PROGRAM DOCUMENTATION

MASTER'S PROGRAM BIOMEDICAL COMPUTING

Fakultät für Informatik, Technische Universität München

March 18th 2019

Name:	Biomedical Computing
Organisational assignment:	Department of Informatics
Degree:	Master of Science (M.Sc)
Regular period of study (credits):	4 Semester / 120 Credits / 79 SWS
Program Type:	Full-time
Admission:	Aptitude Assessment
Begin:	Winter semester 2009/10
Language:	English
Program director:	Prof. Dr. Nassir Navab
Additional specifications for special programs:	Beginning of study in winter terms only
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Der Studiendekan, Prof. Dr. Helmut Seidl:	

1 Degree Program Objectives

1.1 Purpose of the Degree Program

The Master's program in Biomedical Computing is primarily intended for international applicants who have gained fundamental knowledge in engineering sciences, mainly in Computer Science, Mathematics, Physics or Electrical Engineering.

The objectives of the Master's program in Biomedical Computing are designed to fit the growing demand for specialists who are skilled in the field of computer-assisted medical imaging, computer-assisted medical interventions, or medical computer vision. These areas of expertise all lay at the intersection of computer science and medicine. While imaging procedures and guidance systems increasingly support medical diagnosis and treatment, this very particular field plays a crucial role in modern clinical environments.

Therefore, the goal of the Master's program in Biomedical Computing is to provide the required education by pursuing an interdisciplinary approach, involving the Department of Informatics and the medical school at TU Munich. In addition to the mission statements of the Technical University of Munich[1], the BMC program incorporates interdisciplinary, variety of expertise and a strong focus on specialized applications.

> **Interdisciplinary:** The Master's program in Biomedical Computing focuses on bridging the gap between computer science and medicine. Students participate in a mandatory clinical project and dedicated medical modules provided by experts from the medical school. This enables students to gain a unique understanding of medical problems in imaging, interventions and diagnosis.
>
> **Variety of Expertise:** The Master's program in Biomedical Computing aims at creating opportunities to benefit from different views and to exchange approaches related to problem solving in biomedical engineering.
>
> **Strong Focus:** Students are provided with a set of modules that best fit typical professional requirements in the field of biomedical imaging and computer-assisted interventions. Besides the modules designed specifically for the BMC program, students are driven to select related modules from the extended offerings of the Department of Informatics.

Focusing on biomedical image computing and computer assisted interventions, the topics covered in the modules of the BMC Master's program include the following: Medical data acquisition and management, medical terminology and physics of medical imaging, medical image processing, visualization, advanced user interfaces and computer-aided medical solutions.

[1] https://www.tum.de/en/about-tum/our-university/mission-statement/

This includes the specification of the application requirements, the design and analysis of procedures for the solution of the tasks, the development of data structures and algorithms, their implementation in software and/or hardware, as well as the evidence that the so-constructed system meets the requirements.

The possibilities for a clinical project and several newly created modules by the medical school provide students with a unique understanding of medical problems in imaging, interventions and diagnosis. Many lectures and demonstrations take place in the hospitals of the medical school to provide students with a proper insight into clinical routine.

It is the program's main goal to provide the students with not only the required interdisciplinary knowledge that is built upon the basic knowledge earned during a Bachelor's study, but also enable graduates to develop and use novel medical technology in close cooperation with medical personal.

The Master's program in Biomedical Computing provides an education that enables its graduates to enter an advanced professional career in the medical industry or to pursue doctoral level studies at a research institution.

1.2 Strategic Significance of the Program

The Technical University of Munich (TUM) was one of the first universities in Germany to offer a course of studies of computer science. Nowadays, the Bachelor's and subsequent Master's programs in computer science remain a core of the education at the Department of Informatics, which have been developed parallel to the diploma program and replaced it fully since 2005.

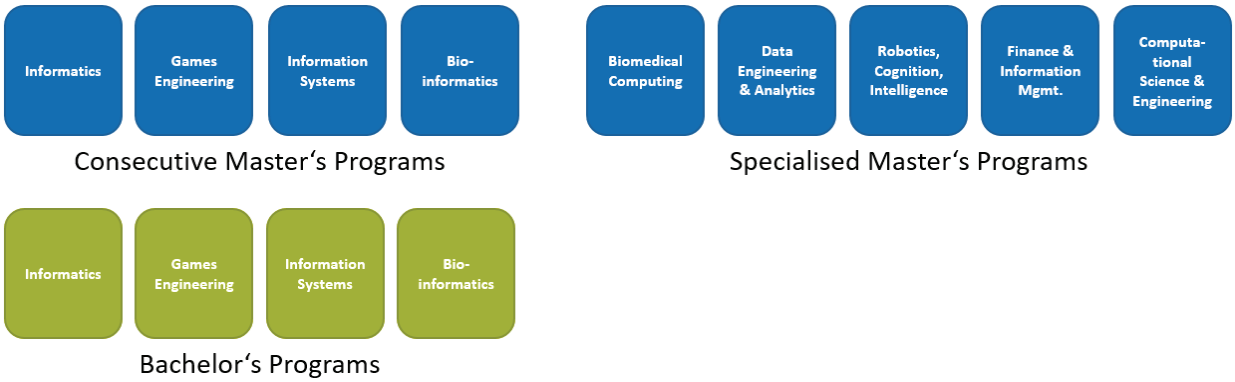
In 2016 the Gesellschaft für Informatik e.V. (GI) released, in collaboration with the Department of Informatics, recommendations for the Bachelor's and Master's degree programs in the field of computer science at universities. Based on this, the general objective of the computer science education at the TUM is a scientifically sound and foundation-orientated education based on a broad and in selected areas deepened technical knowledge. The knowledge provides analytical, creative and constructive skills for development and improvement of software and hardware systems. In particular, the capabilities of students in basic or applied research in the field of computer science are created or strengthened.

The computer science education at TUM enables graduates to enter successful occupations during their entire career. Therefore, the study provides not only current content, but also theoretically substantiated concepts and methods that that will outlast current trends. This education fosters thinking in algorithms, models, concurrent processes, in layers and architectures, human-computer interaction patterns among other things, etc.

With the strong expansion of the department in the direction of information systems, another great pillar has been established with the Bachelor’s and subsequent Master's program in Information Systems in 2001. In the same year, the Bachelor's and Master's program in Bioinformatics has been initialized in close cooperation with the Ludwig-Maximilians-Universität in Munich.

The specialized Master's programs in Computational Science & Engineering (CSE, since 2001), Robotics Cognition Intelligence (since 2009), Data Engineering and Analytics (since 2016) and Biomedical Computing (BMC, since 2009) allow graduates of a Bachelor’s program at the Department of Informatics to focus stronger on one specialized area. These specialized Master’s programs are open for graduates of other Bachelor’s programs and therefore allow the students to study the perspective of a computer science related degree.

Bachelor‘s and Master‘s Programs at the TUM Department of Informatics



The Master's degree program in Biomedical Computing focuses on the interdisciplinary field between computer science and medicine. In this way and due to offerings of clinical projects and modules, the BMC program goes along with the mission statement of the TUM to support interdisciplinarity, and an innovative thinking from an engineering perspective is encouraged. The goal of this specialized Master's degree program is to early expose students to an interdisciplinary environment of real research and economical challenges in computer science for health care. The fundamental teaching of Biomedical Computing covers the wide spectrum of corporative demand for highly qualified graduates. Furthermore, the Master’s program offers a broad variety of elective modules to promote different talents and interests of its students, who can further enhance their knowledge and skills in topics such as Machine Learning and Deep Learning, Augmented Reality or Image Analysis. Many interdisciplinary projects create a considerable potential for technology-based start-ups. Therefore, excellent research and teaching go hand in hand. Based on their extensive research experience, our professors pass on their detailed theoretical and practical knowledge. From the start, students can benefit from the Department’s extended network and cooperations with research institutes and companies, which ensures rapid

knowledge transfer and intensive collaboration from which the students benefit during their projects.

2 Qualification Profile

In order to ensure the compatibility of TUM Master's degrees with other highly qualitative Master degrees in German speaking regions, the Department of Informatics has taken into account the "Empfehlungen für Bachelor- und Masterprogramme im Studienfach Informatik an Hochschulen" by the "Gesellschaft für Informatik e.V. " from July 2016. According to these recommendations, graduates in Biomedical Computing need skills from the fields of "Formal, algorithmic and mathematical skills," "Analysis, design, implementation and project management skills", "technological skills", "interdisciplinary skills", "methodological and transfer competence" as well as "social skills and self-competence" in their careers or for their further advanced studies. These recommendations concur with the "Qualifikationsrahmen für deutsche Hochschulabschlüsse" by the German Rectors' Conference, Standing Conference of the Ministers of Education and the German Ministry for Education and Research (February 2017), transferring aforementioned skills to the four dimensions of competence: "**Knowledge and Understanding**", "**Usage, Application and Generation of Knowledge**", "**Scientific Self-Understanding / Professionalism**" and "**Communication and Cooperation**".

Before the transition to the Bachelor and Master system, the department has discussed these skills in detail and undertaken with broad agreement. In a second step, these learning outcomes have been mapped to learning objectives which are to a large extend newly created, and thus the Bachelor- Curriculum has been established by significant modification of the original Diploma degree program. In particular, the interdisciplinary, social and project management skills are strengthened in the early years of study and further freedom is established for the arrangements during the Master's degree in order to satisfy the dynamism, breadth and interdisciplinary nature of computer science more effectively.

Computer-assisted medical imaging technology plays a crucial role in modern clinical environments, as imaging procedures increasingly support medical diagnosis and treatment. Consequently, there is a growing demand for specialists who are skilled in this very particular field at the intersection of computer science and medicine. The Master's degree program in Biomedical Computing aims to provide the required education by pursuing an interdisciplinary approach, involving the Department of Informatics and the TUM medical school.

In the following overview, the fields of competence of a BMC graduate are described in more detail:

Formal, computational, mathematical skills: Graduates of the Master´s program in Biomedical Computing are able to understand, analyze and solve challenges in medical and life science environment. They are able to transform these to formal mathematical models and transfer these

into efficient algorithms and suitable data structures. They master the concept of formal proofs and are able to verify and evaluate resulting solutions and therefore hold ambitious mathematical competences.

Analysis, design, implementation and project management skills: Graduates are able to analyze specific requirements defined by clinical and life science processes, understand their overall context and apply and evaluate appropriate computational methods in order to enhance efficiency of these processes. They are able to plan and manage ambitious projects and, even with limited resources, are able to develop solutions that comply with quality standards defined by health systems.

Technological skills: Graduates understand the interaction between biomedical soft- and hardware and are familiar with the theoretical foundations of medical imaging systems. They are able to analyze, validate and design cognitive systems, know the different paradigms of artificial intelligence and the characteristics of intelligent systems and are able to validate them. They know models and methods in computer graphics, image understanding/processing, and visualization. Graduates also hold particular competences in analysing and judging the efficiency of related computational methods for proper validation and testing.

Interdisciplinary skills: Given technical, economic and social contexts, graduates are able to solve problems in demanding interdisciplinary projects in medical/biological fields of application and are able to use methods of computer science to develop demanded systems and to manage corresponding projects. They can use document systems in written form and are able to present their findings. Depending on the elective modules chosen, they have deepened knowledge of basic business administration methods and are able to plan, develop and use information systems from an economic point of view. Graduates can choose elective modules strengthening their sufficient legal knowledge and enabling them to understand and negotiate legally binding agreements, knowing the legal foundations of security aspects, as well as those of copyright and product liability. Graduates also have advanced professional English language competences and are able to work in multi-national and multi-cultural teams, understanding ethical standards and the impact of their work on future users, patients and society.

Methodological skills: Graduates are able to work according to research orientated scientific principles, to conduct independent research to advanced knowledge in their challenging field and to introduce new methods in informatics into an existing corporate environment. They understand decision-making processes within a corporate context and can make valuable contributions to them. They are also able to further develop existing methods of computer science and increase current knowledge in the discipline.

Social and personal skills: Graduates are equipped with communicative skills and are able to convincingly present their ideas and findings both verbally and in writing. They are able to recognise and integrate different points of view, even in cases where parties lack expert knowledge

in the field of informatics. Furthermore, they are able to recognise and resolve misunderstandings between different parties involved in the creative process. Their conflict management skills enable them to argue with specific objectives in mind and to deal open-mindedly with criticism. They can appraise the social, economic, organisational, psychological and legal effects of informatics on its environment.

Scientific skills: Graduates are also able to perform self-guided literature research and critical reading of scientific publications, define and evaluate experiments and prepare documents according to scientific standards.

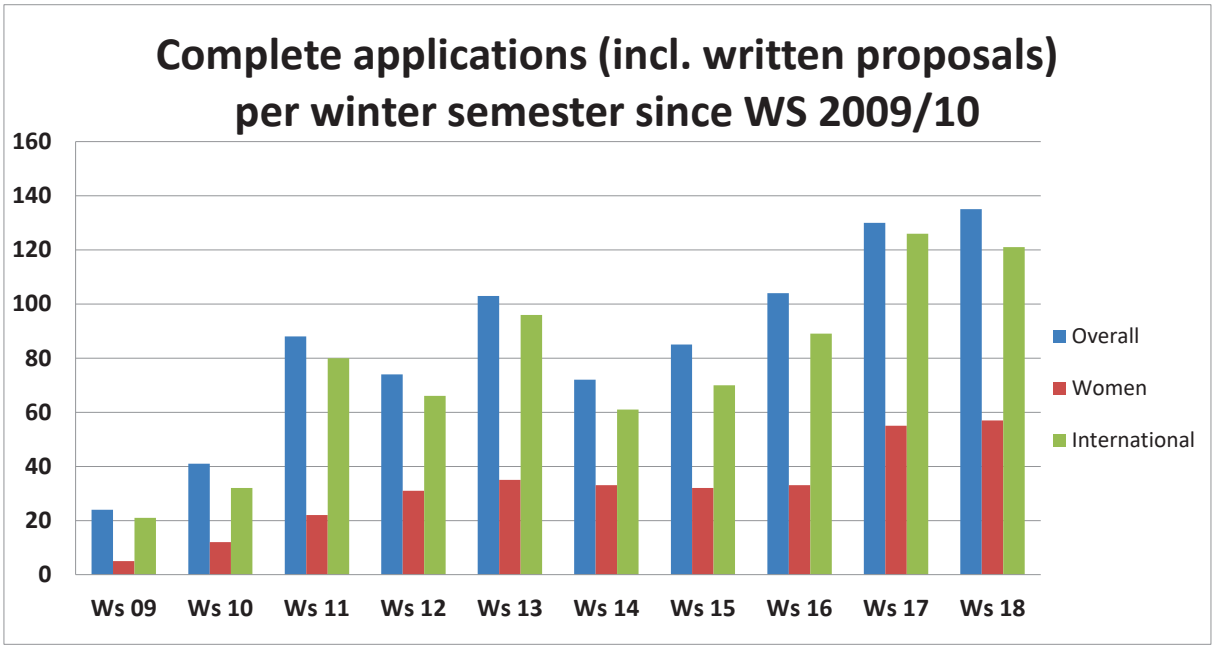
3 Target Groups

3.1 Target Groups

Biomedical Computing is an international Master's program of TUM and it is targeted at motivated above-average students holding a Bachelor's degree in Computer Science, Mathematics, Physics, Electrical Engineering or Mechanical Engineering (or an equivalent degree) from a German or international university. Students should exhibit knowledge of a modern programming language either through their Bachelor's degree, additional modules or relevant extramural projects and activities. Furthermore, the abstraction and transfer of methods in computer science for solving problems in the professional field of Biomedical Computing are a necessary ability. Additionally, students should have an interest in developing medical applications in order to be able to complete specific tasks. English is the language of instruction, as a feature of the international study program. Therefore, required application documents include a confirmation of English language proficiency.

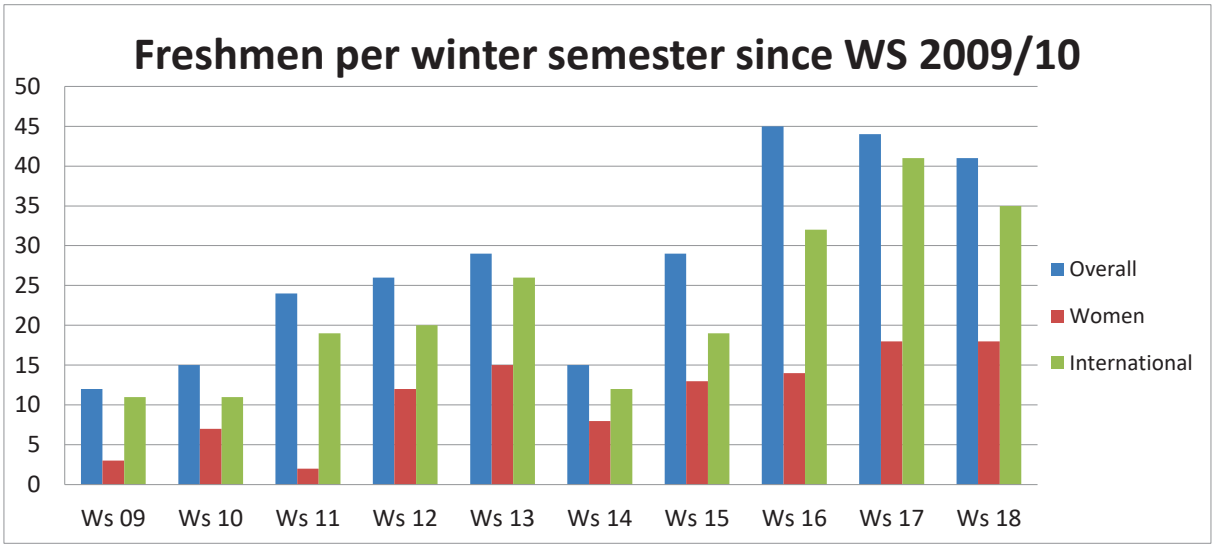
In 2013, the entry requirements were modified in accordance with international standards: Students with a bachelor degree of a university outside the European Union have to show proof of their knowledge e.g. in the form of the "Graduate Record Examination (GRE) General Test" or „Graduate Aptitude Test in Engineering" (GATE) in Computer Science.

3.2 Target Numbers



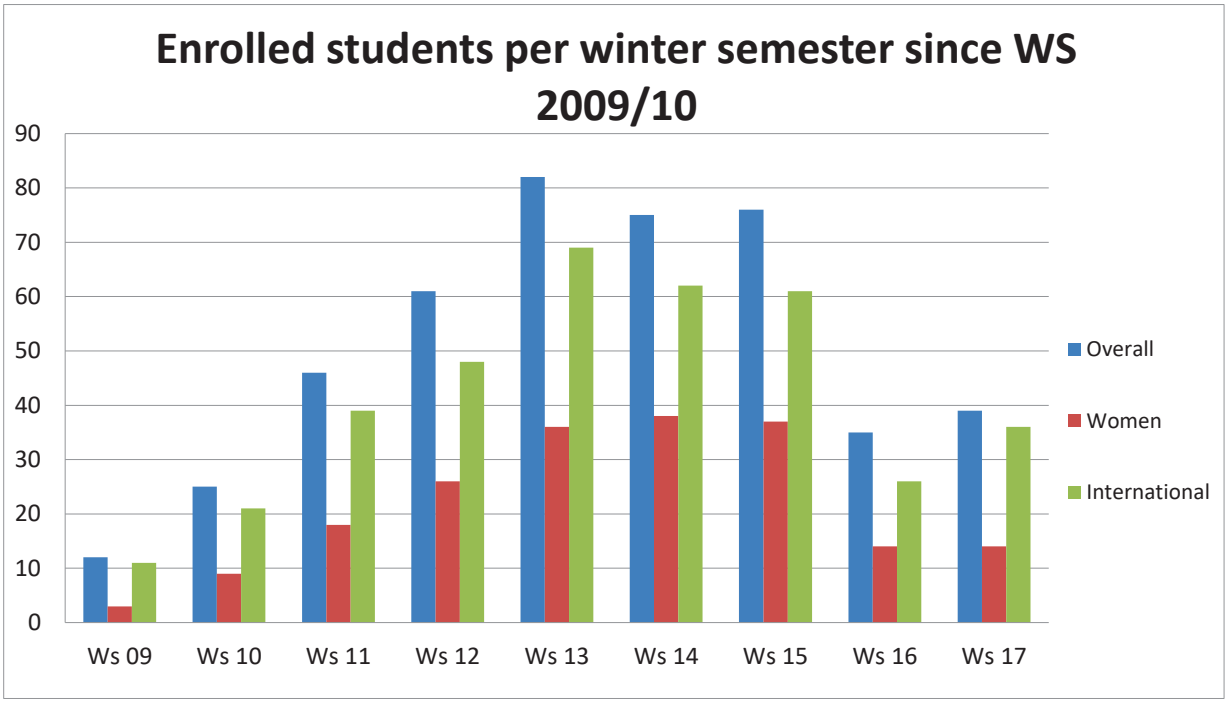
Since the start of BMC Master program in WS 09/10 until WS 14/15, application numbers have constantly increased. The sudden rise for WS 11/12 proofs the extreme popularity of biomedical imaging technology as specialized education as computer science discipline. Due to the international character of BMC Master program, more than 80% of all applications are received from abroad. The fact that all the mandatory modules in the curriculum are thought in English, which is a distinctive feature of the program, attracts students from all around the world, bringing cultural diversity to the BMC Master program as well as an enriching background of experiences from different regions of the world.

Besides a sudden decrease of applications in WS 14/15, which is grounded in the additional requirement for GRE (or equivalent) tests for all international applicants from outside the EU, the BMC Master program receives more than 80 applications on a yearly basis from world-wide. With the support of additional advertisement activities that the Department of Informatics has recently started, we estimate an average of 130 applications per year for the future, continuing the trend from WS 17/18 and WS 18/19.

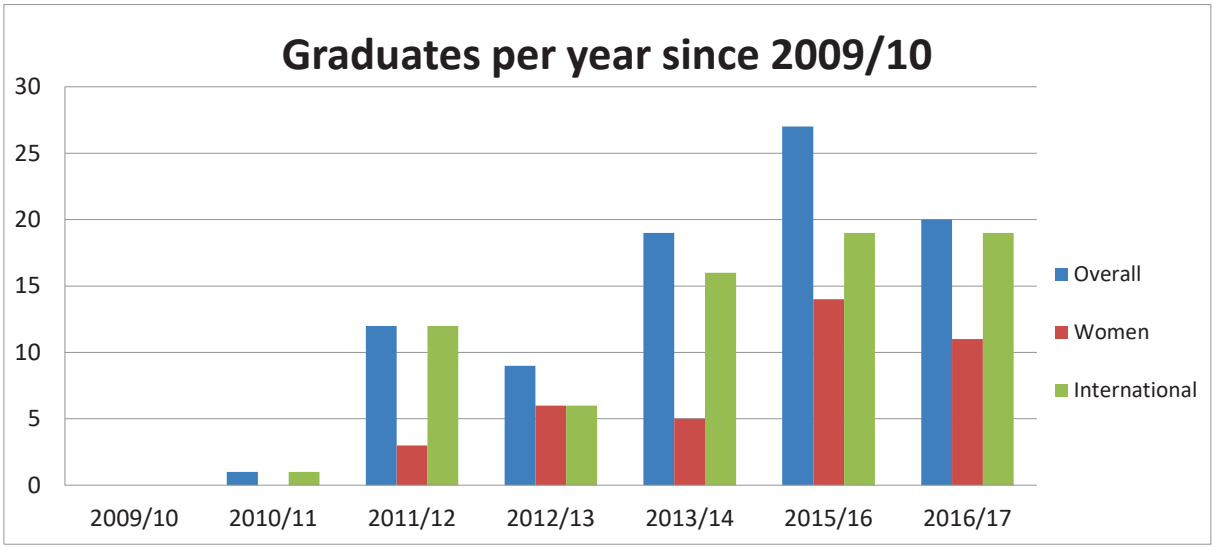


Due to increased numbers of applications for WS 11/12, there has also been a big rise in the number of study beginners until WS 14/15. The sudden decrease in freshman numbers for WS 14/15 follows the observations for applications. For the future, we aim to keep an average a maximum number of 35-40 freshmen per year.

Due to the high amount of international applicants originating from outside the EU, there is a large disparity between the amount of admitted students and actual study beginners. Each year about 25% of admitted applicants do not enroll in BMC due to different reasons related mostly to visa or financial issues.



Numbers of BMC graduates are constantly increasing. Due to the fact that students enrolled in Bachelor Informatics at TUM choose to already collect credits for a subsequent BMC Master's program, statistics indicate that some students finish their degree in a reduced study period. On



the other hand, in particular international students, who are new to the German university system, take one semester in average to get acquainted. Starting from summer 2015, the Master's program Biomedical Computing is offering online preparatory courses for admitted freshman students. It is envisioned to provide the students with basic required knowledge in mathematics and programming as well as introduce them to German university and learning culture.

4 Analysis of Need

Bavaria is a high-tech location holding 32.4% of the total patent applications in Germany in 2017. The Munich metropolitan area is an excellent business location and has had 17 163 business registrations (not including self-employed foundations) with a total of over 92 thousand enterprises registered in 2017.

Information and communication technology represents the supporting pillar within Munich's mixture of businesses. Nowhere else in Germany one can find more IT, software, communications and media technology companies than within and around Munich. There is a multitude of job opportunities created by medical engineering companies and hospitals seeking skilled computer scientists. Graduates holding a Master's degree in Biomedical Computing can pursue a career in research institutes or industry, in both theoretical and application-oriented fields. To name just a few, typical topics to work on include: imaging technologies for medical diagnosis, computer aided navigation in treatment and surgery, software for radiation therapy and medical visualization techniques. Especially Munich and its surroundings offer a vast array of potential employers in the field of medical device manufacturing, life science and healthcare service providers.

Due to its proximity to IT companies, TUM students can socialize intensive contacts already while studying, i.e. in terms of student trainee positions. BMC students are further encouraged to perform their clinical and/or Master's Thesis projects in cooperation with local or international hospitals, research institutes, or companies initiating a strong network that provides support for their professional life after graduation.

As a result, most graduates of BMC have gotten very attractive positions both in academia and industry. With more and more funding opportunities becoming available for startups we also witness an increasing interest of students to found their own company which is highly encouraged by the Chair for Computer Aided Medical Procedures. Graduates of BMC have found employment at medical device manufacturers such as *Siemens*, *BrainLab*, *GE* or *Philips Healthcare*. Due to the recent rise of modern machine learning and Deep Learning, graduates have joined *Nvidia* or *Google* in their AI research. Companies specializing in biomedical image analysis software such as *Definiens AG, Arivis AG* or *BioDataAnalysis GmbH* frequently employ our graduates due to project-based cooperations during the Master's program. Some graduates wish to stay focused on academic research and stay with TUM for their doctoral studies. Others have joined research collaborators such as Helmholtz Institute or Fraunhofer Gesellschaft.

5 Competition Analysis

5.1 External Competition Analysis

The aim of the Master's program in Biomedical Computing is to ensure that the Department of Informatics at TUM is following the global development in industry and research, thus keeping pace with leading international institutes. Internationally renowned universities have created new academic programs similar in focus to Biomedical Computing at TUM. The University of Utrecht is taking a leading role in this context with the Master's degree program in "Biomedical Image Sciences". Besides fundamentals of anatomy and physiology, students are introduced to biomedical imaging technology, image processing and medical physics. The Saarland University created a Master's degree program in "Visual Computing" that provides modules on image processing, visualization, computer vision and applications to medical engineering. Other leading universities, such as the Imperial College of London, the Georgia Institute of Technology in Atlanta or the École Nationale Supérieure Cachan in Paris, have created similar academic programs. The Master's program in Biomedical Computing at TUM stands apart because it is offered jointly by the Department of Informatics and the Medical School, thus ensuring that students are exposed to real-life problems and gain hands-on experience.

5.2 Internal Competition Analysis

The department of mechanical engineering together with the Central Institute for Medical Engineering (IMETUM) is offering the Master's degree program in Medical Engineering (Medizintechnik). This program strongly focuses on a classical engineering perspective and bases itself on

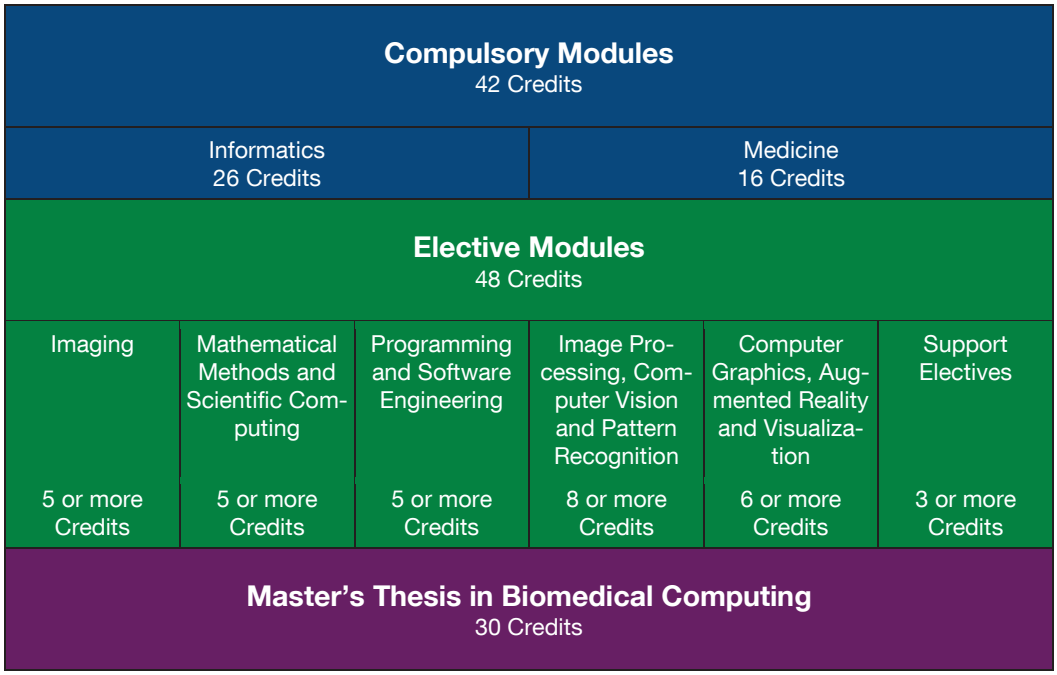
mechanical and electrical engineering, including implant development and tissue engineering. The Master's program in Biomedical Computing instead concentrates on imaging technologies and software-assisted clinical interventions. This requires a thorough education especially in the field of Computer Science, which is hardly covered by the Master's program in Medical Engineering (Medizintechnik).

The Bioinformatics' education on Bachelor as well as Master level offered by TUM in cooperation with the Ludwig-Maximilians-Universität (LMU) München, looks at how computer-aided techniques can be applied to biological processes, particularly in the fields of medicine and pharmaceutical research. It essentially brings together information sciences (informatics, mathematics, statistics) with life sciences (biology, chemistry, medicine, biotechnology). Here, informatics methods are primarily used to construct mathematical models for analyzing biological data and its behavior. Although life sciences are also a focus area of the Master's program in Biomedical Computing, it is predominantly concerned with the related imaging technology (e.g. histopathological imaging) and is entirely complementary to the Master's program in Bioinformatics.

6 Structure of the Study Program

This table presents an overview of the BMC study program and the distinction between compulsory and elective modules:

Semester	Credits	Modules	
		Compulsory	Electives
1	30	Computer Aided Medical Procedures (CAMP) I, 6 Credits Medical Instrumentation and Computer Aided Surgery, 6 Credits	18 Credits
2 & 3	60	Computer Aided Medical Procedures (CAMP) II, 5 Credits Imaging in Radiology, Nuclear Medicine and Radiation Therapy, 4 Credits Master's Seminar, 5 Credits Clinical Internship, 10 Credits Medical Information Processing and Pathophysiology, 6 Credits	30 Credits
4	30	Master's Thesis, 30 Credits	



The disciplines informatics and medicine are covered in the corresponding required modules. Parallel additional skills and knowledge is taught in the elective modules. Within each module block students may choose between sufficiently many modules in order to appropriately take existing experience and preferences into account. There are a minimum number of credits to be chosen within each block, so that the acquisition of a basic common knowledge and of necessary skills is guaranteed and too early or too deep specialization in specific blocks is avoided.

Due to the highly dynamic selection of modules, which are offered each year, the catalogue of elective modules is flexible and the Board of Examiners may add or update modules for each module block.

Within the required modules for informatics in the third semester the master seminar is supposed to guide students to autonomous scientific work through a manageable topic within the seminar. In a similar manner, the clinical internship is supposed to introduce students into a clinical environment, collaboration with medical end-users such as physicians or radiologists and solution-oriented approaches. Both are then combined in the Master's Thesis, which is foreseen in the fourth semester.

The Master's Thesis module, with a duration of six months, is concluded with a written report and a Master colloquium consisting of presentation and scientific discussion. Through the Master colloquium the student is able to defend his/her findings during a presentation in front of a

scientific community, which at the same time strengthens general presentation skills preparing the students to potential subsequent interviews in industry or academia.

According to the Master examination rules, every student is entitled to write a Master's Thesis. A Master's Thesis starts after successful completion of all examinations of the first till the third semester. The period of time between the start and the delivery of the Master's Thesis may not exceed six months. Successful completion of a Master's Thesis will be awarded by 30 credits. The aim of a Master's Thesis is that the students work on a scientific question independently, starting from the concept to the methodological implementation to substantive discussion and conclusion. Based on the Master's Thesis report, it is decided whether the students have acquired thorough expertise and the ability to work independently according to scientific methods.

Depending on available topics and collaborations it is desired to conduct Master's Thesis together with partner institutes abroad. An early introduction into the topic and preparations for the practical work will usually be done at TUM, the practical work will be conducted at the partner institute, and the writing of the Master's Thesis back in Munich.

6.1 Compulsory Modules

The informatics and medical modules provide basic knowledge and guarantee the understanding of the problems faced in today's computer aided medical procedures and therefore are the foundation of research and development.

6.1.1 Informatics (26 credits)

The basics of computer aided medical procedures are presented in these modules. This includes not only commonly known diagnostic imaging methods, such as CT, MRI or PET, but also the basics of image reconstruction, segmentation, registration, interventional imaging, optimization, and other related areas of expertise.

Furthermore, these modules provide a deep insight in the clinical workflow and encourage the student to establish relations with medical personal by performing a clinical internship, which succeeds by finishing a joint project. The student gains practical experience with novel medical image processing and analysis techniques while at the same time being exposed to the theoretical developments in the interdisciplinary field of medicine and computer science.

Computer Aided Medical Procedures I & II. 6+5 Credits: These modules introduce the exciting field of computer aided medical procedures. In part I, students get introduced to tomographic imaging modalities such as CT and MRI. In addition to this, CAMP I focuses on basic and advanced filtering techniques, intensity-based and feature-based methods for image registration, and basic methods for image segmentation. In part II, both more advanced imaging modalities, such as 3D freehand Ultrasound, PET and freehand SPECT, and more advanced techniques for image segmentation, visualization, tracking, etc. are discussed. Both modules also feature invited talks by clinical experts and entrepreneurs and as well as hands-on exercises in a modern

programming language such as MATLAB or Python. After participation in these two modules, students are able to understand the physical background of medical imaging and are able to understand and evaluate different methods of medical image processing and computer-assisted surgery. Furthermore, they are able to identify problems in diagnostics and therapy and understand solutions that are provided through medical image processing, navigation and visualization.

Master Seminar, 5 Credits: Participants work out one assigned topic independently in a seminar paper. They present the results and discuss them. In their paper they do a summary of the fundamental concepts and include a list of references. This module is offered by all research groups within the Department of Informatics. The lecturers select adequate topics of their research area and guide the students so that they can develop the required technical and scientific skills. Participants acquire necessary methodological and interdisciplinary skills for dealing with an academically demanding topic in Informatics. They can produce and present a scientific seminar paper. They can analyze and evaluate the results by contrasting them. They can work with scientific literature (search, evaluation, citation) and are able to present the constituent aspects of their topic in both a written paper and a presentation in front of the group.

Clinical Internship: Project Management and Software Development for Medical Applications, 10 Credits: This clinical project module teaches basic concepts of the software project management and development for medical, healthcare and intra-operative applications. Students are given a brief introduction to software project management and software engineering concepts such as requirement analysis, software design, coding guidelines, and unified modeling language (UML). Furthermore, they are exposed to topics related to version control, deployment, testing and documentation. Students are assigned a medical software project (team or individual) in cooperation with research institutes, clinical or industrial partners in order to apply the mentioned concepts in a real clinical scenario. Participants command the development of a clinical application in an advanced area of expertise using a methodologically clean approach. They are able to use application specific methods and systems that meet the current state of the technology. In teams they work in a goal-oriented way. The participants have the competence to document their approach and present the results.

6.1.2 Medical (16 credits)

The three compulsory modules in this section introduce the student to the field of today's medicine, medical instrumentation, basic knowledge of pathophysiology, nuclear medicine, radiation therapy, computer aided trauma surgery, and medical information processing.

It is crucial to not only understand the problems faced in today's medicine, but also understand the terminology, workflow and state-of-the-art in a medical environment. This helps BMC graduates to find most relevant solutions to the problems they will encounter either in medical research institutions or industry.

Medical Instrumentation and Computer Aided Surgery, 6 Credits: In this module, students learn the current methods, instruments and applications in surgery and endoscopy as well as computer-aided surgery. Furthermore, the students understand from a medical perspective, the use of surgical / endoscopic instruments. The students understand the basics for the application of FEA analysis and 3D model generation. By concluding discussion and Q & A sessions, the learning outcomes will be repeated and deepened.

Imaging in Radiology, Nuclear Medicine and Radiation Therapy, 4 Credits: Students learn the current methods and applications in medical imaging. They understand image acquisition concepts and the underlying technical and physical principles and if applicable image reconstruction. Furthermore, the medical use case of each modality will be determined.

Medical Information Processing and Pathophysiology, 6 Credits: This module introduces the basics of human physiology and pathophysiology with focus on the most relevant diseases. It also provides an overview of different medical informatics principle. After successful participation in this module the student is able to analyze the specific problems and apply dedicated methods of informatics in the medical domain.

6.2 Elective Modules

Elective modules allow students to deepen their knowledge in the specialized area of biomedical computing, which includes imaging techniques, computer vision, computer graphics, augmented reality and soft skills.

6.2.1 Imaging

In the area of imaging the skills in biological imaging, modern imaging or interventional imaging are trained. Furthermore, students can deepen their knowledge by attending modules focusing on the physical basics of modern imaging. Students must collect at least 5 credits from this group of modules. Having a profound understanding of the basics in imaging provides the students with the necessary background for approaching problems in their future career in medical imaging industry.

6.2.2 Mathematical Methods and Scientific Computing

Mathematics is the very basics of every image reconstruction algorithm, biomechanical simulation, parameter estimation, segmentation, and registration method. Therefore, it is crucial for BMC students to attend modules from this group. The variety of applications of computer aided medical procedures allows students to focus on multiple aspects. Students must collect at least 5 credits from this group of modules. Modules from this group provide the students with the fundamentals that they will need at any phase of their career.

6.2.3 Programming and Software Engineering

BMC students are expected to have established knowledge in programming and software engineering during the undergraduate program. However, this group of modules provides basic informatics modules as well as modules focusing on modern computer science problems. To guarantee a wide and robust education of BMC students at least one module from this group must be elected. Students must collect at least 5 credits from this group of modules.

6.2.4 Image Processing, Computer Vision and Pattern Recognition

Current approaches for image processing, computer vision, machine learning and pattern recognition are key methods in computer aided medical procedures. Besides the compulsory modules, these modules allow students to get insight into this extraordinary field of applied computer science. Students must collect at least 8 credits from this group of modules.

6.2.5 Computer Graphics, Augmented Reality and Visualization

When bringing new technology and methods to the medical environment, the application must not only provide benefit, but also needs to be designed according to the recent developments in computer graphics and visualization. Augmented Reality plays a key role in the visualization of information in a real-world view and is therefore an important technique in the medical environment. Students must collect at least 6 credits from this group of modules.

6.2.6 Support Electives

Through this group of modules, students are able to work with scientists of other communities, such as medical researchers, and can get insight into medical technology entrepreneurship. Students must collect at least 3 credits from this group of modules. A Master graduate is usually expected to have better communication and presentation skills as compared to a Bachelor graduate. This is also an expectation of companies or research institution from their potential employee candidates holding Master's degrees. For this reason, it is important to also strengthen skills such as collaborative working, creative discussion, or effective presentation that can be earned by attending to some of the soft skill modules offered as part of BMC curriculum.

6.3 Mobility Encouragement

Students are encouraged to spend up to one semester abroad to enrich their education. It is recommended to do this during coursework semesters 1 to 3. The international advisors of the Department of Informatics together with scientific coordinators of the BMC Master program provide counseling for interested students in order to check upon availability of suitable modules at the host university and to prevent a potential graduation delay. In general, it is possible to transfer credits for both the elective and compulsory modules from the host university to TUM, in particular since the compulsory modules are standard modules in international studies.

For exceptional cases, it is possible for students to perform their Master's Theses at international research institutes. Here, the general rules for external Master's Thesis of the Department of

Informatics have to be respected and topics as well as thesis project plans have to be defined by the Director of Biomedical Computing (Prof. Dr. Nassir Navab). For the time of their international stay, students will be assigned a local TUM supervisor in order to ensure close cooperation and supervision.

6.4 Exemplary Schedules

The BMC program can be finished within three semesters of modules and one semester for the Master's Thesis. This exemplary schedule shows that approximately 30 credits can be collected with 6 or less exams in each semester, while fulfilling all requirements in the study regulations. Note that the study regulations allow students to choose other modules than the ones used in this plan, which cannot be considered in this section.

1st Semester

Module Title	Area	ECTS	Type
Computer Aided Medical Procedures I	Compulsory Informatics	6	W
Medical Instrumentation & Computer Aided Surgery	Compulsory Medical	6	W
Medical Information Processing and Pathophysiology	Compulsory Medical	6	W
Advanced Programming	Programming and Software Engineering	5	W
Interventional Imaging and Image Processing	Imaging	5	W
Business Idea and Market	Support Electives	3	P
		31	

2nd Semester

Module Title	Area	ECTS	
Computer Aided Medical Procedures II	Compulsory Informatics	5	W
Imaging in Radiology, Nuclear Medicine and Radiation Therapy	Compulsory Medical	4	W
Introduction to Digital Signal Processing	Image Processing, Computer Vision, and Pattern Recognition	7	W
Algorithms for Scientific Computing	Mathematical Methods and Scientific Computing	8	W
Image Guided Surgery	Imaging	6	P
		30	

3rd Semester

Module Title	Area	ECTS	
Clinical Internship	Compulsory Informatics	10	P
Master Seminar	Compulsory Informatics	5	S
Computer Vision I	Image Processing, Computer Vision, and Pattern Recognition	8	W
Robotics	Computer Graphics, Augmented Reality and Visualisation	6	W
		29	

Examination Types: **W**: Written Exam **P**: Project Work **S**: Scientific Elaboration

7 Organization and Coordination

The Department of Informatics offers the Master's program in Biomedical Computing. All computer science modules are offered by professors from the Department of Informatics. This includes professors specializing in medical image processing, visualization, advanced user interfaces and computer aided medical solutions. Based on agreements, the Faculty of Medicine is involved with professors from fields like medical data acquisition and management, physics of medical imaging, orthopedics and trauma surgery.

The Faculty of Medicine is admitting students of Biomedical Computing to a selection of medical modules and organizes clinical projects. Cooperation agreements have been formalized for the following modules:

- Medical Instrumentation and Computer Aided Surgery: PD Dr. med. Rainer Burgkart, Prof. Dr. Hubertus Feußner, PD Dr. med. Laszlo Kovacs
- Imaging in Radiology, Nuclear Medicine and Radiation Therapy: PD Dr. Stephan Nekolla, Dr. Jorge Cabello, PD Dr. Dimitrios Karampinos
- Medical Information Processing and Pathophysiology: Prof. Dr. Klaus Kuhn

The composition of the examination board is defined in the study regulations. The study advisors of the Department of Informatics perform study advisory. The Servicebüro Studium of the Department of Informatics governs the application procedure and management of examinations in close collaboration with the Chair for Computer Aided Medical Procedures (I16).

8 Resources

8.1 Staffing Resources

The Department of Informatics hold and will maintain enough personnel resources to ensure the smooth realization of the study program.

Compulsory modules cover modules that are usually taught by the same professor each semester or year. Only lecturers for tutor classes might change yearly.

Required and existing resources are stated in the respective table in the appendix.

8.2 Material Resources/Rooms

The campus Garching offers enough lecture halls and rooms along with laboratories for advanced knowledge of Augmented Reality and Robotics. The Department of Informatics hold and will maintain enough technical and infrastructure resources in order to ensure smooth and optimal implementation and accomplishment of the BMC study program. Close collaboration with laboratories of hospitals enables the students easily to access most of the available medical devices to conduct experiments related to their research.