Simulating the Characterization of Qubits with Quantum State Tomography Software

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Characterizing quantum bits (qubits) is an essential aspect of quantum computing and quantum information science because successful quantum computation requires high fidelity preparation, manipulation, and measurement of qubits. However, fully characterizing qubits with a single measurement is impossible. Therefore, quantum state tomography (QST) – estimating a quantum state using a collection of measurements of copies of that state – is necessary to characterize experimental quantum devices.

Moreover, imperfections in experiments and the inherent randomness of quantum systems complicate qubit tomography. To improve understanding of state tomography and assist in experimentation, I developed a software package to simulate QST for a single qubit.

A qubit's state can be visualized as a point on the surface or interior of a sphere, called a Bloch sphere. The state determines probabilities of observing spin-up or spin-down when measured along a specific axis of the sphere. These axes form an informationally complete set because any quantum state can be uniquely determined from the frequencies with which spin-up and spin-down are observed along those axes. Repeated measurements of copies of that state provides the data that we use to estimate the state. Two estimation strategies were studied, Linear Inversion[1] and Diluted Maximum Likelihood Estimation[2] (MLE).

Currently, the quantum information community does not have a reliable method for attributing uncertainties to qubit state estimates. Numerically simulating state tomography allows bootstrapped samples to be generated and confidence intervals to be created in a setting where the true state is known. We use our initial state estimate to generate a bootstrapped data sample, a collection of measurements created under the assumption that the initial estimate is the true quantum state. Bootstrapped measurement data is sampled to generate several state estimates, ultimately producing confidence intervals for state fidelity. With repeated experimentation, we can test the efficacy of these intervals in capturing the actual fidelity or other properties of a qubit state estimate.

Future additions to this software package include the ability to run state tomography on quantum systems larger than one qubit. Functionality to incorporate empirical data and ancillary solving methods into simulations may also be created.

[1] Glancy, S., Knill, E., & Girard, M. (2012). Gradient-based stopping rules for maximum-likelihood quantum-state tomography. *New Journal of Physics*, *14*(9), 095017.

[2] Kaznady, M. S., & James, D. F. (2008). Quantum State Tomography: The best is the enemy of good enough. *arXiv preprint arXiv:0809.2376*.