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Constant overhead fault-tolerant quantum computation in realistic physical systems

Juan Pablo Bonilla Ataides

Harvard University

Abstract

Quantum low-density parity-check (qLDPC) codes can achieve high encoding rates and good code distance scaling, providing a promising route to low-overhead fault-tolerant quantum computing. However, the long-range connectivity required to implement such codes makes their physical realization challenging. Here, we propose a hardware-efficient scheme to perform fault-tolerant quantum computation with high-rate qLDPC codes on reconfigurable atom arrays, directly compatible with recently demonstrated experimental capabilities. Our approach utilizes the product structure inherent in many qLDPC codes to implement the non-local syndrome extraction circuit via atom rearrangement, resulting in effectively constant overhead in practically relevant regimes. We prove the fault tolerance of these protocols, perform circuit-level simulations of memory and logical operations with these codes, and find that our qLDPC-based architecture starts to outperform the surface code with as few as several hundred physical qubits at a realistic physical error rate of 1e–3. We further find that less than 3000 physical qubits are sufficient to obtain over an order of magnitude qubit savings compared to the surface code, and quantum algorithms involving thousands of logical qubits can be performed using less than 105 physical qubits. Our work paves the way for explorations of low-overhead quantum computing with qLDPC codes at a practical scale, based on current experimental technologies.