Q 60: Quantum Computing and Simulation I

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

Q 60.1 Fri 11:00 Aula

A quantum perceptron gate and a classical Toffoli gate with microwave-driven trapped ions — •Patrick H. Huber[1], Patrick Barthel[1], Sougato Bose[3], Juan José García-Ripoll[4], Johann Haber[1], Yasser Omar[2], Sagar Pratapsi[2], Erik Torrontegui[4], and Christof Wunderlich[1] — [1]University of Siegen, Germany — [2]Universidade de Lisboa, Portugal — [3]University College London, UK — [4]Instituto de Física Fundamental IFF-CSIC, Madrid, Spain

Direct implementation of multi-qubit gates with three or more qubits circumvents decomposition into two-qubit operations, effectively reducing the required depth of quantum circuits. Using the inherent all-to-all coupling in a trapped ion quantum computer, we experimentally realize classical Toffoli and perceptron gates with three microwave-driven hyperfine qubits using $^{171}\mathrm{Yb}^+$ ions. The classical Toffoli gate is used to efficiently implement a half-adder. The perceptron gate, when nested with other perceptrons, can be used as universal approximator. Both, the perceptron and Toffoli gates are implemented by a continuous microwave driving field, while the qubits' coherence is protected by pulsed dynamical decoupling. We report the implementation of a two-layer neural network using successive perceptron gates. Here the $^{171}\mathrm{Yb}^+$ ions are stored in a linear Paul trap exposed to a permanent magnetic field gradient.

Q 60.2 Fri 11:15 Aula

Fast, high-fidelity gates on trapped-ion qubits at Oxford Ionics — •Clemens Löschnauer[1], Amy Hughes[1], Raghavendra Srinivas[1], Jacopo Mosca Toba[1], Marius Weber[1], Maciej Malinowski[1], Roland Matt[1], Steven King[1], Clemens Matthiesen[1], Thomas Harty[1], and Chris Ballance[1,2] — [1]Oxford Ionics, Oxford, UK — [2]Department of Physics, University of Oxford, Oxford, UK

Electronic control of trapped-ion qubits using oscillating magnetic field gradients has delivered some of the highest-fidelity quantum gates ever reported [1, 2]. However, two-qubit entangling operations using this method are typically slower than laser-based gates, limiting overall computing speeds. We demonstrate high-fidelity two-qubit entangling gates with a duration of 100 μs using a chip trap with integrated microwave antenna, thereby reaching the typical speed of laser-based gates in a highly scalable architecture.

[1] T. P. Harty *et al.*, *Phys. Rev. Lett.* **117**, 140501 (2016)

[2] R. Srinivas *et al.*, *Nature* **597**, pp 209-213 (2021)

Q 60.3 Fri 11:30 Aula

Register-based trapped-ion quantum processor on a linear paul trap — •Rodrigo Munoz[1], Florian Ungerechts[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

A promising approach for a trapped-ion based quantum computer is the quantum-charge-coupled-device architecture, as it enables scalability by use of micro-fabrication methods. While using a junction naturally allows all-to-all connectivity of the qubit-array, it is more time efficient to resort to swapping operations for a certain fraction of qubit-shuffles. We present a trap design based on a linear Paul trap that is capable of driving near-field gradient two-qubit gates as well as swapping, merging and splitting two-ion crystals. It also features storage registers using the bucket brigade approach. We will show simulation results that allow extraction of ions from the storage registers as well as merging and swapping.

Q 60.4 Fri 11:45 Aula

Chip based integrated photonics - one key element for upscaling the performance of ion-based quantum computer — •Steffen Sauer[1,2,3], Anastasiia Sorokina[1,2], Carl Grimpe[3], Guochun Du[3], Elena Jordan[3], Fatemeh Salahshoori[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany

The use of compact, robust, and highly scalable quantum experiments will become an increasingly important factor in the coming decades. Chip-integrated photonics offers the perfect solution for a wide range of applications in quantum technology. By miniaturizing and integrating photonic components into a chip, advantages such as improved control and manipulation of light (beam waists of a few μm) to atoms are made possible. Combined with surface traps for ions, photonic layers in the trap realize the scalability of ion-based quantum computers. Within the joint project ATIQ, we develop integrated photonics for an ion-based quantum computer with the goal to realize 40 qubits (ions). We present simulations and measurements of our integrated optical components, such as waveguides or outcouplers, chip designs, and characterization setups for linear and circular light across the UV to IR wavelength range.

Q 60.5 Fri 12:00 Aula

Trapped-ion electric field gates — •Rima X. Schüssler, Matteo Mazzanti, Clara Robalo Pereira, Nella Diepeveen, Louis Gallagher, Zeger Ackerman, Arghavan Safavi-Naini, and Rene Gerritsma — University of Amsterdam, Amsterdam, The Netherlands

Trapped ions are an optimal platform for quantum computation. We plan to combine ions with optical microtraps and oscillating electric fields for a new type of two-qubit geometric phase gate, shown theoretically in [1]. This gate has the advantage that it does not require ground state cooling of the ions. Additionally, the ions involved in the gate can be freely chosen by aligning the tweezers on them. As the electric field couples to all ions equally, the gate works even in very long ion chains.

In our experiment, we use an equidistant ion chain of $^{171}\mathrm{Yb}^+$ ions in a segmented 3D Paul trap. The tweezer shape are produced by a spatial light modulator, while single ion addressing is done by an acousto optical deflector.

The current experimental status as well as steps taken to align the tweezers on the ions will be presented.

[1] Mazzanti, M., Schüssler, R.X., Espinoza, J.A., Wu, Z., Gerritsma, R. and Safavi-Naini, A., 2021. Trapped Ion Quantum Computing Using Optical Tweezers and Electric Fields. Physical Review Letters, 127(26), 260502

Q 60.6 Fri 12:15 Aula

Fast, robust and laser-free universal entangling gates for trapped-ion quantum computing — •Markus Nünnerich[1], Patrick Barthel[1], Patrick Huber[1], Dorna Niroomand[1], Christof Wunderlich[1], Daniel Cohen[2], and Alex Retzker[2] — [1]Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany — [2]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

Entangling gates are an essential building block of any quantum processor, ideally working at high speeds in a in a robust and scalable manner. We introduce and experimentally realize a novel Mølmer-Sørensen-type entangling gate. We implement double-dressing of qubit states [1], thus protecting their coherence and simultaneously inducing the gate interaction. Only a single modulated RF driving field per ion is used. The gate is implemented with trapped 171Yb+-ions in a static magnetic gradient of 19 T/m. We generate symmetric and antisymmetric Bell states in 300 us with fidelities better than 97 %. This is an order-of-magnitude improvement in gate time compared to previous entangling gates using the same small magnetic gradient. [2, 3]. In higher magnetic field gradients, already available, this entangling gate speed can be further improved.

[1] D. Farfurnik et al, Phys. Rev. A, 96, 013850 (2017) [2] Ch. Piltz et al, Sci. Adv.2, e1600093 (2016) [3] P. Barthel et al, New J. Phys., 25, 063023 (2023)

Q 60.7 Fri 12:30 Aula

Towards an entangling gate between bosonic qubits in

trapped ions — •Stephan Welte, Moritz Fontboté-Schmidt, Martin Wagener, Edgar Brucke, Paul Röggla, Ivan Rojkov, Florentin Reiter, and Jonathan Home — ETH Zurich, Zurich, Switzerland

Encoding quantum information in a harmonic oscillator provides a resource-efficient platform for quantum error correction. A promising code is Gottesman-Kitaev-Preskill (GKP) encoding [1], which was realized both in trapped ions [2, 3] and superconducting qubits [4]. State preparation, single qubits rotations, readout, and error correction have been realized in both architectures. However, a universal two-qubit gate has yet to be demonstrated. I will describe our work towards an entangling gate between GKP qubits prepared in the motional modes of Calcium ions in a Paul trap. The modes are coupled via the Coulomb repulsion approximating a beam splitter interaction. Together with squeezing operations, this interaction can realize the desired universal gate. In theoretical work, we investigate this gate for experimentally realistic parameters and finite energy states [5]. In parallel, we are developing an apparatus for an experimental implementation, including the fabrication of a novel ion trap and the implementation of individual addressing with tightly focused laser beams. [1] D. Gottesman, A. Kitaev, and J. Preskill. PRA 64, 012310 (2001) [2] C. Flühmann et al. Nature 566, 513(2019) [3] B. de Neeve et al. Nat. Phys. 18, 296 (2022) [4] V. Sivak et al. Nature 616, 50 (2023) [5] I. Rojkov et al. arXiv:2305.05262 (2023)

Q 60.8 Fri 12:45 Aula

Multi-Band Matching Network for a Microwave Surface-Electrode in a High Fidelity Trapped-Ion Quantum Processors — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Janina Bätge[2], Teresa Meiners[2], Brigitte Kaune[2], Dirk Manteuffel[1], and Christian Ospelkaus[2,3] — [1]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstr. 9A, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100,38116 Braunschweig, Germany

Trapped-ion quantum processors with integrated microwave conductors for near-field quantum control are a promising approach for scalable quantum computers. To reduce error sources and allow high fidelity it is not only the microwave electrode integrated in the processor chip that has to be designed carefully. The connection to the source must as well be efficiently designed to enable error reduction. Different approaches to match integrated and external sources to the quantum processors microwave electrode are presented. Here, the reduction of error sources due to inherent electromagnetic behavior and sensitivity to fabrication tolerances are the main focus. The main problem sources and methods to overcome them are discussed. These include electromagnetic simulations and measurement routines.