QI 1: Certification and Benchmarking of Quantum Systems

Time: Monday 11:00–12:30 Location: HS IX

Invited Talk QI 1.1 Mon 11:00 HS IX

Sound and Efficient Quantum System Quizzing — •Mariami Gachechiladze[1], Jan Nöller[1], Martin Kliesch[2], and Nikolai Miklin[2] — [1]TU Darmstadt, Darmstadt, Germany — [2]TUHH, Hamburg, Germany

The rapid advancement of quantum hardware necessitates the development of reliable methods to certify their correct functioning. Existing certification techniques often fall short: they are either prohibitively expensive and rely on flawless state preparation and measurement (SPAM), or they fail to provide robust guarantees. While current SPAM-robust methods are complete, they lack soundness, meaning they do not ensure the correct implementation of quantum devices. In our recent work, we introduce quantum system quizzing, a simple yet sound certification protocol that enables the certification of entire quantum models in a black-box scenario under the dimension assumption. The protocol identifies deterministic input-output correlations of the ideal target model, which are tested during each round. This black-box approach inherently eliminates SPAM errors. For single-qubit models, we derive rigorous sampling complexity guarantees. Most notably, we establish an inverse linear relationship between average gate infidelities and the number of successful protocol rounds, making the method highly practical for contemporary experimental setups. For multi-qubit quantum computers, we provide sound certification proof in the infinite statistics regime and discuss the methods to derive sample complexity results in the finite statistics regime.

QI 1.2 Mon 11:30 HS IX

Self-testing of memory-bounded quantum computers — •Jan Nöller[1], Nikolai Miklin[2], Martin Kliesch[2], and Mariami Gachechiladze[1] — [1]TU Darmstadt — [2]TU Hamburg

The rapid advancement of quantum computers makes it particularly important to develop methods for certifying their correct functioning. In a single-device setup, we propose a simple protocol called quantum system quizzing. This protocol achieves self-testing of an entire quantum model given by state preparation, gates, and measurement in a black-box scenario under the dimension assumption only. Due to the self-testing approach, this certification method is inherently free of state preparation and measurement errors.

The protocol is fundamentally based on testing deterministic input-ouput correlations which have been previously identified to be chracteristic for the targeted system. These input-output relations are tested on a quantum computer in each protocol round.

A particular challenge here is to recover the tensor-product structure of subsystems purely from the input-output relations, since space-like separation cannot be imposed in such a black-box scenario. Our work is the first to solve this issue without relying on computational assumptions.

For the simplest case of a single-qubit model, we additionally derive rigorous sampling complexity guarantees. Most interestingly, we prove an inverse linear relation between the average gate infidelities and the number of successful rounds in the protocol, rendering our method highly relevant for current experimental setups.

QI 1.3 Mon 11:45 HS IX

Scalable correlated readout error mitigation without randomized measurements — •Adrian Skasberg Aasen[1,2], Andras Di Giovanni[3], Hannes Rotzinger[3], Alexey Ustinov[3], and Martin Gärttner[2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Jena, Germany — [3]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany

Recently, quantum error mitigation techniques have increasingly focused on addressing readout errors. Key attributes sought in these protocols include scalability, practicality, and assumption-free noise models. Among the favored approaches are those utilizing randomized measurements. Despite their favorable scaling in sample complexity, randomized measruemnets are complex to implement. We present an alternative method which avoids randomized measurements, is scalable to large quantum systems, uses only single-qubit Pauli measurements, and captures a very broad class of correlated noise models. It builds on a robust readout error mitigated state tomograpy [1] and makes it scalable by using an efficient characterization of correlated POVMs. The method reconstructs overlapping readout error mitigated reduced density matrices, which gives access to arbitrary low- to medium-order correlators. We demonstrate that they are sample efficient with noisy POVMs extracted from superconducting qubit experiments.

[1] Aasen, A.S. et al. Readout error mitigated quantum state tomography tested on superconducting qubits. Commun Phys 7, 301.

QI 1.4 Mon 12:00 HS IX

Shadow-based characterization of superconducting quantum processors — •Pedro Joaquin Weiler Perez, Florentin Reiter, Thomas Wellens, and Martin Koppenhöfer — Fraunhofer Institut für Angewandte Festkörperphysik (IAF), Freiburg im Breisgau, Deutschland

Characterization techniques for quantum processors have become an important tool to improve quantum gate operations, qubit initialization, and read-out processes. Moreover, efficient characterization techniques guide the development of efficient quantum-error-correction and quantum-error-mitigation strategies, and they allow one to build error models for a more realistic simulation of quantum algorithms. For these different purposes, a variety of benchmarking methods has been developed (e.g., randomized benchmarking tools as well as quantum state, process, and gate-set tomography). Typically, characterization techniques that provide a larger level of detail come at the cost of a higher computational complexity. Recently, it has been pointed out that one can extract many relevant features of a quantum system without having to perform a full tomography. So-called classical shadow tomography emerged as a promising and flexible new characterization technique with provably efficient sampling. In this talk, we discuss our approach to shadow-based characterization of quantum states and quantum processes on superconducting quantum processors

QI 1.5 Mon 12:15 HS IX

Detecting high-dimensional time-bin entanglement in a fiber-loop architecture — •Niklas Euler and Martin Gärttner — Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Many quantum-communication protocols require the distribution of entanglement between the different participating parties. One example of such a protocol is quantum key distribution (QKD), an application which has matured to the brink of commercial use in recent years. However, difficulties remain, especially with noise resilience and channel capacity in long-distance communication. One way to overcome these problems is to use high-dimensional entanglement, which has been shown to be more robust to noise and facilitates higher secret-key rates. It is therefore important to have access to certifiable high-dimensional entanglement sources to confidently implement advanced QKD protocols. Here, we investigate a fiber-loop setup that allows the scalable creation of time-bin entanglement and its certification on the same device. Our certification method builds on previous proposals for the certification of angular-momentum entanglement in photon pairs. In particular, measurements in only two experimentally accessible bases are sufficient to obtain a lower bound on the entanglement dimension for both two- and multiphoton quantum states. Numerical simulations show that the method is robust against typical experimental noise effects and works well even with limited measurement statistics, thus establishing time-bin encoded photons as a viable candidate for high-dimensional QKD.