Abstract

Implementing measurements on contemporary quantum computing devices is a considerable challenge. This is primarily due to pervasive noise effects and the constraints imposed by limited quantum resources such as the number of qubits and available unitary operations. However, in a wide variety of use cases, the complications engendered by these challenges can be reduced through the application of supplementary classical resources (randomness and post-processing). The principal hypothesis advanced in this dissertation contends that

> Auxiliary classical resources can be used to assess and improve the quality of the implementation of noisy quantum measurements

We offer contributions that aim to help better understand the effects of measurement noise on the performance of quantum-information protocols, as well as methods that reduce those effects. In Chapter 3 we introduce new distance measures between quantum objects (in particular, quantum measurements). We call those measures quantum average-case distances (AC distances). AC distance between a noisy measurement and its ideal model allows for quantification of the average-case performance of a noisy detector. The classical resource exploited in this context is classical *randomness*. Specifically, the AC distance between two measurements quantifies how well they can be statistically distinguished if we are given access to the random application of a certain class of random quantum circuits (circuits forming unitary 4-designs).

While the AC distance can be used to quantify the quality of the measurement's implementation, it does not provide an explicit procedure to characterize a given noisy measurement. We tackle this problem in Chapter 4, where we provide an efficient method of reconstructing certain types of local measurement noise from experimental data. The proposed method, Diagonal Detector Overlapping Tomography (DDOT), also exploits classical randomness. Moreover, we show how to use the results of DDOT to reduce the effects of readout noise on the estimation of marginal probability distributions. This is relevant, for example, in the context of the estimation of energy of local Hamiltonians. Our error-mitigation methods are classical in the sense that they are done entirely in *post-processing* of the experimental data obtained in noisy experiments.

Many of the results across the Thesis are supported by extensive numerical simulations. Furthermore, we present results of experimental implementation of noise characterization and mitigation on superconducting quantum hardware from IBM and Rigetti (Chapter 4).

The thesis consists of the following works:

1 *Operational Quantum Average-Case Distances*, F.B. Maciejewski, Z. Puchała, M. Oszmaniec, Quantum 7, 1106 (2023).

2 *Exploring Quantum Average-Case Distances: Proofs, Properties, and Examples*, F.B. Maciejewski, Z. Puchała, M. Oszmaniec, IEEE Transactions on Information Theory, vol. 69, no. 7, pp. 4600-4619 (2023).

3 *Modeling and mitigation of cross-talk effects in readout noise with applications to the Quantum Approximate Optimization Algorithm*, F.B. Maciejewski, F. Baccari, Z. Zimborás, M. Oszmaniec, Quantum 5, 464 (2021).