QI 29: Quantum Information: Concepts and Methods I

Time: Thursday 11:00–13:15 Location: HS IV

Invited Talk QI 29.1 Thu 11:00 HS IV

Measurement-induced entanglement and complexity in shallow 2D quantum circuits — •Max McGinley[1], Wen Wei Ho[2], and Daniel Malz[3] — [1]Cambridge University, UK — [2]NUS, Singapore — [3]University of Copenhagen, Denmark

There has been a great deal of recent interest in understanding how measurements can influence the dynamics of entanglement in many-body systems. In this talk, I will elucidate how long-ranged entanglement can be generated by measuring states prepared by constant-depth 2D quantum circuits, and discuss implications for the complexity of random circuit sampling. We introduce a new theoretical technique, based on ideas from multi-user quantum Shannon theory, which allows us to establish a rigorous lower bound on the amount of entanglement generated by measurements in this setting. Our method avoids the so-called replica approach—the main tool employed for studying such problems so far—which gives concrete results only in the simplest of scenarios. Using this technique, we prove a recent conjecture about generic (random) 2D shallow circuits followed by measurements: Namely, that above some $O(1)$ critical depth, extensive long-ranged measurement-induced entanglement is produced, even though the pre-measurement state is strictly short-ranged entangled. As a consequence of this result, we establish strong evidence that sampling from generic shallow-depth quantum circuits yields a quantum advantage, and analogously that contracting random 2D tensor networks is classically hard above a constant critical bond dimension.

QI 29.2 Thu 11:30 HS IV

Learning Feedback Mechanisms for Measurement-Based Variational Quantum State Preparation — •Daniel Alcalde Puente[1,2] and Matteo Rizzi[1,2] — [1]Forschungszentrum Jülich, Institute of Quantum Control, Peter Grünberg Institut (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany

This work introduces a self-learning protocol that incorporates measurement and feedback into variational quantum circuits for efficient quantum state preparation. By combining projective measurements with conditional feedback, the protocol learns state preparation strategies that extend beyond unitary-only methods, leveraging measurement-based shortcuts to reduce circuit depth. Using the spin-1 Affleck-Kennedy-Lieb-Tasaki state as a benchmark, the protocol learns high-fidelity state preparation by overcoming a family of measurement induced local minima through adjustments of parameter update frequencies and ancilla regularization. Despite these efforts, optimization remains challenging due to the highly non-convex landscapes inherent to variational circuits. The approach is extended to larger systems using translationally invariant ansätze and recurrent neural networks for feedback, demonstrating scalability. Additionally, the successful preparation of a specific AKLT state with desired edge modes highlights the potential to discover new state preparation protocols where none currently exist. These results indicate that integrating measurement and feedback into variational quantum algorithms provides a promising framework for quantum state preparation.

QI 29.3 Thu 11:45 HS IV

Stabilizer entropies are monotones for magic-state resource theory — •Lorenzo Leone and Lennart Bittel — FU Berlin

Magic-state resource theory is a powerful tool with applications in quantum error correction, many-body physics, and classical simulation of quantum dynamics. Despite its broad scope, finding tractable resource monotones has been challenging. Stabilizer entropies have recently emerged as promising candidates (being easily computable and experimentally measurable detectors of nonstabilizerness) though their status as true resource monotones has been an open question ever since. In this Letter, we establish the monotonicity of stabilizer entropies for $\alpha \geq 2$ within the context of magic-state resource theory restricted to pure states. Additionally, we show that linear stabilizer entropies serve as strong monotones. Furthermore, we extend stabilizer entropies to mixed states as monotones via convex roof constructions, whose computational evaluation significantly outperforms optimization over stabilizer decompositions for low-rank density matrices. As a direct corollary, we provide improved conversion bounds between resource states, revealing a preferred direction of conversion between magic states. These results conclusively validate the use of stabilizer entropies within magic-state resource theory and establish them as the only known family of monotones that are experimentally measurable and computationally tractable.

QI 29.4 Thu 12:00 HS IV

Channels and Dynamics Are Almost Always Diagonalizable — •Frederik vom Ende — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

While the Choi matrix of a quantum channel can always be diagonalized—even unitarily—it remains a surprisingly common misconception that the same is true for the channel itself (or, equivalently, for its representation matrix in the standard basis). To clarify this, we provide simple examples of channels that exhibit non-trivial Jordan blocks. The main contribution of this work then is a proof of the statement: *"The collection of all elements of $\mathcal{S}$ that have only simple eigenvalues is dense in $\mathcal{S}$"* for various sets $\mathcal{S}$, including: all quantum channels, unital channels, positive trace-preserving maps, Lindbladians (GKSL-generators), and time-dependent Markovian channels. In particular, this result demonstrates that any element from each of these sets can be approximated to arbitrary precision by diagonalizable elements within the same set.

QI 29.5 Thu 12:15 HS IV

Information processing without directional reference — •Konrad Szymański[1] and Fynn Otto[2] — [1]Research Center for Quantum Information, Bratislava — [2]Universität Siegen, Siegen

If a quantum operation commutes with a group of transformations, it is called group-covariant. In practical scenarios, the unknown group transformation may contribute to noise, represent a parameter to be estimated, or intentionally scramble information. In all these cases, there exist nontrivial operations which can be applied before or after the transformation with the same final result. Here, we present the recent observations related to SU(2) covariance. This group can be interpreted as physical spin rotations or passive 2-mode optical interferometry. We demonstrate how to characterize the states accessible with SU(2)-covariant operations, and discuss the applicability of this theory to quantum information processing tasks, including a variant of quantum key distribution performed without a shared reference frame, and probabilistic amplification of interferometer sensitivity.

QI 29.6 Thu 12:30 HS IV

Towards constructing a parity interferometer — •Freyja Ullinger, Kaisa Laiho, and Matthias Zimmermann — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

In continuous-variable quantum information [1], it is important to characterize quantum states in order to verify the quality of the preparation and to test the output of protocols [2]. For this purpose, we apply the quantum-mechanical parity operator which enables the reconstruction of the phase-space representation of a quantum state [3,4]. However, the implementation of a parity measurement is a subtle issue as many existing schemes are restricted to the particular sets of states to be probed.

In this talk, we present a scheme for parity measurements independent of the physical quantum system. In particular, we reveal the key components necessary for the construction of a parity interferometer. The output of our device measures the parity of a general initial state. We further exploit possible implementations and discuss limitations in such experimental arrangements.

[1] A. L. Braunstein und A. K. Pati, Quantum Information with Continuous Variables (Kluwer Academic Publishers, Dordrecht, 2001).

[2] A. I. Lvovsky and M. G. Raymer, Rev. Mod. Phys. **81**, 299 (2009).

[3] A. Royer, Phys. Rev. A **15**, 449 (1977).

[4] F. Ullinger, 'Interference effects in quadratic potentials', Master's thesis (Ulm University, Ulm, 2022).

QI 29.7 Thu 12:45 HS IV

Symmetry analysis of Two-Local Quantum Spin Dynamics — •Roberto Gargiulo[1,2] and Robert Zeier[1] — [1]Forschungszentrum

Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]University of Cologne, Institute for theoretical physics (THP), 50937 Cologne, Germany

Fundamental tools in the study of dynamics of quantum systems are Lie groups and Lie algebras, which have various applications: In the context of quantum control a Lie-theoretic approach can provide answers to reachability and simulability. In addition to reachability, the knowledge of the Lie algebras corresponding to the given ansätze is necessary for understanding optimization problems in variational quantum algorithms. In many-body systems, these tools lead to a systematic description of physical models based on dynamical properties and in special cases to classical simulability.

We build upon recent work (see [1, 2, 3]), by providing a structured study and classification of Lie algebras obtained by interactions of pairs of qubits with given graph connectivity. Specifically, we consider certain sums of Pauli strings as generators, whereas previous work mainly focused on dynamics generated by single Pauli strings.

[1] Sujay Kazi et al. arXiv: 2410.05187 [quant-ph]
[2] Gerard Aguilar et al. arXiv: 2408.00081 [quant-ph]
[3] Efekan Kökcü et al. arXiv: 2409.19797 [quant-ph]

QI 29.8 Thu 13:00 HS IV

Quantifying the rotating-wave approximation of the Dicke model — •Leonhard Richter, Daniel Burgarth, and Davide Lonigro — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

We analytically find quantitative, non-perturbative bounds to the validity of the rotating-wave approximation (RWA) for the multi-atom generalization of the quantum Rabi model: the Dicke model. Precisely, we bound the norm of the difference between the evolutions of states generated by the Dicke model and its rotating-wave approximated counterpart, that is, the Tavis-Cummings model. The intricate role of the parameters of the model in determining the bounds is discussed and compared with numerical results. Our bounds are intrinsically state-dependent and, in particular, are significantly different in the cases of entangled and non-entangled states; this behaviour also seems to be confirmed by the numerics.