UNIVERSITÀ DI PAVIA – DOTTORATO DI RICERCA IN FISICA

PhD Course on Quantum Computing

December 2018 - February 2019

SCOPE OF THE COURSE:

Quantum computation is becoming of greater and greater interest in computer science, mathematics, physical sciences and engineering. Quantum computers could soon provide breakthroughs in many disciplines, including the simulation and optimisation of complex systems, material design and drug discovery, and artificial intelligence. Already now, quantum computers are no longer objects merely described in books, as they have been realised in practice and open access to quantum chips has been made available by some companies (i.e. IBM, Rigetti). Quantum computers will likely lead to new avenues of technological innovations in communication, computation and cryptography. But to realise those breakthroughs, and to make quantum computers widely useable and accessible, we need to reimagine information processing and the machines that do it, and to reinvent new ways of coding. More than with an increase in computation speed, Quantum Computing deals with a severe change of paradigm.

The course aims at providing an introduction to Quantum Computing from the theoretical bases to main applications. It is addressed to PhD students in Physics and related areas (Mathematics, Engineering, Computer Science, Chemistry) who wish to receive an introduction to the concepts and terminology used in Quantum Computing, to become familiar with the structure and operation of a Quantum Computer, and to understand the basic concepts of quantum programming.

ATTENDANCE AND EXAM:

A certificate of attendance can be delivered, upon request, to registered participants.
PhD students from University of Pavia or from other Universities may ask to take an exam at the end of the course, if their participation covers at least 80% of the lectures (seminar excluded). The exam can be given by presenting either a short code running on publicly available Quantum Machines, like IBM Quantum Experience, or by giving a seminar discussing in depth one of the topics presented during the lectures.
PhD students who pass the final exam will be delivered a specific certificate.

REGISTRATION:

Participation to the course is free of charge. Lectures will be given in English. Everybody is welcome to participate.
Please register at http://fisica.unipv.it/dottorato/corso-quantum-computing.htm.
Please contact the course responsible, prof. Daniela Rebuzzi (daniela.rebuzzi@unipv.it), or the PhD coordinator, prof. Lucio Andreani (lucio.andreani@unipv.it), for further information.

PROGRAM:

Lectures will be given in the Aula Dottorato of the Physics Department, Via Bassi 6, Pavia, according to the calendar below.

C. Macchiavello (UniPV) - **Theoretical basis** (*lecture, 6 hours*)

- 3 December 2018, 10:00-12:00
- 4 December 2018, 10:00-12:00
- 5 December 2018, 10:00-12:00

Basic concepts in quantum computation: description of a quantum bit, single qubit gates, controlled operations, universal set of gates, quantum circuits. Introduction to quantum algorithms: Deutsch-Jozsa algorithm, Simon's problem; Quantum Fourier transform and factorisation algorithm; quantum search algorithms.

D. Gerace (UniPV) - **Universal quantum simulators** (*lecture, 6 hours*)

- 15 January 2019, 10:00-12:00
- 16 January 2019, 10:00-12:00
- 22 January 2019, 10:00-12:00

Basis of digital quantum simulation: from physical models to the quantum circuit representation to be encoded on a quantum processor. Time evolution through the Suzuki-Trotter decomposition. Examples of quantum coding: quantum circuit representation of the Heisenberg and Ising models. Brief overview of existing quantum processors on different platforms: trapped ions, superconducting qubits, quantum dots. A selection of prospective technologies to realize hybrid quantum simulators: hybrid spin-photon qubits, magnetic molecules, electromechanical devices.

I. Tavernelli (IBM, Zürich) - **Superconducting qubits** (*lecture, 8 hours*)

- 12 February 2019, 10:00-12:00 and 15:00-17:00
- 13 February 2019, 10:00-12:00 and 15:00-17:00
- **14 February 2019, 16:00: PhD Colloquium "Quantum computing simulations: applications in physics and chemistry", A102 Physics Department, Via Bassi 6, Pavia**

Short overview of the main quantum computing devices (with focus on superconducting circuits). Fundamentals on digital quantum computing: focus on quantum gates (one-qubit and two-qubit operations) and their implementations. Overview of some optimisation algorithms (mainly VQE). Description of the electronic structure problem and other problems in chemistry and physics (e.g. folding). Implementation and solution of the electronic structure problems.

Introduction to IBM Quantum Experience. Coding of the solution of the problems of the electronic structure using quantum experience. Examples and applications.

D. Bajoni (UniPV) - **Photonic quantum simulators** (*seminar, 2 hours*)

- 23 January 2019, 10:00-12:00

Brief overview of photonics platforms, with focus on integrated photonics. Different types of qubit implementations using photons: polarization, time-bin, and dual rail encoding. Quantum gates and basic algorithms in photonic platforms, photonic simulators. The problem of scaling the number of qubits and possible solutions.

J. I. Latorre (Barcelona) - **Hybrid quantum algorithms** (*seminar, 2 hours*)

- 14 February 2019, 10:00-12:00

The idea of building hybrid quantum algorithms that combine machine learning with quantum circuits is explored in this seminar. In particular, the idea of the application of variational methods opens the possibility of dealing with non-trivial optimisation problems, autoencoders and training of neural networks.

F. Carminati (CERN) - **Quantum Computing for High Energy Physics Applications** (*seminar, 2 hours*)

- 21 February 2019, 10:00-12:00

Some possible avenues to exploit Quantum Computing for High Energy Physics research, in connection with the HEP physicists and the major technology providers. In particular, discussion will focus on the areas where the greatest potential for "Quantum Dominance", and the impact of Quantum Computing on the HEP computing model will be evaluated. The possible usage outside the realm of HEP of the proposed techniques and applications will be also discussed.

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