QI 35: Quantum Computers: Algorithms and Benchmarking

Time: Friday 11:00–13:00 Location: B305

QI 35.1 Fri 11:00 B305

Advantages of Measurement-based Variational Quantum Eigensolvers — •Anna Schroeder[1,2], Matthias Heller[3], and Mariami Gachechiladze[2] — [1]Merck KGaA, Frankfurter Str. 250, Darmstadt, Germany — [2]Quantum Computing Group, TU Darmstadt, Mornewegstr. 30, Darmstadt, Germany — [3]Fraunhofer IGD, Darmstadt, Germany

The variational quantum eigensolver (VQEs) is a hybrid algorithm to compute the lowest eigenvalue and its corresponding eigenvector for a given operator. The idea is to optimize classically over a parametrized quantum circuit, the ansatz, to generate a quantum state that minimizes the cost function, typically the expectation value of the Hamiltonian. Recently, a different approach to VQE has been considered. Ferguson et al., PRL 2021 discussed unifying the VQE framework with measurement-based quantum computing (MB-VQE). Here instead of parametrizing gates, one starts with highly entangled resource states (e.g., graph states) and optimizes over local measurements. This scheme has already demonstrated an advantage over the gate-based model for small perturbations of Toric code Hamiltonians, as it allows for more compact construction of certain ansaetze while enjoying shallower circuit depths - an imperative property for implementation on NISQ hardware. In our work, we deepen the investigation of MB-VQE advantage by considering more general resource states and larger classes of Hamiltonians, which helps us develop a more rigorous understanding of the advantageous ansaetze in MB-VQE for given problem classes.

QI 35.2 Fri 11:15 B305

Molecular Quantum Circuit Design — •Jakob Kottmann — Institut for Computer Science, University of Augsburg

An integral part of science is the formulation of simple concepts capable to capture the essential aspects of complex processes. A prominent examples is the reduction of molecules to simple graphs with the atomic nuclei as vertices connected by edges representing so - called chemical bonds.

Design principles for the construction of quantum circuits are in high demand and are currently being researched heavily - current methodologies however often lack simplicity and interpretability.

Here, an interpretable design concept for quantum circuits based on chemical graphs is presented. It provides physical insight and interpretaility for each individual circuit element and leads to heuristics for the construction, optimisation, and interpretation of quantum circuits suitable for ground state preparation.

QI 35.3 Fri 11:30 B305

Perspectives of running DMFT calculations on NISQ hardware — •Jannis Ehrlich, Daniel F. Urban, and Christian Elsässer — Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany

Quantum computers promise to enhance numerical calculations of correlated electron systems. While the simulation of full electronic systems is far out of reach due to the large number of states that need to be considered, effective model systems can already be implemented on currently available NISQ devices. The Dynamical Mean Field Theory (DMFT) is such an embedding approach, in which the Greens function of a correlated orbital has to match both, the orbitals description as site of a regular lattice and as impurity in an Anderson impurity model (AIM). Both models are solved in an iterative self-consistency loop, where the solution of the AIM is the limiting part of DMFT calculations on conventional computers today. Here, we introduce a possible way of solving the AIP on a quantum computer using hybrid approaches like the variational quantum eigensolver (VQE). We present results of experiments on IBMQ hardware for the two-site DMFT model. Moreover, we show how state-of-the-art error mitigation strategies improve the results. A post-correction scheme is presented to ensure physical symmetries in the final self-consistent Greens function and self-energy and we derive and discuss the requirements on the quantum hardware needed for a successful implementation of the algorithm.

QI 35.4 Fri 11:45 B305

QRydDemo - Quantum Computing with Rydberg Atoms — •Sebastian Weber[1], Philipp Ilzhöfer[2], Govind Unnikrishnan[2], Ratnesh Kumar Gupta[2], Jiachen Zhao[2], Jennifer Krauter[2], Achim Scholz[2], Moritz Wilke[2], Alice Pagano[3], Daniel Jaschke[3], Nicolai Lang[1], Nastasia Makki[1], Hans Peter Büchler[1], Simone Montangero[3], Jürgen Stuhler[4], Tilman Pfau[2], and Florian Meinert[2] — [1]Institute for Theoretical Physics III and IQST, University of Stuttgart, Germany — [2]5th Institute of Physics and IQST, University of Stuttgart, Germany — [3]Institute for Complex Quantum Systems, Ulm University, Germany — [4]Toptica Photonics AG, Gräfelfing, Germany

The QRydDemo Consortium aims to realize a quantum computer demonstrator with up to 500 atomic qubits trapped in arrays of optical tweezers. Exciting the atoms with lasers to Rydberg states, allows for rapidly switching interactions between the atoms on and off, enabling the implementation of fast and high-fidelity gate operations. Our quantum processor based on the optical tweezer architecture promises many exciting new possibilities. One novel aspect we aim to explore is the potential to change the qubit connectivity during a quantum computation. I will provide an overview of the QRydDemo project and demonstrate our online emulator that allows future users of our hardware to get familiar with QRydDemo's native gate operations.

QI 35.5 Fri 12:00 B305

Proposed method to produce large multipartite nonlocality and benchmark quantum computers — •Jan Lennart Bönsel[1], Otfried Gühne[1], and Adán Cabello[2] — [1]Universität Siegen, Germany — [2]Universidad de Sevilla, Spain

Nonlocality is a characteristic of quantum mechanics that does not occur in a local realistic model. Thus, nonlocality is an interesting property to exclude local realistic models, which can be tested by Bell inequalities. Mermin- and Ardehali-Bell inequalities can be formulated for a large number of qubits N. For these inequalities, the ratio of the quantum violation to the classical bound increases exponentially in N. In practice, the amount of nonlocality that can be produced is limited by noise and restrictions on the possible qubit interactions. In addition, to certify nonlocality, a number of terms that grows exponentially with the number of qubits have to be measured, which becomes infeasible for systems with many qubits.

In this work, we address this problem. On the one hand, we consider the Ardehali-Bell operator for the linear cluster state, which can be prepared by nearest neighbour interactions only. On the other hand, we investigate how the violation of the Bell inequality can be estimated by measuring the terms of the Bell operator at random. For this purpose, we study the confidence level for an observed violation given the number of measured observables. As the linear cluster state is important for quantum computations and can be readily prepared on many quantum computing platforms, the violation of the Bell inequality could serve as a benchmark for quantum computers.

QI 35.6 Fri 12:15 B305

Principles of Quantum Functional Testing — Nadia Milazzo[1,2,3], Olivier Giraud[2], •Giovanni Gramegna[1], and Daniel Braun[1] — [1]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [2]Université Paris Saclay, CNRS, LPTMS, Orsay 91405, Franc — [3]ColibrITD, 91, rue du Faubourg Saint-Honoré 75008 Paris

Testing the functionality of quantum devices will be needed as their availability increases. In this context, a complete characterization of the quantum channel implemented by the device is unfeasible except for the simplest and smallest quantum chips. Rather, quantum functional testing aims at determining as fast as possible whether the device can be accepted or rejected according to the producer pecifications on the key characterizing parameters. In particular, it is desirable to waste as little time as possible on devices that do not function properly. We investigate the possibility to speed up the testing process by using repetition of the channel: on one hand this would increase the impact of coherent errors enhancing their detectability, on the other hand the amplification of incoherent errors might have the opposite effect. This also motivates the introduction of non-greedy adaptive experimental design, where the decision on whether to repeat the channel or more generally which sequence of measurement to perform is established based on the information already gathered from previous measurements. Finally, we investigate the impact of different decision criteria on the efficiency of the testing procedure

QI 35.7 Fri 12:30 B305

Characterizing crosstalk of superconducting transmon processors — •Andreas Ketterer and Thomas Wellens — Fraunhofer Institut für Angewandte Festkörperphysik IAF, Tullastr. 72, 79108 Freiburg, Germany

Currently available quantum computing hardware based on superconducting transmon architectures realizes networks of hundreds of qubits with the possibility of controlled nearest-neighbor interactions. However, the inherent noise and decoherence effects of such quantum chips considerably alter basic gate operations and lead to imperfect outputs of the targeted quantum computation. In this talk we focus on the characterization of crosstalk effects which manifest themselves in correlations between simultaneously executed quantum gates on neighboring qubits. After a short explanation of the origin of such correlations we show how to efficiently and systematically characterize the magnitude of such crosstalk effects on an entire quantum chip using the randomized benchmarking protocol. In particular, we demonstrate the introduced protocol by running it on real quantum hardware provided by IBM. Lastly, we use the gained information in order to propose novel and more accurate means to simulate noisy quantum hardware by devising an appropriate crosstalk-aware noise model.

QI 35.8 Fri 12:45 B305

Noise mitigating adaptive quantum tomography — •Adrian Aasen and Martin Gärttner — Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany

Quantum tomography is the process of reconstructing density matrices, or quantum states, and is the golden standard for state discrimination. It is quite an active field partially due to the recent development and benchmarking requirements of quantum computers and hardware. Common for all near term quantum devices is that they are noisy. Knowing how readout errors affect the tomographic estimate and how to mitigate the effect of noise is of significant interest. We leverage two strategies to reduce the overall experimental cost and improve control over noise in experimental setups. Firstly, we limit the use of noisy measurements to fit within a "noise budget". Subsequently we give a theoretical prescription for how to derive an optimal set of measurements within these restrictions, given some noise model. Secondly, we use adaptive strategies, suitable for both maximal likelihood estimation and Bayesian inference, to maximize information extraction per measurement. Combining these two strategies provide an optimal protocol to reach a desired reconstruction accuracy in a noisy environment.