Information Flow in Quantum Algorithms: Structure and Optimization

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Quantum algorithms are often described in terms of computational speedups, query complexity, or circuit constructions. In this talk I will take a complementary, more physical point of view: a quantum algorithm is a controlled process in which information about an unknown object is encoded, transported through a quantum state, and finally extracted by measurement. From this perspective, the central question is not only whether the answer can be obtained, but how information flows through the quantum system, which correlations carry it, and how this flow can be optimized. I will first discuss oracle problems as communication tasks, where the hidden property of an oracle plays the role of a message encoded into a quantum system. This reformulation makes mutual information a natural figure of merit and reveals a connection between optimal measurements, quantum correlations, and coherence [1]. I will then show how the same idea can be used operationally in quantum Hamiltonian learning [2]: in Quantum Likelihood Estimation, one can choose the initial state, evolution time, and measurement basis so as to maximize the expected information gain about the unknown Hamiltonian. This leads to a physically motivated optimization principle for adaptive quantum experiments. Finally, I will briefly connect this viewpoint to hidden subgroup algorithms, emphasizing the role of the quantum Fourier transform as a mechanism for making latent group-theoretic information observable [3]. Overall, the talk will present information flow as a unifying physical language for understanding both the structure and optimization of quantum algorithms.

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[1] A. Te'eni, Z. Schwartzman-Nowik, M. Nowakowski, P. Horodecki, and E. Cohen, arXiv:2409.15549.

[2] A. Levi, Z. Ossi, E. Cohen, and A. Te'eni, Quantum Sci. Technol. 11 (2026) 015029.

[3] A. Te'eni, Y. Oz, and E. Cohen, arXiv:2510.10538.