Informatics Board of Studies - Course Proposal

Proposed course title: Introduction to Quantum Computing
Proposer(s): Elham Kashefi
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1. Case for Support

1a. Overall contribution to teaching portfolio

Quantum Computation has been a rapidly growing field of research, attracting scientists from various native disciplines including Physics, Mathematics and Computer Science. Quantum Information Processing has resulted in a range of spectacular results from the foundations of quantum mechanics to the realization of actual quantum-based security protocols. Recent breakthroughs on the practical implementation of long-distance and networked quantum key distribution protocols have made quantum technology a realistic enterprise for our lifetime. Despite this diverse interest, this topic is not covered at all at the University of Edinburgh, and in Scotland in general it has been reserved for Physics students, at the PhD level. Even within the physics community the only existing course, called Quantum Information, offered through SUPA (Scottish Universities Alliance in Physics) for the Physics degree in Photonics, does not cover the computational aspects of the field.

In contrast, essentially all top universities in Canada, the US, and various countries in Europe and Asia offer courses in Quantum Computation. Within the UK, top universities such as Oxford, Cambridge, Imperial College, UCL and etc, also offer such a course, very often in the departments of Computer Science or Applied Mathematics. Quantum Computation is an emergent field stemming from both the foundations of Quantum Mechanics and theoretical Computer Science, and as such, has an overlap with other courses in both the foundations of computer science and quantum physics. Given the continued growth of the field, Quantum Computation is becoming an indispensable element of the computer science curriculum, and as such should be taught at University of Edinburgh, having one of the strongest departments for computer science in Europe.

The aim of this course is to bring this hot topic closer to students in the equally suitable field of Computer Science. During this course, the mathematical framework required to understand the basics of Quantum Computation is given and two models, the commonly used Quantum Circuit model and the more recent Measurement-Based Quantum Computing model, will be explained. Possible applications of quantum computing will be presented along with a couple of more interesting quantum algorithms. The final lectures will cover additional topics, such as the novel cryptographic protocol of Universal Blind Quantum Computing and Quantum Verification scheme.

1b. Target audience and expected demand

Any student from Physics or Informatics who has passed Quantum Mechanics has the required background. However for the student from Informatics or Mathematics it is also suffices to have passed only the Introduction to Linear Algebra and Probability with Applications. In general any undergraduate or master student from the college of science with basic knowledge of linear algebra, vector spaces, probability theory, complex numbers, models of computation, computability and intractability would be able to take the course. I anticipate good turn out for this course as almost all students from Physics and Informatics will take the above courses and in the past I have been approached at many occasions by for project within this topics. Up to my knowledge all the similar courses run in Europe and Canada and other UK based university have been very popular and packed with minimum 50 students.
1c. Relation to existing curriculum

This course is primarily assigned to the CS programme areas however it is open to MSc students in other areas as well. In particular the course should be listed for the following specialist areas:

Analytical and Scientific Databases
Computer Systems, Software Engineering and High Performance Computing
Knowledge Management, Representation and Reasoning
Theoretical Computer Science

Given the importance of quantum information processing and its effect on the security infrastructure of our current system, the basic familiarity with the concepts are also essential for undergraduate students in the following degrees. This is the case of all the standard computer science degree in North America and we would prepare our students in a competitive market by offering them the choice.

Artificial Intelligence and Computer Science (BSc Hons)
Artificial Intelligence and Mathematics (BSc Hons)
Computer Science (BEng Hons)
Computer Science (BSc Hons)
Computer Science and Electronics (BEng Hons)
Computer Science and Mathematics (BSc Hons)
Computer Science and Physics (BSc Hons)
Informatics (MInf)
Software Engineering (BEng Hons)

I have already contacted the Physics department and the director of teaching has agreed to make this course as one of the option to their degree program. The lecturer of the Quantum mechanics course (Prof. Del Debbio) has informed me of the students’ great interest in the topic of quantum computing (that appears only as the last lecture in his course) and their eagerness to continue their project and graduate study in quantum computing. However despite the success of Quantum Information Scotland Network (QUISCO) we seem to be losing these talented students due to the lack of an appropriate bridge to link them to the ongoing research activity in Scotland. It is worth mentioning that Quantum Mechanics (PHYS09017) has 87 students this year, who are eligible to take the Quantum Computation course.

1d. Resources

This is a level 11 fourth-year course in Computer Science, open to undergraduates taking CS degrees in their final year; to MInf students in year 5; and to all MSc students. Contents of approximately 16 out of 20 lecture hours will be examined, whereas the last remainder will be reserved for the purposes of material reviewing and discussions of advanced topics in Quantum Computation (not appearing in the final exam). If the number of registered students goes above 20, I would need a tutor to run an hour session per week. Both my current Ph.D. students, Einar Pius and Theodoros Kapourniotis and my postdoc Vedran Dunjko are able to do so. I am also interested to make the course to be a 20 credit one instead by expanding the advance topics specially if by teaching this I could cover my teaching duties.

2. Course descriptor

Course Title: Introduction to Quantum Computing

SCQF Credit Points: 10
SCQF Credit Level: 10
Normal Year Taken: 4/5/MSc

Appropriate for the following Degree Programmes:

Artificial Intelligence and Computer Science (BSc Hons), Artificial Intelligence and Mathematics (BSc Hons), Computer Science (BEng Hons), Computer Science (BSc Hons), Computer Science and Electronics (BEng Hons), Computer Science and Mathematics (BSc Hons), Computer Science and Physics (BSc Hons), Informatics (MInf), Software Engineering (BEng Hons), Analytical and Scientific Databases (MSc), Computer Systems, Software Engineering and High Performance Computing (MSc), Knowledge Management, Representation and Reasoning (MSc), Theoretical Computer Science (MSc)

Timetabling information: Semester 1
School Acronym: INF-?-??

Short Course Description:

The aim of this course is to give students a basic overview of the rapidly growing field of Quantum Computation (QC). The course will start with a brief introduction of the mathematical framework of QC. The two models of quantum circuit and measurement-based quantum computing, will be introduced. Through these models various key concepts in QC such as entanglement and teleportation will be discussed. In order to compare QC and classical computing, simple quantum algorithms with their complexity analysis will be presented. We finish the course by highlighting the recent development of the field in secure delegated QC.

Pre-Requisite Courses:

Co-Requisite Courses: None

Prohibited Combinations: None

Other Requirements:

Basic knowledge of linear algebra, vector spaces, probability theory, complex numbers, models of computation, computability and intractability.

Undergraduate students must have passed either PHYS09017 (Quantum Mechanics) or both MATH08057 (Introduction to Linear Algebra) and MATH08067 (Probability with Applications).

Postgraduate or visiting students must have taken similar courses providing this background in their undergraduate degrees.
Available to Visiting Students: Yes

Summary of Intended Learning Outcomes:

A student who has successfully completed this course should be able to:

1 - use the mathematical framework of quantum computing
2 - critically read and understand scientific papers on quantum computing
3 - explain and analyse any quantum algorithms described in quantum circuit or measurement-based quantum computing models
4 - relate quantum complexity classes to the classical ones

Assessment Information

Assessment Weightings:

Written Examination: 80%
Assessed Assignments: 20%
Oral Presentations: 0%

The students who successfully complete the course will have a general understanding of the current topics in Quantum Computing, and will be able to critically read and understand scientific papers pertaining to the field. This being one of the main purposes of the course, it will be examined via oral presentation of well chosen articles. Indeed in Quantum Computing there are many elementary concepts in the field that are still under investigation and we aim to encourage the students to get familiar with these ongoing research topics as part of their study. The students will be also required to complete a moderate amount of independent one take-home assignments, the main purpose of which will be to aid the students in understanding the presented material and help in the preparation for the final exam. A written examination contributes 80% of the final grade. The remaining 20% will be based on two assessed coursework, one of which is the oral presentation of a research paper. Each student will get a 10 minutes slot to discuss the main points of the paper. We plan to arrange this outside of the required lectures hours. However if the number of students exceeds 20 the oral presentation option will be replaced with another take home coursework.

Academic description:

Syllabus:

- Basic concepts from Linear Algebra necessary for understanding the axioms of Quantum Mechanics,
- Axioms of Quantum Mechanics, describing quantum system, quantum operators, composition, entanglement and measurements
- The no cloning, no deleting theorems and the consequences for computation
- Quantum Computing via quantum circuit model: Description of qubit and universal set of gates.
- Quantum space and depth complexity and oracle model
- Classical simulation of quantum circuit and Gottesman-Knill Theorem
- Quantum Algorithms: Grover’s Search and Deutsch-Jozsa problem
- The first quantum protocols: Quantum teleportation and super dense coding
- Quantum Computing via measurement-based model: Description of graph state and measurement calculus
- Advance Topics: Information flow in measurement-based model, unconditionally secure quantum cloud computing

Relevant QAA Computing Curriculum Sections:

Transferrable skills:

Ability to analyse complex system and to design syntaxes to capture computational phenomena, familiarity with information encoding in natural system and distinguishing the boundary between classical and physical computation

Reading List:

The principal source will be lectures slides provided during the course. Other textbook for the course are “Quantum Computation and Quantum Information” by Nielsen and Chuang, “An Introduction to Quantum Computing” by Kaye, Laflamme and Mosca. Also a useful supporting textbook for the course is “Quantum Information” by Stephen Barnett.

Study Abroad: None

Study Pattern:

2 lecture hours and 1 tutorial hour each week, with 2 coursework assignments.

Lectures 20
Tutorials 8
Timetabled Laboratories 0
Coursework Assessed for Credit 12
Other Coursework / Private Study 60
Total 100

Keywords: Quantum computing, quantum algorithm, quantum mechanics, quantum complexity, quantum protocol
3. Course materials

Please see attached PDF files for sample question

3d. Any other relevant materials

None

4. Course management

4a. Course information and publicity

There will be a website for the course available at the start of the term where the slides of the first 5 lectures and general introduction including the course structure will be made accessible. During the course period further slides will be uploaded. Also tutorial materials and assignments together with any other paper references will be distributed through this website. The course itself will be advertised on QUISCO (quantum information Scotland network), SUPA and SICSA mailing list.

4c. Feedback

4b. Management of teaching delivery

All the required communication with the students will be performed via the course website. The other staff of the course if approved will be the tutor from my current quantum group at the school where we have already weekly meeting. Any required discussion about the course and the progress of the students will be covered in these meeting.

5. Comments

All the comments I have obtained from Jane Hilston, Ian Stark and Michael Rovatsos have been already incorporated in the proposal.