QI 16: Quantum Computing Theory III

Time: Tuesday 14:00–15:30 Location: HS IV

QI 16.1 Tue 14:00 HS IV

Time-Evolution Approach for Dynamical Mean Field Theory Calculations on a Quantum Computer — •Jannis Ehrlich and Daniel F. Urban — Fraunhofer-Institut für Werkstoffmechanik IWM, 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 of the underlying auxiliary model due to the explicit treatment of electron interactions. We present a time-evolution approach for extracting the Greens function by simulating the quantum system on a quantum computer. We explicitly investigate the influence of errors on the results and show that an efficient treatment of the time-evolution operator along with proper error mitigation strategies allows for simulations even on current NISQ devices.

QI 16.2 Tue 14:15 HS IV

Preparing ground-states of frustration-free Hamiltonians using measurement-and-feedback algorithms — •Tobias Schmale[1], Maria Kalabakov[2], and Hendrik Weimer[1,2] — [1]Institut für Theoretische Physik, Appelstr. 2, 30167 Hannover — [2]Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin

Many physically interesting Hamiltonians are frustration-free, meaning that the global ground-state is also a local ground-state. We investigate a measurement-and-feedback scheme for preparing such ground-states on a quantum computer: First partition the (possibly non-commuting) local terms of a given Hamiltonian into sublattices, such that terms of the same sublattice commute. Then, repeatedly iterate through the sublattices and perform simultaneous measurements of commuting terms of the Hamiltonian, and remove excitations by making use of unitary operations and of the classical knowledge about the location of the excitations. Of particular interest here are situations where it can be guaranteed, that these "correction" unitaries do not create new excitations on any sublattice. We present numerical examples of this scheme converging to the ground-state of physically interesting Hamiltonians, as well as some examples where the ground-state is reached in a time independent of system size. We show that in general the runtime is bounded by the Hamiltonian gap, and present further efforts into an analytic understanding of convergence criteria and convergence rates of this scheme.

QI 16.3 Tue 14:30 HS IV

First hitting time of a monitored quantum walk with long-range hopping — •Sayan Roy[1], Shamik Gupta[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Department of Theoretical Physics, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India

The time needed by a quantum walker to reach a target site on a lattice can be minimized by implementing a resetting protocol, which lets the walker restart its motion at the initial site if it did not reach the target within a certain interval. This requires monitoring the target site by means of a detector. The optimal resetting rate is intimately related to the evolution of the probability that the detector clicks. We analyse the characteristic timescales of the monitored dynamics when the coupling between sites at distance d decays algebraically as $d^{-\alpha}$ with $\alpha \in (0, \infty)$ and the dynamics induced by the detector is encompassed by a non-Hermitian Hamiltonian. Our study allows to determine the optimal resetting time as a function of α. We identify three different behaviors: For $\alpha > 2$, the optimal resetting time can be understood in terms of the walker's wave packet propagating causally towards the target: Resetting faster this characteristic time will localize the walker about the initial site giving rise to an effective Zeno-effect. For $\alpha \in (1/2, 2)$, the optimal resetting time decreases monotonously with the lattice size and finally for $\alpha \in (0, 1/2)$, convergence is warranted only by continuously resetting, thereby realizing a dynamics that is reminiscent of an anti-Zeno effect.

QI 16.4 Tue 14:45 HS IV

Quantum combinatorial optimization beyond the variational paradigm: simple schedules for hard problems — •Tim Bode, Krish Ramesh, and Tobias Stollenwerk — Institute for Quantum Computing Analytics, Forschungszentrum Jülich

Advances in quantum algorithms suggest a tentative scaling advantage on certain combinatorial optimization problems. Recent work, however, has also reinforced the idea that barren plateaus render variational algorithms ineffective on large Hilbert spaces. Hence, finding annealing protocols by variation ultimately appears to be difficult. Similarly, the adiabatic theorem fails on hard problem instances with first-order quantum phase transitions. Here, we show how to use the spin coherent-state path integral to shape the geometry of quantum adiabatic evolution, leading to annealing protocols at polynomial overhead that provide orders-of-magnitude improvements in the probability to measure optimal solutions, relative to linear protocols. These improvements are not obtained on a controllable toy problem but on randomly generated hard instances (Sherrington-Kirkpatrick and Maximum 2-Satisfiability), making them generic and robust. Our method works for large systems and may thus be used to improve the performance of state-of-the-art quantum devices.

QI 16.5 Tue 15:00 HS IV

Hybrid Quantum-Classical Method for Excited-State Calculations — •Sumeet Sumeet, Max Hörmann, and Kai Phillip Schmidt — Chair for Theoretical Physics V, FAU Erlangen-Nürnberg, Germany

We present a comprehensive hybrid quantum-classical framework for calculating excited-state energies in the thermodynamic limit, integrating the variational quantum eigensolver (VQE) with numerical linked-cluster expansions (NLCE), a method we call NLCE+VQE [1]. This methodology introduces a cost function designed to minimize the off-diagonal elements of the Hamiltonian, decoupling subspaces of the Hamiltonian via a single unitary transformation, T, derived from the periodic-Hamiltonian variational ansatz.

The transformation T' is subsequently reformulated into a manifestly local unitary operator, T, through a projective cluster-additive transformation[2], ensuring the preservation of cluster additivity. This localized quasi-particle representation is systematically extended to the entire lattice using NLCE.

We validate the proposed approach by benchmarking its performance against traditional NLCEs with exact diagonalization (ED) for several non-integrable one-dimensional spin models and the transverse-field Ising model (TFIM) on the square lattice. The results demonstrate the efficacy of the method in capturing excited-state physics.

[1] Sumeet, M. Hörmann, and K. P. Schmidt, Phys. Rev. B 110, 155128 (2024).

[2] M. Hörmann, K. P. Schmidt, SciPost Phys. 15, 097 (2023).

QI 16.6 Tue 15:15 HS IV

Limitations of Quantum Approximate Optimization in Solving Generic Higher-Order Constraint-Satisfaction Problems — Thorge Müller[1,3], •Ajainderpal Singh[2], Frank K. Wilhelm[2,3], and Tim Bode[2] — [1]German Aerospace Center (DLR), Institute for Software Technology, Department High-Performance Computing, 51147 Cologne, Germany — [2]Institute for Quantum Computing Analytics (PGI-12),Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

The ability of the Quantum Approximate Optimization Algorithm (QAOA) to deliver a quantum advantage on combinatorial optimization problems is still unclear. Recently, a scaling advantage over a classical solver was postulated to exist for random 8-SAT at the satisfiability threshold. At the same time, the viability of quantum error mitigation for deep circuits on near-term devices has been put in doubt. Here, we analyze the QAOA's performance on random MaxkXOR as a function of k and the clause-to-variable ratio. As a classical benchmark, we use the Mean-Field Approximate Optimization Algorithm (MF-AOA) and find that it performs better than or equal to the QAOA on average. Still, for large k and numbers of layers p, there may remain a window of opportunity for the QAOA. However, by extrapolating our numerical results, we find that reaching high levels of satisfaction would require extremely large p, which must be considered rather difficult both in the variational context and on near-term devices.