Q 47: Quantum Information: Quantum Computer

Time: Thursday 10:30–12:45 Location: BAR Schön

Q 47.1 Thu 10:30 BAR Schön

Digital quantum simulation with trapped ions — Benjamin P. Lanyon^{1,2}, •Cornelius Hempel^{1,2}, Markus Müller^{1,3}, Florian Zähringer^{1,2}, Markus Rambach^{2}, René Gerritsma^{1}, Philipp Schindler^{2}, Daniel Nigg^{2}, Julio T. Barreiro^{2}, Markus Hennrich^{2}, Rainer Blatt^{1,2}, and Christian F. Roos^{1} — ^{1}Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria — ^{2}Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — ^{3}Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

A universal quantum simulator is a highly controllable quantum system that can be programmed to efficiently simulate the dynamics of any other quantum system with local interactions. The long term goal is to use such a device to gain new insights into quantum systems, which are believed to be permanently beyond the calculating power of the conventional classical model of information processing. Quantum simulations performed to date have been 'analog', whereas in this work we demonstrate an alternative and potentially more powerful approach known as digital quantum simulation [1]. We use a system of trapped ions, on which a finite set of coherent operations is performed, to simulate a range of different systems of interacting spin-1/2 particles, including the Ising, XY and Heisenberg models. Using complex stroboscopic sequences of up to 80 coherent operations, we achieve accurate digital simulations of both time-independent and time-dependent dynamics. [1] Lloyd, S., Science 273, 1073 (1996).

Q 47.2 Thu 10:45 BAR Schön

Quantum memories based on engineered dissipation — •Fernando Pastawski, Lucas Clemente, and Ignacio Cirac — Max-Planck-Institut für Quantenoptik Hans-Kopfermann-Str. 1 D-85748 Garching, Germany

Storing quantum information for long times without disruptions is a major requirement for most quantum information technologies. A very appealing approach is to use *self-correcting* Hamiltonians, i.e. tailoring local interactions among the qubits such that when the system is weakly coupled to a cold bath the thermalization process takes a long time. Here we propose an alternative but more powerful approach in which the coupling to a bath is engineered, so that dissipation protects the encoded qubit against more general kinds of errors. We show that the method can be implemented locally in four dimensional lattice geometries by means of a toric code, and propose a simple 2D set-up for proof of principle experiments.

Q 47.3 Thu 11:00 BAR Schön

Deterministic entanglement of ions in separate traps — •Maximilian Harlander^{1}, Regina Lechner^{1}, Michael Brownnutt^{1}, Wolfgang Hänsel^{1,2}, and Rainer Blatt^{1,2} — ^{1}Institut für Experimentalphysik, Universität Innsbruck — ^{2}Institut für Quantunoptik und Quanteninformationsbearbeitung, Innsbruck

Trapped-ion systems are a promising candidate to experimentally realize a powerful quantum information processor. A major challenge achieving this goal is scaling such systems to large numbers of ions. In 2000 Cirac and Zoller presented a route to interconnect neighbouring, independently trapped ions by using the small dipole moment of their oscillations as a quantum-mechanical link. Since the dipole-dipole interaction strength between ions at distance d scales with $1/d^3$, microfabrication techniques are neccessary to create separate potential wells at distances at the scale of tens of microns. The experimental demonstration of quantum information exchange is reported between ions in two potential wells separated by $54\,\mu$m. This enables possible schemes to provide entangling gates between two trapping zones, using a Mølmer-Sørensen type interaction.

Q 47.4 Thu 11:15 BAR Schön

Coherent Photon Conversion enabling Nonlinear Optical Quantum Computing — Nathan K. Langford^{1,2}, •Sven Ramelow^{1,2}, Robert Prevedel^{1,2}, William J. Munro^{3}, Gerard J. Milburn^{4}, and Anton Zeilinger^{1,2} — ^{1}University of Vienna, Austria — ^{2}IQOQI Vienna, ÖAW, Austria — ^{3}NTT Laboratories, Japan — ^{4}University of Queensland, Australia

Photonic systems offer many advantages for quantum information technologies such as minimal decoherence and almost trivial single qubit operations. The key unresolved challenges for a working optical quantum computer are scaleable on-demand single photon sources; deterministic two-photon interactions; and near 100%-efficient detection. Here, we introduce a novel four-wave mixing process called coherent photon conversion (CPC). This process potential provides a very wide range of tools for optical quantum information processing and promises to enable scalable sources, efficient detection and deterministic entangling gates. The CPC process is a pumped $\chi(3)$ interaction inducing an effective $\chi(2)$ nonlinearity which is enhanced by the pump power. With a single-photon input and high enough effective nonlinearity deterministic photon doubling can be achieved - one key element in our scheme. We present first experiments with photonic crystal fibers that demonstrate the four-colour nonlinear process underlying CPC. We observe correlated photon-pair production at the predicted wavelengths, experimentally characterise the enhancement of the interaction strength by varying the pump power and discuss how to reach the near-deterministic regime with current technology.

Q 47.5 Thu 11:30 BAR Schön

Scalable Architecture for a Room Temperature Solid-State Quantum Information Processor — Norman Y. Yao^{1}, Liang Jiang^{2}, Alexey V. Gorshkov^{2}, Peter Maurer^{1}, •Geza Giedke^{3}, J. Ignacio Cirac^{3}, and Mikhail D. Lukin^{1} — ^{1}Physics Department, Harvard University, Cambridge, MA 02138, USA — ^{2}Institute for Quantum Information, California Institute of Technology, Pasadena, CA 91125, USA — ^{3}Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany

We propose and analyze an architecture for a scalable, solid-state quantum information processor capable of operating at or near room temperature. Our approach is based upon recent experimental advances involving Nitrogen-Vacancy color centers in diamond. The architecture involves a hierarchy of control at successive length scales and makes use of nuclear-spin quantum memory and dark-spin chains to couple different NV senters. The architecture is applicable to realistic conditions which include disorder and relevant decoherence mechanisms.

Q 47.6 Thu 11:45 BAR Schön

Controlling qubit arrays with XXZ Heisenberg interaction by acting on a single qubit — •Vladimir M. Stojanovic^{1}, Rahel Heule^{1}, Christoph Bruder^{1}, and Daniel Burgarth^{2} — ^{1}Department of Physics, University of Basel, Switzerland — ^{2}Institute for Mathematical Sciences, Imperial College London, United Kingdom

With the aim of exploring local quantum control in arrays of interacting qubits, we study anisotropic XXZ Heisenberg spin-1/2 chains with control fields acting on one of the end spins. In this work, which hinges on a recent Lie-algebraic result pertaining to the local controllability of spin chains with "always-on" interactions, we determine piecewise-constant control pulses corresponding to optimal fidelities for quantum gates such as spin-flip, controlled-NOT, and square-root-of-SWAP. We find the minimal times for realizing different gates depending on the anisotropy parameter of the model, showing that the shortest gate times are reached for particular values of this parameter larger than unity. To study the influence of possible imperfections in anticipated implementations of qubit arrays, we analyse the robustness of the obtained gate fidelities to random variations in the control-field amplitudes and finite rise time of the pulses. Finally, we discuss the implications of our findings for superconducting charge-qubit arrays.

Q 47.7 Thu 12:00 BAR Schön

Continuous-variable quantum logic gate decompositions — •Seckin Sefi and Peter van Loock — Max Planck Institute for the Science of Light, Erlangen, Germany

We will present a general and efficient method for decomposing an arbitrary exponential operator of bosonic mode operators into a set of universal logic gates [1]. Our work is mainly oriented towards the field of continuous-variable quantum computation, but our results might have implications on any field that incorporates exponential operator decompositions such as quantum control, discrete-variable quantum computation or Hamiltonian simulation. We will also discuss possible optical experimental implementations.

[1]arXiv:quant-ph/1010.0326

Q 47.8 Thu 12:15 BAR Schön

Holonomic quantum computing using symmetry-protected topological order — •Joseph M. Renes[1], Akimasa Miyake[2], Gavin K. Brennen[3], and Stephen D. Bartlett[4] — [1]TU Darmstadt, Darmstadt, Germany — [2]Perimeter Institute, Waterloo, Canada — [3]Macquarie University, Sydney, Australia — [4]University of Sydney, Sydney, Australia

We propose an architecture for performing holonomic quantum computation via local adiabatic control of at most two-body nearest-neighbor interactions. Logical qubits are constructed from the degenerate gapped ground states of Haldane phase spin-1 chains, and logical gates are executed by manipulating the boundary spins. The computational scheme inherits significant robustness to disorder and noise from the symmetry-protected topological order of the Haldane phase. Similarity to the circuit model provides a means of ensuring fault-tolerance, and the architecture could feasibly be implemented with current state of the art technology. We illustrate this by describing an implementation based on ultracold polar molecules trapped in optical lattices.

Q 47.9 Thu 12:30 BAR Schön

Catalysis and activation of magic states in fault tolerant architectures — •Earl Campbell — Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

Fault tolerance techniques enable quantum computers to operate despite noise. In many architectures, fault tolerant quantum computing is achieved by a combination of fault tolerant coherent dynamics, preparation of cold qubits in an appropriate quantum state, and measurements. Typically, the fault tolerance coherent dynamics can be simulated efficiently by a classical computer, as they are within the so-called Clifford group. To promote the device beyond a classical computer, cold qubits must be available in a “magic state”, which is a suitable nonstabilizer state. These magic states constitute a resource for driving the fault tolerant quantum computation, and are consumed throughout the computation. Here we propose novel protocols that exploit multiple species of magic states in surprising ways, providing insights into a comprehensive resource theory of magic states. Our protocols provide examples of previously unobserved phenomena that are analogous to catalysis and activation well known in entanglement theory. Magic state catalysis demonstrates that catalytic resources can enable useful transformations without depleting the resource. The phenomena of magic state activation exploits bound magic states, which appear to be computationally inert when they are the only available resource. However, our protocols show that bound resources can be utilized when accompanied by an activating resource.