Quantum Information and Quantum Computation

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Introduction

Quantum computers and communication systems are devices that store and process information on quantum systems such as atoms, photons, superconducting systems, etc. Quantum information processing differs from classical information processing in that information is stored and processed in a way that preserves quantum coherence. The Quantum Information Group is investigating methods for constructing quantum computers and quantum communication systems using atomic physics,quantum optics, and superconducting systems. The group is investigating applications of quantum information processing including novel quantum algorithms and communication protocols. In addition, we are investigating the role of quantum coherence in biological processes such as photosynthesis.

1. W.M. Keck Center for Extreme Quantum Information Theory (xQIT)

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W.M.Keck Foundation

Project Staff
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Over the last half century, the components of computers have gotten smaller by a factor of two every year and a half, the phenomenon known as Moore's law. In current computers, the smallest wires and transistors are coming close to a size of one hundred nanometers across, a thousand times the diameter of an atom. Quantum mechanics is the theory of physics that describes the behavior of matter and energy in extreme conditions such as short times and tiny distances. As transistors and wires become smaller and smaller, they inevitably begin to behave in intrinsically quantum mechanical ways.

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Quantum computers store and process information at the level of individual quanta--atoms, photons, and electrons. Even if Moore's law persists, commercial quantum computers are not yet due on the shelves for another few decades; nonetheless, prototype quantum computers consisting of a small number of atoms and quantum communication systems that use single photons have been built and operated.

Researchers at the W.M. Keck Center for Extreme Quantum Information Theory (xQIT) are working to investigate the limits of computation and communication. We are working to uncover the abilities of quantum computers to solve hard problems. We are investigating the capacities of noisy quantum channels. We are applying techniques of state and process tomography to uncover the quantum limits of detection and imaging.

2. Superconducting Quantum Computers

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Professor Seth Lloyd, Professor Leonid Levitov, Professor Terry Orlando, Professor J.E. Mooij, Haidong Yuan, William Kaminsky

Superconducting systems present a variety of opportunities for quantum information processing. We are currently collaborating with Delft and NEC to investigate mechanisms of errors and decoherence in superconducting quantum bits and are designing experiments to demonstrate quantum logic operations, quantum algorithms and quantum entanglement using superconducting systems. We have presented novel designs for quantum computers that compute while remaining in their ground state. We have shown how adiabatic methods can be used to perform coherent quantum computation. We have developed techniques for the control of complex superconducting circuits and are applying them to two- and three-qubit devices.

This year we made progress in uncovering limits to adiabatic quantum computation. We are applying methods of superconducting quantum computing to investigate transport processes in biological systems.

3. Quantum Coherence in Biological Systems

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DARPA, ENI, MITEI

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Recent evidence from femtosecond spectroscopy shows that quantum coherence plays an important role in energy transport in photosynthesis. We have shown that photosynthetic bacteria employ a variety of sophisticated techniques, including quantum coding, to protect excitons in the energy transport process and to enhance the effiiciency of energy transport. Dr. Lloyd is the PI on a $1.3M DARPA QuBE grant to investigate the effects of quantum coherence in energy transport and sending in biological systems.

Publications

Journal Articles Published

C. Weedbrook, S. Pirandola, S. Lloyd, T.C. Ralph, “Quantum cryptography approaching the classical limit,” *Phys. Rev. Lett.* **105**, 110501 (2010); arXiv:1004.3345.

A. Hamma, F. Markopopoulou, S. Lloyd, F. Caravelli, S. Severini, K. Markstrom, “A quantum Bose-Hubbard model with evolving graph as toy model for emergent spacetime,” *Phys. Rev. D* **81**,104032 (2010); arXiv:0911.5075.

A. Casaccino, S. Lloyd, S. Mancini, S. Severini, “Quantum state transfer through a qubit network with energy shifts and fluctuations,” *Int. J. Quant. Inf.* **7**, 1417 (2009); arXiv:0904.4510.

S. Pirandola, S.L. Braunstein, S. Lloyd, “On the security and degradability of Gaussian channels,” *Lecture Notes in Computer Science* **5906**, 47 (2009); arXiv:0903.3441.

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Journal Articles, Submitted for Publication

S. Lloyd, L. Maccone, R. Garcia-Patron, V. Giovannetti, Y. Shikano, “The quantum mechanics of time travel through post-selected teleportation,” arXiv:1007.2615, submitted to Physical Review A.

S. Lloyd, M. Mohseni, “Symmetry-enhanced supertransfer of delocalized quantum states,” arXiv:1005.2219, to appear in New Journal of Physics.

S. Lloyd, L. Maccone, R. Garcia-Patron, V. Giovannetti, Y. Shikano, S. Pirandola, L.A Rozema, A. Darabi, Y. Soudagar, L.K. Shalm, A.M. Steinberg, “Closed timelike curves via post-selection: theory and experimental demonstration,” arXiv:1005.2219, submitted to Physical Review Letters.