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Promotionsverfahren von **Herrn M.Sc. Raphael Amadeus Brieger**
Auslage der Dissertation und Gutachten sowie Termin der mündlichen Prüfung
Anlage: Einseitige Zusammenfassung der Dissertation

Sehr geehrte Damen und Herren,

in dem oben genannten Promotionsverfahren wird die Annahme der Dissertation

Characterizing quantum hardware with imperfect control

von den Berichterstattenden Prof. Dr. M. Kliesch und Prof. Dr. D. Bruß beantragt. Sie kann zusammen mit den Gutachten in der Zeit

vom 02.06.2024 bis 13.06.2024

eingesehen werden. Bitte wenden Sie sich zur Einsicht an das Promotionsbüro (promotionmnf@hhu.de).

Einsprüche gegen diese Dissertation können nur zwei Tage nach der vorgenannten Frist geltend gemacht werden. Erfolgt kein Einspruch, so gilt die Dissertation als angenommen (§ 7 Ziffer (5) PO).

Sofern die Dissertation angenommen wird, findet die mündliche Prüfung am

18.06.2024 um 14:30 Uhr

im Raum **25.32.03.51** statt. Als Prüferinnen bzw. Prüfer sind vorgesehen:

Prof. Dr. G. Pretzler, Prof. Dr. H. Löwen und Prof. Dr. R. Egger.

Die Öffentlichkeit ist bei der Befragung zugelassen.

Mit freundlichen Grüßen
im Auftrag

Daniela Schleiffer

Kurzfassung der Dissertation

Titel: Characterizing quantum hardware with imperfect control
Autor: Raphael Brieger

Quantum computers promise to solve a variety of computational problems faster than existing classical computers, among them the factorization of prime numbers, unstructured database search and the simulation of quantum chemistry systems. We are right in the era where actual computational advantages of current early quantum computers are demonstrated, albeit not yet in computation tasks of practical interest. In order to continuously improve these systems, reliable and efficient verification of their correct operation, as well as methods to characterize remaining error sources are vital.
The ongoing maturing process of quantum computers comes with tighter demands on characterization and verification tasks. Not only is there an increased need for efficiency in the number of measurements and classical post-processing time, but progressively smaller errors need to be resolved as well. In order to achieve the latter task and to estimate ('learn') properties of quantum systems in a reliable way, errors in the measurement process due to imperfect control need to be taken into account. For this reason, self-consistent protocols were proposed, which not only characterize individual quantum operations (gates), but learn a mathematical a model of the system and its dynamics as a whole. This approach is known as gate set tomography, and it has become a standard technique to characterize and improve quantum experiments. Unsurprisingly, learning a model of the whole system comes at a huge cost in the measurement and classical post-processing effort. For this reason it has only been applied sparingly and to small subsystems.
The main contribution of this thesis is the development of a new data processing framework for gate set tomography, which allows us to construct a mathematical model of a subsystem from few random measurement settings with a reduced post-processing time compared to the previous state-of-the-art method. We achieve this by learning a compressed model, which reduces the number of parameters that need to be learned, while still capturing the most relevant degrees of freedom. Since the underlying optimization problem for learning a compressed gate set model is highly non-trivial to solve, we develop a new optimization algorithm on the Riemannian manifold of physical gate sets, which uses techniques from machine learning to arrive at an optimal point. We make this algorithm accessible through a publicly available Python package and use it to accurately learn a full description of a two-qubit trapped ion system.
A different task that we focus on in this thesis is the estimation of physical properties of a quantum state, which we assume can be repeatedly prepared on the system. Previous works showed that using randomized measurements, numerous properties of the quantum state can be estimated, while the number of required measurements remains independent of the system size. Thus far, errors introduced due to imperfect control in the implementation of randomized measurements were insufficiently accounted for. In this thesis we analyze the effects of general gate-dependent noise on the randomized measurement protocol. Central to our results are analytical bounds, which show that for most properties of interest, the randomized measurement protocol is resilient against general gate-dependent noise. However, we also find that certain properties are more difficult to estimate, since for those properties there are noise models under which errors are exponentially amplified in the estimation procedure.
Overall, the results of this thesis contribute to bringing important characterization protocols for early quantum computers significantly closer to current experimental requirements.

Düsseldorf, 14.3.2024