A Novel Union-Find-Based Decoding Algorithm for Scalable Real-Time Syndrome Processing in Quantum Error Correction

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Fault tolerant quantum computing (FTQC) provides huge promises for industrial and scientific progress, such as in drug discovery and cryptography. Part of the technology stack required for FTQC is a robust decoder able to detect and correct errors from ancillary syndrome measurements faster than they come in, as to avoid a detrimental backlog. In this work, I present a novel decoding algorithm called Cluster-As-You-Go (ClAYG). ClAYG builds upon the established Union-Find (UF) decoder but introduces a key innovation: instead of waiting for all measurement rounds to be completed, the decoder processes rounds sequentially, allowing it to operate in parallel with the measurement process. This approach has the potential to significantly improve decoding speed. To compare ClAYG with UF, two implementations were developed. The first, a slower proof-of-concept, was built using an existing framework. Encouraged by promising results, a second, high-performance implementation was developed from scratch. The two algorithms were evaluated based on their error thresholds—the physical error rate beyond which increasing the code size no longer improves logical error suppression – which were calculated using Montecarlo-sampling. The Union-Find decoder achieved the expected literature value of 2.4%, while Cluster-As-You-Go attained a threshold of 1.6%. If ClAYG enables faster decoding within the practical constraints of real quantum devices, it represents a significant step toward the feasibility of using Union-Find-based methods for real-time quantum error correction. This work provides a foundation for further exploration of parallelized decoding strategies, contributing to the broader effort of making fault-tolerant quantum computing a practical reality.

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