Study Guide
Bachelor and Master in Computational Engineering

Academic Year 2013/2014

October 11, 2013

Vorbemerkung

Grundlage für dieses Dokument ist die Fachprüfungsordnung des Bachelor- und Masterstudiengangs in Computational Engineering (Rechnergestütztes Ingenieurwesen) an der Technischen Fakultät der Friedrich-Alexander-Universität Erlangen-Nürnberg, FPOCE, die im Wintersemester 2013/2014 in Kraft tritt. Dieser Studienführer wendet sich in erster Linie an Studierende des Bachelors und Masters in Computational Engineering an der Universität Erlangen-Nürnberg und enthält für die Studiengestaltung relevante Informationen, die regelmässig auf den aktuellen Stand gebracht werden. Verbindlich und in Zweifelsfällen maßgebend sind jedoch ausschließlich die Regelungen in der FPOCE.

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Chapter 1

Computational Engineering

1.1 Introduction

Modern powerful desktop computers are used to solve complex problems in science and engineering research. In addition to theoretical analysis and physical experimentation computer simulations are a fundamental tool to gain new knowledge. New bachelor and master programs have been created in order to meet the demand for scientists and engineers with the broad understanding necessary to develop and apply these new investigative tools to scientific research and engineering design. The major aim of these programs is an interdisciplinary education to produce scientists and engineers with a broad background, people who understand the fundamental physical principles involved in a problem of design or analysis, as well as the mathematical and computational tools required to solve it. The traditional diploma or bachelor degree programs in computer science or engineering only partially fulfill these new professional requirements. Therefore, several international universities have created special interdisciplinary programs in computational engineering.

The University of Erlangen-Nuremberg is in a good position to offer such a program: the Computer Science Department is part of the School of Engineering and there are many projects carried out jointly by computer scientists and other engineers.

Interdisciplinary education in computer-oriented technical subjects is thus a specialty of the University of Erlangen-Nüremberg. The university was the first in Germany to offer Computational Engineering (CE abbreviated) at bachelor and master levels.

1.2 What is Computational Engineering?

Computational Engineering is an innovative discipline fusing together the expertise of well-established engineering fields, computational sciences and applied mathematics. This discipline comprises the design and implementation of software systems to solve problems in engineering and science. It focuses not only on the development of algorithms for the solution of mathematical equations, but also on methods for the visualization and analysis of the computed results.

1.3 The Curriculum

An education in Computational Engineering requires an interdisciplinary curriculum, see Figure 1.1 Faculty members from several engineering departments, as well as from the computer science, mathematics and physics departments are in charge of the program. Each of the application fields is carefully adapted to the student's background, career goals, and research interests. The study plan tailored individually for each student will include adequate course work in:

- Computer science (e.g. algorithms, software engineering, computer architecture)
- Mathematics (e.g. two years of engineering mathematics, numerical analysis, numerical linear algebra)
- An application field from engineering or physical science: in this academic year, thermo- and fluid dynamics, mechatronics, computational optics, mechanics and dynamics, automation and control, and information technology.

Because of the interdisciplinary nature of the curriculum, students take courses in subjects outside their area of specialization to prepare them for graduate courses. Graduates of the Computational Engineering program are well prepared for research and development positions in the industry, as well as for an academic career.

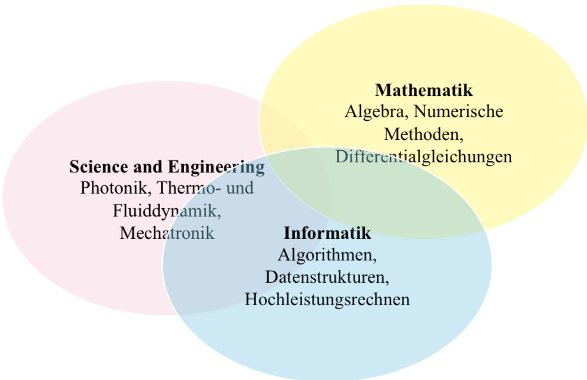


Figure 1.1: The Curriculum of the Degree Programs in Computational Engineering

1.4 A Summary of Some History

In the 1997/1998 winter term, the Faculty of Engineering began its English-language based Master Program in Computational Engineering with funding from the German Academic Exchange Service (Deutscher Akademischer Austauschdienst - DAAD). In the winter term 1999/2000 the German- language based bachelor program was added, and the master program was revised according to the experience gained. The degrees offered at present are: Bachelor of Science after 6 semesters, and Master of Science after a further 4 semesters. With a total of ten semesters, the level of the Master degree is comparable with a German *Diploma* degree. The Master degree is also acknowledged as a prerequisite for German PhD programs.

The combined bachelor-master program consists of a compulsory set of courses in computer science and applied Mathematics, a Technical Application Field (TAF) chosen from the School of Engineering (excluding computer science), and Elective Technical Subjects (Technische Wahlmodule).

In this program, the TAF is central and has therefore significantly more weight than a subsidiary subject of the traditional kind. Thus it becomes possible to teach fundamentals of a technical discipline to which computer-science methods can then be applied fruitfully.

1.5 Goals of the Programs

These programs were created with the following goals in mind:
Demand. Graduates of both the bachelor and master program have excellent job prospects. With the double qualification in computer science and in engineering, graduates can be employed in both of these areas. Bachelor students can participate in advanced user-oriented courses by specializing early and can thereby obtain an attractive qualification for the job market. In the master program, subjects may be given more breadth and depth, so that students can be introduced to current topics of academic or industrial research. A successfully completed master?s degree will be acknowledged as prerequisite for being admitted to PhD programs at German universities. Actual admission to a PhD program, however, requires also proof of high research potential, as preferably demonstrated by an outstanding master?s thesis.
International Orientation. The program complies the internationally accepted bachelor-master structure. The majority of the courses in the master program are in English, thus making it attractive for foreign students who do not speak German. At the same time, German students in the bachelor program are gradually introduced to English as an international scientific language. That way it becomes also easier for German students to work or study abroad after the bachelor program. The possibility of studying abroad is additionally enhanced by the program's compatibility with the Anglo- American university system.
Interdisciplinary. Computational Engineering is an interdisciplinary field. The program includes computer science, applied mathematics and an engineering field (TAF). Courses given jointly by faculty members from more than one department encourage interdisciplinary working.
Flexibility. The integration of many different special fields requires a flexible organization of the study plans. Following the Anglo-American pattern, students are encouraged to choose an individualized study plan from a wide selection of fields to suit their individual interests. The program is modular, as defined by the examination regulations (Prüfungsordnung. In order to ensure optimal support students are assisted by special academic advisors (Studienberater) for the CE program on the one hand and by the assignation of a mentor on the other hand.

1.6 Educational Goal

The desired goal that is to be achieved by the study of Computational Engineering at the School of Engineering is the education of thoroughly skilled engineers with a specifically formed profile. Using the methodical skills and knowledge acquired during their education these engineers should be able to solve engineering tasks independently and responsibly which are located at the interface of the areas of computer science, applied mathematics, and an engineering discipline. They should also be able to develop new perceptions of their field of activity and to judge them critically.

1.7 Education

The Bachelor program Computational Engineering consists of modules spread over six semesters. Those modules include a 8 weeks internship or a practical course that has to be accomplished during the study program and according to the internship guidelines. Beginning with the third semester it is possible to choose elective modules, thus students can specialize according to their personal interests. The bachelor program includes a bachelor thesis work of 15 ECTS credit points. After the completion of all modules and the bachelor thesis students achieve 180 ECTS credit points and are awarded the degree Bachelor of Science (BSc). The master program takes 4 semesters and consists of modules in the areas computer science, applied mathematics, and a technical application field. The fourth semester (6 months) is completely dedicated to the master thesis work. After the completion of all modules and the master thesis students achieve 120 ECTS credit points and are awarded the degree Master of Science (MSc).

Chapter 2

Information for Prospective Students

2.1 Admission and enrollment to the program

There are no restrictions to the admission into the Bachelor program, i.e. it is a *zulassungsfreier Studiengang*. That is why an application is not necessary. Prospective students can directly enroll to the program with the ordinary university procedure as it is described at the site

http://www.uni-erlangen.de/studium/zulassung/einschreibung

Prospective students have to pre-enroll online. The pre-enrollment is opened usually from the 20th July onwards. This date might change from year to year.

2.2 Study records

After enrollment student receive a transcript book and a sheet of records. It is the responsibility of the students to write into the sheet of records the name of the modules attended during the study. The sheet of records documents that the student has regularly completed the study program.

2.3 Mathematics Revision Course (Repetitorium)

In a two weeks revision course at the beginning of the winter term, and before the begin of the lectures, students have the opportunity to review the school work in mathematics that will be especially needed during the first semesters. The respective topics are rehashed during lectures in the morning and exercised in small groups and under close supervision in the afternoon. The revision course includes fundamentals of linear systems of equations, sequences and progressions, functions, complex numbers, differential calculus, integral calculus, curves and vector analysis. The repetitorium is strongly recommended for students in Computation Engineering.

2.4 Welcome and Introductory presentation

There is a general introductory presentation of the School of Engineering for all new bachelor students at the first day of lectures from 8:15 to 8:45 am in the lecture halls H7, H8, and H9. It is followed by a presentation specifically organized for the students of Computational Engineering. All important aspects of the organization, requirements and formalities of the program are explained in this presentation. It is strongly recommended to take part of it. Afterwards students can take part of the Campusralley, it consists of guided tours to important institutions on the campus of the School of Engineering, where students of higher semester will answer questions related to the study and the life as student in Erlangen.

2.5 Information for higher semesters

Report (Rückmelden): The report serves as a confirmation for the enrollment to the next semester. The report does not happen personally, but by the bank transfer of the tuition fee (592 Euros). All students receive a remittance slip together with their semester documents. Students have to observe the respective dates. Failure to observe the time-limit may result in expulsion! The payment has to be done 6 - 8 weeks before the semester starts. You find the list with the corresponding deadlines at the website http://www.uni-erlangen.de/studium/zulassung/formulare/semesterplan.shtml under the entry "Rückmeldung".

Chapter 3

The Fachschaftsinitiative

Fachschaftsinitiative
Computational
Engineering

3.1 Information of the Fachschaftsinitiative

Do you have trouble within your studies or with professors? Do you feel left alone in the academic labyrinth? American scientists have found out that probably all students have those feelings some time during their first semesters. But here is the good news: It does not have to be like this for you because we, the *Fachschaftsinitiative CE* (FSCE), try to give you orientation during your studies!

We are a group of dedicated CE students in the Bachelor's or the Master's program and strive to help and stand aside all CE students. Starting with the *Schülerinfotag* and the *Erstsemester-Einführung* we help you avoid unnecessary difficulties by guiding you through your daily studies. We represent you in official committees like the *Studienkommission*, which makes important decisions about the study programs, and in the *Studiengebührenkommission*.

As there is more on life than studying we also organize social events like BBQs or we meet for a beer in one of Erlangen's pubs. Your are also invited for a coffee at the weekly coffee hour in our room (U1.251 in the *Hörsaalgebäude*). The exact date and time can be found on our web page ce.fsi.uni-erlangen.de. You will receive more information about our activities via the e-mail distribution lists we set up for each year of CE students.

Should you encounter any problems during your studies we can also act as a middleman between you and the lecturer but you are, of course, welcome to just drop by in our weekly coffee hour.

CE as a fairly new study program still needs advertisement. Therefore we try to raise the awareness for the CE study program by attending information events for prospective students.

If you want to have a look behind the scenes of the university life, make new experiences and meet many interesting people from different semesters, we would be very happy if you get involved in the work of the FSCE! We appreciate every new member - no matter if you just want to have a short look, help at some events or spend many hours. If you are interested, contact us, inform yourself on our web page or just come to the next coffee hour or the next FSCE meeting.

Chapter 4

The BSc and MSc General Program Structure

4.1 Overall Structure of the Program

The bachelor and master programs are interdisciplinary. In general a student will take courses in the areas of applied mathematics, computer science and engineering. The bachelor program is horizontally divided into columns or sections representing the fields covered by the program. The vertical structure shows the succession of semesters from bottom to top. It normally takes six semesters to obtain the bachelor's degree. The program is in German but students have the possibility to attend English lectures as well. It is open to anyone with the German high school qualification (Abitur, Allgemeine Hochschulreife) or an equivalent degree. Besides the sections Mathematics, Computer Science, and Technical Application Field (TAF), students have the opportunity to further specialize by selecting courses from the section Elective Technical Subjects. Furthermore, students have to take a seminar, a course on softskills and complete a practical internship at industry (Industriepraktikum) or optional a practical course. The degree is obtained after finishing the bachelor's thesis. The master program is international and offered in German and in English. It covers four semesters of lectures. The last semester is mainly dedicated to the preparation of the master's thesis. The horizontal structure of the program consists of the three sections Mathematics, Computer Science and Technical Application Field. Students have to attend a seminar. Generally, admission to the masters program requires an above average Bachelor or higher degree and is granted on a competitive basis. In the following sections a detailed description of both the bachelor and the master programs is given.

4.2 Technical Application Field - TAF

At the of the second and before the third semester starts students have to choose an area of specialization from engineering or physical science (e.g., thermo- and fluid dynamics, computational optics or information technology), the Technical Application Field or TAF. The list of currently offered TAFs can be found in Section Technical Application Fields. For each TAF there is a designated contact person or TAF advisor, see Section Contact Persons and Addresses. A short introduction to the TAFs will be given during the second semester. For more information students are encouraged to contact the study advisor or the advisor of the

TAF.

4.3 The ECTS, the credit point system

According to the European Credit Transfer System (ECTS) a course is measured by a number of points, so-called ECTS-points. Typically, a single study module is evaluated with 2,5; 5; 7,5 or 10 ECTS-points. Students need to gather 30 ECTS-points per semester. Remark. ECTS replaces the older evaluation system which was based on the number of SWS = Semesterwochenstunde (Woche=week, Stunde=hour/lesson). One SWS equals one academic hour (45 minutes) per week for the duration of a semester. It usually corresponds to 1,25 ECTS-points. (e.g. 2 SWS = 2,5 ECTS).

4.4 Modularity: the Format of Courses

A bachelor or a master program comprises a set of modules. The value of each module is given with the ECST credit point system. A module constitutes a consistent and temporally coherent study unit that is usually but not always concluded with an examination. Examinations are studienbegleitend, which means that the written or oral examination takes place during the semester or during the following audit period. A module usually consists of a lecture (Vorlesung) and an exercise class or tutorial (Übung). Some modules might also contain a lab (Praktikum) or computer lab. A lecture and the accompanying exercise course or tutorial belong together and cannot be taken as separate classes.

Typically, the lecture is given by a faculty member, while the exercise course or tutorial is taught by a research or teaching assistant. Students are strongly advised to actively participate in the exercises. The exercise courses are often accompanied by weekly assignments. For each module there are one or more faculty members which are responsible for that module. The module content and examination modality are specified in detail in the module description (Modulbeschreibung). A module examination (Modulprüfung) might consist of one or more partial examinations (Teilprüfungen). Apartial examination can be just passed (unbenoteter Schein oder Studienleistung) or graded (benoteter Schein oder Prüfungsleistung). The final grade of the module (Modulnote) is computed as a weighted sum of the grades obtained in the partial examinations.

Finally, there are seminars (Seminar) which focus on different research topics each semester. Students are requested to actively participate. Generally, the instructor of each class announces what is required to successfully pass of the module. Those requirements sometimes deviate from the general guidelines mentioned above, and it is each student's responsibility to inform herself/himself about the actual regulations.

4.5 Study Plan (Studienkonzept)

Establishing an individual study plan (Studienkonzept) is an important and mandatory aspect of the CE program. At the beginning of their studies all students have to create a new study plan within the bebop system [1]. Students have to specify their TAF at the end of the second and before the begin of the third semester. The study plan states the modules, which have to

[1] https://bebop.informatik.uni-erlangen.de/studyplan/ce/index.php

be passed in order to obtain the degree. Each TAF provides a study plan, the standard study plan (Standard-Studienkonzept), for both the BSc and the MSc programs with a workload of at least 30 ECTS per semester.

The modules of the sections Mathematic, Computer Science and Technical Application Field (TAF) in the bachelor program are mandatory. The section Elective Technical Subjects consists of elective modules. In this section the standard study plan proposes a set of modules recommended for the selected TAF. Each student is free, however, to choose modules from other bachelor programs offered by the School of Engineering and from the physics or the mathematics departments. The academic advisors for CE will assist students with their choice. Any change in the study plan must be acknowledged by the advisor of the bachelor program and the advisor of the corresponding TAF.

The master program comprises mostly elective modules. In the section Computer Science only modules from the Computer Science Department can be included. In the section Mathematics the student can choose modules from the department of applied mathematics, or modules from other departments of the School of Engineering that have a mathematical orientation. In the section Technical Application Field the student can choose modules from any department of the School of Engineering or the School of Science. Modules from the department of computer science or applied mathematics cannot be included in this section. The advisor of the master program and the advisor of the TAF must acknowledge any change in the study plan. The study regulations allow students to change their Technical Application Field and to replace elective modules. Students are even allowed to replace modules with failed examinations. Any failed attempt (Fehlversuch) will be charged to the new TAF or substituting modules.

4.6 UnivIS = University Information System

Important information on modules at the university is published in the web system UnivIS. This includes dates, times and places of all current and past modules. UnivIS allows students to generate their timetables. UnivIS also includes useful information such as addresses, phone numbers and email address of the faculty in charge of the lectures or exercise courses. Students need to refer to UnivIS often, therefore it is important that they familiarize themselves with the system as early as possible. UnivIS is located at http://univis.uni-erlangen.de.

4.7 Examinations

Exams of modules are Studienbegleitend, i.e. examinations take place during the lecture period or in the first exam period following the lecture. The exam period is determined by the registrar's office (Prüfungsamt). It might be required by the module description (Modulbeschreibung) that assignments and programming exercises are successfully completed a part of the module examination. Exams may be either written or oral, as it is determined in the module description . The lecturer will explain at the beginning of the semester which are requirements and examination modality.

The final grade is computed from the grades obtained for each one of the modules. Modules of the first two semesters (Grundlagen- und Orientierungsphase) are weighted with 0,75. Modules from the bachelor phase with the factor 1,0. If a student fails a course she or he must repeat the exam in the next audit period. The exam of modules in the GOP (Grundlagen-und Orientierungsprüfung) can be repeated only once, the exams of all other modules can be repeated twice.

4.8 Exam Registration

Time and place of the registration for exams are announced by the registrar's office usually several weeks in advance. Students have to register online by using the *mein campus* system of the university. The URL of this page is: https://www.campus.uni-erlangen.de/

4.9 Mentors

Students have the opportunity to choose a personal mentor. A mentor is a member of the respective faculty staff who can advise students in matters not only concerning the program, and is also available if problems occur. In order to ensure a high standard of support, each mentor is responsible for a small group of students only.

4.10 Relevant Boards of the University

There are two boards of the university of particular interest for students of Computational Engineering. The Study Commission (Studienkommission) for Computational Engineering is responsible for academic questions concerning the program. It consists of various faculty members and other university staff who are closely associated with the program. A student representative is also part of the study commission. The Examination Committee (Prüfungsausschuss) is officially responsible for all questions concerning examinations. The Admission Committee (Zugangskommission) is in charge of the applications to the master program.

Chapter 5

Bachelor Program

5.1 General Information

Due to its interdisciplinary nature, the program requires to take modules in computer science, mathematics and in a technical application field (TAF). Therefore, students have to decide which TAF they wish to study during semester which TAF corresponds better to her or his personal interests. The modules of the first two semesters are common for all TAFs. The list of the TAFs offered in this academic year together with their description and corresponding study plans are given in section Technical Application Fields.

5.2 Admission

Admission to the bachelor program is currently – as for most programs in Germany – open to anyone with the German high school qualification Allgemeine Hochschulreife, or an acknowledged foreign equivalent degree.

5.3 Languages

The bachelor program in Computational Engineering contains modules in German. Therefore, foreign students must take the DSH language proficiency test for admission. The DSH 2 level is the minimum requirement. Students have the possibility to take some of the elective technical modules in English. This is a good opportunity for German students to familiarize to English as the international language of science.

5.4 Horizontal Structure of the Program

The overall structure of the bachelor program is shown in Table 1. The horizontal structure of the program comprises in addition to the three major sections Mathematics, Computer Science and the Technical Application Field, a section with Elective Technical Subjects, an internship at industry or a practical course, softskills modules (Schlüsselqualifikation), a seminar and the bachelor's thesis.

Mathematics (Mathematik) [37,5 ECTS]. This section contains mandatory modules corresponding to the usual engineering mathematics. These are complemented with two further modules in numerical mathematics.

Computer Science (Informatik) [47,5 ECTS]. This section contains modules from the bachelor program in computer science together with two modules in scientific computing offered by the Computer Science Department.

Technical Application Field (Technisches Anwendungsfach, TAF) [min. 40 ECTS]. Each student has to choose a TAF the second semester. The list of currently offered TAFs can be found in Sec. Technical Application Fields. The modules in the section TAF are mandatory. Each TAF has a TAF advisor (TAF-Vertreter) who supports students in all questions related to the TAF.

Elective Technical Subjects (Technische Wahlmodule) [max. 20 ECTS]. This section offers the students the possibility to improve their academic skills by selecting modules from the engineering and computer science departments. A complete set of recommended modules is given for each TAF in the Standard Study Plan. The Standard Study Plans of the several TAFs are listed in Section Technical Application Fields. Students are encouraged to consult the study advisor and the TAF advisors about the modules appropriate for the respective application field. Furthermore, students should consult the UnivIS for courses offered by the different chairs.

Internship and Softskills (Praktikum und Schlüsselqualifikationen) [15 ECTS]. An internship in industry comprises 8 weeks. Optional students might choose a practical course from a list of modules determined by the Study Commission (Studienkommission). For courses in softskills please consult the study advisor and look at the UnivIS.

Bachelor Program						
6		SiWiR II (7,5 ECTS)				
5		SiWiR II (7,5 ECTS) Simulation and Modelling I (5 ECTS)	Modules depend on TAF	Modules are provided in study plan	Internship (10 ECTS) Softskills (5 ECTS)	Thesis (15 ECTS) Seminar (5 ECTS)
4	Mathe IV A (5 ECTS) Numerik II (5 ECTS)	SiWiR II (7,5 ECTS)				
3	Mathe III A (5 ECTS) Numerik I (5 ECTS)	Systemprogrammierung (5 ECTS)				
2	Mathe für CE 2 (10 ECTS)	Systemprogrammierung (5 ECTS)				
1	Mathe für CE 1 (7,5 ECTS)	Algorithmen und Datenstrukturen (10 ECTS) CE I (7,5 ECTS)	Eperimentalphysik f. NatWiss. I (7,5 ECTS)			
	Min. 37,5 ECTS	47,5 ECTS	Min. 40 ECTS	Max. 20 ECTS	15 ECTS	20 ECTS
	Mathematics	**Computer Science**	**TAF**	**Elective Technical Subjects**	**Intership Softskills**	**Thesis Seminar**

Table 5.1: Organization of the Bachelor Program in Computational Engineering

Seminar [5 ECTS]. In the seminar a group of students focuses on a particular topic and is requested to actively participate. The student has to prepare and give a presentation of at least 45 minutes and deliver a written report. The topic of the seminar has to be from within the area of computer science or an area related to the TAF.

Bachelor's Thesis (Bachelor-Arbeit) [15 ECTS]. The bachelor's thesis comprises a research work of about 360 hours and has to be completed within five months after the registration. The student can register for the bachelor's thesis as soon as she or he has achieved 100 ECTS credit points. The topic of the thesis must be in the area of Computational Engineering under the guidance of a qualified faculty member of the School of Engineering. At the end of the bachelor's thesis the student has to give a 30 minutes presentation followed by a closing discussion.

5.5 Vertical Structure of the Program

The vertical structure of the Bachelor program gives the temporal view of the study and is divided into two levels. The introductory level (Grundlagen- und Orientierungsphase) comprises the two first semesters. The bachelor level extends from the third to the sixth semester including the seminar and the bachelor thesis.

Grundlagen- und Orientierungsprüfung GOP [Min 30 ECTS]. The GOP comprises the examination of modules with a minimum of 30 ECTS credit points. In this phase the student has to show that she/he is able to afford the exigency of a scientific study in Computational Engineering. GOP modules can be chosen from a list of 7 modules form the introductory level of the program. The electable modules are marked by a dot in the first column of the Standard Study Concept. The GOP has to be passed within the first three semesters. The examination of a GOP module can be repeated only once, i.e. only one failed attempt (Fehlversuch) is possible.

Introductory Level (1st & 2nd Semester). The first two semesters are common to all TAFs, i.e. students have the same set of modules independent of the TAFs. This level comprises 7 modules. Students have to choose modules for at least 30 ECTS credit points for the GOP. The lectures at this level are all in German. The following table gives the modules for the introductory level in CE. Each one of these modules is electable for the GOP.

GOP	Semester	WS	SS
	Informatik	ECTS	
·	Algorithmen und Datenstrukturen	10,0	
·	CE I (Rechnerarchitektur)	7,5	
	Mathematik		
·	Mathematik für CE 1	7,5	
·	Mathematik für CE 2		10,0
	TAF		
·	Experimentalphysik f. NatWiss. I	7,5	
·	Experimentalphysik f. NatWiss. I		7,5
·	CE II		5,0

Table 5.2: Modules electable for the GOP

Bachelor Level (3rd – 6th Semester). At this level students pursue their specialization up to the bachelor's degree. The bachelor's degree encompasses modules with a total of 180 ECTS, including the bachelor's thesis with 15 ECTS. The degree is obtained regularly after six semesters.

Standard period of Study (Regelstudienzeit). The bachelor's degree with 180 ECTS can be obtained within six semesters. It is possible to extend this period by two further semesters. After these two extra semesters the student has to apply for a further semester at the registrar's office (Prüfungsamt) and justify the delay.

5.6 Standard Study Plan Bachelor

For each TAF a standard study plan (Standard-Studienkonzept) specifies a complete catalogue of recommended modules, including the modules of the GOP, the mandatory modules in the sections computer science and mathematics, and the mandatory and the elective modules for each specific TAF. Modules in the section Elective Technical Modules can be changed. Any change in the study plan has to be approved and acknowledged by the study advisor and the advisor of the corresponding TAF. If a student does not change any one of the elective modules, she or he automatically has to take the courses specified in the standard study plan.

Chapter 6

Master Program

6.1 General Information

The master program is designed to allow students to pursue studies both in Computer Science and in an engineering field of their choice. For this reason, applicants are required to have knowledge in both of these areas. Ideally, students have either a bachelor's degree in Computational Engineering or an engineering degree with a strong computer science component. A good mathematical background is essential. The program requires a minimum of 2 years of engineering mathematics at the university level. Additionally, knowledge in numerical mathematics is strongly recommended. The master program takes a minimum of four semesters. The main purpose of the last semester is the preparation of the master's thesis. The thesis is intended to introduce students to research work at the university.

6.2 Admission

One of the application requirements for the master program is a bachelor's degree in Computational Engineering, Computer Science, Applied Mathematics, or in an engineering discipline. Since the program contains components from computer science, engineering and applied mathematics it is important that applicants have a sufficient background in these areas. Students who have completed the bachelor program in Computational Engineering at the University of Erlangen-Nürnberg and apply for the Master degree in Computational Engineering are called **consecutive students**. Students with a bachelor degree other than in Computational Engineering are called **non consecutive students**, these are for example international students. The application procedure is different for consecutive and non-consecutive students.

6.2.1 Consecutive Students: Students of the Erlangen CE bachelor program

The application for the master program must be done online at *Online-Bewerbungsportal für Master-Studiengänge* of the university:

`https://movein-uni-erlangen.moveonnet.eu/movein/portal/studyportal.php`

Here you will find a detailed information on the application process. Students of the Erlangen CE bachelor program must deliver besides the online form the following documents:

- a letter of intent
- a curriculum vitae
- record of studies.

Application deadlines for consecutive students are

- **July 15** for the winter term
- **January 15** for the summer term

6.2.2 Non consecutive students: German and International Students with a degree other than Computational Engineering

The application for the master program must be done online at *Online-Bewerbungsportal für Master-Studiengänge* of the university:

`https://movein-uni-erlangen.moveonnet.eu/movein/portal/studyportal.php`

All applicants should meet the following criteria:

- Completion of an excellent Bachelors degree or a corresponding qualification in Computer Science, in a related scientific or technical field, or in Mathematics.
- Proficiency and experience in both using and programming computers. Besides familiarity with the basic concepts of computers and Computer Science, we expect that you have solid programming experience with procedural and object oriented languages like C and C++.
- A well rounded education in Engineering Mathematics.
- Interest in learning how to use high-performance computers to solve problems in engineering.
- International Students
  - A solid command of the English language - TOEFL score of at least 560 or equivalent qualification.
  - A good score on the GRE - The General Test. (see `http://www.ets.org/gre`)
  - students should be interested in a stay in Germany, as learning German is part of the program.

Students with a degree from outside the University of Erlangen-Nürnberg or with a degree other than Computational Engineering should prepare the following documents:

- completed Personal Information Sheet (PIS 2011, rtf)
- letter of intent

- curriculum vitae
- record about previous studies and employments
- course transcripts
- at least two letters of recommendation.

If there are questions about the application please send a email to `ce-masterinformatik.uni-erlangen.de`.

What happens with your application

The full application documents will be evaluated by two experts and the CE selection committee will decide on your selection. Only if this committee selects you, we will invite you to apply again officially online at the university and send your application as hard copy to the Master Office. The Master Office will check your documents formally and only if everything is ok with your documents, you will get the official admission letter. Successful applicants might still have to take an oral examination. In certain cases the Admission Commission demands of the applicants to take additional exams in computer science, mathematics, or the technical application field. These exams have to be taken within one year before the applicant is fully admitted to the master program. It is recommended to contact the study advisor for details of the admission procedure as early as possible. Prospective foreign students should contact the International Student Advisor at their earliest convenience.

Application deadline

The master program can be started only in the winter term. The deadline for the application is:
April 30 for students who require a visa (Non-EU Citizens)
July 15 for students who do not require a visa (EU Citizens)

6.3 Language

Due to its international orientation, the modules of the master program are offered in English. If students prefer they can take modules in German. Examinations and the master's thesis can be taken or written either in English or German.

6.4 Horizontal Structure of the Program

The overall structure of the master program is shown in Table 6.1. The master program in Computational Engineering consists of a seminar, the three sections Mathematics, Computer Science and Technical Application Field, and the master's thesis. There is a standard study plan for each TAF. Nevertheless, all modules in the master program are elective. Students can choose modules from the module catalogue for the different master studies in the Computer Science, Engineering, Applied Mathematics, and Physics departments.

Mathematics (Mathematik) [minimum 20 ECTS]. Mathematics modules for the master program can be taken from module catalogue offered by the department of applied mathematics and from the different departments of the School of Engineering. The modules must have a mathematical orientation.

Computer Science (Informatik) [minimum 20 ECTS]. The student can select modules offered by the Computer Science Chairs for the master program in computer science.

Technical Application Field (Technisches Anwendungsfach, TAF) [minimum 20 ECTS]. In this section the student can select modules from all master programs offered by the School of Engineering. The only exception are modules from the department of computer science.

<table>
<tr><td>10</td><td colspan="3">Master thesis (30 ECTS)</td><td rowspan="4">Seminar (5 ECTS)</td></tr>
<tr><td>9</td><td rowspan="3">Modules with a strong mathematical background</td><td rowspan="3">Modules from the computer science department</td><td rowspan="3">Modules related to the TAF</td></tr>
<tr><td>8</td></tr>
<tr><td>7</td></tr>
<tr><td>Semester</td><td>Mathematics (minimum 20 ECTS)</td><td>Computer Science (minimum 20 ECTS)</td><td>TAF (minimum 20 ECTS)</td><td>$\sum$ 120 ECTS</td></tr>
</table>

Table 6.1: Organization of the Master Program

Seminar [5 ECTS]. The students can take a seminar of any master program from the department of computer science, or a department of the School of Engineering related to the TAF.

Master Thesis (Master-Arbeit) [30 ECTS]. The master's thesis can be registered at the registrar's office as soon as the student has successfully collected 70 ECTS point credits. It has an extent of about 810 hours and has to be completed within six months after the registration. The topic of the thesis must be related to subjects studied by the student during the master program. Usually a special thesis advisor is assigned to each student. The thesis may involve regular meetings with the thesis advisor and also the participation in a larger research group. It can be written in English. An oral presentation of the results of about 30 minutes as well as a consecutive discussion are obligatory.

6.5 Vertical Structure of the Program

Master Level (7th – 10th Semester). The master program contains courses with a total of 90 ECTS, plus the master's thesis with 30 ECTS. As a rule, the Master degree can be obtained within four semesters after the Bachelor degree.

Standard period of Study (Regelstudienzeit). The Master degree with 120 ECTS can be obtained within four semesters. It is possible to extend this period by one further semester. After this extra semester the student has to apply for a further semester at the registrar's office and justify the delay.

6.6 Standard Study Plan Master

For each TAF in the master program a standard study plan (Standard-Studienkonzept found at [1]) specifies the recommended modules for the three section computer science, mathematics and TAF. All modules are elective and can be changed. Any change in the study plan has to be acknowledged by the study advisor of the master program and the advisor of the corresponding TAF. Note that you must create a study plan within the bebop system [2] when you start your studies.

6.7 Bavarian Graduate School of Computational Engineering

The Bavarian Graduate School of Computational Engineering (BGCE) was established in 2004 within the framework of the Elite Network Bavaria. As its primary objective, this Bavaria wide initiative aims at both challenging and individually training and furthering the most excellent and motivated graduate students in our three participating master's programs Computational Engineering (CE) at the Friedrich-Alexander-Universitt Erlangen-Nürnberg as well as Computational Mechanics (COME) and Computational Science and Engineering (CSE) at the Technische Universität München.

Do more get more! is the motto of our elite program. After their first semester in one of the three master's programs, our selected applicants are admitted to BGCE, in parallel to their ongoing master's studies. During their next two semesters, they earn 30 additional credits for a tailored combination of summer schools, block tutorials, advanced courses, project based education, and soft skills training. At the end, all successful BGCE participants will be awarded a Master of Science with honours degree, which manifests their outstanding excellence throughout their graduate studies. BGCE's course program is a highly attractive offer to those who are willing to invest a bit more of work in order to get a deeper insight into modern research topics in the field of computational engineering. For example, BGCE students get the opportunity to take part in renowned summer schools such as the Ferienakademie in Northern Italy or JASS in St. Petersburg, Russia; they are invited to attend block tutorials given by leading experts of their respective field; they can experience writing numerical software in larger teams, sometimes in cooperation with industry partners; and they are offered specially designed seminars on soft skills topics such as presentation and communication, teamwork, project management, or leadership.

Participants to the elite program are required to have excellent grades and maintain a grade average of 2.0 or better. 10 credits have to be taken from either of the two partner programs at TU Munich. Participation in the elite program will therefore be most seamless for the TAFs which fit to those at TUM Munich, such as Thermo- and Fluid Dynamics, Mechatronics, or Computational Optics. The study plan of students in the elite program must include at least Numerical PDE I, and either a course in Optimization or Numerical PDE II. In the computer science field, at least 10 ECTS must be taken in continuous simulation, the remaining 10 ECTS form a choice of visualization, pattern recognition, simulation, or high performance computing. The 30 credits of Elite courses can be taken from an annually changing catalogue. These courses and the study plan must be approved by the chairperson of the Elite program.

[1] http://www.ce.uni-erlangen.de/students/standard-studienkonzepte-master/lang-pref/en/
[2] https://bebop.informatik.uni-erlangen.de/studyplan/ce/index.php

6.8 Double Degree in Computational Engineering

Starting in the fall semester 2008, students of Computational Engineering can obtain a double Master's degree from two leading European universities. Students who wish to use the opportunity must study one year at each of FAU Erlangen-Nürnberg and Kungl. Tekniska Högskolan, Stockholm, Sweden. According to the agreement between the universities, both universities will award the candidate a master's degree, giving the graduates an important extra qualification for the international job market.

The study program is essentially symmetric. Students from FAU can, following successful completion of first year's study, move to KTH, and Swedish students can complete their second year in Erlangen. The first year program at the "home" university covers advanced basics of Computational Engineering, and the second year at the "Guest" university is devoted to depth in a choice of specializations, and to the writing of the Master's thesis.

The programs at KTH and FAU are international and the instructional language is English. At least for the study, no further language skills are required, with the result that a large percentage of the students are from third countries. The DAAD academic mobility funding agency supports the double degree program with travel grants and scholarships for participating students. In the near future it will also be defined how the double degree can be combined with participation in BGCE and the graduation "with honours".

Acknowledging the need for highly trained personnel in the area of CSE, both in industry and in academia, Master Courses in CSE were introduced by the two partner universities independently as early as 1997. The two universities therefore belong to the first pioneers of this new field in Europe. However, both institutions did not only initiate the systematic CSE education in Europe, but they have been continuously active in the further development of CSE education. The continuous adaptation is essential because of the rapid evolution in this exciting new branch of science.

What is CSE? Why CSE? The demand for CSE skills is driven by the remarkable development of large scale computing into the third paradigm of science, where computing complements theory and experiment to become a third fundamental approach to scientific discovery. With computer simulations and optimization of mathematical models this multidisciplinary field has been established as a new discipline. CSE offers scientists new insight in scientific problems and tools for extracting and using detailed information from volumes of data. CSE has enabled drastic shortening and economization of the design cycle for products and processes, and virtual prototyping is used successfully by aerospace, automotive, and processing industries, as well as in medical technology.

For the students participating in the program, a notably high measure of flexibility and mobility may be assumed. The program strongly encourages leaving well-trodden paths in favor of venturing into the new and unknown. Students will also become effectively tri-lingual, in the everyday life sense, in German, Swedish, and English, in addition to their mother tongue. Through the study program they achieve mastery of a number of the disciplines involved in CSE and become an interesting resource for industrial partners. Many firms have seen the potential of early promotion of their specific applications and take the opportunity to form close ties with highly qualified future collaborators.

Such promotion is of special interest for corporations with activities in Sweden and Germany and in the home countries of the participating students. Internships, thesis projects, and scholarships open the door for the companies to human resource management by ways of scientific collaboration with academia, and for graduates to exciting careers in industry.

Chapter 7

Technical Application Fields

The master program requires students to choose their Technical Application Field. Students are encouraged to consult the study advisor or to contact the persons in charge of the TAFs (TAF-Vertreter) to obtain further information related to the application area. A list of addresses is provided in section Contact Persons and Addresses. The offered TAFs in this academic year are (listed in alphabetical order):

- Automatic Control (Regelungstechnik)
- Computational Materials Science
- Computational Optics (Photonik und Optik)
- Information Technology (Informationstechnologie)
- Mechatronics (Mechatronik)
- Medical Engineering
- Solid Mechanics and Dynamic (Festkörpermechanik und Dynamik)
- Thermo- and Fluid Dynamics (Thermo- und Fluiddynamik)

A short description of each TAF together with the corresponding standard study plan is given in the following subsections.

7.1 Computer Science and Mathematics in the Bachelor Program

The first two semesters and the sections Computer Science and Mathematics in the study plan for the bachelor program are common to all the TAFs. Students of Computational Engineering have to attend to the obligatory courses listed in the table below regardless of their TAF. This table also specifies the modules that can be chosen for the GOP. Modules in Table 7.1 marked with • are eligible for the GOP.
Remark: Instead of Numerik I für Ingenieure and Numerik II für Ingenieure students that are particularly interested in numerical applications and mathematics can take the modules

GOP	Semester	1 (WS)	2 (SS)	3 (WS)	4 (SS)	5 (WS)	6 (SS)
	Computer Science						
•	Algorithmen und Datenstrukturen	10,0					
•	CE I (Rechnerarchitektur)	7,5					
	Systemprogrammierung		5,0	5,0			
	Simulation and Modeling 1					5,0	
	Simulation und Wissenschaftliches Rechnen I					7,5	
	Mathematics						
•	Mathematik für CE 1	7,5					
•	Mathematik für CE 2		10,0				
	Mathematik f. Ingenieure III A			5,0			
	Mathematik f. Ingenieure IV A				5,0		
	Numerik f. Ingenieure I			5,0			
	Numerik f. Ingenieure II				5,0		
	TAF						
•	Experimentalphysik f. Naturwissenschaftler I	7,5					
•	Experimentalphysik f. Naturwissenschaftler II		7,5				
•	CE II (Modellierung)		5,0				

Table 7.1: Obligatory modules common to all TAF in the bachelor program

Neinführung in die Numerik (10 ECTS) and Gewöhnliche Differentialgleichungen (5 ECTS). This election is accordance with the Examination Regulations for the bachelor program in Computational Engineering.

7.2 Elective and Obligatory Modules in the Master Program

In the master program there are some modules which are obligatory. These modules are marked with a P (Pflichtmodul). Furthermore, there is a list of elective modules that must be chosen from a restricted list. These modules are marked with a WP and are called in German Wahlpflicht-Modul. The remaining modules are all elective and can be elected from a large list of modules according to the general restrictions determined by the examination regulations of Computation Engineering. Summarizing, modules are classified according to

- P obligatory module
- WP elective technical module from a short list of options
- W elective technical module

The WP modules are further classified into the following classes:

- WP–INFORMATIK and WP–COMPUTER–SCIENCE: these are WP modules typical for the computer science education in Computation Engineering which are held in German or in English.
- WP–PROJEKT: these are computer science modules mainly consisting of project work in the area of high performance computing and numerical computation.

- WP–MATHEMATIK: these are modules from the area of mathematics.
- WP–APPLIED-MATH: these are modules from the area of applied mathematics.
- WP–NUMERICAL–ANALYSIS: these are modules from the area of numerical analysis.
- WP–SCIENTIFIC–COMPUTING: these are modules from the area of high performance computing.

The list with the WP modules offered in this academic year is given in Table 7.2.

Group	Name	Sem.	ECTS
WP-MATHEMATIK	Numerical Linear Algebra	7.5	WS
WP-MATHEMATIK	Elementary Numerical Mathematics	7.5	WS
WP-MATHEMATIK	Numeric of PDE 1	10.0	WS
WP-MATHEMATIK	Numeric of PDE 2	10.0	SS
WP-PROJEKT-MODULE	Numerical Simulation of Fluids	7.5	SS
WP-PROJEKT-MODULE	Computational Optics	7.5	SS
WP-PROJEKT-MODULE	Cluster and Grid Computing	7.5	SS
WP-PROJEKT-MODULE	Parallele Systeme - VUP	7.5	SS
WP-PROJEKT-MODULE	High End Simulation in Practice	7.5	SS
WP-PROJEKT-MODULE	Simulation and Modeling II	7.5	SS
WP-INFORMATIK	Computer Graphics	7.5	WS
WP-SCIENTIFIC-COMPUTING	Programming Techniques for Supercomputers-VU	7.5	SS
WP-SCIENTIFIC-COMPUTING	Simulation and Scientific Computing 2	7.5	SS
WP-NUMERICAL-ANALYSIS	Numeric of PDE 2A - Theorie und Numerik hyperbolischer Erhaltungsgleichungen	5.0	SS
WP-NUMERICAL-ANALYSIS	Numeric of PDE 2B	5.0	SS
WP-NUMERICAL-ANALYSIS	Introduction to the Finite Element Method	5.0	SS
WP-NUMERICAL-ANALYSIS	Multigrid Methods	5.0	SS
WP-NUMERICAL-ANALYSIS	Convex Optimization in Communications and Signal Processing	5.0	WS
WP-COMPUTER-SCIENCE	Computer Architecture	5.0	WS
WP-COMPUTER-SCIENCE	Efficient Combinatorial Algorithms	7.5	WS
WP-COMPUTER-SCIENCE	Geometric Modeling	7.5	WS
WP-COMPUTER-SCIENCE	Computer Graphics	7.5	WS
WP-COMPUTER-SCIENCE	Applied Visualization	5.0	SS

Table 7.2: List of WP modules for the consecutive and non-consecutive master program

7.3 TAF Automation Control (Regelungstechnik)

Remark: This TAF is offered only in German language

Automatic Control is about taking influence on the dynamic behavior of engineering processes. Thus, automatic control is a prerequisite for most of nowadays engineering solutions – from low-cost consumer products (e.g. DVD Players) to large scale industrial applications (e.g. chemical processes).

Technically, Automatic Control draws from systems theory to mathematically characterize desirable behavior. This characterization typically refers to a closed-loop configuration of a process model and the yet unknown controller. The core question becomes how to “solve these design equations”. The mandatory and recommended courses of this Technical Application Field will discuss this question in depth and from a variety of perspectives, incl. classical methods (frequency domain, PID control), state space methods (static and dynamic feedback, linear and nonlinear processes), optimal control (dynamic programming, Kalman filtering), digital control (for DSP based realizations), and supervisory control (control for formal languages and finite automata).

Automatic Control - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Einführung in die Regelungstechnik			5.0				
	Regelungstechnik B (Zustandsraummethoden)			5.0				
	Regelungstechnisches Praktikum f. MB u. CE				5.0			
	Modellbildung in der Regelungstechnik					5.0		40.0
	Elective Technical Subjects – max. 20.0 ECTS							
	Grundlagen der Schaltungstechnik				5.0			
	Digital System Verification				5.0			
	Digitale Regelung				5.0			
	Ereignisdiskrete Systeme						5.0	
	Tutorial Simulation and Modeling 1					2.5		22.5
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I		5.0					
	Internship at Industry II					5.0		
	Softskill			5.0				15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar					5.0		5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	27.5	35.0	30.0	30.0	27.5	182.5

Automatic Control **Standard study plan for master students**						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-PROJEKT-MODUL	WP			7.5		
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
WP-MATHEMATICS	WP	7.5				
Functional Analysis for Engineers	P	5.0				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP		5.0			25.0
TAF – 30.0 ECTS						
Mehrgrößen-Zustandsregelung	W	5.0				
Nichtlineare Systeme	W	5.0				
Optimalsteuerung	W		5.0			
Regelung nichtlinearer Systeme	W		5.0			
Robuste Regelung	W		5.0			
Praktikum Regelungstechnik II	W			5.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		30.0	35.0	20.0	30.0	85.0

This TAF is offered only in German langauage

7.4 TAF Computational Materials Science

Computational Materials Science is a relatively new and rapidly evolving discipline that brings together elements from materials science, physics, chemistry, mechanical engineering, mathematics and computer science. The reason for the strong demand for Computational Materials

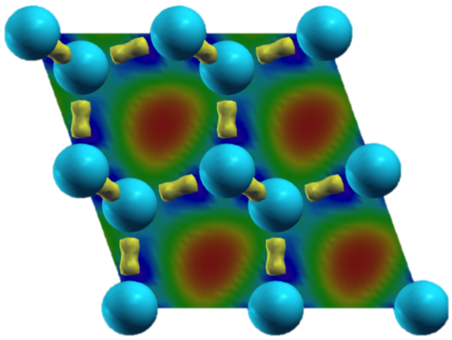
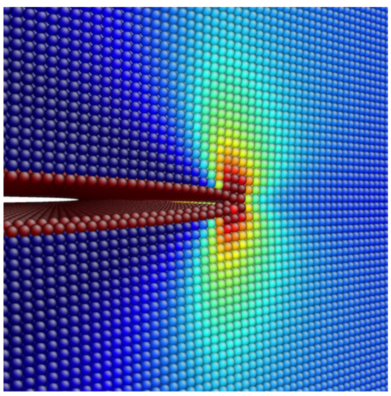
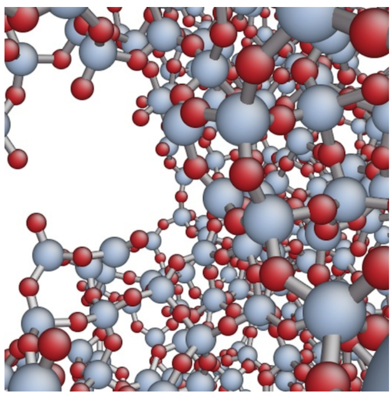


Figure 7.1: Charge density distribution in a silicon crystal

Scientist both in industry and academic research is manifold: properties of materials are not only determined by their respective chemical composition, but also to a large degree by their microstructure. Studying the interrelation between processing, structure and properties of materials is thus at the heart of materials science. The often competing, complex mechanisms take place on a range of different length- and time scales, requiring the development of new simulation methods suitable for scale-bridging. The investigation of crystal and defect properties for example, requires quantum mechanical calculations and atomistic simulation methods with typical time scales ranging from femtoseconds through nanoseconds and length scales ranging from Angströms to several hundred nanometers. Studying the interactions, statistics and self-organization of lattice defects on the so-called meso-scale requires methods able to adequately describe complex many-body problems over long time scales. On the macro-scale, finite-element models, which incorporate microstructure information using averaging constitutive laws, are used in the design of engineering structures and devices. Stu-



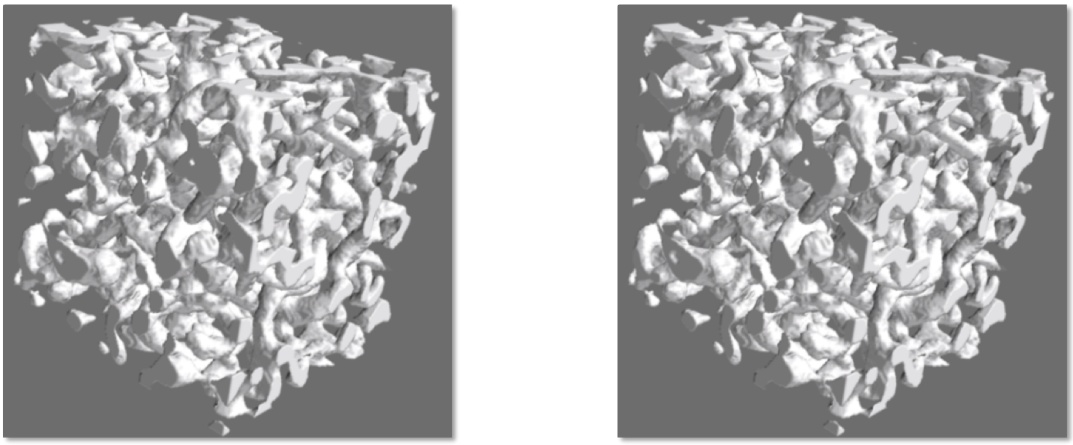
(a) Stress field around a crack tip in a nickel single crystal



(b) Crack in a silicate glass

Figure 7.2: Visualization of a crack for different crystal structures

dents of the TAF Computational Materials Science will receive a solid foundation in materials science with a focus on mechanical properties. The TAF will provide them with conceptual foundations as well as with theoretical and numerical background knowledge required to perform state-of-the art materials simulations. Direct, hands-on teaching enables the students to build up their own “computational toolbox” with which they can address the most common tasks in computational materials science and engineering. Planning and conducting small research projects further fosters the students’ research competence. Modeling and simulation



(a) Stress field around a crack tip in a nickel single crystal

(b) Crack in a silicate glass

Figure 7.3: Simulation of an experimental foam structure with very high porosity

are nowadays regarded as the third pillar of the scientific method, complementing theory and experiment. Modeling and simulation tools are thus finding increasing applications not only in fundamental materials-science research, but also in real-world design and optimization of new materials. Graduates in the field of Computational Materials Science find excellent job opportunities in academia and corporate research & development departments.

7.4.1 Courses in the Master program

Fundamentals of Materials and Material Structure
This course provides an introduction to materials science, starting with presenting the different classes of materials, their atomic structure, the different types of interatomic bonding and the arrangement of atoms in crystal lattices.
Further topics include

- defects in crystals (1D, 2D, 3D)
- mechanical properties of metals (basics)
- dislocations and strengthening mechanisms
- phase diagrams
- phase transformations in metals (basic nucleation theory, microstructure formation)
- structure and properties of ceramics
- corrosion

Fundamentals of Material Properties
The lecture enables the students gain an insight into the mechanical properties and behavior of materials used for engineering and technological applications. The course aims to bring together materials science and engineering perspectives towards understanding, design and application of materials. A high level of student involvement through presentations ensures hands-on participation in the course.
Topics include:

- Introduction to Tensors
- Elasticity
- Plasticity and failure
- Fracture mechanics
- Mechanical behavior of metals
- Fatigue
- Creep

Foundations of Computational Materials Science I & II
These lectures provide conceptual foundations and theoretical background knowledge for state-of-the art materials simulation.
Topics include:

- Atomistic theory of matter - from electrons to interaction potentials
- Statistical mechanics of materials: equilibrium and non-equilibrium systems and ensembles
- Stochastic processes and stochastic modeling
- Coarse graining methods (how to pass from one scale to another?)
- Continuum models of materials and microstructures

Multiscale Simulation Methods I & II
These lectures provide a broad overview of simulation methods operating on length scales from the atomistic to the continuum scale. Methods introduced include Molecular Dynamics, equilibrium and kinetic Monte Carlo simulation, mesoscopic methods such as Dislocation Dynamics and the Phase Field method, and continuum-level modeling of materials behavior in Finite Element simulations. The introduction of methods operating on different scales is complemented by a discussion of multiscale approaches, i.e. the linking of models operating on different scales. This course is accompanied by practicals where the students will have the opportunity to numerically implement one-scale models in a hands-on manner. This will be complemented by examples of information passing between different scales and the construction of simple multiscale models.
Numerical Methods in Materials Science: Atomistic Modeling
The aim of the course is to build the theoretical basis required to perform and analyze cutting-edge atomistic simulations in materials science, and to provide the students with a "computational toolbox" for the most common tasks in atomistic modeling. The focus of this course lies on direct hands-on teaching. The students will work on multiple little projects related to current research topics. This will enable the students to independently perform simulations using classical molecular dynamics (MD) codes like IMD and QuantumEspresso for DFT calculations.
Topics include:

- General theory of atomistic simulations
- Advanced methods for the generation of atomistic samples
- MD integration algorithms for different thermodynamic ensembles (NVE,NVT,NPT)
- Energy minimization algorithms and structure optimization
- Introduction to Density Functional Theory
- Determination of defect properties
- Atomic interaction potentials, including EAM, BOP and Tight-Binding Methods
- Advanced analysis and visualization methods for atomistic samples
- Monte Carlo and kinetic Monte Carlo methods
- Modeling thermally activated events: transition state theory, nudged elastic band calculations, hyperdynamics

Generalized Continuum Models of Materials with Microstructure
The behavior of materials with complex microstructures can not always be described by standard approaches of continuum mechanics. In particular, theoretical modeling of small scale plasticity with its associated size effects requires modification of conventional modelling approaches. The lecture shows how this can be achieved by using different generalizations of classical continuum models to account for account for microstructural heterogeneity and length scales, including

- Cosserat continua
- Micromorphic continua
- Nonlocal and gradient-dependent models
- Stochastic models of heterogeneous microstructures

Dislocation Theory and Dislocation Simulation
The lecture covers the foundations of dislocation theory (stress and strain fields, dislocation energetics and interactions) as well as dislocation-based modeling of plastic deformation processes, including both discrete and continuous simulation approaches.
Computer Lab
Practical experience in materials modelling and materials simulation, using C++ as programming language. Practicals can be chosen from:

- Molecular dynamics
- Monte-Carlo simulation and optimization
- Microstructure dynamics using the phase field method
- Plasticity modeling using dislocation models
- Finite Element plasticity
- Simulation of fracture processes

Each practical provides the student with a “toolbox” of programs and a research question. Task of the student is to assemble and adapt the necessary tools and to use them for investigation and analysis of a specific materials problem. Examples are typically taken from research work done during the past decade.

Computational Materials Science Standard study plan for master students						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-PROJEKT-MODUL	WP		7.5			
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
WP-NUMERICAL-ANALYSIS	WP	5.0				
Functional Analysis for Engineers	P	5.0				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-MATHEMATICS	WP			7.5		25.0
TAF – 30.0 ECTS						
Fundamentals of Material and Materials Structure	W	3.0				
Foundations of Computational Material Science I	W	3.0				
Multiscale Simulation Methods I	W	3.0				
Fundamentals of Material Properties	W	1.5				
Generalized Continuum Models of Materials with Microstructures	W		1.5			
Numerical Methods in Material Science: Atomistic Modeling	W		3.0			
Multiscale Simulation Methods II	W		3.0			
Foundations of Computational Material Science II	W		3.0			
Dislocation Theory and Dislocation Simulation	W			3.0		
Computer Lab	W			6.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		28.0	33.0	24.0	30.0	85.0

7.5 TAF Computational Optics (Photonik und Optik)

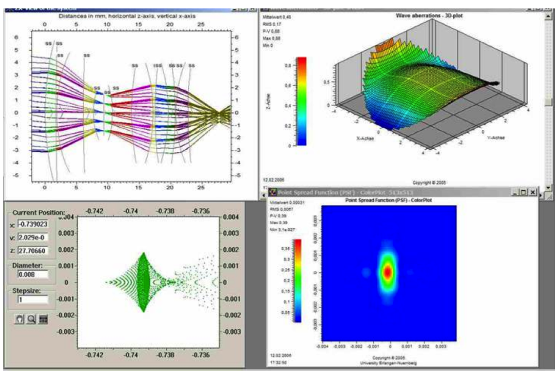
Remark: This TAF is offered only in German language

Light is the most important carrier of information. We experience our environment mainly optically. Traditional applications as image collection, recognition and evaluation are still a major field of optics. However, since the invention of the laser optics has entered completely different fields as well. If we make a phone with a mobile or a cell phone the generated data stream travels most of its journey as a sequence of extremely short pulses in a silica fiber. Optical technologies allow us to measure 3d shapes with high speed and nanometer precision without even touching them. The application of high power solid state lasers for welding has revolutionized automotive engineering and shipbuilding.

Those examples demonstrate how optics is on the way to penetrate all areas of modern society including our daily live. The foundations of this amazing development were already laid in the 19th century. But, only nowadays our understanding of light propagation and our abilities to model the field evolution have developed so far that a broad application of optics has become possible. Computers are now an essential tool in design, modeling and managing of all these application of optics. This development was recognized by the introduction of the subject (Technisches Anwendungsfach Optik) TAF Optics into Computational Engineering.

TAF Optics is based in both faculties that of engineering and that of natural sciences. Students having chosen optics specialize on the modeling of light propagation in optical systems. In addition to the standard curriculum students learn about the basics of physics in about 15% of their time during the Bachelor course. This percentage is increased to about 30% in the Masters course. It now includes lectures on modern trends of optics and photonics.

Students who are interested in the TAF Optics should enjoy numerical modeling as well, but should also have a certain interest in physics and in particular in optics and wave propagation.



(a) Numerical modeling of an optical objective

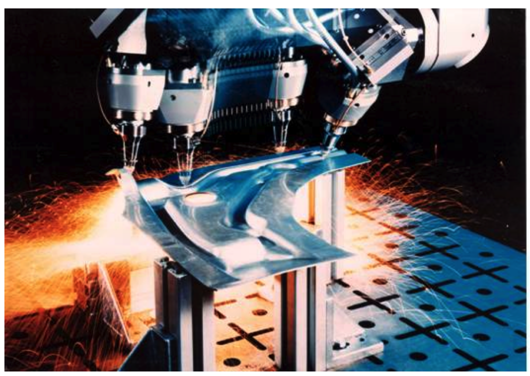

(b) Laser welding in automotive industry

Figure 7.4: Application areas of TAF Computational Optics

Computational Optics - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Grundkurs Optik I: Geometrische und Technische Optik			5.0				
	Grundkurs Optik II: Wellen- und Fourieroptik				5.0			
	Photonik I					5.0		
	Praktikum Photonik/Lasertechnik 1					2.5		
	Seminar Photonik/Lasertechnik					2.5		40.0
	Elective Technical Subjects – max. 20.0 ECTS							
	Computational Optics				5.0			
	Concepts and Architecture of Optical Communications Systems						5.0	
	Komponenten optischer Kommunikationssysteme			5.0				
	Diagnostic Medical Image Processing-V					5.0		
	Tutorial Simulation and Modeling 1					2.5		22.5
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I		5.0					
	Internship at Industry II				5.0			
	Softskill			5.0				15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar				5.0			5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	27.5	35.0	30.0	30.0	27.5	182.5

Computational Optics Standard study plan for master students						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-PROJEKT-MODUL	WP			7.5		
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
Functional Analysis for Engineers	P	5.0				
WP-MATHEMATICS	WP	7.5				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP			5.0		25.0
TAF – 30.0 ECTS						
Experimentalphysik für Physiker III	W	7.5				
Biologisches und Technisches Sehen	W	5.0				
Photonik II	W		5.0			
Quantenoptik und -kommunikation	W		5.0			
Concepts and Architecture of Optical Communications Systems	W			5.0		
Nichtlineare Optik	W			5.0		32.5
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		32.5	25.0	30.0	30.0	87.5

This TAF is offered only in German langauage

7.6 TAF Information Technology (Informationstechnologie)

The scope of the Technical Application Field 'Information Technology' (TAF-IT) encompasses theoretical foundations and applications of information technology from the perspective of communication engineers and computer scientists. It is based on mathematical models for information, signals, and systems, and derives advanced methodologies to solve technical problems in such areas as communication networks, data transmission, or signal processing. Accordingly, the TAF-IT not only emphasizes deepening of the theoretical background but also offers a wide range of application-oriented courses including lab courses which reach from signal processing for speech and audio, image and video, to designing high-rate transmission systems or optimizing mobile radio networks.

Information Technology - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Einführung in die Grundlagen der Elektrotechnik für CE-Studierende			2.5				
	Signals and Systems I			5.0				
	Signals and Systems II				5.0			
	Digitale Signalverarbeitung					5.0		
	Information Theory					5.0		42.5
	Elective Technical Subjects – max. 20.0 ECTS							
	Stochastische Prozesse				5.0			
	Communication Networks					5.0		
	Nachrichtentechnische Systeme					7.5		
	Tutorial Simulation and Modeling 1					2.5		20.0
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I			5.0				
	Internship at Industry II						5.0	
	Softskill				5.0			15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar				5.0			5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	22.5	32.5	30.0	37.5	27.5	182.5

Information Technology - Digital Signal Processing Standard study plan for master students						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-PROJEKT-MODUL	WP			7.5		
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
WP-MATHEMATICS	WP	7.5				
Functional Analysis for Engineers	P	5.0				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP		5.0			25.0
TAF – 30.0 ECTS						
Multidimensional Signals and Systems	W	5.0				
Speech and Audio Signal Processing	W		5.0			
Statistical Signal ProcessIng	W		5.0			
Multimedia Communication I - Image and Video Compression	W		5.0			
Mensch-Maschine Schnittstelle	W		2.5			
Digital Sound Synthesis	W			2.5		
Visual Computing for Communication (Multimedia Communications II)	W			5.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		25.0	37.5	22.5	30.0	85.0

Information Technology - Digital Transmision Standard study plan for master students						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-PROJEKT-MODUL	WP		7.5			
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
WP-NUMERICAL-ANALYSIS	WP	5.0				
Functional Analysis for Engineers	P	5.0				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-MATHEMATICS	WP			7.5		25.0
TAF – 30.0 ECTS						
Digital Communications	W	5.0				
Fundamentals of Mobile Communications	W	5.0				
Communication Networks	W	5.0				
Transmission and Detection for Advanced Mobile Communications	W		2.5			
Optische Übertragungssysteme - Sender- und Empfängerkonzepte	W		2.5			
Optical Communication Networks	W			2.5		
Equalization and adaptive systems for digital communications	W			2.5		
Channel Coding	W			5.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		32.5	27.5	25.0	30.0	85.0

7.7 TAF Mechatronics (Mechatronik)

Mechatronics combines the two disciplines electrical and mechanical engineering. A major part of mechatronics is concerned with the development of new sensors and actuators with enhanced properties. Each modern industrial process environment needs sensors to detect the involved physical quantities (e.g. electric current, mechanical torque, temperature, etc.), a signal conditioning circuit and an interface to computers, where the process parameters are controlled. Closing the loop an interfacing to the actuators, which will steer the industrial process is also needed (see Figure 7.5). The focus of the TAF is concerned with the modeling

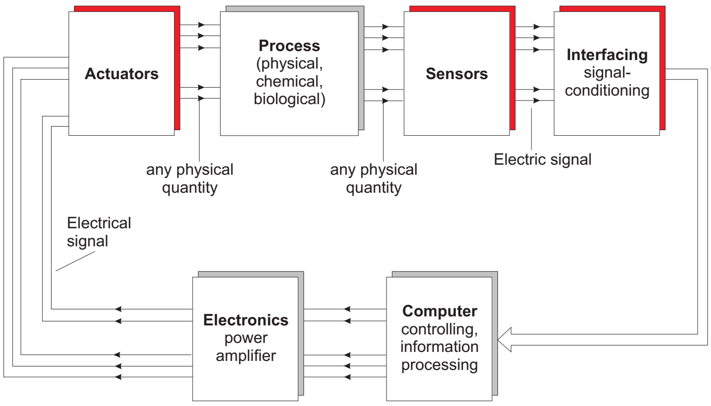


Figure 7.5: Industrial process

and precise numerical simulation of mechatronic sensors and actuators. These sensors, actuators and sensor-actuator-systems are based on the mutual interaction of the mechanical field with a magnetic, an electrostatic or an electromagnetic field. Examples are: piezoelectric stack actuators for common rail injection systems, micromachined electrostatic gyro sensors used in stabilizing systems of automobiles, ultrasonic imaging systems for medical diagnostics, surface acoustic wave filters as used in mobile phone, etc. Within the Bachelors program the students will get a comprehensive knowledge of the physical principles of modern mechatronic sensors and actuators. In addition, the students have the opportunity to get into contact with modern PC-controlled measurement setups and signal processing. Further on, the students will learn about modern fabrication processes and get the possibility to perform own steps within the fabrication process of a sensor/actuator. Within the Masters program, the focus is concentrated on the mathematical modeling and numerical simulation of mechatronic sensors and actuators. Therewith, the students will learn latest numerical simulation techniques and their implementation on PCs as well as supercomputers.

Mechatronics - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Grundlagen der Elektrotechnik I			7.5				
	Grundlagen der Elektrotechnik III					5.0		
	Elektromagnetische Felder I				2.5			
	Sensorik					5.0		40.0
	Elective Technical Subjects – max. 20.0 ECTS							
	Statik und Festigkeitslehre				7.5			
	Introduction to the Finite Element Method						5.0	
	Computerunterstützte Messdatenerfassung					5.0		
	Tutorial Simulation and Modeling 1					2.5		20.0
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I		5.0					
	Internship at Industry II				5.0			
	Softskill			5.0				15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar				5.0			5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	27.5	32.5	30.0	30.0	27.5	180.0

Mechatronics **Standard study plan for master students**						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS		ECTS				
Advanced Programming Techniques	W	7.5				
WP-PROJEKT-MODUL	WP		7.5			
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
Functional Analysis for Engineers	P	5.0				
WP-MATHEMATICS	WP	7.5				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP			5.0		25.0
TAF – 30.0 ECTS						
Strömungsmechanik I für Maschinenbau	W	5.0				
CAE of Sensors and Actuators	W	7.5				
Technische Akustik	W		5.0			
Numerical Simulation of Electromechanical Transducers	W		7.5			
Numerische Strömungsmechanik I	W			7.5		32.5
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		32.5	35.0	20.0	30.0	87.5

7.8 TAF Solid Mechanics and Dynamics (Festkörpermechanik und Dynamik)

7.8.1 Bachelor Program

Statics, Elastostatics and Strength of Materials/ Dynamics
The module Statics, Elastostatics and Strength of Material deals with the statics of rigid bodies (stereo statics) and the statics of deformable bodies (elastostatics). After the mechanical fundamentals and definitions, planar and stereo structures are regarded, reaction forces and momentums as well as internal force variables are introduced. Besides friction and the principle of virtual work, the description of characteristic area properties (center of gravity, moment of inertia) is regarded, providing a basis for the following elastostatics. Introducing the local loads, stresses and strains, the lecture leads to the stress and deformation of straight slender beams, loaded by tension, bending, torsion and shear forces. Finally, basic energy methods are shown and an introduction to the theory of strength of materials is given. The module Dynamics deals with kinematic and kinetic of mass points, systems of mass points and rigid bodies. Based on the principles of linear and angular momentum, the conservation equations are derived and discussed. The lecture ends with an introduction to the theory of vibrations for systems with one degree of freedom.
Mechanical Vibrations
The module Mechanical Vibrations deals with technological relevant mechanical vibration problems. To this end, firstly the equations of motion have to be formulated based on an appropriate physical/mathematical modelling. Thereby the focus is on discrete systems with one and multiple degrees of freedom. The solution of the resulting (ordinary) differential equations allows the analysis and assessment of technological systems that are susceptible to mechanical vibrations. The module Multi body Dynamics extends these treatments to the case of multi body systems.
Finite Element Methods
The module Finite Element Methods provides a general framework for the computational solution of boundary value problems from various different engineering applications. In the present lecture, we introduce its theoretical background, discuss its characteristic features and illustrate its algorithmic realization. Starting with a one dimensional model problem, we discuss the strong form of the governing equations, the derivation of the related weak form and its computational solution. We then turn to the evaluation of more complex problems, such as heat conduction, bending problems or the classical elasticity problem. In addition, finite element specific aspects like the isoparametric concept or numerical integration will be addressed. Computational examples and related MATLAB codes will be provided throughout to illustrate the algorithmic realization of the Finite Element Method.

7.8.2 Master Program

Linear Continuum Mechanics
Continuum mechanics provides the basic framework for the solution of a number of mechanically oriented engineering problems, e.g. the characterization of relations between loading and deformation or between stress and strain. This lecture deals with the main aspects of geometrically linear continuum mechanics, formulated in terms of a modern tensorial notation. As such, the lecture can be understood as a conceptual supplementation of the basic lectures

on mechanics. Moreover, it provides a profound basis for more enhanced lectures, e.g. the lecture Linear Finite Element Methods.

Nonlinear Continuum Mechanics

Nonlinear continuum mechanics provides the basic framework for the solution of a number of mechanically oriented engineering problems, e.g. the buckling and failure of structural elements. This lecture deals with the main aspects of geometrically nonlinear continuum mechanics, formulated in terms of a modern tensorial notation. As such, the lecture can be understood as a conceptual supplementation of the lecture on linear continuum mechanics. Moreover, it provides a profound basis for more enhanced lectures, e.g. the lecture Nonlinear Finite Element Methods.

Nonlinear Finite Element Methods

Based on the lecture Finite Element Methods, nonlinear methods are to be discussed in the lecture Nonlinear Finite Element Methods. Hence, the basics of nonlinear continuum mechanics are considered at first. For the special case of a geometrically nonlinear rod the main ideas of linearization, finite element discretization, geometric and material part of the tangential stiffness matrix, and the iterative solution with a Newton-Raphson scheme are introduced. Analogously to the lecture Finite Element Methods the numerical implementation is realized with MATLAB. Furthermore, stability analyses of truss frameworks are considered as well as appropriate numeric algorithms, for example, the arc length method. Following the detailed investigation of the one-dimensional rod element, the nonlinear finite element method is generalized towards continuum elements resulting from nonlinear continuum mechanics. The goal is to extend the isoparametric triangular and rectangular elements which where first introduced and implemented during the lecture in the frame of a linear theory to the fully nonlinear case.

Computational Dynamics

The lecture Computational Dynamics deals with the formulation and numerical treatment of the equations of motion for mechanical systems based on the principles of analytical mechanics. Thereby the focus is on the Hamiltonian principle, which leads to the Lagrange equations, and the Hamiltonian canonical equations. Related numerical time integration methods are outlined in connection with spatially discrete systems (e.g. particle systems, rigid bodies or FE-discretized elastic bodies). Thereby the relevant conservation properties of these algorithms are analyzed.

Materials Modelling and Simulation

This modul focuses on the theory and numerics of material models. Important material models as elasticity, viscoelasticity, elastoplasticity and viscoplasticity are investigated for both, the one-dimensional and the three-dimensional context. General theoretical and numerical concepts are introduced. The lecture requires basic knowledge in linear continuum mechanics.

Biomechanics

In past years biomechanical problems had a strong impact on the research done in the field of computational and continuum mechanics. To name but a few, fields of application are the numerical simulation of blood flow running through veins, adaptation of bone structures or modeling of tissues. A numerical implementation of appropriate phenomenological models within the finite element method, for example, leads to illuminative insights into biological processes and is supposed to complete detailed medical examinations or even replace them in the future. The lecture gives an overview of computational and continuum mechanical treatments of biomechanical problems and discusses their numerical implementation based on selected topics.

Solid Mechanics and Dynamics - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Statik			5.0				
	Elastostatik und Festigkeitslehre				7.5			
	Dynamik starrer Körper					7.5		40.0
	Elective Technical Subjects – max. 20.0 ECTS							
	Maschinendynamik I				5.0			
	Strömungsmechanik I für Maschinenbau					5.0		
	Strömungsmechanik II für Maschinenbau						5.0	
	Methode der Finiten Elemente						5.0	
	Tutorial Simulation and Modeling 1					2.5		22.5
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I			5.0				
	Internship at Industry II					5.0		
	Softskill			5.0				15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar				5.0			5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	22.5	35.0	27.5	32.5	32.5	182.5

Solid Mechanics and Dynamics **Standard study plan for master students**						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-COMPUTER-SCIENCE	WP		7.5			
WP-PROJEKT-MODUL	WP			7.5		30.0
Mathematics – 30.0 ECTS						
Functional Analysis for Engineers	P	5.0				
WP-MATHEMATICS	WP	7.5				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP			5.0		
Seminar	W			5.0		30.0
TAF – 30.0 ECTS						
Numerische Methoden in der Mechanik	W	5.0				
Linear Continuum Mechanics	W	5.0				
Nonlinear Continuum Mechanics	W		5.0			
Materials Modeling and Simulation	W		5.0			
Nonlinear Finite Elements	W			5.0		
Computational Dynamics	W			5.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		30.0	32.5	27.5	30.0	90.0

7.9 TAF Thermo and Fluid Dynamics (Thermo- und Fluiddynamik)

Among the various application fields in the Erlangen CE curriculum, thermo- and fluid mechanics has some strong links to computer sciences since many decades. In fact, many high performance computing activities were driven by applications in Computational Fluid Mechanics (CFD) since the early 70ies. A prominent example is the simulation of turbulence with its outstanding computer requirements. Today, the entire field of fluid mechanics, in research as well as industries, is influenced by CFD to a very large extent, with industrial increase rates of nearly 20 percent per year. With the increasing potential of modern supercomputers also the requirements with respect to their efficient programming increased dramatically. The efficient use of today's Supercomputers requires a sound understanding of hardware specifics and programming paradigms also including the use of high level communication languages or code analysis software. These topics are usually not covered in the classical engineering curricula, such as aerodynamics and mechanical or chemical engineering. On the other side, in the computer science curricula have moved away from the physical and engineering disciplines and students often lack the background that would be necessary for working in interdisciplinary teams. The introduction of thermo- and fluid mechanics as part of the CE curriculum in Erlangen aims to fill the gap between the physical and the computer science aspects of the numerical simulation. During the Bachelors program, the students are familiarized with the basic concepts in physics, thermodynamics and heat and mass transfer in the first two years. After that, a focus on basic aspects of fluid mechanics is presented, including the introduction to the mathematical theory of the conservation equations and ways to their solution. Special attention is paid for the introduction to turbulence as one of the most important issues in fluid mechanics. In connection with practical exercises and tutorials the lecture "Numerical Fluid Mechanics" introduces to the main topic in two semesters. Special lectures in selected fields of fluid mechanics, also related to experimental techniques, are recommended. Finally, the students are supposed to perform a master thesis in the field of numerical simulation with a clear focus on actual engineering problems in thermo- or fluid mechanics. Besides that, they are supposed to contribute with a presentation in a seminar on fluid mechanics or thermodynamics.

Thermo and Fluiddynaics - Standard Study Plan Bachelor								
GOP	Semester	1	2	3	4	5	6	Σ
	Computer Science – 47.5 ECTS	ECTS						
•	Algorithmen und Datenstrukturen	10.0						
•	CE I (Rechnerarchitekturen)	7.5						
	Systemprogrammierung			10.0				
	Simulation and Modeling I					5.0		
	Simulation and Scientific Computing 1					7.5		
	Simulation and Scientific Computing 2						7.5	47.5
	Mathematics – min. 37.5 ECTS							
•	Mathematik für CE 1	7.5						
•	Mathematik für CE 2		10.0					
	Mathematik für Ingenieure III A			5.0				
	Mathematik für Ingenieure IV A				5.0			
	Numerik für Ingenieure I			5.0				
	Numerik für Ingenieure II				5.0			37.5
	TAF – min. 40.0 ECTS							
•	Experimentalphysik für Naturwissenschaftler I	7.5						
•	Experimentalphysik für Naturwissenschaftler II		7.5					
•	CE II		5.0					
	Engineering Thermodynamics I for CE			5.0				
	Thermodynamik II (Technische Thermodynamik (Vertiefung) für CBI, CE)				5.0			
	Wärme und Stoffübertragung				5.0			
	Strömungsmechanik I für Maschinenbau					5.0		40.0
	Elective Technical Subjects – max. 20.0 ECTS							
	Applied Visualization				5.0			
	Strömungsmechanik II für Maschinenbau						5.0	
	Angewandte Strömungsmechanik					5.0		
	Transportprozesse				5.0			
	Tutorial Simulation and Modeling 1					2.5		22.5
	Internship and Softskills – 15.0 ECTS							
	Internship at Industry I		5.0					
	Internship at Industry II			5.0				
	Softskill			5.0				15.0
	Seminar and Bachelor Thesis – 20.0 ECTS							
	Seminar					5.0		5.0
	Bachelor Thesis						15.0	20.0
	Bachelor	32.5	27.5	35.0	30.0	30.0	27.5	182.5

7.9.1 Master Program

Students with a degree other than Computational Engineering have to attend and successfully pass the course "Fundamentals of Thermo-Fluiddynamics" (or alternatively a practical course in fluid mechanics, to be announced) for CE students during the orientations semester. The content of the Masters Program depends strongly on the pre-knowledge of the students. Basic topics are related with Numerical Fluid Mechanics (Numerische Ströungsmechanik) and with the physics of turbulence. Students without prior knowledge in basic fluid mechanics have to fill this important gap, while students with low knowledge on computer science topics and numerical methods have to focus on these items. Many courses can be selected either in the Technical Application Field or in the Computer Science Field or in the Mathematics Field.

Thermo and Fluiddynaics Standard study plan for master students						
Semester		7	8	9	10	Σ
Computer Science – 30.0 ECTS	ECTS					
Advanced Programming Techniques	W	7.5				
WP-SCIENTIFIC-COMPUTING	WP		7.5			
WP-PROJEKT-MODUL	WP			7.5		
WP-COMPUTER-SCIENCE	WP			7.5		30.0
Mathematics – 30.0 ECTS						
WP-MATHEMATICS	WP	7.5				
Functional Analysis for Engineers	P	5.0				
Optimierung für Ingenieure mit Praktikum	P		7.5			
WP-NUMERICAL-ANALYSIS	WP			5.0		25.0
TAF – 30.0 ECTS						
Mikrofluiddynamik	W	5.0				
Numerical Fluid Mechanics I	W	7.5				
Numerical Fluid Mechanics II	W		7.5			
Applied Thermofluid Dynamics	W			5.0		
Physics of Turbulence and Turbulence Modeling I	W			5.0		30.0
Referat und Masterarbeit – 30.0					30.0	30.0
Master CE, total		32.5	22.5	30.0	30.0	85.0

Chapter 8

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