QI 12: Quantum Computing Theory II

Time: Tuesday 11:00–12:45 Location: HS IV

Invited Talk QI 12.1 Tue 11:00 HS IV

Classical reasoning methods for quantum circuit analysis — •Tim Coopmans[1,2], Lieuwe Vinkhuijzen[3], Arend-Jan Quist[3], Jingyi Mei[3], and Alfons Laarman[3] — [1]QuTech, Delft, The Netherlands — [2]EEMCS, Delft University of Technology, The Netherlands — [3]Leiden University, Leiden, the Netherlands

Simulating, evaluating and optimizing quantum circuits is provably difficult, yet we will still need to do so to bring theoretical proposals for scalable quantum computers closer to what can be demonstrated in experiments. Fortunately, computationally-hard tasks also feature heavily in the well-established field of classical reasoning, a branch of classical computer science which focus on developing logic-based algorithms for searching large yet structured spaces.

In this talk, I will show how we merged one such classical-reasoning technique, decision diagrams, with the stabilizer formalism for quantum circuit simulation. And that, asymptotically, the resulting decision diagram provably scales incomparably to other techniques such as Matrix Product States and Clifford+T circuit simulation. If time allows, I will also show how quantum-circuit simulation can also be done using another classical-reasoning technique, weighted #SAT.

QI 12.2 Tue 11:30 HS IV

Quantum Optimization using LR-QAOA — •Karthik Jayadevan, Vanessa Dehn, and Thomas Wellens — Fraunhofer Institut für Angewandte Festkörperphysik (IAF)

The Quantum Approximate Optimization Algorithm (QAOA) is a promising approach for solving Combinatorial Optimization Problems (COPs) potentially more efficiently than classical algorithms. However, standard QAOA faces challenges owing to the complexity of optimizing the variational parameters, which itself is an NP-hard optimization problem [1], thus limiting its expected advantage. Recent work has suggested that fixed linear ramp schedules could serve as a universal set of QAOA parameters, potentially offering scaling advantages [2]. In this study, we investigate the application of a modified QAOA variant utilizing Linear Ramp QAOA (LR-QAOA) to certain COPs. Since LR-QAOA significantly reduces the parameter optimization complexity, it enables the determination of good candidates for circuit parameters through extrapolation from smaller to larger problem sizes. Further, we examine the runtime scaling of LR-QAOA for these use cases and compare it with the best-known classical methods.

[1] L. Bittel and M. Kliesch, Physical review letters 127, 120502 (2021).

[2] J. A. Montanez-Barrera and K. Michielsen, Towards a universal QAOA protocol: Evidence of a scaling advantage in solving some combinatorial optimization problems, 2024.

QI 12.3 Tue 11:45 HS IV

Quantum spatial searches with long-range hopping — •Emma King[1], Moritz Linnebacher[1], Peter Orth[1], Matteo Rizzi[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institut fuer Theoretische Physik, Universität zu Köln, D-50937 Köln, Germany

Grover's search algorithm is paradigmatic for quantum computing, demonstrating how quantum coherence might lead to a supremacy of quantum over classical information processing. A continuous-time implementation of Grover search can be achieved with a quantum walk on a graph, where vertices represent the elements of the database and the target state is tagged by an energy shift. Defining optimal search as an algorithm achieving near unit fidelity in time $T = \mathcal{O}(\sqrt{N})$, this analog realization of quantum search executed on d-dimensional hypercubic lattices with nearest-neighbor hopping is optimal when $d > 4$. We extend these results to consider lattices with hopping terms scaling as a power law $1/r^\alpha$ with the intersite distance r. In the presence of this tuneable connectivity, we assess the requirements on the exponent α for which the spatial search can achieve Grover's optimal scaling, and then relate the result to the spectral dimension d_s. At $d_s = 4$ we identify a continuous transition from a region where optimal search exists to a region of suboptimality. Numerically, we demonstrate that the search is robust to disorder in the lattice onsite energy. These results enhance our understanding of analog quantum search in low spatial dimensions and could be accessible experimentally using trapped ultracold atoms.

QI 12.4 Tue 12:00 HS IV

Ordering operators for an effective ansatz in VQE calculations — •Sahil Sarbadhikary, Walter Hahn, and Thomas Wellens — Fraunhofer IAF, Freiburg im Breisgau, Germany

The Variational Quantum Eigensolver (VQE) is a promising candidate for a quantum algorithm with near-term applications. It aims to solve a problem central to quantum chemistry: computing the ground state energy of a Hamiltonian describing a molecule. To implement an ansatz for the variational wave function on a quantum computer, the first-order Suzuki-Trotter expansion is usually used, which entails the problem of the non-equivalent order of the operators defining the ansatz. In this talk, we explore the effect of the order of operators in the ansatz on the accuracy of VQE calculations by considering different molecules. We show that the order of operators has an impact on the accuracy of VQE calculations and evaluate possible effective ordering schemes.

QI 12.5 Tue 12:15 HS IV

Solving the travelling salesman problem on a quantum system — •Kapil Goswami[1], Rick Mukherjee[1,2], and Peter Schmelcher[1,3] — [1]The Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Quantum Center, The University of Tennessee, 701 East Martin Luther King Boulevard, Chattanooga, USA — [3]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Germany

The Traveling Salesman Problem (TSP) is a well-known NP-hard combinatorial optimization problem that seeks the optimal route for visiting a set of cities once and returning to the starting point. Current quantum methods for solving TSPs typically use gate-based or binary variable-based encoding, which is resource-intensive and less effective than classical algorithms, even for small problems. We present a framework that solves TSP using a single qubit, utilizing quantum parallelism. In this approach, cities are represented as quantum states on the Bloch sphere, allowing simultaneous exploration of multiple paths through superposition states. By employing optimal control techniques, a selective superposition of quantum states is created to find the shortest route. Numerical simulations for four to nine cities yield exact solutions. Our algorithm can be implemented on any quantum platform capable of rotating a qubit and facilitating state tomography. It demonstrates greater resource efficiency and accuracy compared to existing quantum methods, with potential for scalability and a polynomial speed-up over classical algorithms.

QI 12.6 Tue 12:30 HS IV

Impact of unital and non-unital noise on quantum phase estimation and Grover search algorithms — •Muhammad Faryad, Muhammad Faizan, and Amber Riaz — Department of Physics, Lahore University of Management Sciences, Lahore, Pakistan

Quantum phase estimation (QPE) and Grover search algorithms are basic sub-routines in many advanced quantum algorithms. To understand the impact of noise on these algorithms, we computed the phase estimated using the QPE and the probability of success of the Grover algorithm as a function of error probability induced by noise. We consider both unital noise processes such as depolarization noise and non-unital processes such as amplitude damping noise. This noise is modeled as a trace-preserving quantum channel. In the absence of amplitude damping, the performance of the QPE and Grover algorithm strongly depends upon the error probability of bit-flip, phase-flip, and depolarizing noise channel. However, the presence of amplitude damping seems to suppress the impact of unital noise processes.

References: [1] Ijaz and Faryad, Scientific Reports, 13, 20144 (2023). [2] Faizan and Faryad, Proc. SPIE, 12911-88 (2024).