Q 3: Quantum Information (Quantum Computing) I

Time: Monday 10:30–12:30 Location: S HS 001 Chemie

Invited Talk Q 3.1 Mon 10:30 S HS 001 Chemie

Quantum information scrambling and hybrid machine learning with trapped ions — •Norbert M. Linke[1], Kevin A. Landsman[1], Daiwei Zhu[1], and Chris Monroe[1,2] — [1]Joint Quantum Institute, University of Maryland, College Park, MD 20742, USA — [2]IonQ, Inc., College Park, MD 20740, USA

Trapped ions are a promising candidate system to realize a scalable quantum computer. We present a system comprised of a chain of 171Yb+ ions with individual Raman beam addressing and individual readout [1]. This fully connected processor can be configured to run any sequence of single- and two-qubit gates, making it in effect an arbitrarily programmable quantum computer.

We use this versatile system to perform a teleportation-based protocol to verify quantum information scrambling. This phenomenon describes the dispersal of local information into many-body quantum entanglements and correlations, and has recently been conjectured to shed light on the black-hole information paradox.

Quantum-classical hybrid systems offer a path towards the application of near-term quantum computers to different optimization tasks. We present several demonstrations relating to machine learning in such a hybrid approach, such as finding the ground state binding energy of the deuteron nucleus, the training of shallow circuits [3], and the preparation of quantum critical states using a quantum approximate optimization algorithm (QAOA) scheme. Recent results from these efforts, and concepts for scaling up the architecture will be discussed.

[1] Nature 563:63 (2016) [2] arXiv:1806.02807 [3] arXiv:1801.07686

Q 3.2 Mon 11:00 S HS 001 Chemie

Certifying quantum memories with coherence — •Timo Simnacher, Nikolai Wyderka, Cornelia Spee, Xiao-Dong Yu, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

In order to work, quantum computers need reliable and well-characterized routines and devices. The loss of quantum coherence, however, is one of the major obstacles on the way to a scalable platform for quantum computing and the suppression of decoherence is known as one of the DiVincenzo criteria for quantum computers. One main ingredient in any computing architecture is the memory. Quantum computers are no exception and furthermore, quantum memories play a central role in the development of quantum repeaters. Consequently, the search for reliable systems that store quantum states for a reasonable amount of time while preserving quantum properties is an active area of research.

We present a general method to characterize and test these devices based on their ability to preserve coherence. We introduce a quality measure for quantum memories and characterize it in detail for the qubit case. The measure can be estimated from sparse experimental data and may be generalized to characterize other building blocks, such as quantum gates or teleportation schemes.

Q 3.3 Mon 11:15 S HS 001 Chemie

Ein Quantenprozessor mit Ionenkristallen — •Janine Hilder, Daniel Pijn, Vidyut Kaushal, Alexander Stahl, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz

Wir berichten über einen Quantenprozessor basierend auf gefangenen Ionen. In einer linearen segmentierten Paulfalle zeigen wir Qubit Register Rekonfigurationen wie das Trennen und Vereinen von Kristallen [1] und SWAP Operationen durch Kristallrotationen [2]. Unter Verwendung dieses Shuttling-basierten Ansatzes und durch kontinuierliche technische Verbesserungen zeigten wir bisher erfolgreich die Erzeugung eines Vier-Qubit GHZ Zustandes [3]. Von grundlegender Bedeutung für die Realisierung eines Quantenprozessors ist neben Einzel- und Zwei-Qubit Gattern mit hoher Qualität die Quantenfehlerkorrektur. Wir zeigen aktuelle Ergebnisse zur Realisierung fehlertoleranter Stabilisatormessungen durch ein Flag-basiertes Auslesen mit vier Daten Qubits und zwei zusätzlichen Ancilla Qubits [4].

[1] A. Walther et al., Phys. Rev. Lett. 109, 080501 (2012)
[2] H. Kaufmann et al., Phys. Rev. A 95, 052319 (2017)
[3] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[4] A. Bermudez et al., Phys. Rev. X 7, 041061 (2017)

Q 3.4 Mon 11:30 S HS 001 Chemie

Multilayer ion trap technology for quantum simulation and quantum computation — •Amado Bautista-Salvador[1,2], Hening Hahn[1,2], Giorgio Zarantonello[1,2], Jonathan Morgner[1,2], Matthias Kohnen[2], Martina Wahnschaffe[2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische-Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig

We present a novel ion trap fabrication method enabling the realization of large-scale ion trap arrays for scalable quantum information processing and quantum simulation [1]. We benchmark the method by fabricating a multilayer surface-electrode ion trap with embedded 3D microwave circuitry for implementing entangling quantum logic gates. We demonstrate ion trapping and microwave control of the hyperfine states of a laser cooled $^{9}\mathrm{Be}^{+}$ ion held at a distance of 35 μm above the trap surface. We discuss the trap design, electromagnetic full-wave simulations and characterization of the multilayer ion trap using a single ion as a local near-field probe [2]. In this design the measured detrimental AC Zeeman shifts is three orders of magnitude less compared to previous traps [3]. The device presented here can be viewed as an entangling gate component in a scalable library for surface-electrode ion traps aimed for quantum logic operations.

[1] A. Bautista-Salvador et al., in preparation [2] H. Hahn et al., in preparation [3] M. Wahnschaffe et al., Appl. Phys. Lett. **110**, 034103 (2017).

Q 3.5 Mon 11:45 S HS 001 Chemie

Comparison of QAOA with Quantum and Simulated Annealing — •Michael Streif[1,2] and Martin Leib[1] — [1]Data:Lab, Volkswagen Group, Ungererstr. 69, 80805 München, Germany — [2]Physikalisches Institut, Universität Freiburg, Herrmann-Herder-Straße 3, 79104 Freiburg, Germany

Demonstrating the advantage of quantum computers over their classical counterparts is the space race of our current scientific world. Good candidates in the near future are hybrid algorithms, which combine the power of digital computation with the quantum nature. The Quantum Approximate Optimization Algorithm (QAOA) is a such a hybrid algorithm, designed to solve combinatorial optimization problems, and showing promising indication for near-term quantum supremacy. Consequently, it is crucial to find suitable problems and to gauge strengths and weaknesses of QAOA within the zoo of available classical and quantum algorithms. We present a comparison between QAOA and two widely studied competing methods, Quantum Annealing (QA) and Simulated Annealing (SA). To achieve this, we define a subclass of k-local spin glass instances, characterized by their spectral properties, which are exactly solvable with QAOA. Within this class, we find 4-local instances which are hard to solve with both QA and SA. Our results thus define a first demarcation between QAOA, SA and QA.

Q 3.6 Mon 12:00 S HS 001 Chemie

Classifying images with hierarchical quantum neural networks — •Andrea Skolik and Martin Leib — Volkswagen Data:Lab, Ungererstr. 69, 80805 München

With noisy intermediate scale quantum devices now being available, algorithms that don't require fully error corrected quantum computers are receiving increased attention. One particularly promising area in this respect is quantum machine learning, where noise is even conjectured to be beneficial, based on findings in the classical counterpart. In this work, we investigate parametrized quantum circuits based on an image classification task. An image is classified according to the measurement of a designated qubit after the variational circuit acted on an initial state that is generated based on information of the respective image. Starting with random values we optimize the gate parameters in a classical external learning loop such that the training data gets classified correctly. We perform extensive numerical studies to investigate the capabilities of this nascent technique, and show that even quantum circuits with a modest size of parameters can achieve up to 95% classification accuracy on a set of handwritten digits.

Q 3.7 Mon 12:15 S HS 001 Chemie

Correspondence of Quantum and Classical Hardness for QAOA Algorithms with MAX-SAT problems — •Martin Leib

and Michael Streif — Data:Lab Volkswagen AG, Munich, Germany

The Quantum Approximate Optimization Algorithm (QAOA) has emerged in recent years as one of the leading contenders of quantum algorithms that can be executed on noisy intermediate scale quantum computing devices. QAOA belongs to a class of classical-quantum hybrid algorithms where a parametrized quantum circuit is optimized by a classical outer training-loop. We examine potential signs of quantum advantage by gauging the complexity involved in the outer classical training loop as well as the entanglement build up in the quantum circuit during training and for the fully trained circuit. To achieve this we create random instances of MAX-SAT problems where we tune the complexity with the ratio of variables to clauses. We solve these instances with QAOA runs and examine for each complexity class the involved complexity of the outer training loop and the amount of entanglement build up during training and for the final trained circuit.