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Low-cost quantum error correction using looped pipelines

Zhenyu Cai

University of Oxford

Abstract

Noise in quantum computers is the single biggest obstacle in their practical realisation, which needs to be tackled using quantum error correction (QEC). However, even the leading QEC code – surface codes – faces many practical challenges like large spatial overhead for storing quantum information and large space-time overhead for logical gates. In order to achieve large-scale fault-tolerant quantum computation, we explore a concept called 'looped pipelines' which permits one to obtain many of the advantages of a 3D lattice while operating a strictly 2D device. The concept leverages qubit shuttling, a well-established feature in platforms like semiconductor spin qubits and trapped-ion qubits. The looped pipeline architecture has similar hardware requirements to other shuttling approaches, but can process a stack of surface codes instead of just one, allowing for higher qubit density and much more efficient logical gates. We find that this can achieve a cost saving of up to a factor of ~ 80 in the space-time overhead for magic state distillation (and a factor of ~ 200 with modest additional hardware). Using numerical modelling and experimentally-motivated noise models we verify that the looped pipeline approach provides these benefits without significant reduction in the code's threshold. In addition, we can also use looped pipeline to remove almost all the space-time costs in implementing virtual distillation, which is one of the leading quantum error mitigation schemes.