QI 1: Quantum Computing and Algorithms I

Time: Monday 9:30–12:45 Location: BEY/0137

QI 1.1 Mon 9:30 BEY/0137

The Complexity of Simulating Inertially Coupled Bosonic Hamiltonians — •Refik Mansuroglu[1], Lilith Zschetzsche[1], and Norbert Schuch[1,2] — [1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria — [2]University of Vienna, Faculty of Mathematics, Oskar-Morgenstern-Platz 1, 1090 Vienna, Austria

The computational complexity of simulating physically natural quantum systems is a central question at the interface of quantum physics and computer science. While recent work has established the BQP-completeness of simulating an exponential number of coupled classical oscillators [Babbush et al.], the complexity of more general bosonic dynamics has remained unresolved. Here we prove that simulating inertially coupled bosonic systems, a broad class that includes quantum harmonic oscillators as a special case, is BQP-complete. In the Hamiltonian framework, we consider the problem of deciding whether the expectation value of an R-local observable is polynomially separated from zero, given only polynomially many nonzero initial amplitudes $q_j(0)$ and $p_j(0)$. We show that the Hamiltonians governing continuous-time quantum walks can be expressed as inertially coupled bosonic systems, thereby unifying two paradigms of quantum dynamics within a single complexity-theoretic classification.

QI 1.2 Mon 9:45 BEY/0137

Equivalence of Quantum Walk and Coupled Classical Oscillator Simulation — •Lilith Zschetzsche[1], Refik Mansuroglu[1], András Molnár[1,2], and Norbert Schuch[1,2] — [1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Wien, Austria — [2]University of Vienna, Faculty of Mathematics, Oskar-Morgenstern-Platz 1, 1090 Vienna, Austria

We present direct and physically well-motivated reductions between the simulation of quantum walk Hamiltonians and the simulation of exponentially many coupled classical oscillators, problems that are known to be BQP-complete. Mapping the complex amplitudes of the quantum walk to the displacements and conjugate momenta of the classical oscillators allows us to identify the equations of motions of the quantum walk with those of the harmonic oscillators. That is, we construct a classical Hamiltonian of harmonic oscillators from a quantum walk Hamiltonian (and vice versa), such that energy terms for oscillators and vertex populations of the quantum walk are identified as measurement outcomes on the time-evolved state. Given the BQP-completeness of one of those problems, our reduction can be seen as an alternative proof for BQP-hardness of the other, although the reduction reaches beyond BQP-complete versions of the problem.

QI 1.3 Mon 10:00 BEY/0137

Block encoding and QSVT for solving differential equations — •Abhishek Setty — Forschungszentrum Jülich, Germany — University of Cologne, Germany

We present a unified framework for efficient block encoding of arbitrary sparse matrices, addressing the key barriers to practical quantum algorithms: multi-controlled gate overhead, amplitude reordering, and hardware connectivity. Our method combines a combinatorial-optimization strategy for control-qubit assignment with coherent permutation operators, yielding explicit gate-level constructions with reduced depth. Building on this, we outline a quantum linear systems pathway for solving differential equations within the QSVT paradigm. We demonstrate this on a complex linear system and extend it to CFD problems, including the heat equation and Carleman-linearized Burgers equation. These results highlight both the potential and limitations of current methods, underscoring the need for efficient estimation of minimum singular value, depth-reduction techniques, and benchmarks against classical reachability. This pathway lays a foundation for advancing quantum linear system methods toward large-scale applications.

QI 1.4 Mon 10:15 BEY/0137

Exploring Variational Entanglement Hamiltonians — •Yanick S. Kind[1,2] and Benedikt Fauseweh[1,2] — [1]TU Dortmund, Dortmund, Germany — [2]German Aerospace Center, Cologne, Germany

Recent advances in analog and digital quantum-simulation platforms have enabled exploration of the spectrum of entanglement Hamiltonians via variational algorithms. We investigate the convergence properties of a variational algorithm and benchmark the results against numerically exact calculations. By interpreting the cost function as an integral, we employ an iterative quadrature scheme, reducing the measurement overhead by several orders of magnitude. We further demonstrate that a modified Bisognano-Wichmann ansatz allows better convergence in lattice models and provides a diagnostic for quantum phase transitions. Finally, we show that a lower cost function does not necessarily lead to a lower trace distance. However, it still faithfully reproduces degeneracies in the entanglement spectrum, which are essential for topological applications. Y. S. Kind, B. Fauseweh, arXiv:2505.10530, 2025

QI 1.5 Mon 10:30 BEY/0137

The sub-Riemannian geometry of measurement based quantum computation — •Lukas Hantzko — Leibniz Universität, Hannover, DE

The computational power of symmetry-protected phases of matter can be accessed through local measurements, but what is the most efficient way of doing so? In this work, we show that minimizing operational resources in measurement-based quantum computation (MBQC) on subsystem symmetric resource states amounts to solving a sub-Riemannian geodesic problem between the identity and the target logical unitary. This reveals a geometric structure underlying MBQC and offers a principled route to optimize quantum processing in computational phases.

QI 1.6 Mon 10:45 BEY/0137

Entanglement-informed construction of variational quantum circuits — Alina Joch[1,2], Götz Uhrig[1], and •Benedikt Fauseweh[1,2] — [1]Condensed Matter Theory, TU Dortmund University, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Institute of Software Technology, German Aerospace Center (DLR), 51147 Cologne, Germany

The variational quantum eigensolver is a promising tool for simulating ground states of quantum many-body systems on noisy quantum computers. Its effectiveness relies heavily on the ansatz, which must be both hardware-efficient for implementation on noisy hardware and problem-specific to avoid local minima and convergence problems. Here, we explore entanglement-informed ansatz schemes that naturally emerge from specific models, aiming to balance accuracy with minimal use of two-qubit entangling gates. We investigate quasi-1D Hamiltonians focusing on entanglement barriers and long-range interactions. We find that including the entanglement structure in the parameterized quantum circuit reduces the resources necessary to achieve a given accuracy. A better assessment is obtained by analyzing how the ansatz captures the entanglement spectrum. Our comprehensive analysis provides a new perspective on the design of ansätze based on the expected entanglement structure of the approximated state.

Quantum Sci. Technol. 10 035032 (2025)

30min. break

QI 1.7 Mon 11:30 BEY/0137

Measurement-driven Quantum Approximate Optimization — •Tobias Stollenwerk[1] and Stuart Hadfield[2,3] — [1]Institute for Quantum Computing Analytics (PGI-12), Jülich Research Centre, Wilhelm-Johnen-Straße, 52428 Jülich, Germany — [2]Quantum Artificial Intelligence Lab (QuAIL), NASA Ames Research Center, Moffett Field, CA 94035, USA — [3]USRA Research Institute for Advanced Computer Science (RIACS), Mountain View, CA 94043, USA

Algorithms based on non-unitary evolution have attracted much interest for ground state preparation on quantum computers. In this work we specialize and extend one recently proposed approach that employs mid-circuit measurements and control to the setting of constrained and unconstrained combinatorial optimization. For this we compare and contrast both penalty-based and feasibility-preserving approaches, elucidating the significant advantages of the latter approach. We show how to select parameters such that the success probability of each measurement step is bounded away from 1/2. Our approach is general and may be applied to easy-to-prepare initial states as a standalone algorithm, or deployed as a quantum postprocessing stage. We then propose a more sophisticated variant of our algorithm that adaptively

applies a mixing operator or not, based on the measurement outcomes seen so far, as to speeds up the algorithm and helps the system evolution avoid slowing down or getting stuck suboptimally. In particular, we show that mixing operators from QAOA can be imported directly, both for the necessary eigenstate scrambling operator and for initial state preparation, and discuss quantum resource tradeoffs.

QI 1.8 Mon 11:45 BEY/0137

Greens Function on Quantum Computers: Error Mitigation and application in Dynamical Mean Field Theory — •Jannis Ehrlich[1], Aljoscha F. Baumann[1], Daniel F. Urban[1,2], and Christian Elsässer[1,2] — [1]Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany — [2]Freiburger Materialforschungszentrum, Universität Freiburg, Germany

Dynamical Mean Field Theory (DMFT) has become a powerful tool for investigating the physics of materials that exhibit strong electronic correlations, like high-temperature superconductivity or metal-insulator transitions. The numerically challenging part is the calculation of the Greens function (GF) of the underlying Anderson impurity auxiliary model due to the explicit treatment of electron interactions, which is also directly connected to the energy of the system and the spectral function.

We present a time-evolution approach for extracting the GF by simulating the quantum system on a quantum computer and show its performance for the auxiliary Anderson impurity model of DMFT on real quantum processors with systems of increasing sizes. We further investigate the relevance of accuracy in the ground-state preparation and demonstrate possibilities to reduce and mitigate errors of current quantum devices.

QI 1.9 Mon 12:00 BEY/0137

Generation of Fermionic Gaussian States: Optimal and Approximate Matchgate Circuits — •Marc Langer[1,2], Raúl Morral-Yepes[1,2], Adam Gammon-Smith[3,4], Frank Pollmann[1,2], and Barbara Kraus[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK

Fermionic Gaussian states (FGS), and the related matchgates, play an important role in the study of various phenomena. Despite being able to represent highly entangled states, they are still tractable on classical computers. A naturally arising question is how to optimally create such states, for instance when using matchgate circuits acting on product states. In this work, we present algorithms for explicitly constructing such circuits that provably yield the minimal number of gates. Our techniques furthermore allow us to characterize which states can be represented exactly with a low depth matchgate circuit. Some applications of these results include approximate state preparation, robust disentangling algorithms and classical simulation methods.

QI 1.10 Mon 12:15 BEY/0137

Adaptive, efficient and provable energy estimation on noisy intermediate-scale quantum computers — •Bruno Murta[1], Alexander Gresch[2], and Martin Kliesch[1] — [1]TUHH - Hamburg University of Technology — [2]eleQtron GmbH

Estimating the energy of a prepared quantum state from measurements is a central subroutine in quantum simulation algorithms. In a noisy intermediate-scale quantum (NISQ) setting, this estimation must be carried out with shallow readout circuits. In this work, we introduce an energy estimation framework that both tightens theoretical guarantees and reduces the cost of measuring molecular and solid-state Hamiltonians on NISQ devices. Our protocol exploits empirical (co)variance information gathered during measurement collection to adapt the estimation to the specific state, interpolates between qubit-wise and global commutativity to provide a trade-off between circuit depth and shot efficiency, and is supported by rigorous error bounds. Numerical benchmarks on molecular and lattice models indicate that the resulting scheme achieves a significant suppression of shot noise for a fixed measurement budget, while keeping quantum resources compatible with current NISQ hardware.

QI 1.11 Mon 12:30 BEY/0137

A Constant Measurement Quantum Algorithm for Graph Connectivity — •Maximilian Balthasar Mansky[1], Chonfai Kam[2], and Claudia Linnhoff-Popien[1] — [1]LMU Munich — [2]Palermo University

We introduce a novel quantum algorithm for determining graph connectedness using a constant number of measurements. The algorithm can be extended to find connected components with a linear number of measurements. It relies on non-unitary abelian gates taken from ZX calculus. Due to the fusion rule, the two-qubit gates correspond to a large single action on the qubits. The algorithm is general and can handle any undirected graph, including those with repeated edges and self-loops. The depth of the algorithm is variable, depending on the graph, and we derive upper and lower bounds. The algorithm exhibits a state decay that can be remedied with ancilla qubits. We provide a numerical simulation of the algorithm.