Q 47: Quantum Computing I

Time: Thursday 14:30–16:15 Location: P 2

Group Report Q 47.1 Thu 14:30 P 2

Generation and application of scalable entanglement in an ion trap — •Thomas Ruster, Henning Kaufmann, Jonas Schulz, David von Lindenfels, Vidyut Kaushal, Christian T. Schmiegelow, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Entanglement is an important resource for applications such as quantum computation and high precision sensing. In a segmented Paul trap, entanglement can be created by combining laser-driven logic gates and ion-shuttling operations. We present how we encode a qubit with coherence times in the 1 s range in the valence electron spin of $^{40}Ca^+$ ions. The implementation of the set of shuttling operations required for scalable protocols is outlined. We show how to conduct high-fidelity gate operations, which are insensitive against motion excited by the shuttling operations.

We combine gate and shuttling operations to generate a 4-ion GHZ state $|\uparrow\uparrow\uparrow\uparrow\rangle + |\downarrow\downarrow\downarrow\downarrow\rangle$. By applying dynamical decoupling techniques, we can keep the entangled state alive for about 1 s.

As an application of spatially distributed entanglement, we employ Bell states $|\uparrow\downarrow\rangle+|\downarrow\uparrow\rangle$ for sensing inhomogeneous magnetic fields. These states accumulate a phase, which depends on the magnetic field difference between the locations of the constituent ions. By measuring the accumulated phase, we map out dc magnetic fields with accuracies down to 270 pT.

Q 47.2 Thu 15:00 P 2

Adaptive selective addressing of microwave-driven trapped ion qubits — •Patrick Huber, Theeraphot Sriarunothai, Sabine Wölk, Gouri Giri, and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

Cold ions stored in Paul traps are well suited for experiments in quantum information science. Applying a spatially varying magnetic field results in a MAgnetic Gradient Induced Coupling (MAGIC) between ions and allows for conditional quantum dynamics. Due to this gradient qubit resonances are individually shifted and become position dependent, thereby making them addressable in frequency space. We apply microwave pulses to realize single qubit gates, to control conditional gates with several ions, and for dynamical decoupling. Such quantum gates rely on the precise knowledge of qubit resonance frequencies that may, however, vary during the execution of a quantum algorithm. Here we report on the implementation of adaptive individual addressing of trapped ion qubits, that is, we measure resonance frequencies periodically using Ramsey interferometry and adapt the microwave pulses' frequency accordingly. First experiments showed that the application of this method results in a twelve-fold reduction of the width of the resonance frequencies' distribution. This improvement in determining qubit resonances is expected to lead to a significant improvement of the fidelity of multi-qubit conditional quantum gates.

Q 47.3 Thu 15:15 P 2

The equivalence of static and dynamic magnetic gradient induced coupling — •Sabine Wölk and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

A laser-less interaction between internal and motional states of trapped ions can be induced by a static [1] or by a dynamic [2] magnetic gradient field. Taking advantage of such Magnetic Gradient Induced Coupling (MAGIC), conditional quantum dynamics with effective spin states and motional states can be carried out which is useful for a variety of experiments in quantum information science.

Here, we show that the coupling mechanism in the presence of a dynamic gradient is the same, in a dressed state basis, as in the case of a static gradient [3]. This insight can be used to overcome demanding experimental requirements when using a dynamic gradient field. At the same time it opens new experimental perspectives when using a dynamic gradient field by taking advantage of long range coupled ions, for example, for multi-qubit dynamics.

[1] F. Mintert and Ch. Wunderlich, Phys. Rev. Lett. **87**, 257904 (2001)
[2] C. Ospelkaus et al., Nature **476**, 181 (2011)
[3] S. Wölk and Ch. Wunderlich, arXiv: 1606.04821

Q 47.4 Thu 15:30 P 2

Quantum supremacy via simulation of Ising models on the square lattice. — Juan Bermejo-Vega[1], •Dominik Hangleiter[1], Martin Schwarz[1], Jens Eisert[1], and Robert Raussendorf[2] — [1]Fachbereich Physik, Institut für theoretische Physik, Freie Universität Berlin — [2]Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada

An important near-term goal in the field of quantum simulation is to demonstrate *quantum supremacy* in the lab by performing a simple experiment whose outcome cannot efficiently be predicted on a classical computer. Here, we propose a wide range of architectures and settings constructed from simple building blocks that show quantum supremacy. Specifically, we show that efficiently classically simulating the dynamics of translation-invariant Ising models on the 2D square lattice is impossible even for a constant time assuming three reasonable complexity-theoretic conjectures to hold. Our proposal requires translation-invariant on-site measurements on the square lattice. We discuss trade-offs in experimental resources relevant to different possible physical architectures, as well as variants of specific assumptions that enter the complexity-theoretic arguments. Our proofs invoke ideas from measurement-based quantum computation. Finally, we show how all considered state preparations can be certified using translation-invariant local measurements. This yields a rigorous certificate that the measurement outcomes originate from the considered distribution giving rise to the situation in which the correctness of the quantum state preparation can be certified.

Q 47.5 Thu 15:45 P 2

An efficient quantum algorithm for spectral estimation — •Adrian Steffens[1,2], Patrick Rebentrost[2], Iman Marvian[2], Jens Eisert[1], and Seth Lloyd[2,3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139 — [3]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

We develop an efficient quantum implementation of an important signal processing algorithm for line spectral estimation: the matrix pencil method, which determines the frequencies and damping factors of signals consisting of finite sums of exponentially damped sinusoids. Our algorithm provides a quantum speedup in a natural regime where the sampling rate is much higher than the number of sinusoid components. Along the way, we develop techniques that are expected to be useful for other quantum algorithms as well – consecutive phase estimations to efficiently make products of asymmetric low rank matrices classically accessible and an alternative method to efficiently exponentiate non-Hermitian matrices. Our algorithm features an efficient quantum-classical division of labor: The time-critical steps are implemented in quantum superposition, while an interjacent step, requiring only exponentially few parameters, can operate classically. We show that frequencies and damping factors can be obtained in time logarithmic in the number of sampling points, exponentially faster than known classical algorithms.

Q 47.6 Thu 16:00 P 2

Fidelity witnesses for certifying digital quantum simulations of fermionic linear optics — •Marek Gluza[1], Martin Kliesch[2], Jens Eisert[1], and Leandro Aolita[3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]National Quantum Information Centre, University of Gdansk, Poland — [3]Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

Recently, digital quantum simulations in platforms based on trapped ions, cavity QED and superconducting circuits have been reported in which systems consisting of few qubits were evolved under a programmable set of gates. These studies were successfully certified by quantum state tomography, which will not be possible in future simulations of larger systems due to the exponential growth of the Hilbert space dimension.

We address this conceptual issue by employing ideas of geometrical separation and importance sampling in order to construct a fidelity witness. Specifically, we provide a method to efficiently certify preparations of pure Gaussian fermionic target states, which are captured by the formalism of fermionic linear optics. Moreover, we apply our fidelity witness to dynamical quenches in the paradigmatic critical transverse field Ising model and additionally describe possible applications to adiabatic quantum computation. The number of state preparations needed to certify the fidelity of prepared states is a polynomial of a small degree in the number of the system's constituents, which allows for the certification of scalable quantum simulations.