QI 29: Quantum Information: Concept and Methods II

Time: Thursday 15:00–17:45 Location: HFT-TA 441

QI 29.1 Thu 15:00 HFT-TA 441

Information and uncertainty in the fermionic phase space — Nicolas Cerf and •Tobias Haas — Centre for Quantum Information and Communication, Université libre de Bruxelles, Belgium

We put forward several information-theoretic measures for the information encoded in phase-space distributions of a single fermion using the theory of supernumbers. In contrast to the bosonic case, the anticommuting nature of Grassmann variables allow us to provide simple expressions for the phase-space distributions of arbitrary physical states. We show that all physical states are Gaussian and thus can be described by positive (negative) thermal Wigner W-distributions of positive (negative) temperature. We prove uncertainty relations for general measures of disorder, including, e.g. the fermionic analogs of the unproven phase-space majorization and Wigner entropy conjectures as well as the Lieb-Solovej theorem and the Wehrl-Lieb inequality.

QI 29.2 Thu 15:15 HFT-TA 441

Experiments to refute real quantum mechanics suffer from the entanglement loophole — •Pedro Barrios[1,2], Michael Epping[1], Dagmar Bruss[2], and Hermann Kampermann[2] — [1]Institute for Software Technology, German Aerospace Center (DLR), Cologne, Germany — [2]Heinrich-Heine Universität Düsseldorf, Germany

Complex numbers are used extensively in quantum mechanics. The question of whether they are merely helpful or indeed necessary in the formalism is still unresolved. There have been many successful attempts of formulations using real numbers only [PRL 102 020505 (2009)]. Nevertheless, a particular Bell-type experiment has been proposed [Nature 600, 625 (2021)], where a certain class of theories of real quantum mechanics fails to reproduce the predictions of standard quantum theory, thereby falsifying these theories. However, we show that this result suffers from the following loophole, which cannot be closed in practice: If the involved parties initially share entanglement, then the experiment can be explained with real numbers only. Therefore, experimentally, both formulations are still undistinguishable.

QI 29.3 Thu 15:30 HFT-TA 441

Time-optimal multi-qubit gates: Complexity, efficient heuristic and gate-time bounds — •Pascal Bassler[1], Markus Heinrich[1], and Martin Kliesch[2] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Institute for Quantum Inspired and Quantum Optimization, Hamburg University of Technology, Germany

Multi-qubit entangling interactions arise naturally in several quantum computing platforms and promise advantages over traditional two-qubit gates. In particular, a fixed multi-qubit Ising-type interaction together with single-qubit X-gates can be used to synthesize global ZZ-gates (GZZ gates). We develop a method to synthesize such global ZZ-gate with optimal gate time. First, we show that the synthesis of such quantum gates that are time-optimal is NP-hard. Second, we develop a heuristic algorithm with polynomial runtime for synthesizing fast multi-qubit gates. Third, we derive lower and upper bounds on the optimal GZZ gate-time. Based on explicit constructions of GZZ gates and numerical studies, we conjecture that any GZZ gate can be executed in a time O(n) for n qubits. We expect that our efficient synthesis of fast multi-qubit gates allows for faster and, hence, also more error-robust execution of quantum algorithms.

QI 29.4 Thu 15:45 HFT-TA 441

Virtual subsystems under pseudo-Hermitian evolution — •Himanshu Badhani — The Institute of Mathematical Sciences, Chennai

Given a bipartite system undergoing evolution under a pseudo-Hermitian Hamiltonian, its evolution is unitary in the appropriately chosen metric Hilbert space. If the metric operator does not have a tensor product decomposition (even if the underlying vector space has a tensor product structure), then the Hilbert space does not have a tensor product structure. It is therefore not clear how one should define a subsystem in such Hilbert spaces. In our work, we establish a general prescription to define the ”subsystems” in such scenarios. We propose two different methods of partially tracing out the degrees of freedom: one of the methods exploits the equivalence of the pseudo-Hermiticity and Hermiticity. The other method considers a purely geometric approach wherein the Hilbert space is given a vector bundle structure over a base space. Partial tracing is then defined as the sum of the parallel transported states to any one of the fibers of the vector bundle. We show that these two methods of "partial trace" are equivalent. While the choice of the metric has no bearing on the system's properties, these subsystems can depend on the chosen metric since they correspond to the virtual subsystems of the original system. We prove this statement by establishing the C *-algebra in the non-trivial Hilbert space and its *-isomorphism to the algebra of the virtual bi-partition.

arXiv:2309.03042v1 and arXiv:2109.10682v2

QI 29.5 Thu 16:00 HFT-TA 441

Construction of perfect tensors using biunimodular vectors — •suhail rather — Max Planck Institute for the Physics of Complex Systems Dresden, Germany

Dual unitary gates are highly non-local bipartite unitary gates that have been studied extensively in quantum many-body physics and quantum information in the recent past. A special subset of dual unitary gates consists of rank-four perfect tensors, which are equivalent to highly entangled multipartite pure states called absolutely maximally entangled (AME) states. In this work, numerical and analytical constructions of dual unitary gates and perfect tensors that are diagonal in a special maximally entangled basis are presented. The main ingredient in our construction is a phase-valued (unimodular) two-dimensional array whose discrete Fourier transform is also unimodular. We obtain perfect tensors for several local Hilbert space dimensions, particularly, in dimension six. A perfect tensor in local dimension six is equivalent to an AME state of four qudits, denoted as AME(4,6), and such a state cannot be constructed from existing constructions of AME states based on error-correcting codes and graph states. The existence of AME(4,6) states featured in well-known open problem lists in quantum information, and was settled positively in Phys. Rev. Lett. 128 080507 (2022). We provide an explicit construction of perfect tensors in local dimension six that can be written in terms of controlled unitary gates in the computational basis, making them amenable for quantum circuit implementations.

QI 29.6 Thu 16:15 HFT-TA 441

Entropy constraints from the spectral quantum marginal problem — Felix Huber[1,2] and •Nikolai Wyderka[3] — [1]Faculty of Physics, Astronomy and Applied Computer Science, Institute of Theoretical Physics, Jagiellonian University, ul. Lojasiewicza 11, 30-348 Krakow, Poland — [2]NAQUIDIS Center, Talence, France — [3]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany

Deciding whether given eigenvalues of reduced density matrices are compatible with a joint state is known as the spectral quantum marginal problem. Its applications range from the sums of Hermitian matrices problem to optimizing trace polynomials on the positive cone and deciding the compatibility of local invariants. Even though the problem is hard to decide in general, we show how to formulate a complete hierarchy of semidefinite programs that is able to generate dimension-free certificates of spectral incompatibility in some cases. Consequently, we apply this hierarchy to derive stronger entropy inequalities that bound entropies of a quantum system and it parts.

15 min. break

QI 29.7 Thu 16:45 HFT-TA 441

Measuring beam deflections via weak measurements — •Carlotta Versmold[1,2,3], Elina Köster[1], Florian Huber[1,2,3], Lev Vaidman[4], Harald Weinfurter[1,2,3], and Jan Dziewior[1,2,3] — [1]Department für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, Israel

The technique of weak value amplification makes it possible to measure small angular and spatial displacements of a laser beam precisely by using an interferometric measurement device. So far, weak value amplification setups could only measure displacements occurring due to an interaction inside the measurement device. Here, we present an interferometric weak measurement setup able to measure displacements of a light beam that occur outside of the device. For this, we implement a Sagnac-type interferometer with a dove prism in one of its arms. The dove prism mirrors the displacements, which occurred outside the interferometer, and introduces a relative deflection between the light beams in the two interferometer arms. Then, the center of mass of the resulting interference pattern will shift depending on the initial displacement times the weak amplification factor of the pre- and postselected interferometer states. In this experiment we demonstrate how tuning the interferometer to a large amplification factor allows a clear increase in the resolution for both external beam deflections and displacements.

QI 29.8 Thu 17:00 HFT-TA 441

The Min-Entropy of Classical-Quantum Combs for Measurement-Based Applications — •Isaac D. Smith, Marius Krumm, Lukas J. Fiderer, Hendrik Poulsen Nautrup, and Hans J. Briegel — Institute for Theoretical Physics, UIBK, 6020 Innsbruck, Austria

Learning a hidden property of a quantum system typically requires a series of interactions. In this work, we formalise such multi-round learning processes using a generalisation of classical-quantum states, called classical-quantum combs. Here, 'classical' refers to a random variable encoding the hidden property to be learnt, and 'quantum' refers to the quantum comb describing the behaviour of the system. The optimal strategy for learning the hidden property can be quantified by applying the comb min-entropy to classical-quantum combs. To demonstrate the power of this approach, we focus attention on an array of problems derived from measurement-based quantum computation (MBQC) and related applications. Specifically, we describe a known blind quantum computation (BQC) protocol using the combs formalism and thereby leverage the min-entropy to provide a proof of single-shot security for multiple rounds of the protocol, extending the existing result in the literature. Furthermore, we consider a range of operationally motivated examples related to the verification of a partially unknown MBQC device. These examples involve learning the features of the device necessary for its correct use, including learning its internal reference frame for measurement calibration.

QI 29.9 Thu 17:15 HFT-TA 441

Hardware-Tailored Mutually Unbiased Bases — •Kyano Levi[1,2], Eric Kuehnke[2], Daniel Miller[2], and Jens Eisert[2] — [1]Technische Universität Berlin — [2]Freie Universität Berlin

Gathering sufficient statistics for quantum state tomography poses a bottleneck for applications on current quantum hardware. In our work, we address this bottleneck by constructing hardware-tailored and near-optimal quantum circuits for diagonalizing entire stabilizer groups on $n \leq 6$ qubits.

We use the new circuits to craft sets of mutually unbiased bases that are tailored to important hardware connectivities. Our results allow for an exponential reduction of the sample complexity when performing full-state tomography on up to $n = 12$ qubits, as verified by theory, simulations, and experiments on quantum hardware. Specifically, we achieve a 1.8x shot reduction over state-of-the-art tensor product bases for three-qubit full-state tomography with a cloud-based quantum computer. With classical simulations, we demonstrate a theoretical shot reduction of 11.4x for $n = 11$ qubits.

Our circuits feature a two-qubit gate depth that is within reach for present-day, erroneous quantum hardware, rendering them a versatile building block for meaningful applications on existing devices.

QI 29.10 Thu 17:30 HFT-TA 441

Quantum Wasserstein distance based on an optimization over subsets of physical quantum states — •Géza Tóth[1,2,3,4] and József Pitrik[4,5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, ES-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), ES-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, ES-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, HU-1525 Budapest, Hungary — [5]Alfréd Rényi Institute of Mathematics, HU-1053 Budapest, Hungary — [6]Department of Analysis, Institute of Mathematics, Budapest University of Technology and Economics, HU-1111 Budapest, Hungary

We define the quantum Wasserstein distance such that the optimization of the coupling is carried out over bipartite separable states rather than bipartite quantum states in general, and examine its properties. Surprisingly, we find that the self-distance is related to the quantum Fisher information. We present a transport map corresponding to an optimal bipartite separable state. We discuss how the quantum Wasserstein distance introduced is connected to criteria detecting quantum entanglement. We define variance-like quantities that can be obtained from the quantum Wasserstein distance by replacing the minimization over quantum states by a maximization. Besides separable states, we consider other relevant subsets of physical quantum states. We extend our results to a family of generalized quantum Fisher information quantities.

[1] G. Tóth and J. Pitrik, Quantum 7, 1143 (2023); arXiv:2209.09925.