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High-Performance and Quantum Computing for Students

Peter Faber[1] Helena Liebelt[2]

Abstract: Many technical advances have been applied in the area High-Performance Computing for the first time, and this also seems to hold for Quantum Computing. Traditionally, however, experts in these fields come from a diverse educational background. Recently, Technische Hochschule Deggendorf (Deggendorf Institute of Technology, DIT) introduced a new master's program „High-Performance Computing / Quantum Computing" to offer students a direct way into the application specific aspects of these field of expertise. To our knowledge, this is the first course of studies of its kind. This work describes this new program of studies and tentatively identifies some of the first lessons learned so far.

Keywords: Master's program; High-Performance Computing; Quantum Computing

1 Introduction

The field of both, High-Performance Computing (HPC) and Quantum Computing (QC), is becoming more and more important in today's world that relies on large scale data processing and ever more complex problems to be solved.

Thus, it should come as no surprise that markets in this area show rising numbers, even through pandemic times, and are gaining public interest, both locally in Germany as well as globally [Fö22; In21; Ka22; Ru21].

Therefore, Technische Hochschule Deggendorf (Deggendorf Institute of Technology, DIT) has introduced a new master's program called „High-Performance Computing / Quantum Computing" (HPC/QC). To our knowledge, this is the first course of studies of its kind: Technische Hochschule Deggendorf is a so-called university for applied sciences. This type of university focuses much more on aspects of applications than typical universities. This focus on immediate applicability in computing centers also distinguishes this course of studies from similar programs like the Master in Quantum Engineering at ETH Zürich [ET], the Master Quantum Engineering at University of Saarbrücken [Un], or the joint Master's Program in Quantum Science & Technology at Technische Universiät München and Ludwig-Maximilians-Universität München [TL] that have also been launched recently and turn their focus more specifically to the foundations and technologies of QC in particular.

[1] Technische Hochschule Deggendorf (THD / DIT), Dieter-Görlitz-Platz 1, 94469 Deggendorf, Germany
peter.faber@th-deg.de
[2] Technische Hochschule Deggendorf (THD / DIT), Dieter-Görlitz-Platz 1, 94469 Deggendorf, Germany
helena.liebelt@th-deg.de

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In contrast, the HPC/QC program tries to give students insights into immediately available applications. This also means combining high-performance and quantum computing in one course of studies. This makes sense for multiple reasons: Firstly, as can be seen throughout the history of computing, new performance improving technologies are mainly picked up by High-Performance Computing (HPC) architectures before reaching more general computing devices. Secondly, the immediate availability of an already existing and growing job market, which the building and maintenance of HPC systems offers, establishes a secure outlook for students. However, even for purely traditional HPC workloads, the mindset needed for the development of quantum circuits represents a valuable asset. Thus, we see large overlaps in the application of these two topics of the master program and exploit resulting synergies.

2 Structure of the Program

Since bachelor programs in Germany usually extend over seven semesters (210 ECTS), master programs typically cover three semesters (180 ECTS). Most courses at THD/DIT cover 5 ECTS in order to be able to reuse modules; therefor, modules are generally tailored to contain one course with an appropriate workload.

Figure 1 supplies a brief overview of the curriculum of this course of studies, an adapted version of the presentation at the program's website [Te21]. The program aims to offer a structured approach to developing expertise in design, maintenance, and development for modern HPC systems, as well as the newly appearing QC systems.

As can be gleaned from Figure 1, the overall course can be divided into four pillars:

1. Hardware Design and Efficiency
2. Software Engineering and Optimization
3. System Design and Application
4. General Competences

In the hardware design part, students in their first semester are introduced to (quantum) physics as a foundation of QC. This course can also be seen as an introduction to scientific reasoning and thus builds a base for the whole course of studies.[3] Students are also introduced to technologies fundamental to both HPC and QC systems; e.g., an understanding of networking technology is important not only for the operation of classical HPC systems but also for estimating problems and problem sizes that may be approached with QC.

The second pillar aims at introducing the students to programming techniques and frameworks for both, HPC as well as QC architectures. Students are not only introduced to parallel

[3] Since the course of studies actually started in the winter semester, this basic course was offered in both, the winter and the summer semester at the start of the program.

Master Program HPC/QC (M.Sc.)		Hours per week (SWS)					
Module / course	**Contents**	**SWS**	**1. Sem.**	**2. Sem.**	**3. Sem.**	**ECTS**	**Exam**
Hardware Design and Efficiency							
Physics for HPC/QC	Physical basics (in particular for QC)	4	4			5	written
Computer Architectures for HPC/QC	Concepts of modern computing systems (cluster systems, quantum computers)	4		4		5	written
Networks for HPC/QC	General and advanced topics of networking (advanced technologies)	4		4		5	written
Software Engineering and Optimization							
Software Engineering	Advanced methods of software engineering	4	4			5	written
HPC/QC Programming Lab	Modern methods of HPC and QC programming (frameworks and concepts)	4	4			5	project
Optimization Methods	Optimizing compilers, performance analysis & optimizations	4		4		5	project
System Design and Application							
HPC/QC Technology	Technical particularities of HPC and/or QC systems	4	4			5	project
HPC/QC Infrastructure	Infrastructure of modern computing systems in computing centers	4		4		5	written
System Design and Application of HPC/QC Systems	Complex system design (realizing an actual project from scratch)	4		4		5	project
General Competences							
Advanced Mathematics for HPC/QC	Mathematical foundations of scientific analyses	4	4			5	written
Advanced Mathematics and Physics for HPC/QC	Advanced mathematical and physical topics (scientific calculations)	4		4		5	written
Faculty Elective I**	Elective, in particular for deepening knowledge relevant for the area of HPC/QC	4	4			5	depends on subject
Faculty Elective II**	Elective, in particular relevant for the student's area of expertise	4			4	5	depends on subject
Master's colloquium	Presentation and disputation of the master's thesis	2			2	2	oral
Master's thesis	Academic research and writing	0			0	23	thesis
Total SWS		54 SWS	24	24	6		
Total ECTS			30	30	30	90 ECTS	

Fig. 1: Curriculum of the HPC/QC master program

programming using well known frameworks such as OpenMP [Op21] and MPI [Me21] (and also exposed to modern optimizing compilers etc.), but also to frameworks for quantum computing. In particular, simulator environments, partly based on HPC technology, are introduced for this purpose, including (but not restricted to) the Intel Quantum Simulator (IQS) [Gu20] and Google's cirq [Ci21].

The system design part leads students through maintenance and development tasks for HPC and/or QC systems. Again, HPC and QC systems are usually viewed together here, with HPC systems building frontends for QC systems. The final goal in this field of expertise is to develop a complete system from scratch during the second semester; a task for which students can finally draw from their complete knowledge attained in the preceding courses.

The field of general competencies contains a special approach to electives selection: Experts in the areas of HPC and QC oftentimes come from a variety of different careers and academic backgrounds, such as computer science, but also mathematics, physics, electrical engineering etc. Therefore, elective courses during the first semester should serve to deepen the student's knowledge in areas that are relevant to HPC or QC, in particular if the individual student's prior work and experiences themselves may not have provided adequate deeper knowledge in that area. This helps to ascertain a common level of knowledge for all students. However, it also implies that study program coordinators evaluate the applicability of different available courses for each student separately.

As a university of applied sciences, THD/DIT strives to build its programs in collaboration with other research facilities and industry partners alike to maximise the student's exposure to new developments and technologies. The partner network includes most of the major market players in both QC and HPC industries. Thus, courses are developed holistically, regularly receiving presentations and multi-day workshops from partners. Established regular „office-hours" with industry partners act as a direct line between students and the engineering teams from Intel, Microsoft and others to provide unbureaucratic support and guidance. Furthermore students have the opportunity to engage with industry mentors from various segments. Contributions by industry partners are planned together with the partners so that, depending on the possibilities, different kinds of contributions (from single presentations to multi-day workshops) can be integrated into the corresponding courses.

3 Experiences

The master program, primarily addressing students with degrees in mathematics, physics and computer science, is available for students from anywhere around the globe. Therefore, applicant numbers tend to be quite high: since contents and quality standards in education across countries and universities vary significantly, the application process for this program had to include an efficient way to identify suitable applicants. To that end, applicants have to pass a partially automated application test that contains questions from the fields of mathematics / logic, physics, operating systems and networks, programming, and modelling.

The test consists of a mixture of different question types ranging from multiple choice questions, through calculations to descriptions of their work in their previous studies. These tests were processed in one semester using a quiz in a separately managed instance of the school's e-learning platform Moodle, and in one semester using ARLA [El20], an experimental, automatic test system that is being developed at European Campus Rottal Inn (ECRI, part of THD). Both approaches proved valid alternatives for this task.

In its first semester, the program attracted 631 applications. 25 applicants were admitted to the program. In the summer semester (the regular start), 453 applications were received, 23 students were admitted. 26 students are currently registered. Thus, the rigorous test regime effectively helped to filter out suitable candidates and remove bogus applications.

The student's performance so far can be seen as adequate: On the German scale from 1 (best) to 5 (failure), students in their first semester reached an average of about 2.4.

On the other hand, students seem to be content with their course of studies. Although feedback up to now does not yet allow for statistical soundness, the general attitude towards the program according to a feedback loop of six anonymous students (and an anonymous follow-up interview) was quite positive. On a scale from 1 (not at all) to 5 (completely), students said on average:

1. they feel well-prepared for their future job: 4.0
2. they feel the subjects build a good fit together: 4.2
3. they recommend this course of studies: 4.3
4. the course of studies matched their expectations: 4.3
5. they were pleased with the invitations of guest speakers from the industry: 4.7

Students also named points for improvement such as better module descriptions online and that the mode of exams during the pandemic opened too many possibilities for cheating, which will be addressed by the coordinators of the program.

4 Conclusions

The new master program „High-Performance-Computing / Quantum Computing“ has taken off with a promising start. The application process seems to have successfully picked committed students. Since the program has only just begun, it is too early for a reliable quantitative analysis yet, but all in all, the program seems to be on the right track.

Further impulses are to be expected from an accreditation process that is currently running as well as from the new bachelor's program „Data Center Management“ [Te22] that is currently being introduced and should complement this program on the bachelor level.

References

[Ci21] Cirq Developers: Cirq, version v0.12.0, See full list of authors on Github: https://github .com/quantumlib/Cirq/graphs/ contributors, Aug. 2021, URL: https://doi.org/10.5281/zenodo.5182845.

[El20] Elkout, A.: Developing a Web Portal for Academic Readiness Level Assessment, MA thesis, Technische Hochschule Deggendorf / Deggendorf Institute of Technology, 2020.

[ET] ETH Zürich: Master in Quantum Engineering, last accesses 2022-07-10, URL: https://master-qe.ethz.ch/.

[Fö22] Förster, M.: Mainframe-Ausbildung: Glänzende Berufsaussichten, fehlt jedoch im Studium meist, Text in German, 2022, URL: https://www.heise.de/news/Mainframe-Ausbildung-Glaenzende-Berufsaussichten-fehlt-jedoch-im-Studium-meist-7101451.html, visited on: 05/25/2022.

[Gu20] Guerreschi, G. G.; Hogaboam, J.; Baruffa, F.; Sawaya, N. P.: Intel Quantum Simulator: A cloud-ready high-performance simulator of quantum circuits. Quantum Science and Technology 5/3, p. 034007, 2020.

[In21] Intersect360: Total HPC Market Revenue Grew 5.2% to $41.0 Billion in 2021, Says Intersect360 Research, 2021, URL: https://www.intersect360.com/total-hpc-market-revenue-grew-5-2-to-41-0-billion-in-2021-says-intersect360-research/, visited on: 05/25/2022.

[Ka22] Kaufmann, W.: High Performance Computing, Modularität und Made in Germany, Text in German, 2022, visited on: 05/25/2022.

[Me21] Message Passing Interface Forum: MPI: A Message-Passing Interface Standard Version 4.0, June 2021, URL: https://www.mpi-forum.org/docs/mpi-4.0/mpi40-report.pdf.

[Op21] OpenMP Architecture Review Board: OpenMP Application Program Interface Version 5.2, Nov. 2021, URL: https://www.openmp.org/wp-content/uploads/OpenMP-API-Specification-5-2.pdf.

[Ru21] Russel, J.: The (Resilient) HPC Market Writ Large in 100-plus Slides by Hyperion, 2021, URL: https://www.hpcwire.com/2021/06/28/the-resilient-hpc-market-writ-large-in-100-plus-slides-by-hyperion/, visited on: 05/25/2022.

[Te21] Technische Hochschule Deggendorf / Deggendorf Institute of Technology: HPC/QC master program website, 2021, URL: https://www.th-deg.de/qc-m, visited on: 05/26/2022.

[Te22] Technische Hochschule Deggendorf / Deggendorf Institute of Technology: Data Center Management bachelor program website, 2022, URL: https://www.th-deg.de/dcm-b, visited on: 05/26/2022.

[TL] Technische Universiät München; Ludwig-Maximilians-Universität München: Master's Program in Quantum Science & Technology, last accesses 2022-07-10, URL: https://www.mcqst.de/support/master-in-qst/.

[Un] Universiät des Saarlandes: Master Quantum Engineering, last accesses 2022-07-10, URL: https://www.uni-saarland.de/studium/angebot/master/quantum-engineering.html.