UNIVERSITÄT
DES
SAARLANDES

Faculty of Mathematics and Computer Science

Module Descriptions

Visual Computing MSc

17th December 2024

List of module categories and modules

Module Category 1

Image Acquisition

Image Acquisition Methods — IAM

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

responsible Dr. Pascal Peter

lecturers Dr. Pascal Peter

entrance requirements Undergraduate knowledge in mathematics (e.g. *Mathematik für Informatiker I-III*). Basic knowledge in physics is helpful, but the lecture is designed to be self-contained in this regard.

assessments / exams Passing the exam or re-exam. Regular attendance in the weekly assignments which are intended to be solved and discussed during the tutorial session.

course types / weekly hours

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

Homework assignments (theory and programming) and classroom assignments.

total workload

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

grade The final grade reflects the performance in the exam or the re-exam. The better grade counts.

language English

aims / competences to be developed

A broad variety of image acquisition methods is described, including imaging by virtually all sorts of electromagnetic waves, acoustic imaging, magnetic resonance imaging and more. While medical imaging methods play an important role, the overview is not limited to them.

Starting from physical foundations, description of each image acquisition method extends via aspects of technical realisation to mathematical modelling and representation of the data.

content

1. Introduction and Basic Concepts
2. Imaging by Visible Light 2.1 Electromagnetic Spectrum 2.2 Optics, Sensorics, Photography 2.3 Colour Spaces, Telescopes, Mirrors, Microscopy 2.4 Dual Photography, Depth Imaging, Holography, Light Fields
3. Imaging by Invisible Electromagnetic Radiation 3.1 X-Ray and Gamma-Ray Imaging in 2-D 3.2 Computerised X-Ray Tomography 3.3 Radioastronomy, Radar, Terahertz Radiation, Microwave and Radio Wave Imaging 3.4 Magnetic Resonance Imaging
4. Imaging without Electromagnetic Radiation 4.1 Electron Microscopy 4.2 Acoustic Waves, Sonar, Ultrasound

literature & reading

- B. Jähne, H. Haußecker, P. Geißler, editors, Handbook of Computer Vision and its Applications. Volume 1: Sensors and Imaging. Academic Press, San Diego 1999.
- S. Webb, The Physics of Medical Imaging. Institute of Physics Publishing, Bristol 1988.

- C. L. Epstein, Introduction to the Mathematics of Medical Imaging. Pearson, Upper Saddle River 2003.
- R. Blahut, Theory of Remote Image Formation. Cambridge University Press, 2005.
- A. C. Kak, M. Slaney, Principles of Computerized Tomographic Imaging. SIAM, Philadelphia 2001.
- Articles from journals and conferences.

Physikalische Akustik 1 PhysAk1

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

responsible Prof. Dr. Ute Rabe

lecturers Prof. Dr. Ute Rabe

entrance requirements none

assessments / exams benotete Klausur (schriftlich oder mündlich)

course types / weekly hours
```
  2 SWS Vorlesung
= 2 SWS
```

total workload
```
  30 h Präsenzstudium
+ 60 h Eigenstudum (Vor- und Nachbereitung, Prüfung)
= 90 h (= 3 ECTS)
```

grade Wird aus den Leistungen in der Klausur ermittelt. Die genauen Modalitäten werden zu Beginn des Moduls bekannt gegeben.

language Deutsch

aims / competences to be developed

Die Studierenden erwerben umfangreiche Kenntnisse und Fertigkeiten in:

- Grundkonzepte der physikalischen Akustik
- Einführung in die Materialprüfung mit Ultraschall
- Gerätetechnische Aspekte
- Praxisbezogene Anwendungsbeispiele

content

- Schwingungen, Schallwellen, Ultraschall
- Anregung und Empfang von Ultraschallwellen, Methoden der Bildgebung (A-B-C-Scan)
- Beugung und Fehlergrößenbestimmung
- Ultraschall-Mikroskopie
- Anwendungsbeispiele

literature & reading

Literaturhinweise werden zu Beginn der Veranstaltung bekannt gegeben.

- A. Ehrhard, Verfahren der zerstörungsfreien Materialprüfung, DVS Media Gmbh, Berlin, 2014

additional information

Methoden: Powerpoint-Präsentation über Beamer unterstützt durch Overhead-Projektor, Demonstrationsexperimente

Physikalische Akustik 2 — PhysAk2

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

responsible Prof. Dr. Ute Rabe

lecturers Priv. Doz. Dr. Martin Spies
und Mitarbeiter des IZFP

entrance requirements *Physikalische Akustik 1* (empfohlen)

assessments / exams benotete Klausur (schriftlich oder mündlich)

course types / weekly hours

```
  2 SWS Vorlesung
+ 1 SWS Übung
= 3 SWS
```

total workload

```
   45 h Präsenzstudium
+  75 h Eigenstudum (Vor- und Nachbereitung, Prüfung)
= 120 h (= 4 ECTS)
```

grade Wird aus den Leistungen in der Klausur ermittelt. Die genauen Modalitäten werden zu Beginn des Moduls bekannt gegeben.

language Deutsch

aims / competences to be developed

Die Studierenden erwerben umfangreiche Kenntnisse und Fertigkeiten in:

- Grundlegende Konzepte der Bildgebung und Rekonstruktion
- Beschreibung der Schallausbreitung in komplexen Werkstoffen
- Grundlagen der Modellierung und Simulation
- Theoretische Grundlagen der Beschreibung der verschiedenen Wellenarten
- Praxisbezogene Anwendungsbeispiele

content

- Beschreibung der Ultraschallwellen im 3-dimensionalen Medium
- Methoden der Simulation
- Ausbreitung von Ultraschall in elastisch anisotropen Medien
- Phased Array, Total Focusing Method, Synthetic Aperture Focusing Technique (SAFT)
- Anwendungsbeispiele

literature & reading

Literaturhinweise werden zu Beginn der Veranstaltung bekannt gegeben.

- James P. Wolfe, Imaging Phonons, Acoustic Wave Propagation in Solids, Cambridge University Press, 1998
- B.A. Auld, Acoustic Fields and Waves in Solids, Vol I, II, Robert E. Krieger Publishing, 1990

additional information

Methoden: Powerpoint-Präsentation über Beamer unterstützt durch Overhead-Projektor, Demonstrationsexperimente, rechnerische Vertiefung der Vorlesungsinhalte im Rahmen der Übung

Ultrasound Imaging — UltraImg

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

responsible Dr. Marc Fournelle

lecturers Dr. Marc Fournelle

entrance requirements none

assessments / exams
- Regular attendance of classes
- Final exam (oral or written)

course types / weekly hours
```
  2 h lectures
= 2 h (weekly)
```

total workload
```
   30 h of classes
+  80 h private study
= 120 h (= 4 ECTS)
```

grade Will be determined from the performance in the final exam. The exact modalities will be announced at the beginning of the course.

language English

aims / competences to be developed

Understanding of ultrasound physics of technical applications and medical imaging.

content

The lecture deals with the generation, the detection, the processing and the visualization of ultrasound signals in technical (e.g. sonar, level or flow control) and biomedical applications (medical imaging, navigation, therapy/therapy control):

- Physics and mathematics of ultrasound and ultrasound signal processing
- Description of the entire signal pipeline of an ultrasound system
- Basics of different measurement and imaging methods

literature & reading

Kuttruff - Physik und Technik des Ultraschalls. More will be announced at the beginning of the course.

additional information

This module was previously known as *Bildgebende Verfahren: Ultraschall*.

Module Category 2

Image Analysis

Advanced Image Analysis AIA

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

responsible Prof. Dr. Joachim Weickert

lecturers Prof. Dr. Joachim Weickert

entrance requirements Requires undergraduate knowledge in mathematics (e.g. *Mathematik für Informatiker I-III*), and elementary C knowledge. Basic knowledge in image processing and computer vision is recommendable.

assessments / exams In order to qualify for the exams, attendance of the tutorials is mandatory. There will be an exam and a re-exam. Further modalities (such as written or oral exam) will be communicated at the beginning of the lecture.

course types / weekly hours

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

total workload

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

grade The grade reflects the performance in the exam or the re-exam. The better grade counts.

language English

aims / competences to be developed

In this lecture, we will discuss advanced topics in the fields of image processing and computer vision. Most of the presented methods fuse the information from several images in order to produce an enhanced composite image. Examples for such techniques are super-resolution, high dynamic range (HDR) imaging, tone mapping and gradient domain techniques.

content

1. Introduction and Overview
2. Finding Correspondences
3. Super-Resolution
4. High Dynamic Range Imaging
5. Tone Mapping
6. Exposure Fusion
7. Alignment of Exposure Series
8. Deghosting and Joint Super-Resolution and HDR
9. Focus Stacking
10. Gradient Domain Techniques

literature & reading

There is no specific book that covers the complete content of this class. Many lectures will be based on articles from journals and conferences. However, the book of R. Szeliski covers some of the topics and additionally summarises most of the intensively studied areas of computer vision research:

- R. Szeliski: Computer Vision: Algorithms and Applications. ISBN: 978-1-84882-934-3, Springer, Berlin, 2011.

Correspondence Problems in Computer Vision — CoPCV

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

responsible Prof. Dr. Joachim Weickert

lecturers Dr. Pascal Peter

entrance requirements Undergraduate mathematics (e.g. "Mathematik für Informatiker I-III") is required, as well as elementary C knowledge (for the programming assignments). Knowledge in image processing or differential equations is useful.

assessments / exams

- Regular attendance of lecture and tutorial
- 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 exams. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

Correspondence problems are a central topic in computer vision. Thereby, one is interested in identifying and matching corresponding features in different images/views of the same scene. Typical corresondence problems are the estimation of motion information from consecutive frames of an image sequence (optic flow), the reconstruction of a 3-D scene from a stereo image pair and the registration of medical image data from different modalities (e.g. CT and MRT). Central part of this lecture is the discussion of the most important correspondence problems as well as the modelling of suitable algorithms for solving them.

content

```
1.  Introduction and Overview
2.  General Matching Concepts
    2.1 Block Matching
    2.2 Correlation Techniques
    2.3 Interest Points
    2.4 Feature-Based Methods
3.  Optic Flow I
    3.1 Local Differential Methods
    3.2 Parameterisation Models
4.  Optic Flow II
    4.1 Global Differential Methods
    4.2 Horn and Schunck
5.  Optic Flow III
    5.1 Advanced Constancy Assumptions
    5.2 Large Motion
```

```
6.  Optic Flow IV
    6.1 Robust Data Terms
    6.2 Discontinuity-Preserving Smoothness Terms
7.  Optic Flow V
    7.1 High Accuracy Methods
    7.2 SOR and Lienar Multigrid
8.  Stereo Matching I
    8.1 Projective Geometry
    8.2 Epipolar Geometry
9.  Stereo Matching II
    9.1 Estimation of the Fundamental Matrix
10. Stereo Matching III
    10.1 Correlation Methods
    10.2 Variational Approaches
    10.3 Graph Cuts
11. Medical Image Registration
    11.1 Mutual Information
    11.2 Elastic and Curvature Based Registration
    11.3 Landmarks
12. Particle Image Velocimetry
    12.1 Div-Curl-Regularisation
    12.2 Incompressible Navier Stokes Prior
```

literature & reading

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

Differential Equations in Image Processing and Computer Vision DIC

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

Differential Geometric Aspects of Image Processing DGAIP

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

responsible Prof. Dr. Joachim Weickert

lecturers Dr. Marcelo Cárdenas

entrance requirements undergraduate mathematics (e.g. *Mathematik für Informatiker I-III*)

assessments / exams
- Written or oral exam at end of course
- A re-exam takes place during the last two weeks before the start of lectures in the following semester.

course types / weekly hours
```
  3 h lectures
+ 1 h tutorial
= 4 h (weekly)
```

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

grade The final grade reflects the performance in the exam or re-exam.

language English

aims / competences to be developed

Students will learn basic concepts from differential geometry and how they can be applied to image analysis problems.

content

The course is concerned with modern methods of digital image processing which rely on the differential geometry of curves and surfaces. This includes methods of image enhancement (like smoothing methods) as well as feature extraction and segmentation (like locating contours with active contour models).

The course aims at combining theoretical foundation directly with a variety of applications from the above-mentioned fields; the range of topics extends up to recent research problems.

An introduction to the relevant concepts and results from differential geometry will be included in the course.

Topics include:

- curves and surfaces in Euclidean space
- level sets
- curve and surface evolutions
- variational formulations and gradient descents
- diffusion of scalar and non-scalar data
- diffusion on manifolds
- active contours and active regions

literature & reading

- F. Cao, Geometric Curve Evolution and Image Processing. Lecture Notes in Mathematics, vol. 1805, Springer, Berlin 2003.

- R. Kimmel, Numerical Geometry of Images. Springer, Berlin 2004.
- S. Osher, N. Paragios, eds., Geometric Level Set Methods in Imaging, Vision and Graphics. Springer, Berlin 2003.
- G. Sapiro, Geometric Partial Differential Equations and 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
1-2	**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

Image Compression IC

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
1-2	**4**	**occasional**	**1 semester**	**6**	**9**

responsible Dr. Pascal Peter

lecturers Dr. Pascal Peter

entrance requirements Basic mathematics courses (such as *Mathematik für Informatiker I-III*) are required. Image processing lectures such as *Image Processing and Computer Vision* are helpful for some specific topics, but not necessary. For the programming assignments, some elementary knowledge of C is required.

assessments / exams Passing of the exam or the re-exam. These are open book written exams. Regular attendance at tutorials is expected. The tutorials include homework assignments as well as classroom assignments. Homework assignments are handed in and graded, while classroom assignements are solved during the tutorials. Homework consists of both theoretical and programming assignments, while classroom assignments are all theoretical. Working together in groups of up to 3 people is permitted and highly encouraged.

course types / weekly hours

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

total workload

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

grade The final grade reflects the performance in the exam or re-exam. The better grade counts.

language English

aims / competences to be developed

Motivation: High resolution image data is becoming increasingly popular in research and commercial applications (e.g. entertainment, medical imaging). In addition, there is also a high demand for content distribution via the internet. Due to the resulting increase in storage and bandwidth requirements, image compression is a highly relevant and very active area of research.

Teaching Goals: The course is designed as a supplement for image processing lectures, to be attended before, after or parallel to them. After the lecture, participants should understand the theoretical foundations of image compression and be familiar with a wide range of classical and contemporary compression methods.

content

The lecture can be seperated into two parts: The first half of the lecture deals with lossless image compression. We discuss the information theoretic background of so-called entropy coders (e.g. Huffman-coding, arithmetic coding, ...), talk about dictionary methods (e.g. LZW), and discuss state-of-the-art approaches like PPM and PAQ. These tools are not limited to compressing image data, but also form core parts of general data compression software such as BZIP2. Knowledge about entropy coding and prediction is key for understanding the classic and contemporary lossless codecs like PNG, gif or JBIG.

The second part of the lecture is dedicated to lossy image compression techniques. We deal with classic transformation based compression (JPEG, JPEG2000), but also with emerging approaches like inpainting-based compression. Furthermore, we consider related topics like human perception, error measurements, and offer a short introduction to video coding.

literature & reading

There is no specific book that covers the complete content of this class. However, each of the following books covers several of the topics discussed in the lecture:

- T. Strutz: Bilddatenkompression. Vieweg+Teubner (in German)
- D. Hankerson, G. A. Harris, and P. D. Johnson, Jr.: Introduction to Information Theory and Data Compression. Chapman & Hall/CRC
- K. Sayood: Introduction to Data Compression. Morgan Kaufmann

Further references will be given during the lecture.

Image Processing and Computer Vision — IPCV

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

Probabilistic Graphical Models and their Applications — PGM

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

responsible	Prof. Dr. Bernt Schiele
lecturers	Prof. Dr. Bernt Schiele
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 class is to understand the concepts behind graphical models and to give hands-on knowledge such that one is able to design models for computer vision applications but also in other domains. Therefore the lecture is roughly divided in two parts: learning about graphical models and seeing them in action.

content

This course will introduce the basic concepts of probabilistic graphical models. Graphical Models are a unified framework that allow to express complex probability distributions in a compact way. Many machine learning applications are tackled by the use of these models, in this course we will highlight the possibilities with computer vision applications.

literature & reading

Probabilistic Methods in Image Analysis PMIA

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

responsible Prof. Dr. Joachim Weickert

lecturers Prof. Dr. Joachim Weickert

entrance requirements Undergraduate mathematics such as *Mathematik für Informatiker I-III* is required. Knowledge of probability theory or statistics is helpful but not required

assessments / exams The homework assignments are intended to be solved at home and have to be submitted in the lecture break, or earlier. In order to qualify for the exams one must obtain 50% of the possible points on average.

course types / weekly hours

```
  2 h lectures
+ 2 h tutorials
= 2 h (weekly)
```

total workload

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

grade The grade reflects the performance in the exam or the re-exam. The better grade counts. The modality of the exam (written or oral) will be communicated in the beginning of the lecture.

language English

aims / competences to be developed

Probabilistic techniques are employed quite successfully in the processing and analysis of images, however, they also play a vital role in pattern classification, data mining and learning theory. This lecture introduces to some of the basic approaches.

content

In this course we will discuss

- basic notions from probability theory and statistics as well as from image processing
- histogram based image analysis and enhancement methods
- the probabilistic background of the Karhunen-Loeve expansion used for data compression, for example
- independent component analysis and applications
- the notion of entropy in image registration
- and, if time permits, we will give an introduction to the basic ideas of Markov random fields and simulated annealing.

literature & reading

Relevant references will be provided in the lecture.

Module Category 3

Image Synthesis / Geometric Foundations

Computation and Fabrication — CaF

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

responsible Prof. Dr. Hans-Peter Seidel

lecturers Prof. Dr. Hans-Peter Seidel
Dr. Vahid Babaei

entrance requirements Some background in visual computing is recommended but not required.

assessments / exams Nanoquiz: At the beginning of each lecture, we ask a few questions as a recapitulation of the last class.

Programming Assignment: The assignments give you the opportunity to apply what you have learned in class. It is also a chance for you to let us know about the topics that give you particular difficulty.

Project: You will have the opportunity to see your new learnings applied in a research context. You will start the projects (in groups of two or three) in the middle of the semester and you will present them during the last session and deliver a report.

Exam: There will be an oral exam.

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
- Nanoquiz
- Assignments
- Project
- Exam

The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

After successful completion of this course, you will be able to:

- Explain the fundamental mission of Computational Fabrication, why it is relevant and what is the necessary skill set for successfully applying it to real-world problems.
- Evaluate different representations of geometric models for manufacturing and create easily modifiable shapes.
- Review different manufacturing technologies, with a focus on additive manufacturing (3D printing), and analyze their advantages and disadvantages.
- Analyze the appearance reproduction workflow, including measuring, modeling and fabrication of object's appearance.
- Apply halftoning algorithms to enable printers to approximate continuous inputs, thereby overcoming their inherent binary limitation.
- Understand necessary components for simulating the deformation of solid objects using the finite element method (FEM), including different measures of deformation, constitutive models of materials, and measuring mechanical properties of objects.

content

- Solid Modeling
- 3D Printing Software Pipeline
- 3D Printing Hardware Pipeline
- Halftoning Algorithms
  - Appearance Printing Pipeline
- Mass Spring Systems
- Continuum Mechanics
- Finite Element Method
- Design Space Exploration

literature & reading

Unfortunately, there is no single textbook covering all materials of this course. We provide reading materials (mostly accessible online) at the end of each lecture.

Computer Graphics CG

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

Geometric Modelling GM

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

responsible Prof. Dr. Hans-Peter Seidel

lecturers Prof. Dr. Hans-Peter Seidel
Dr. Rhaleb Zayer

entrance requirements calculus and basic programming skills

assessments / exams

- Regular attendance and participation.
- Weekly Assignments (10% bonus towards the course grade; bonus points can only improve the grade; they do not affect passing)
- Passing the written exams (mid-term and final exam).
- The mid-term and the final exam count for 50% each, but 10% bonus from assignments will be added.
- A re-exam takes place at the end of the semester break or early in the next semester.

course types / weekly hours

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

Practical assignments in groups of 3 students (practice)
Tutorials consists of a mix of theoretical + practical assignments.

total workload

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

grade Will be based on the performance in exams, exercises and practical tasks. The detailed terms will be announced by the module coordinator.

language English

aims / competences to be developed

Gaining knowledge of the theoretical aspect of geometric modelling problems, and the practical solutions used for modelling and manipulating curves and surfaces on a computer. From a broader perspective: Learning how to represent and interact with geometric models in a discretized, digital form (geometric representations by functions and samples; design of linear function spaces; finding “good” functions with respect to a geometric modelling task in such spaces).

content

- Differential geometry Fundamentals
- Interpolation and Approximation
- Polynomial Curves
- Bezier and Rational Bezier Curves
- B-splines, NURBS
- Spline Surfaces
- Subdivision and Multiresolution Modelling
- Mesh processing
- Approximation of differential operators
- Shape Analysis and Geometry Processing

literature & reading

Will be announced before the term begins on the lecture website.

Perception for Computer Graphics PfCG

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

responsible Dr. Karol Myszkowski

lecturers Dr. Karol Myszkowski

entrance requirements Computer graphics, image processing, and the related math.

assessments / exams Regular attendance of lecture. Written exam at the end of the course.

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 examinations. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

The target audience are students in computer science or related fields. This course covers topics from psychology and physiology that are relevant to computer graphics, and novel perception research and applications in computer graphics and vision. The objective is to transfer knowledge, experience and competencies that are required for doing research in perceptual computer graphics, and that are useful in many related fields, such as experimental psychology, or usability studies in human-computer interaction.

content

As computer graphics is producing images and videos that are ultimately perceived by a human, it's mandatory to account for how the human visual system (HVS) is processing this information. The HVS is complex, exhibiting many non-linearities as well as feedback and is only partially understood. While this poses a challenge, it can also be seen as an opportunity which can be exploited in image compression, watermarking, denoising, enhancement, upsampling, etc. Computational models which can predict the human response to the distortion of visual content are important when this opportunity is taken. To this end, our course covers the basic theory of perception research, including:

- What is perception?
- Designing experiments,
- Analysis and statistics,

and the practical applications in computer graphics, including:

- Eye physiology and image formation,
- Brightness and contrast,
- Color,
- High dynamic range and tone reproduction,
- Image compression and image quality,
- Depth and shape perception,
- Material perception.

literature & reading

The following list contains the most relevant books for this lecture:

- Vision Science: Photons to Phenomenology, Stephen E. Palmer, The MIT Press, 2002.
- Foundations of Vision, Brian A. Wandell, Sinauer Associates, Inc., 1995.
- Seeing: The Computational Approach to Biological Vision, John P. Frisby and James V. Stone, The MIT Press, 2010.
- Experimental Design: From User Studies to Psychophysics, Douglas W. Cunningham and Christian Wallraven, A K Peters/CRC Press, 2011.
- Seeing in Depth: Basic Mechanics (Vol. 1) and Seeing in Depth: Depth Perception (Vol. 2), Ian P. Howard and Brian J. Rogers, Oxford Psychology Series, 2012.
- Visual Perception from a Computer Graphics Perspective, William Thompson, Roland Fleming, Sarah Creem-Regehr and Jeanine Kelly Stefanucci, A K Peters/CRC Press, 2011.
- High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting, Erik Reinhard, Greg Ward, Paul Debevec, Sumanta Pattanaik, Wolfgang Heidrich and Karol Myszkowski, Morgan Kaufmann Publishers, 2nd edition, 2010.
- High Dynamic Range Video, Karol Myszkowski, Rafal Mantiuk and Grzegorz Krawczyk. Synthesis Digital Library of Engineering and Computer Science. Morgan & Claypool Publishers, San Rafael, USA, 2008.
- Color Imaging: Fundamentals and Applications Erik Reinhard, Erum Arif Khan, Ahmet Oguz Akyuz and Garrett M. Johnson, A K Peters, 2007.
- High Dynamic Range Imaging: an article in Wiley Encyclopedia of Electrical and Electronics Engineering 2015.

Further literature will be announced during the course.

Realistic Image Synthesis RIS

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

Image Related Fields

Artificial Intelligence

AI

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

responsible Prof. Dr. Jörg Hoffmann

lecturers Prof. Dr. Jörg Hoffmann

entrance requirements *Programming 1*, *Programming 2*, *Fundamentals of Data Structures and Algorithms*, and *Elements of Machine Learning* or other courses in machine learning are recommended.

assessments / exams

- Regular attendance of classes and tutorials
- Solving of weekly assignments
- Passing the final written 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 exams. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

Knowledge about basic methods in Artificial Intelligence

content

Search:

- Uninformed- and informed search procedures
- Monte-Carlo tree search

Planning:

- Formalism and complexity
- Critical-path heuristics
- Delete relaxation heuristics
- Abstraction heuristics

Markov decision processes:

- Discounted reward and expected cost
- Value iteration
- Informed search
- Reinforcement learning

Games:

- Adversarial search
- Learning from self-play

literature & reading

Russel & Norvig Artificial Intelligence: A Modern Approach;
further 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
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*.

Digital Transmission & Signal Processing — DTSP

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
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 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*.

Elements of Data Science and Artificial Intelligence — ElDSAI

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	4	every winter semester	1 semester	6	9

responsible Prof. Dr. Jörg Hoffmann
Prof. Dr. Jens Dittrich
Prof. Dr. Bernt Schiele
Prof. Dr. Vera Demberg

lecturers Prof. Dr. Jörg Hoffmann
Prof. Dr. Jens Dittrich
Prof. Dr. Bernt Schiele
Prof. Dr. Vera Demberg

entrance requirements none

assessments / exams Weekly assignments,
Exam (qualification for exam depends on performance in assignments)

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 Based on exam. The exact modalities are specified by the lecturers.

language English

aims / competences to be developed

Overview of challenges and methods in Data Science and AI. Basic knowledge of key concepts and algorithms.

content

Introduction to history and concepts of Data Science and AI

- Machine Learning (supervised, unsupervised, reinforcement, neural networks)
- (adversarial) Search, Planning
- Reasoning
- Modeling and Simulation
- Data Management, Big Data Engineering, and Analytics

The methods will be covered in the context of applications, such as Game Playing, Computer Vision, Autonomous Driving, Language Processing, Social Networks.

The exercises will cover methodological, algorithmic, as well as practical aspects. Where basic programming or scripting skills are required, the lecture and exercises will introduce these skills.

literature & reading

Elements of Machine Learning — EML

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	4	every winter semester	1 semester	4	6

responsible Prof. Dr. Jilles Vreeken
Prof. Dr. Isabel Valera

lecturers Prof. Dr. Jilles Vreeken
Prof. Dr. Isabel Valera

entrance requirements The lecture assumes basic knowledge in statistics, linear algebra, and programming. It is advisable to have successfully completed *Mathematics for Computer Scientists 2* and *Statistics Lab*. The exercises use the programming language R. We will give a basic introduction to R in the first tutorial. In addition, for preparation the following materials are useful: *R for Beginners* by Emmanuel Paradis (especially chapters 1, 2, 3 and 6) and *An introduction to R* (Venables/Smith).

assessments / exams Prerequisite for admission to the examination is a cumulative 50% of the points of the theoretical and a cumulative 50% of the points of the practical tasks on the exercise sheets. Depending on the number of participants, the examinations are either written or oral. The final modality will be announced in the first two weeks of the lecture.

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 exams.

language English

aims / competences to be developed

In this course we will discuss the foundations – the elements – of machine learning. In particular, we will focus on the ability of, given a data set, to choose an appropriate method for analyzing it, to select the appropriate parameters for the model generated by that method and to assess the quality of the resulting model. Both theoretical and practical aspects will be covered. What we cover will be relevant for computer scientists in general as well as for other scientists involved in data analysis and modeling.

content

The lecture covers basic machine learning methods, in particular the following contents:

- Introduction to statistical learning
- Overview over Supervised Learning
- Linear Regression
- Linear Classification
- Splines
- Model selection and estimation of the test errors
- Maximum-Likelihood Methods
- Additive Models

- Decision trees
- Boosting
- Dimensionality reduction
- Unsupervised learning
- Clustering
- Visualization

literature & reading

The course broadly follows the book *An Introduction to Statistical Learning with Applications in R*, Springer (2013). In some cases, the course receives additional material from the book *The Elements of Statistical Learning*, Springer (second edition, 2009). The first book is the introductory text, the second covers more advanced topics. Both books are available as free PDFs. Any change of, or additional material will be announced before the start of the course on the course webpage.

Human Computer Interaction HCI

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
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.

Information Retrieval and Data Mining — IRDM

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

responsible Prof. Dr. Gerhard Weikum

lecturers Prof. Dr. Gerhard Weikum

entrance requirements Good knowledge of undergraduate mathematics (linear algebra, probability theory) and basic algorithms.

assessments / exams

- Regular attendance of classes and tutor groups
- Presentation of solutions in tutor groups
- Passing 2 of 3 written tests (after each third of the semester)
- Passing the final exam (at the end of the 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 by the performance in written tests, tutor groups, and the final exam. Details will be announced on the course web site.

language English

aims / competences to be developed

The lecture teaches models and algorithms that form the basis for search engines and for data mining and data analysis tools.

content

Information Retrieval (IR) and Data Mining (DM) are methodologies for organizing, searching and analyzing digital Inhalts from the web, social media and enterprises as well as multivariate datasets in these contexts. IR models and algorithms include text indexing, query processing, search result ranking, and information extraction for semantic search. DM models and algorithms include pattern mining, rule mining, classification and recommendation. Both fields build on mathematical foundations from the areas of linear algebra, graph theory, and probability and statistics.

literature & reading

Will be announced on the course web site.

Internet Transport

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
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

- 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*.

Machine Learning ML

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
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.

Neural Networks: Theory and Implementation — NNTI

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	4	every winter semester	1 semester	6	9

responsible Prof. Dr. Dietrich Klakow

lecturers Prof. Dr. Dietrich Klakow

entrance requirements *Mathemathik für Informatiker I - III* or comparable; good programming skills.

assessments / exams Written Exam

course types / weekly hours

```
  2 h lectures
+ 2 h tutorial
+ 2 h project work
= 6 h (weekly)
```

total workload

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

grade Written exam and graded projects. Exact details will be announced in the first lecture.

language English

aims / competences to be developed

The participants will be introduced to the key ideas of basic classification algorithms and in particular neural networks. A focus is also the implementation and applications to relevant problems. To achieve this, there will be theoretical exercises as well as project work.

content

- Classification
- Regression
- Linear Classifiers
- Perceptron
- Support Vector Machines
- Multy-Layer Perceptrons
- Deep Learning Software
- Autoencoders
- LSTMs
- Recurrent Neural Networks
- Sequence-to-sequence learning

literature & reading

Ian Goodfellow and Yoshua Bengio and Aaron Courville
Deep Learning
MIT Press, 2016
http://www.deeplearningbook.org

Statistical Natural Language Processing SNLP

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	4	every summer semester	1 semester	4	6

responsible Prof. Dr. Dietrich Klakow

lecturers Prof. Dr. Dietrich Klakow

entrance requirements For graduate students: none

assessments / exams Written Exam

course types / weekly hours

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

total workload

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

grade Final Exam Mark

language English

aims / competences to be developed

Acquire core competencies in the mathematical basics of language processing and practice the implementation of essential methods.

content

- language processing: basic terms
- mathematical foundations
- word sense disambiguation
- part-of-speech tagging
- named-entity recognition
- information retrieval
- text classification

literature & reading

Chris Manning and Hinrich Schütze
Foundations of Statistical Natural Language Processing

Topics in Algorithmic Data Analysis — TADA

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	**4**	**every summer semester**	**1 semester**	**2**	**6**

responsible Prof. Dr. Jilles Vreeken

lecturers Prof. Dr. Jilles Vreeken

entrance requirements a background in statistics, machine learning, and/or data mining is strongly recommended (e.g. *Elements of Machine Learning*, *Elements of Statistical Learning*, *Machine Learning*, or *Information Retrieval and Data Mining*)

assessments / exams oral exam and written assignments

course types / weekly hours
```
  2 h lectures
= 2 h (weekly)
```

total workload
```
   30 h of classes
+ 150 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 module.

language English

aims / competences to be developed

- Thorough understanding of selected advanced topics in data analysis.
- Ability to quickly understand the main gist in scientific literature, without getting lost in details, critically assessing claims, seeing through the hype.
- Ability to comparatively analyse and reason about (seemingly disparate) concepts and methods, quickly developing meta-level understanding of advanced topics.

content

During the course we consider hot topics in machine learning and data mining that are also important to understand deeply. The exact topics we will cover will differ per year, but for example often include aspects of Pattern Discovery, Dependency Discovery, Causal Inference, and Fairness.

literature & reading

Recent scientific publications from the top venues in machine learning and data mining.

Trusted AI Planning — TAIP

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

responsible Prof. Dr. Jörg Hoffmann

lecturers Prof. Dr. Jörg Hoffmann

entrance requirements *Programming 1*, *Programming 2*, *Fundamentals of Data Structures and Algorithms*, and *Elements of Machine Learning* or other courses in machine learning are recommended. The *Artificial Intelligence* core course provides useful background but is not necessary.

assessments / exams

- Regular attendance of classes and tutorials
- Solving of weekly assignments
- Passing the final written exam
- A re-exam takes place during the last two weeks before the start of lectures in the following semester.

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 the performance in exams. The exact modalities will be announced at the beginning of the module.

language English

aims / competences to be developed

Knowledge about methods for learning, verifying and testing action policies in AI Planning; understanding of algorithmic techniques enabling these methods.

content

- Introduction to basic AI concepts needed in the course
- Partial-order reduction
- Dominance pruning
- SAT-based planning
- ASNet action policies
- Safety verification of neural action policies, basic methods
- Safety verification of neural action policies: policy predicate abstraction
- Testing methods for learned action policies, deterministic and probabilistic settings

literature & reading

There is no text book covering the course topics. Links to relevant publications and other material where available will be provided on the slides

additional information

This module was formerly also known as *AI Planning*.

Zerstörungsfreie Prüfverfahren I — ZFP I

st. semester	std. st. sem.	cycle	duration	SWS	ECTS
3	4	jedes Sommersemester	1 Semester	2	3

responsible Prof. Dr. Christian Boller

lecturers Prof. Dr. Christian Boller

entrance requirements none

assessments / exams Schriftliche Klausur am Ende des Moduls (Dauer 2 Stunden)

course types / weekly hours

```
  2 SWS Vorlesung
= 2 SWS
```

total workload

```
    30 h Präsenzstudium
+   60 h Eigenstudium
=   90 h (= 3 ECTS)
```

grade Wird aus Leistungen in Klausur primär ermittelt. Praktische Übungsaufgaben können bis zu 20% ergänzend einfließen. Die genauen Modalitäten werden zu Beginn der Veranstaltung bekannt gegeben.

language Deutsch

aims / competences to be developed

Erlernen und verstehen akustischer (mechanischer) und elektromagnetischer Prüfverfahren

content

Einführung:
Was ist zerstörungsfreie Prüfung? Warum ZfP? Qualitätssicherung, Schadenstolerantes Bauen

Schwingungen:
Harmonische ungedämpfte Schwingung einer federnd gelagerten Masse; Periodische Funktionen und Fourier-Analyse; Nutzung der harmonischen Schwingungen zur Schadensanalyse (elementare Modalanalyse) durch Ableitung der Verformungsgleichungen am Biegebalken; Modalanalyse am delaminierten Biegebalken; Gekoppelte Schwingungen; Steifigkeitsmatritzen; Viskos gedämpfte Schwingung und Dämpfung als Parameter; Anwendungen der Modalanalyse; Freie Seilschwingungen; Wellengleichung und Wellenausbreitung; Seilschwingungen auf elastischer Basis; Wellenausbreitung auf elastischer Basis und Dispersion; Phasengeschwindigkeit und Gruppengeschwindigkeit.

Akustik und Ultraschall:
Elementare Wellenformen: Longitudinalwellen, Transversalwellen, Oberflächenwellen, Volumenwellen; Parameter der Wellenausbreitung (Amplitude, Frequenz, Phase, Geschwindigkeit, etc.); Eindimensionale Wellenausbreitung; Wellenausbreitung und Steifigkeit; Akustische Impedanz; Räumliche Wellenausbreitung; Reflexion und Transmission; Snellius'sches Brechungsgesetz; Parameter des Schalls (Geschwindigkeit, Intensität, Dämpfung, Temperatur); Schwingungsformen und Frequenzspektrum; Akustische Schwingungen und mechanische Spannungen wie Spannungsanalyse (1D, 2D, 3D), Umwandlung von Spannungen in Dehnungen, Spannungstensoren, Verallgemeinertes Hooke'sches Gesetz, Anisotropie; Geführte Wellen (Oberflächenwellen, Plattenwellen); Piezoelektrischer Effekt zur Schallerzeugung; Piezoelektrische Wandler (Aufbau, Kopplung); Schallausbreitung (Nahfeld, Fernfeld, Abstrahlverhalten); Fehlererkennung (Wellenlänge vs. Fehlergröße); Formen der US-Prüfung (Pitch-Catch vs. Puls-Echo); Bedeutung des Einschallwinkels; Aufbau eines Ultraschallprüfgeräts; Fehlerprüfung (6 dB-Methode, Ersatzfehlergrößen, AVG-Diagramm); Darstellung von US-Ergebnissen (A-, B-, C- und D-Diagramm, 3D-Visualisierung); Prüfung mit Gruppenstrahlern (Phased Array); Synthetic Aperture Focussing Technique (SAFT); Ausbreitung von Ultraschallwellen; Time of Flight Diffaction (TOFD); Detektion von Rissen (Inspektionsstrategien, Fehlermöglichkeiten); Luftultraschall; Laser-induzierter Ultraschall; Elektromagnetisch induzierter Ultraschall (EMUS); Prüfung mit Ultraschall (Beispiele): Schweißnähte,

Schichtdicken (z.B. Härtetiefen), Eisenbahnachsen, Eisenbahnräder, Lichtmaste, Pipelines, Prüfung heißer Rohre, Akustisches Mikroskop; Zukunft des Ultraschalls – Structural Health Monitoring

Magnetik:
Magnete und Magnetfelder; Spulen; Ursachen der Magnetik (Atommodelle); Magnetische Induktion (Permeabilität, Induktivität, Hall-Effekt, Giant Magnetic Resistors (GMR)); Hauptarten des Magnetismus (Ferromagnetismus, Paramagnetismus, Diamagnetismus); Magnetische Hysterese; Erzeugen von Magnetfeldern; Superposition von Magnetfeldern; Messung von Magnetfeldern; Magnetisches Prüfkonzept; Magnetisierung und Mikrostruktur (Domänen, Bloch-Wände, Weiß'sche Bezirke, etc.); Permeabilität; Streufluss; Oberwellenanalyse; Barkhausenrauschen; Wirbelstromimpedanz; 3MA-Konzept und seine Anwendungen: Spannungsmessungen (1D, 2D, Eigenspannungen), Härtemessung, Härtetiefe, Schleifbrand, Restaustenit, Simultane Messungen; Weitere Anwendungsbeispiele: Materialversprödung, Plastische Dehnung; Magnetische Kraftmikroskopie (Magnetik auf der Mikroebene): Schichtdicken, Eigenspannungen.

Wirbelstrom:
Induktivität (Faraday-Regel); Selbstinduktivität; Induzierter Widerstand (Lenz'sche Regel); Elektrische Impedanz; Prinzip des Wirbelstroms; Wirbelstrom in Medien; Eindringtiefe (Skin-Effekt); Impedanzebenen und Interpretation; Messprinzip des Wirbelstroms: Messaufbau, Spulen, Absolut- versus Differenzprüfköpfen, Magnetfeldbeeinflussung, Kalibrieren, Analoggeräte: Anwendungsbeispiele: Werkstoffdetektion (Verwchslungsprüfung), Dickenprüfung, Kohlefaserverbundprüfung, Charakterisierung von Korrosionszuständen.

literature & reading

www.ndt.net

www.ndt-ed.org

A. Erhard, 2014: Verfahren der zerstörungsfreien Materialprüfung; DGZfP (Hrsg.); DVS Media GmbH

Jiles D.C., 2008: Principles of Materials Evaluation; CRC Press, Taylor & Francis, Boca Raton/FL, USA

Module Category 5

Seminars

Seminar

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

responsible	Studiendekan der Fakultät Mathematik und Informatik Studienbeauftragter der Informatik
lecturers	Dozent/inn/en der Fachrichtung
entrance requirements	Grundlegende Kenntnisse im jeweiligen Teilbereich des Studienganges.
assessments / exams	• Thematischer Vortrag mit anschließender Diskussion • Aktive Teilnahme an der Diskussion • Gegebenenfalls schriftliche Ausarbeitung oder Projekt
course types / weekly hours	`2 SWS Seminar`

total workload	`30 h Präsenzstudium`
	`+ 180 h Eigenstudium`
	`= 210 h (= 7 ECTS)`

grade	Wird aus den Leistungen im Vortrag und der schriftlichen Ausarbeitung und/oder dem Seminarprojekt ermittelt. Die genauen Modalitäten werden von dem/der jeweiligen Dozenten/in bekannt gegeben.
language	Deutsch oder Englisch

aims / competences to be developed

Die Studierenden haben am Ende der Veranstaltung vor allem ein tiefes Verständnis aktueller oder fundamentaler Aspekte eines spezifischen Teilbereiches der Informatik erlangt.

Sie haben weitere Kompetenz im eigenständigen wissenschaftlichen Recherchieren, Einordnen, Zusammenfassen, Diskutieren, Kritisieren und Präsentieren von wissenschaftlichen Erkenntnissen gewonnen.

content

Weitgehend selbstständiges Erarbeiten des Seminarthemas:

- Lesen und Verstehen wissenschaftlicher Arbeiten
- Analyse und Bewertung wissenschaftlicher Aufsätze
- Diskutieren der Arbeiten in der Gruppe
- Analysieren, Zusammenfassen und Wiedergeben des spezifischen Themas
- Erarbeiten gemeinsamer Standards für wissenschaftliches Arbeit
- Präsentationstechnik

Spezifische Vertiefung in Bezug auf das individuelle Thema des Seminars.

Der typische Ablauf eines Seminars ist üblicherweise wie folgt:

- Vorbereitende Gespräche zur Themenauswahl
- Regelmäßige Treffen mit Diskussion ausgewählter Beiträge
- ggf. Bearbeitung eines themenbegleitenden Projekts
- Vortrag und ggf. Ausarbeitung zu einem der Beiträge

literature & reading

Material wird dem Thema entsprechend ausgewählt.

additional information

Die jeweils zur Verfügung stehenden Seminare werden vor Beginn des Semesters angekündigt und unterscheiden sich je nach Studiengang.

Module Category 6

Master Seminar and Thesis

Master Seminar (Visual Computing)

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
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
+  30 h contact with supervisor
+ 150 h private study
= 210 h (= 7 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