Module Catalogue

for the Subject

Computational Mathematics

as a Master’s with 1 major

with the degree "Master of Science"

(120 ECTS credits)

Examination regulations version: 2016
Responsible: Institute of Mathematics
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Learning Outcomes

German contents and learning outcome available but not translated yet.

Wissenschaftliche Befähigung

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, sich selbständig mithilfe von Fachliteratur in aktuelle Forschungsgebiete der Mathematik, insbesondere der Numerischen Mathematik einzuarbeiten.
- Die Absolventinnen und Absolventen sind in der Lage, ihre Kenntnisse, Ideen und Problemlösungen zu komplexen Sachverhalten einem Fachpublikum gegenüber verständlich zu präsentieren.
- Die Absolventinnen und Absolventen besitzen die für selbstständiges wissenschaftliches Arbeiten, insbesondere für ein Promotionsstudium erforderlichen Fachkenntnisse, Denk- und Arbeitsweisen und Methodenkenntnisse.
- Die Absolventinnen und Absolventen kennen die Regeln guter wissenschaftlicher Praxis und sind in der Lage, sie bei umfangreichen Arbeiten zu beachten.
- Die Absolventinnen und Absolventen besitzen vertiefte Kenntnisse und Überblick über die aktuelle Forschung in mindestens einem Teilgebiet der Mathematik.
- Die Absolventinnen und Absolventen kennen aktuelle Gebiete und moderne Methoden eines weiteren Fachs aus dem Bereich der Naturwissenschaften und der Informatik.

Befähigung zur Aufnahme einer Erwerbstätigkeit

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, ihre Kenntnisse, Ideen und Problemlösungen zielgruppenorientiert verständlich zu formulieren und zu präsentieren.
- Die Absolventinnen und Absolventen sind in der Lage, komplexe Probleme aus anderen Gebieten zu erkennen, strukturieren und modellieren, mit mathematischen Methoden Lösungswege zu entwickeln und diese Ergebnisse zu interpretieren und bewerten.
- Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
- Die Absolventinnen und Absolventen sind in der Lage, konstruktiv und zielorientiert in Teams zu arbeiten und hierbei Verantwortung zu tragen.
- Die Absolventinnen und Absolventen sind in der Lage, sich neue Wissensgebiete und aktuelle Entwicklungen selbständig, effizient und systematisch zu erschließen.
- Die Absolventinnen und Absolventen besitzen die Fähigkeit, Projekte in interdisziplinär zusammengesetzten Teams im Bereich der Informatik, Natur- und Ingenieurwissenschaften verantwortlich mitzugestalten.

Persönlichkeitsentwicklung

- Die Absolventinnen und Absolventen sind geschult in analytischem Denken, besitzen ein stark ausgeprägtes Abstraktionsvermögen, universell einsetzbare Problemlösungskompetenz und die Fähigkeit, komplexe Zusammenhänge zu strukturieren.
- Die Absolventinnen und Absolventen sind in der Lage, in partizipativen Prozessen gestaltend mitzuwirken.
• Die Absolventinnen und Absolventen besitzen ein ausgeprägtes Durchhaltevermögen bei der Lösung komplexer Probleme.
• Die Absolventinnen und Absolventen sind in der Lage, komplexe Ideen und Lösungsvorschläge allgemeinverständlich zu formulieren und professionell zu präsentieren.
Abbreviations used

Course types: E = field trip, K = colloquium, O = conversatorium, P = placement/lab course, R = project, S = seminar, T = tutorial, Ü = exercise, V = lecture

Term: SS = summer semester, WS = winter semester

Methods of grading: NUM = numerical grade, B/NB = (not) successfully completed

Regulations: (L)ASPO = general academic and examination regulations (for teaching-degree programmes), FSB = subject-specific provisions, SFB = list of modules

Other: A = thesis, LV = course(s), PL = assessment(s), TN = participants, VL = prerequisite(s)

Conventions

Unless otherwise stated, courses and assessments will be held in German, assessments will be offered every semester and modules are not creditable for bonus.

Notes

Should there be the option to choose between several methods of assessment, the lecturer will agree with the module coordinator on the method of assessment to be used in the current semester by two weeks after the start of the course at the latest and will communicate this in the customary manner.

Should the module comprise more than one graded assessment, all assessments will be equally weighted, unless otherwise stated below.

Should the assessment comprise several individual assessments, successful completion of the module will require successful completion of all individual assessments.

In accordance with

the general regulations governing the degree subject described in this module catalogue:

ASPO2015

associated official publications (FSB (subject-specific provisions)/SFB (list of modules)):

13-Jan-2016 (2016-1)

This module handbook seeks to render, as accurately as possible, the data that is of statutory relevance according to the examination regulations of the degree subject. However, only the FSB (subject-specific provisions) and SFB (list of modules) in their officially published versions shall be legally binding. In the case of doubt, the provisions on, in particular, module assessments specified in the FSB/SFB shall prevail.
Compulsory Electives
(90 ECTS credits)
Subfield Numerical Mathematics and Optimization

(30-60 ECTS credits)
## Applied Analysis

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<td>10-M=AAAN-161-m01</td>
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
10

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

## Contents

## Intended learning outcomes
The student is acquainted with the fundamental notions, methods and results of higher analysis. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics and other natural and engineering sciences.

## Courses
(V (4) + Ü (2)
Module taught in: German and/or English

## Method of assessment
(a) written examination (approx. 90 to 120 minutes, usually chosen) or (b) oral examination of one candidate each (approx. 20 minutes) or (c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English
creditable for bonus

## Allocation of places
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## Additional information
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## Referred to in LPO I
(examination regulations for teaching-degree programmes)
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<th>Module title</th>
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<td>Selected Topics in Optimization</td>
<td>10-M=VOPT-161-m01</td>
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<th>Duration</th>
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<td>1 semester</td>
<td>graduate</td>
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</table>

**Contents**

Selected topics in optimization, e.g. inner point methods, semidefinite programs, non-smooth optimization, game theory, optimization with differential equations.

**Intended learning outcomes**

The student is acquainted with advanced methods in continuous optimization. He gains the ability to work on contemporary research questions in continuous optimization.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

Creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

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<td>graduate</td>
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**Contents**

Selected topics in mathematical physics, for example continuum mechanics, fluid dynamics, mathematical material sciences, geometric field theory, advanced topics in quantum theory.

**Intended learning outcomes**

The student is acquainted with an advanced topic in mathematical physics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Fundamental methods and techniques in continuous optimization, unrestricted optimization, conditions for optimality, restricted optimization, examples and applications in natural and engineering sciences as well as economics.

**Intended learning outcomes**

The student knows the fundamental methods of continuous optimization, can judge their strengths and weaknesses and can decide which method is the most suitable in applications.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents
Partial differential equations and/or variational methods in the context of continuum mechanics.

### Intended learning outcomes
The student masters the mathematical methods in mathematical continuum mechanics and knows about their main fields of application.

### Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + Ü (1)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

### Allocation of places
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### Additional information
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### Referred to in LPO I
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
--

**Contents**
Discretisation of elliptic differential equations, classical iteration methods, preconditioners, multigrid methods.

**Intended learning outcomes**
The student is acquainted with the most important methods for solving large systems of equations, and knows the most efficient way to solve a given system of equations.

**Courses**
(type, number of weekly contact hours, language — if other than German)

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<td>Ü</td>
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Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English creditable for bonus

**Allocation of places**
--

**Additional information**
--

**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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# Module Catalogue for the Subject Computational Mathematics

## Master’s with 1 major, 120 ECTS credits

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## Contents

- Types of partial differential equations, qualitative properties, finite differences, finite elements, error estimates (numerical methods for elliptic, parabolic and hyperbolic partial differential equations; finite elements method, discontinuous Gelerkin finite elements method, finite differences and finite volume methods).

## Intended learning outcomes

The student is acquainted with advanced methods for discretising partial differential equations.

## Courses

<table>
<thead>
<tr>
<th>(type, number of weekly contact hours, language — if other than German)</th>
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<tr>
<td>V (4) + Ü (2)</td>
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Module taught in: German and/or English

## Method of assessment

<table>
<thead>
<tr>
<th>(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)</th>
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</thead>
<tbody>
<tr>
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</table>

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

## Allocation of places

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## Additional information

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## Referred to in LPO I

(examination regulations for teaching-degree programmes)

--
### Module Catalogue for the Subject
Computational Mathematics
Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Optimal Control</td>
<td>10-M=VOST-161-m01</td>
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<table>
<thead>
<tr>
<th>Module coordinator</th>
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<tr>
<td>Dean of Studies</td>
<td>Institute of Mathematics</td>
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<tr>
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<table>
<thead>
<tr>
<th>Duration</th>
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<tbody>
<tr>
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<td>graduate</td>
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</table>

### Contents
Basics in optimal control of ordinary and partial differential equations, theory of optimal control, conditions for optimality, methods for numerical solution.

### Intended learning outcomes
The student is acquainted with advanced methods in optimal control. He gains the ability to work on contemporary research questions in continuous optimization.

### Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + Ü (1)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
creditable for bonus

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)
--
## Inverse Problems

### Module title
Inverse Problems

### Abbreviation
10-M=VIPR-161-m01

### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
5

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
Linear operator equations, ill-posed problems, regularisation theory, Tikhonov regularisation, iterative regularisation methods, examples of ill-posed problems.

### Intended learning outcomes
The student can judge whether a given problem is well posed or ill posed. He/She can apply regularisation methods and examine them regarding stability and convergence, and is familiar with selected inverse problems.

### Courses
V (3) + Ü (1)

### Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 60 to 90 minutes, usually chosen) or
- b) oral examination of one candidate each (approx. 15 minutes) or
- c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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Subfield Mathematics
(10-40 ECTS credits)
## Module Catalogue for the Subject Computational Mathematics

### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td><strong>Topics in Algebra</strong></td>
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### Contents

Contemporary topics in algebra, for example coding theory, elliptic curves, algebraic combinatorics or computer algebra.

### Intended learning outcomes

The student is acquainted with fundamental concepts and methods in a contemporary field of algebra, and is able to apply these skills to complex questions.

### Courses

- **V (4) + Ü (2)**

Module taught in: German and/or English

### Method of assessment

- a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Differential Geometry</td>
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**Contents**

Central and advanced results in differential geometry, in particular about differentiable and Riemannian manifolds.

**Intended learning outcomes**

The student is acquainted with concepts and methods for differentiable manifolds or Riemannian manifolds, is able to apply these methods and knows about the interaction of local and global methods in differential geometry.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Module title | Abbreviation
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Complex Analysis | 10-M=AFTH-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

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### Contents

In-depth study of mapping properties of analytic functions and their generalisations with modern analytic and geometric methods. Structural properties of families of holomorphic and meromorphic functions. Special functions (e.g. elliptic functions).

### Intended learning outcomes

The student is acquainted with the fundamental notions, methods and results of higher complex analysis, in particular the (geometric) mapping properties of holomorphic functions. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

### Courses (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English

creditable for bonus

### Allocation of places

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### Additional information

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## Module Catalogue for the Subject Computational Mathematics

### Master's with 1 major, 120 ECTS credits

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<tr>
<td>Geometric Structures</td>
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### Contents

- Tits buildings, generalised polygons or related geometric structures, automorphisms, BN pairs in groups, Moufang conditions, classification results.

### Intended learning outcomes

The student is acquainted with the fundamental notions, methods and results concerning a type of geometric structure. He/She is able to establish a connection between these results and broader theories, and learns about the interactions of geometry and other fields of mathematics.

### Courses

- **Module taught in:** German and/or English

  - **V (4) + Ü (2)**

### Method of assessment

- **a)** written examination (approx. 90 to 120 minutes, usually chosen)
- **b)** oral examination of one candidate each (approx. 20 minutes)
- **c)** oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

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<td>Industrial Statistics 1</td>
<td>10-M=AIST-161-m01</td>
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</table>

**Contents**

Theory of parameter and domain estimates, tests for statistical estimates, distribution models, empirical distribution analysis, comparative analysis, statistical product testing, survey sampling, audit sampling.

**Intended learning outcomes**

The student masters the fundamental statistical methods for industrial applications.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
credible for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

**Lie Theory**

### Abbreviation

10-M=ALTH-161-m01

### Module coordinator

Dean of Studies Mathematik (Mathematics)

### Module offered by

Institute of Mathematics

### ECTS

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### Contents

Linear Lie groups and their Lie algebras, exponential function, structure and classification of Lie algebras, classic examples, applications, e.g. in physics and control theory.

### Intended learning outcomes

The student is acquainted with the fundamental results, theorems and methods in Lie theory. He/She is able to apply these to common problems, and knows about the interactions of group theory, analysis, topology and linear algebra.

### Courses

<table>
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Module taught in: German and/or English

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<td>Control Theory</td>
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**Contents**

Introduction to mathematical systems theory: stability, controllability and observability, state feedback and stability, basics in optimal control.

**Intended learning outcomes**

The student is acquainted with the fundamental notions and methods of control theory. He/She is able to establish a connection between these results and broader theories, and learns about the interactions of geometry and other fields of mathematics.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO 1** (examination regulations for teaching-degree programmes)

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<td>Stochastic Models of Risk Management</td>
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**Contents**

Measure theory, risk diagrams, failure mode and effects analysis, risk assessment in auditing, shortfall measures, value at risk, conditional value at risk, axiomatic of risk measures, modelling of interdependencies, copula, modelling of functional interrelations, regression models, basics in time series modelling, aggregated losses, estimates of shortfall measures, estimates of value at risk and conditional value at risk, basics in empirical time series analysis, methods of exponential smoothing, predictions and prediction domains, estimates of value at risk in time series, elementary empirical regression analysis, simulation methods.

**Intended learning outcomes**

The student is acquainted with the fundamental methods of stochastic risk analysis.

**Courses**

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

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Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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Module title  |   Abbreviation
---|---
Stochastical Processes | 10-M=ASTP-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
10 | numerical grade | --

Duration | Module level | Other prerequisites
1 semester | graduate | --

Contents
Markov chains, queues, stochastic processes in $\mathbb{C}[0,1]$, Brownian motion, Donsker's theorem, projective limits.

Intended learning outcomes
The student is acquainted with the fundamental notions and methods of stochastical processes and can apply them to practical problems.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Language of assessment: German or English
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<td>Topology</td>
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**Contents**

Set-theoretic topology, topological invariants (e.g. fundamental group, connection), construction of topological spaces, covering spaces.

**Intended learning outcomes**

The student is acquainted with the fundamental results, theorems and methods in topology and is able to apply these to common problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English

creditable for bonus

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**Additional information**

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<td>Insurance Mathematics 1</td>
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

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### Contents
The module discusses policies on one life: distributions of future lifetime, life tables, life table approximations, types of benefits, present value, expectation principle, premium calculation, commutation functions, reserves and policy values, expenses, bonus, recursive methods, Thiele's differential equation.

### Intended learning outcomes
The student is acquainted with the fundamental notions and methods of life insurance mathematics and can apply them to practical problems.

### Courses
V (4) + Ü (2)
Module taught in: German and/or English

### Method of assessment
A) written examination (approx. 90 to 120 minutes, usually chosen) or B) oral examination of one candidate each (approx. 20 minutes) or C) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)
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Module title
Time Series Analysis 1

Abbreviation
10-M=AZRA-161-m01

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

ECTS 10
Method of grading numerical grade

Duration 1 semester
Module level graduate

Other prerequisites

Contents
Additive model, linear filters, autocorrelation, moving average, autoregressive processes, Box-Jenkins method.

Intended learning outcomes
The student is acquainted with the fundamental methods of time series analysis and can apply them to practical problems.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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<td>1 semester</td>
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**Contents**

Number-theoretic functions and their associated Dirichlet series resp. Euler products, their analytic theory with applications to prime number distribution and diophantine equations; discussion of the Riemann hypothesis, overview of the development of modern number theory.

**Intended learning outcomes**

The student is acquainted with the fundamental methods of analytics number theory, can deal with algebraic structures in number theory and knows methods for the solution of diophantine equations. He/She has insight into modern developments in number theory.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
## Module Title

**Giovanni Prodi Lecture (Master)**

**Abbreviation**

10-M=AGPCin-152-m01

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## Module Coordinator

Dean of Studies Mathematik (Mathematics)

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## Module Offered by

Institute of Mathematics

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## ECTS

5

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## Method of Grading

Numerical grade

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## Only after succ. compl. of module(s)

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## Duration

1 semester

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## Module Level

Graduate

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## Other Prerequisites

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## Contents

Introduction to a specialised topic in mathematics by an international expert.

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## Intended Learning Outcomes

The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

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## Courses

V (3) + Ü (1)

Module taught in: English

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## Method of Assessment

(a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: English

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## Allocation of Places

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## Additional Information

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**Contents**

In-depth discussion of a specialised topic in analysis taking into account recent developments and interrelations with other mathematical concepts.

**Intended learning outcomes**

The student is acquainted with advanced results in a selected topic in analysis, and is able to apply these to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)  
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester  
Language of assessment: German or English

**Allocation of places**  
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**Additional information**  
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<td>Selected Topics in Financial Mathematics</td>
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**Contents**

Selected topics in financial mathematics, e.g. conditional expectation and martingales, fundamental theorem of asset pricing in discrete time for finite spaces, American put, Snell envelope, stopping time, optimal stopping, stochastic integration, stochastic differential equations and Ito calculus, Black-Merton-Scholes model.

**Intended learning outcomes**

The student is acquainted with advanced results in financial mathematics. He/She gains the ability to work on contemporary research questions in financial mathematics and can apply his/her skills to complex problems.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Module title | Abbreviation
---|---
Groups and their Representations | 10-M=VGDS-161-m01

Module coordinator | Module offered by
Dean of Studies Mathematik (Mathematics) | Institute of Mathematics

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
10 | numerical grade | --

Duration | Module level | Other prerequisites
1 semester | graduate | --

Contents
Finite permutation groups and character theory of finite groups, interrelations and special techniques such as the S-rings of Schur.

Intended learning outcomes
The student masters advanced algebraic concepts and methods. He/She gains the ability to work on contemporary research questions in group theory and representation theory and can apply his/her skills to complex problems.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Language of assessment: German or English
creditable for bonus

Allocation of places
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Additional information
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**Contents**

Linear models, regression analysis, nonlinear regression, experimental design, basics in time series modelling, basics in empirical time series analysis, methods of exponential smoothing, predictions and prediction domains, statistical process monitoring.

**Intended learning outcomes**

The student masters advanced statistical methods for industrial applications.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Contents**

Contingency tables, categorical regression, one-factorial variance analysis, two-factorial variance analysis, discriminant function analysis, cluster analysis, principal component analysis, factor analysis.

**Intended learning outcomes**

The student is acquainted with the fundamental methods in statistical analysis and can apply them to practical problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

- V (4) + Ü (2)  
  Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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  Assessment offered: In the semester in which the course is offered and in the subsequent semester  
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**Allocation of places**

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**Additional information**

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**Contents**

This module discusses modern valuation approaches and multiple decrement models regarding one life or two lives: modern valuation in life insurance mathematics, axiomatic derivation of the product measure approach, Markov chain models, Kolmogorov's differential equations, Thiele's differential equations, numerical applications, joint life policies.

**Intended learning outcomes**

The student is acquainted with advanced methods in insurance mathematics. He gains the ability to work on contemporary research questions in insurance mathematics and can apply his/her skills to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German or English
creditable for bonus

**Allocation of places**  
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**Additional information**  
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

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### Duration
1 semester

### Module level
graduate

### Other prerequisites
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### Contents
State-space models, Kalman filter, frequency spaces, Fourier analysis, periodograms, characterisation of autocovariance functions.

### Intended learning outcomes
The student is acquainted with advanced methods in time series analysis. He gains the ability to work on contemporary research questions in this field.

### Courses
(type, number of weekly contact hours, language — if other than German)

- V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- a) written examination (approx. 90 to 120 minutes, usually chosen) or
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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

### Allocation of places
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### Additional information
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**Module coordinator**

Dean of Studies Mathematik (Mathematics)

**Module offered by**

Institute of Mathematics

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**Duration**

1 semester

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**Contents**

Fundamentals of dynamical systems, e.g. stability theory, ergodic theory, Hamiltonian systems.

**Intended learning outcomes**

The student masters the mathematical methods in the theory of dynamic systems, and is able to analyse their quality.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Additional information**

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**Contents**

Mathematical fundamentals of image processing and computer vision such as elementary projective geometry, camera models and camera calibration, rigid and non-rigid registration, reconstruction of 3D objects from camera pictures; algorithms; module might also include an introduction to geometric methods and tomography.

**Intended learning outcomes**

The student masters the mathematical methods in the theory of image processing and knows about their main fields of application.

**Courses** (type, number of weekly contact hours, language — if other than German)

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Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English
Creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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<table>
<thead>
<tr>
<th>Contents</th>
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</thead>
<tbody>
<tr>
<td>Selected topics in linear and non-linear control theory, e.g. networked linear control systems, controllability of bilinear systems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intended learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student gains insight into contemporary research problems in control theory. He/She masters advanced techniques in this field and can apply them to complex problems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Courses (type, number of weekly contact hours, language — if other than German)</th>
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<tbody>
<tr>
<td>V (4) + Ü (2)</td>
</tr>
<tr>
<td>Module taught in: German and/or English</td>
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<table>
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<tr>
<th>Additional information</th>
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<table>
<thead>
<tr>
<th>Referred to in LPO I (examination regulations for teaching-degree programmes)</th>
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</tbody>
</table>
### Module title
Non-linear Analysis

### Abbreviation
10-M=VNAN-161-m01

<table>
<thead>
<tr>
<th>Module coordinator</th>
<th>Module offered by</th>
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<tbody>
<tr>
<td>Dean of Studies Mathematik (Mathematics)</td>
<td>Institute of Mathematics</td>
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<tr>
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<tr>
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<th>Other prerequisites</th>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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</tbody>
</table>

### Contents
Methods in nonlinear analysis (e.g. topological methods, monotony and variational methods) with applications.

### Intended learning outcomes
The student is acquainted with the concepts of non-linear analysis, can compare them and assess their applicability on practical problems.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

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### Additional information
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<table>
<thead>
<tr>
<th>Module title</th>
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<tr>
<td>Networked Systems</td>
<td>10-M=VVSY-161-m01</td>
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</tbody>
</table>

**Contents**

Contemporary topics in networked linear and non-linear dynamical systems (homogenous and non-homogenous systems); analysis of control-theoretical aspects (controllability, accessibility, etc.).

**Intended learning outcomes**

The student is acquainted with advanced methods in the field of networked systems. He gains the ability to work on contemporary research questions in networked systems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + Ü (1)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 60 to 90 minutes, usually chosen) or b) oral examination of one candidate each (approx. 15 minutes) or c) oral examination in groups (groups of 2, approx. 10 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title
Complex Geometry

### Abbreviation
10-M=VKGE-161-m01

### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
10

### Method of grading
Numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
Graduate

### Other prerequisites
--

### Contents
The module builds on the topics covered in module 10-M=ADGM and discusses these in more detail: Wirtinger calculus, complex structures and complex manifolds, metrics on complex manifolds (e.g. conformal, hermitian, Kähler), differential operators on complex manifolds, classification of complex manifolds.

### Intended learning outcomes
The student knows and masters advanced methods and notions in complex differential geometry. He is familiar with the central concepts in this field and is able to apply the fundamental proof methods independently.

### Courses
(type, number of weekly contact hours, language — if other than German)

- V (4) + Ü (2)

Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

Creditable for bonus: --

### Allocation of places
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### Additional information
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<tr>
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<tbody>
<tr>
<td>Partial Differential Equations of Mathematical Physics</td>
<td>10-M=VPDP-161-m01</td>
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**Contents**

Elliptic, parabolic, and hyperbolic equations; Laplace equation, heat equation and wave equation as standard examples; initial and boundary value problems; well-posed and ill-posed problems; solution methods; extensions and generalisations; Hilbert space methods; Sobolev spaces and Fourier transforms.

**Intended learning outcomes**

The student is acquainted with fundamental concepts and solution methods in the theory of partial differential equations, as well as standard examples from mathematical physics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: German and/or English

**Method of assessment**

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

creditable for bonus

**Allocation of places**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject: Computational Mathematics

#### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Pseudo Riemannian and Riemannian Geometry</td>
<td>10-M=VPRG-161-m01</td>
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</table>

#### Contents

The module builds on the topics covered in module 10-M=ADGM and discusses these in more detail: Riemannian and pseudo-Riemannian manifolds, Levi-Civita connection and curvature, geodesics and the exponential map, Jacobi fields, comparison theorems in Riemannian geometry, submanifolds, integration, d'Alembert and Laplace operators, causal structure of Lorenz manifolds, Einstein equations and applications in general relativity theory.

#### Intended learning outcomes

The student is acquainted with advanced topics in differential geometry on Riemannian and pseudo-Riemannian manifolds. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

#### Courses

<table>
<thead>
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Module taught in: German and/or English

#### Method of assessment

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</table>

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English creditable for bonus

#### Allocation of places

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#### Additional information

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<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Functional Analysis</td>
<td>10-M=AFAN-161-m01</td>
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</table>

**Contents**
Banach and Hilbert spaces, bounded operators, principles of functional analysis, further contemporary topics in functional analysis and applications to other fields of mathematics.

**Intended learning outcomes**
The student is acquainted with fundamental concepts and methods in a contemporary field of functional analysis, and is able to apply these skills to complex questions.

**Courses** (type, number of weekly contact hours, language — if other than German)
- V (4) + Ü (2)

*Module taught in: German and/or English*

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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*Assessment offered: In the semester in which the course is offered and in the subsequent semester*

*Language of assessment: German or English*

*Creditable for bonus:

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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## Module Catalogue for the Subject
Computational Mathematics

### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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</thead>
<tbody>
<tr>
<td>Applied Differential Geometry</td>
<td>10-M=VADG-161-m01</td>
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### Module coordinator
Dean of Studies Mathematik (Mathematics)

### Module offered by
Institute of Mathematics

### ECTS
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</table>

### Method of grading
1 semester

### Module level
graduate

### Other prerequisites
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### Contents
The module builds on the topics covered in module 10-M=ADGM and discusses selected applications of differential geometry, e.g. at the interface of control theory and mechanics (subriemannian geometry), in the smooth optimisation on manifolds or applications in physics.

### Intended learning outcomes
The student is acquainted with selected advanced applications of differential geometry. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and questions in physics.

### Courses
V (4) + Ü (2)
Module taught in: German and/or English

### Method of assessment
a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate) Assessment offered: In the semester in which the course is offered and in the subsequent semester Language of assessment: German or English creditable for bonus

### Allocation of places
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### Additional information
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<tr>
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<tbody>
<tr>
<td>Giovanni Prodi Lecture Selected Topics (Master)</td>
<td>10-M- VGPSin-152-m01</td>
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</table>

**Contents**

Introduction to a specialised topic in mathematics by an international expert.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

Module taught in: English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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<tbody>
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<td>Giovanni Prodi Lecture Advanced Topics (Master)</td>
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**Contents**

Introduction to a specialised topic in mathematics by an international expert.

**Intended learning outcomes**

The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)
Module taught in: English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 120 minutes, usually chosen) or b) oral examination of one candidate each (approx. 20 minutes) or c) oral examination in groups (groups of 2, 15 minutes per candidate)

Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: English
creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
Module title
Giovanni Prodi Lecture Modern Topics (Master)

Abbreviation
10-M=VGPM-In-152-m01

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

ECTS
10

Method of grading
numerical grade

Only after succ. compl. of module(s)
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Duration
1 semester

Module level
graduate

Other prerequisites
--

Contents
Introduction to a specialised topic in mathematics by an international expert.

Intended learning outcomes
The student is acquainted with the fundamental concepts and methods of a contemporary research topic in mathematics. He/She is able to establish a connection between his/her acquired skills and other branches of mathematics and applications in other subjects.

Courses (type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)
Module taught in: English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: English creditable for bonus

Allocation of places
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Additional information
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**Contents**

Supervising a tutorial or study group in the Bachelor's programme under guidance of the respective lecturer.

**Intended learning outcomes**

The student gains his/her first experience in teaching university mathematics. He/She knows basic didactical methods and can apply them in practical situations.

**Courses** (type, number of weekly contact hours, language — if other than German)

T (0)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Assessment of tutoring activities by supervising lecturers or exercise supervisors (1 to 2 teaching units)

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
Subfield Research in Groups and Seminars
(10-40 ECTS credits)
**Module title**
Research in Groups - Mathematics in the Sciences

**Abbreviation**
10-M=GMSC-161-m01

**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

<table>
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<tr>
<th>ECTS</th>
<th>Method of grading</th>
<th>Only after succ. compl. of module(s)</th>
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<thead>
<tr>
<th>Duration</th>
<th>Module level</th>
<th>Other prerequisites</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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**Contents**
A modern topic in mathematics in the sciences.

**Intended learning outcomes**
The student gains insight into contemporary research problems in mathematics in the sciences. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses**
(type, number of weekly contact hours, language — if other than German)

V (2) + S (2)
Module taught in: German and/or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
--

**Additional information**
--

**Referred to in LPO I**
(examination regulations for teaching-degree programmes)
--
## Module Title

**Research in Groups - Numerical Mathematics and Applied Analysis**

### Abbreviation

10-M=GNMA-161-m01

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### Module Coordinator

Dean of Studies Mathematik (Mathematics)

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### Module Offered by

Institute of Mathematics

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### ECTS

10

- **Method of grading**: numerical grade
- **Duration**: 1 semester
- **Module level**: graduate
- **Other prerequisites**: --
- **Contents**: Selected topics in numerical mathematics, applied analysis or scientific computing.
- **Intended learning outcomes**: The student gains insight into a contemporary research problems in numerical mathematics or applied analysis. He/She masters advanced techniques in this field and can apply them to complex problems.

### Courses

- **(type, number of weekly contact hours, language — if other than German)**
  - V (2) + S (2)
  - Module taught in: German and/or English

### Method of assessment

- **(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)**
  - talk (60 to 120 minutes)
  - Assessment offered: In the semester in which the course is offered and in the subsequent semester
  - Language of assessment: German or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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</table>

**Contents**

Selected modern topics in robotics, optimisation and control theory.

**Intended learning outcomes**

The student gains insight into contemporary research problems in robotics, optimization and control theory. He/She masters advanced techniques in this field and can apply them to complex problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)

Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<td>graduate</td>
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</table>

**Contents**

A modern topic in the research expertise of the current holder of the Giovanni Prodi Chair.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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<td>Assessment offered: In the semester in which the course is offered and in the subsequent semester</td>
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<tr>
<td>Language of assessment: English</td>
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**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
Interdisciplinary Seminar

Module title
Interdisciplinary Seminar

Module coordinator
Dean of Studies Mathematik (Mathematics)

Module offered by
Institute of Mathematics

ECTS
5

Method of grading
numerical grade

Only after succ. compl. of module(s)
--

Duration
1 semester

Module level
graduate

Other prerequisites
--

Contents
A modern topic in mathematics with interdisciplinary aspects.

Intended learning outcomes
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

Courses (type, number of weekly contact hours, language — if other than German)

S (2)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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</table>

**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
--

**Contents**
A modern topic in mathematics in the sciences.

**Intended learning outcomes**
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

<table>
<thead>
<tr>
<th>Type</th>
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<th>Language</th>
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**Module taught in:** German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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<tr>
<td>talk</td>
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<td>German or English</td>
<td>In the semester in which the course is offered and in the subsequent semester</td>
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**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
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<th>Module title</th>
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<tr>
<td>Seminar in Numerical Mathematics and Applied Analysis</td>
<td>10-M-SPMA-161-m01</td>
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</table>

**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

**ECTS** | **Method of grading** | **Only after succ. compl. of module(s)**
---|---|---
5 | numerical grade | --

**Duration** | **Module level** | **Other prerequisites**
---|---|---
1 semester | graduate | --

**Contents**
A modern topic in numerical mathematics or applied analysis.

**Intended learning outcomes**
The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2)

Module taught in: German and/or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

talk (60 to 120 minutes)
Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
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<th>Module title</th>
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<td>Seminar in Optimization</td>
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<tr>
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</tbody>
</table>

**Contents**

A modern topic in optimisation.

**Intended learning outcomes**

The student is able to elaborate a contemporary research topic. This includes comprehending and structuring of the topic and the available literature, preparing a talk and the ability to participate in a scientific discussion.

**Courses**

<table>
<thead>
<tr>
<th>type, number of weekly contact hours, language — if other than German</th>
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<td>S (2) Module taught in: German and/or English</td>
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**Method of assessment**

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<th>type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus</th>
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</thead>
<tbody>
<tr>
<td>talk (60 to 120 minutes) Assessment offered: In the semester in which the course is offered and in the subsequent semester Language of assessment: German or English</td>
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**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

--
Subfield Optional Application Subject and/or Intership
(10-40 ECTS credits)
Application Subject Biology and Medicine

(ECTS credits)
## Module: Bioinformatics

<table>
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<th>Abbreviation</th>
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<td>Bioinformatics</td>
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<tbody>
<tr>
<td>holder of the Chair of Bioinformatics</td>
<td>Faculty of Biology</td>
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<tr>
<th>Duration</th>
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<th>Contents</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
<td>Advances and current results of bioinformatics are explained and discussed, this includes results from genome and sequence analysis, protein domains and protein families, large-scale data analysis (e.g. net generation sequences, proteomics data), analysis of different functional RNAs (e.g. miRNAs, IncRNAs).</td>
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</table>

### Intended learning outcomes

Understand recent results in bioinformatics. Discuss their implications. Have an advanced (Master) level knowledge of typical technologies and research questions in bioinformatics.

### Courses

<table>
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<th>Type</th>
<th>Number of weekly contact hours</th>
<th>Language</th>
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<tbody>
<tr>
<td>V (2)</td>
<td>S (1)</td>
<td>German and/or English</td>
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Module taught in: German and/or English

### Method of assessment

Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) oral examination of one candidate each (30 to 60 minutes) or c) oral examination in groups of up to 3 candidates (30 to 60 minutes)

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject
Computational Mathematics

### Master's with 1 major, 120 ECTS credits

<table>
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### Contents
Detailed insight into methods in bioinformatics; depending on the topic selected, fields covered include: genomics (sequence-, domain analysis and annotation), omics data analysis (NGS, transcriptomics, metabolomics, proteomics), topological and structural analysis of biological interactions including statistical methods, phylogenetic analysis, protein structure analysis. Results are documented in the form of a presentation, a publication or a term paper.

### Intended learning outcomes
Students have gained knowledge on experimental setups and methods used in the field of bioinformatics. They are able to design experiments, collect data and interpret them statistically, adhering to the principles of good scientific practice.

### Courses
(type, number of weekly contact hours, language — if other than German)

P (14) + S (1)
Module taught in: German and/or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) log (15 to 30 pages) or c) oral examination of one candidate each (30 to 60 minutes) or d) oral examination in groups of up to 3 candidates (30 to 60 minutes) or e) presentation (20 to 45 minutes)

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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Contents

Advanced insight into methods in bioinformatics; depending on the topic selected, fields covered include: genomics (sequence-, domain analysis and annotation), omics data analysis (NGS, transcriptomics, metabolomics, proteomics), topological and structural analysis of biological interactions including statistical methods, phylogenetic analysis, protein structure analysis. The techniques applied are evaluated on the basis of the results obtained and are modified where necessary. Results are documented in the form of a presentation, a publication or a term paper.

Intended learning outcomes

Proficiency in one or more methods in bioinformatics that allows students to independently perform and organise a scientific project in the field of bioinformatics and to document the results obtained. Students are able to design a research project and are prepared for working on a scientific question for their thesis.

Courses

(P 29) + S (1)
Module taught in: German and/or English

Method of assessment

Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) log (15 to 30 pages) or c) oral examination of one candidate each (30 to 60 minutes) or d) oral examination in groups of up to 3 candidates (30 to 60 minutes) or e) presentation (20 to 45 minutes)

Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

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### Contents
Advances and current results of bioinformatics are explained and discussed, this includes results from genome and sequence analysis, protein domains and protein families, large-scale data analysis (e.g. net generation sequences, proteomics data), analysis of different functional RNAs (e.g. miRNAs, lncRNAs).

### Intended learning outcomes
Understand recent results in bioinformatics. Discuss their implications. Have an advanced (Master) level knowledge of typical technologies and research questions in bioinformatics.

### Courses (type, number of weekly contact hours, language — if other than German)
V (2)  
Module taught in: German and/or English

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen:  
a) written examination (30 to 60 minutes, including multiple choice questions)  
b) oral examination of one candidate each (30 to 60 minutes)  
c) oral examination in groups of up to 3 candidates (30 to 60 minutes)  
Language of assessment: German and/or English

### Allocation of places
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### Additional information
--

### Referred to in LPO I (examination regulations for teaching-degree programmes)
--
Module title | Abbreviation
---|---
Systems Biology | 07-M53S-152-m01

Module coordinator | Module offered by
holder of the Chair of Bioinformatics | Faculty of Biology

ECTS | Method of grading | Only after succ. compl. of module(s)
---|---|---
10 | numerical grade | --

Duration | Module level | Other prerequisites
---|---|---
1 semester | graduate | --

Contents
Advances and current results of computational systems biology are explained and discussed, this includes results from functional genomics, dynamics of the transcriptome, of metabolism and metabolic networks as well as regulatory networks.

Intended learning outcomes
Understand recent results in systems biology. Discuss their implications. Have an advanced (Master) level knowledge of typical technologies and research questions of systems biology.

Courses (type, number of weekly contact hours, language — if other than German)
V (2) + S (1)
Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) oral examination of one candidate each (30 to 60 minutes) or c) oral examination in groups of up to 3 candidates (30 to 60 minutes)
Language of assessment: German and/or English

Allocation of places
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Additional information
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<tr>
<td>Systems Biology F1</td>
<td>07-MS3SYF1-152-m01</td>
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</tbody>
</table>

Module coordinator

holder of the Chair of Bioinformatics

Module offered by

Faculty of Biology

<table>
<thead>
<tr>
<th>ECTS</th>
<th>Method of grading</th>
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<tr>
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<th>Module level</th>
<th>Other prerequisites</th>
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</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>graduate</td>
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</tr>
</tbody>
</table>

Contents

The practical course will provide students with advanced insights into a field of systems biology and will, in particular, make students proficient in a dynamical method in systems biology (areas that may be selected include protein structure analysis and protein folding, genome analysis and evolution; dynamic network analysis, the dynamics of protein-protein interactions, modelling cellular regulation; modelling metabolism, statistical modeling).

Intended learning outcomes

Students have gained knowledge on experimental setups and methods used in the field of systems biology. They are able to design scientific research, to collect data and to interpret them statistically, adhering to the principles of good scientific practice.

Courses (type, number of weekly contact hours, language — if other than German)

P (14) + S (1)

Module taught in: German and/or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) log (15 to 30 pages) or c) oral examination of one candidate each (30 to 60 minutes) or d) oral examination in groups of up to 3 candidates (30 to 60 minutes) or e) presentation (20 to 45 minutes)

Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

--
Module title
Systems Biology F2

Abbreviation
07-MS3SYF2-152-m01

Module coordinator
holder of the Chair of Bioinformatics

Module offered by
Faculty of Biology

ECTS
15

Method of grading
Only after succ. compl. of module(s)

Duration
1 semester

Module level
graduate

Contents
The practical course will provide students with advanced insights into a field of systems biology and will, in particular, make students proficient in a dynamical method in systems biology (areas that may be selected include protein structure analysis and protein folding, genome analysis and evolution; dynamic network analysis, the dynamics of protein-protein interactions, modelling cellular regulation; modelling metabolism, statistical modelling). The techniques applied are evaluated on the basis of the results obtained and are modified where necessary. Results are documented in the form of a presentation, a publication or a term paper.

Intended learning outcomes
Proficiency in one or more methods in systems biology that allows students to independently perform and organise a scientific project in the field of bioinformatics and to document the results obtained. Students are able to design a research project and are prepared for working on a scientific question for their thesis.

Courses
P (29) + S (1)

Module taught in: German and/or English

Method of assessment
Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) log (15 to 30 pages) or c) oral examination of one candidate each (30 to 60 minutes) or d) oral examination in groups of up to 3 candidates (30 to 60 minutes) or e) presentation (20 to 45 minutes)

Language of assessment: German and/or English

Allocation of places
--

Additional information
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Referred to in LPO I
( examination regulations for teaching-degree programmes)
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<td>Systems Biology B</td>
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| Module coordinator                                                                 |
| holder of the Chair of Bioinformatics                                             |

| Module offered by                                                                 |
| Faculty of Biology                                                               |

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<td>graduate</td>
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</table>

**Contents**

Advances and current results of computational systems biology are explained and discussed, this includes results from functional genomics, dynamics of the transcriptome, of metabolism and metabolic networks as well as regulatory networks.

**Intended learning outcomes**

Understand recent results in systems biology. Discuss their implications. Have an advanced (Master) level knowledge of typical technologies and research questions of systems biology.

**Courses** (type, number of weekly contact hours, language — if other than German)

<table>
<thead>
<tr>
<th>V (2)</th>
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<tbody>
<tr>
<td>Module taught in: German and/or English</td>
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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Students will be informed about the method, length and scope of the assessment prior to the course. Usually, one of the following options will be chosen: a) written examination (30 to 60 minutes, including multiple choice questions) or b) oral examination of one candidate each (30 to 60 minutes) or c) oral examination in groups of up to 3 candidates (30 to 60 minutes)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Application Subject Chemie
(ECTS credits)
<table>
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<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tr>
<td>Laser Spectroscopy</td>
<td>08-PCM1a-161-m01</td>
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<th>Module offered by</th>
</tr>
</thead>
<tbody>
<tr>
<td>lecturer of seminar &quot;Laserspektroskopie&quot; (Laser Spectroscopy)</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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</table>

**Contents**

German contents available but not translated yet.

Das Modul führt in die Grundlagen der Laserspektroskopie ein. Als experimentelle Methoden werden die Absorptions- und Emissionsspektroskopie behandelt.

**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Die Studierenden sind in der Lage, Aufbau und Funktionsweise eines Lasers sowie die optischen Grundlagen zu erklären. Er/Sie kann das Prinzip der Absorptions- und Emissionsspektroskopie darstellen.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2) + Ü (1)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tr>
<td>Advanced Physical Chemistry (Lab)</td>
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</thead>
<tbody>
<tr>
<td>lecturer of seminar &quot;Laserspektroskopie&quot; (Laser Spectroscopy)</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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<td>graduate</td>
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</table>

**Contents**

German contents available but not translated yet.


**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Die Studierenden können moderne experimentelle Methoden der Physikalischen Chemie sicher praktisch durchführen. Er/Sie kann erhaltene Messwerte inhaltlich und graphisch mit geeigneten Computerprogrammen sowie rechnerisch analysieren und in einem wissenschaftlichen Protokoll formulieren.

**Courses**

(type, number of weekly contact hours, language — if other than German)

P (4)

Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Vortestate/Nachtestate (pre and post-experiment examination talks approx. 15 minutes each, log approx. 5 to 10 pages each) and assessment of practical performance (2 to 4 random examinations)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Statistical Mechanics and Reaction Dynamics</td>
<td>08-PCM2-161-m01</td>
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<th>Module offered by</th>
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<tbody>
<tr>
<td>lecturer of seminar &quot;Chemische Dynamik&quot; (Chemical Dynamics)</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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<td>1 semester</td>
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</table>

**Contents**

The module deals with selected contents of statistical mechanics and reaction dynamics. It introduces the basic principles of statistical thermodynamics and conveys the transition state theory. Other topics are unimolecular and bimolecular reactions as well as charge and energy transfer.

**Intended learning outcomes**

The students are familiar with selected contents of statistical mechanics and reaction dynamics. They know the basic principles of statistical thermodynamics and can apply them.

<table>
<thead>
<tr>
<th>Courses (type, number of weekly contact hours, language — if other than German)</th>
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</thead>
<tbody>
<tr>
<td>S (2) + Ü (1) Module taught in: German or English</td>
</tr>
</tbody>
</table>

**Method of assessment**

Type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus

- a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) talk (approx. 30 minutes)
- Language of assessment: German and/or English

**Allocation of places**

--

**Additional information**

--

**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
**Module title**
Nanoscale Materials

**Abbreviation**
08-PCM3-161-m01

**Module coordinator**
Lecturer of the seminar "Nanoskalige Materialien"

**Module offered by**
Institute of Physical and Theoretical Chemistry

**ECTS**
5

**Method of grading**
numerical grade

**Only after succ. compl. of module(s)**
--

**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
--

**Contents**
German contents available but not translated yet.


**Intended learning outcomes**
German intended learning outcomes available but not translated yet.

Die Studierenden sind in der Lage, nanoskalige Materialien zu charakterisieren. Er/Sie kann Analysenmethoden sowie Anwendungsgebiete nanoskaliger Materialien anführen.

**Courses**
(type, number of weekly contact hours, language — if other than German)
S (2) + Ü (1)
Module taught in: German or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) talk (approx. 30 minutes)
Language of assessment: German and/or English creditable for bonus

**Allocation of places**
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**Additional information**
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**Referred to in LPO I**
(examination regulations for teaching-degree programmes)
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<table>
<thead>
<tr>
<th>Module title</th>
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<tr>
<td>Ultrafast spectroscopy and quantum-control</td>
<td>08-PCM4-161-m01</td>
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<tbody>
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<td>Institute of Physical and Theoretical Chemistry</td>
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<td>1 semester</td>
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<td>Prior completion of modules 08-PCM1a and 08-PCM1b recommended.</td>
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</table>

### Contents

German contents available but not translated yet.

Das Modul behandelt spezielle Themen der Ultrakurzzeitspektroskopie und Quantenkontrolle. Schwerpunkte sind ultrakurze Laserimpulse, zeitaufgelöste Laserspektroskopie sowie kohärente Kontrolle.

### Intended learning outcomes

German intended learning outcomes available but not translated yet.


### Courses

(type, number of weekly contact hours, language — if other than German)

S (2) + Ü (1)

Module taught in: German or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) talk (approx. 30 minutes)

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject Computational Mathematics

#### Master’s with 1 major, 120 ECTS credits

<table>
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<th>Module title</th>
<th>Abbreviation</th>
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<tbody>
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<td>Physical chemistry of supramolecular assemblies</td>
<td>08-PCM5-161-m01</td>
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<th>Module offered by</th>
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<tbody>
<tr>
<td>lecturer of the seminar &quot;Physikalische Chemie Supramolekularer Strukturen&quot;</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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#### Contents

German contents available but not translated yet.


#### Intended learning outcomes

German intended learning outcomes available but not translated yet.


#### Courses

<table>
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<th>Type, number of weekly contact hours, language — if other than German</th>
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<td>S (2) + Ü (1)</td>
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Module taught in: German or English

#### Method of assessment

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<tr>
<td>a) written examination (approx. 90 minutes) or b) oral examination of one candidate each (approx. 20 minutes) or c) talk (approx. 30 minutes)</td>
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Language of assessment: German and/or English

#### Allocation of places

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#### Additional information

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#### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<table>
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<td>Physical Chemistry (Advanced Lab)</td>
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<tr>
<td>Physikalische Chemie (Physical Chemistry)</td>
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</table>

**Contents**

German contents available but not translated yet.

Das Modul bietet den Studierenden die Möglichkeit, in einem Arbeitskreis des Instituts für Physikalische Chemie mit zu arbeiten sowie spezifische Synthese- und Analysemethoden kennen zu lernen.

**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Die Studierenden können für einen Arbeitskreis der Physikalischen Chemie typische Untersuchungsmethoden anwenden sowie die erhaltenen Ergebnisse analysieren um aktuelle Fragestellungen der Physikalischen Chemie zu beantworten.

**Courses** (type, number of weekly contact hours, language — if other than German)

P (4)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

presentation (approx. 20 minutes)

Language of assessment: German and/or English

**Allocation of places**

--

**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
### Module title
Basics and applications of quantum chemistry

### Abbreviation
08-TCM2-161-m01

### Module coordinator
lecturer of lecture "Computational Chemistry"

### Module offered by
Institute of Physical and Theoretical Chemistry

### ECTS
5

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
The module introduces students to computational chemistry.

### Intended learning outcomes
German intended learning outcomes available but not translated yet.

Die Studierenden sind in der Lage, die theoretischen Grundlagen der Computational Chemistry zu erklären sowie Methoden der Computational Chemistry anzuwenden.

### Courses
(type, number of weekly contact hours, language — if other than German)
S (2) + Ü (2)

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
a) written examination (approx. 90 to 180 minutes) or b) oral examination of one candidate each (20 to 30 minutes) or c) oral examination in groups of up to 3 candidates (approx. 15 minutes per candidate) or d) log (approx. 20 pages) or e) presentation (approx. 30 minutes)
Language of assessment: German and/or English

### Allocation of places
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### Additional information
--

### Referred to in LPO I
(examination regulations for teaching-degree programmes)
--
Module title | Abbreviation
---|---
Numerical Methods and Programming | 08-TCM3-161-m01

Module coordinator | Module offered by
lecturer of lecture "Programmieren in Theoretischer Chemie" | Institute of Physical and Theoretical Chemistry

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Contents

German contents available but not translated yet.

Das Modul führt in Grundlagen der Programmierung in der Theoretischen Chemie ein und zeigt Anwendungsbereiche auf.

Intended learning outcomes

German intended learning outcomes available but not translated yet.

Die Studierenden können eine in der Theoretischen Chemie verwendete Programmiersprache theoretisch erklären und praktisch anwenden sowie Anwendungsmöglichkeiten anführen.

Courses (type, number of weekly contact hours, language — if other than German)

S (2) + Ü (2)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 180 minutes) or b) oral examination of one candidate each (20 to 30 minutes) or c) oral examination in groups of up to 3 candidates (approx. 15 minutes per candidate) or d) log (approx. 20 pages) or e) presentation (approx. 30 minutes)

Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

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<table>
<thead>
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<th>Module title</th>
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<td>Quantum Dynamics</td>
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<tbody>
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<td>lecturer of lecture &quot;Quantendynamik&quot;</td>
<td>Institute of Physical and Theoretical Chemistry</td>
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</table>

**Contents**

Time-dependent Schrödinger equation, propagators, time-dependent perturbation theory, adiabatic theorem, diabatic and adiabatic states, non-adiabatic dynamics, mixed quantum-classical dynamics.

**Intended learning outcomes**

The students possess knowledge about the time-dependent description of the nuclear and electronic dynamics in molecules. Their insight into the methods and the numerical realizations allow them to carry out applications in the field of theoretical chemistry.

**Courses** (type, number of weekly contact hours, language — if other than German)

| S (2) + Ü (2) |

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 180 minutes) or b) oral examination of one candidate each (20 to 30 minutes) or c) oral examination in groups of up to 3 candidates (approx. 15 minutes per candidate) or d) log (approx. 20 pages) or e) presentation (approx. 30 minutes)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO 1** (examination regulations for teaching-degree programmes)

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**Contents**

The module introduces students to theoretical chemistry.

**Intended learning outcomes**

German intended learning outcomes available but not translated yet.

Die Studierenden können mathematische und physikalische Grundlagen quantenchemischer und quantendynamischer Ansätze der Theoretischen Chemie darstellen.

**Courses** (type, number of weekly contact hours, language — if other than German)

S (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

a) written examination (approx. 90 to 180 minutes) or b) oral examination of one candidate each (20 to 30 minutes) or c) oral examination in groups of up to 3 candidates (approx. 15 minutes per candidate) or d) log (approx. 20 pages) or e) presentation (approx. 30 minutes)

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents

The module offers students the opportunity to work in a group of the Institute for Theoretical Chemistry as well as to become familiar with typical working methods. The main focus of the practical course is Quantum Chemistry.

### Intended learning outcomes

The students are able to apply typical working methods of the Theoretical Chemistry, especially in the area of Quantum Chemistry. He/She can explain specific contents of Quantum Chemistry.

### Courses

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### Allocation of places

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### Additional information

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(examination regulations for teaching-degree programmes)

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**Contents**

The module offers students the opportunity to work in a group of the Institute for Theoretical Chemistry as well as to become familiar with typical working methods. The main focus of the practical course is Quantum Dynamics.

**Intended learning outcomes**

The students are able to apply typical working methods of the Theoretical Chemistry, especially in the area of Quantum Dynamics. He/She can explain specific contents of Quantum Dynamics.

**Courses** (type, number of weekly contact hours, language — if other than German)

| P (5) |

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

presentation (approx. 30 minutes)
Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Application Subject Computer Science and Aerospace Computer Science
(ECTS credits)
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### Contents

Independent review of a current topic in computer science based on literature and, where applicable, software with written and oral presentation.

### Intended learning outcomes

The students are able to independently review a current topic in computer science, to summarise the main aspects in written form and to orally present these in an appropriate way.

### Courses

(type, number of weekly contact hours, language — if other than German)

**S (2)**

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

**term paper (10 to 15 pages) and presentation (30 to 45 minutes) with subsequent discussion on a topic from the field of computer science**

Language of assessment: German and/or English

### Allocation of places

--

### Additional information

Focuses available for students of the Master's programme Informatik (Computer Science, 120 ECTS credits): AT, SE, IT, IS, ES, LR, HCI.

**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

**Advanced Programming**

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### Module coordinator

holder of the Chair of Computer Science II

### Module offered by

Institute of Computer Science

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### Contents

With the knowledge of basic programming, taught in introductory lectures, it is possible to realize simpler programs. If more complex problems are to be tackled, suboptimal results like long, incomprehensible functions and code duplicates occur. In this lecture, further knowledge is to be conveyed on how to give programs and code a sensible structure. Also, further topics in the areas of software security and parallel programming are discussed.

### Intended learning outcomes

Students learn advanced programming paradigms especially suited for space applications. Different patterns are then implemented in multiple languages and their efficiency measured using standard metrics. In addition, parallel processing concepts are introduced culminating in the use of GPU architectures for extremely quick processing.

### Courses

(type, number of weekly contact hours, language — if other than German)

| V (2) + Ü (2) |

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- written examination (approx. 60 to 120 minutes).
- If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
- Language of assessment: German and/or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Contents

Advanced topics in automation systems as well as instrumentation and control engineering, for example from the field of sensor data processing, actuators, cooperating systems, mission and trajectory planning.

### Intended learning outcomes

The students have an advanced knowledge of selected topics in automation systems. They are able to implement advanced automation systems.

### Courses

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<th>(type, number of weekly contact hours, language — if other than German)</th>
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### Method of assessment

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### Allocation of places

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### Additional information

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**Contents**

Algorithmic foundations of geographic information systems and their application in selected problems of acquisition, processing, analysis and presentation of spatial information. Processes of discrete and continuous optimisation. Applications such as the creation of digital height models, working with GPS trajectories, tasks of spatial planning as well as cartographic generalisation.

**Intended learning outcomes**

The students are able to formalise algorithmic problems in the field of geographic information systems as well as to select and improve suitable approaches to solving these problems.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Module title  | Abbreviation
--- | ---
Computational Geometry | 10-l=AG-161-m01

Module coordinator  | Module offered by
holder of the Chair of Computer Science I | Institute of Computer Science

ECTS  | Method of grading  | Only after succ. compl. of module(s)
5 | numerical grade | --

Duration  | Module level  | Other prerequisites
1 semester | graduate | --

Contents
In many areas of computer science -- for example robotics, computer graphics, virtual reality and geographic information systems -- it is necessary to store, analyse, create or manipulate spatial data. This class is about the algorithmic aspects of these tasks: We will acquire techniques that are needed to plan and analyse geometric algorithms and data structures. Every technique will be illustrated with a problem in the practical areas listed above.

Intended learning outcomes
The students are able to decide which algorithms or data structures are suitable for the solution of a given geometric problem. The students are able to analyse new problems and to come up with their own efficient solutions based on the concepts and techniques acquired in the lecture.

Courses (type, number of weekly contact hours, language — if other than German)
V (2) + Ü (2)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 60 to 120 minutes).
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Language of assessment: German and/or English creditable for bonus

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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Module Catalogue for the Subject
Computational Mathematics
Master's with 1 major, 120 ECTS credits

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### Contents

The task of finding the optimal solution for a given problem is omnipresent in computer science. Unfortunately, there are many problems without an efficient algorithm for an optimal solution. As a result, in practice, methods are used which do not always give the optimal solution but always give good solutions. This lecture will discuss drafting and analysing techniques for algorithms which have a proven approximation quality. With the help of practical optimisation problems, the lecture will introduce students to important drafting techniques such as greedy, local search, scaling as well as methods based on linear programming.

### Intended learning outcomes

The students are able to analyse easy approximation methods in terms of their quality. They understand fundamental drafting techniques such as greedy, local search and scaling as well as methods based on linear programming and are able to apply these to new problems.

### Courses

(type, number of weekly contact hours, language — if other than German)

| (V (2) + Ü (2)) |

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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# Module Catalogue for the Subject
Computational Mathematics

## Master's with 1 major, 120 ECTS credits

### Module title
Automata Theory

### Abbreviation
10-I=AUT-161-m01

### Module coordinator
Dean of Studies Informatik (Computer Science)

### Module offered by
Institute of Computer Science

### ECTS
5

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

## Contents
Finite automata, regular languages, star-free languages, natural equivalence relations, predicate logic with words, language acceptance through monoids, syntactic monoid, predicate logical and algebraic characterisation of regular languages and star-free languages, two-way automata.

## Intended learning outcomes
The students possess a fundamental and applicable knowledge in the areas of finite automata, regular languages, star-free languages, natural equivalence relations, predicate logic with words, language acceptance through monoids, syntactic monoid, predicate logical and algebraic characterisation of regular and star-free languages, two-way automata.

## Courses
**Type, number of weekly contact hours, language — if other than German**

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## Method of assessment
**Type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus**

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Language of assessment: German and/or English creditable for bonus

## Allocation of places
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## Additional information
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## Referred to in LPO I
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## Module Catalogue for the Subject
### Computational Mathematics

**Master's with 1 major, 120 ECTS credits**

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### Contents

The course *Avionik-Systeme* (*Avionics Systems*) offers an overview of software, hardware, sensors, actuators and communication of airplanes and satellites: 1. software module and the software structure 2. control 3. ground control, 4. sensors and actuators, 5. sensor fusion, 6. reliability

### Intended learning outcomes

At the end of the course, the students should be familiar with typical structures of avionic systems for satellites and airplanes. They should be able to design these. They should be able to program simple controls.

### Courses (type, number of weekly contact hours, language — if other than German)

| (type) | V (2) + Ü (2) |

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I (examination regulations for teaching-degree programmes)

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Module title: Multimodal User Interfaces  
Abbreviation: 10-HCI-MMUI-161-m01

Module coordinator: holder of the Chair of Computer Science IX  
Module offered by: Institute of Computer Science

ECTS: 5  
Method of grading: Only after succ. compl. of module(s)

Duration: 1 semester  
Module level: graduate  
Other prerequisites: --

Contents:
The multimodal interaction paradigm simultaneously uses various modalities like speech, gesture, touch, or gaze, to communicate with computers and machines. Basically, multimodal interaction includes the analysis as well as the synthesis of multimodal utterances. This course concentrates on the analysis, i.e., the input processing. Input processing has the goal to derive meaning from signal to provide a computerized description and understanding of the input and to execute the desired interaction. In multimodal systems, this process is interleaved between various modalities and multiple interdependencies exist between simultaneous utterances necessary to take into account for a successful machine interpretation.

In this course, students will learn about the necessary steps involved in processing unimodal as well as multimodal input. The course will highlight typical stages in multimodal processing. Using speech processing as a primary example, they learn about:
1. A/D conversion
2. Segmentation
3. Syntactical analysis
4. Semantic analysis
5. Pragmatic analysis
6. Discourse analysis

A specific emphasis will be on stages like morphology and semantic analysis. Typical aspects of multimodal interdependencies, i.e., temporal and semantic interrelations are highlighted and consequences for an algorithmic processing are derived. Prominent multimodal integration (aka multimodal fusion) approaches are described, including transducers, state machines, and unification.

Intended learning outcomes:
After the course, the students will be able to build their own multimodal interfaces. They will have a broad understanding of all the necessary steps involved and will know prominent algorithmic solutions for each of them. Students will learn about available tools for reoccurring tasks and their pros and cons.

Courses:
V (2) + Ü (2)

Method of assessment:
presentation of project results (approx. 40 minutes)
Language of assessment: German and/or English
creditable for bonus

Allocation of places:
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Additional information:
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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**Contents**

Gödel numbering, computable functions, decidable and countable sets, halting problem, m-reducibility, creative and productive sets, relative computability, Turing reduction, countable degrees, arithmetic hierarchy.

**Intended learning outcomes**

The students possess a fundamental and applicable knowledge in the areas of Gödel numbers, countable functions, decidable and countable sets, halting problem, m-reducibility, creative and productive sets, relative computability, Turing reduction, countable degrees, arithmetic hierarchy.

**Courses**

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**Method of assessment**

Method of examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)

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**Contents**

Fundamental principles of bioinformatics.

**Intended learning outcomes**

Students are proficient in methods for the analysis of DNA and protein databases.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Compiler Construction**

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**Contents**

Lexical analysis, syntactic analysis, semantics, compiler generators, code generators, code optimisation.

**Intended learning outcomes**

The students possess knowledge in the formal description of programming languages and their compilation. They are able to perform transformations between them with the help of finite automata, push-down automata and compiler generators.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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### Contents

Syntax and semantics of logic programs; data structures, program structures and applications for Prolog; analytical methods for Datalog; negation and stratification; disjunctive logic programs.

### Intended learning outcomes

The students possess expertise in working with Prolog and Datalog (including negation and disjunction).

### Courses (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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**Contents**

Learning paradigms, learning system types, author systems, learning platforms, standards for learning systems, intelligent tutoring systems, student models, didactics, problem-oriented learning and case-based training systems, adaptive tutoring systems, computer-supported cooperative learning, evaluation of learning systems.

**Intended learning outcomes**

The students possess a theoretical and practical knowledge about eLearning and are able to assess possible applications.

**Courses** (type, number of weekly contact hours, language — if other than German)

| V (2) + Ü (2) |

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus.

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Module title | Abbreviation
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Introduction into Human-Computer Interaction | 10-MCS=HCI-161-m01

Module coordinator | Module offered by
holder of the Chair of Computer Science IX | Institute of Computer Science

ECTS | Method of grading | Only after succ. compl. of module(s)
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5 | numerical grade | --

Duration | Module level | Other prerequisites
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1 semester | graduate | --

Contents
Human-Computer Interaction is concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. This course gives an introduction into the principle biological, physiological, and psychological constraints as defined by the human user and relates these constraints to the conceptual and technical solutions of today's computer systems and existing as well as prospective interaction metaphors between humans and computers.

The course covers topics about human perception and cognition, memory and attention, the design of interactive systems, prominent evaluation methods, the principles of computer systems, typical input processing techniques, interface technology, and examples of typical interaction metaphors, from text-based input to graphical desktops to multimodal interfaces. Accompanying lab-work will introduce students to typical tasks involved in this field, i.e., prominent evaluation methods and prototyping of interfaces.

Intended learning outcomes
After the course, the students will have a broad understanding of the underlying principles of human users and computer systems. They will understand the constraints and capabilities of current user interfaces and they will learn about the necessary steps applied in user-centered design and development approaches.

Courses (type, number of weekly contact hours, language — if other than German)
V (2) + Ü (2)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
presentation of project results (approx. 30 minutes)

Language of assessment: German and/or English creditable for bonus

Allocation of places
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Additional information
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**Contents**

Models of embedded systems, implementation methods (ASIC, AISIP, micro controller), verification of embedded systems, implementation planning static, periodic and dynamic, binding problems, hardware synthesis, software synthesis.

**Intended learning outcomes**

The students are familiar with the technical possibilities for the design of embedded systems and master the most important techniques for the modelling, verification and optimisation of such systems in hardware and software.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).
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Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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### Contents
Program analysis, model creation in software engineering, program quality, test of programs, process models.

### Intended learning outcomes
The students are able to analyse programs, to use testing frameworks and metrics as well as to judge program quality.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).
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Language of assessment: German and/or English creditable for bonus

### Allocation of places
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**Contents**

IR models (e. g. Boolean and vector space model, evaluation), processing of text (tokenising, text properties), data structures (e. g. inverted index), query elements (e. g. query operations, relevance feedback, query languages and paradigms, structured queries), search engine (e. g. architecture, crawling, interfaces, link analysis), methods to support IR (e. g. recommendation systems, text clustering and classification, information extraction).

**Intended learning outcomes**

The students possess theoretical and practical knowledge in the area of information retrieval and have acquired the technical know-how to create a search engine.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

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Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

| 3D User Interfaces                       | 10-HCI=3DUI-161-m01 |

### Module coordinator

| holder of the Chair of Computer Science IX | Institute of Computer Science |

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### Duration

| 1 semester | graduate | -- |

### Contents

This module will give students the opportunity to learn about the specificities of 3D User Interfaces (3DUI) development using Virtual, Augmented or Mixed Reality technologies. The module content will be mainly dedicated to learn and practice the skills essential to the design and implementation of high-quality 3D interaction techniques. Design guidelines as well as classical and innovative 3D Interaction techniques will be studied. In addition, the course will address novel research themes such as 3D interaction for large displays and games; and integrating 3DUIs with mobile devices, robotics, and the environment. Students will be assessed through a group practical project (team work), which will consist of a program, a presentation, a technical report (2 ages) and a video. Previous years, the assignment replicated the IEEE 3DUI Contest 2011, where teams of students competed between each other to find the best solution (see results at [https://www.youtube.com/watch?v=gYs-pBW7Agc](https://www.youtube.com/watch?v=gYs-pBW7Agc) and [https://www.youtube.com/watch?v=gYs-pBW7Agc](https://www.youtube.com/watch?v=gYs-pBW7Agc))

### Intended learning outcomes

After the course, the students will gain a solid background on the theory and the methods to create your own 3D spatial interfaces. They will have a broad understanding of the particular difficulties of designing and developing spatial interfaces, as well as evaluating then. Students will also learn about traditional and novel 3D input/output devices (e.g., motion tracking system and Head-mounted Display).

### Courses

| type, number of weekly contact hours, language — if other than German |
| V (2) + Ü (2) |

### Method of assessment

| type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus |
| presentation of project results (approx. 30 minutes) |
| Language of assessment: German and/or English creditable for bonus |

### Allocation of places

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### Additional information

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**Contents**

Properties of NP-complete sets, autoreducibility, interactive proof systems, polynomial time hierarchy, complexity of probabilistic algorithms.

**Intended learning outcomes**

The students possess a fundamental and applicable knowledge in the areas of properties of NP-complete sets, autoreducibility, interactive proof systems, polynomial time hierarchies, complexity of probabilistic algorithms.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German and/or English

creditable for bonus

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**Additional information**

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### Contents
Intelligent agents, uninformed and heuristic search, constraint problem solving, search with partial information, propositional and predicate logic and inference, knowledge representation.

### Intended learning outcomes
The students possess theoretical and practical knowledge about artificial intelligence in the area of agents, search and logic and are able to assess possible applications.

### Courses
(V (2) + Ü (2))

### Method of assessment
Written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

### Allocation of places
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### Additional information
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### Contents

Planning, probabilistic closure and Bayesian networks, utility theory and decidability problems, learning from observations, knowledge while learning, neural networks and statistical learning methods, reinforcement learning, processing of natural language.

### Intended learning outcomes

The students possess theoretical and practical knowledge about artificial intelligence in the area of probabilistic closure, learning and language processing and are able to assess possible applications.

### Courses

| (type, number of weekly contact hours, language — if other than German) |
| V (2) + Ü (2) |

### Method of assessment

- written examination (approx. 60 to 120 minutes).
  - If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
  - Language of assessment: German and/or English
  - Creditable for bonus

### Allocation of places

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### Additional information

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### Contents
Traffic theoretic models, fundamental concepts of theory of probability, transformation techniques, stochastic processes, methods for performance analysis of technical systems, queue-/traffic theory, analysis of Markov, non-Markov and time critical systems, matrix analytical method, practical examples for performance analysis of computer systems and networks: throughput and goodput analysis and other characteristics.

### Intended learning outcomes
The students possess the methodic knowledge and the practical skills necessary to model technical systems by means of the theory of probability and mathematical statistics.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

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**Module coordinator**

Dean of Studies Informatik (Computer Science)

**Module offered by**

Institute of Computer Science

**ECTS**

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**Duration**

1 semester

**Module level**

graduate

**Other prerequisites**

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**Contents**

Propositional logic, first-order predicate logic, proof and deduction, Gödel’s completeness theorem, Tarski theorem, Gödel’s incompleteness theorem, undecidability and nonaxiomatisability of elemental arithmetic.

**Intended learning outcomes**

The students possess a fundamental and applicable knowledge in the areas of propositional logic, first-order predicate logic, proof and deduction, Gödel’s completeness theorem, Tarski theorem, Gödel’s incompleteness theorem, undecidability and nonaxiomatisability of elemental arithmetic.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes). If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate). Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Module coordinator**

holder of the Chair of Computer Science VI

**Module offered by**

Institute of Computer Science

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**Duration**

1 semester

**Module level**

graduate

**Other prerequisites**

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**Contents**

Electronic patient folder, coding of medical data, hospital information systems, operation of computers in infirmary and functional units, medical decision making and assistance systems, statistics and data mining in medical research, case-based training systems in medical training.

**Intended learning outcomes**

The students possess theoretical and practical knowledge about the application of computer science methods in medicine.

**Courses** (type, number of weekly contact hours, language — if other than German)

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**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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### Contents

Introduction to performance engineering of commercial software systems, performance measurement techniques, benchmarking of commercial software systems, modelling for performance prediction, case studies.

### Intended learning outcomes

The students possess a fundamental and applicable knowledge in the areas of performance metrics, measurement techniques, multi-factorial variance analysis, data analysis with R, benchmark approaches, modelling with queue networks, modelling methods, resource demand approximation, petri nets.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English

creditable for bonus

### Allocation of places

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### Additional information

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**Contents**

Spaces of numerical computation, raster and rounding, definition and implementation of computational arithmetic and interval calculation.

**Intended learning outcomes**

The students possess knowledge about the spaces of numerical computation, raster and roundings, definition and implementation of computational arithmetic and interval calculation. They master the application of algorithms.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title

Robotics 1

### Abbreviation

10-I=RO1-152-m01

### Module coordinator

holder of the Chair of Computer Science VII

### Module offered by

Institute of Computer Science

### ECTS

8

### Method of grading

numerical grade

### Duration

1 semester

### Module level

graduate

### Other prerequisites

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### Contents

History, applications and properties of robots, direct kinematics of manipulators: coordinate systems, rotations, homogenous coordinates, axis coordinates, arm equation. Inverse kinematics: solution properties, end effector configuration, numerical and analytical approaches, examples of different robots for analytical approaches. Workspace analysis and trajectory planning, dynamics of manipulators: Lagrange-Euler model, direct and inverse dynamics. Mobile robots: direct and inverse kinematics, propulsion system, tricycle, Ackermann steering, holonomes and non-holomite restrictions, kinematic classification of mobile robots, posture kinematic model. Movement control and path planning: roadmap methods, cell decomposition methods, potential field methods. Sensors: position sensors, speed sensors, distance sensors.

### Intended learning outcomes

The students master the fundamentals of robot manipulators and vehicles and are, in particular, familiar with their kinematics and dynamics as well as the planning of paths and task execution.

### Courses

V (4) + Ü (2)

### Method of assessment

written examination (approx. 60 to 90 minutes)

creditable for bonus

### Allocation of places

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**Module offered by**
Institute of Computer Science

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**Contents**
Foundations of dynamic systems, controllability and observability, controller design through pole assignment: feedback and feed-forward, state observer, feedback with state observer, time discrete systems, stochastic systems: foundations of stochastics, random processes, stochastic dynamic systems, Kalman filter: derivation, initialising, application examples, problems of Kalman filters, extended Kalman filter.

**Intended learning outcomes**
The students master all fundamentals that are necessary to understand Kalman filters and their use in applications of robotics. The students possess a knowledge of advanced controller and observer methods and recognise the connections between the dual pairs controllability - observability as well as controller design and observer design. They also recognise the relationship between the Kalman filter as a state estimator and an observer.

**Courses**
(type, number of weekly contact hours, language — if other than German)
V (4) + Ü (2)

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
written examination (approx. 60 to 90 minutes)  
creditable for bonus

**Allocation of places**
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**Contents**

Introduction to simulation techniques, statistical groundwork, creation of random numbers and random variables, random sample theory and estimation techniques, statistical analysis of simulation values, inspection of measured data, planning and evaluation of simulation experiments, special random processes, possibilities and limits of model creation and simulation, advanced concepts and techniques, practical execution of simulation projects.

**Intended learning outcomes**

The students possess the methodic knowledge and the practical skills necessary for the stochastic simulation of (technical) systems, the evaluation of results and the correct assessment of the possibilities and limits of simulation methods.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (4) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English
credible for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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Real-Time Interactive Systems

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Contents

This course provides an introduction into the requirements, concepts, and engineering art of highly interactive human-computer systems. Such systems are typically found in perceptual computing, Virtual, Augmented, Mixed Reality, computer games, and cyber-physical systems. Lately, these systems are often termed Real-Time Interactive Systems (RIS) due to their common aspects.

The course covers theoretical models derived from the requirements of the application area as well as common hands-on and novel solutions necessary to tackle and fulfill these requirements. The first part of the course will concentrate on the conceptual principles characterizing real-time interactive systems. Questions answered are: What are the main requirements? How do we handle multiple modalities? How do we define the timeliness of RIS? Why is it important? What do we have to do to assure timeliness? The second part will introduce a conceptual model of the mission-critical aspects of time, latencies, processes, and events necessary to describe a system's behavior. The third part introduces the application state, its requirements of distribution and coherence, and the consequences these requirements have on decoupling and software quality aspects in general. The last part introduces some potential solutions to data redundancy, distribution, synchronization, and interoperability. Along the way, typical and prominent state-of-the-art approaches to reoccurring engineering tasks are discussed. This includes pipeline systems, scene graphs, application graphs (aka field routing), event systems, entity and component models, and others. Novel concepts like actor models and ontologies will be covered as alternative solutions. The theoretical and conceptual discussions will be put into a practical context of today's commercial and research systems, e.g., X3D, instant reality, Unity3d, Unreal Engine 4, and Simulator X.

Intended learning outcomes

After the course, the students will have a solid understanding of the boundary conditions defined by both, the physiological and psychological characteristics of the human users as well as by the architectures and technological characteristics of today's computer systems. Participants will gain a solid understanding about what they can expect from today's technological solutions. They will be able to choose the appropriate approach and tools to solve a given engineering task in this application area and they will have a well-founded basis enabling them to develop alternative approaches for future real-time interactive systems.

Courses (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

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Language of assessment: German and/or English creditable for bonus

Allocation of places

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Additional information

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### Contents

Current topics in the area of aerospace.

### Intended learning outcomes

The students possess a fundamental and applicable knowledge about advanced topics in software engineering with a focus on modern software architectures and fundamental approaches to model-driven software engineering.

### Courses (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Language of assessment: German and/or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I (examination regulations for teaching-degree programmes)

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Module title
Machine Learning (for User Interfaces)
Abbreviation
10-HCI=MLUI-161-m01

Module coordinator
holder of the Chair of Computer Science IX
Module offered by
Institute of Computer Science

ECTS
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Method of grading
numerical grade

Duration
1 semester
Module level
graduate

Contents
Machine learning is the science of getting computers to act without being explicitly programmed. In the past decade, machine learning has given us practical speech recognition, effective web search, self-driving cars, and a vastly improved understanding of the human genome. Machine learning is so pervasive today that you probably use it dozens of times a day without knowing it. It is one of today's prominent paradigms in HCI applicable in all areas where the understanding of user input of high variability, specifically for natural interactions using, e.g., gesture, speech, or eye-gaze, is paramount. Many researchers also think it is the best way to make progress towards human-level AI.

In this course, students will learn about the most effective machine learning techniques, and gain practice implementing them and getting them to work. Students not only learn the theoretical underpinnings of learning, but also gain the practical know-how needed to quickly and powerfully apply these techniques to new problems. Finally, they learn about some of Silicon Valley's best practices in innovation as it pertains to machine learning and AI.

This course provides a broad introduction to machine learning, data-mining, and statistical pattern recognition. Topics include: (i) Supervised learning (parametric/non-parametric algorithms, support vector machines, kernels, neural networks). (ii) Unsupervised learning (clustering, dimensionality reduction, recommender systems, deep learning). (iii) Best practices in machine learning (bias/variance theory; innovation process in machine learning and AI). The course will also draw from numerous case studies and applications, so that you’ll also learn how to apply learning algorithms to building gesture-based and multimodal interfaces, text and speech understanding (web search, anti-spam), smart robots (perception, control), computer vision, medical informatics, audio, database mining, and other areas.

Intended learning outcomes
After the course, the students will be able to solve machine learning tasks on their own using assistive technologies, e.g., like Octave. In addition, they will be able to derive main principles and apply these in own programs. Students will be able to choose the appropriate approach and tools to solve a given machine learning task in various application area, specifically in HCI.

Courses (type, number of weekly contact hours, language — if other than German)
V (2) + Ü (2)

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
presentation of project results (approx. 40 minutes)
Language of assessment: German and/or English creditable for bonus

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
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<thead>
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<td>Visualization of Graphs</td>
<td>10-I=VG-161-m01</td>
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<td>holder of the Chair of Computer Science I</td>
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**Contents**

This course covers the most important algorithms to draw graphs. Methods from the course *Algorithmische Graphentheorie* (*Algorithmic Graph Theory*) such as divide and conquer, flow networks, integer programming and the planar separator theorem will be used. We will become familiar with measures of quality of a graph drawing as well as algorithms to optimise these measures.

**Intended learning outcomes**

The participants get an overview of graph visualisation and become familiar with typical tools. They consolidate their knowledge about the modelling and solving of problems with the help of graphs and graph algorithms.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

Written examination (approx. 60 to 120 minutes).

If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).

Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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**Contents**

Selected topics in algorithmics and theory.

**Intended learning outcomes**

The students understand the basic approach of algorithmic computer science. They are able to understand the solutions of complex problems in this area and apply them to similar questions.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).
If announced by the lecturer at the beginning of the course, the written examination may be replaced by an oral examination of one candidate each (approx. 20 minutes) or an oral examination in groups of 2 candidates (approx. 15 minutes per candidate).
Language of assessment: German and/or English creditable for bonus

**Allocation of places**

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**Additional information**

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### Contents

Selected topics in algorithmics and theory.

### Intended learning outcomes

The students understand the basic approach of theoretical computer science. They are able to understand the solutions of complex problems in this area and apply them to similar questions.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (2) + Ü (2)

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

written examination (approx. 60 to 120 minutes).

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Language of assessment: German and/or English creditable for bonus

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<td>Image and Signal Processing in Physics</td>
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### Module coordinator
Managing Director of the Institute of Applied Physics

### Module offered by
Faculty of Physics and Astronomy

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### Contents
Periodic and aperiodic signals; principles of discreet and exact Fourier transformation; principles of digital signal and image processing; discretisation of signals/sampling theorem (Shannon); homogeneous and linear filters, convolution product; tapering functions and interpolation of images; the Parseval theorem, correlation and energetic observation; statistical signals, image noise, moments, stationary signals; tomography: Hankel and Radon transformation.

### Intended learning outcomes
The students have advanced knowledge of digital image and signal processing. They know the physical principles of image processing and are familiar with different methods of signal processing. They are able to explain different methods and to implement them, especially in the field of tomography.

### Courses
(V (2) + Ü (2))
Module taught in: German or English

### Method of assessment
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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### Module Title

**Quantum Information Technology**

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### Module Coordinator

Managing Director of the Institute of Applied Physics

### Module Offered by

Faculty of Physics and Astronomy

### ECTS

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### Contents

Basic concepts of quantum mechanics, quantum bits and algorithms, quantal measurements, experimental approaches towards quantum computing (on the basis of photons, ions and nuclear spins), quantum operations and quantum noise, quantum information and communication.

### Intended Learning Outcomes

The students are familiar with the basic quantum mechanical terms of quantum information technology. They know experimental approaches for the realisation of quantum computers and for the transfer of quantum information.

### Courses

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Module taught in: German or English

### Method of Assessment

**Type, Scope, Language** — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of Places

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### Additional Information

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(examination regulations for teaching-degree programmes)

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</table>

**Contents**

General properties of various material groups such as liquids, liquid crystals and polymers; magnetic materials and superconductors; thin films, heterostructures and superlattices. Methods of characterising these material groups; two-dimensional layer materials.

**Intended learning outcomes**

The students know the properties and characterization methods of some modern materials.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents

This lecture covers the basic principles of spin transport, with a particular emphasis on the phenomena of giant magnetoresistance and tunnel magnetoresistance. As a last point, we discuss new phenomena from the field of spin dynamics and current-induced spin phenomena.

### Intended learning outcomes

The students know the basic principles of spin transport models and the applications of spin transport in information technology. They have gained an overview of current findings in this field (giant magnetoresistance, tunnel magnetoresistance).

### Courses

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Module taught in: German or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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**Contents**

Modern scattering methods; neutron scattering as a method to investigate the atomic and magnetic structure and excitations such as phonons and magnetic waves; resonant elastic X-ray scattering and absorption; investigation of magnetic, orbital and charge order; X-ray and neutron reflectometry; investigation of the structural, magnetic and electronic properties of thin films and superlattices; resonant inelastic X-ray scattering; investigation of excitations in solids and thin films; STEM ("scanning transmission electron microscopy"); further topics upon agreement.

**Intended learning outcomes**

The students know different modern scattering methods such as neutron scattering, resonant elastic X-ray scattering, modern scattering theory, X-ray and neutron reflectometry and resonant inelastic X-ray scattering. They are familiar with the theoretical principles and applications of these methods.

**Courses** (type, number of weekly contact hours, language — if other than German)

- V (4) + R (2)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Contents**


**Intended learning outcomes**

The students have specific and advanced knowledge in the field of solid-state spectroscopy. They know different types of spectroscopy and their fields of application. They understand the theoretical principles and the current developments in research.

**Courses**

(type, number of weekly contact hours, language — if other than German)

V (3) + R (1)
Module taught in: German or English

**Method of assessment**

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I**
(examination regulations for teaching-degree programmes)
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Module title: Magnetism  
Abbreviation: 11-MAG-161-m01

Module coordinator: Managing Director of the Institute of Applied Physics
Module offered by: Faculty of Physics and Astronomy

ECTS: 6  
Method of grading: numerical grade  
Duration: 1 semester  
Module level: graduate  
Other prerequisites: --

Contents: Dia- and paramagnetism, exchange interaction, ferromagnetism, antiferromagnetism, anisotropy, domain structure, nanomagnetism, superparamagnetism, experimental methods to measure magnetic properties, Kondo effect.

Intended learning outcomes: The students know basic terms, concepts and phenomena of magnetism and measuring methods for magnetic experiments; they are skilled in simple model building and in the formulation of mathematical-physical approaches and are able to apply them to tasks in the stated areas; they have competencies in independently working on problems of these areas; they are able to evaluate the accuracy of observations and analyses.

Courses: (type, number of weekly contact hours, language — if other than German)  
V (3) + R (1)  
Module taught in: German or English

Method of assessment: (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)  
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Allocation of places: --

Additional information: --

Referred to in LPO I (examination regulations for teaching-degree programmes) --
### Module title
Semiconductor Physics

### Abbreviation
11-HLPH-161-m01

### Module coordinator
Managing Director of the Institute of Applied Physics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
6

### Method of grading
Numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
Graduate

### Other prerequisites
--

### Contents
1. Symmetry properties
2. Crystal formation and electronic band structure
3. Optical excitations and their coupling effects
4. Electron-phonon coupling
5. Temperature-dependent transport properties
6. Magnetic semiconductors

### Intended learning outcomes
The students are familiar with the principles of Semiconductor Physics. They understand the structure of semiconductors and know their physical properties and effects. They know important applications.

### Courses
V (3) + R (1)
Module taught in: German or English

### Method of assessment
Written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Optical Properties of Semiconductor Nanostructures</td>
<td>11-HNS-161-m01</td>
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<td>Managing Director of the Institute of Applied Physics</td>
<td>Faculty of Physics and Astronomy</td>
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<tr>
<td>1 semester</td>
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</table>

**Contents**

Semiconductor nanostructures are frequently referred to as "artificial materials". In contrast to atoms, molecules or macroscopic crystals, their electronic, optical and magnetic properties can be systematically tailored by changing their size. The lecture addresses technological challenges in the preparation of semiconductor nanostructures of varying dimensions (2D, 1D, 0D). It provides the basic theoretical concepts to describe their properties, with a focus on optical properties and light-matter coupling. Moreover, it discusses the challenges and concepts of novel optoelectronic and quantum photonic devices based on such nanostructures, including building blocks for quantum communication and quantum computing architectures.

**Intended learning outcomes**

The students know the theoretical principles and characteristics of semiconductor nanostructures. They have knowledge of the technological methods to fabricate such structures, and of their applications to novel photonic devices. They are able to apply their knowledge to problems in this field of research.

**Courses**

(V (3) + R (1))

Module taught in: German or English

**Method of assessment**

Written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I**

(examination regulations for teaching-degree programmes)
### Module title
Quantum Transport

### Abbreviation
11-QTH-161-m01

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### Contents
The lecture addresses the fundamental transport phenomena of electrons in nanostructures. This includes the topics of: ballistic and diffuse transport, electron interference effects, quantisation of conductivity, interaction phenomena between electrons, Coulomb blockade, thermoelectric properties, description of spin-dependent transport phenomena, topological insulators, solid-state quantum computers.

### Intended learning outcomes
The students have mastered the basics of electronics of nanostructures in theory and practice. They know functions and applications of respective components.

### Courses
V (3) + R (1)  
Module taught in: German or English

### Method of assessment
- written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes)  
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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)
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## Module title
Methods of Observational Astronomy

<table>
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<tr>
<th>Abbreviation</th>
<th>11-ASM-161-m01</th>
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### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

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### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
Methods of observational astronomy across the electromagnetic spectrum. Evaluation of observational data from radio, optical, X-ray and gamma-ray telescopes.

### Intended learning outcomes
Overview of the methods used in observational astronomy in various parts of the electromagnetic spectrum (radio, optical, X-ray and gamma-ray energies). Knowledge of principles and applications of these methods and ability to conduct astronomical observations.

### Courses
V (3) + R (1)

Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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Master's with 1 major Computational Mathematics

2016

JMU Würzburg • generated 03-Apr-2021 • exam. reg. data record Master (120 ECTS) Computational Mathematics - 2016

page 139 / 178
Module title
Experimental Particle Physics

Abbreviation
11-TPE-161-m01

Module coordinator
Managing Director of the Institute of Applied Physics

Module offered by
Faculty of Physics and Astronomy

ECTS
6

Method of grading
numerical grade

Only after succ. compl. of module(s)

Duration
1 semester

Module level
graduate

Other prerequisites
--

Contents
Physics with modern particle detectors at the LHC and at the Tevatron. Discovery of the Higgs boson. Search for supersymmetry and other physics beyond the standard model. Determination of the top quark mass and W mass as well as other parameters of the standard model. Introduction to modern methods of analysis and assessment of systematic errors.

Intended learning outcomes
The students are familiar with the principles of modern particle detector physics, especially with currently open questions of Particle Physics, which are examined by using these detectors. They know modern methods of analysis and are able to put results into context and to assess their systematic uncertainties.

Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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<td>Introduction to Space Physics</td>
<td>11-ASP-161-m01</td>
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</table>

**Contents**

1. Overview  
2. Dynamics of charged particles in magnetic and electric fields  
3. Elements of space physics  
4. The sun and heliosphere  
5. Acceleration and transport of energetic particles in the heliosphere  
6. Instruments to measure energetic particles in extraterrestrial space

**Intended learning outcomes**

The students acquire basic knowledge of Space Physics, in particular regarding the characterisation of the dynamics of charged particles in space and the heliosphere. They know relevant parameters and theoretical concepts and corresponding measuring methods.

**Courses**

V (3) + R (1)  
Module taught in: German or English

**Method of assessment**

- written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes)  
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Assessment offered: In the semester in which the course is offered and in the subsequent semester

**Language of assessment**: German and/or English

**Allocation of places**

-  

**Additional information**

-  

**Referred to in LPO I**

(examination regulations for teaching-degree programmes)
Module title: Multi-wavelength Astronomy  
Abbreviation: 11-MAS-161-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics
Module offered by: Faculty of Physics and Astronomy

ECTS: 6
Duration: 1 semester

Method of grading: Only after succ. compl. of module(s)

Module level: graduate
Other prerequisites: --

Contents:
1. Phenomenology of active galactic nuclei and extragalactic jets
2. Jet-emission processes
3. VLBI observations of jets
4. High-energy observations of jets
5. Multimessenger signatures of jets

Intended learning outcomes:
The students acquire knowledge of multiwavelength astronomy by studying the observations of active galactic nuclei and their extragalactic jets. They gain insights into a special, not yet solved astrophysical question and practice writing an observational proposal.

Courses:
V (3) + R (1)
Module taught in: German or English

Method of assessment:
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places: --

Additional information: --

Referred to in LPO I (examination regulations for teaching-degree programmes): --
Quantum Mechanics II

11-QM2-161-m01

Managing Director of the Institute of Theoretical Physics and Astrophysics

Faculty of Physics and Astronomy

ECTS | Method of grading | Only after succ. compl. of module(s)
--- | --- | ---
8 | numerical grade | --

Duration & Module level & Other prerequisites
1 semester & undergraduate & --

Contents
The contents of this lecture build upon and will be chosen in accordance with the topics of the Bachelor's degree course "Quantum Mechanics I". Topics might include:
for QM:
1. Historical introduction
2. Single-particle states in a central potential
3. Principles of quantum mechanics
4. Spin and angular momentum
5. Approximations of energy eigenvalues
6. Approximations for time-dependent problems
7. Second quantisation
8. Potential scattering
9. General scattering theory
10. Canonical formalism
11. Charged particles in electromagnetic fields
12. Quantum theory of radiation
13. Quantum entanglement

Intended learning outcomes
The students acquire in-depth knowledge of advanced quantum mechanics. This knowledge is highly relevant to most of the theoretical Master's degree courses in Astrophysics, Particle Physics and Condensed Matter Physics. The completion of this course is highly recommended.

Courses (type, number of weekly contact hours, language — if other than German)

V (4) + R (2)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)

--
**Module title** | **Abbreviation**
--- | ---
Theory of Relativity | 11-RTT-161-m01

**Module coordinator** | **Module offered by**
--- | ---
Managing Director of the Institute of Theoretical Physics and Astrophysics | Faculty of Physics and Astronomy

**ECTS** | **Method of grading** | **Only after succ. compl. of module(s)**
--- | --- | ---
6 | numerical grade | --

**Duration** | **Module level** | **Other prerequisites**
--- | --- | ---
1 semester | graduate | --

**Contents**

1. Mathematical Foundations  
2. Differential forms  
3. Brief Summary of the special relativity  
4. Elements of differential geometry  
5. Electrodynamics as an example of a relativistic gauge theory  
6. Field equations of the fundamental structure of general relativity  
7. Stellar equilibrium and other astrophysical applications  
8. Introduction to cosmology

**Intended learning outcomes**

The students become familiar with the principal physical and mathematical concepts of general relativity. The main topics include modern formulation on the basis of differential forms. Furthermore, the similarities between electrodynamics as a gauge theory and general relativity are emphasised. The students learn to apply the theory to simple models of stellar equilibrium and are introduced to basic elements of cosmology.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)  
Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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## Module Catalogue for the Subject
Computational Mathematics

### Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<td>Many Body Quantum Theory</td>
<td>11-QVTP-161-m01</td>
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<tbody>
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</table>

### Contents

In this lecture, Quantum Physics of many-particle systems are introduced on the basis of the perturbative methods of the Green's functions. A possible outline might be:

1. Single-particle Green's function
2. Review of second quantisation
3. Perturbation theory using many-particle Green's functions at temperature T=0
4. Perturbation theory for finite temperatures
5. Landau theory of Fermi liquids
6. Superconductivity
7. One-dimensional systems and bosonisation

### Intended learning outcomes

The students acquire knowledge of the methods of quantum field theory in a non-relativistic context. This knowledge enables them to study properties of Fermi liquids (and bosonic systems) beyond the one-particle picture, and to understand the effects of interactions, including superconductivity and the Kondo effect.

### Courses

<table>
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<th>Type</th>
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<th>Language</th>
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Module taught in: German or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(Examination regulations for teaching-degree programmes)

--
## Physics of Complex Systems

### Module title
Physics of Complex Systems

### Abbreviation
11-PKS-161-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
6

### Method of grading
numerical grade

### Only after succ. compl. of module(s)
--

### Duration
1 semester

### Module level
graduate

### Other prerequisites
--

### Contents
1. Theory of critical phenomena in thermal equilibrium
2. Introduction into the physics out of equilibrium
3. Entropy production and fluctuation
4. Phase transitions away from equilibrium
5. Universality
6. Spin glass
7. Theory of neural networks

### Intended learning outcomes
The students acquire in-depth knowledge of a wide variety of concepts and methods essential for a thorough understanding of cooperative phenomena in complex many-particle systems. The main focus includes a thorough understanding of the concepts of entropy, entropy production and universality. The students are prepared for research activities in different areas of physics of complex systems.

### Courses
V (2) + R (2)

Module taught in: German or English

### Method of assessment
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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<table>
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<td>Quantum Information and Quantum Computing</td>
<td>11-QIC-161-m01</td>
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### Contents

1. Brief summary of classical information theory
2. Quantum theory seen from the perspective of information theory
3. Composite systems and the Schmidt decomposition
4. Entanglement measures
5. Quantum operations, POVMs, and the theorems of Kraus and Stinespring
6. Quantum gates and quantum computers
7. Elements of the theory of decoherence

### Intended learning outcomes

The students acquire a comprehensive understanding of quantum states and density matrices beyond the usual textbook interpretation. They learn how to safely handle tensor products and multipartite quantum systems. The main topics of the lecture include basic mathematical concepts of quantum information theory and the limits of quantum computing arising from decoherence.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (3) + R (1)
Module taught in: German or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

- written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

--
Module title: Theoretical Solid State Physics
Abbreviation: 11-TFK-161-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics
Module offered by: Faculty of Physics and Astronomy

ECTS: 8
Method of grading: numerical grade
Only after succ. compl. of module(s): --

Duration: 1 semester
Module level: graduate
Other prerequisites: --

Contents:
The contents of this two-term course will depend on the choice of the lecturer, and may include parts of the syllabus which could alternatively be offered as "Quantum Many Body Physics" (11-QVTP).
A possible syllabus may be:
1. Band structure (Sommerfeld theory of metals, Bloch theorem, k.p approach and effective Hamiltonians for topological insulators (TIs), bulk-surface correspondence, general properties of TIs)
2. Electron-electron interactions in solids (path integral method for weakly interacting fermions, mean field theory, random phase approximation (RPA), density functional theory)
3. Application of mean field theory and the RPA to magnetism
4. BCS theory of superconductivity

Intended learning outcomes:
During the two-semester lecture, the students acquire a basic understanding of many topics of Solid-State Physics, which are addressed in classical textbooks, and thereby advance their knowledge of the underlying concepts and the methods of description. The course builds upon the courses "Experimental Condensed Matter Physics" and "Quantum Mechanics".

Courses:
(type, number of weekly contact hours, language — if other than German)
V (4) + R (2)
Module taught in: German or English

Method of assessment:
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places:
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Additional information:
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Referred to in LPO I (examination regulations for teaching-degree programmes):
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## Module title

### Theoretical Solid State Physics 2

### Abbreviation

11-TFK2-161-m01

## Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

## Module offered by

Faculty of Physics and Astronomy

## ECTS

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## Contents

A continuation of the first semester (11-TFK) might be the following syllabus:

1. Theoretical Solid State Physics
2. Advanced topics of the theory of superconductivity (Bogoliubov-de Gennes equations, effective field theory, Anderson-Higgs description of the Meissner effect)
3. Unconventional superconductors (e.g., copper-oxide high-Tc superconductors)
4. Green's function methods and Feynman diagrammatic technique
5. The Kondo Effect (Anderson's "poor man's scaling", renormalization group)

## Intended learning outcomes

During the two-semester lecture, the students acquire a basic understanding of many topics of Solid-State Physics, which are addressed in classical textbooks, and thereby advance their knowledge of the underlying concepts and the methods of description. The course builds upon the courses "Experimental Condensed Matter Physics" and "Quantum Mechanics".

## Courses

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Module taught in: German or English

## Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

## Allocation of places

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## Additional information

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## Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Module title
Field Theory in Solid State Physics

### Abbreviation
11-FTFK-161-m01

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### Contents
This will usually be a course on quantum many particle physics using the method of functional integration. An outline could be:
1. Coherent states and review of second quantization
2. The functional integral formalism at finite temperatures $T$
3. Perturbation theory at $T=0$
4. Order parameters and broken symmetry
5. Green's functions
6. The Landau theory of Fermi liquids
7. Further developments

### Intended learning outcomes
The students are enabled to apply the modern methods of path and functional integrals to quantum many-particle systems. These methods complement the traditional methods of Green's functions and Feynman diagrams.

### Courses (type, number of weekly contact hours, language — if other than German)
V (4) + R (2)
Module taught in: German or English

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### Additional information
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**Contents**

Topologically ordered phases possess no order in the conventional sense (i.e., no broken symmetry and no local order parameter). The order is instead characterized by topological quantum numbers. In the course, the general concepts will be illustrated with the study of specific examples of systems with topological order. The topics discussed may include:

1. Fractional charge and statistics in quantized Hall fluids
2. Spin charge separation in spin chains and chiral spin liquids
3. Non-Abelian statistics of fractionalized excitations
4. Majorana zero modes in p-wave superconductors
5. Topological degeneracies on higher genus surfaces (e.g., torus geometry)
6. Spinons and visons in spin liquids including Kitaev models.

**Intended learning outcomes**

The students acquire in-depth knowledge of topological order in quantum condensates.

**Courses**

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Module taught in: German or English

**Method of assessment**

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Contents

1. Geometric phase in quantum systems
2. Mathematical basics of topology
3. Time-reversal symmetry
4. Hall conductance and Chern numbers
5. Bulk-boundary correspondence
6. Graphene (as a topological insulator)
7. Quantum Spin Hall insulators
8. Z2 invariants
9. Topological superconductors

### Intended learning outcomes

The students acquire a theoretical understanding of topological concepts in modern Solid-State Physics. These concepts serve as a basis of many research activities of the Faculty of Physics and Astronomy at the University of Würzburg.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (3) + R (1)

Module taught in: German or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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### Module title

**Theory of Superconductivity**

### Abbreviation

11-TSL-161-m01

### Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by

Faculty of Physics and Astronomy

### ECTS

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### Contents


### Intended learning outcomes

This lecture focuses on the understanding of unconventional superconductivity and the interactions with magnetism in the current research context. The first part of the lecture addresses conventional molecular field theory of superconductivity (BCS theory), which fails when applied to new material classes such as high-temperature superconductors. Subsequently, it introduces tools of quantum field theory necessary to expand BCS theory. Therefore it especially focuses on Meissner effect and Higgs mechanism. The last part of the lecture discusses current developments concerning the description and analysis of (un)conventional superconductors and their fascinating connection to competing magnetic phases.

### Courses

- (type, number of weekly contact hours, language — if other than German)
  - V (3) + R (1)
  - Module taught in: German or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I

(examination regulations for teaching-degree programmes)

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## Module Catalogue for the Subject

**Computational Mathematics**

*Master's with 1 major, 120 ECTS credits*

### Module title

**Computational Materials Science (DFT)**

### Abbreviation

11-CMS-161-m01

### Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by

Faculty of Physics and Astronomy

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### Duration

1 semester

### Module level

graduate

### Other prerequisites

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### Contents

1. Density functional theory (DFT)
2. Wannier functions and localized basis functions
3. Numerical evaluation of topological invariants
4. Hartree-Fock and static mean-field theory
5. Many-body methods for solid state physics
6. Anderson impurity model (AIM) and Kondo physics
7. Dynamical mean-field theory (DMFT)
8. DFT + DMFT methods for realistic modeling of solids
9. Strongly correlated electrons

### Intended learning outcomes

Aside from the theoretical discussion of these topics, the students carry out hands-on exercises from the CIP pool. The participants are introduced to the use of DFT software packages such as VASP or Wien2k and to the construction of maximally localised Wannier functions through the projection of DFT results on atom orbitals with the software wannier90. Furthermore, the students learn how to construct many-particle solutions of AIM and observe border cases such as the Kondo regime. Impurity solvers such as exact diagonalisation or continuous-time quantum Monte Carlo are utilised to solve the self consistency equations of dynamic molecular field theory (DMFT). These steps are necessary to reach the peak of the lecture: a DFT-DMFT calculation of a strongly correlated transition metal oxide such as SrVO3.

### Courses

(type, number of weekly contact hours, language — if other than German)

V (4) + R (2)

Module taught in: German or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

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**Contents**

Conformal field theory (CFT) was developed in the 1980s and found immediate application in string theory and two-dimensional statistical mechanics, where critical exponents and correlation functions for many models (Ising, tricritical Ising, 3-state Potts, etc.) could be exactly calculated. The physical idea is that the principle of scale invariance is elevated from a global to a local invariance, which, for reasons of consistency, amounts to invariance under conformal transformations. This, in turn, yields a rich and fascinating mathematical structure for two-dimensional systems (either two space dimensions or one time and one space dimension). CFT has become relevant to many interesting areas of condensed matter physics, including Abelian and non-Abelian bosonisation, quantised Hall states (where the bulk wave function is described in terms of conformal correlators, and the edge in terms of 1+1 dimensional CFTs), the two-channel Kondo effect, fractional topological insulators, and in particular fault-tolerant topological quantum computers involving non-Abelian anyons (Ising and Fibonacci anyons, for example, owe their names to the fusion rules of the associated conformal fields.) A potential syllabus for the first term of the course is:

**0. Introduction** (scale and conformal invariance, critical exponents, the transverse Ising model at the self-dual point)

**1. Conformal theories in D dimensions** (conformal group, conformal algebra in 2D, constraints on correlation functions)

**2. Conformal theories in D=2** (primary fields and correlation functions, quantum field theory, canonical quantisation and Noether's theorem, radial quantisation and Polyakov's theorem, time ordering and functional integration, the free boson and vertex operators, conformal Ward identities)

**3. Central charge and Virasoro algebra** (central charge, the Schwarzian derivative, free fermion, (Abelian) bosonisation, mode expansions and Virasoro algebra, cylinder geometry and Casimir effect, in- and out-states, highest weight states, descendant fields and operator product expansions, conformal blocks, duality and bootstrap)

**4. Kac determinant and unitarity** (Verma modules and null states, Kac determinant formula, non-unitarity proof, conformal grids, minimal models in general).

**Intended learning outcomes**

The students acquire practical and conceptional familiarity with the methods of conformal field theory. As the completion of "Quantum Mechanics II" (11-QM2) is the only prerequisite to take part in this course, the students also acquire basic knowledge of critical phenomena, quantum field theory and functional integrals. The course is primarily addressed to students of Theoretical Physics and aims to increase their general level of knowledge by becoming acquainted with a sophisticated subdiscipline with applications in many subdisciplines of Condensed Matter Physics.

**Courses** (type, number of weekly contact hours, language — if other than German)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

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| Managing Director of the Institute of Theoretical Physics and Astrophysics | Faculty of Physics and Astronomy |

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### Contents

5. Minimal models (critical statistical mechanics models (Ising, tricritical Ising, 3 state Potts model, restricted solid-on-solid models), correlation functions of the critical Ising model, fusion rules and Verlinde algebra, Landau-Ginzburg description of minimal models, modified Coulomb gas method and its application to the Ising model, superconformal models)

6. Free bosons and fermions (mode expansions, twist fields, fermionic zero modes and fermion parity)

7. Free fermions on the torus (operator implementation of the partition function, vacuum energies, representations of Virasoro algebra, modular group and fermionic spin structures, Virasoro characters, critical Ising model on the torus, Jacobi theta function identities)

8. Free bosons on the torus (Lagrangian formulation of the partition function, fermionisation, orbifolds in general, $S_1/Z_2$ orbifold, Gaussian and Askin-Teller models, duality between original and orbifold theories, marginal operators, the space of $c=1$ theories)

### Intended learning outcomes

The students acquire practical and conceptional familiarity with the methods of conformal field theory. As the completion of "Quantum Mechanics II" (11-QM2) is the only prerequisite to take part in this course, the students also acquire basic knowledge of critical phenomena, quantum field theory and functional integrals. The course is primarily addressed to students of Theoretical Physics and aims to increase their general level of knowledge by becoming acquainted with a sophisticated subdiscipline with applications in many subdisciplines of Condensed Matter Physics.

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V (3) + R (1)

Module taught in: German or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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## Module Catalogue for the Subject
### Computational Mathematics
#### Master's with 1 major, 120 ECTS credits

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### Contents

The contents of the course vary from year to year and include topics such as spin-wave theory, spin-chains, spin ladders and spin liquids with topological orders. Depending on the lecturer, the focus may lie on magnetically ordered systems or on spin liquids.

Possible topics are:

2. Magnetic order (Holstein-Primakoff bosons and spin-wave theory)
3. Valence bond solids in spin chains (Majumdar-Gosh and AKLT Models, spinon confinement and the Haldane gap)
4. Critical spin-1/2 chains (spinon excitations in the Haldane-Shastry model, holon excitations in the Kuramoto-Yokohama model)
5. Coupled spin chains and ladders
6. Chiral spin liquids (Abelian and possibly non-Abelian)
7. Kitaev’s toric code model (spinon and vison excitations)

### Intended learning outcomes

The students develop an understanding of the electronic origins of magnetism, spin-wave theory, spin-charge separation in one dimensional systems and spin-liquids as examples of systems with a topological order in two dimensions.

### Courses

(type, number of weekly contact hours, language — if other than German)

- **V (3)** + **R (1)**

Module taught in: German or English

### Method of assessment

(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

--
## Module title

Topological Quantum Physics

### Abbreviation

11-TQP-161-m01

## Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

## Module offered by

Faculty of Physics and Astronomy

## ECTS

6

## Method of grading

numerical grade

## Only after succ. compl. of module(s)

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## Duration

1 semester

## Module level

graduate

## Other prerequisites

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## Contents

The course is aimed at Masters students pursuing either experimental or theoretical work in their thesis. Depending on the lecturers emphasis, it is meant to provide an introduction to topological superconductors and insulators assuming only "Quantum mechanics II" (11-QM2) as a prerequisite. The contents may include:

1. Introduction to superconductivity (including BCS theory)
2. Majorana fermions and topological superconductors in 1D (Kitaev wires)
3. Topological superconductors in two dimensions (2D) (including Majorana edge states and non-Abelian statistics)
4. Integer quantum Hall effect and Chern insulators (Haldane model, Jackiw-Rebbi solitons and edge states)
5. Berry's phase and Chern invariants
6. Time reversal symmetry and topological insulators in 2D
7. Topological insulators in 3D

## Intended learning outcomes

In-depth understanding of the topological concepts of Quantum Physics relevant to current research projects of Condensed Matter Physics at the University of Würzburg.

## Courses

V (3) + R (1)

Module taught in: German or English

## Method of assessment

written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

## Allocation of places

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## Additional information

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## Referred to in LPO I

( examination regulations for teaching-degree programmes)
Module title: Renormalization Group and Critical Phenomena
Abbreviation: 11-CRP-161-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics
Module offered by: Faculty of Physics and Astronomy

ECTS: 6
Method of grading: Only after succ. compl. of module(s)
Numerical grade: --
Duration: 1 semester
Module level: graduate
Other prerequisites: --

Contents:
1. Phase transitions
2. Mean field theory
3. The concept of the renormalization group (RG) Phase diagrams and fixed points
4. Perturbation-theoretical renormalization group
5. Low-dimensional systems
6. Conformal symmetry

Intended learning outcomes:
The students acquire profound knowledge of the principles of scale invariance and of the renormalisation group (RG) in Statistical Physics. They understand the concept of RG flow with respect to effective field theories in both statistical and quantum field theory.

Courses:
V (3) + R (1)
Module taught in: German or English

Method of assessment:
written examination (approx. 90 to 120 minutes) or oral examination of one candidate each (approx. 30 minutes) or oral examination in groups (groups of 2, approx. 30 minutes per candidate) or project report (approx. 8 to 10 pages) or presentation/talk (approx. 30 minutes).
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places: --

Additional information: --

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<td>Bosonisation and Interactions in One Dimension</td>
<td>11-BWW-161-m01</td>
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**Contents**

1. Instability of Fermi systems in one dimension (1D)
2. Abelian bosonisation and Luttinger liquids (spinless fermions, correlation functions, models with spin, renormalization group, and the sine-Gordon model).

The below mentioned topics will be presented in different years:
3. Interacting fermions on a lattice (Hubbard model, t/J model, transport properties)
4. Bethe ansatz
5. Spin-1/2 chains
6. Disordered systems
7. Non-abelian bosonisation and the WZW model (Kac-Moody algebras, Sugawara construction, Knizhnik-Zamolodchikov equation, applications of the WZW model)

**Intended learning outcomes**

The students become familiar with the peculiarities of one-dimensional (1D) electron systems and acquire the theoretical tools to understand phenomena relevant to experiments, including disorder effects and transport in 1D.

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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## Gauge Theories

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<td>11-EIT-161-m01</td>
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### Contents

The main topic of the course will usually be lattice gauge theories. The concepts may be taught and illustrated by elaborating on the role of lattice gauge theories in spin systems.

A possible outline might be:
1. Introduction to lattice gauge theories for spin systems
2. Phase transitions
3. The transfer matrix
4. The two-dimensional (2D) Ising model
5. Ising lattice gauge theory
6. Abelian lattice gauge theories
7. The planar Heisenberg (XY) model in 2D (Kosterlitz-Thouless transition)
8. Non-Abelian lattice gauge theories

### Intended learning outcomes

The students acquire in-depth understanding of gauge fields in classical and Quantum Physics. They are able to apply this knowledge to spin systems, illustrating the interplay between microscopic models and field-theoretic descriptions.

### Courses

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Module taught in: German or English

### Method of assessment

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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### Referred to in LPO I (examination regulations for teaching-degree programmes)

--
Introduction to Gauge/Gravity Duality

11-GGD-161-m01

Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

Module offered by
Faculty of Physics and Astronomy

ECTS
8

Method of grading
numerical grade

Only after succ. compl. of module(s)
--

Duration
1 semester

Module level
graduate

Other prerequisites
--

Contents

1. Elements of quantum field theory:
   - Quantisation of the free field
   - Interactions
   - Renormalisation Group
   - Gauge Fields
   - Conformal Symmetry
   - Large N expansion
   - Supersymmetry

2. Elements of gravity
   - Manifolds, coordinate covariance and metric
   - Riemann curvature
   - Maximally symmetric spacetimes
   - Black holes

3. Elements of string theory
   - Open and closed strings
   - Strings in background fields
   - Type IIB String Theory
   - D-Branes

4. The AdS/CFT correspondence
   - Statement of the correspondence
   - Near-horizon limit of D3-Branes
   - Field-operator correspondence
   - Tests of the correspondence: Correlation functions
   - Tests of the correspondence: Conformal anomaly
   - Holographic principle

5. Extensions to non-conformal theories
   - Holographic renormalisation group
   - Holographic C-Theorem

6. Applications I: Thermo- and hydrodynamics
   - Quantum field theory at finite temperature
   - Black holes
   - Holographic linear response formalism
   - Transport coefficients: Shear viscosity and conductivities

7. Applications II: Condensed matter physics
   - Finite charge density and Reissner-Nordström black holes
   - Quantum critical behaviour
   - Holographic fermions
- Holographic superconductors
- Entanglement entropy

8. Applications III: Particle physics
- Gravity dual of confinement
- Gravity dual of chiral symmetry breaking
- Quark-gluon plasma

**Intended learning outcomes**

The students acquire a thorough understanding of the foundations of gauge/gravity duality and the ability to carry out basic tests. Depending on the pre-existing knowledge and interests of the students, the module addresses a selection of the aforementioned topics. Knowledge of quantum mechanics and classical electrodynamics is a prerequisite for this course. Knowledge of quantum field theory and general relativity is useful, but not a prerequisite.

**Courses** (type, number of weekly contact hours, language — if other than German)

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Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester.

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

--
**Module title**
Introduction to Fractional Quantisation

**Abbreviation**
11-EFQ-161-m01

**Module coordinator**
Managing Director of the Institute of Theoretical Physics and Astrophysics

**Module offered by**
Faculty of Physics and Astronomy

**ECTS**
6

**Method of grading**
numerical grade

**Only after succ. compl. of module(s)**
--

**Duration**
1 semester

**Module level**
graduate

**Other prerequisites**
--

**Contents**
The course will elaborate on instances of fractional quantisation in nature, mostly employing examples from the following list:

1. Midgap states in polyacethylene
2. Abelian quantised Hall states (Laughlin states, fractional charge and statistics, hierarchy states, effective Chern-Simons theory)
3. Non-Abelian quantised Hall states (Pfaffian states, Majorana fermions, non-Abelian statistics, Read-Rezayi states)
4. Spin chains (Haldane-Shastry model, spinon excitations, holon excitations in the Kuramoto-Yokoyama model, Yangian symmetry)

**Intended learning outcomes**
The students become familiar with emergent phenomena in many-particle systems and with Anderson’s philosophical principle of "More is different" by studying specific examples of quantum condensates exhibiting fractional quantisation.

**Courses**
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1)

Module taught in: German or English

**Method of assessment**
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I** (examination regulations for teaching-degree programmes)
--
## Module title
Topological Effects in Electronic Systems

## Abbreviation
11-TEF-161-m01

### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

### ECTS
6

### Method of grading
Numerical grade

### Only after succ. compl. of module(s)
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### Duration
1 semester

### Module level
Graduate

### Other prerequisites
--

### Contents
The continuous development of the field of topological phases including topological insulators, superconductors, and spin liquids requires a continuous adaptation of the graduate curriculum. The course aims to deepen the students understanding of concepts related to contemporary research and/or to keep up with contemporary developments. The specific choice of topics will vary with the lecturers from year to year.

### Intended learning outcomes
The course offers the opportunity to get acquainted with topics of immediate relevance to research conducted at the University of Würzburg.

### Courses
V (3) + R (1)
Module taught in: German or English

### Method of assessment
Type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

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<td>Field Theoretical Aspects of Solid State Physics</td>
<td>11-FTAS-161-m01</td>
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### Contents

The topics of the course will vary from year to year and may include the description of superconductors through classical field theory (the Higgs mechanism), non-linear sigma models for spin chains, Chern-Simons and axion theories as effective descriptions of quantised Hall fluids and topological insulators, respectively, or the SU(2) level k Wess-Zumino-Witten model as an example of a conformal field theory with a symmetry group (or algebra) beyond the Virasoro algebra.

### Intended learning outcomes

The students acquire an in-depth understanding of quantum field theory and its fundamental importance for almost all areas of Condensed Matter Physics.

### Courses (type, number of weekly contact hours, language — if other than German)

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### Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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### Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places

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### Additional information

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Contents
Expanding space-time, Friedmannian cosmology, basics of general relativity, the early universe, inflation, dark matter, primordial nucleosynthesis, cosmic microwave background, structure formation, galaxies and galaxy clusters, intergalactic medium, cosmological parameters.

Intended learning outcomes
The students have basic knowledge of cosmology. They know the theoretical methods of cosmology and are able to relate them to observations. They have gained insights into current research topics and are able to process scientific questions.

Courses (type, number of weekly contact hours, language — if other than German)
V (3) + R (1)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places
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Additional information
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Referred to in LPO I (examination regulations for teaching-degree programmes)
--
## Module title

Theoretical Astrophysics

| Abbreviation | 11-AST-161-m01 |

## Module coordinator

Managing Director of the Institute of Theoretical Physics and Astrophysics

## Module offered by

Faculty of Physics and Astronomy

## ECTS

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## Contents

Topics in theoretical astrophysics such as e.g. white dwarfs, neutron stars and black holes, supernovae, pulsars, accretion and jets, shock waves, radiation transport, and gravitational lensing

## Intended learning outcomes

Knowledge of basic processes and methods of Theoretical Astrophysics. Ability to formulate theoretical models.

## Courses

| type, number of weekly contact hours, language — if other than German | |
| V (2) + R (2) | |

Module taught in: German or English

## Method of assessment

| type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus | |
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| Language of assessment: German and/or English | |

## Allocation of places

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## Additional information

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## Referred to in LPO I

(examination regulations for teaching-degree programmes)

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<table>
<thead>
<tr>
<th>Module title</th>
<th>Abbreviation</th>
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</thead>
<tbody>
<tr>
<td>High Energy Astrophysics</td>
<td>11-APL-161-m01</td>
</tr>
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</table>

<table>
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<tr>
<th>Module coordinator</th>
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<th>Duration</th>
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</table>

**Contents**

Radiative processes, interaction of light with matter, particle acceleration processes, pair creation, nuclear processes, pion production, astrophysical shock waves, kinetic equations

**Intended learning outcomes**

The student gains knowledge in fundamentals of High-Energy Astrophysics, such as particle acceleration and non-thermal radiative processes in astrophysical objects

**Courses** (type, number of weekly contact hours, language — if other than German)

V (3) + R (1)

Module taught in: German or English

**Method of assessment** (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

**Allocation of places**

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**Additional information**

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**Referred to in LPO I** (examination regulations for teaching-degree programmes)

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### Module title
Relativistic Quantum Field Theory

### Abbreviation
11-RQFT-161-m01

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### Contents
1. Symmetries
2. Relativistic single-particle states
3. Lagrange formalism for fields
4. Field quantisation
5. Scattering theory and S-matrix
6. Gauge principle and interaction
7. Perturbation theory
8. Feynman rules
9. Quantum electrodynamic processes in Born approximation
10. Radiative corrections
11. Renormalisation (optional)

### Intended learning outcomes
The students have mastered the principles and underlying mathematics of relativistic quantum field theories. They know how to use perturbation theory and how to apply Feynman rules. They are able to calculate basics processes in the framework of quantum electrodynamics in leading order. Moreover, they have a basic understanding of radiative corrections and renormalisation.

### Courses
(type, number of weekly contact hours, language — if other than German)

V (4) + R (2)
Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I
(examination regulations for teaching-degree programmes)

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<tr>
<td>Quantum Field Theory II</td>
<td>11-QFT2-161-m01</td>
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Contents

1. Generating Functionals
2. Path Integrals
3. Renormalization
4. Renormalization group
5. Gauge theories
6. Spontaneous Symmetry Breaking
7. Effective Field Theory (optional)

Intended learning outcomes

The students have advanced knowledge of the methods and concepts of quantum field theory. They have mastered the principles, especially of renormalisation and gauge theories. They are able to formulate and solve problems of quantum field theory by using the acquired calculation methods.

Courses (type, number of weekly contact hours, language — if other than German)

V (4) + R (2)
Module taught in: German or English

Method of assessment (type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)

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Assessment offered: In the semester in which the course is offered and in the subsequent semester

Language of assessment: German and/or English

Allocation of places

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Additional information

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Referred to in LPO I (examination regulations for teaching-degree programmes)

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### Module Catalogue for the Subject
Computational Mathematics
Master's with 1 major, 120 ECTS credits

<table>
<thead>
<tr>
<th>Module title</th>
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<tbody>
<tr>
<td>Theoretical Elementary Particle Physics</td>
<td>11-TEP-161-m01</td>
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### Contents

1. Fundamental particles and forces
2. Symmetries and groups
3. Quark model of hadrons
4. Quark parton model and deep inelastic scattering
5. Principles of quantum field theory
6. Gauge theories
7. Spontaneous symmetry breaking
8. Electroweak standard model
9. Quantum chromodynamics
10. Extensions of the standard model.

### Intended learning outcomes
The students are familiar with the mathematical methods of Elementary Particle Physics. They understand the structure of the standard model based on symmetry principles and experimental observations. They know calculation methods for the processing of simple problems and processes of Elementary Particle Physics. Furthermore, they know the tests and limits of the standard model and the basics of extended theories.

### Courses
(type, number of weekly contact hours, language — if other than German)
V (4) + R (2)
Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

### Allocation of places
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### Additional information
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## Module Catalogue for the Subject
Computational Mathematics

**Master's with 1 major, 120 ECTS credits**

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<thead>
<tr>
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<tr>
<td>Selected Topics of Theoretical Elementary Particle Physics</td>
<td>11-ATTP-161-m01</td>
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### Module coordinator
Managing Director of the Institute of Theoretical Physics and Astrophysics

### Module offered by
Faculty of Physics and Astronomy

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### Duration
1 semester

### Module level
graduate

### Other prerequisites
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### Contents
A selection of topics from the following fields will be covered in different years:
1. Advanced techniques for precision calculations of scattering amplitudes
2. Phenomenology of particle accelerators
3. Higgs physics
4. Top quark physics

### Intended learning outcomes
The students are familiar with the tests and limits of the standard model of Particle Physics, Higgs physics and neutrino physics. They are able to formulate extensions of the standard model. Furthermore, they know how to test these extensions in low energy experiments, at high energy colliders and in cosmology.

### Courses
(type, number of weekly contact hours, language — if other than German)
V (3) + R (1) Module taught in: German or English

### Method of assessment
(type, scope, language — if other than German, examination offered — if not every semester, information on whether module is creditable for bonus)
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

### Allocation of places
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### Additional information
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### Referred to in LPO I (examination regulations for teaching-degree programmes)
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Module title: Models Beyond the Standard Model of Elementary Particle Physics
Abbreviation: 11-BSM-161-m01

Module coordinator: Managing Director of the Institute of Theoretical Physics and Astrophysics
Module offered by: Faculty of Physics and Astronomy

ECTS: 6
Method of grading: numerical grade
Only after succ. compl. of module(s): --

Duration: 1 semester
Module level: graduate
Other prerequisites: --

Contents:
1. Principles of the standard model of Elementary Particle Physics
2. Tests of the standard model in low energy experiments and at high energy colliders
3. Neutrino physics
4. Higgs physics.

In addition, a selection of topics from the following fields will be covered in different years:
- Phenomenology of experiments at the LHC,
- particle cosmology,
- extended gauge theories,
- models with extended Higgs sectors,
- supersymmetry,
- models with additional space-time dimensions

Intended learning outcomes:
The students are familiar with the tests and limits of the standard model of Particle Physics, Higgs physics and neutrino physics. They are able to formulate extensions of the standard model. Furthermore, they know how to test these extensions in low energy experiments, at high energy colliders and in cosmology.

Courses:
V (3) + R (1)
Module taught in: German or English

Method of assessment:
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Assessment offered: In the semester in which the course is offered and in the subsequent semester
Language of assessment: German and/or English

Allocation of places:
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Additional information:
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Referred to in LPO I (examination regulations for teaching-degree programmes):
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Thesis
(30 ECTS credits)
<table>
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<tbody>
<tr>
<td>Master Thesis Computational Mathematics</td>
<td>10-M=MACM-161-m01</td>
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**Module coordinator**
Dean of Studies Mathematik (Mathematics)

**Module offered by**
Institute of Mathematics

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**Duration**
graduate

**Other prerequisites**
--

**Contents**
Independently researching and writing on a topic in mathematics selected in consultation with the supervisor.

**Intended learning outcomes**
The student is able to work independently on a given mathematical topic and apply the skills and methods obtained during his/her studies in the master programme. He/She can write down the result of his/her work in a suitable form.

**Courses**
No courses assigned to module

**Method of assessment**
Master’s thesis (750 to 900 hours total)
Registration and assignment of topic in consultation with supervisor.
Language of assessment: German or English

**Allocation of places**
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**Additional information**
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**Referred to in LPO I**
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