UNIVERSITÄT
DES
SAARLANDES

FACULTY OF MATHEMATICS AND COMPUTER SCIENCE

MODULE DESCRIPTIONS

Visual Computing (2025)

20th March 2026

List of module categories and modules

Module Category 1

Stammvorlesungen Visual Computing

Computer Graphics CG

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-3	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr. Philipp Slusallek

lecturers Prof. Dr. Philipp Slusallek

entrance requirements Solid knowledge of linear algebra is recommended.

assessments / exams

- Successful completion of weekly exercises (30% of final grade)
- Successful participation in rendering competition (10%)
- Mid-term written exam (20%, final exam prerequisite)
- Final written exam (40%)
- In each of the above a minimum of 50% is required to pass

A re-exam typically takes place during the last two weeks before the start of lectures in the following semester.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade The grade is derived from the above assessments. Possible changes will be announced at the beginnning of each semester.

language English

aims / competences to be developed

This course provides the theoretical and practical foundation for computer graphics. It gives a wide overview of topics, techniques, and approaches used in various aspects of computer graphics but has some focus on image synthesis or rendering. The first part of the course uses ray tracing as a driving applications to discuss core topics of computer graphics, from vector algebra all the way to sampling theory, the human visual system, sampling theory, and spline curves and surfaces. A second part then uses rasterization approach as a driving example, introducing the camera transformation, clipping, the OpenGL API and shading langue, plus advanced techniques.

As part of the practical exercises the students incrementally build their own ray tracing system. Once the basics have been covered, the students participate in a rendering competition. Here they can implement their favorite advanced algorithm and are asked to generate a high-quality rendered image that shows their techniques in action.

content

- Introduction
- Overview of Ray Tracing and Intersection Methods
- Spatial Index Structures
- Vector Algebra, Homogeneous Coordinates, and Transformations
- Light Transport Theory, Rendering Equation
- BRDF, Materials Models, and Shading
- Texturing Methods
- Spectral Analysis, Sampling Theory
- Filtering and Anti-Aliasing Methods

- Recursive Ray Tracing & Distribution Ray-Tracing
- Human Visual System & Color Models
- Spline Curves and Surfaces
- Camera Transformations & Clipping
- Rasterization Pipeline
- OpenGL API & GLSL Shading
- Volume Rendering (opt.)

literature & reading

Will be announced in the lecture.

Human Computer Interaction HCI

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-3	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr. Jürgen Steimle

lecturers Prof. Dr. Jürgen Steimle

entrance requirements undergraduate students: *Programmierung 1* and *2*
graduate students: none

assessments / exams Regular attendance of classes and tutorials
Successful completion of exercises and course project
Final exam
A re-exam takes place (as written or oral examination).

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Will be determined from performance in exams, exercises and practical tasks. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

This course teaches the theoretical and practical foundations for human computer interaction. It covers a wide overview of topics, techniques and approaches used for the design and evaluation of modern user interfaces.

The course covers the principles that underlie successful user interfaces, provides an overview of input and output devices and user interface types, and familiarizes students with the methods for designing and evaluating user interfaces. Students learn to critically assess user interfaces, to design user interfaces themselves, and to evaluate them in empirical studies.

content

- Fundamentals of human-computer interaction
- User interface paradigms, input and output devices
- Desktop & graphical user interfaces
- Mobile user interfaces
- Natural user interfaces
- User-centered interaction design
- Design principles and guidelines
- Prototyping

literature & reading

Will be announced before the start of the course on the course page on the Internet.

Image Processing and Computer Vision — IPCV

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-3	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr. Joachim Weickert

lecturers Prof. Dr. Joachim Weickert

entrance requirements Undergraduate mathematics (e.g. Mathematik für Informatiker I-III) and elementary programming knowledge in C

assessments / exams

- For the homework assignments one can obtain up to 24 points per week. Actively participating in the classroom assignments gives 12 more points per week, regardless of the correctness of the solutions. To qualify for both exams one needs 2/3 of all possible points.
- Passing the final exam or the re-exam.
- A re-exam takes place during the last two weeks before the start of lectures in the following semester.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Will be determined from the performance in the exam or the re-exam. The better grade counts.

language English

aims / competences to be developed

Broad introduction to mathematical methods in image processing and computer vision. The lecture qualifies students for a bachelor thesis in this field. Together with the completion of advanced or specialised lectures (9 credits at least) it is the basis for a master thesis in this field.

content

```
Inhalt

1. Basics
   1.1 Image Types and Discretisation
   1.2 Degradations in Digital Images
2. Colour Perception and Colour Spaces
3. Image Transformations
   3.1 Continuous Fourier Transform
   3.2 Discrete Fourier Transform
   3.3 Image Pyramids
   3.4 Wavelet Transform
4. Image Compression
5. Image Interpolation
6. Image Enhancement
   6.1 Point Operations
```

```
   6.2 Linear Filtering and Feature Detection
   6.3 Morphology and Median Filters
   6.3 Wavelet Shrinkage, Bilateral Filters, NL Means
   6.5 Diffusion Filtering
   6.6 Variational Methods
   6.7 Deconvolution Methods
7. Texture Analysis
8. Segmentation
   8.1 Classical Methods
   8.2 Variational Methods
9. Image Sequence Analysis
   9.1 Local Methods
   9.2 Variational Methods
10. 3-D Reconstruction
   10.1 Camera Geometry
   10.2 Stereo
   10.3 Shape-from-Shading
11. Object Recognition
   11.1 Hough Transform
   11.2 Invariants
   11.3 Eigenspace Methods
```

literature & reading

Will be announced before the start of the course on the course page on the Internet.

Machine Learning

ML

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-3	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr. Isabel Valera

lecturers Prof. Dr. Isabel Valera

entrance requirements The lecture gives a broad introduction into machine learning methods. After the lecture the students should be able to solve and analyze learning problems.

assessments / exams

- Regular attendance of classes and tutorials.
- 50% of all points of the exercises have to be obtained in order to qualify for the exam.
- Passing 1 out of 2 exams (final, re-exam).

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Determined from the results of the exams, exercises and potential projects. The exact grading modalities are announced at the beginning of the course.

language English

aims / competences to be developed

The lecture gives a broad introduction into machine learning methods. After the lecture the students should be able to solve and analyze learning problems.

content

- Bayesian decision theory
- Linear classification and regression
- Kernel methods
- Bayesian learning
- Semi-supervised learning
- Unsupervised learning
- Model selection and evaluation of learning methods
- Statistical learning theory
- Other current research topics

literature & reading

Will be announced before the start of the course on the course page on the Internet.

Module Category 2

Vertiefungsvorlesungen Visual Computing

Advanced Topics in Neuro Rendering and Reconstruction

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2-3	**4**		**1**	**2**	**3**

responsible	Prof. Dr. Christian Theobalt
lecturers	Prof. Dr. Christian Theobalt Dr. Marc Habermann Dr. Thomas Leimkühler Dr. Rishabh Dabral Dr. Vladislav Golyanik
entrance requirements	Computer Graphics and Image Processing and Computer Vision and mathematics courses in the study semester or comparable knowledge from other mathematics courses are recommended.
assessments / exams	final or re-exam
course types / weekly hours	2 h lectures = 2 h (weekly)
total workload	30 h of classes + 60 h private study = 90 h (= 3 ECTS)
grade	Will be determined from performance in exams. The exact modalities will be announced at the beginning of the module.
language	English

aims / competences to be developed

Neural rendering and reconstruction form the foundation of digitizing the physical world, with applications in virtual/augmented reality (VR/AR), film production, robotics, and beyond. This course explores state of the art topics in this space, emphasizing data-driven approaches using neural models. The course covers foundational concepts in graphics and 3D scene representation and reconstruction, as well as more advanced topics, for instance neural reconstruction and rendering, differentiable rendering, generative models, morphable models, human reconstruction and synthesis, quantum vision etc.

content

Neural rendering and reconstruction form the foundation of digitizing the physical world, with applications in virtual/augmented reality (VR/AR), film production, robotics, and beyond. This course explores state of the art topics in this space, emphasizing data-driven approaches using neural models. The course covers foundational concepts in graphics and 3D scene representation and reconstruction, as well as more advanced topics, for instance neural reconstruction and rendering, differentiable rendering, generative models, morphable models, human reconstruction and synthesis.

literature & reading

Will be announced before the start of the course on the course page on the Internet.

Audio-Visual Communication and Networks AVCN

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2-3	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr.-Ing. Thorsten Herfet

lecturers Prof. Dr.-Ing. Thorsten Herfet

entrance requirements Solid foundation of mathematics (differential and integral calculus) and probability theory. The course will build on the mathematical concepts and tools taught in TC I while trying to enable everyone to follow and to fill gaps by an accelerated study of the accompanying literature. *Signals and Systems* as well as *Digital Transmission and Signal Processing (TC I)* are strongly recommended but not required.

assessments / exams Regular attendance of classes and tutorials Passing the final exam
Oral exam directly succeeding the course. Eligibility: Weekly excersises / task sheets, grouped into two blocks corresponding to first and second half of the lecture. Students must provide min. 50% grade in each of the two blocks to be eligible for the exam.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Final Exam Mark

language English

aims / competences to be developed

AVCN will deepen the students' knowledge on modern communications systems and will focus on wireless systems.

Since from a telecommunications perspective the combination of audio/visual data – meaning inherently high data rate and putting high requirements on the realtime capabilities of the underlying network – and wireless transmission – that is unreliable and highly dynamic with respect to the channel characteristics and its capacity – is the most demanding application domain.

content

As the basic principle the course will study and introduce the building blocks of wireless communication systems. Multiple access schemes like TDMA, FDMA, CDMA and SDMA are introduced, antennas and propagation incl. link budget calculations are dealt with and more advanced channel models like MIMO are investigated. Modulation and error correction technologies presented in Telecommunications I will be expanded by e.g. turbo coding and receiver architectures like RAKE and BLAST will be introduced. A noticeable portion of the lecture will present existing and future wireless networks and their extensions for audio/visual data. Examples include 802.11n and the terrestrial DVB system (DVB-T2).

literature & reading

Will be announced before the start of the course on the course page on the Internet.

additional information

This module was formerly also known as *Telecommunications II*.

Differential Equations in Image Processing and Computer Vision — DIC

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2-3	4	at least every two years	1 semester	6	9

responsible Prof. Dr. Joachim Weickert

lecturers Prof. Dr. Joachim Weickert

entrance requirements Undergraduate mathematics (e.g. "Mathematik für Informatiker I-III") and some elementary programming knowledge in C is required. Prior participation in "Image Processing and Computer Vision" is useful.

assessments / exams

- For the homework assignments one can obtain up to 24 points per week. Actively participating in the classroom assignments gives 12 more points per week, regardless of the correctness of the solutions. To qualify for both exams one needs 2/3 of all possible points.
- Passing the final exam or the re-exam.
- The re-exam takes place during the last two weeks before the start of lectures in the following semester.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

Homework assignments (theory and programming) and classroom assignments.

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Will be determined from the performance in the exam or the re-exam. The better grade counts.

language English

aims / competences to be developed

Many modern techniques in image processing and computer vision make use of methods based on partial differential equations (PDEs) and variational calculus. Moreover, many classical methods may be reinterpreted as approximations of PDE-based techniques. In this course the students will get an in-depth insight into these methods. For each of these techniques, they will learn the basic ideas as well as theoretical and algorithmic aspects. Examples from the fields of medical imaging and computer aided quality control will illustrate the various application possibilities.

content

```
1.  Introduction and Overview
2.  Linear Diffusion Filtering
    2.1  Basic Concepts
    2.2  Numerics
    2.3  Limitations and Alternatives
3.  Nonlinear Isotropic Diffusion Filtering
    3.1  Modeling
    3.2  Continuous Theory
    3.2  Semidiscete Theory
    3.3  Discrete Theory
    3.4  Efficient Sequential and Parallel Algorithms
```

4. Nonlinear Anisotropic Diffusion Filtering
    4.1 Modeling
    4.2 Continuous Theory
    4.3 Discrete Aspects
    4.4 Efficient Algorithms
5. Parameter Selection
6. Variational Methods
    6.1 Basic Ideas
    6.2 Discrete Aspects
    6.3 TV Regularisation and Primal-Dual Methods
    6.4 Functionals of Two Variables
7. Vector- and Matrix-Valued Images
8. Unification of Denoising Methods
9. Osmosis
    9.1 Continuous Theory and Modelling
    9.2 Discrete Theory and Efficient Algorithms
10. Image Sequence Analysis
    10.1 Models for the Smoothness Term
    10.2 Models for the Data Term
    10.3 Practical Aspects
    10.4 Numerical Methods
11. Continuous-Scale Morphology
    11.1 Basic Ideas
    11.2 Shock Filters and Nonflat Morphology
12. Curvature-Based Morphology
    12.1 Mean Curvature Motion
    12.2 Affine Morphological Scale-Space
13. PDE-Based Image Compression
    13.1 Data Selection
    13.2 Optimised Encoding and Better PDEs

literature & reading

- J. Weickert: Anisotropic Diffusion in Image Processing. Teubner, Stuttgart, 1998.
- G. Aubert and P. Kornprobst: Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations. Second Edition, Springer, New York, 2006.
- T. F. Chan and J. Shen: Image Processing and Analysis: Variational, PDE, Wavelet, and Stochastic Methods. SIAM, Philadelphia, 2005.
- F. Cao: Geometric Curve Evolutions and Image Processing. Lecture Notes in Mathematics, Vol. 1805, Springer, Berlin, 2003.
- R. Kimmel: The Numerical Geometry of Images. Springer, New York, 2004.
- G. Sapiro: Geometric Partial Differential Equations in Image Analysis. Cambridge University Press, 2001.
- Articles from journals and conferences.

High-Level Computer Vision

HLCV

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2-3	**4**	**at least every two years**	**1 semester**	**4**	**6**

responsible Prof. Dr. Bernt Schiele

lecturers Prof. Dr. Bernt Schiele
Prof. Dr. Mario Fritz

entrance requirements none

assessments / exams Written or oral exam and the end of the course.

course types / weekly hours

```
  2 h lectures
+ 2 h tutorial
= 4 h (weekly)
```

total workload

```
   60 h of classes
+ 120 h private study
= 180 h (= 6 ECTS)
```

grade Will be determined from performance in examinations and exercises. The exact modalities will be announced at the beginning of the course.

language English

aims / competences to be developed

The main goal of the lecture is to develop an understanding of recent and state-of-the-art methods in high level computer vision, which are often based on Deep Neural Networks and Machine Learning.

content

This course will cover essential techniques for high-level computer vision including deep learning and other modern machine learning methods. These techniques facilitate semantic interpretation of visual data, as it is required for a broad range of applications like robotics, driver assistance, multi-media retrieval, surveillance etc. In this area, the recognition and detection of objects, activities and visual categories have seen dramatic progress over the last decade. We will discuss the methods that have lead to state-of-the-art performance in this area and provide the opportunity to gather hands-on experience with these techniques.

literature & reading

- ”Computer Vision: Algorithms and Applications” by Richard Szeliski (in particular chapter on image formation)
- ”Pattern recognition and machine learning” by Christopher M. Bishop
- ”Computer vision” by David A. Forsyth and Jean Ponce
- Recent Scientific Papers that will be announced during the lecture

Realistic Image Synthesis RIS

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2-3	4	at least every two years	1 semester	6	9

responsible Prof. Dr. Philipp Slusallek

lecturers Prof. Dr. Philipp Slusallek
Dr. Karol Myszkowski
Guprit Singh

entrance requirements Related core lecture: *Computer Graphics*.

assessments / exams

- Theoretical and practical exercises (50% of the final grade)
- Final oral exam (other 50%)
- A minimum of 50% of needs to be achieved in each part to pass.
- A re-exam takes place during the last two weeks before the start of lectures in the following semester.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade The final grade is be based on the assessments above. Any changes will be announced at the beginning of the semester.

language English

aims / competences to be developed

At the core of computer graphics is the requirement to render highly realistic and often even physically-accurate images of virtual 3D scenes. In this lecture students will learn about physically-based lighting simulation techniques to compute the distribution of light even in complex environment. The course also covers issues of perception of images, including also HDR technology, display technology, and related topics.

After this course students should be able to build their own highly realistic but also efficient rendering system.

content

- Rendering Equation
- Radiosity and Finite-Element Techniques
- Probability Theory
- Monte-Carlo Integration & Importance Sampling
- Variance Reduction & Advanced Sampling Techniques
- BRDFs and Inversion Methods
- Path Tracing & * Bidirectional Path Tracing
- Virtual Point-Light Techniques
- Density Estimation & Photon Mapping
- Vertex Connection & Merging
- Path Guiding
- Spatio-Temporal Sampling & Reconstruction
- Approaches for Interactive Global Illumination
- Machine Learning Techniques in Rendering

- Human Perception
- HDR & Tone-Mapping
- Modern Display Technology
- Perception-Based Rendering

literature & reading

Litrature will be announced in the first lecture of the semester.

But here are some relevant text books:

- Pharr, Jakob, Humphreys, Physically Based Rendering : From Theory to Implementation, Morgan Kaufmann
- Shirley et al., Realistic Ray Tracing, 2. Ed., AK. Peters, 2003
- Jensen, Realistic Image Synthesis Using Photon Mapping, AK. Peters, 2001
- Dutre, at al., Advanced Global Illumition, AK. Peters, 2003
- Cohen, Wallace, Radiosity and Realistic Image Synthesis, Academic Press, 1993
- Apodaca, Gritz, Advanced Renderman: Creating CGI for the Motion Pictures, Morgan Kaufmann, 1999
- Ebert, Musgrave, et al., Texturing and Modeling, 3. Ed., Morgan Kaufmann, 2003
- Reinhard, Ward, Pattanaik, Debevec, Heidrich, Myszkowski, High Dynamic Range Imaging, Morgan Kaufmann Publishers, 2nd edition, 2010.
- Myszkowski, Mantiuk, Krawczyk. High Dynamic Range Video. Synthesis Digital Library of Engineering and Computer Science. Morgan & Claypool Publishers, San Rafael, USA, 2008.
- Glassner, Principles of Digital Image Synthesis, 2 volumes, Morgan Kaufman, 1995

Module Category 3

Stammvorlesungen Wider Visual Computing

Convex Analysis and Optimization — CAO

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2	4	at least every two years	1 semester	6	9

responsible Prof. Dr. Peter Ochs

lecturers Prof. Dr. Peter Ochs

entrance requirements Undergraduate mathematics (e.g. *Mathematik für Informatiker I*, *II* and *III*) and some elementary programming knowledge is recommended.

assessments / exams
- Regular attendance of classes and tutorials
- Solving accompanying exercises
- Successful participation in the final or re-exam

course types / weekly hours
```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload
```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Will be determined from performance in exams, exercises and practical tasks. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

After taking the course, students know about the most relevant concepts of convex analysis and convex optimization. They are able to read and understand related scientific literature. Moreover, they can rate the difficulty of convex optimization problems arising in applications in machine learning or computer vision and select an efficient algorithm accordingly. Moreover, they develop basic skills in solving practical problems with Python.

content

1. Introduction
   - Introduction
   - Applications
2. Convex Geometry
   - Foundations
   - Convex Feasibility Problems
3. Convex Analysis Background
   - Preliminaries
   - Convex Functions
4. Smooth Convex Optimization
   - Optimality Conditions
   - Gradient Descent Method
   - Lower complexity bounds
   - Accelerated and Inertial Algorithms

5. Non-smooth Convex Analysis
    - Continuity of Convex Functions
    - Convexity from Epigraphical Operations
    - The Subdifferential
6. Non-smooth Convex Optimization
    - Fermat's Rule
    - Duality in Optimization and Primal / Dual Problems
    - Algorithms
    - Lower complexity bounds
    - Saddle Point Problems

literature & reading

- T. Rockafellar: Convex Analysis. Princeton University Press, 1970.
- Y. Nesterov: Introductory Lectures on Convex Optimization: A Basic Course. Kluwer Academic Publishers, 2004.
- D.P. Bertsekas: Convex Analysis and Optimization. Athena Scientific, 2003.
- S. Boyd: Convex Optimization. Cambridge Univeristy Press, 2004.
- H. H. Bauschke and P. L. Combettes: Convex Analysis and Monotone Operator Theory in Hilbert Spaces. Springer, 2011.
- T. Rockafellar and R. J.-B. Wets: Variational Analysis. Springer-Verlag Berlin Heidelberg, 1998.

Cyber-Physical Systems

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr. Martina Maggio

lecturers Prof. Dr. Martina Maggio

entrance requirements none

assessments / exams
- Written exam at the end of the course.
- A re-exam takes place before the start of the following semester.

course types / weekly hours
```
  4 h lectures
+ 2 h tutorials
= 6 h (weekly)
```

total workload
```
   75 h lectures
+  15 h mandatory assignments
+ 180 h individual study
= 270 h (= 9 ECTS)
```

grade Will be determined from performance in exams and assignments. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

By completing the Cyber-Physical Systems course, students will acquire the ability to model, analyze, control, and implement embedded systems that interact with the physical world, equipping them to design reliable and efficient systems for a variety of applications in modern technology.

content

Cyber-Physical Systems are embedded systems that integrate computation with physical processes. These systems are ubiquitous in our daily lives, powering technologies such as smart watches, household appliances, mobile phones, and automotive control systems. In fact, the majority of modern computing devices are embedded systems, with an estimated 98% of new CPUs being embedded in larger systems.

This course provides a comprehensive foundation for understanding, designing, and programming cyber-physical systems, emphasizing their theoretical and practical aspects. It is structured into three interconnected parts:

1. *Models:* Students will learn how to represent the physical systems that embedded systems interact with, exploring dynamical systems in both continuous and discrete time. Additionally, the course will briefly introduce more advanced models, which combine discrete state systems with dynamical systems.
2. *Control:* This module focuses on principles for modifying the behavior of physical systems through computation. Students will study and apply control techniques such as state feedback and PID control, learning how these methods influence the interaction between embedded systems and their environments.
3. *Implementation:* The final course part addresses practical challenges in embedded systems programming. Topics include scheduling, communication, and fault tolerance. This ensures that students are equipped to implement robust and efficient embedded systems in real-world scenarios.

By the end of this course, students will possess the skills needed to design and implement cyber-physical systems that meet specific functional and performance requirements, preparing them for roles in cutting-edge industries where embedded systems play a critical role, such as the automotive industry and for research in the cyber-physical systems domain.

literature & reading

Will be announced before the start of the course on the course page on the Internet.

additional information

This module was formerly also known as *Embedded Systems*.

Digital Transmission & Signal Processing — DTSP

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2	4	at least every two years	1 semester	6	9

responsible Prof. Dr.-Ing. Thorsten Herfet

lecturers Prof. Dr.-Ing. Thorsten Herfet

entrance requirements The lecture requires a solid foundation of mathematics (differential and integral calculus) and probability theory. The course will, however, refresh those areas indispensably necessary for telecommunications and potential intensification courses and by this open this potential field of intensification to everyone of you.

assessments / exams Regular attendance of classes and tutorials
Passing the final exam in the 2nd week after the end of courses.
Eligibility: Weekly exercises / task sheets, grouped into two blocks corresponding to first and second half of the lecture. Students must provide min. 50% grade in each of the two blocks to be eligible for the exam.

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Final exam mark

language English

aims / competences to be developed

Digital Signal Transmission and Signal Processing refreshes the foundation laid in "Signals and Systems" [Modulkennung]. Including, however, the respective basics so that the various facets of the introductory study period (Bachelor in Computer Science, Vordiplom Computer- und Kommunikationstechnik, Elektrotechnik or Mechatronik) and the potential main study period (Master in Computer Science, Diplom-Ingenieur Computer- und Kommunikationstechnik or Mechatronik) will be paid respect to.

content

As the basic principle, the course will give an introduction into the various building blocks that modern telecommunication systems do incorporate. Sources, sinks, source and channel coding, modulation and multiplexing are the major keywords, but we will also deal with dedicated pieces like A/D- and D/A-converters and quantizers in a little bit more depth.

The course will refresh the basic transformations (Fourier, Laplace) that give access to system analysis in the frequency domain, it will introduce derived transformations (z, Hilbert) for the analysis of discrete systems and modulation schemes and it will briefly introduce algebra on finite fields to systematically deal with error correction schemes that play an important role in modern communication systems.

literature & reading

Will be announced before the start of the course on the course page on the Internet.

additional information

This module was formerly also known as *Telecommunications I*.

Internet Transport

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
2	**4**	**at least every two years**	**1 semester**	**6**	**9**

responsible Prof. Dr.-Ing. Thorsten Herfet

lecturers Prof. Dr.-Ing. Thorsten Herfet

entrance requirements

- Motivation for networks and communication
- Practical experience (e.g. through *Hands on Networking*) is recommended
- Knowledge of the fundamentals of communication (e.g. through *Digital Transmission & Signal Processing*) is recommended

assessments / exams

- Regular attendance of classes and tutorials
- Eligibility for exam through quizzes and assignments
- Final Exam
- A re-exam typically takes place during the last two weeks before the start of lectures in the following semester

course types / weekly hours

```
  4 h lectures
+ 2 h tutorial
= 6 h (weekly)
```

total workload

```
   90 h of classes
+ 180 h private study
= 270 h (= 9 ECTS)
```

grade Will be determined from performance in exams, quizzes and assigments. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

Today the majority of all services is available via Internet-connections. Other than in the past this comprises not only data- but also media-services (like Voice Over IP or Video Streaming) and even Cyber-Physical Systems with their networked control loops.

The course introduces the basic characteristics of Internet-based communication (packetization on different layers, packet error detection and correction). It shows how existing protocols like HTTP, TCP and UDP can be shaped and evolved to fulfill the service requirements and how new protocols should be designed to serve the large variety of services.

content

- Introcudion of *EverythingoverIP* and *IPoverEverything*
- Theory of erasure channels (i.i.d, Gilbert-Elliott, channel capacity, minimum redundancy information)
- Wireless link layers (WiFi, PHY-bursts, Logical Link Control with DCF & EDCA, aggregation and ACK-techniques)
- Frame Check Sums, Cyclic Redundancy Checks
- Time Sensitive Networking
- Transport Layer services (flow control, congestion control, error control, segmentation and reassembly)
- QUIC media transport
- Error Coding under predictable reliability and latency (MDS-codes, binary codes)
- Upper layer protocols (HTTP, RTP/RTSP, DASH)

literature & reading

The course will come with a self-contained interactive manuscript. Complementary material will be announced before the start of the course on the course page on the Internet.

additional information

This module was formerly also known as *Future Media Internet* and *Multimedia Transport*.

Module Category 4

Vertiefungsvorlesungen Wider Visual Computing

Grundlagen der Signalverarbeitung GSV

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-2	**4**	**jährlich**	**1 Semester**	**4**	**6**

responsible	Prof. Dr. Dietrich Klakow
lecturers	Prof. Dr. Dietrich Klakow
entrance requirements	none
assessments / exams	Benotete Prüfung (Klausur)
course types / weekly hours	2 SWS Vorlesung + 2 SWS Übung = 4 SWS
total workload	30 h Präsenzzeit Vorlesungen + 30 h Präsenzzeit Übungen + 70 h Vor- und Nachbereitung + 50 h Klausurvorbereitung = 180 h (= 6 ECTS)
grade	Klausurnote
language	Deutsch

aims / competences to be developed

Im Kurs werden die zentralen Verfahren der Signalverarbeitung behandelt. Auf der einen Seite werden die theoretischen Grundlagen und die damit verbundenen mathematischen Methoden besprochen, so dass die Studierenden in die Lage versetzt werden das Übertragungsverhalten einfacher LTI-Systeme zu bestimmen. Darüber hinaus werden die numerischen Aspekte der Fouriertransformation betont

content

- Lineare Zeitinvariante Systeme
- Fouriertransformation
- Numerische Berechnung der Fouriertransformation
- Korrelation von Signalen
- Statistische Signalbeschreibung
- z-Transformation
- Filter

literature & reading

- Hans Dieter Lüke, Signalübertragung, Springer
- Bernd Girod, Rudolf Rabenstein, Alexander Stenger, Einführung in die Systemtheorie, Teubner, 2003
- Beate Meffert und Olaf Hochmuth, Werkzeuge der Signalverarbeitung, Pearson 2004
- Alan V. Oppenheim, Roland W. Schafer, John R. Buck, Zeitdiskrete Signalverarbeitung, Pearson 2004

Optimization for Machine Learning OptML

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-2	**4**	**at least every two years**	**1 semester**	**4**	**6**

responsible	Dr. Sebastian Stich
lecturers	Dr. Sebastian Stich
entrance requirements	Recommended: Previous coursework in calculus, linear algebra, probability, and familiarity with machine learning (e.g. Machine Learning) and continuous optimization (e.g., Continuous Optimization or other courses that introduce gradient methods).
assessments / exams	• Regular attendance of classes and tutorials. • Solving accompanying exercises and programming tasks (assignments are not graded). • Passing the course project is a final exam prerequisite. • Successful participation in the midterm and the final exam.
course types / weekly hours	2 h lectures + 2 h tutorial = 4 h (weekly)
total workload	60 h of classes + 40 h mini-project + 80 h private study = 180 h (= 6 ECTS)
grade	Will be determined from performance in exams and practical tasks. The exact modalities will be announced at the beginning of the module.
language	English

aims / competences to be developed

The goal of this lecture is to provide students with a thorough understanding of modern mathematical optimization methods crucial for machine learning and data science applications. By the end of the course, students will be proficient in assessing the scalability of algorithms, applying mathematical proofs, and implementing optimization techniques on large datasets. The course also aims to familiarize students with recent advancements and state-of-the-art methodologies in optimization, ensuring they are well-prepared for research and practical applications in these fields.

content

Optimization for Data Science: - Introduction to Optimization - Theory of Convex Functions - Gradient Descent - Stochastic Gradient Methods - Projected Gradient Descent and Coordinate Descent - Non-Convex Optimization: Convergence to Critical Points, Alternating Minimization, Neural Network Training

Parallel and Distributed Optimization: - Asynchronous Methods - Decentralized and Federated Optimization - Local Stochastic Gradient Descent

Advanced Topics: - Variance Reduction Methods - Adaptive Gradient Methods - Computational Trade-Offs (Time vs Data vs Accuracy) - Other current research topics

literature & reading

Will be announced in the first lecture. Complementary references: - S. Bubeck. Convex Optimization: Algorithms and Complexity, 2015. - S. Boyd and L. Vandenberghe. Convex Optimization, 2004. - Y. Nesterov. Lectures on Convex Optimization, 2018.

Module Category 5

Seminare

Seminar Computer Science

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	**4**	**every semester**	**1 semester**	**2**	**7**

responsible Dean of Studies of the Faculty of Mathematics and Computer Science
Dean of Studies of the Department of Computer Science

lecturers Lecturers of the department

entrance requirements Basic knowledge of the relevant sub-field of the study program.

assessments / exams
- Thematic presentation with subsequent discussion
- Active participation in the discussion
- short written report and/or project possible

course types / weekly hours `2 h seminar (weekly)`

total workload
```
  30 h of lectures and exercises
+ 180 h project work
= 210 h (= 7 ECTS)
```

grade Will be determined from the performance in the presentation and the written report and/or the seminar project. The exact modalities will be announced by the respective instructor.

language English or German

aims / competences to be developed

At the end of the seminar, students have primarily gained a deep understanding of current or fundamental aspects of a specific subfield of computer science.

They have gained further competence in independent scientific research, classifying, summarizing, discussing, criticizing and presenting scientific findings.

content

Largely independent research of the seminar topic:

- Reading and understanding of scientific papers
- Analysis and evaluation of scientific papers
- Discussion of the scientific work in the group
- Analyzing, summarizing and reporting the specific topic
- Developing common standards for scientific work
- Presentation techniques

Specific in-depth study related to the individual topic of the seminar.

The typical procedure of a seminar is usually as follows:

- Preparatory discussions for topic selection
- Regular meetings with discussion of selected presentations
- if applicable, work on a project related to the topic
- Presentation and, if necessary, writing a report on one of the presentations

literature & reading

Material is selected according to the topic.

additional information

The seminars available will be announced prior to the beginning of the semester and will vary by study programme.

Module Category 6

Master-Seminar und -Arbeit

Master Seminar

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	**4**	**every semester**	**1 semester**	**2**	**12**

responsible Dean of Studies of the Faculty of Mathematics and Computer Science
Study representative of computer science

lecturers Professors of the department

entrance requirements Acquisition of at least 30 CP

assessments / exams
- Preparation of the relevant scientific literature
- Written elaboration of the topic of the master thesis
- Presentation about the planned topic with subsequent discussion
- Active participation in the discussion

course types / weekly hours `2 h seminar (weekly)`

total workload
```
     30 h seminar
 +   40 h contact with supervisor
 +  290 h private study
 =  360 h (= 12 ECTS)
```

grade graded

language English or German

aims / competences to be developed

The Master seminar sets the ground for carrying out independent research within the context of an appropriately demanding research area. This area provides sufficient room for developing own scientific ideas.

At the end of the Master seminar, the basics ingredients needed to embark on a successful Master thesis project have been explored and discussed with peers, and the main scientific solution techniques are established.

The Master seminar thus prepares the topic of the Master thesis. It does so while deepening the students' capabilities to perform a scientific discourse. These capabilities are practiced by active participation in a reading group. This reading group explores and discusses scientifically demanding topics of a coherent subject area.

content

The methods of computer science are systematically applied, on the basis of the "state-of-the-art".

literature & reading

Scientific articles corresponding to the topic area in close consultation with the lecturer.

Master Thesis

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
4	4	every semester	6 months	-	30

responsible	Dean of Studies of the Faculty of Mathematics and Computer Science Study representative of computer science
lecturers	Professors of the department
entrance requirements	Successful completion of the *Master Seminar*
assessments / exams	Written elaboration in form of a scientific paper. It describes the scientific findings as well as the way leading to these findings. It contains justifications for decisions regarding chosen methods for the thesis and discarded alternatives. The student's own substantial contribution to the achieved results has to be evident. In addition, the student presents his work in a colloquium, in which the scientific quality and the scientific independence of his achievements are evaluated.
course types / weekly hours	none

total workload	`  50 h contact with supervisor`
	`+ 850 h private study`
	`= 900 h (= 30 ECTS)`

grade	Grading of the Master Thesis
language	English or German

aims / competences to be developed

In the master thesis the student demonstrates his ability to perform independent scientific work focusing on an adequately challenging topic prepared in the master seminar.

content

In the master thesis the student demonstrates his ability to perform independent scientific work focusing on an adequately challenging topic prepared in the master seminar.

literature & reading

According to the topic