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tqec: A Python package for topological quantum error correction

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Summary

tqec is a Python-based open-source compiler that takes a logical-level quantum computation model represented as connected 3D primitive blocks and translates it into a detailed, fault-tolerant, physical-level circuit. The result is a `Stim` circuit with all the detailed information needed for simulation or to run on real quantum hardware. This enables both quantum algorithm designers and experimentalists to rapidly iterate and obtain exact low-level circuits, facilitating efficient performance simulation or experimental demonstration. At present, tqec is primarily centered on the surface code.

Statement of Need

Simulations of quantum computer operations in the large-scale error correction regime are currently infeasible. Building the logical `Stim` circuits is a hassle, and Monte Carlo simulations at the scale of, for example, hierarchical memory systems involving yoked surface codes, are difficult to perform exactly, C. Gidney et al. (2025). The full-scale simulations performed by `tqec` provide more accurate fault-tolerant resource estimation than empirical extrapolations.

`tqec` is designed to be used by students and researchers who seek to understand the theory of quantum error correction and experiment with scalable quantum computer system and circuit designs. A poster featuring preliminary research and an educational tutorial enabled by `tqec` have been approved for conference proceedings: Dubey & Smith (2025) and Kan et al. (2025) . A further software package has been recently built to enable better interfacing between PyZX and `tqec`: Bolanos & Fowler (2025). The functionality of the `tqec` package is based on several academic papers (Polian & Fowler (2015), A. G. Fowler et al. (2012), McEwen et al. (2023), C. Gidney et al. (2025), Kissinger & van de Wetering (2020)), and makes substantial use of Craig Gidney's `Stim` package, Craig Gidney (2021).

State of the Field

The tqec library emerged from Austin Fowler's call-to-action presentation at the Munich Quantum Software Forum (A. Fowler (2023)) which advocated for an open-source collaborative effort to build software for quantum error correction (QEC). Several software libraries have been released publicly to attempt to tackle the various challenges related to fault-tolerant compilation. Of the compiler libraries discussed in this section, tqec stands out as uniquely positioned to tackle these obstacles. Where many alternatives offer limited functionality or have fallen into disrepair, tqec is actively developed and supported by a thriving community.

To our knowledge, the `Lattice Surgery Compiler` by Watkins et al. (2024b) was the first publicly released software to compile a QASM circuit into lattice surgery operations based on the surface code. While active development on this project has ceased (Watkins et al. (2024a)), an upgraded version of the compiler was released (Leblond et al. (2024)) to enable hardware aware, resource optimized, DAG-based parallel compilation of lattice surgery instructions for the Clifford + T gate set circuits. Robertson et al. (2025) introduced another surface code lattice surgery compiler that factors in resource estimation to compile quantum computations fault-tolerantly building on the approach presented in Litinski (2019). This software extends beyond tqec by incorporating logical qubit mapping, routing, and allocation; each a critical component of a fully automated compilation pipeline. All three projects employ their own native intermediate representation and gate-level compilation strategies tailored to their research goals, limiting their flexibility. Unlike tqec, these tools do not output `Stim` circuits, which are essential for gauging the performance of Clifford computations before deploying to physical hardware. tqec directly represents lattice surgery via its native `BlockGraph` data structure, enabling both manual and automated optimization. Introducing hardware aware compilation capabilities is on the tqec roadmap and will be addressed in the future.

`Substrate Scheduler` by Liu et al. (2023) compiles fault tolerant graph states based on the formalism in Litinski (2019) weighing the tradeoffs between the speed of the computation and qubit overhead in surface code patches. `Substrate Scheduler` was designed with the goal to minimize the space-time volume of the generated fault-tolerant computation. It is limited to fault-tolerant compilation of graph states and is no longer under active development.

`Loom Design` by Entropica Labs (2025) is a software project designed to evaluate the performance of QEC protocols in general. The project contains a built-in library of QEC codes (color codes, surface codes, rotated surface codes, etc.) to implement end-to-end lattice surgery protocols. While tqec utilizes multiple spatial junction types and stretched stabilizers for hook error handling in surface codes, `Loom Design` is limited by a generic surface code layout. Compared to the `Loom Design` 3D visualizer, tqec also provides support for a comprehensive range of 3D structures enabling automated correlation surface finding.

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