COLLEGE OF ENGINEERING
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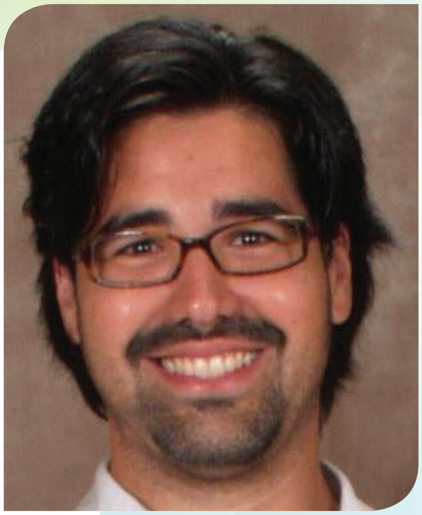

Hector Garcia

Hybrid Techniques for Simulation of Quantum Circuits Using the Heisenberg Representation

ABSTRACT:

Simulation of quantum information processing remains a major challenge with important applications for quantum computer science and engineering. Generic quantum-circuit simulation appears intractable for conventional computers and may be unnecessary because useful quantum circuits exhibit significant structure that can be exploited during simulation. For example, Gottesman identified an important subclass, called stabilizer circuits, which can be simulated efficiently using the Heisenberg representation for quantum computers. Stabilizer circuits are exclusively composed of stabilizer gates – Hadamard, Phase and CNOT – followed by computational-basis measurements. Such circuits are applied to a computational-basis state and produce so-called stabilizer states. Aaronson generalized stabilizer-circuit simulation to additionally handle a small number of non-stabilizer gates. We design new, more efficient data structures and algorithms for such beyond-stabilizer simulation using superpositions of stabilizer states. Our primary data structure, called stabilizer frame, offers more compact storage than previous approaches but requires additional algorithms to maintain the global phases of each state in the superposition. To explore the advantages and limitations of frame-based simulation, we analyze the geometric structure of stabilizer states and design efficient algorithms for computing distances, angles and volumes between them. The main advantages are: (i) stabilizer subcircuits are simulated with high efficiency, (ii) superpositions can be restructured and compressed on the fly to reduce resource requirements, and (iii) operations performed on such superpositions lend themselves to parallel processing. Our software implementation, called Quipu, simulates certain quantum arithmetic circuits and quantum Fourier transform circuits in polynomial time and space for specific input states. On such instances, linear-algebraic techniques, such as the (state-of-the-art) BDD-based simulator QuIDDPro, take exponential time. We simulate quantum fault-tolerant circuits, and the results indicate that Quipu empirically outperforms QuIDDPro in all cases. While previous structure-aware simulators were difficult to parallelize, we demonstrate a parallel version of Quipu that achieves a computational speedup.

Chair: Prof. **Igor Markov**

Thurs., December 12, 2013 10:00 am – 12:00 noon 3725 Beyster Building