BOOK OF ABSTRACTS

TALKS

SFB BEYONDC

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CAMPUS TECHNIK UNIVERSITY OF INNSBRUCK

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1. TOWARDS EXTENDING THE STORAGE TIME FOR REMOTE ENTANGLEMENT IN A QUANTUM NETWORK NODE WITH AN INTEGRATED OPTICAL CAVITY

JAMES BATE I UIBK

Memory coherence time is a critical parameter in a network node. The trapped-ion platform has achieved record memory coherence times of tens of seconds and more and, separately, ion-trap network nodes with integrated cavities offer powerful capabilities for interfacing with photons. However, bringing these capabilities together without significant compromise has not yet been achieved. In this talk I will report on progress towards realising two methods to extend the memory coherence time in our cavity-integrated ion-trap system. The first technique uses radio-frequency spin echos to protect the ion-qubit from magnetic field noise. The second technique encodes the ion-qubit into a decoherence free-subspace formed by entangled states of two co-trapped ions. We'll show promising early results towards storing entanglement between an ion and a photon for many seconds.

2. SPIN SQUEEZING AND ENTANGLEMENT GENERATION IN TWO-DIMENSIONAL ION CRYSTALS WITH UP TO 105 IONS

MATTHIAS BOCK I UIBK

Linear strings of trapped ions are a well-established platform for quantum simulation. However, linear strings feature some drawbacks, such as difficulties in scaling the system size beyond 50. Here we present our ion trap apparatus which is capable of trapping and coherently manipulating two-dimensional ion crystals of up to 105 Ca ions. In the first part we will briefly present techniques to cool and control large planar ion crystals as well as some experiments to characterize their properties. In the second part we present laser-mediated coupling of the spin state to the motional modes and the realization of the long-range transverse Ising model. To assess the performance of our quantum simulator we implement a recently developed protocol to create spin-squeezed states. We show the creation of highly-squeezed states with Wineland parameters of more than 8dB for up to 105 particles which verifies multi-partite entanglement in planar ion crystals.

3. WAVEGUIDE INTERFEROMETERS FOR FUNDAMENTAL INVESTIGATION OF QUANTUM MECHANICS

SEBASTIAN GSTIR I UIBK

Quantum mechanics is built upon a set of axioms and in our work, we choose two to investigate experimental platforms to test them for violations. The first axiom is Born's rule, which establishes the connection between quantum mechanical wave functions and measurable probabilities. The second axiom is about the number system used to describe quantum mechanical states. Whereas Born's rule is indirectly tested via probing for the existence of higher-order interference, the second axiom is tested by probing whether hypercomplex numbers are needed to describe quantum mechanical states. We show two high-performance interferometers realised in two distinct photonic waveguide platforms (fused silica and Si_3N_4, respectively), both designed for each of the two tests. We benchmark their performance running each test with classical light and analyse the impact of different error sources on the measurements. The main limitations of these experiments are crosstalk and residual shutter transmission.

4. TOWARDS EXPLAINABLE QUANTUM ARTIFICIAL INTELLIGENCE

MARIUS KRUMM I UIBK

Probably the most promising application of near-term quantum computers is quantum machine learning. Currently, classical machine learning (ML) is revolutionizing science and technology. Many applications of machine learning have a direct impact on the life of humans, such as automated medical diagnosis. Therefore, it is crucial to develop methods that allow to understand AI decisions. This lead to the classical field of explainable artificial intelligence (XAI). However, most quantum machine learning research focuses on the search for a quantum advantage regarding efficiency. This focus neglects the severe problem that the counter-intuitive nature of quantum physics introduces extra obstacles for explaining the decision making process. In this talk, I will present approaches that help to make quantum artificial intelligence more understandable, focusing on two of them. The first focus point is given by quantum causal models. These are quantum analogues of classical causal models which explain statistical data in terms of cause-effect relations. The second focus point is the quantization of classical models which are by design interpretable. The central example for an interpretable classical machine learning method will be projective simulation (PS), which was recently quantized in a linear optics setting.

5. LOWER BOUNDS ON GROUND-STATE ENERGIES OF LOCAL HAMILTONIANS THROUGH THE RENORMALIZATION GROUP

ILYA KULL I UNIVIE

Optimization problems occurring in quantum many-body physics, such as determining the ground-state properties of a system, are often addressed through the variational ansatz approach. This has led to unprecedented accuracy, but---because of its variational nature---only gives us one-sided approximations: upper bounds on the ground-state energy. Complementary to this is the relaxation approach in which the optimization problem is simplified by omitting constraints, thus leading to lower bounds. Relaxation methods have been used to study many-body systems in physics and chemistry since the 50s and have also been an important tool in tackling problems in quantum information theory. Such methods, however, suffer from an exponential scaling of complexity with the accuracy of the solution, which is limiting their performance. In contrast, variational tensor-network methods which are based on renormalization exhibit polynomial scaling. In this talk I will describe an approach that allows to compress relaxations of many-body problems by applying a renormalization procedure to the constraints involved. I will present the results we obtained with this method for translation-invariant spin chains where we observe a polynomial scaling of the complexity with the accuracy. I will also outline how this approach cab be applied to address further problems in quantum many-body physics and quantum information.

6. THE RANDOMIZED MEASUREMENT TOOLBOX

RICHARD KÜNG I JKU

The complexity of large quantum systems is the source of computational power but also makes them difficult to control precisely or characterize accurately using measured classical data. We review protocols for probing the properties of complex many-qubit systems using measurement schemes that are practical using today's quantum platforms. In these protocols, a quantum state is repeatedly prepared and measured in a randomly chosen basis; then a classical computer processes the measurement outcomes to estimate the desired property. The randomization of the measurement procedure has distinct advantages that range from *tractability* (easy to implement on current architectures) to *scalability* (can be extended to 100s of qubits) and *trustworthyness* (comes with rigorous performance guarantees).

7. RYDBERG-BLOCKADE-BASED PARITY QUANTUM OPTIMIZATION

MARTIN LANTHALER I UIBK

A major research effort in quantum information science focuses on exploring a potential quantum advantage in the solution of combinatorial optimization problems on near-term quantum devices. A particularly promising platform implementing quantum optimization algorithms are arrays of trapped neutral atoms, laser coupled to highly excited Rydberg states. However, encoding arbitrary combinatorial optimization problems in atomic arrays is challenging due to limited interqubit connectivity of the finite-range dipolar interactions. Here, we present a scalable architecture for solving higher-order constrained binary optimization problems on current neutral-atom hardware operating in the Rydberg blockade regime. A paradigmatic combinatorial optimization problem directly encodable on such devices is the maximum-weight independent set (MWIS) problem on disk graphs. We extend this approach to generic combinatorial optimization problems by utilizing the recently developed parity encoding of arbitrary connected higher-order constrained optimization problems. The parity encoding only requires problem-encoding local fields and problem-indepedent quasi-local interactions among 2 x 2 plaquettes of nearest-neighbor physical qubits on a square lattice geometry. We formulate the required plaquette-logic as MWIS problem, which allows one to build our architecture from small MWIS modules in a problem-independent way, crucial for practical scalability. Furthermore, we provide an efficient method to compensate for the long-range interaction tails of the van der Waals interaction between Rydberg atoms.

8. SIMULATING LATTICE GAUGE THEORIES WITH QUDITS

MICHAEL METH I UIBK

Representing information in a binary format was carried over from the classical computing to the quantum world. Most quantum systems however offer a manifold of states beyond two logical states zero and one. In such qudits, information is encoded in higher dimensions, allowing for a more natural description of many problems found in nature. A prime example for such a problem is lattice gauge theories, which describe the fundamental interaction between matter and forces, mediated by high-dimensional gauge fields. We demonstrate ways to design controlled interactions in a universal qudit quantum processor and discuss applications for the simulation of lattice gauge theories.

9. SOLVING RANK CONSTRAINED SDPS IN POLYNOMIAL TIME

JOSHUA MORRIS I UNIVIE

Often in physics, one can fully understand a problem yet be unable to actually compute it. Orbital mechanics has been studied for hundreds of years yet a closed form solution to the three body problem remains elusive. Many body physics has brilliantly accurate approximations that are needed to sidestep the monstrous computational requirements an exact calculation would require and in the recent renaissance that semidefinite programming has enjoyed, rank constraints are firmly in the class of hard-to-compute. We consider a subset of the latter such problem wherein a rapidly converging algorithm may be constructed. We show that optimising over the semidefinite cone with a rank constraint and only additional linear constraints yields fast solutions for a class of open problems in quantum physics, including the pure state case of the quantum marginal problem and the identification of unistochastic matrices.

10. QUANTUM ELECTRO-OPTICS: TOWARDS SUPERCONDUCTING QUANTUM NETWORKS

LIU QIU I ISTA

Recent advances in quantum technologies have enabled quantum control and engineering in various microscopic systems. A timely formidable task is to construct a hybrid quantum network, by leveraging full potential of individual quantum systems, including microwave superconducting quantum circuit. Cavity electro-optics offers a promising route to quantum microwave-optical transduction and distributed quantum entanglement between superconducting circuits over optical networks. In this work, I will discuss about our recent results in quantum electro-optics, including optical coherent control of superconducting microwave cavity, microwave-optical quantum transduction and entanglement generation, using an electro-optical (EO) device. Our experiments establish a general platform for quantum optical manipulation of superconducting microwave circuits using microwave photonics, and offers a viable route towards optical quantum networks of superconducting quantum processors.

11. SIMULATING QUBIT CORRELATIONS WITH CLASSICAL COMMUNICATION

MARTIN RENNER I UNIVIE

Cancelled.

12. EXPERIMENTAL ASPECTS OF INDEFINITE CAUSAL ORDER IN QUANTUM MECHANICS

LEE ROZEMA I UNIVIE

The field of indefinite causal order in quantum mechanics has seen more and more interest in recent years. In such processes, multiple parties act in a superposition of different orders. Since the first experimental realization of a process with an indefinite causal order, the quantum SWITCH, a host of protocols taking advantage of this new resource have emerged. Previous work verified their experimental implementations by measuring so-called 'causal witnesses' or by demonstrating advantages at specific tasks. Nevertheless, the full process matrix has only never been measured. In this talk I will present our complete experimental reconstruction of the quantum SWITCH. To enable this procedure, we developed a new passively-stable fiber-based architecture for the quantum SWITCH based on time-bin encoded qubits. This architecture is based on ultra-fast optical switches, providing a route to scale processes with an indefinite causal order up to more parties in the near future.

13. QUANTUM SIMULATION ON NOISY DEVICES

DOMINIK WILD I MPQ

The simulation of quantum systems is among the most promising near-term applications of quantum computers. On current devices, however, the maximum simulation time is limited by noise and the dynamics remain classically tractable. In this talk, I will present a set of tools that extends the reach of noisy quantum computers. I will show that large Trotter steps work astonishingly well due to the phenomenon of Floquet prethermalization. By combining this insight with an error mitigation scheme for local observables, we are able to significantly extend the range of accessible simulation times. We predict that beyond-classical quantum simulation will be within reach for superconducting qubits with modest improvements over current noise rates. Based on join work with Y. Yang, A. Christianen, S. Coll-Vinent, V. Smelyanskiy, M. C. Bañuls, T. E. O'Brien, and J. I. Cirac.

14. GARFIELD STATES IN SUPERCONDUCTING CIRCUITS (IN HIGH Q CAVITIES)

IAN YANG I ISTA

The observation of quantum phenomena often needs sufficiently pure states, a requirement that can be challenging to achieve. For example, in circuit QED experiments, filters and attenuators in the drive and measurement lines are used to prevent thermal noise reaching the quantum systems. In this talk, I will show how we prepare a non-classical state originating from a mixed state, utilising dynamics that preserves the initial purity of the state. We generate a Schrödinger's cat state within a high coherence microwave cavity, operating at a mode temperature of up to two Kelvin, which is one hundred times hotter than its environment, using a unitary interaction with a transmon qubit. Our experimental findings have implications for other bosonic degrees of freedom, such as the motion of a massive particle, and they reduce the purity requirements of the initial state for certain quantum state generation protocols.