A New MSc Curriculum in Computer Science and Mathematics at the University of Zagreb

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Abstract. *A new graduate curriculum in computer science and mathematics is presented. The curriculum is offered by the Department of Mathematics, University of Zagreb, and it provides students with competence in mathematics, computer science and software engineering. The emphasis is on mathematical theory relevant for computing and software, on long-term knowledge and on abstract approaches to problem solving. The teaching and assessment methods are compatible with the Bologna declaration.*

Keywords. university studies, graduate curriculum, master of science, computer science, mathematics, software engineering, Bologna declaration.

1. Introduction

University of Zagreb has a long tradition of educating mathematicians. Presently, about 1600 students are studying at the Department of Mathematics. Although some of the students are preparing themselves for careers of pure mathematicians or traditional mathematics teachers, the vast majority of them are following curricula focused on applied mathematics, computer science, statistics or financial mathematics.

In the academic year 2004/2005, all university institutions in Croatia jointly launched a thorough reform of their studies. As a part of that reform, the present study profiles at the Department of Mathematics are planned to be gradually replaced by three undergraduate, eight graduate, and two postgraduate curricula compatible with the Bologna declaration.

The aim of this paper is to present one of the above mentioned eight new graduate curricula at the Department of Mathematics. More precisely, we are going to present the MSc Programme in Computer Science and Mathematics. The new course of studies incorporates all our previous experience in combining mathematics with computer science. It also introduces significant novelties, both in contents and in teaching-and-assessment methods. The curriculum has been approved by the relevant authorities in Croatia. Start of realization is scheduled for the academic year 2008/2009, after the first generation of students should have completed adequate undergraduate studies.

The paper is organized as follows. Section 2 provides general information about the new curriculum. Section 3 gives a more detailed description of courses, years of studies, and teaching-and-assessment methods. Section 4 makes a comparison with other curricula or guidelines in Croatia and elsewhere. Section 5 concludes with some additional remarks.

2. General information

The official name of our curriculum is *University Graduate Programme in Computer Science and Mathematics*, and it is offered by the Department of Mathematics, University of Zagreb. The basic entry requirement is completion of an adequate university undergraduate programme, presumably in mathematics, with at least 180 ECTS credits. On entry, some programming skills are also assumed. The academic title obtained upon completion of the studies is: *Master of Computer Science and Mathematics*. Duration of the programme is two academic years, i.e. four semesters, with 120 ECTS credits earned.

Our graduate programme offers students to simultaneously acquire competence in mathematics, computer science and software engineering. In more detail, this means the following abilities, skills and knowledge:

- good knowledge of the main areas of mathematics which are relevant for computer science, such as mathematical logic, computability, abstract algebra, graph theory, etc,
- good knowledge of the mathematical theory of computation and formal methods of computer science, e.g. complexity of algorithms, formal languages and automata, formal specification and verification of algorithms and systems, etc,
- good knowledge of modern paradigms and methods for software or information systems development, such as object-oriented modeling, net-centric design, relational data modeling, component-based development, etc.
- skills and practical experience in application of up-to-date technologies and tools for the purpose of software or information systems development,
- the ability of abstract thinking and mathematical modeling within the area of computer science and software engineering,
- the ability to easily adopt new ideas, methods and tools of computer science and software engineering.

We intend our masters of computer science and mathematics to be readily employable either in research/higher-education, or in industry/finance, or in government/public administration. In research/higher education they would be qualified for positions of assistants or research fellows, undertaking teaching or research in computer science and other fields. In industry/finance our graduates will be fully qualified to work as software engineers or developers, and to take part in industrial research and development. In government/public administration our graduates might work as ICT specialists on design and development of information systems.

3. Programme description

The studies consist of a fixed core, elective courses and master's thesis. The fixed core consists of 16 compulsory courses. Each student must also select altogether 6 elective courses from appropriate lists with the total of 22 electives offered. Both compulsory and elective courses may be classified as either fundamental or specialized. Out of 16 compulsory courses, 6 of them may be considered fundamental, while the others are specialized. Out of 22 electives, 5 are fundamental and 17 are specialized.

Fundamental courses deal mainly with theory, and they refer to a specific discipline of mathematics related to computer science or to mathematical theory of computation, such as: *Computability, Complexity of Algorithms, Formal Methods of Computer Science, Mathematical Logic in Computer Science* and similar. Specialized courses mainly deal with a specific discipline of computer science or software engineering, involving also application of particular development methods and software tools, such as: *Object-oriented Programming (C++), Artificial Intelligence, Database Systems, Computer Graphics, Multimedia Systems* etc. A distinguished type of specialized courses are *Computer Lab 2* and *Computer*

Table 1. List of courses - first year of studies

COURSE	FALL SEMESTER		SPRING SEMESTER	
	HRS PER WEEK (L+T+S)	ECTS CREDITS	HRS PER WEEK (L+T+S)	ECTS CREDITS
Computer Architecture	2+1+0	5	0+0+0	0
Design and Analysis of Algorithms	2+1+0	5	0+0+0	0
Interpretation of Programs	2+1+0	5	0+0+0	0
Artificial Intelligence	2+1+0	5	0+0+0	0
Mathematical Logic	2+2+0	5	0+0+0	0
Elective Course 1	3	5	0+0+0	0
Operating Systems	0+0+0	0	2+1+0	5
Computability	0+0+0	0	2+1+0	5
Database Systems	0+0+0	0	2+1+0	5
Object-oriented Programming (C++)	0+0+0	0	2+2+0	5
Computer Lab 2	0+0+0	0	1+3+0	5
Elective Course 2	0+0+0	0	3	5
TOTAL	19	30	20	30

Lab 3, targeting hands-on skills in modern information and communication technologies and integration of knowledge from different computing disciplines.

Compulsory fundamental and specialized courses provide students with firm knowledge of all the main relevant disciplines of mathematics, computer science and software engineering. On the other hand, the electives target particular disciplines in more detail and often represent a direct continuation of some compulsory courses. For instance, the compulsory course *Artificial Intelligence* gives an overview of the discipline, while elective courses *Soft Computing, Machine Learning* and *Natural Language Processing* deal in detail with specific topics within the artificial intelligence framework. Similarly, the elective course *Advanced Database Systems* builds on the compulsory course *Database Systems*. Also, all students attend the compulsory course *Formal Methods in Computer Science*, while those interested to learn more may select the elective *Mathematical Logic in Computer Science*.

Appropriate selection of courses may result in certain specialization of the studies. For instance, it is possible to structure the studies towards theoretical computer science, or towards a particular discipline such as artificial intelligence, or towards software engineering. It is expected that a student aspiring to an academic career would mainly select fundamental courses, while students who are preparing themselves for employment in industry/finance would mainly select specialized subjects.

During the fourth semester, each student shall complete his/her individual master's thesis which should, in principle, be the result of a software project elaborated by the student for a real user under the leadership of a mentor. Exceptionally, for a student who is preparing himself/herself for an academic career, the thesis may be rather theoretical and represent the preparation for a future doctoral dissertation. The topic of the thesis should be in line with selection of elective courses.

The actual schedule of courses according to years and semesters of studies is given in Tables 1, 2 and 3. Table 1 presents the compulsory courses taken at the first year of studies, Table 2 lists the compulsory courses at the second year, while Table 3 comprises all electives, which can be taken either at the first or at the second year subject to some ordering restrictions. For each course, the

Table 2. List of courses - second year of studies

COURSE	FALL SEMESTER		SPRING SEMESTER	
	HRS PER WEEK (L+T+S)	ECTS CREDITS	HRS PER WEEK (L+T+S)	ECTS CREDITS
Complexity of Algorithms	2+1+0	5	0+0+0	0
Software Engineering	2+1+0	5	0+0+0	0
Cryptography and Network Security	2+1+0	5	0+0+0	0
Distributed Processes	2+1+0	5	0+0+0	0
Elective Course 3	3	5	0+0+0	0
Elective Course 4	3	5	0+0+0	0
Formal Methods in Computer Science	0+0+0	0	2+1+0	5
Computer Lab 3	0+0+0	0	1+3+0	5
Elective Course 5	0+0+0	0	2+1+0	5
Elective Course 6	0+0+0	0	2+1+0	5
Master's Thesis	-	0	-	10
TOTAL	18	30	13	30

teaching load is expressed in terms of contact hours per week (lectures, tutorials and seminars, respectively). A course usually brings 5 ECTS credits. A detailed description of each course including aims, objectives, syllabus, prerequisites and reading lists can be found at [8].

All parts of the studies envisage similar teaching and assessment methods, which are compatible with the intentions and trends of the Bologna process [4]. Thus class attendance and active participation is obligatory for students. Most courses rely on homework assignments, mid-term exams, and study projects. Tutorials are usually held in computer laboratories which are equipped with adequate hardware and software. The same laboratories are also available to students for their individual activities. All essential literature is available at the department library. Each student is assigned to an advisor, who helps the student during studies, in particular with selection of courses and finding the topic and mentor of the thesis.

4. Comparison with other studies

Our new graduate programme has been brought in line, and is absolutely compliant, with the recommendations [5] given by the *Joint IEEE/ACM Task Force on Computing Curricula*. The curriculum namely includes the entire "body of knowledge" defined in [5], and expands it considerably with mathematical contents of theoretical computer science. Our curriculum also conforms to the guidelines [3] given by the *Mathematics tuning Group for Harmonization of European degrees in mathematics*. At the same time, the programme fits very well into the official Croatian development strategy *Croatia in the 21-st Century* [1].

Besides compliance with general recommendations and guidelines such as [1,2,4], our studies are also directly compatible with several existing European curricula, for instance [2,6]. Programmes similar to ours usually come from mathematics departments also engaged in computer science. Since the Bologna-inspired reform of the European higher-education systems is still in progress, it is to be expected that more of comparable curricula will emerge in near future.

The new graduate programme may be viewed as the successor to the existing curriculum offered by the Department of Mathematics within the profile called *Graduated Engineer of Mathematics*. The old programme has started in 1993 and was proved to be very successful in attracting students

Table 3. Elective courses - both years of studies

COURSE	FALL SEMESTER		SPRING SEMESTER	
	HRS PER WEEK (L+T+S)	ECTS CREDITS	HRS PER WEEK (L+T+S)	ECTS CREDITS
Computer Graphics	2+1+0	5	0+0+0	0
Meta-Heuristics	2+1+0	5	0+0+0	0
Introduction to Parallel Computing	2+1+0	5	0+0+0	0
Game Theory	2+1+0	5	0+0+0	0
Introduction to Optimization	2+1+0	5	0+0+0	0
Combinatorics	2+1+0	5	0+0+0	0
Programming for Modern Processors	2+1+0	5	0+0+0	0
Multimedia Systems	2+1+0	5	0+0+0	0
Soft Computing	2+1+0	5	0+0+0	0
Social and Professional Aspects of ICT	1+0+2	5	0+0+0	0
Introduction to Data Mining	2+1+0	5	0+0+0	0
Mathematical Logic in Computer Science	0+0+0	0	2+1+0	5
Machine Learning	0+0+0	0	2+1+0	5
Natural Language Processing	0+0+0	0	2+1+0	5
Mathematical Software	0+0+0	0	1+2+0	5
Applications of Parallel Computing	0+0+0	0	2+1+0	5
Operational Research	0+0+0	0	2+1+0	5
Applied Statistics	0+0+0	0	2+1+0	5
Software Project Management	0+0+0	0	2+1+0	5
Advanced Database Systems	0+0+0	0	2+1+0	5
Computational Statistics	0+0+0	0	2+1+0	5
Mathematics of Search Engines	0+0+0	0	2+1+0	5

and producing good mathematicians and computer scientists. In comparison with the old programme, the new curriculum brings the following distinctions in content:

- a careful update of all existing course descriptions, particularly syllabi and reading lists,
- more emphasis on the mathematical contents of theoretical computer science, by pulling some relevant topics from the post-graduate down to the graduate level,
- introduction of several previously uncovered topics, such as formal methods, distributed systems, computer graphics, multimedia systems, social aspects, special topics within artificial intelligence, etc.

The new study programme also brings the following novelties regarding the teaching-and-assessment methods:

- adjustment according to European standards and Bologna declaration, e.g. adoption of the ECTS,
- putting more emphasis on software projects, active participation of students and team work,
- introduction of the advisory system with continuous monitoring of each student's performance.

Our new curriculum can also be compared with those of other Croatian computer-science, software-engineering or "informatics" studies, which are offered by technical or management-oriented university departments or polytechnics. The main differences

that can immediately be spotted are the following.

- Our curriculum relies heavily on mathematics and on mathematical contents of theoretical computer science, which the other curricula tend to avoid.
- Even within the realm of mainstream computer science and software engineering, our curriculum puts more emphasis on long-term knowledge and general concepts, and less on the trends and buzzwords of the day, viewing the latter in terms of general notions.

There are however some curricula offered by other mathematics departments in Croatia that follow similar guidelines as ours, for instance [7]. Still, those are at this moment more closely related to our old pre-Bologna programme than to the new one.

5. Concluding remarks

Computer science (as distinct from computer engineering) is tightly coupled with mathematics. Consequently, our graduate curriculum builds upon competence acquired through a thorough undergraduate education in mathematics, and extends it towards computers and software. In our opinion, this is the proper way of producing graduates who would really be able to pursue meaningful research in computer science.

The ability of abstract thinking and mathematical modeling is also very important in modern software engineering. New paradigms and methods quickly enter the industrial arena and replace previous ones. Developing the ability to adopt new conceptual frameworks and new notations swiftly is one of the principal benefits of a good mathematical education. Hence our graduates will adapt easily to change, and we believe that they will in the long run turn out to be more flexible software engineers than those educated at technical or management-oriented institutions.

Our graduate curriculum is in many aspects different from, and complementary to other software-oriented studies in Croatia. Inside the Croatian higher-education system we are trying to cover an important niche addressing conceptual and long-term knowledge and understanding of principles underlying modern technology. From our point of view, the competence to be acquired through our programme is of strategic importance for further development of science, higher education and industry in Croatia.

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