THU 2: Quantum Information: Concepts and Methods I

Time: Thursday 14:15–16:15 Location: ZHG002

THU 2.1 Thu 14:15 ZHG002

Concentration of ergotropy in many-body systems — •Karen Hovhannisyan[1], Rick P. A. Simon[2,1], and Janet Anders[1,2] — [1]University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [2]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

Ergotropy—the maximal amount of unitarily extractable work—measures the “charge level” of quantum batteries. We prove that in large many-body batteries ergotropy exhibits a concentration of measure phenomenon. Namely, the ergotropy of such systems is almost constant for almost all states sampled from the Hilbert–Schmidt measure. We establish this by first proving that ergotropy, as a function of the state, is Lipschitz-continuous with respect to the Bures distance, and then applying Levy's measure concentration lemma. In parallel, we showcase the analogous properties of von Neumann entropy, compiling and adapting known results about its continuity and concentration properties. Furthermore, we consider the situation with the least amount of prior information about the state. This corresponds to the quantum version of the Jeffreys prior distribution—the Bures measure. In this case, there exist no analytical bounds guaranteeing exponential concentration of measure. Nonetheless, we provide numerical evidence that ergotropy, as well as von Neumann entropy, concentrate also in this case.

THU 2.2 Thu 14:30 ZHG002

Learning in Continuously-Monitored and Repeatedly-Interacting Quantum Systems — •Felix Binder — Trinity College Dublin, Dublin, Ireland

To characterise a quantum system, we must observe it. The observation record the allows us to estimate the parameters governing its behaviour. While conventional approaches to parameter estimation and tomography rely on repeated measurements under reset conditions, we ask what can be learned in a single shot when memory persists between sequential measurements. We consider two separate scenarios: a continuously monitored open quantum system and a system coupled to a finite-sized environment probed at discrete time steps.

In the first case, we focus on quantum trajectories in the jump unravelling and develop analytic and computational tools to compute the Fisher Information in both renewal and non-renewal processes. Our methods account for data compression and post-selection, and are illustrated with physically relevant examples.

In the second case, we introduce a learning framework where only the system is probed and the environment acts as a hidden quantum memory. We characterise the gauge freedoms arising in this scenario, define a suitable gauge-invariant distance between quantum processes, and show how the Fisher Information matrix reveals the dimensionality of the accessible model space.

THU 2.3 Thu 14:45 ZHG002

An infinite hierarchy of quantum-enhanced learning tasks — •Jan Nöller[1], Viet Tran[2], and Richard Kueng[2] — [1]Technische Universität Darmstadt — [2]Johannes-Kepler-Universität Linz

Learning properties of quantum states from empirical data is arguably the most fundamental quantum learning challenge. Seminal work over the past years has shown that the sample complexity associated with such tasks strongly depends on the underlying measurement primitive. As an example, determining all Pauli-observables on an n-qubit becomes sample-efficient if we allow entangling measurements on pairs of state copies, where an exponential number of samples is required if only single-copy measurements are performed. Similar separations also apply to purity testing. However, so far it has been unclear whether such exponential separation results also hold for 3 or more state copies: are there learning tasks that must be exponentially hard for (k -1)-copy measurements, but become very efficient if we allow k-copy measurements? Here, we answer this question affirmatively for every k that is a prime number. The underlying learning challenges arise from carefully extending n-qubit Pauli tomography to Weyl-Heisenberg tomography on n qudits. Up to our knowledge, our findings describe the first infinite family of rigorous separation results for multi-copy state learning.

THU 2.4 Thu 15:00 ZHG002

Relative entropy of magic — •Carolin Deckers, Justus Neumann, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine Universität Düsseldorf, Germany

We investigate the relative entropy of magic for a single qubit and for two qubits. Although the relative entropy of resource has favorable properties, it is difficult to compute in general. We apply the partial results derived for the relative entropy of entanglement [Friedland, Gour, J. Math. Phys. 52, 052201 (2011)] to the resource theory of magic. In the single-qubit case, we analyze the geometric behavior and derive an approximate analytic expression for identifying the closest stabilizer state to a pure magic state. We further investigate the two-qubit case by explicitly treating a minimal set of facets.

THU 2.5 Thu 15:15 ZHG002

Efficient distributed inner product estimation via Pauli sampling and its applications: a matter of magic and entanglement — Marcel Hinsche[1], Marios Ioannou[1], Sofiene Jerbi[1], Lorenzo Leone[1], Janek Denzler[1], Santiago Varona[2], Tommaso Guaita[1], Jens Eisert[1], and •Jose Carrasco[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Instituto de Física Teórica, UAM-CSIC, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain

Cross-device verification (a.k.a. distributed inner product estimation) allows two remote parties to estimate inner products $\mathrm{tr}(\rho\sigma)$, with each having black-box access to copies of ρ and σ, respectively. When the states ρ and σ exhibit low entanglement or can be prepared with few non-Clifford gates, this task can be reduced to independently learning efficient classical descriptions of each state using established techniques, and sharing this description in order to compute the overlap. In this talk, we will argue that efficient cross-device verification is also possible via Pauli sampling without the need to explicitly learn classical descriptions of the states (arXiv: 2405.06544). This allows us to do efficient cross-device verification in more complex scenarios where tensor network and stabilizer-based methods are insufficient (arXiv: 2501.11688). We discuss possible applications of the results in secure quantum communication, cryptography and verification.

THU 2.6 Thu 15:30 ZHG002

Optimal randomized measurements for a family of non-linear quantum properties — Zhenyu Du[1], •Yifan Tang[2], Andreas Elben[3], Ingo Roth[4], Jens Eisert[2], and Zhenhuan Liu[1] — [1]Tsinghua University, Beijing, China — [2]Freie Universität Berlin, Berlin, Germany — [3]Paul Scherrer Institute, Villigen, Switzerland — [4]Technology Innovation Institute, Abu Dhabi, United Arab Emirates

Quantum learning encounters fundamental challenges when estimating non-linear properties, owing to the inherent linearity of quantum mechanics. Although recent advances in single-copy randomized measurement protocols have achieved optimal sample complexity for specific tasks, generalizing these protocols to estimate broader classes of non-linear properties without sacrificing optimality remains an open problem. In this work, we introduce the observable-driven randomized measurement (ORM) protocol enabling the estimation of $\mathrm{Tr}(O\rho^2)$ for an arbitrary observable O—an essential quantity in quantum computing and many-body physics. We establish an upper bound for ORM's sample complexity and prove its optimality for all Pauli observables, closing a gap in the literature. Furthermore, we develop simplified variants of ORM for local Pauli observables and introduce a braiding randomized measurement protocol for fidelity estimation, both of which significantly reduce circuit complexities in practical applications. Numerical experiments validate that ORM requires substantially fewer state samples to achieve the same precision compared to classical shadows.

THU 2.7 Thu 15:45 ZHG002

Sparse semidefinite programming in quantum information theory — •Lucas Vieira[1,2] and Costantino Budroni[3] — [1]Dept. of Computer Science, TU Darmstadt, Darmstadt, 64289 Germany — [2]IQOQI-Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria — [3]Dept. of Physics "E. Fermi", Univ. of Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy

Large-scale semidefinite programs (SDPs) are ubiquitous in quantum information, typically arising from relaxations of harder underlying problems. These relaxations usually incur significant computational costs, requiring efficient representations before numerical tractability. Since relaxations may not yield feasible solutions to the original problem (e.g., the solution only satisfies a relaxed constraint), one typically prioritizes obtaining an optimal value for the objective function over its corresponding optimizer in the relaxation. Inspired by this, we introduce a heuristic method for constructing sparse representations of general SDPs, specifically targeting the sparse structure arising from their sparse objective: a typical scenario in quantum information. Unlike existing approaches, our heuristic method discards irrelevant variables and constraints by finding the effective sparsity implicit in an instance of a problem, not directly apparent from its full definition, but which emerges naturally from its structure. Our method works by iteratively assembling a self-sufficient subset of variables and constraints which, directly or indirectly, affect the objective function. This talk will outline our method and demonstrate its significant advantages in typical SDP relaxations encountered in quantum information.

THU 2.8 Thu 16:00 ZHG002

Quantum signal processing as time evolution — •Shawn Skelton — Leibniz Universität Hannover

The quantum circuit model has become a standard tool in quantum algorithm development. However, it can be preferable to formulate quantum algorithms as the time evolution generated by a Hamiltonian, for example as is done in quantum adiabatic computing. While adiabatic quantum computation can be polynomially mapped to the circuit model, algorithms developed in the circuit model and adiabatic quantum computation remain conceptually and practically separate.

In this talk, I consider a template for quantum algorithm development in the circuit model, known as quantum signal processing (QP). I derive the generator and time-evolved operator corresponding to a given QSP circuit. I then show how, for a restricted class of Hamiltonians, any QSP circuit can be implemented with a quantum adiabatic evolution. Algorithms have been developed for every major quantum computation problem with QSP, and it is known that QSP can solve BQP-complete problems. Thus, my work provides a pathway for many quantum algorithms to be reformulated in terms of well-understood physical time evolution.