FOCUS WEEK 4: QUANTUM COMPUTING

TITLES AND ABSTRACTS

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MINICOURSE (3 hours)

Speaker: Ashley Montanaro

Title: Quantum algorithms and complexity

Abstract: Quantum computers are designed to outperform their classical counterparts by running quantum algorithms. In this series of 3 talks, I will briefly introduce the theory of quantum computing, and some key results in this area. In the first talk, I will describe some classic results and subroutines in quantum algorithms, including the famous algorithms of Shor and Grover, which have important practical applications as well as a high level of mathematical elegance. In the second talk, I will introduce the theory of quantum computational supremacy: quantum computers going beyond the capability of any realistic classical computer. In the third talk, I will focus on more recent developments in quantum algorithm design, including algorithms for efficient simulation of quantum-mechanical systems.

The talks will assume basic knowledge of quantum information theory (e.g. Dirac notation, Hilbert space, tensor products) but will not assume any knowledge of quantum computing or algorithmics. The topics covered can be adjusted based on the audience's interests.

References:
- lecture notes for a unit on Quantum Computation: https://people.maths.bris.ac.uk/~csxam/teaching/qc2019/lecturenotes.pdf
- a survey paper on quantum computational supremacy: https://www.nature.com/articles/nature23458
- a brief survey paper on quantum algorithms: https://www.nature.com/articles/npjqi201523

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TALKS

Speaker: Jop Briët

Title: Quantum query algorithms are not entangled games

Abstract: At first sight, quantum query algorithms and entangled nonlocal games don't seem to have more in common than just having something quantum in them. But common connections with Grothendieck's inequality and characterizations in terms of similar-looking tensor norms suggest these models might be closely connected. In 2012, Pisier even asked if the two relevant tensor norms are equivalent, which would in a sense imply that the distinction between quantum algorithms and games is superficial. This talk is about the recent resolution of this question in the negative, supporting the first impression that quantum algorithms and nonlocal games are indeed quite different after all.
Based on joint works with Srinivasan Arunachalam and Carlos Palazuelos

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Speaker: Toby Cubitt

Title: Analogue Hamiltonian Simulation and Universal Quantum Hamiltonians

Abstract: Physical (or "analogue") Hamiltonian simulation involves engineering a Hamiltonian of interest in the laboratory, and studying its properties experimentally (somewhat analogous to building a model of an aeroplane and studying it in a wind tunnel). This is often touted as the most promising near-term application of quantum computing technology, because (it is claimed) it does not require a scalable, fault-tolerant quantum computer.

Despite this, the theoretical basis for Hamiltonian simulation is surprisingly sparse. Even a precise definition of what it means to simulate a Hamiltonian was lacking. By drawing on techniques ranging from Hamiltonian complexity to Jordan algebra homomorphisms, we put analogue Hamiltonian simulation on a rigorous theoretical footing.

This is far more fruitful than a mere mathematical tidying-up exercise. In work with Gemma de las Cuevas [Science, 351:6278, p.1180, 2016], we used this new theoretical insight to prove for the first time that there exist universal spin models that are capable of simulating any other classical spin system, and showed that the simple 2D classical Ising model with fields is such a universal model. Followup work with Tamara

Kohler extended this to translationally invariant systems [J. Stat. Phys.176:228 (2019)]. In work with Ashley Montanaro and Stephen Piddock [Proc. Natl. Acad. Sci. 115:38 p.9497, 2018], we extended these results to the quantum case. First constructing a rigorous theory of quantum Hamiltonian simulation, then proving a complete classification of the simulation power of two-qubit interactions, showing that even simple models such as the 2D Heisenberg model are universal quantum Hamiltonians. Along the way, we took a first step towards rigorously justifying why error correction may not be necessary in Hamiltonian simulation.

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Speaker: David Gosset

Title: Classical algorithms for quantum mean values

Abstract: Consider the task of estimating the expectation value of an n-qubit tensor product observable in the output state of a shallow quantum circuit. This task is a cornerstone of variational quantum algorithms for optimization, machine learning, and the simulation of quantum many-body systems. In this talk I will describe three special cases of this problem which are "easy" for classical computers. This is joint work with Sergey Bravyi and Ramis Movassagh.

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Speaker: Stacey Jeffery

Title: Quadratic speedup for finding marked vertices by quantum walks

Abstract: A quantum walk algorithm can detect the presence of a marked vertex on a graph quadratically faster than the corresponding random walk algorithm (Szegedy, FOCS 2004). However, quantum algorithms that actually find a marked element quadratically faster than a classical random walk were only known for the special case when the marked set consists of just a single vertex, or in the case of some specific graphs. We present a new quantum algorithm for finding a marked vertex in any graph, with any set of marked vertices, quadratically faster than the corresponding classical random walk.
This is joint work with Andris Ambainis, András Gilyén, and Martins Kokainis.

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Speaker: Iordanis Kerenidis

Title: Quantum algorithms for supervised and unsupervised learning

Abstract: We will provide an overview of recent results on supervised and unsupervised learning. In particular we will briefly discuss Recommendation Systems, classification, clustering and quantum neural networks. We will try to break down these algorithms to some quantum subroutines that can be useful for understanding where the power of quantum machine learning algorithms comes from.

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Speaker: Robert Koenig

Title: Quantum advantage with noisy shallow circuits

Abstract: Prior work has shown that there exists a relation problem which can be solved with certainty by a constant-depth quantum circuit composed of geometrically local gates in two dimensions, but cannot be solved with high probability by any classical constant depth circuit composed of bounded fan-in gates. Here we provide two extensions of this result. Firstly, we show that a separation in computational power persists even when the constant-depth quantum circuit is restricted to geometrically local gates in one dimension. The corresponding quantum algorithm is the simplest we know of which achieves a quantum advantage of this type. It may also be more practical for future implementations. Our second, main result, is that a separation persists even if the shallow quantum circuit is corrupted by noise. We construct a relation problem which can be solved with near certainty using a noisy constant-depth quantum circuit composed of geometrically local gates in three dimensions, provided the noise rate is below a certain constant threshold value. On the other hand, the problem cannot be solved with high probability by a noise-free classical circuit of constant depth. A key component of the proof is a quantum error-correcting code which admits constant-depth logical Clifford gates and single-shot logical state preparation. We show that the surface code meets these criteria. To this end, we provide a protocol for single-shot logical state preparation in the surface code which may be of independent interest.

This is joint work with Sergey Bravyi, David Gosset and Marco Tomamichel.

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Speaker: Giannicola Scarpa

Title: Computational complexity of PEPS zero testing

Abstract: Projected entangled pair states aim at describing lattice systems in two spatial dimensions that obey an area law. They are specified by associating a tensor with each site, and they are generated by patching these tensors. We consider the problem of determining whether the state resulting from this patching is null, and prove it to be NP-hard; the PEPS used to prove this claim have a boundary and are homogeneous in their bulk. A variation of this problem is next shown to be undecidable. These results have various implications: they question the possibility of finding a canonical form for PEPS; there are PEPS for which the presence of a symmetry is undecidable; there exist parent hamiltonians of PEPS for which the existence of a gap above the ground state is undecidable.

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