
# Computer Science

MSc, Integrated PhD Program

# Contents

# Disclaimer

As of September 1, 2014 the School of Engineering and Science and the School of Humanities and Social Sciences have been replaced by the Focus Areas Health, Mobility and Diversity. Handbooks and policies might still refer to the old structure of Schools.

If this is the case, references to the School of Engineering and Science include courses offered within the following disciplines

- Electrical Engineering and Computer Science
- Life Sciences
- Logistics
- Mathematical Sciences
- Natural and Environmental Sciences

References to the School of Humanities and Social Sciences include courses offered within the following disciplines:

- Economics and Management
- History
- Humanities
- Law
- Psychology
- Social Sciences
- Statistics and Methods

# 1 Introduction to the Computer Science Graduate Program

The Computer Science graduate program provides graduate level education in Computer Science. It is offered by the School of Engineering and Science at the Jacobs University Bremen. This section describes the overall philosophy, the degrees offered, the career options and the target audience.

## 1.1 Philosophy

As humans we can sense, act, speak, listen, decide and sometimes understand. The 21st century will witness technologies that can do the same. We will see cars that negotiate with each other in order to optimize traffic flow. Our T-shirts may have their own Internet addresses and tell the manufacturer if they are only rarely worn. In addition to their well-established role as programmable machine-tools, robots are also more and more used in domains where some autonomy and intelligence is necessary. They work under conditions where the robot is not constantly supervised by a human operator and where it has to be adaptive as its developer can not fully predict which situations it will encounter in its application environment. We all know future descriptions of this kind, we also know that they are no longer science fiction, although real future may still look quite differently. But whatever course the future takes, it will be scientists and engineers who help in shaping it. They will develop systems (yet unthinkable) that could likewise be described as robots, user interfaces, web agents, enhanced reality or personal assistants. The hallmark of such computer systems is their integration of technologies from communication networks, Internet services, artificial intelligence, machine learning, robotics, and many more. These systems may even imitate social systems for achieving some benefit and will be exceedingly complex. Scientists and engineers who take an active role in creating such systems will have to master a highly diverse repertoire of professional techniques as a matter of course. In addition, they will need to cope with complexity itself: making heterogeneous system components communicate with each other, integrating diverse knowledge representations, blending hardware with software with sensors with users, and overall understanding the dynamical properties of complex dynamical systems.

Jacobs University takes part in this rapidly growing, boldly interdisciplinary endeavor. Coordinated by the Computer Science group, a highly future-oriented graduate program in Computer Science is offered. It integrates a rigorous training in several important subdisciplines, especially networks, artificial intelligence, robotics and the mathematics of complex systems. A student acquires in this graduate program the knowledge to work at the forefront of technological developments.

## 1.2 Degrees

The Computer Science graduate program offers the following two degrees in three interconnected tracks:

### 1.2.1 Master of Science (M.Sc.) in Computer Science

The M.Sc. program at Jacobs University Bremen takes two years or four semesters. The first two semesters (one years of study) of the Master's degree include regular course work, i.e., lectures and labs, and the opportunity to engage in scientific work. After completing the course phase, the student is permitted to complete a Master's thesis during the second year.

Upon graduation, Jacobs University Bremen awards the "*Master of Science in Computer Science*".

### 1.2.2 Doctor of Philosophy (Ph.D.) in Computer Science

Students with an excellent record of achievement in their Bachelor's or Master's studies may apply to pursue a Ph.D. degree at Jacobs University.

Students joining the program's Ph.D. track with a B.Sc degree are required to complete successfully up to two semesters of taught courses and a semester of research proposal work before progressing towards the Ph.D. dissertation. The qualification phase lasts three semesters. The goal this phase is to obtain at least 90 ECTS credits. The course phase is equal to the M.Sc. study plan for the first three semesters. The students who have successfully completed the qualification phase are expected to do research. In the qualification phase the students chooses a Ph.D. supervisor, who takes care of the Ph.D. position.

Students who have already achieved a Master's degree and have demonstrated an aptitude to research may, subject to the discretion of the Dean, progress immediately after matriculation to independent research and to the completion of a Ph.D. dissertation. In total, the completion of a Ph.D. degree will typically take three years.

Upon graduation, Jacobs University Bremen awards the "*Doctor of Philosophy in Computer Science*". Upon request to the city state of Bremen, this Ph.D. can be transformed into a German doctorate degree.

## 1.3 Prospects and Career Options for Graduates

The prime goal of this program is to prepare students for a scientific career (Ph.D. or postdoctoral research) or leading positions in industry, where the skills of *data analysis*, *modeling and simulation*, and the *development of complex algorithms and systems* form the basis for professional excellence. In addition to the training of these fundamental skills, the program provides training that covers the knowledge from the industrial fields of *Robotics*, *Automation*, *Network and Distributed Systems*, *Man Machine Interaction*, *Artificial Intelligence*, *Control Engineering*, *Data Mining*, *Databases and Web-Based Information Systems Technology*, *Machine Vision*, and *Computer Graphics and Visualization*.

## 1.4 Target Audience

The target audience of the Computer Science graduate program are

- students who have completed their B.Sc. in Computer Science or related disciplines and who want to deepen their knowledge and proceed to research oriented work towards a Master or Ph.D. degree,
- graduate students who have completed their Master's degree and would like to continue their graduate education.

The two-year Master program's goal is to *qualify* students to carry out independent research, while in the three-year Ph.D. program highly qualified students *do* research. Consequently, the Master program offers a highly structured educational program, whereas the Ph.D. program can be seen as a stage on which the student defines, and executes, his/her own research in a professional collaboration with a chosen supervisor. The integrated Ph.D. program is designed for research oriented students entering the program with a B.Sc.

# 2 The M.Sc. Program

The M.Sc. program is a two year program aiming at qualifying students for independent research and development of information and communication systems.

## 2.1 Program Structure

The structure of the Master program is highly research oriented. In addition to the regular course work within the Master track, the students have to engage in projects. The projects serve as platform to learn about research-oriented methodologies. The students are furthermore guided via the projects towards conference participation and publications for which credits can be earned.

| Sem. | Description | Credits | Sem. Total | Running Total |
|---|---|---|---|---|
| 1 | 2 Lectures | $2 \cdot 5 = 10$ | 10 | 10 |
| 1 | 2 Graduate Labs | $2 \cdot 5 = 10$ | 20 | 20 |
| 1 | 1 Graduate Project | 10 | 30 | 30 |
| 2 | 2 Lectures | $2 \cdot 5 = 10$ | 10 | 40 |
| 2 | 2 Graduate Labs | $2 \cdot 5 = 10$ | 20 | 50 |
| 2 | 1 Graduate Project | 10 | 30 | 60 |
| 3 | Master Thesis Proposal | 30 | 30 | 90 |
| 4 | Master Thesis | 30 | 30 | 120 |

Figure 1: The structure of the M.Sc. program

Figure 1 gives an overview over the structure; all credits involved are ECTS credits. For a detailed account of course contents, see Section 5. The first year features advanced lectures, labs, and a research project in all research areas of the graduate program. They introduce the topics and cover pertinent results and methods of the respective field. These lectures and labs often come in pairs which alternate over a 4-semester interval. Typically, lecture and lab of one field are co-requisites of each other. In the projects, each student will work out and present an assigned topic from research papers or from original research on the topic.

In their first and second semesters, Masters students will need to acquire 30 credits from two core Computer Science lectures and labs, as well as from a research project. In some cases, Jacobs University undergraduate courses or courses from other Jacobs University graduate programs can be admitted by the Computer Science faculty into this category.

In the third semester, the student works on a 20-page (target length) thesis proposal guided by an academic supervisor chosen at the beginning of the semester. The purpose of this document is to introduce the student to academic writing and focus the research interest and efforts towards the eventual thesis topic. A research proposal with a passing grade gives 30 credits.

In the fourth and last semester, the student researches and writes the Master's thesis guided and supported by the chosen academic supervisor. The resulting document (target size 60 pages) presents the research of the student. The thesis will be jointly judged by a thesis committee which consists of the thesis supervisor and at least one other member. The other member(s) can be Jacobs University faculty members or external members. The thesis will be graded using the Jacobs University grading system ranging from 1 (excellent) to 5 (fail). A thesis with a passing grade gives 30 credits.

| Number | Credits | Type | Title |
|---|---|---|---|
| 320501 | 30 | Thesis | Master/Doctorate Thesis Proposal |

Figure 2: The Structural Components of the Computer Science Program

## 2.2 Graduation Requirements and Regulations

The following list summarizes the formerly announced guidelines. All specified credits are minimum requirements.

- 120 ECTS credits are needed to graduate. These credits have to be earned as follows:
  - 20 credits from Computer Science lectures. Undergraduate courses or courses from other graduate programs can be taken upon approval of the program coordinator.
  - 20 credits from Computer Science labs. Undergraduate courses or courses from other graduate programs can be taken upon approval of the program coordinator.
  - 20 credits from Computer Science projects.
  - 30 credits from the master thesis proposal.
  - 30 credits from the master thesis.
- Master's thesis credits are awarded only if the grade is better than 4.0. In case the thesis does not fulfill this requirement, the examination committee may grant the right to resubmit it within three months.
- Failed examinations may be retaken once, at most one semester later.
- At least 20 ECTS credits must be earned in every semester, with an average grade of at least 3.0 or better, otherwise the student will be placed on academic probation by the registrar. Any graduate student whose GPA in any given semester is worse than 4.33 will be automatically suspended.
- Students intending to take undergraduate courses or courses outside the Computer Science curriculum need the approval of the program coordinator. Credits will be counted according to the program from which the courses are taken.
- Language courses and university study courses are generally not admissible here, and credits possibly acquired while taking them will not be counted towards the amount of 120 credits needed to obtain the M.Sc. degree.

## 2.3 Graduate Course Overview

In the following we will introduce the contents of the lectures, labs, seminars, and projects in the Master's track of the Computer Science graduate program.

Research is considered to be an essential part of the education at Jacobs University. Therefore master students will already be involved in research projects during their first semesters. The purpose of the is to introduce topics and to cover pertinent results and methods of the research areas. The courses are complemented by a projects each semester. In addition, there are graduate courses in mathematics, physics, and possibly other disciplines of relevance for CS master students, depending on their chosen specialization area.

The following tables list the lectures, lab modules, and projects that are offered on a regular basis in the program.

### 2.3.1 Scalable Information Systems

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320302 | 5 ECTS | Lecture | Databases and Web Applications |
| 1 | 320473 | 5 ECTS | Lab | Databases and Web Applications Lab |
| 1 | 320454 | 10 ECTS | Project | Big Data Project A |
| 2 | 320411 | 5 ECTS | Lecture | Information Architectures |
| 2 | 320622 | 5 ECTS | Lab | Information Architectures Lab |
| 2 | 320554 | 10 ECTS | Project | Big Data Project B |

### 2.3.2 Robotics

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1a | 320311 | 5 ECTS | Lecture | Robotics |
| 1a | 320463 | 5 ECTS | Lab | Robotics Lab |
| 1b | 320521 | 5 ECTS | Lecture | Autonomous Systems |
| 1b | 320611 | 5 ECTS | Lab | Autonomous Systems Lab |
| 1 | 320484 | 10 ECTS | Project | Topics in Robotics Project A |
| 2a | 320421 | 5 ECTS | Lecture | Advanced Robotics |
| 2a | 320601 | 5 ECTS | Lab | Advanced Robotics Lab |
| 2b | 320523 | 5 ECTS | Lecture | Advanced Autonomous Systems |
| 2b | 320533 | 5 ECTS | Lab | Advanced Autonomous Systems Lab |
| 2 | 320584 | 10 ECTS | Project | Topics in Robotics Project B |

### 2.3.3 Machine Learning

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320372 | 5 ECTS | Lecture | Machine Learning |
| 1 | 320453 | 5 ECTS | Lab | Machine Learning Lab |
| 1 | 320444 | 10 ECTS | Project | Machine Learning Project A |
| 2a | 320643 | 5 ECTS | Lecture | Applied Machine Learning |
| 2a | 320641 | 5 ECTS | Lab | Applied Machine Learning Lab |
| 2b | 320574 | 5 ECTS | Lecture | Modeling Complex Systems |
| 2b | 320572 | 5 ECTS | Lab | Modeling Complex Systems Lab |
| 2 | 320544 | 10 ECTS | Project | Machine Learning Project B |

### 2.3.4 Knowledge Representation

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320441 | 5 ECTS | Lecture | Computational Logic |
| 1 | 320612 | 5 ECTS | Lab | Computational Logic Lab |
| 1 | 320434 | 10 ECTS | Project | Computational Logic Project |
| 2 | 320541 | 5 ECTS | Lecture | Computational Semantics of Natural Language |
| 2 | 320591 | 5 ECTS | Lab | Computational Semantics of Natural Language Lab |
| 2 | 320534 | 10 ECTS | Project | Computational Semantics Project |

### 2.3.5 Visualization and Computer Graphics

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320322 | 5 ECTS | Lecture | Graphics and Visualization |
| 1 | 320513 | 5 ECTS | Lab | Graphics and Visualization Lab |
| 1 | 320494 | 10 ECTS | Project | Topics in Graphics Project |
| 2a | 320491 | 5 ECTS | Lecture | Advanced Graphics |
| 2a | 320632 | 5 ECTS | Lab | Advanced Graphics Lab |
| 2b | 320581 | 5 ECTS | Lecture | Advanced Visualization |
| 2b | | | | |
| 2 | 320564 | 10 ECTS | Project | Topics in Visualization Project |

#### 2.3.6 Machine Perception

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320331 | 5 ECTS | Lecture | Artificial Intelligence |
| 1 | 320433 | 5 ECTS | Lab | Artificial Intelligence Lab |
| 1 | 320443 | 10 ECTS | Project | Artificial Intelligence Project |
| 2 | 320671 | 5 ECTS | Lecture | Machine Vision |
| 2 | 320681 | 5 ECTS | Lab | Machine Vision Lab |
| 2 | 320691 | 10 ECTS | Project | Machine Vision Project |

#### 2.3.7 Computer Networks and Distributed Systems

| Sem | Number | Credits | Type | Title |
|---|---|---|---|---|
| 1 | 320301 | 5 ECTS | Lecture | Computer Networks |
| 1 | 320414 | 5 ECTS | Lab | Internet of Things Lab |
| 1 | 320424 | 10 ECTS | Project | Computer Networks Project A |
| 2 | 320402 | 5 ECTS | Lecture | Advanced Computer Networks |
| 2 | 320404 | 5 ECTS | Lab | Internet Measurement and Management Lab |
| 2 | 320524 | 10 ECTS | Project | Computer Networks Project B |

## 2.4 Change Management & Transition Rules

This handbook introduces considerable changes to the study plan in previous years. Even though students who entered the CS M.Scprogram in 2012 will continue their studies wrt. the study plan laid down in the 2011-2013 handbook, the changes may still affect them. There are two problem areas

- The seminars previously given in the spring semesters will be discontinued with the new program.
- Not all of the graduate courses alternate yearly any more.

Students who have missed a seminar or course in their first year, may replace it with a course or lab after coordination with the program coordinator and their academic advisor.

# 3 The Ph.D. Program

The three-year Ph.D. track is devoted to focused research within the research group of an academic supervisor. Students who enter the Ph.D. program from the Master's track typically choose their supervisor after the second Master semester, whereas students who enter the program by a direct application typically choose the supervisor during the application/acceptance process.

| Sem. | Title | Activity |
|---|---|---|
| 1 | Ph.D. project definition | development of a PhD proposal; public defense of thesis proposal no later than eight months after the entrance into the PhD program |
| 2 | Ph.D. project research | e.g., experiment design, detailed implementation specification |
| 3 | Ph.D. project research | e.g., running experiments, implementation phase |
| 4 | Ph.D. project research | evaluation and refinement phase; written progress assessment by the thesis committee at end of semester |
| 5 | Ph.D. project research | thesis preparation, publications |
| 6 | Ph.D. thesis and defense | write-up of the Ph.D. thesis; public defense |

Figure 3: The structure of the Ph.D. program

Figure 3 shows an overview of a typical Ph.D. project. In the first semester, the student works out a thesis proposal in collaboration with the academic supervisor. This proposal (target size 15–20 pages) must

- demonstrate that the student masters the professional terminology in the research domain and has the requisite background knowledge,
- identify and motivate a relevant and feasible research question,
- connect the question to the state of the art by a focused and illustrative literature overview,
- lay out a design for planned experiments, theoretical investigations or implementations, including a schedule,
- and describe criteria for evaluating the eventual success of the project.

Three month after registration, a doctoral thesis committee is constituted and the proposal is defended in a public presentation.

After (and if) the thesis proposal is successfully defended, in the remaining time the proposed research is carried out. It is only natural that the originally stated objectives are refined or even re-defined in this process. Progress is monitored by presentations within the graduate program, and of course on a day-by-day basis in close interaction with the supervisor.

At the end of semester 4, the thesis committee gives a written progress assessment report based on the presentations, any publications by the students, and available research results. This report will also contain suggestions about prioritizing the remaining research, and expected results.

The last semester is devoted to writing up the thesis document (target size 80–150 pages). At the end of the program, the findings are presented to the graduate program and the university in a public Ph.D. thesis defense. The thesis committee judges the presentation in the thesis defense together with the content and form of the thesis to determine whether to accept or reject the thesis. The Ph.D. thesis is not graded with respect to the Jacobs University grading system but may be awarded with an honor's predicate.

Ph.D. students are encouraged but not required to enlist in courses offered in the Computer Science or related graduate programs that can deepen and expand the perspective of the own chosen area of research.

Teaching experience is part of graduate education. All graduate students are encouraged to work in undergraduate courses as teaching assistants (TAs). This involves among other activities giving tutorials, grading exercise sheets, and supervising lab or undergraduate project work. According to their experience, Ph.D. students may also work out exercise sheets or define undergraduate projects and offer seminars. TA work is paid according to the general Jacobs University policies.

# 4 The Integrated Ph.D. Program

Students with a B.Sc. degree may obtain a Ph.D degree in the integrated Ph.D. Program. Initially, the students are admitted to the M.Sc. program (cf. page 4). Students, who excel in the first two semesters, choose a Ph.D. supervisor, who provides the Ph.D. position and change into the integrated Ph.D. program.

In the third semester, integrated Ph.D. students take one graduate lecture and lab, work on a research proposal, and take the qualifying exam.

## 4.1 Study Plan for the Qualification Phase

The study plan for the qualification phase is shown in Table 4. It is identical to the M.Sc. program, except that the proposal in the third semester covers the contents of the Ph.D. project. The qualification phase takes three semesters during which 90 ECTS credits must be earned. Students progressing to Ph.D. research must pass a qualifying exam at the end of the 3rd semester.

| Sem. | Description | Credits | Sem. Total | Running Total |
|---|---|---|---|---|
| 1 | See M.Sc. program (Fig. 1) | | | |
| 2 | See M.Sc. program (Fig. 1) | | | |
| 3 | Ph.D. Research Proposal | 30 | 30 | 90 |
| Qualifying Exam | | | | |

Figure 4: The structure of the qualification phase for the integrated Ph.D. program

The Ph.D. qualifying exam will take place before the beginning of the fourth semester, assuming that the student has completed the coursework requirements. The Ph.D. qualifying exam will be an oral exam offered by the Computer Science faculty, where at least three professors must be present, and the typical duration is no less than one hour. The Qualifying Examination has the outcome "pass" or "fail". Students have to demonstrate an advanced knowledge of computer science. Different fields of computer science will be covered during the exam. Students have to pass the Ph.D. qualifying exam to continue with the final Ph.D. phase.

## 4.2 Final Ph.D. Phase

The three-year Ph.D. phase is devoted to focused research within the research group of an academic supervisor. Based on the research proposal the student develops a Ph.D. Proposal, which is presented in public no later than eight months after the qualifying exam. A research phase follows which concludes with the writing of a Ph.D. thesis and a public defense.

| Sem. | Title | Activity |
|---|---|---|
| 4 | Ph.D. project definition | development of a PhD proposal; public defense of thesis proposal no later than eight months after the entrance into the 4th semester |
| 5 | Ph.D. project research | e.g., experiment design, detailed implementation specification |
| 6 | Ph.D. project research | e.g., running experiments, implementation phase |
| 7 | Ph.D. project research | evaluation and refinement phase; written progress assessment by the thesis committee at end of semester |
| 8 | Ph.D. project research | thesis preparation, publications |
| 9 | Ph.D. thesis and defense | write-up of the Ph.D. thesis; public defense |

Figure 5: The structure of the integrated Ph.D. program

# 5 Course Descriptions

Jacobs University Bremen reserves the right to substitute courses by replacements and/or reduce the number of mandatory/mandatory elective courses offered

The following sections contain more detailed descriptions of the graduate courses offered in the Computer Science program.

The course descriptions below specify prerequisites both internal to the program as well as in terms of Jacobs University undergraduate courses. The meaning of the latter is that master's students that have obtained their bachelor's degree at other universities should have passed courses whose content is equivalent to the respective Jacobs University courses. Their content of the Jacobs University courses listed as prerequisite is specified in the undergraduate handbooks, which can be obtained from Jacobs' web site at http://www.jacobs-university.de/.

Students need to talk to the instructor of record and obtain a prerequisite waiver to be able to register for the course in case they miss any prerequisites.

The purpose of projects is to drill down on particular topics of interest in the research areas and introduce the students to the state of the art. In the projects, each student will work out and present an assigned topic from research papers or from original research on the topic.

## 5.1 Scalable Information Systems

### 320302 – Databases and Web Applications

| | |
|---|---|
| *Short Name:* | CSDBWA |
| *Type:* | Lecture |
| *Semester:* | 5 |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | 320201 |
| *Corequisites:* | None |

**Course contents** This course introduces (relational) database systems in theory and practice, with special emphasis on Web-based information services. Topics addressed include database design (ER, UML), SQL, relational design theory, transaction management, security, web applications, 3-tier architectures, XML, XPath/XQuery, and an outlook on novel paradigms like NewSQL.

In the homeworks, the core of a database-enabled Web service is implemented. Students arrange themselves into small teams. Each team picks some individual application it finds exciting and agrees it with the instructor. In a guided process over the semester, the team then designs, documents, implements, and validates its chosen service based on a LAMP platform provided.

The course requires basic knowledge about algebraic expressions and laws, basic data structures like trees, object-oriented concepts, as well as basics of HTML and – for the homeworks – Linux.

Learning goals are (i) knowledge about databases and Web-based information systems and (ii) skills in designing and building database and Web services for science, engineering, and business domains.

### 320473 – Databases and Web Applications Lab

| | |
|---|---|
| *Short Name:* | DBWALab |
| *Type:* | Lab |
| *Semester:* | 1st |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320302 |

**Course contents** This lab course runs in parallel to the Databases and Web Applications (DBWA) course. Students pursue advanced semester projects, which, while utilizing concepts and techniques practiced in the DBWA homeworks, transcend these homework projects in demand and complexity.

Typically, these projects are derived from and contribute to international collaborations and the research group's standardization work in geo services and SQL. Hence, successful projects become visible internationally to large-scale data centers. Further, as part of the final reporting a scientific conference publication is foreseen, which, following acceptance, will be presented by the students.

Students receive individual coaching on their technical work and scientific publishing, and additionally are offered in-depth training on speech and presentation techniques to cope with manifold situations.

## 320454 – Big Data Project A

*Short Name:* ProjWebInfSysA
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320473

**Course contents** This project course is to be taken together with the Databases and Web Applications course and the Databases and Web Applications Lab. Students work on a current research problem related to the course under close supervision of the instructor.

## 320411 – Information Architectures

*Short Name:* InfArch
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320302
*Corequisites:* None

**Course contents** The title of this course can, and should, be understood in a twofold way. On conceptual level, mastering the rapidly growing volume and complexity of information in industry, science, and society requires improved modelling and design methodologies. On implementation level, existing storage, retrieval, and delivery techniques have to be revisited and new ones have to be designed in order to meet the challenges formulated conceptually. While these issues largely fall into the fields of databases, information retrieval, and Internet technology, the questions arising clearly transcend these fields and call for interdisciplinary research on more efficient and effective methods.

The course, therefore, starts with an overview of existing knowledge in the core fields and then covers selected themes in more depth. Among the candidate themes are non-standard applications such as spatio-temporal databases, array databases, parallel and distributed databases, XML databases, and NoSQL / NewSQL databases.

The goal is to make students familiar with the state of the art in Web-enabled information systems so that they will be successful database / Internet professionals in the IT industry and also have a sound knowledge base to specialize towards a scientific career in the field.

## 320622 – Information Architectures Lab

*Short Name:* InfArchLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320411

**Course contents** This lab complements the Information Architectures lecture by providing hands-on experiences with Big Data technology and state-of-the-art NewSQL, specifically: Array Databases. These complement standard relational databases with data and query models for large, multi-dimensional arrays. Arrays appear in manifold variants in Earth, Space, and Life sciences, but also in the humanities, industry, and business. Examples include 1-D sensor timeseries, 2-D satellite images, 3-D x/y/t image timeseries and x/y/z confocal microscopy and CAT scan imagery, as well as 4-D and 5-D climate and ocean simulation output.

Topics on both server engine and applications are available, driven by and embedded in our international collaborations and geo service standardization work. Hence, successful projects become visible internationally to large-scale data centers. Further, as part of the final reporting a scientific conference publication is foreseen which, following acceptance, will be presented by the students.

Students receive individual coaching on their technical work and scientific publishing, and additionally are offered in-depth training on speech and presentation techniques to cope with manifold situations.

## 320554 – Big Data Project B

*Short Name:* ProjWebInfSysB
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320622

**Course contents** This project course is to be taken together with the Information Architectures course and the Information Architectures Lab. Students work on a current research problem related to the course under close supervision of the instructor.

## 5.2 Robotics

### 320311 – Robotics

*Short Name:* CSR
*Type:* Lecture
*Semester:* 5
*Credit Points:* 5 ECTS
*Prerequisites:* 320201 and 320222
*Corequisites:* None

**Course contents** Robotics is a field that spans the entire range from low-level mechatronics and signal processing to high-level cooperation protocols of intelligent agents, and thus touches large portions of both CS and EE. Correspondingly, the course aims at an integrative, practically oriented education that enables students to practically combine methods he/she has encountered in various more specialized courses before.

The course is offered biannually (alternating with "Autonomous Systems").

### 320463 – Robotics Lab

*Short Name:* RobLab
*Type:* Lab
*Semester:* 1st
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320311

**Course contents** This lab course is to be taken together with the Robotics course. It provides hands-on experiences with the robotics equipment of the Jacobs Robotics group including advanced robots equipped with state of the art sensors.

### 320521 – Autonomous Systems

*Short Name:* CSAS
*Type:* Lecture
*Semester:* 5
*Credit Points:* 5 ECTS
*Prerequisites:* 320201 and 320222
*Corequisites:* None

**Course contents** There is an increasing interest and need to generate artificial systems that can carry out complex missions in unstructured environments without permanent human supervision. Intelligent mobile robots are often used as prototype or even defining example of according autonomous systems. The investigation of autonomous systems is driven from two different perspectives. First, it is motivated by the engineering aspects of generating application oriented devices. Second, artificial autonomous systems offer new ways to investigate and constructively understand natural cognition.

The course is offered biannually (alternating with "Robotics").

## 320533 – Advanced Autonomous Systems Lab

*Short Name:* AdvAutSysLab
*Type:* Lab
*Semester:* 1st
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320523

**Course contents** This lab course is to be taken together with the Advanced Autonomous Systems course. It provides more in-depth hands-on experiences with the robotics equipment of the Jacobs Robotics group related to Autonomous Systems.

## 320484 – Topics in Robotics Project A

*Short Name:* ProjTopRobA
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320611 or 320463

**Course contents** This project course is to be taken together with the Autonomous Systems Lab or the Robotics Lab. Students work on a current research problem under close supervision of the instructor.

## 320421 – Advanced Robotics

*Short Name:* AdvRob
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320311
*Corequisites:* None

**Course contents** The Advanced Robotics course builds upon the Robotics course offered in the previous semester of that academic year. The Advanced Robotics course covers selected areas of robotics in more profound depth. The content of the course is hence devoted to most recent state of the art research in a field related to work of Jacobs Robotics like Underwater Robotics or 3D Perception and Mapping.

## 320601 – Advanced Robotics Lab

*Short Name:* AdvRobLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320421

**Course contents** This lab course is to be taken together with the Advanced Robotics course. It provides more in-depth hands-on experiences with the robotics equipment of the Jacobs Robotics group.

## 320523 – Advanced Autonomous Systems

*Short Name:* AdvAutSys
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320521
*Corequisites:* None

**Course contents** The Advanced Autonomous Systems course builds upon the Autonomous Systems course offered in the previous semester of that academic year. The Advanced Autonomous Systems course covers selected areas in more profound depth. The content of the course is hence devoted to most recent state of the art research on Autonomy like Cooperation or Cognitive Models.

## 320611 – Autonomous Systems Lab

*Short Name:* AutSysLab
*Type:* Lab
*Semester:* 1st
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320521

**Course contents** This lab course is to be taken together with the Autonomous Systems course. It provides hands-on experiences with the robotics equipment of the Jacobs Robotics group.

## 320584 – Topics in Robotics Project B

*Short Name:* ProjTopRobB
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320601 or 320611

**Course contents** This project course is to be taken together with the Topics in Robotics seminar. Students work on a current research problem reated to the course under close supervision of the instructor.

## 5.3 Machine Learning

### 320372 – Machine Learning

*Short Name:* CSML
*Type:* Lecture
*Semester:* 5
*Credit Points:* 5 ECTS
*Prerequisites:* 120112 and 120201
*Corequisites:* None

**Course contents** Machine learning (ML) is all about algorithms which are fed with (large quantities of) real-world data, and which return a compressed "model" of the data. An example is the "world model" of a robot: the input data are sensor data streams, from which the robot learns a model of its environment – needed, for instance, for navigation. Another example is a spoken language model: the input data are speech recordings, from which ML methods build a model of spoken English – useful, for instance, in automated speech recognition systems. There is a large number of formalisms in which such models can be cast, and an equally large diversity of learning algorithms. However, there is a relatively small number of fundamental challenges which are common to all of these formalisms and algorithms: most notably, the "curse of dimensionality" and the almost deadly-dangerous problem of under- vs. overfitting. This lecture introduces such fundamental concepts and illustrates them with a choice of elementary model formalisms (linear classifiers and regressors, radial basis function networks, clustering, mixtures of Gaussians, Parzen windows). Furthermore, the course also provides an intense refresher of the requisite concepts from probability theory, statistics, and linear algebra.

### 320453 – Machine Learning Lab

*Short Name:* MLLab
*Type:* Lab
*Semester:* 1st
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320372

**Course contents** This Lab is the graduate escort to the lecture Machine Learning. It extends and deepens the material from that lecture by small projects, compressed tutorials on mathematical background, and seminar-style reading and discussion of original research literature.

## 320444 – Machine Learning Project A

*Short Name:* ProjMLA
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320643

**Course contents** This project course is to be taken together with the Machine Learning lecture. Students will be required to complete a (guided) research project. Topics will be determined on a case-by-case basis, suiting the background and interests of the student.

## 320643 – Applied Machine Learning

*Short Name:* AppML
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320372
*Corequisites:* None

**Course contents** This Spring course builds on the introductory Fall course "Machine Learning" and presents a number of machine learning techniques which are widely used in application practice: adaptive linear filters (employed virtually everywhere in signal processing and control), feedforward neural networks (employed when it comes to learn complex nonlinear input-output relationships, as e.g. in financial time series prediction or image recognition), hidden Markov models (the workhorse for speech recognition), and fuzzy logic (used by engineers to predict and control very nonlinear systems). From a math/methods side, the two main classes of supervised learning algorithms are studied: optimization by gradient descent, and by "expectation-maximization" algorithms.

## 320641 – Applied Machine Learning Lab

*Short Name:* AppMLLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320643

**Course contents** This lab extends the Applied Machine Learning lecture by hands-on miniprojects, compressed tutorials on mathematical background, and seminar-style reading and discussion of original research literature.

## 320574 – Modeling Complex Systems

*Short Name:* ModCompSys
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320372
*Corequisites:* None

**Course contents** This Spring course builds on the introductory Fall course "Machine Learning" and presents a number of machine learning techniques which aspire to model extremely complex real-world datasets and systems. Examples: robots navigating in unknown stochastic environments, image and video collections, the space shuttle, VLSI circuits, the weather. Modeling of such systems is an inherently probabilistic task: there is never enough data available to completely know the real system's state or laws – the gap must be filled by statistics. Therefore, the emphasis in this course lies on statistical modelling and other methods that allow one to cope with uncertainty. A choice from the following techniques will be covered: (i) sampling methods and representations of probability distributions, optimization by simulated annealing, (ii) Bayesian networks and graphical models, with exact, Monte Carlo, and/or variational inference techniques, (iii) input-output models used in agent modelling and control (POMDP's, input-output-OOMs), (iv) recurrent neural networks.

## 320572 – Modeling Complex Systems Lab

*Short Name:* ModCompSysLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320574

**Course contents** This Lab extends the Modeling Complex Systems lecture by hands-on miniprojects, compressed tutorials on mathematical background, and seminar-style reading and discussion of original research literature.

## 320544 – Machine Learning Project B

*Short Name:* ProjMLB
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320574 or 320643

**Course contents** This project course is to be taken together with the Machine Learning lecture and lab twins (Applied ML or Modeling Complex Systems). Students work on a current research problem reated to the course under close supervision of the instructor. Topics will be determined on a case by case basis, suiting the background and interests of the student.

## 5.4 Knowledge Representation

### 320441 – Computational Logic

| | |
|---|---|
| *Short Name:* | CSCL |
| *Type:* | Lecture |
| *Semester:* | 5 |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | 320211 |
| *Corequisites:* | None |

**Course contents** In this course we will cover the basics of computational logic. We will introduce the syntax and semantics of first-order logic, and discuss calculi, soundness, completeness on this system. We will cover machine-oriented inference calculi like analytic tableaux, and resolution and apply them to theorem proving and logic programming applications.

We will discuss the non-deductive reasoning modes of abduction and induction and briefly introduce computational methods for mechanizing them. Finally, we will give an introduction to knowledge representation and description logics, leading to an introduction of "semantic web" techniques.

### 320612 – Computational Logic Lab

| | |
|---|---|
| *Short Name:* | CompLogLab |
| *Type:* | Lab |
| *Semester:* | 1st |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320441 |

**Course contents** This lab course is to be taken together with the Computational Logic course and provides hands-on programming exercises where selected topics of the course will be implemented in the programming language PROLOG.

### 320434 – Computational Logic Project

| | |
|---|---|
| *Short Name:* | CompLogProj |
| *Type:* | Project |
| *Semester:* | 1st |
| *Credit Points:* | 10 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320612 |

**Course contents** This project course is to be taken together with the Computational Logic Course/Lab. Students work on a current research problem related to the course under close supervision of the instructor. Topics will be determined on a case by case basis, suiting the background and interests of the student.

## 320541 – Computational Semantics of Natural Language

*Short Name:* CompSem
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320441
*Corequisites:* None

**Course contents** In this course we will cover the logical and linguistic foundation of syntactical and semantic modeling of natural language in computational linguistics (the study of natural languages from a computational perspective). We will proceed by the "method of fragments", where fragments of natural language are studied on a syntactic level (grammar and lexicon), the semantic level (transforming syntactic structures into logical forms), and a pragmatic level (inferring material that is not explicitly realized linguistically).

We will build up a sequence of fragments of increasing coverage (covering selected salient features of language) and discuss the linguistic and logical phenomena involved in detail.

The course will be accompanied by a hands-on programming lab, where the topics of the course will be implemented in the programming language PROLOG.

## 320591 – Computational Semantics of Natural Language Lab

*Short Name:* CompSemLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320641

**Course contents** This lab course is to be taken together with the Computational Semantics of Natural Language course and provides hands-on programming exercises where selected topics of the course will be implemented in the programming language PROLOG.

## 320534 – Computational Semantics Project

*Short Name:* CompSemProj
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320591

**Course contents** This project course is to be taken together with the Computational Semantics Course/Lab. Students work on a current research problem reated to the course under close supervision of the instructor. Topics will be determined on a case by case basis, suiting the background and interests of the student.

## 5.5 Visualization and Computer Graphics

### 320322 – Graphics and Visualization

| | |
|---|---|
| *Short Name:* | CSGV |
| *Type:* | Lecture |
| *Semester:* | 5 |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | 320202 and 320222 |
| *Corequisites:* | None |

**Course contents** This is an introductory class into the concepts and techniques of 3D interactive computer graphics and visualization. Mathematical foundations, basic algorithms and principles, and advanced methods of real-time rendering and visualization are being taught. This course is recommended for all EECS students with an interest in data visualization and computer graphics.

**Topics** Geometric foundations, object representation, raster graphics, color models, shading and lighting, textures, animation and modelling, scientific visualization.

### 320513 – Graphics and Visualization Lab

| | |
|---|---|
| *Short Name:* | GraphVizLab |
| *Type:* | Lab |
| *Semester:* | 1st |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320322 |

**Course contents** This lab course complements the introductory course to 3D interactive computer graphics and visualization. The introductory course covers concepts and techniques, while the lab puts them into practice. The lab extends and deepens the covered topics on object representation and modeling, real-time and photorealistic rendering, and scientific visualization.

## 320494 – Topics in Graphics Project

*Short Name:* ProjGrafx
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320322

**Course contents** This course is about diving into a specific question within the field of computer graphics. It can be within the areas of modeling, rendering, or animation. The chosen topic addresses a research-related task. The project is carried through under intense supervision of the instructor. The handling of the project includes getting oneself into the given task (specifying the problem and working out contribution and impact), developing novel ideas on how to push the state of the art, and implementing the respective ideas.

## 320491 – Advanced Graphics

*Short Name:* AdvGrafx
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320322
*Corequisites:* None

**Course contents** Computer graphics deals with the digital synthesis and manipulation of visual content, typically embedded in a three-dimensional scene. Prominent tasks in computer graphics are geometry processing, rendering, and animation. Geometry processing is concerned with object representations such as surfaces and their modeling, rendering is concerned with simulating light transport to get physically-based photorealistic images of 3D scenes or applying a certain style to create non-photorealistic images, and animation is concerned with descriptions for objects that move or deform over time. Methods that tackle these three tasks are being taught.

The course deepens, broadens, and enhances the knowledge in 3D computer graphics obtained from the undergraduate course on ”Graphics and Visualization” in terms of graphics methods.

## 320632 – Advanced Graphics Lab

*Short Name:* AdvGrafxLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320491

**Course contents** This lab course is to be taken together with the Advanced Graphics course and provides hands-on exercises of selected topics of the course.

## 320581 – Advanced Visualization

*Short Name:* AdvViz
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320322
*Corequisites:* None

**Course contents** Scientific visualization deals with the visualization of data with a natural spatial interpretation such as computer-generated data from numerical simulations (physics, chemistry) or measured data using scanning or sensor techniques (medicine, life sciences, geosciences). Volume visualization methods such as segmentation, surface extraction, and direct volume rendering for structured and unstructured gridded as well as scattered data are being taught. These include techniques for scalar field, vector field, and tensor field visualization.

Information visualization deals with the visualization of abstract data with no spatial interpretation such as graph- or network-based data (life sciences, social sciences, computer networks) or multi-dimensional data (economics, databases). Methods that tackle these visualization problems are being taught.

The course deepens, broadens, and enhances the knowledge in visualization obtained from the undergraduate course on ”Graphics and Visualization” in terms of visualization methods.

## 320621 – Advanced Visualization Lab

*Short Name:* AdvVizLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320581

**Course contents** This lab course is to be taken together with the Advanced Visualization course and provides hands-on exercises of selected topics of the course.

## 320564 – Topics in Visualization Project

*Short Name:* ProjViz
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* 320322
*Corequisites:* None

**Course contents** This course is about diving into a specific question within the field of visualization. It can be within the areas of scientific visualization and information visualization. The chosen topic addresses a research-related task. The project is carried through under intense supervision of the instructor. The handling of the project includes getting oneself into the given task (specifying the problem and working out contribution and impact), developing novel ideas on how to push the state of the art, and implementing the respective ideas.

## 5.6 Machine Perception

### 320331 – Artificial Intelligence

| | |
|---|---|
| *Short Name:* | CSAI |
| *Type:* | Lecture |
| *Semester:* | 5 |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | 320201 and 320211 |
| *Corequisites:* | None |

**Course contents** Among the disciplines of CS, Artificial Intelligence is one of the most interdisciplinary, with connections to robotics, pattern recognition, machine learning, high-level programming, databases, software engineering and many more. To provide a modern treatment of the subject, the course focuses on approaches and techniques which enable an intelligent agent to plan, learn, and make decisions in stochastic environments.

**Topics** Dynamic programming and search, probabilistic reasoning, inference in Bayesian networks, Hidden Markov Models, Kalman filter, dynamic Bayesian networks, decision-theoretic expert systems, Markov decision processes, intelligent control, information entropy and decision trees, classification and regression, reinforcement learning, various applications in robotics and machine perception.

### 320433 – Artificial Intelligence Lab

| | |
|---|---|
| *Short Name:* | AILab |
| *Type:* | Lab |
| *Semester:* | 1st |
| *Credit Points:* | 5 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320331 |

**Course contents** This lab course is to be taken together with the Artificial Intelligence course and provides hands-on exercises of selected topics of the course.

## 320443 – Artificial Intelligence Project

*Short Name:* AIProj
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320433

**Course contents** This project course is to be taken together with the Artificial Intelligence course and lab. Students work on a current research problem related to the course under close supervision of the instructor.

## 320671 – Machine Vision

*Short Name:* MachViz
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 120201 (ESM 3A)
*Corequisites:* None

**Course contents** Machine vision algorithms are used in a variety of real-world applications, such as surveillance and object tracking, 3D model building (photogrammetry), and object recognition. Apart from their visual appeal, these algorithms also represent elegant applications of advanced linear algebra and optimization techniques. Topics covered in this course include image-formation and camera calibration, image homographies, segmentation, feature detection and matching, structure from motion, 3D point-cloud processing, and an introduction to object-recognition.

## 320681 – Machine Vision Lab

*Short Name:* MachVizLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320671

**Course contents** This lab course is to be taken together with the Machine Vision course and provides hands-on exercises of selected topics of the course.

## 320691 – Machine Vision Project

| | |
|---|---|
| *Short Name:* | MachVizProj |
| *Type:* | Project |
| *Semester:* | 2nd |
| *Credit Points:* | 10 ECTS |
| *Prerequisites:* | None |
| *Corequisites:* | 320681 |

**Course contents** This project course is to be taken together with the Machine Vision course and lab. Students work on a current research problem reated to the course under close supervision of the instructor.

## 5.7 Computer Networks and Distributed Systems

### 320301 – Computer Networks

*Short Name:* CSCN
*Type:* Lecture
*Semester:* 5
*Credit Points:* 5 ECTS
*Prerequisites:* 320202
*Corequisites:* None

**Course contents** The course discusses network protocols in some depth in order to enable students to understand the core issues involved in network protocol design. Fundamental algorithms and principles are explained in the context of existing IEEE / Internet protocols in order to demonstrate how they are applied in real-world scenarios. This course is recommended for all students with a strong interest in communication networks and distributed systems.

The course covers topics such as local area networks (IEEE 802), Internet protocols, routing algorithms and protocols, flow and congestion control mechanisms, data representation, application layer protocols, remote procedure calls, network security.

### 320414 – Internet of Things Lab

*Short Name:* IoTLab
*Type:* Lab
*Semester:* 1st
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 320301

**Course contents** An increasing number of real-world objects are getting equipped with small, embedded computers and suitable network interfaces, allowing these real-world objects to become connected to the Internet. This lab introduces relevant technologies ranging from hardware aspects, over embedded operating system aspects and up to application design aspects. Topics covered are low-power wireless radios, embedded operating systems, adaptations of IP protocols to fit the requirements of resource constrained devices, new application protocols supporting communication with networked real-world objects.

## 320424 – Computer Networks Project A

*Short Name:* ProjCompNetA
*Type:* Project
*Semester:* 1st
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320414

**Course contents** This project course is to be taken together with the Computer Networks course and the Internet of Things Lab. Students work on a supervised research project on a specific topic related to computer networks.

## 320402 – Advanced Computer Networks

*Short Name:* AdvCompNet
*Type:* Lecture
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* 320301
*Corequisites:* None

**Course contents** This course covers advanced computer networking concepts such as multimedia communication and content distribution. The course covers voice communication in packet switched IP networks, related signaling and transport protocols, quality of service approaches (integrated and differentiated services), and multicast group communications. Some attention will be given to reliability and security aspects. Finally, the course covers technologies popular in backbone networks such as MPLS and new technologies of the IEEE 802 family of standards used in modern optical access networks.

## 320404 – Internet Measurement and Management Lab

*Short Name:* IMMLab
*Type:* Lab
*Semester:* 2nd
*Credit Points:* 5 ECTS
*Prerequisites:* None
*Corequisites:* 3203-AdvCompNet

**Course contents** The Internet has become a large critical infrastructure increasingly replacing traditional infrastructures such as telephony networks. Furthermore, many enterprises depend critically on the functioning of the Internet these days. This lab introduces Internet measurement and management technologies that can be used to detect performance or security problems and technologies that provide means to securely manage and control large distributed infrastructures.

## 320524 – Computer Networks Project B

*Short Name:* ProjCompNetB
*Type:* Project
*Semester:* 2nd
*Credit Points:* 10 ECTS
*Prerequisites:* None
*Corequisites:* 320402 and 320404

**Course contents** his project course is to be taken together with the Advanced Computer Networks course and the Internet Measurement and Management Lab. Students work on a supervised research project on a specific topic related to computer networks.

## 5.8 Master Thesis

In their third semester students elaborate a Master Thesis proposal, based on which they prepare their Master Thesis during the fourth semester.

### 320501 – Master Thesis Proposal

*Short Name:* MThProp
*Type:*
*Semester:* 3rd
*Credit Points:* 30 ECTS
*Prerequisites:* None
*Corequisites:* None

**Course contents** The work out of a master/doctorate thesis proposal is done by graduate students after sucessfully finishing their first year of studies. The preparation of the proposal is carries out in collaboration with the according academic supervisor. The proposal (target size 20 pages) must

- demonstrate that the student masters the professional terminology in the research domain and has the requisite background knowledge,
- identify and motivate a relevant and feasible research question,
- connect the question to the state of the art by a focussed and illustrative literature overview,
- lay out a design for planned experiments, theoretical investigations or implementations, including a schedule,
- and describe criteria for evaluating the eventual success of the project.