Quantum Computation and Quantum Information (QCQI)

Programme: B.Tech.	Year: 4th year	Semester : 7th
Course type : Elective	Credits : 3	Contact Hours : 40

Course Context and Overview:
The world of science and technology has become highly inter-disciplinary and the field of Quantum computation and quantum information is a prime example of this. The subject combines three major revolutions of last century - the physics of quantum mechanics, the theory of computation and information theory which leads to a new paradigm of computation and information processing. A lot of theoretical and experimental effort is being made by a lot of Universities/institutions around the world as well as by companies like Google, Microsoft, IBM etc. to develop large enough quantum computers to explore the possibilities that this new paradigm of computation and information processing offers.

The course is intended to be a first course in Quantum Computation and Quantum Information (that is, no familiarity with the subject assumed). Keeping in mind the interdisciplinary nature of the subject, the students will be introduced to the basic concepts from the theory of computation which will be followed by an elementary introduction to quantum mechanics before plunging into quantum computation. After introducing the basic notions of qubits, quantum gates, entanglement etc. the students will be exposed to certain well known quantum algorithms like Shor's algorithm and Grover's algorithm which highlight the power of quantum computation in comparison to the standard computation. Finally, we look at the use of quantum concepts in information processing tasks including quantum cryptography. The various concepts will be discussed with examples.

A first exposure to the subject is desirable of students at master's level or final year undergraduate level as this might motivate them to explore the field further. Even otherwise, once (computationally) large quantum computers become available, the initial exposure would mean that the subject would not be completely alien to them and if their job demands, they would be in a position to use it with some effort.

Prerequisites:
Linear algebra is the only real prerequisite for the course (we will nevertheless discuss linear algebra in brief). Exposure to any or all of the following subjects - quantum mechanics, theory of computation and information theory - though not necessary will be helpful.

On completion of this course
CO1: Students would have a broad overview of the theory of computation and information theory and an appreciation of how the relevant notions might depend on the underlying physics.
CO2: Students should have a working knowledge/understanding of simple finite dimensional quantum systems.
CO3: Students should be able to analyze simple quantum circuits.
CO4: With some effort students should be able to translate between quantum circuits and quantum algorithms.
CO5: Students should develop an understanding/appreciation for how quantum physics (and quantum entanglement) might give an edge over classical information theory and classical cryptography.

Course Topics:

Topics	No. of lectures (approximate**)
Introduction	1
Introduction to some basic concepts in the theory of computation (including Turing machines and the circuit model of computation, reversible computers)	6-7
Introduction to basics of quantum mechanics (including linear algebra)	6-7
Preliminary notions in quantum computation – qubits and quantum gates, single qubit quantum systems (including measurement) and application to quantum key distribution	3
Multiple-qubit systems – tensor product space, quantum entanglement, multi-qubit quantum gates, no cloning theorem, quantum circuits – reversible and quantum versions of simple gates, controlled gates and universal gates, quantum versions of classical computations, EPR paradox and Bell states, applications to quantum dense coding and quantum teleportation,	7
Simple quantum algorithms – Deutsch algorithm, Deutsch-Jozsa problem, Bernstein-Vazirani problem, Simon's problem	3
Quantum Fourier transform and Shor's factoring algorithm	4
Grover's algorithm	3
Decoherence and Quantum error correction	4
Physical realization of quantum computers	3
Total	**40-42**
* Considering the nature of the course, it is open for master's students in Physics and maths and for M.Tech. and B.Tech. final year students from CSE, CCE and ECE. However, motivated students from MME can also take this course if they wish.	

Text Books:
1. Quantum Computing: *A Gentle Introduction* – E. Rieffel and W. Polak (The MIT Press, 2014).
2. Quantum Computing: From Linear Algebra to Physical Realizations – M. Nakahara and T. Ohmi (CRC Press, 2008).
3. Quantum Computer Science: *An Introduction* – N. David Mermin (Cambridge University Press, 2007).

Reference Books:
1. Quantum Computation and Quantum Information – M.A. Nielsen and I.L. Chuang (Cambridge Univ. Press, 2010).
2. Classical and Quantum Computation – A. Yu. Kitaev, A.H. Shen and M.N. Vyalyi (Graduate Studies in Mathematics, AMS, 2007) (Indian edition by Universities Press).
3. An Introduction to Quantum Computing – P. Kaye, R. Laflamme and M. Mosca (Oxford Univ. Press, 2007).

Additional Resources:

1. Online lecture notes of John Preskill's course on Quantum Computation can be found at http://www.theory.caltech.edu/people/preskill/ph229/
2. Online edX lectures on Quantum Information Science by Issac Chuang and Peter Shor can be found at https://www.edx.org/course/quantum-information-science-i and https://www.edx.org/course/quantum-information-science-i-part-2-mitx-8-370-2x

Evaluation:

Item	Weightage
3-4 quizzes	25
1 midterm	25
1 endterm	50

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