QI 10: Certification and Benchmarking of Quantum Systems

Time: Thursday 10:45–12:30 Location: H5

QI 10.1 Thu 10:45 H5

Machine-learning framework for customized optimal quantum state tomography — •Violeta Ivanova-Rohling[1,2,3], Guido Burkard[1], and Niklas Rohling[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Fastest quantum state tomography (QST) schemes which reach a desired precision are of high practical relevance. Rarely, analytical solutions are known, e.g. non-degenerate projective measurements whose eigenbases form a complete set of mutually unbiased bases (MUBs) [1]; mutually unbiased subspaces (MUSs) constructed from a complete set of MUBs if measuring one out of N qubits [2]. Our flexible scheme finds numerically an optimized QST measurement set given the system's specifications, e.g. for a qubit-qutrit system (e.g. NV center in diamond), a QST measurement set closely approximating MUSs [3]. Furthermore, machine learning approaches now for individual rank-1 measurements in eight dimensions [4] outperform standard numerical methods yielding high-performing measurement sets with complex structure and symmetries. Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund, contract No KP-06-PM 32/8

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Bodmann, Haas, Proc. Amer. Math. Soc. 146, 2601 (2018).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.
[4] Ivanova-Rohling, Rohling, Cyb. Inf. Technol. 20 (6), 61 (2020).

QI 10.2 Thu 11:00 H5

Optimal quantum state tomography measurement set under noise — Violeta Ivanova-Rohling[1,2,3], •Niklas Rohling[1], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Quantum state tomography (QST) is an essential yet time-consuming tool for the verification of a quantum device. An informaion-theory-based quality measure for QST measurement sets allowed Wootters and Fields to prove that a set of n+1 mutually unbiased bases is ideal for QST in an n-dimensional system with non-degenerate measurements [1]. The same quality measure can be used to obtain a numerically optimized QST measurement set for degenerate measurements, e.g. for measurements projecting on one-dimensional [2] or n/2-dimensional subspaces [3]. Here, we add a noise-dependent correction factor to the quality measure. We find optimal QST measurement schemes for two qubits measured in a standard basis preceded by a gate sequence including noisy two-qubit gates.

Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund,contract No KP-06-PM 32/8.

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Ivanova-Rohling, Rohling, PRA 100, 032332 (2019).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.

QI 10.3 Thu 11:15 H5

Wigner state and process tomography on near-term quantum devices — •Amit Devra[1,2], Niklas J. Glaser[3,4], and Steffen J. Glaser[1,2] — [1]Technische Universität München, Department of Chemistry, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]Technische Universität München, Department of Physics, 85748 Garching, Germany — [4]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany

We present a scanning-based tomography approach in the context of finite-dimensional Wigner representations on near-term quantum devices. These representations completely characterize and visualize operators using shapes assembled from linear combinations of spherical harmonics [1]. The shapes can also be experimentally recovered by measuring the expectation value of rotated axial tensor operators. Here, we present the translation of a nuclear magnetic resonance (NMR) based experimental approach for state tomography [2] and known quantum propagators (gates) [3] for general quantum computers based on projective measurements and showcase results of simulations and experiments on the IBM quantum experience platform.

References: 1. A. Garon, R. Zeier, and S. J. Glaser, Phys. Rev. A 91, 042122 (2015). 2. D. Leiner, R. Zeier, and S. J. Glaser, Physical Review A 96, 063413 (2017). 3. D. Leiner and S. J. Glaser, Physical Review A 98, 012112 (2018).

QI 10.4 Thu 11:30 H5

Gate set tomography via Riemannian optimization — •Raphael Brieger[1], Martin Kliesch[1], and Ingo Roth[2] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Quantum research centre, Technology Innovation Institute, Abu Dhabi, UAE

Flexible characterization techniques that quantify and identify noise under realistic assumptions are crucial for the development of near term quantum computers. Gate set tomography (GST) has been proposed as a technique that simultaneously extracts tomographic information on an entire set of quantum gates, the state preparation and the measurements under minimal assumptions. We argue that the problem of reconstructing the gate set subject to physicality constraints, such as complete positivity, can naturally be cast as an optimization problem on the complex Stiefel manifold. We develop a second order manifold optimization algorithm that allows us to perform GST accurately from random circuit data. In contrast to traditional approaches our algorithm does not need a structured gate set and an elaborate circuit design to perform GST, while matching the performance of state of the art methods. Furthermore, it can naturally include low-rank constraints on the gate set in order to reduce the scaling problems inherent in quantum process tomography.

QI 10.5 Thu 11:45 H5

Certifying multiparticle entanglement with randomized measurements — •Andreas Ketterer[1], Satoya Imai[2], Nikolai Wyderka[3], and Otfried Gühne[2] — [1]University of Freiburg, Freiburg, Germany — [2]University of Siegen, Siegen, Germany — [3]Heinrich Heine University Düsseldorf, Düsseldorf, Germany

We consider statistical methods based on finite samples of locally randomized measurements in order to certify different degrees of multiparticle entanglement in intermediate-scale quantum systems. We first introduce hierarchies of multi-qubit criteria satisfied by states which are separable with respect to partitions of different size, involving only second moments of the underlying probability distribution. Then, we analyze in detail the statistical error of the estimation in experiments and show how to infer the statistical significance based on large deviation bounds. In this way we are able to characterize the measurement resources required for the certification of multiparticle correlations, as well as to analyze given experimental data.

QI 10.6 Thu 12:00 H5

Generalizing optimal Bell inequalities — •Fabian Bernards and Otfried Gühne — Universität Siegen, Siegen, Germany

Bell inequalities are central tools for studying nonlocal correlations and their applications in quantum information processing. Identifying inequalities for many particles or measurements is, however, difficult due to the computational complexity of characterizing the set of local correlations. We develop a method to characterize Bell inequalities under constraints, which may be given by symmetry or other linear conditions. This allows to search systematically for generalizations of given Bell inequalities to more parties. As an example, we find all possible generalizations of the two-particle inequality by Froissart [Il Nuovo Cimento B64, 241 (1981)], also known as I3322 inequality, to three particles. For the simplest of these inequalities, we study their quantum mechanical properties and demonstrate that they are relevant, in the sense that they detect nonlocality of quantum states, for which all two-setting inequalities fail to do so.

QI 10.7 Thu 12:15 H5

When can a quantum measurement be regarded as happened? — •Zhen-Peng Xu, Jonathan Steinberg, Hai Chau Nguyen, and Otfried Guehne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

Whether measurements in quantum mechanics can be regarded as absolute events is at the center of the debates in the foundation of quantum mechanics, which have been recently shown to be deeply linked to the concept of Wigner friends as well as that of Bell nonlocality. We argue that, the subtlety is not at the interaction between the measurement device and the system, rather at how the outcomes are perceived. In particular, we show that even regarding measurements of which the outcomes are already partially read as absolutely happens, when combined with the assumptions of the so-called locality and no superdeterminism, is also incompatible with quantum mechanics at its universal validity. This shares also the spirit in Lüders rule of measurements in quantum mechanics, as well as Peres' argument for contextuality.