteht aus:<br>• Bearbeitung (zwei)wöchentlicher Aufgabenblätter in Gruppenarbeit. Für diese unbenotete Studienleistung sind alle Aufgabenblätter korrekt zu lösen und abzugeben.<br>• mündliche Prüfung (Dauer: 30 Minuten)<br>• Die Studierenden dürfen individuell frei wählen, ob sie die Prüfung in deutscher oder englischer Sprache absolvieren möchten. |
| 11 | **Grading procedure** | Portfolio (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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 |

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|---|---|---|---|
| 1 | **Module name**<br>621649 | **Advanced Optical Communication Systems**<br>Advanced optical 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Bernhard Schmauß |
| 5 | **Contents** | Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing<br>• Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems<br>• Noise and Power Management: power budget, OSNR management, OSNR calculation<br>• Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons<br>• Spectral Efficiency: definition, increase of spectral efficiency<br>• Modulation Formats:intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission<br>• Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration |
| 6 | **Learning objectives and skills** | Students<br>• gain detailed Knowledge on concepts and structure of various optical transmission systems.<br>• are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts.<br>• are able to develop and to optimize link designes of optical transmission systems.<br>• are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results. |
| 7 | **Prerequisites** | **Prerequisites:**<br>• Fundamentals in signals and systems.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h |

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| | | 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<br><br>Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001.<br><br>Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002.<br><br>Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008.<br><br>Lecture notes. |

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|---|---|---|---|
| 1 | **Module name**<br>96875 | **Ausgewählte Kapitel der Audiodatenreduktion**<br>Advanced topics in perceptual audio coding | **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 | - | |

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| 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.<br>The selected topics include:<br>Efficient coding of several audio channels / parametric multi- channel coding<br>Typical coding artifacts; subjective and objective quality assessment<br>Scalable audio coding<br>Bandwidth extension<br>Semi-parametric audio coding<br>Low-delay audio coding<br>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.<br>• 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.<br>• Anwenden - Die Studenten können übliche mathematische Analysemethoden verwenden, um einfache Coder-Componenten zu beschreiben und gegebenenfalls zu modifizieren.<br>• Analysieren - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge dazu analysieren um die zugrundeliegenden Konzepte und Anforderungen zu erfassen.<br>• Evaluieren (Beurteilen) - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge evaluieren um zu beurteilen, welcher |

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| | | Standard bzw. welches Messwerkzeug das passendste ist für einen bestimmten Anwendungsfall.<br>• Synthese - Die Studenten können eine Liste von Anforderungen und Bewertungskriterien für Audiocodecs zusammenstellen für gewünschte Anwendungsfälle.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>96010 | **Architekturen der digitalen Signalverarbeitung**<br>Architectures for digital signal processing | **5 ECTS** |
| 2 | Courses / lectures | Übung: Übungen zu Architekturen der Digitalen Signalverarbeitung (2.0 SWS)<br>Vorlesung: Architekturen der Digitalen Signalverarbeitung (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Sebastian Peters<br>Timo Maiwald | |

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

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| | | • 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<br>• can construct a realtime digital signal processing system and dimension its components according requirements<br>• can review pros and cons of analogue versus digitzal signal processing<br>• can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>44522 | **Audio Processing for the Internet of Things**<br>Audio processing for the Internet of Things | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Audio Processing for the Internet of Things (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Nils Peters | |

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| 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).<br>• Foundation (history, components, current challenges)<br>• Overview of relevant wireless protocols (bandwidth, range, latency, spectrum)<br>• Audio device synchronization (NTP, PTP, device orchestration, acoustic wireless sensor networks, asynchronous and event-driven audio sampling)<br>• Acoustic Sensing for Voice User Interfaces (keyword spotting, speech recognition, speaker verification, anti-spoofing)<br>• Acoustic Scene Detection (event detection, scene classification, anomaly detection, sound tagging, blind reverb estimation)<br>• Sound Creation (text-to-speech, sound generative networks)<br>• Data-over-sound (sound-beacon, watermarking, acoustic fingerprint)<br>• 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<br>• understand the principles, key components, and current in IoT<br>• know the differences between various wireless transmission protocols and can give recommendations based on the IoT use case<br>• understand the differences of edge- and cloud-based audio signal processing<br>• understand algorithmic strategies to enhance privacy in IoT use cases<br>• understand the algorithmic components in a voice user interface<br>• understand state-of-the art methods for detection and classification of acoustic scenes and events<br>• learn and apply algorithms to transmit data via acoustic signals<br>• quantify the impact of latency in audio networks and apply strategies for acoustic device synchronization |
| 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** | mündlich (30 Minuten) |

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| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>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 |

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| 1 | **Module name**<br>947709 | **Auditory Models**<br>Auditory models | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Auditory Models (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Bernd Edler | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Bernd Edler |
| 5 | **Contents** | • Main components of the human auditory system<br>• Common models<br>• Mechanical models<br>• Physiological models<br>• Psychoacoustic models<br>• Applications (hearing aids, audio coding, . . . ) |
| 6 | **Learning objectives and skills** | Goals<br>• Students understand the structure and function of the human auditory system<br>• Students gain deeper insight into psychoacoustic phenomena, such as masking, directional and spatial hearing<br>• Students implement and evaluate perceptual models for various applications<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>816185 | **Body Area Communications**<br>Body area 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Georg Fischer |
| 5 | **Contents** | Contents:<br>The Lecture and exercise deals with the following topics:<br>• Introduction to Body Area Communications<br>• Electromagnetic Characteristics of Human Body<br>• Electromagnetic Analysis Methods<br>• Body Area Channel Modeling<br>• Modulation/Demodulation<br>• Body Area Communication Performance<br>• Electromagnetic Compatibility Consideration |
| 6 | **Learning objectives and skills** | Learning objectives<br>• Students understand the challenges in designing Body Area Communication (BAC) systems<br>• Students can conduct basic design decisions with BAC systems, like frequency and modulation selection<br>• Students understand electromagnetic wave propagation in bodies<br>• Students understand the frequency dependent loss and propagation behavior of electromagnetic waves<br>• Students can analyze the communication performance of a BAC system<br>• Students can evaluate Electromagnetic Compatibility of a BAC system<br>• 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<br>• Students can sketch block diagrams of BAC systems<br>• tudents can derive channel models for BAC |
| 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |

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| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>412023 | **Channel Coding on Graphs**<br>Channel coding on graphs | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Channel Coding on Graphs (3.5 SWS)<br>Übung: Channel Coding on Graphs - Tutorial (0.5 SWS) | 5 ECTS<br>- |
| 3 | Lecturers | Prof. Dr. Laura Cottatellucci<br>Nikita Shanin | |

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| 4 | **Module coordinator** | Prof. Dr. Laura Cottatellucci |
| 5 | **Contents** | *Description*<br>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.<br>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.<br>*Technical Content*<br>• Role of channel coding in a communication system.<br>• Idealized channel models : the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel.<br>• Some preliminary basic concepts from linear block codes: Parity Check, Hamming distance, weight enumerating functions, performance evaluations, and performance bounds.<br>• Factor graphs and belief propagation.<br>• Binary random-like codes: LDPC codes and message-passing decoding, threshold behaviour of message passing decoding: density evolution analysis. Design of LDPC ensembles.<br>• Polar Codes: Polarization, polar channel coding, performance, encoding and decoding.<br>• Binary convolutional codes : the algebraic structure, the dynamic structure, Viterbi decoding, performance analysis via weight enumerating function, the forward-backward algorithm.<br>• Other random-like codes: the Turbo Codes. Efficient decoding of Turbo Codes via forward-backward algorithm and |

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

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| | | Interprets turbo decoders as factor graphs and justifies their implementation via message passing<br>Assesses the performance of turbo codes using exit charts<br><br>Formulates the concept of source polarization and relates it to polar channel coding<br>Interprets polar channel coding as factor graphs<br>Designs polar channel codes<br>Argues about capacity achievability of polar channel codes |
| 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** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>44445 | **Cognitive Neuroscience for AI Developers**<br>Cognitive neuroscience for AI developers | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Cognitive Neuroscience for AI Developers (4.0 SWS) | 5 ECTS |
| 3 | Lecturers | Dr. Patrick Krauß<br>Prof. Dr. Andreas Kist<br>Prof. Dr.-Ing. Andreas Maier<br>Dr. rer. nat. Achim Schilling | |

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| 4 | **Module coordinator** | |
| 5 | **Contents** | Neuroscience has played a key role in the history of artificial intelligence (AI), and has been an inspiration for building human-like AI, i.e. to design AI systems that emulate human intelligence.<br>Neuroscience provides a vast number of methods to decipher the representational and computational principles of biological neural networks, which can in turn be used to understand artificial neural networks and help to solve the so called black box problem. This endeavour is called neuroscience 2.0 or machine behaviour. In addition, transferring design and processing principles from biology to computer science promises novel solutions for contemporary challenges in the field of machine learning. This research direction is called neuroscience-inspired artificial intelligence.<br>The course will cover the most important works which provide the cornerstone knowledge to understand the biological foundations of cognition and AI, and applications in the areas of AI-based modelling of brain function, neuroscience-inspired AI and reverse-engineering of artificial neural networks. |
| 6 | **Learning objectives and skills** | The students<br>• Explain the principles of neural information processing in the brain<br>• compare and analyze methods from neuroscience to study neural networks<br>• explain the neuroscientific underpinnings of artificial intelligence<br>• explain principles and concepts of cognitive science<br>• explain principles and concepts of neuroscience<br>• compare and analyze machine learning methods to analyze neural data<br>• explain approaches from deep learning to model brain function<br>• discuss the commonalities of neuroscience and artificial intelligence<br>• implement the presented methods in Python<br>• explain concepts from cognitive neuroscience for the design of artificial intelligence systems |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |

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| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Variabel (90 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 90 h<br>Independent study: 60 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Gazzaniga, Michael. Cognitive Neuroscience - The Biology of the Mind. W. W. Norton & Company, 2018.<br><br>Ward, Jamie. The Student's Guide to Cognitive Neuroscience. Taylor & Francis Ltd., 2019.<br><br>Bermúdez, José Luis. Cognitive Science: An Introduction to the Science of the Mind. Cambridge University Press, 2014.<br><br>Friedenberg, Jay D., and Silverman, Gordon W. Cognitive Science: An Introduction to the Study of Mind. SAGE Publications, Inc., 2015.<br><br>Gerstner, Wulfram, et al. Neuronal dynamics: From single neurons to networks and models of cognition. Cambridge University Press, 2014. |

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| 1 | **Module name**<br>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! | |

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

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| | | • can plan a simulation strategy for analysing transceivers - can categorise transceiver architectures for single or multiple antennas<br>• Can develop a predistorion system for power amplifiers |
| 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt)<br>Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt) |
| 14 | **Module duration** | ?? semester (no information for Module duration available) |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | Ralf Rudersdorfer, Radio Receiver Technology: Principles, Architectures and Applications, Wiley, 2014<br><br>Frank Ellinger, Radio Frequency Integrated Circuits and Technologies, Springer, 2008<br><br>Abbas Mohammadi und Fadhel M. Ghannouchi, RF Transceiver Design for MIMO Wireless Communications, Springer, 2012 |

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| 1 | **Module name**<br>43821 | **Computer Graphics**<br>Computer graphics | **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 | - | |

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

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| | | • illustrieren und untersuchen die Datenstrukturen zur Beschreibung virtueller 3D Modelle und komplexer Szenen<br>• erläutern die Funktionsweise der Rasterisierung und Scankonvertierung in der Graphikpipeline<br>• lösen Aufgaben zu Beleuchtung und Texturierung von 3D virtuellen Modellen<br>• klassifizieren Schattierungsverfahren<br>• bestimmen den Unterschied zwischen lokaler und globaler Beleuchtung und formulieren Algorithmen für Ray Tracing und Radiocity<br>*Educational objectives and skills:*<br>Students should be able to<br>• describe the processing steps in the graphics pipeline<br>• explain clipping algorithms for lines and polygons<br>• 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<br>• depict techniques to compute depth, occlusion and visibility<br>• compare the different color models<br>• describe data structures to represent 3D virtual models and complex scenes<br>• explain the algorithms for rasterization and scan conversion<br>• solve problems with shading and texturing of 3D virtual models<br>• classify different shadowing techniques<br>• explain the difference between local and global illumination techniques and formulate algorithms for ray tracing and radiosity |
| 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** | Übungsleistung<br>Klausur (60 Minuten) |
| 11 | **Grading procedure** | Übungsleistung (0%)<br>Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german<br>english |
| 16 | **Bibliography** | • P. Shirley: Fundamentals of Computer Graphics. AK Peters Ltd., 2002<br>• Hearn, M. P. Baker: Computer Graphics with OpenGLD. Pearson |

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| | | • Foley, van Dam, Feiner, Hughes: Computer Graphics - Principles and Practice<br>• Rauber: Algorithmen der Computergraphik<br>• Bungartz, Griebel, Zenger: Einführung in die Computergraphik<br>• Encarnação, Strasser, Klein: Computer Graphics |

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| 1 | **Module name**<br>713618 | **Computer vision** | **5 ECTS** |
| 2 | Courses / lectures | Übung: Computer Vision Exercise (2.0 SWS)<br>Vorlesung: Computer Vision (2.0 SWS) | 2,5 ECTS<br>2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Bernhard Egger<br>Prof. Dr. Tim Weyrich | |

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| 4 | **Module coordinator** | Prof. Dr. Bernhard Egger<br>Prof. Dr.-Ing. Andreas Maier |
| 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<br>• beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen,<br>• erklären die Studierenden die behandelten Methoden,<br>• diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen,<br>• implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code,<br>• entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme,<br>• erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation,<br>• diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen,<br>• diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens.<br>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<br>• describe perspective projection, rotations, and related geometric foundations,<br>• explain the presented methods, |

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| | | • discuss the advantages and disadvantages of different modalities for acquiring 3-D information,<br>• implement individually and in small groups code,<br>• discover best practices in data acquisition,<br>• explore and rank different choices for evaluation,<br>• discuss and present in groups the advantages and disadvantages of their implementations,<br>• discuss and reflect the social impact of applications of computer vision algorithms. |
| 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** | Variabel (90 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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. |

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|---|---|---|---|
| 1 | **Module name**<br>96850 | **Convex Optimization in Communications and Signal Processing**<br>Convex 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 | - | |

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| 4 | **Module coordinator** | 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<br>• characterize convex sets and functions,<br>• recognize, describe and classify convex optimization problems,<br>• determine the solution of convex optimization problems via the dual function and the KKT conditions,<br>• apply numerical algorithms in order to solve convex optimization problems,<br>• apply methods of convex optimization to different problems in communications and signal processing |
| 7 | **Prerequisites** | Signals and Systems, Communications |
| 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** | schriftlich oder mündlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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 |

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| 1 | **Module name**<br>901895 | **Deep Learning**<br>Deep learning | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Deep Learning (2.0 SWS)<br>Übung: DL E (2.0 SWS) | 2,5 ECTS<br>2,5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Andreas Maier<br>Zijin Yang<br>Alexander Barnhill | |

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| 4 | **Module coordinator** | Felix Denzinger<br>Prof. Dr.-Ing. Andreas Maier<br>Fabian Wagner |
| 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.<br>This lecture introduces the core elements of neural networks and deep learning, it comprises:<br>• (multilayer) perceptron, backpropagation, fully connected neural networks<br>• loss functions and optimization strategies<br>• convolutional neural networks (CNNs)<br>• activation functions<br>• regularization strategies<br>• common practices for training and evaluating neural networks<br>• visualization of networks and results<br>• common architectures, such as LeNet, Alexnet, VGG, GoogleNet<br>• recurrent neural networks (RNN, TBPTT, LSTM, GRU)<br>• deep reinforcement learning<br>• unsupervised learning (autoencoder, RBM, DBM, VAE)<br>• generative adversarial networks (GANs)<br>• weakly supervised learning<br>• applications of deep learning (segmentation, object detection, speech recognition, ...)<br>The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks. |
| 6 | **Learning objectives and skills** | The students<br>• explain the different neural network components,<br>• compare and analyze methods for optimization and regularization of neural networks,<br>• compare and analyze different CNN architectures,<br>• explain deep learning techniques for unsupervised / semi-supervised and weakly supervised learning,<br>• explain deep reinforcement learning,<br>• explain different deep learning applications,<br>• implement the presented methods in Python,<br>• autonomously design deep learning techniques and prototypically implement them, |

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| | | • effectively investigate raw data, intermediate results and results of Deep Learning techniques on a computer,<br>• autonomously supplement the mathematical foundations of the presented methods by self-guided study of the literature,<br>• discuss the social impact of applications of deep learning applications. |
| 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** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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.<br>• Christopher Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006<br>• Yann LeCun, Yoshua Bengio, Geoffrey Hinton: Deep learning. Nature 521, 436444 (28 May 2015) |

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| 1 | **Module name**<br>44150 | **Diagnostic Medical Image Processing**<br>Diagnostic medical image processing | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Medical Image Processing for Diagnostic Applications (VHB-Kurs) (4.0 SWS) | 5 ECTS |
| 3 | Lecturers | | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andreas Maier |
| 5 | **Contents** | English version:<br>The contents of the module comprise basics about medical imaging modalities and acquisition hardware. Furthermore, details on acquisition-dependent preprocessing are covered for image intensifiers, flat-panel detectors, and MR. The fundamentals of 3D reconstruction from parallel-beam to cone-beam reconstruction are also covered. In the last chapter, rigid registration for image fusion is explained.<br><br>Deutsche Version:<br>Die Inhalte des Moduls umfassen Grundlagen der medizinischen Bildverarbeitung und Aufnahmeprinzipien. Darüber hinaus werden Details der Vorverarbeitung für Bildverstärker, Flachpaneldetektoren und MR erklärt. Die Grundlagen der Rekonstruktion von Parallelstrahl bis hin zur Kegelstrahl-Tomographie werden ebenfalls behandelt. Im letzten Kapitel wird starre Registrierung für Bildfusion erläutert. |
| 6 | **Learning objectives and skills** | English Version:<br>The participants<br>• understand the challenges in interdisciplinary work between engineers and medical practitioners.<br>• develop understanding of algorithms and math for diagnostic medical image processing.<br>• learn that creative adaptation of known algorithms to new problems is key for their future career.<br>• develop the ability to adapt algorithms to different problems.<br>• are able to explain algorithms and concepts of the module to other engineers.<br>Deutsche Version:<br>Die Teilnehmenden<br>• verstehen die Herausforderungen in der interdisziplinären Arbeit zwischen Ingenieuren und Ärzten.<br>• entwickeln Verständnis für Algorithmen und Mathematik der diagnostischen medizinischen Bildverarbeitung.<br>• erfahren, dass kreative Adaption von bekannten Algorithmen auf neue Probleme der Schlüssel für ihre berufliche Zukunft ist.<br>• entwickeln die Fähigkeit Algorithmen auf verschiedene Probleme anzupassen.<br>• sind in der Lage, Algorithmen und Konzepte des Moduls anderen Studierenden der Technischen Fakultät zu erklären. |
| 7 | **Prerequisites** | Ingenieurmathematik |

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| | | Engineering Mathematics |
| 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** | schriftlich/mündlich (60 Minuten) |
| 11 | **Grading procedure** | schriftlich/mündlich (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 0 h<br>Independent study: 150 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>43400 | **Entzerrung und adaptive Systeme in der digitalen Übertragung**<br>Equalisation and adaptive systems for digital 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 | - | |

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| 4 | **Module coordinator** | 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),<br>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.<br>Lernziel:<br>Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt<br>werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen.<br>Content:<br>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.<br>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. |

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| 6 | **Learning objectives and skills** | Die Studierenden<br>• beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung,<br>• setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten,<br>• vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität,<br>• wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus,<br>• entwerfen neuartige Verfahren für gegebene Anforderungen,<br>• formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal,<br>• ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu.<br>Learning Objectives and Competences:<br>The students<br>- describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation,<br>- realize various approaches in block diagrams and optimize their components,<br>- compare equalization methods in terms of their performance, characterized by the error rate, and complexity,<br>- select suitable methods for various applications such as wired and wireless transmission,<br>- design novel schemes for given requirements,<br>- formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel,<br>- assign suitable adaptation algorithms to equalization schemes. |
| 7 | **Prerequisites** | Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h |

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| | | 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.<br><br>Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992.<br><br>Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999.<br><br>Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995.<br><br>Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996. |

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| 1 | **Module name**<br>645618 | **Human Computer Interaction**<br>Human computer interaction | **5 ECTS** |
| 2 | Courses / lectures | Übung: Human Computer Interaction Exercises (1.0 SWS)<br>Vorlesung: Human Computer Interaction (3.0 SWS) | 1,25 ECTS<br>3,75 ECTS |
| 3 | Lecturers | Ann-Kristin Seifer<br>Madeleine Flaucher<br>Prof. Dr. Björn Eskofier<br>Syrine Slim | |

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| 4 | **Module coordinator** | Prof. Dr. Björn Eskofier<br>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.<br>Die folgenden Themen werden im Modul behandelt:<br>• Einführung in die Grundlagen der Mensch-Computer-Interaktion, historische Entwicklung<br>• Entwurfsprinzipien und Modelle für moderne Benutzungsschnittstellen und interaktive Systeme<br>• Informationsverarbeitung des Menschen, Wahrnehmung, Motorik, Eigenschaften und Fähigkeiten des Benutzers<br>• Interaktionskonzepte und -stile, Metaphern, Normen, Regeln und Style Guides<br>• Ein- und Ausgabegeräte, Entwurfsraum für interaktive Systeme<br>• Analyse-, Entwurfs- und Entwicklungsmethoden und -werkzeuge für Benutzungsschnittstellen<br>• Prototypische Realisierung und Implementierung von interaktiven Systemen, Werkzeuge<br>• Architekturen für interaktive Systeme, User Interface Toolkits und Komponenten<br>• Akzeptanz, Evaluationsmethoden und Qualitätssicherung<br>Contents:<br>The module aims to teach basic knowledge of concepts, principles, models, methods and<br>techniques for developing highly user-friendly Human-Computer Interfaces. Beyond traditional<br>computer systems, modern user interfaces are also discussed in the context of automobile<br>and intelligent environments, mobile devices and embedded systems.<br>This module addresses the following topics:<br>• Introduction to the basics of Human-Computer Interaction<br>• Design principles and models for modern user interfaces and interactive systems |

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| | | • Information processing of humans, perception, motor skills, properties and skills of the users<br>• Interaction concepts, metaphors, standards, norms and style guides<br>• In- and output devices, design space for interactive systems<br>• Analysis-, design- and development of methodologies and tools for easy-to-use user interfaces<br>• Prototypic implementation of interactive systems<br>• Architectures for interactive systems, User Interface Toolkits and components<br>• Acceptance, evaluation methods and quality assurance |
| 6 | **Learning objectives and skills** | • Studierende entwickeln ein Verständnis für Modelle, Methoden und Konzepte der Mensch-Computer-Interaktion.<br>• Sie lernen verschiedene Ansätze für den Entwurf, die Entwicklung und Bewertung von Benutzungsschnittstellen kennen und verstehen deren Vor- und Nachteile.<br>• Die Teilnahme an der Veranstaltung versetzt Studierende in die Lage, einen Entwicklungsprozess in der Mensch-Computer-Interaktion zu verstehen und umzusetzen.<br>• Sie werden weiterhin in die Lage versetzt, dies vor dem Hintergrund der Informationsverarbeitungsfähigkeit, Wahrnehmung und Motorik des Benutzers zu gestalten.<br>• Passende Methoden der Evaluation sowie Akzeptanz- und Qualitätssicherung werden erlernt.<br>Learning Objectives and Competences:<br>• Students develop an understanding of models, methods and concepts in the field of Human-Computer Interaction.<br>• They learn different approaches for designing, developing and evaluating User Interfaces and their advantages and disadvantages.<br>• Joining the course enables students to understand and execute a development process in Human-Computer Interaction.<br>• Students will be able to do a UI evaluation by learning the basics of information processing, perception and motoric skills of the user.<br>• Appropriate evaluation methods, as well as acceptance and quality assurance aspects, will be learned. |
| 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** | Klausur<br>Electronic exam (in presence), 90min |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in summer semester |

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| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>447324 | **Image, Video, and Multidimensional Signal Processing**<br>Image, video and multidimensional signal processing | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Image, Video, and Multidimensional Signal Processing (2.0 SWS, )<br>Übung: Supplements for Image, Video, and Multidimensional Signal Processing () | 5 ECTS<br>- |
| 3 | Lecturers | Prof. Dr.-Ing. Andre Kaup | |

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| 4 | **Module coordinator** | |
| 5 | **Contents** | no content description available! |
| 6 | **Learning objectives and skills** | no learning objectives and skills description available! |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | no Module frequency information available! |
| 13 | **Workload in clock hours** | Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt)<br>Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt) |
| 14 | **Module duration** | ?? semester (no information for Module duration available) |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>96312 | **Bild-, Video- und mehrdimensionale Signalverarbeitung**<br>Image, video and multidimensional 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 | - | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andre Kaup |
| 5 | **Contents** | *Punktoperationen*<br>Histogrammausgleich, Gamma-Korrektur<br>*Binäroperationen*<br>Morphologische Filter, Erosion, Dilatation, Opening, Closing<br>*Farbräume*<br>Trichromat, RGB- Farbraum, HSV-Farbraum<br>*Mehrdimensionale Signale und Systeme*<br>Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter<br>*Interpolation von Bildsignalen*<br>Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation<br>*Merkmalsdetektion in Bildern*<br>Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix<br>*Skalierungsraumdarstellung*<br>LoG, DoG, SIFT, SURF<br>*Bildabgleich*<br>Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC<br>*Bildsegmentierung*<br>Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos<br>*Bildverarbeitung im Transformationsbereich*<br>Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT<br>*Content:*<br>*Point operations*<br>Histogram equalization, gamma correction<br>*Binary operations*<br>Morphological filters, erosion, dilation, opening, closing<br>*Color spaces*<br>Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity<br>*Multidimensional signals and systems*<br>Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering<br>*Interpolation of image signals*<br>Bi-linear interpolation, bi-cubic interpolation, spline interpolation |

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| | | *Image feature detection*<br>Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix<br>*Scale space representation*<br>Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform<br>*Image matching*<br>Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm<br>*Image segmentation*<br>Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video<br>*Transform domain image processing*<br>Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• verstehen Punktoperationen an Bilddaten und Gamma-Korrektur<br>• testen die Wirkung von Rangordnungs- und Medianfiltern an Bilddaten<br>• unterscheiden und bewerten verschiedene Farbräume für Bilddaten<br>• erklären das Prinzip der zwei-dimensionalen linearen Filterung für Bildsignale<br>• berechnen und bewerten die zweidimensionale diskrete Fourier-Transformierte eines Bildsignales<br>• bestimmen vergrößerte diskrete Bildsignale mit Methoden der bilinearen und Spline-Interpolation<br>• überprüfen Bilddaten auf ausgewählte Textur-, Kanten- und Bewegungsmerkmale<br>• analysieren Bild- und Videodaten auf Merkmale in unterschiedlichen Scale-Spaces<br>• erläutern und beurteilen Methoden für das Matching von Bilddaten<br>• segmentieren Bilddaten durch Programmierung von einfachen Klassifikations- oder Clustering-Verfahren<br>• verstehen das Prinzip von Transformation auf Bilddaten und können diese an Beispielen anwenden.<br>The students<br>• understand point operations for image data and gamma correction<br>• test the effects of rank order and median filters for image data<br>• evaluate and differentiate between different color spaces for image data<br>• explain the principle of two-dimensional linear filtering for image signals<br>• calculate and evaluate the two-dimensional discrete Fourier transform of an image signal |

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| | | • determine enlarged discrete image signals by bi-linear and spline interpolation<br>• verify image data for selected texture, edge and motion features<br>• analyze image and video data for features in different scale spaces<br>• explain and evaluate methods for the matching of image data<br>• segment image data by implementing basic classification and clustering methods<br>• understand the principle of transformations on image data and apply them exemplarily |
| 7 | **Prerequisites** | Vorlesung Signale und Systeme I und II |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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<br><br>J. W. Woods: \|Multidimensional Signal, Image, and Video Processing and Coding\|, Academic Press, 2^nd^ edition, 2012 |

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| 1 | **Module name**<br>44140 | **Interventional Medical Image Processing**<br>Interventional medical image processing | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Medical Image Processing for Interventional Applications (VHB-Kurs) (4.0 SWS) | 5 ECTS |
| 3 | Lecturers | | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Andreas Maier |
| 5 | **Contents** | English Version:<br>This module focuses on recent developments in image processing driven by medical applications.<br>All algorithms are motivated by practical problems.<br>The mathematical tools required to solve the considered image processing tasks will be introduced.<br>The module starts with an overview on preprocessing algorithms such as scatter correction for x-ray images, edge detection, super-resolution and edge-preserving noise reduction.<br>The second chapter describes automatic image analysis using feature descriptors, key point detection, and segmentation using bottom-up algorithms such as the random walker or top-down approaches such as active shape models.<br>Furthermore, the module covers geometric calibration algorithms for single view calibration, epipolar geometry, and factorization.<br>The last part of the module covers non-rigid registration based on variational methods and motion-compensated image reconstruction.<br><br>Deutsche Version:<br>Das Modul ist auf die jüngsten Entwicklungen in der Verarbeitung von medizinischen Bildern ausgerichtet.<br>Alle Algorithmen werden durch praktische Probleme motiviert.<br>Die mathematischen Werkzeuge, die für die Bildverarbeitungsaufgaben benötigt werden, werden eingeführt.<br>Das Modul beginnt mit einem Überblick über Vorverarbeitungsalgorithmen, wie zum Beispiel Streustrahlkorrektur für Röntgenbilder, Kantenerkennung, Superresolution und kantenerhaltende Rauschunterdrückung.<br>Das zweite Kapitel beschreibt die automatische Bildanalyse mit Merkmalsdeskriptoren, Punkterkennung und Segmentierung mit Bottom-up-Algorithmen wie dem Random-Walker oder Top-Down-Ansätzen wie aktiven Formmodellen.<br>Darüber hinaus deckt die Vorlesung auch geometrische Kalibrierungsalgorithmen zur Einzelansicht-Kalibrierung, Epipolargeometrie und Faktorisierung ab.<br>Der letzte Teil des Moduls deckt nicht-starre Registrierung auf der Grundlage von Variationsmethoden und bewegungskompensierter Bildrekonstruktion ab. |
| 6 | **Learning objectives and skills** | English Version:<br>The participants<br>• summarize the contents of the lecture. |

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| | | • apply pre-processing algorithms such as scatter correction and edge-preserving filtering.<br>• extract information from images automatically by image analysis methods such as key point detectors and segmentation algorithms.<br>• calibrate projection geometries for single images and image sequences using the described methods.<br>• develop non-rigid registration methods using variational calculus and different regularizers.<br>• adopt algorithms to new domains by appropriate modifications.<br>Deutsche Version:<br>Die Teilnehmenden<br>• fassen die Inhalte der Vorlesung zusammen.<br>• wenden Vorverarbeitungsalgorithmen wie Streustrahlkorrektur und kantenerhaltende Filterung an.<br>• extrahieren automatisch Informationen aus Bildern, indem sie Bildanalyseverfahren wie Punktdetektoren und Segmentierungsalgorithmen verwenden.<br>• kalibrieren Projektionsgeometrien für Einzelbilder und Bildsequenzen mit den beschriebenen Methoden.<br>• entwickeln nicht-starre Registrierungsmethoden mit Hilfe von Variationsrechnung und unterschiedlichen Regularisierern.<br>• wenden Algorithmen auf neue Modalitäten durch entsprechende Änderungen im Algorithmus an. |
| 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** | schriftlich/mündlich (60 Minuten) |
| 11 | **Grading procedure** | schriftlich/mündlich (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 0 h<br>Independent study: 150 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>43405 | **Introduction to Deep Learning**<br>Introduction to 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 | - | |

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| 4 | **Module coordinator** | |
| 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),<br>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.<br>Lernziel:<br>Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt<br>werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen.<br>Content:<br>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.<br>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 |

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| | | • beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung,<br>• setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten,<br>• vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität,<br>• wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus,<br>• entwerfen neuartige Verfahren für gegebene Anforderungen,<br>• formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal,<br>• ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu.<br>Learning Objectives and Competences:<br>The students<br>- describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation,<br>- realize various approaches in block diagrams and optimize their components,<br>- compare equalization methods in terms of their performance, characterized by the error rate, and complexity,<br>- select suitable methods for various applications such as wired and wireless transmission,<br>- design novel schemes for given requirements,<br>- formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel,<br>- assign suitable adaptation algorithms to equalization schemes. |
| 7 | **Prerequisites** | Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung<br>Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich. |
| 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** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | every semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |

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| 15 | **Teaching and examination language** | |
| 16 | **Bibliography** | Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung.<br><br>Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992.<br><br>Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999.<br><br>Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995.<br><br>Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996. |

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| 1 | **Module name**<br>267499 | **Linear and non-linear fibre optics** | **5 ECTS** |
| 2 | Courses / lectures | Übung: Linear and non-linear fibre optics: Exercise (2.0 SWS)<br>Vorlesung: Linear and non-linear fibre optics (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Andreas Rittler | |

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| 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<br>• Understand structure and operation of components of optical communication systems<br>• Rate the optical properties of components and evaluate the influence of operational parameters on system performance<br>• Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance<br>• Can make use of system simulation tools to engineer optical links |
| 7 | **Prerequisites** | Recommended prior knowledge:<br>• Semiconductor physics<br>• Ray optics<br>• Photonics |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |

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| 13 | **Workload in clock hours** | Contact hours: 60 h<br>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<br><br>Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002<br><br>Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008 |

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| 1 | **Module name**<br>428256 | **Maschinelles Lernen für Zeitreihen**<br>Machine learning for time series | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr. Björn Eskofier<br>Dr. Dario Zanca |
| 5 | **Contents** | Aim of the lecture is to teach Machine learning (ML) and Deep Learning (DL) methods for a variety of time series applications. The following topics will be covered:<br>• Fundamentals and an overview of applications of time series analysis.<br>• Fundamentals of ML methods, such as Gaussian processes, State Space models, and Autoregressive models for time series.<br>• Design, implementation and evaluation of ML methods in order to address time series problems.<br>• Advanced DL methods for time-series, such as Convolutional, Recurrent, and Attention-based models.<br>• Working with widely-used toolboxes that can be used for implementation of ML methods, such as Tensorflow or PyTorch. |
| 6 | **Learning objectives and skills** | • Students can describe concepts of time series problems and their wide applications in industry, medicine, finance, etc.<br>• Students can explain concepts of ML/DL methods in general and tackling time series problems in particular<br>• Students understand the characteristics of time series data and are capable of developing and implementing ML/DL methods to model, predict and manipulate such data in concrete problems |
| 7 | **Prerequisites** | This is a specialisation lecture; successful completion of the lectures "IntroPR" and/or "Pattern Recognition" / "Pattern Analysis" is recommended. Concepts taught in "IntroPR" are assumed here as basic knowledge. |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>electronic exam (remote), 90 min. |
| 10 | **Method of examination** | Variabel (90 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |

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| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | • Pattern recognition and machine learning. Christopher M. Bishop, Springer, 2006<br>• The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Trevor Hastie, Robert Tibshirani, Jerome Friedman, Springer, 2009<br>• Machine Learning: A Probabilistic Perspective. Kevin Murphy, MIT press, 2012<br>• Deep Learning. Ian Goodfellow and Yoshua Bengio and Aaron Courville, MIT Press, 2016 |

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| 1 | **Module name**<br>668129 | **Machine Learning in Communications**<br>Machine learning in communications | **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 | - | |

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| 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.<br>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<br>• know and explain the fundamentals of machine learning with special attention to machine learning over graphs.<br>• apply these principles in the design and optimisation of wireless communications systems and mobile networks. |
| 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>48440 | **Machine Learning in Signal Processing**<br>Machine learning in 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 | - | |

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| 4 | **Module coordinator** | Jürgen Seiler |
| 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.<br>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<br>• understand regression and classification problems<br>• apply PDF estimation algorithms<br>• understand Gaussian mixture models and expectation-maximization<br>• apply principal component analysis and independent component analysis<br>• assess different estimation algorithms<br>• explain the application of machine learning to system identification<br>• apply hidden Markov models<br>• understand different artificial neural network architectures<br>• explain deep learning principles<br>• apply artificial neural networks<br>• devise learning strategies for deep neural networks<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |

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| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Literature:<br>• C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML<br>• S. Theodoridis and K. Koutroumbas: Pattern Recognition<br>• M. Nielsen: Neural Networks and Deep Learning. |

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| 1 | **Module name**<br>96300 | **MIMO Communication Systems**<br>MIMO communication systems | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: MIMO Communication Systems (3.0 SWS)<br>Übung: MIMO Communication Systems - Tutorial (1.0 SWS) | 5 ECTS<br>- |
| 3 | Lecturers | Hedieh Ajam<br>Prof. Dr.-Ing. Robert Schober | |

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| 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<br>• learn about different MIMO channel models,<br>• analyze MIMO communication systems with respect to their channel capacity and reliability,<br>• determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain,<br>• compare and evaluate different MIMO receiver designs,<br>• characterize the rate region of multiuser systems,<br>• analyze massive MIMO systems,<br>• discuss the advantages and disadvantages of different relay network architectures.<br>Die Studierenden<br>• lernen verschiedene MIMO-Kanalmodelle kennen,<br>• analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit,<br>• ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn,<br>• vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien,<br>• charakterisieren die Ratenregion von Mehrteilnehmersystemen,<br>• analysieren Massive-MIMO-Systeme,<br>• 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 |

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| | | Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>454183 | **Molecular Communications**<br>Molecular communications | **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 | - | |

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| 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 learn how to design synthetic molecular communication systems. They develop an understanding of natural communication processes in biological systems and how to harness these natural processes for the construction of man-made molecular communication systems. The students also learn how to analyse, model, and simulate molecular communication systems. |
| 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |

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

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|---|---|---|---|
| 1 | **Module name**<br>687141 | **Multiuser Information and Communications Theory**<br>Multiuser information and communications theory | **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 | - | |

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| 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.<br>The students apply various algorithms for multiuser detection.<br>The students explain various types of multiuser channels and their limits to transport information.<br>The students explain the limits of distributed source coding algorithms.<br>The students apply the cut-set bound.<br>The students explain the method of dirty-paper coding.<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |

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

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|---|---|---|---|
| 1 | **Module name**<br>302148 | **Musiksignalverarbeitung - Analyse**<br>Music processing - Analysis | **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 | - | |

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|---|---|---|
| 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<br>Understand<br>• The students present central tasks in music processing in their own words and outline possible solutions.<br>• The students understand the properties of different forms of representation of music.<br>Apply<br>• The students apply basic algorithms for the analysis and comparison of music signals.<br>• Students can predict how different musical properties will affect the signal analysis.<br>Analyze<br>• The students observe and discuss the meaning and impact of parameters in music analysis.<br>• The students compare different methods of analyzing periodicities.<br>Evaluate<br>• The students question assumptions that are often implicitly made when using analytical methods.<br>• Students estimate when methods might work when analyzing specific music signals and when they typically fail.<br>Learning and methodological skills<br>• The students prepare for the lecture using selected literature and Jupyter notebooks.<br>• 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

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| | | • Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>639119 | **Music Processing Analysis - Lecture and Exercise**<br>Music processing analysis - Lecture and exercise | **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 | - | |

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|---|---|---|
| 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<br>Verstehen<br>• Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze.<br>• Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik.<br>• Die Studierenden interpretieren Signaleigenschaften anhand von Visualisierungen (Exercise).<br>Anwenden<br>• Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an.<br>• Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken.<br>• Die Studierenden implementieren Algorithmen zur Analyse, zum Vergleich und zur inhaltsbasierten Suche von Musiksignalen (Exercise).<br>Analysieren<br>• Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse.<br>• Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber.<br>• Die Studierenden analysieren und erforschen Eigenschaften von Musiksignalen mittels automatisierter Methoden (Exercise). |

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

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| | | Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Portfolio |
| 11 | **Grading procedure** | Portfolio (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Meinard Müller<br><br>Fundamentals of Music Processing<br><br>Using Python and Jupyter Notebooks<br><br>2nd edition, 495 p., hardcover<br><br>ISBN: 978-3-030-69807-2<br><br>Springer, 2021<br><br>http://www.music-processing.de/<br><br>https://www.audiolabs-erlangen.de/FMP |

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|---|---|---|---|
| 1 | **Module name**<br>502007 | **Musiksignalverarbeitung - Synthese**<br>Music processing - synthesis | **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 | - | |

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| 4 | **Module coordinator** | Maximilian Schäfer |
| 5 | **Contents** | • Verarbeitung von Audiosignalen durch parametrische Filter und Effekte<br>• Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese<br>• Klangwiedergabe in echten und virtuellen Räumen<br>• Klangbeispiele und Demonstrationen<br>• Programmiersprachen für Audio-Echtzeit-Verarbeitung<br>*Content*:<br>• a short history of electrical and electronic music<br>• processing of audio signals by parametric filters and effects<br>• digital sound synthesis<br>• sound reproduction in real and in virtual environments<br>• sound examples and demonstrations<br>• programming languages for audio real-time processing |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung,<br>• wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an,<br>• gestalten eigene Software-Realisierungen zur Klangsynthese,<br>• entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen.<br>The students<br>• specify the special requirements for audio realtime processing,<br>• apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds,<br>• design their own software realizations for sound synthesis<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |

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

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| 1 | **Module name**<br>96895 | **Music Processing - Synthesis**<br>Music processing - synthesis | **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 | - | |

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|---|---|---|
| 4 | **Module coordinator** | Maximilian Schäfer |
| 5 | **Contents** | • Verarbeitung von Audiosignalen durch parametrische Filter und Effekte<br>• Erzeugung von künstlichen Klängen mit Mitteln der digitalen Klangsynthese<br>• Klangwiedergabe in echten und virtuellen Räumen<br>• Klangbeispiele und Demonstrationen<br>• Programmiersprachen für Audio-Echtzeit-Verarbeitung<br>*Content*:<br>• a short history of electrical and electronic music<br>• processing of audio signals by parametric filters and effects<br>• digital sound synthesis<br>• sound reproduction in real and in virtual environments<br>• sound examples and demonstrations<br>• programming languages for audio real-time processing |
| 6 | **Learning objectives and skills** | Die Studierenden<br>• beschreiben die speziellen Anforderungen für Audio-Echtzeit-Verarbeitung,<br>• wenden ihre theoretischen Kenntnisse zeitdiskreter Signale und Systeme für die Verarbeitung und Erzeugung musikalischer Klänge an,<br>• gestalten eigene Software-Realisierungen zur Klangsynthese,<br>• entwerfen technische Systeme für musikalisch motivierte Aufgabenstellungen.<br>The students<br>• specify the special requirements for audio realtime processing,<br>• apply their theoretical knowledge about discrete-time signals and systems to processing and synthesis of musical sounds,<br>• design their own software realizations for sound synthesis<br>• 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** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h |

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| | | Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>43000 | **Optische Kommunikationsnetze**<br>Optical communication networks | **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 | - | |

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|---|---|---|
| 4 | **Module coordinator** | Prof. Dr. Herbert Haunstein |
| 5 | **Contents** | Global communication between billions of subscribers utilizing a multitude of devices is accomplished over a trans-continental fiber-optic transport network. End users worldwide access this network over copper cable (xDSL, HFC), by wireless technologies like WLAN, GSM, UMTS, LTE and also via GPON, EPON and WDM-PON (PON: Passive Optical Network). After a short distance ("the last mile") data streams from many users are aggregated (e.g. by IP routers) into higher data rate transport streams, which are then carried over cost-efficient and highly reliable optical connections.<br><br>Rapid increase of data traffic has quickly evolved from Gigabit Ethernet (1GbE) to 10GbE and 100GbE data rates.<br>To operate optical networks on a global scale, standards like OTN (Optical Transport Network) have been developed to provide high capacity links by use of many wavelengths together with operations and maintenance (OAM) functions. Automated protection and restauration schemes provide a high level of availabilty and can guarantee carrier-grade Quality of Service (QoS). Future data rate increase will be driven by video streaming as well as the introduction of 5G wireless technology and the Internet of Things (IoT).<br><br>The course shall provide a fundamental understanding of modern fiber optic networks from fixed and mobile access through metropolitan area to core networks.<br>1) Introduction – Evolution of optical networks<br>2) Network layers - Internet Protocol – TCP/IP<br>3) Label switching – MPLS – MPLS-TP<br>4) Quality of Service - traffic classification – resource allocation<br>5) Ethernet - switching and physical transport<br>6) Optical Transport Network - OTN<br>7) Optical fiber properties – optical amplification<br>8) Optical transmitter – laser – modulator<br>9) Optical receiver – photo detection – Clock&Data recovery – Bit Error Ratio calculation<br>10) Modulation formats – transmission - margin allocation<br>11) Coherent detection – optical signal processing<br>12) Optical networks – optical switching<br>13) Network control & automation |

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| 6 | **Learning objectives and skills** | Students ...<br>• explain the functional building blocks of optical networks<br>• can eloborate on the different tasks provided by the logical/ control plane (routing), the physical layer and transmission/ data plane of optical networks<br>• refer which standardisation organisation contributes to the different function of optical networks<br>• explain the purpose of different protocols that interact along an end-to-end communication channel<br>• describe technologies for E/O and O/E conversion and optical switches<br>• express the design challenges of future optical systems for fixed and mobile access, data center interconnects,<br>• metro-regional, core, ultra-long-haul and submarine networks |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | 1) R. Ramaswami and K.N. Sivarajan: “Optical Networks”, Morgan Kaufman Publishers, 1998<br>2) U. Black: “Optical Networks - Third generation transport systems”, Prentice Hall, 2002<br>3) P. Tomsu and Chr. Schmutzer: “Next generation optical networks”, Prentice Hall, 2002<br>4) M. Bossert, M. Breitbach: “Digitale Netze”, Teubner Verlag, 1997<br>5) I. Kaminow and T. Li (eds.): “Optical fiber telecommunications IVA+B”, Academic Press, 2002<br>6) D.E. Comer, „Computernetworks and Internets, Pearson“, 2009<br>7) G.P. Agrawal, “Fiber optic communication systems”, Wiley, 1992, (new 1997)<br>8) G.P. Agrawal, “Nonlinear fiber optics”, Academic Press, 1995<br>9) K. Petermann: “Laser Diode Modulation and Noise”, Kluver, 1991<br>10) I. Kazovsky et al., „Optical Fiber Communication Systems“, Artech House, 1996 |

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| | | 11) K.-P. Ho, „Phase-Modulated Optical Communication Systems“, Springer 2005<br>12) H. Haunstein, Presentation material (slides) of the lectures (in English)<br>13) |

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|---|---|---|---|
| 1 | **Module name**<br>849203 | **Optische Kommunikationsnetze**<br>Optical communication networks | **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. Herbert Haunstein |
| 5 | **Contents** | Global communication between billions of subscribers utilizing a multitude of devices is accomplished over a trans-continental fiber-optic transport network. End users worldwide access this network over copper cable (xDSL, HFC), by wireless technologies like WLAN, GSM, UMTS, LTE and also via GPON, EPON and WDM-PON (PON: Passive Optical Network). After a short distance ("the last mile") data streams from many users are aggregated (e.g. by IP routers) into higher data rate transport streams, which are then carried over cost-efficient and highly reliable optical connections.<br><br>Rapid increase of data traffic has quickly evolved from Gigabit Ethernet (1GbE) to 10GbE and 100GbE data rates.<br>To operate optical networks on a global scale, standards like OTN (Optical Transport Network) have been developed to provide high capacity links by use of many wavelengths together with operations and maintenance (OAM) functions. Automated protection and restauration schemes provide a high level of availabilty and can guarantee carrier-grade Quality of Service (QoS). Future data rate increase will be driven by video streaming as well as the introduction of 5G wireless technology and the Internet of Things (IoT).<br><br>The course shall provide a fundamental understanding of modern fiber optic networks from fixed and mobile access through metropolitan area to core networks.<br>1) Introduction – Evolution of optical networks<br>2) Network layers - Internet Protocol – TCP/IP<br>3) Label switching – MPLS – MPLS-TP<br>4) Quality of Service - traffic classification – resource allocation<br>5) Ethernet - switching and physical transport<br>6) Optical Transport Network - OTN<br>7) Optical fiber properties – optical amplification<br>8) Optical transmitter – laser – modulator<br>9) Optical receiver – photo detection – Clock&Data recovery – Bit Error Ratio calculation<br>10) Modulation formats – transmission - margin allocation<br>11) Coherent detection – optical signal processing<br>12) Optical networks – optical switching<br>13) Network control & automation |
| 6 | **Learning objectives and skills** | Students ...<br>• explain the functional building blocks of optical networks |

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|---|---|---|
| | | • can eloborate on the different tasks provided by the logical/ control plane (routing), the physical layer and transmission/ data plane of optical networks<br>• refer which standardisation organisation contributes to the different function of optical networks<br>• explain the purpose of different protocols that interact along an end-to-end communication channel<br>• describe technologies for E/O and O/E conversion and optical switches<br>• express the design challenges of future optical systems for fixed and mobile access, data center interconnects,<br>• metro-regional, core, ultra-long-haul and submarine networks |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich (30 Minuten) |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | 1) R. Ramaswami and K.N. Sivarajan: “Optical Networks”, Morgan Kaufman Publishers, 1998<br>2) U. Black: “Optical Networks - Third generation transport systems”, Prentice Hall, 2002<br>3) P. Tomsu and Chr. Schmutzer: “Next generation optical networks”, Prentice Hall, 2002<br>4) M. Bossert, M. Breitbach: “Digitale Netze”, Teubner Verlag, 1997<br>5) I. Kaminow and T. Li (eds.): “Optical fiber telecommunications IVA+B”, Academic Press, 2002<br>6) D.E. Comer, „Computernetworks and Internets, Pearson“, 2009<br>7) G.P. Agrawal, “Fiber optic communication systems”, Wiley, 1992, (new 1997)<br>8) G.P. Agrawal, “Nonlinear fiber optics”, Academic Press, 1995<br>9) K. Petermann: “Laser Diode Modulation and Noise”, Kluver, 1991<br>10) L. Kazovsky et al., „Optical Fiber Communication Systems“, Artech House, 1996<br>11) K.-P. Ho, „Phase-Modulated Optical Communication Systems“, Springer 2005 |

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| | | 12) H. Haunstein, Presentation material (slides) of the lectures (in English) |

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| 1 | **Module name**<br>44120 | **Pattern Analysis**<br>Pattern analysis | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Pattern Analysis (3.0 SWS)<br>Übung: PA-Prog (1.0 SWS) | 3,75 ECTS<br>1,25 ECTS |
| 3 | Lecturers | Christian Riess<br>Dalia Rodriguez Salas | |

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| 4 | **Module coordinator** | Christian Riess |
| 5 | **Contents** | This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods.<br>The topics comprise:<br>• clustering methods: soft and hard clustering<br>• classification and regression trees and forests<br>• parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees<br>• mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking<br>• linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps<br>• Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling<br>• Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts<br>Das Modul führt in das Design von Musteranalysesystemen sowie die zugrundeliegenden mathematischen Methoden ein.<br>Die Vorlesung umfasst im Einzelnen:<br>• Clustering-Methoden: Soft- und Hard-Clustering<br>• Klassifikations- und Regressionsbäume/-wälder<br>• parametrische und nicht-parametrische Dichteschätzung: Verfahren sind ML- und MAP-Schätzung, Histogramme, Parzenschätzung, Zusammenhang gefaltete Histogramme und Parzenschätzung, adaptives Binning mit Regressionsbäumen.<br>• 'Mean Shift'-Algorithmus: lokale Maximierung durch Gradientenaufstieg bei nicht-parametrischen Dichtefunktionen, Anwendungen des 'Mean Shift'-Algorithmus zum Clustering, Farbquantisierung und Objektverfolgung<br>• Linear and Non-Linear Manifold Learning: Curse of Dimensionality, Verschiedene Methode zur |

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| | | Dimensionsreduktion: Principal Component Analysis (PCA), Multidimensionsional Scaling (MDS), Isomap, Laplacian Eigenmaps<br>• Gaußsche Mischverteilungsmodelle (GMM) und Hidden-Markov-Modelle (HMM): 'Expectation Maximization'-Algorithmus, Parameterschätzung, Bestimmung der optimalen Zustandsfolge/Viterbi-Algorithmus, Vorwärts-Rückwärts-Algorithmus, Skalierung<br>• Markov-Zufallsfelder: Definition, Wahrscheinlichkeiten auf ungerichteten Graphen, Cliquen-Potenziale, Hammersley-Clifford-Theorem, Inferenz mit Gibbs-Sampling und Graph Cuts |
| 6 | **Learning objectives and skills** | The students<br>• explain the discussed methods for classification, prediction, and analysis of patterns,<br>• compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem,<br>• compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem,<br>• apply non-parametric probability density estimation to pattern analysis problems,<br>• apply dimensionality reduction techniques to high-dimensional feature spaces,<br>• explain statistic modeling of feature sets and sequences of features,<br>• explain statistic modeling of statistical dependencies,<br>• implement presented methods in Python,<br>• supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature,<br>• discuss the social impact of applications of pattern analysis solutions.<br>Die Studierenden<br>• erläutern die behandelten Methoden zur Klassifikation, Vorhersage und Analyse von Mustern,<br>• vergleichen und analysieren Methoden des Manifold Learning und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus,<br>• vergleichen und analysieren Methoden zur Dichteschätzung und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus,<br>• wenden nicht-parametrische Dichteschätzung auf Probleme der Musteranalyse an,<br>• wenden Dimensionsreduktion bei hochdimensionalen Merkmalsräumen an,<br>• erläutern statistische Modellierung von Merkmalsmengen und Merkmalsfolgen,<br>• erklären statistische Modellierung abhängiger Größen, |

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| | | • implementieren vorgestellte Verfahren in Python.<br>• ergänzen eigenständig mathematische Grundlagen der präsentierten Methoden durch selbstbestimmtes Studium der Literatur<br>• diskutieren die gesellschaftlichen Auswirkungen von Anwendungen der Musteranalyse |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Variabel (60 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Begleitende Literatur / Accompanying literature:<br>• C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006<br>• T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009<br>• A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013 |

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|---|---|---|---|
| 1 | **Module name**<br>44130 | **Pattern Recognition**<br>Pattern recognition | **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 | - | |

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

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| | | • beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung<br>• verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren<br>Students<br>• understand the structure of machine learning systems for simple patterns<br>• explain the mathematical foundations of selected machine learning techniques<br>• apply classification techniques in order to solve given classification tasks<br>• evaluate various classifiers with respect to their suitability to solve the given problem<br>• 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<br>• The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful.<br>• Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english<br>english |
| 16 | **Bibliography** | • Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001<br>• Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009<br>• Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006 |

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|---|---|---|---|
| 1 | **Module name**<br>96316 | **Radar, RFID and Wireless Sensor Systems (RWS)**<br>Radar, RFID and wireless sensor systems (RWS) | **5 ECTS** |
| 2 | Courses / lectures | Übung: Radar, RFID and Wireless Sensor Systems Exercises (2.0 SWS)<br>Vorlesung: Radar, RFID and Wireless Sensor Systems (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Dr.-Ing. Christian Carlowitz<br>Prof. Dr.-Ing. Martin Vossiek | |

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| 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.<br>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.<br>RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme  DSR. |
| 6 | **Learning objectives and skills** | The students<br>• learn about the setup, function and application of wireless sensors, Radar and RFID-systems<br>• can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases<br>• can determine the underlying physical limitations and sources of errors<br>• are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems<br>• can create and define independently applications and system designs of RWSs |
| 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** | schriftlich (90 Minuten) |
| 11 | **Grading procedure** | schriftlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |

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| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009<br><br>Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999<br><br>Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008<br><br>"RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009.<br><br>RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012. |

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| 1 | **Module name**<br>44400 | **Radar Signal Processing**<br>Radar 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 | - | |

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| 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.<br>The lecture covers the following topics:<br>• Introduction (radar principles & applications, signal & noise models, interference, Doppler shift)<br>• Basics of Signal Processing with Python (Jupyter Notebooks)<br>• Data Acquisition (I/Q demodulation, complex signal representation, sampling, quantization)<br>• Range Processing (radar waveforms, pulse compression, ambiguity function, sidelobe reduction)<br>• Doppler Processing (MTI, clutter suppression, range-Doppler ambiguities, spectral estimation)<br>• Detection Theory (target models, Neyman-Pearson criterion, CFAR detector, CRBs)<br>• Multi-Channel Processing (spatial filtering, interference suppression, adaptive beamforming)<br>• Synthetic Aperture Radar (basics of coherent imaging, SAR data model, time-domain processing)<br>• SAR Focusing Algorithms (range-Doppler, chirp scaling, motion compensation, autofocus)<br>• SAR Image Analysis (image statistics, speckle filtering, segmentation, classification)<br>• Radar Polarimetry (wave representations, scattering models, polarimetric decomposition)<br>• Interferometry (interferometric processing chain, statistical performance models, applications) |

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| | | • Tomography (principles of 3-D imaging, tomographic processing, remote sensing applications)<br>• Space-Time Adaptive Processing (GMTI, optimum processor, pre- & post-Doppler STAP)<br>• Advanced Topics (bi- & multistatic radar, MIMO radar, compressive sensing) |
| 6 | **Learning objectives and skills** | Fachkompetenz<br>Verstehen<br>• understand the basic principles and applications of radar systems<br>• understand the statistical properties of SAR images and their combinations<br>• understand current developments associated with bi- and multistatic SAR, MIMO radar, etc.<br>Anwenden<br>• implement signal processing algorithms for radar detection and parameter estimation<br>• use performance metrics for the evaluation of radar systems and signal processing algorithms<br>• focus coherent radar raw data into high-resolution SAR images<br>• apply space-time adaptive processing techniques for ground moving target indication<br>Analysieren<br>• select and apply spectral processing techniques for clutter and interference suppression<br>• simulate the performance of radar systems in complex environments<br>Erschaffen<br>• 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 und linearer Algebra. Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete: statistische Signalverarbeitung, Hochfrequenztechnik, Radar und/oder 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Resit examinations** | The exams of this moduls can only be resit once. |
| 14 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 15 | **Module duration** | 1 semester |

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| 16 | **Teaching and examination language** | english |
| 17 | **Bibliography** | • The handouts distributed at the beginning of each lecture cover the entire material and are fully sufficient for exam preparation.<br>• The following literature can be consulted if detailed information is needed on individual aspects:<br><br>- M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014<br><br>- I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004<br><br>- J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991<br><br>- F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014<br><br>- C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004<br><br>- H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002<br><br>- J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015<br><br>- R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001<br><br>- J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008 |

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| 1 | **Module name**<br>257359 | **Random Matrices in Communications and Signal Processing** | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Random Matrices in Communications and Signal Processing (2.0 SWS, ) | 5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Ralf Müller | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Ralf Müller |
| 5 | **Contents** | no content description available! |
| 6 | **Learning objectives and skills** | no learning objectives and skills description available! |
| 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** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt)<br>Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt) |
| 14 | **Module duration** | ?? semester (no information for Module duration available) |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>93185 | **Reinforcement Learning**<br>Reinforcement learning | **5 ECTS** |
| 2 | Courses / lectures | Vorlesung mit Übung: Reinforcement Learning | - |
| 3 | Lecturers | Dr.-Ing. Christopher Mutschler | |

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| 4 | **Module coordinator** | Dr.-Ing. Christopher Mutschler |
| 5 | **Contents** | The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics:<br>• Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes)<br>• Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration)<br>• Model-Free Prediction<br>• Model-Free Control<br>• Value Function Approximation (Linear VFA and DQNs)<br>• Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO)<br>• Model-based RL<br>• Offline RL<br>• Explainable RL<br>• Exploration-Exploitation<br>• Simulation to Reality Transfer<br>• Research frontiers & hot topics, Sim2Real & Real-World Applications |
| 6 | **Learning objectives and skills** | The students will learn to<br>• understand the basic principle behind sequestration decision making problems and how to translate them into a formal model<br>• compare and analyze methods different agents to search for policies<br>• implement the presented methods in PyTorch,<br>• discuss the social impact of applications that automate decision making |
| 7 | **Prerequisites** | Es handelt sich hier um eine Spezialisierungsvorlesung, eine erfolgreiche Absolvierung der Vorlesungen IntroPR" und/oder Pattern Recognition"/"Pattern Analysis" wird empfohlen. Konzepte, die in IntroPR" vermittelt werden, werden hier als Grundwissen vorausgesetzt. |
| 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** | Variabel (60 Minuten) |
| 11 | **Grading procedure** | Variabel (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |

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|---|---|---|
| 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.<br>• Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5.<br>• Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers.<br>• Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley.<br>• 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.<br>• Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific.<br>• Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning.<br>• Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics. |

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| 1 | **Module name**<br>96410 | **Schaltungen und Systeme der Übertragungstechnik** | **5 ECTS** |
| 2 | Courses / lectures | Übung: Übungen zu Schaltungen und Systeme der Übertragungstechnik (2.0 SWS)<br>Vorlesung: Schaltungen und Systeme der Übertragungstechnik (2.0 SWS) | -<br>5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Norman Franchi<br>Victor Shatov<br>Maximilian Lübke | |

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| 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<br>notwendigen Grundlagen erarbeitet.<br>Grundlagen:<br>• Funkkanaleigenschaften<br>• Modellierung<br>• Modulation, Codierung, Vielfachzugriff<br>Fahrzeugkommunikationssysteme:<br>• Übertragungssysteme für die Fahrassistenz<br>• Car-to-Car und Car-to-X-Kommunikation<br>• Breitbandige In-Car-Datenübertragung<br>Fahrzeugsensorik:<br>• Fahrzeugortung (lokal und global)<br>• Automobilradar und Umfeldüberwachung<br>• Sensorische Erfassung von Bioparametern im Fahrzeug |
| 6 | **Learning objectives and skills** | Die Studierenden sind nach der erfolgreichen Teilnahme am Modul in der Lage:<br>Funkkanaleigenschaften und Modelle für spezifische Anwendungs- und Betriebsszenarien anzuwenden<br>Modulationstechniken zu erläutern und zu analysieren<br>Moderne Codierungs- und Vielfachzugriffstechniken zu erläutern<br>Architekturen und Anwendungen von Fahrzeugkommunikationssystemen zu erläutern und zu analysieren<br>Architekturen und Anwendungen von Fahrzeugsensoriksystemen zu erläutern und zu analysieren |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |

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| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 60 h<br>Independent study: 90 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>48451 | **Selected Topics in ASC** | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Selected Topics in ASC - Summer 2024 (Prof. Harald Haas) (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr.-Ing. Ralf Müller | |

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| 4 | **Module coordinator** | Prof. Dr.-Ing. Ralf Müller |
| 5 | **Contents** | This course covers the fundamentals of Content Distribution, i.e., how to jointly store/cache and<br>deliver information over a cache-enabled network, and the fundamentals of Service Distribution, i.e.,<br>how to jointly store, process, and deliver information over a distributed cloud network with integrated<br>storage, computation, and communication resources.<br>The course is highly recommended for students and researchers in the basic science areas of<br>statistics, signal processing, data compression, and data transmission, as well as the applied science<br>fields of communications, networking, and cloud computing.<br><br>Detailed syllabus<br>• PART 1: Content Distribution<br>• Network information flow, network coding, multicast<br>• Caching, index coding, content reuse<br>• Fundamental of network compression<br>• Fundamental distributed storage which special focus on dynamic content<br>• PART 2: Service Distribution<br>• Cloud network flow, service representation, cloud-network representation<br>• end-to-end service optimization, joint communication-computation-storage<br>• resource allocation<br>• Dynamic cloud network control, stability region, Lyapunov control,<br>• o Network slicing, system automation, metaverse experiences |
| 6 | **Learning objectives and skills** | This course provides students with the knowledge, tools, and methods to understand:<br>• the fundamentals of content distribution, i.e., how to jointly store/cache and deliver<br>information over a cache-enabled network<br>• the fundamentals of service distribution, i.e., how to jointly store, process, and deliver<br>information over a network with storage, computation, and communication resources.<br>The knowledge learned in this course has wide applicability to highly impactful technology sectors, |

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| | | from the design and optimization of communication networks and systems, the design and<br>optimization of content delivery networks, systems, and algorithms, and the design and optimization<br>of future highly distributed cloud-integrated networks supporting next-generation applications. |
| 7 | **Prerequisites** | The students who will take this course should have a working knowledge of Probability Theory and Stochastic Processes along with the underlying requisite Mathematics (like calculus and algebra).<br>They should also have a basic background in Communication Systems.<br>Finally, some acquaintance with notions of optimization will be useful. |
| 8 | **Integration in curriculum** | semester: 2 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | Klausur (90 Minuten) |
| 11 | **Grading procedure** | Klausur (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |
| 16 | **Bibliography** | |

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|---|---|---|---|
| 1 | **Module name**<br>250058 | **Signalanalyse**<br>Signal analysis | **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 | - | |

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

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| | | • explain different approaches for time-frequency analysis<br>• describe the analysis of signals by means of filter-banks and wavelets<br>• explain methods for frequency estimation<br>• formulate approaches for spatial signal analysis. |
| 7 | **Prerequisites** | Fundierte Kenntnisse in digitaler Signalverarbeitung.<br>Requirements<br>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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich<br>Mündliche Prüfung mit einer Dauer von 30 min.<br><br>Oral examination of 30 min duration. |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>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 |

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| 1 | **Module name**<br>788996 | **Speech Enhancement**<br>Speech enhancement (oral examination) | **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 | - | |

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| 4 | **Module coordinator** | Prof. Dr. Emanuël Habets |
| 5 | **Contents** | *Course Description*<br>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.<br>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.<br>*Relation to other courses*<br>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<br>• Formulate the speech enhancement problem mathematically.<br>• Derive optimal single- and multi-channel filters to reduce noise and reverberation.<br>• Evaluate and compare the performance of single- and multi-channel filters for speech enhancement.<br>• Understand how reference signals and other prior information can be used in a speech enhancement system.<br>• Understand the limitations and challenges of existing speech enhancement systems.<br>• Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids.<br>• Design a microphone array and analyze its performance.<br>• Design a speech enhancement system for a given acoustic scenario.<br>• Evaluate both subjectively and objectively the performance of a speech enhancement system in terms of the speech quality and intelligibility. |

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| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | semester: 1 |
| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german or english |
| 16 | **Bibliography** | |

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| 1 | **Module name**<br>498723 | **Transformationen in der Signalverarbeitung**<br>Transforms in signal processing | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Transformationen in der Signalverarbeitung (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Jürgen Seiler | |

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| 4 | **Module coordinator** | 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.<br>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.<br>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<br>• Anwendungsmöglichkeiten von Transformationen bestimmen<br>• Integraltransformationen gegenüberstellen und untersuchen<br>• die Existenz von Transformationen hinterfragen<br>• die Eindeutigkeit von Transformationen überprüfen<br>• Sätze und Eigenschaften von Transformationen entwickeln<br>• zu Transformationen zugehörige inverse Transformationen einschätzen<br>• die Zusammenhänge zwischen verschiedenen Transformationen einschätzen<br>• auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern<br>• Symmetriebeziehungen von Transformationen ausarbeiten |

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| | | • Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten<br>Educational Objectives and Competences:<br>After attending the lecture, students will be able to<br>• determine applications of transforms<br>• contrast and examine integral transforms<br>• question the existence of transforms<br>• evaluate the uniqueness of transforms<br>• develop theorems and properties of transforms<br>• evaluate to transforms corresponding inverse transforms<br>• evaluate the relationships between different transforms<br>• asses the relationship between original signal and transformed signals<br>• devise the symmetry properties of transforms<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | mündlich |
| 11 | **Grading procedure** | mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | german |
| 16 | **Bibliography** | K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig<br><br>B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart |

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| 1 | **Module name**<br>43420 | **Transmission and Detection for Advanced Mobile Communications**<br>Transmission and detection for advanced mobile communications | **2,5 ECTS** |
| 2 | Courses / lectures | Vorlesung: Transmission and Detection for Advanced Mobile Communications (2.0 SWS) | 2,5 ECTS |
| 3 | Lecturers | Prof. Dr. Wolfgang Gerstacker | |

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| 4 | **Module coordinator** | 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<br>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<br>• describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE),<br>• apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system,<br>• formulate channel estimation methods for mobile communication systems,<br>• characterize the interference problem in GSM / EDGE,<br>- design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively,<br>• characterize the performance of mobile communication networks for different reception schemes,<br>• devise receivers for the realization of diversity gains for multiple receive antennas,<br>• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, |

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| | | • describe transmission schemes which are based on code-division multiple access (CDMA),<br>• apply reception techniques for CDMA to the UMTS system,<br>• characterize the uplink transmission in the Long Term Evolution (LTE) system,<br>• develop receivers for LTE.<br>Die Studierenden<br>• beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE),<br>• wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an,<br>• formulieren Kanalschätzverfahren für Mobilfunksysteme,<br>• charakterisieren das Interferenzproblem bei GSM/EDGE,<br>• entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen,<br>• bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren,<br>• konzipieren Empfänger zur Realisierung von Diversitätsgewinnnen bei empfangsseitiger Antennendiversität<br>• entwerfen Space-Time-Codierverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität,<br>• beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren,<br>• wenden Empfangsverfahren für CDMA auf das UMTS-System an,<br>• charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE),<br>• 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<br>Technische Wahlpflichtmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in summer semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | english |

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| 16 | **Bibliography** | Lecture notes |

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| 1 | **Module name**<br>96314 | **Virtual Vision**<br>Virtual vision | **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 | - | |

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| 4 | **Module coordinator** | Dr.-Ing. Christian Herglotz |
| 5 | **Contents** | Menschliches Sehen<br>Sichtfeld und Fovea<br>Dynamic Range<br>Stereoskopie<br>Eigenschaften der Lichtfeldunktion<br>• Helligkeit<br>• 3D und Tiefe<br>• Farben<br>• Räumliche und zeitliche Auflösung<br>Energieeffizienz in der Videokommunikation.<br>Content:<br>Human Vision<br>Field of view and fovea<br>Dynamic Range<br>Stereoscopy<br>Properties of the light field funtion<br>• Brightness<br>• 3D and depth<br>• Colors<br>• Spatial and temporal resolution<br>Energy efficiency in video communications |
| 6 | **Learning objectives and skills** | The students<br>• give an overview on basic properties of the human visual system<br>• know and explain all hardware and software components necessary to perform video capturing, processing, and display.<br>• describe differences and properties of video formats such as fisheye, 360°, or high dynamic range<br>• distinguish video formats and discuss advantages and disadvantages<br>• show real-time demonstrations of these video formats with common portable devices<br>• assess the quality and the compression performance of video formats<br>• come up with new strategies to improve processing algorithms like stitching or compression. |
| 7 | **Prerequisites** | None |
| 8 | **Integration in curriculum** | no Integration in curriculum available! |

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| 9 | **Module compatibility** | Technische Wahlmodule Master of Science Communications and Multimedia Engineering 20232 |
| 10 | **Method of examination** | schriftlich oder mündlich |
| 11 | **Grading procedure** | schriftlich oder mündlich (100%) |
| 12 | **Module frequency** | only in winter semester |
| 13 | **Workload in clock hours** | Contact hours: 30 h<br>Independent study: 45 h |
| 14 | **Module duration** | 1 semester |
| 15 | **Teaching and examination language** | |
| 16 | **Bibliography** | Literaturhinweise werden in der Vorlesung gegeben.<br><br>References for further reading will be given in the lecture. |