Machine Learning Approaches for Debugging a Quantum Computer

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Abstract

In the past decades, the mounting evidence that quantum algorithms can solve specific tasks with efficiency beyond the capability of a state-of-the-art classical computer has attracted tremendous interest in the field. A turning point was Shor's algorithm for prime factorization, a polynomial quantum algorithm solving a problem that is hard for classical computers. Various physical systems for quantum computation have already been developed, and hybrid quantum algorithms, which aim at solving optimization problems more efficiently, can run on existing noisy intermediate-sized quantum devices. However, a fullsize general-purpose quantum computer is still out of reach. As the size and complexity of the quantum computer grow, more sophisticated techniques for calibration and evaluation of their performance are required in order to develop fault-tolerant devices. Quantum state tomography (QST) is a technique for the verification of a quantum computer, which allows for the reconstruction of a given quantum state from measurement data. It is known nown as the "gold standard" for the verification of a quantum device. QST is however computationally costly, which makes it infeasible for a system larger than few qubits. Efficient QST would have a high impact in the attempts to create a generalpurpose quantum device. One aspect of the efficiency of the QST procedure depends on the choice of the measurement scheme, which determines the number of measurements one needs to do in order to perform the QST. Finding a measurement scheme that minimizes the number of required measurements can be formulated as an optimization problem. Here we develop and investigate various optimization and machine learning methods with the goal of finding measurement schemes, which minimize the number of measurements needed. By using prior knowledge of the landscape of potential solutions, such as particular symmetries and invariances, one could improve the exploration of the search space and find the optimal measurement schemes. Geometric deep learning approaches combined with reinforcement learning present us with a powerful toolset for multidimensional landscapes fo the search space with invariances and equivariances. Various approaches of reinforcement learning demonstrate its usefulness for gate sequence optimization in the context of QST. Methods of deep geometric learning for gate sequence optimization are investigated also for exchange-only quantum computaton, where each logical qubit is encoded using three physical spin qubits, with the goal of protecting from noise generated by external magnetic fields.