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Exponential improvement in precision for Hamiltonian-evolution simulation

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We provide a quantum algorithm for simulating the dynamics of sparse Hamiltonians with complexity sublogarithmic in the inverse error, an exponential improvement over previous methods for Hamiltonian simulation. Specifically, we show that a d-sparse Hamiltonian H can be simulated for time t with precision eps using O(T log(τ/eps)/loglog(τ/eps)) queries, where T = d^2 ||H|| t. The algorithm is also time efficient. Unlike previous approaches based on product formulas, its query complexity is independent of the number of qubits acted on and its time complexity is only logarithmic in the norm of the derivative of the Hamiltonian. Our algorithm is based on a significantly improved simulation of the continuous- and fractional-query models using discrete quantum queries, showing that the former models are not much more powerful even for very small error. We also dramatically simplify the analysis of this conversion, avoiding the need for a complex fault correction procedure. Our simplification relies on a new form of "oblivious amplitude amplification" that can be applied even though the reflection about the input state is unavailable. Finally, we prove lower bounds showing that, surprisingly, our algorithms are optimal as a function of the error.