QI 8: Quantum Computing Theory I

Time: Monday 17:00–19:00 Location: HS IV

Invited Talk QI 8.1 Mon 17:00 HS IV

Quantum Informatics - From Quantum Gates to Quantum Software Engineering — •Ina Schaefer — KIT, Karlsruhe, Germany

While quantum computing hardware is becoming more and more available, the demand for quantum software is also increasing. As in classical computing, the expectation is that after quantum computing hardware has reached a certain maturity, the main value creation in quantum computing will be obtained from quantum software. In order to facilitate the use of quantum computing to solve industrial-scale applications, advances in quantum informatics, and especially in quantum software engineering are needed.

In this presentation, I will explore the relationship between quantum computing and classical software engineering by focusing on three main aspects. First, I will show what can be learnt from classical programming language and compiler technology for the implementation of quantum programming languages. Second, for scaling the development of quantum programs, I will present first results on design patterns for quantum programming. Third, in order to ensure correctness of quantum programs, I will focus on verification techniques and correctness-by-construction development for quantum programs.

QI 8.2 Mon 17:30 HS IV

Tensor-Programmable Quantum Circuits for Solving Differential Equations — Pia Siegl[1,2], •Greta Sophie Reese[1,3], Tomohiro Hashizume[1], Nis-Luca van Hülst[1], and Dieter Jaksch[1,4] — [1]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute of Software Methods for Product Virtualization, German Aerospace Center (DLR), Zwickauerstraße 46, 01069 Dresden, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [4]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK

We present a quantum approach for solving partial differential equations, leveraging a versatile matrix product operator (MPO) representation. By incorporating mid-circuit measurements and a state-dependent norm correction, this method bypasses the limitations of unitary operators, enabling the direct implementation of a wide range of differential equations that describe both classical and quantum system dynamics.

QI 8.3 Mon 17:45 HS IV

Real-time measurement error mitigation for one-way quantum computation — Tobias Hartung[1], •Stephan Schuster[2], Joachim von Zanthier[2], and Karl Jansen[3] — [1]Northeastern University - London — [2]Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg — [3]Center for Quantum Technology and Applications (CQTA), Desy Zeuthen

We present a quantum error mitigation method for single-qubit measurements, particularly suited for one-way quantum computation. Our method is capable of mitigating errors of single-shot measurements in real-time, i.e., during the processing measurements of a one-way quantum computation and avoids any preceding calibration measurements. For that, we utilize an ancillary qubit register which is entangled with the to-be measured qubit and is additionally measured afterwards. Occurring measurement errors can then be mitigated in real-time by applying a voting protocol to all measurement outcomes, while the computation proceeds. We provide analytical expressions for the remaining missidentifaction probability of a measurement outcome, in dependence of the error rate and the ancilla register size, and for the required register size to fall below a certain missidentification rate, in dependence of the measurement error rate. Additionally, we show in proof-of-principle simulations that our method can reduce the measurement errors significantly using only a small number of ancilla qubits.

QI 8.4 Mon 18:00 HS IV

Robustness of optimal quantum annealing protocols — Niklas Funcke and •Julian Berberich — Institute for Systems Theory and Automatic Control, University of Stuttgart, 70569 Stuttgart, Germany

Quantum annealing addresses optimization problems by smoothly interpolating between two Hamiltonians. When implementing quantum annealing protocols on current hardware, errors can cause significant problems and may destroy any potential computational advantages. In this contribution, we study the robustness of optimal quantum annealing protocols against coherent control errors, which correspond to over- or underrotation errors and were shown to be particularly detrimental. We prove that the influence of coherent control errors on quantum annealing is bounded by the norm of the Hamiltonian that is applied to the system. We then leverage this bound to design robust quantum annealing protocols which minimize not only the cost Hamiltonian but also an additional regularization term penalizing the norm of the Hamiltonian. The regularization is weighted by a tuning parameter which allows to trade off two objectives: optimality and robustness. Next, using tools from optimal control theory, we analyze the optimal structure of robust quantum annealing protocols. We prove that the regularization causes a fundamental change of the structure, leading to a higher preference of smooth annealing phases over bang-bang solutions. This provides theoretical evidence that quantum annealing is more robust than variational quantum optimization techniques. Numerical simulations confirm our theoretical findings.

QI 8.5 Mon 18:15 HS IV

Adaptive Lie-algebra ansatz for ground-state calculations in a globally-driven Rydberg platform — •Marco Dall'Ara, Martin Koppenhöfer, Thomas Wellens, Florentin Reiter, and Walter Hahn — Fraunhofer Institute for Applied Solid State Physics IAF, Tullastr. 72, 79108 Freiburg, Germany

Hybrid quantum-classical algorithms have emerged as a promising tool to accurately determine ground states, for example of molecules, on quantum computers and quantum simulators. We propose a novel method for the variational preparation of ground states of Hamiltonians on a globally-driven Rydberg-atom platform. This novel method is based on a dynamical-Lie-algebra ansatz combined with an adaptive construction of the pulse sequence. When using our method to determine the ground state of molecules in numerical simulations, it outperforms a brute-force ansatz and shows clear advantages with respect to the dCRAB algorithm of quantum optimal control regarding the number of free parameters and expectation-value evaluations. In particular, we introduce an effective dynamical Lie algebra to avoid the calculation of the full dynamical Lie algebra, which is computationally intractable for larger systems. The method proposed is applicable to simulators beyond the Rydberg-atom architecture and to quantum computers.

QI 8.6 Mon 18:30 HS IV

Increasing Accuracy of the Variational Quantum Eigensolver with the Inverted-Circuit Zero-Noise Extrapolation — •Tobias Nauck, Kathrin König, Walter Hahn, and Thomas Wellens — Fraunhofer IAF

Simulating entangled quantum states is inherently challenging for classical computers, which makes this task a prime target for quantum computers. The Variational Quantum Eigensolver (VQE) is a promising method for approximating molecular ground states, but current quantum hardware's noise hinders its practical implementation. In this talk, we discuss results achieved by using the recently proposed noise mitigation technique Inverted-Circuit Zero-Noise Extrapolation (IC-ZNE) [1] in VQE calculations. We present noisy simulations of VQE circuits comparing IC-ZNE with the standard Zero-Noise Extrapolation method for various molecules and show an increased accuracy of the results when using IC-ZNE.

[1] https://journals.aps.org/pra/abstract/10.1103/PhysRevA.110.042625

QI 8.7 Mon 18:45 HS IV

Why we should expect that quantum computers cannot factor efficiently — •Liam McGuinness — University of Ulm, Ulm, Germany

Quantum information science currently poses a troubling contradiction. It can be summarized as:

1) To factor efficiently, quantum computers must perform exponentially precise energy estimation.

2) Exponentially precise energy estimation is impossible according to the Heisenberg time-energy uncertainty principle.

It is surprising that such a dramatic contradiction exists between two accepted predictions of quantum mechanics, and yet this contradiction is not widely discussed. It is even more surprising when one notes it is not a minor discrepancy – the two statements differ by an exponential margin. Not only that, whether 1) or 2) is correct is of fundamental importance to the realisation of most quantum technologies. If 2) is correct, then quantum computers are much less powerful than expected.

This talk surveys the available experimental evidence regarding this contradiction. I highlight that all current evidence agrees with 2). I also give clear theoretical reasons why only 2) is consistent with quantum mechanics. In short there are strong reasons to expect that quantum computers cannot factor efficiently.