1. Study Program Documentation

Master NeuroEngineering

Department of Electrical and Computer Engineering,
Technische Universität München
October 2015

Formal Indications

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<th>NeuroEngineering</th>
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<td>Academic Department:</td>
<td>Department of Electrical and Computer Engineering</td>
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<tr>
<td>Degree:</td>
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</tr>
<tr>
<td>Standard Study Period/ Credits:</td>
<td>4 Semesters</td>
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<td>120 Credits + 30 Credits Research Excellence Certificate</td>
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<td>Form of Study:</td>
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<td>Admission:</td>
<td>Aptitude test pursuant to the program's FPSO</td>
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<td>WS 2016/17</td>
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<td>Language of instruction:</td>
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<tr>
<td>Person/s responsible for the Study program:</td>
<td>Prof. Dr. Jörg Conradt, Prof. Dr. Gordon Cheng</td>
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<tr>
<td>Additional explanations for special program:</td>
<td>Elite Master with funding from Elitenetzwerk Bayern (ENB)</td>
</tr>
<tr>
<td>Contact for further questions:</td>
<td>Dr. Thomas Maul</td>
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Under Article 3, Paragraph 2 of the German Constitution, women and men and their respective rights are considered equitable. Any and all masculine person references in the following charter apply equally to both men and women.

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2. Goals and Strategic Objectives of the Program

2.1. Goals of the Program

Neuroengineering is an emerging interdisciplinary field that aims to translate findings in neuroscience to real-world practical engineering applications. The successful development of neuro-inspired technical approaches will lead to a new generation of smart systems which achieve complex functions in an efficient manner, and will simultaneously advance our understanding of neuroscience.

The overall goal of neuroengineering programs is to educate and to train students in the interdisciplinary area between engineering and neuroscience; thereby providing knowledge and skills, and broadening their mind, to envision and to create innovative neuro-inspired systems.

The new ENB Elite Master Program in NeuroEngineering at TUM will fill an existing gap in bridging engineering and neuroscience; and will ultimately provide a better quality of life for German citizens and create a significantly more competitive German industry in a rapidly developing technological domain.

The ENB Elite Master Program in NeuroEngineering (MSNE) will, in accordance with the guidelines from the ENB to train specifically high-performing applicants towards a research oriented elite, train open-minded, international, high-performing students to become leaders in this novel interdisciplinary area. MSNE will provide students with a unique skill set that will open up career possibilities beyond the conventional job market and will become even more relevant in the future. The fact that graduates of other neuroengineering programs at elite universities throughout the world are in high demand in industry as well as academia stresses the importance of creating such training for elite students in Bavaria.

2.2. Strategic importance of the study program

TUM’s strategic development directions list interdisciplinary research and teaching for selected national and international applicants as priority. The TUM Board recently decided to establish the TUM School of Bioengineering as an Interdisciplinary Research Center comprising engineers, natural scientists, and medical scientists. As a related topic to neuroengineering, the Master program contributes both as a focal point for the school as well as a perfect environment for elite students to drive interdisciplinary innovations.
The MSNE program builds on experience with existing lectures and seminars that are part of the established Master "Elektrotechnik und Informationstechnik" and the "Master Track" of the Graduate School of Systemic Neurosciences (GSN, former ENB, currently DFG Excellence Initiative); While upcoming NeuroEngineering-specific courses, especially in individual student-teacher supervisory concept, should be reserved for the Elite program, method-orientated modules will also be available for students with respective specialization in other Master programs.

TUM/LMU have across board the ranges of disciplines to take on this highly interdisciplinary field, from biology, neuroscience and (strong) engineering. A substantial commitment from the host faculty and across the universities has been shown to this new field. The TUM Department of Electrical and Computer Engineering (EI) recently reformed its structure from a traditional institute setup towards more flexibility in representing the research focus areas in centers of competence (CoCs), where research groups cooperate on extended research topics. Today, methods and systems of electrical engineering and information technology are used almost everywhere spanning from automotive construction to medicine or from telecommunications to satellite navigation (GPS). The department EI is actively extending competence in the CoC NeuroEngineering, which allows adding specific lectures and small laboratory classes to the proposed Master program. Core faculty for intense student mentoring has been identified and has agreed to participate. TUM with its international network can provide the richest in multi-disciplinarity needed to make the MSNE program a success. This Master Program strengthens TUM’s strategic growth areas of “Healthcare" (aging society) and “Information and Communication”. This Master’s program will not only deliver engineers and researchers to the industry, but also benefits the relevant research in TUM. After the course work, some of the students will choose the possibility to continue their PhD at TUM.

2.3. Target Groups

The MSNE is applicable to candidates who hold a Bachelor of Science or Bachelor of Engineering or an equivalent degree from areas including electronics and computer engineering, biomedical engineering, computer science, neuroscience, and physics. Prospective students need to demonstrate self-initiated prior activity in the inter-disciplinary area between neurosciences or bio-medicine and engineering. We actively identify students with such a proven inter-disciplinary track record. For candidates with English not as the native language or the medium of instruction during previous studies, a proof of appropriate language skills is required, according to European Reference Guidelines level C1, such as the „Test of
English as a Foreign Language” (TOEFL), „International English Language Testing System” (IELTS) or the „Cambridge Main Suite of English Examinations“.
3. Qualification Profile

After successful completion of this Master program, the graduates will not only enhance their knowledge in neuroengineering, but also develop research skills through the coursework and thesis. Apart from the cutting edge knowledge and technical skills acquired, graduates also develop their basic soft skills.

Beyond the skillsets of only one or two disciplines, MSNE graduates are proficient in neuroscience, engineering, mathematics, psychology, and informatics, which is specifically geared towards solving complex engineering problems with high societal impact.

Graduates are able to apply state-of-the-art neuroimaging, neurophysiology and electrophysiology techniques and are able to use the techniques to conduct Brain-Computer-Interface research. They understood the functional gross anatomy and the function of neuros as to design the research method for the specific applications. They are able to derive results from such data with appropriate statistical methods and large-scale data analysis. By using computational methods to abstract neural systems and their behaviors as well as modelling such behaviors in software and hardware (both with analog and digital systems), graduates are able to investigate brain functions to conduct research and participate in ongoing research projects.

Upon graduation they are profound in current hot-spots of research in the field of neuroengineering and can name strengths and weaknesses of their chosen individual topic based on recent publications and own research projects. They understand the functionality of neuro-inspired systems and showed their ability to engineer aspects of such systems during their thesis. This involves the ability to consider the impact of such systems to the brain and balance the possibilities of engineering and their responsibility towards society regarding the influence their research can have to humankind.

The core skills acquired in the MSNE program are complemented by hands-on labs, early-career training for independent research (e.g. project design, or presentation and debating skills), and awareness of ethical aspects and societal acceptance of neuro-technology. Graduates are able to use inter-disciplinary methods between the fields combined with integrated soft-skills training (e.g. science-communication, entrepreneurship, leadership), so that they can better serve the growing academic, economical and societal demand in neuroengineering topics, e.g. cognitive systems.

Students can do their thesis and internship under professors or in companies. They will be able to handle a research project independently, analyse the topic, find out the challenges,
apply knowledge and methodologies acquired during coursework, and solve the problem. Finally, they will present the work as a scientific thesis. As a key building block, students will develop a pertinent awareness of ethical aspects of neuroengineering and its influences on society. After graduation, the MSNE students are prepared for future leadership positions in academia or industry by strong emphasis on developing skills of pursuing research independently, on personal engagement through multiple interactive research presentations, publication-like reports, and scientific debating.

Students opting to take the additional "Research Excellence Certificate" select additional elective courses, perform an additional research project, and present their research project results within their peer group at the NeuroEngineering Summit. Students that graduate with the certificate are able to combine several aspects of neuro-inspired systems and are able to define an own research focus, thereby going beyond the ability to conduct research with the ability to identify an individual research field that allows a smooth transition into doctoral studies. They are able to transform solutions within their individual research field into publications, present and defend them during a research conference setup.
4. Demand Analysis

Graduates will be future driving-forces in industry and academic research, and develop cutting-edge technology such as neuro-prostheses, neuro-rehabilitation devices, medical diagnostics, as well as next-generation computing technologies and autonomous systems. MSNE graduates are trained to act out their future career in an ethically and societally responsible manner, being aware of, and addressing contemporary and future societal needs and challenges.

Graduates of the MSNE program will be of high interest to research-oriented industry and will be very attractive for Ph.D. research (given their intense exposure to ongoing research) as well as local Ph.D. programs such as the Graduate School of Systemic Neurosciences or the "Medical Life Science and Technology" graduate program. Several companies like Bosch GmbH, Brain Products GmbH, and IBM Research GmbH confirmed their demand for graduates proficient in neuroengineering.

Based on experience from similar programs, e.g. "Neural Systems and Computation" at ETH Zürich, there is primarily an interest of potential students in Western Europe and North America with approximately 200 applications and 30 enrolled students. Demand in developing countries is only recently picking up with an increasing awareness in local societies for neurosciences. With the increasing relevance of an ageing society and the development of treatment options, a further growth of applicants specifically from central Asia is expected.

Through the special boundary conditions of an Elite program funded by the ENB, the MSNE is designed as a program for a limited number of students to ensure a high student-teacher ratio and continuous interaction. The funding is based on a student population of approximately 30 students per intake.

4.1. Target Figures (zu Zielgruppen)

The Target figure is 30 students per academic year and class. The target figure is set so as to assure that during all labs and lectures, the capacities of the facilities are not exceeded and the student teacher ratio does not hinder close interaction between the students and lecturers.
5. Competition

5.1. External Competitive Analysis

As the Master “NeuroeEngineering” is an interdisciplinary program there is a certain overlap with several other programs. Most notably, the LMU offers a Master “Neuroscience”, formerly also under the framework of the Elitenetzwerk Bayern (now DFG funded). This program focusses on foundations on cellular level and has therefore a strong focus on Biology with links to the also formerly ENB-supported Master “Neurocognitive psychology”. Certain aspects of these Master programs are also relevant for the engineering point of view covered in the Master “NeuroEngineering”. In consequence and in accordance with the guidelines set by the ENB, some modules are available for students of all the aforementioned Master programs to specialise.

In an international context mainly ETH Zürich and EPFL offer Masters with a neuroengineering focus, namely “Neural Systems and Computation” with a mostly informatics oriented profile and “Translational Neuroscience and Neuroengineering” with strong similarities to the proposed program. Both Universities and TUM will compete for a similar pool of excellent students, but agreed to an exchange, e.g. for internships and theses.

US universities like Georgia Tech, University of Illinois, and Drexel University already offer competing Master courses. Programs with similarities to a lesser extent exist e.g. at Birmingham University, USC and University of Wisconsin. This underlines the estimated applicants’ demand primarily in the western hemisphere.

5.2. Internal Competitive Analysis

The MSNE as an interdisciplinary program has certain overlaps with other disciplines at TUM as well. As an engineering program, the most similarities can be found with the Master Elektrotechnik und Informationstechnik where a core module named “Neuroengineering” is also present. As the Master “Elektrotechnik und Informationstechnik” is a program covering the whole area of Electrical and Computer Engineering, the core module “Neuroengineering” only covers the engineering aspects of neuroengineering, while the MSNE as an interdisciplinary program involves more than just the engineering point of view. Still, in accordance with the guidelines set by the ENB, some modules are available for students of both Master programs. The qualification profile of graduates therefore are clearly different between “NeuroEngineering” and “Elektrotechnik und Informationstechnik”.

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To a lesser extent this holds true for Masters in the field of Biology and Informatics, where certain content, specifically anatomy and computational methods, is also included. As foundation methods they are used similarly, but for a different purpose and qualification profile.
6. Structure of the program

The program is designed as 2-year full time (120 ECTS) Master-of-Science training, with an optional Research Excellence Certificate (additional 30 ECTS). The curriculum is innovative in the sense that all mandatory modules include hands-on implementation of acquired knowledge in small-team projects with tight supervision to ensure the students are able to apply the relevant methods and techniques. Due to the interdisciplinary character, the mandatory modules ensure that all aspects of the qualification profile (neuroscience, engineering, mathematics, psychology, and informatics) are covered, while still leaving students the choice of the preferred form of implementation during tutorials and labs. The Literature Seminar, Scientific Debating, Colloquium builds a framework for individual choice of a topic and related research papers, strengthening their ability to identify relevant research, analyze it, and convert it to their own contribution. Furthermore, the program includes up to two individual research projects (of 8 and 12 ECTS, respectively) during the semester breaks to enable students to perform independent research early during their education.

We offer a mandatory set of core courses to cover all basic aspects of neuroengineering from brain anatomy to neuro-recording, electronics, and computational processing; thereby MSNE students gain a rich toolbox and a deep understanding of neuroengineering concepts, despite the breadth of the field. The courses are conducted in a way that they set the framework for the topic it covers, but enables students during the tutorials and labs to focus on individual problems, thereby preparing the individual qualification towards research excellence. Students are free to select remaining courses (Learning Agreement). The overall timeline is 3 semesters of classes including hands-on projects, intense projects during the semester breaks (possibly abroad); with a 4th semester for the mandatory Master thesis.

Course List

All fundamental / methodological courses in bold are designed for the MSNE program and contain a theoretical introduction part combined with a practical hands-on component. Courses in blue are required for the optional Research Excellence Certificate (+30 ECTS).

1. Semester (30(+8) ECTS)
   - (a) Neuro-Recording Methods¹ 5 ECTS
   - (b) Statistics and Probability Theory 5 ECTS
   - (c) Neuro-Anatomy and Neuro-Physiology² 5 ECTS
   - (d) Computational Neuroscience 5 ECTS
   - (e) Mentor-Assigned Make-Up-Course or Elective Course 5 ECTS
   - (f) Elective Course 5 ECTS

¹ Includes clinical studies with TUM hospital patients, attended by MSNE students in small groups.
² As a follow-up, students can apply for a limited number of MSNE stipends to attend the "Munich BrainAnatomy Course" by Prof. Danek (3-day optional block course, offered annually in Feb/Mar).
- (g) Elective Course 5 ECTS

Followed by a **6 Weeks Research Project** typically at one of the participating groups in Munich 8 ECTS

**2. Semester (31+10 ECTS)**
- (a) Large-Scale Modeling and Large-Scale Data Analysis 5 ECTS
- (b) Signal Processing and Dynamic System Modeling 5 ECTS
- (c) Mixed Signal Electronics 5 ECTS
- (d) Literature Seminar, Scientific Debating, Colloquium 6 ECTS
- (e) Elective Course 5 ECTS
- (f) Elective Course 5 ECTS
- (g) Elective Course 5 ECTS
- (h) Elective Course 5 ECTS

Followed by a **9 Weeks Research Project** possibly outside Munich at one of the partner institutions 12 ECTS

**3. Semester (29+7 ECTS)**
- (a) Neuro-inspired Systems Engineering 6 ECTS
- (b) Societal Impact, Ethics 5 ECTS
- (c) Literature Seminar, Scientific Debating, Colloquium 6 ECTS
- (d) Elective Course 5 ECTS

Annual one-day **Symposium ("NeuroEngineering Summit"), end of WS, presentation of research results (poster and talk)** 2 ECTS

**4. Semester (30+5 ECTS)**
- (a) Master Thesis 30 ECTS
- (b) Elective Course 5 ECTS

**Total 120 ECTS (+ 30 ECTS)**

The mentor-assigned make-up course (1e) in the first semester allows students to fill-in possibly underrepresented knowledge depending on their earlier education program. Students without required make-up course can already select a first elective class.

The research projects after semester one (optional) and semester two (mandatory) give students first exposure to individual independent application of learned concepts. All associated faculty and international partners agreed to offer small, tightly supervised research projects during the semester breaks, thereby allowing students an exploration of their interests and an early specialization. Results of those research projects can optionally get published as small papers and shall be presented in the NeuroEngineering Summit (after semester 3).

All courses offered at TUM/LMU at master level (LMU instructor permission required; granted by all associated faculty) are eligible as elective courses, subject to approval in the learning agreement between student and mentor. All MSNE students can individually adjust / specialize
their curriculum by selecting at least three elective courses. Students opting to take the additional "Research Excellence Certificate" select additional four elective courses and perform an additional research project, thereby allowing a substantially stronger individual specialization and acquisition of competencies beyond a regular Master's graduate profile, geared towards a transition to doctoral studies.

Table 6.1 shows an exemplary study plan.\(^3\)

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\(^3\) Modules in green and yellow colours are core modules and elective modules respectively. Modules in grey are projects/thesis in block.
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<td>Large-Scale Modeling and Large-Scale Data Analysis</td>
<td>Neuro-inspired Systems Engineering</td>
<td>Master's Thesis</td>
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<td>Signal Processing and Dynamic System Modeling</td>
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<td>Mixed Signal Electronics</td>
<td>Literature, Scientific Debating, Colloquium 2</td>
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<tr>
<td>8 ECTS</td>
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<td>Elective (Research Excellence Certificate)</td>
<td>NeuroEngineering Summit</td>
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<td>2 ECTS</td>
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<td>8 Credits</td>
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<td>7 Credits</td>
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Table 6.1
7. Organization and Responsibilities

The Master “NeuroEngineering” is offered by the Department of Electrical and Computer Engineering of Technische Universität München with support of the Elitenetzwerk Bayern.

Administrative matters and responsibilities are listed below:

• Course Guidance

Course Guidance is given by the Department EI and TUM general student guidance office

Department EI: http://www.ei.tum.de/studium/studienberatung/

TUM: http://portal.mytum.de/studium/studienberatung/

• Application

The application is submitted via TUMonline in accordance with TUM regulations

• Student Management / Quality Management

The Student Management is done by the Program management of the Department EI. The Master will be included in the department’s quality management process and reported as per regulations of ENB.

• Examination Management

The Examination Management is done by the departments Examination Board for Master programs.