Unified formalism of optimal and collective quantum tomography

Shuixin Xiao[1]

[1]*School of Engineering, Australian National University, ACT 2601, Australia*

Quantum tomography is a standard technique for characterizing, benchmarking and verifying quantum systems/devices and plays a vital role in developing quantum technology and understanding the foundations of quantum mechanics. Achieving high accuracy is a fundamental task in quantum tomography, and elucidating the optimality condition remains a core open problem. Here, we present a unified characterization of the estimation accuracy using infidelity metric in quantum state, detector and process tomography. Under this framework, we establish a sufficient and necessary condition for achieving the optimal infidelity scaling $O(1/N)$ after consuming N state copies, which provides a useful guideline for designing optimal tomography algorithms. We develop algorithms with provably optimal infidelity scalings for quantum state, detector and process tomography. Numerical results and quantum optical experiment demonstrate the effectiveness of the proposed methods, with the experiments for the first time to reach the optimal infidelity scaling in ancilla-assisted process tomography.

Another appealing approach to quantum state tomography is collective quantum state tomography, where measurements are performed collectively on multiple identically prepared state copies. We propose a closed-form solution and provide an analytical characterization of its computational complexity and mean squared error scaling. Additionally, we reformulate the problem as a sum-of-squares optimization with semialgebraic constraints. We validate our algorithms using two-copy collective experimental data, where entangled measurements extract state purity information. Compared to previous methods, our algorithms achieve lower errors and approach the collective error bound by leveraging purity information more efficiently.