Benchmarking in Encoded Magic State Injection

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For many schemes of fault-tolerant quantum computation, magic states play a core role in facilitating computation and may make up the bulk of necessary resources. In order to achieve fault-tolerance, these magic states are prepared separately and injected into the encoded computation, compensating for the gates which the code cannot perform fault-tolerantly.

The most basic of these circuits requires two encoded qubits and a magic state preparation scheme, still resulting in a fairly involved experiment for many current devices. However, these circuits will be foundational components in larger NISQ computations, and as architectures scale up in size, the performance of these injection circuits on smaller devices will indicate the challenges that larger devices on the same architecture must meet.

We investigate how physical noise gets transformed into logical noise on these injection circuits using classical simulations. We demonstrate that Pauli error models become biased at the logical level when our injection circuit is encoded in the Steane code [1, 2]. In the case of implementing $T = \sqrt[4]{Z}$, the logical error of our noisy process T biases towards Z Pauli noise. This biasing even occurs for error models where there are no Z errors at the physical level. This result is a reflection of both the injection operation and the predominant errors in logical state preparation. Beyond Pauli error models, we also investigate the impact of physical coherent noise on the logical process. Understanding exactly how physical noise is transformed through the encoding process will allow us to tailor our code and preparation routines in order to suppress the dominant physical noise of a given architecture.

[1] C. Chamberland & A. Cross, Fault-tolerant magic state preparation with flag qubits *Quantum* **3**, 143 (2019).

[2] H. Goto, Minimizing resource overheads for fault-tolerant preparation of encoded states of the Steane code *Sci. Rep.* **6**, 19578 (2016).