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Critical noise parameters for fault tolerant quantum computation

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Noise is imminent to a quantum computing process. With the help of quantum error correcting codes, the logical information in a qubit can be preserved by encoding it in a system of several physical qubits and by performing gates in a fault tolerant manner. However, it is crucial to know the noise model affecting the physical qubits, in order to estimate the error on the logical qubit and thereby the overhead required for fault tolerant quantum computation. For some specific types of quantum channels it is easy to identify a parameter of the physical channel that controls the logical error rate. However, for a realistic noise model, it is unclear which of the physical parameters are critical to the logical error rate.

In this work, we aim to determine the parameters of a single qubit channel that can tightly bound the logical error rate of the concatenated Steane code. We do not assume any a priori structure for the physical quantum channel, except that it is a completely positive trace preserving (CPTP) map. Our method of estimating the logical error rate differs significantly from the standard and computationally expensive Monte-Carlo sampling of the error distribution. We employ a technique to compute the complete effect of a physical CPTP map, at the logical level, with just one round of error correction. By such numerical simulations on random quantum channels, we have studied the predictive power of several physical noise metrics on the logical error rate, and show that, on their own, none of the natural physical metrics lead to accurate predictions about the logical error rate. We then show how machine learning techniques help us to explore which features of a random quantum channel are important in predicting its effect at the logical level.

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