Quantum Computing – From Algorithms to Applications

Universitätszentrum Obergurgl,

15.-19. April 2019

time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7:30 – 8:30	Arrival	breakfast	breakfast	breakfast	breakfast	reakfast	breakfast
							Departure
8:30 – 9:15		M. Lukin	L. Rozema	J. Home	A. Walraff	T. Karzig	
9:15 – 10:00		H. Pichler	A. Laing	Rick v Bijnen	S. Sheldon	C. Marcus	
10:00 – 10:30		coffee	coffee	coffee	coffee	coffee	
10:30 – 11:15		Xiao Xue	Ding Xing	H. Biegel	N. Wiebe	Y. Herasymenko. J. Tura	
11:30 – 16:00		free time	free time	free time	free time	free time	
11:30 – 16:30		coffee / snacks	coffee / snacks	coffee / snacks	coffee / snacks	coffee / snacks	
16:30 – 17:15		I. Cirac	J. Emerson	T. Monz	Y. Guryanova H Poulsen Nautrup	M. Troyer	
17:15 – 18:00		discussion Rydberg / qu. dots	discussion photons	discussion atoms / ions	discussion solid state	discussion resources	
19:00 – 20:30	dinner until late	dinner	dinner	dinner	dinner	dinner	
evening		discussion @ bar	poster	discussion @ bar	poster	discussion @ bar	

Overview workshop program

Monday

08:30 – 09:15	Mikahil D. Lukin *Quantum information processing and programmable quantum simulations using Rydberg atom arrays*
09:15 – 10:00	Hannes Pichler *From many-body physics to quantum information with Rydberg atoms*
10:00 – 10:30	Coffee
10:30 – 11:15	Xiao Xue *Quantum computation and simulation with quantum dots - "spins-inside"*
11:15 – 16:30	free time for discussion and outdoor activities 16h00 Tyrolian snack
16:30 – 17:15	Ignacio Cirac *Solving classical and quantum problems with quantum computers*
17:15	Discussion: QIP implementation with Rydberg atoms and quantum dots

Tueday

08:30 – 09:15	Lee Rozema *Photonic Quantum Information and Quantum Computing*
09:15 – 10:00	Anthony Laing *Quantum simulations in integrated photonics*
10:00 – 10:30	Coffee
10:30 – 11:15	Ding Xing *Towards "quantum supremacy" with photons*
11:15 – 16:30	free time for discussion and outdoor activities 16h00 Tyrolian snack
16:30 – 17:15	Joseph Emerson *Cycle Benchmarking: A. Breakthrough Tool for Benchmarking and Optimizing NISQ-Era Performance for Useful Applications*
17:15	Discussion: QIP implementation with photons
after dinner	*Poster session*

Wednesday

08:30 – 09:15	Jonathan Home *Scaling trapped-ion quantum computing systems*
09:15 – 10:00	Rick v Bijnen *Algorithms for quantum information processing with ion traps*
10:00 – 10:30	Coffee
10:30 – 11:15	Hans Biegel *Learning and artificial intelligence in the quantum domain*
11:15 – 16:30	free time for discussion and outdoor activities 16h00 Tyrolian snack
16:30 – 17:15	Thomas Monz *Ion-trap based quantum computing - Pushing towards fault-tolerance*
17:15	Discussion: QIP implementation with ion traps

Overview workshop program

Thursday

08:30 – 09:15	Andreas Wallraff *Entanglement Stabilization of Superconducting Qubits using Parity Detection and Reals-Time Feedback*
09:15 – 10:00	Sahra Sheldon *Benchmarking NISQ Devices*
10:00 – 10:30	Coffee
10:30 – 11:15	Nathan Wiebe *Outlook for Chemistry: Simulation on Near Term Quantum Computers*
11:15 – 16:30	free time for discussion and outdoor activities 16h00 Tyrolian snack
16:30 – 16:52	Yelena Guryanova *Ideal Projective Measurements Have Infinite Resource Costs*
16:53 – 17:15	Hendrik Poulsen Nautrup *Optimizing Quantum Error Correction Codes with Reinforcement Learning*
17:15	Discussion: QIP implementation with superconducting electronics
after dinner	*Poster session*

Friday

08:30 – 09:15	Torsten Karzig *Scalable quantum computing with Majorana Zero Models*
09:15 – 10:00	Charlie Marcus *The status of Majorana based quantum information processing*
10:00 – 10:30	Coffee
10:30 – 11:52	Herasymenko Yaroslav *Physically motivated ansatz for variational quantum algorithms*
10:53 – 11:15	Tura, Jordi *Quantum heuristics for near-term devices*
11:15 – 16:30	free time for discussion and outdoor activities 16h00 Tyrolian snack
16:30 – 17:15	Matthias Troyer Outlook on Quantum Information Processing
17:15	Discussion: Resources needed to implement QIP

Algorithms for quantum information processing with ion traps

Rick v Bijnen
University of Innsbruck, Austria

Learning and artificial intelligence in the quantum domain

Hans Briegel
University of Innsbruck, Austria

Solving classical and quantum problems with quantum computers

Ignacio Cirac
MPI für Quantenoptik, Germany

In this talk I will address the difficulty of classical computers to solve problems in quantum many-body systems and how quantum computers can considerably speed-up their solution. First, I will review how one can simulate the dynamics of such a system efficiently with quantum devices. Then, I will introduce other algorithms based on phase estimation and amplitude amplification to prepare the state at zero temperature. Finally, I will mention how those and other algorithms could be used with classical problems that can be encoded in the zero temperature states of quantum many-body systems.

Toward “quantum supremacy” with photons

Xing Ding
University of Science and Technology of China, Hefei, P.R. China

Boson sampling is considered as a strong candidate to demonstrate the "quantum supremacy" over classical computers. However, previous proof-of-principle experiments suffered from small photon number and low sampling rates owing to the inefficiencies of the single-photon sources and multi-port optical interferometers [1].

By using a QD-micropillar, we produced single photons with high purity (>99%), near-unity indistinguishability for> 1000 photons [2], and high extraction efficiency [3] all combined in a single device compatibly and simultaneously. By using an elliptical micropillar, we design an excitation-collection scheme that allows the creation and collection of single photons with an indistinguishability of 0.976(1) and a degree of polarization of 91% [4]. With these state-of-the-art QD single photon source, We build 3-, 4-, and 5-bosonsampling machines which runs >24,000 times faster than all the previous experiments, and for the first time reaches a complexity about 100 times faster than the first electronic computer (ENIAC) and transistorized computer (TRADIC) in the human history [5,6].

We also report an experiment on boson sampling with photon loss, and demonstrate that boson sampling with a few photons lost can increase the sampling rate [7]. We implement and validate lossy boson sampling with one and two photons lost, and obtain sampling rates of 187 kHz, 13.6 kHz, and 0.78 kHz for five-, six- and seven-photon boson sampling with two photons lost, which is 9.4, 13.9, and 18.0 times faster than the standard boson sampling, respectively. Our experiment shows an approach to significantly enhance the sampling rate of multiphoton boson sampling.

References:

[l] J.-W. Pan *et al*. Multi-photon entanglement and interferometry, Rev. Mod. Phys **84**, 777 (2012).
[2] H. Wang *et al*. Near transform-limited single photons from an efficient solid-state quantum emitter, Phys. Rev. Lett. **116**, 213601 (2016).
[3] X. Ding *et al*. On-demand sing le photons with high extraction efficiency and near-unity indistinguishability from a resonantly driven quantum dot in a micropillar, Phys. Rev. Lett. **116**, 020401 (2016).
[4] Y.-M. He *et al*. Polarized indistinguishable single photons from a quantum dot in an elliptical micropillar, arXiv 1809.10992 (2018).
[5] H. Wang *et al*. Multi-photon boson-sampling machines beating early classical computers, Nature Photonics **11**, 361 (2017).
[6] Y. He *et al*. Time-bin-encoded boson sampling with a single-photon device, Phys. Rev. Lett. **118**, 190501 (2017).
[7] H. Wang *et al*. Toward Scalable Boson Sampling with Photon Loss. Phys. Rev. Lett. **120**, 230502 (2018).

Cycle Benchmarking: A Breakthrough Tool for Benchmarking and Optimizing NISQ-Era Performance for Useful Applications

Joseph Emerson
University of Waterloo, Canada

In this talk I will describe how the limitations of Randomized Benchmarking are overcome by a new method, called Cycle Benchmarking, which is a scalable and practical tool for diagnosing errors and full-system performance under parallelized and many-body gate operations. In particular, with a small and experimentally practical number of shots for arbitrarily large numbers of qubits, Cycle Benchmarking provides a means to assess the scalability of gate operations and to scalable diagnose cross-talk and other many-body correlated error sources, which are currently the leading bottleneck to robust implementations of quantum algorithms. Cycle Benchmarking also enables a cross-platform benchmarking method, which we call Quantum Processing Power, which overcomes biases and limitations of Quantum Volume and Cross-Entropy Benchmarking, most notably; Quantum Processing Power can assess performance in what I call the Quantum Discovery Regime where quantum solutions cannot be verified by classical computing. Lastly, I will describe how Cycle Benchmarking provides a means to verify the accuracy of quantum solutions under any user-supplied algorithm in the Quantum Discovery Regime, enabling an practical, measurable objective function for systematically optimizing the implementation under both the connectivity and the impact of the diagnosed residual error profile on the circuit implementation.

This is an overview of research progress including contributions from J. Wallman, I. Hincks. A. Dugas, K Boone, S. Flammia, R. Harper, and R. Blatt's research group.

Scaling trapped-ion quantum computing systems

Jonathan Home
ETH Zürich

Quantum error correction is essential for realizing the full potential of large-scale quantum information processing devices, but getting to the level of successful error-correcting codes already requires significant scaling of system size. This raises a number of new challenges, such as crosstalk in the presence of repeated measurement, fast calibration of the qubit system, and the ability to wire up distant parts of a quantum processor. I will describe initial results towards meeting these challenges in the context of trapped-ion qubits, including the use of multi-species ion chains for repeated ancilla readout, Bayesian techniques for calibrating gates and shuttling operations for “flying” qubits. Integration will be a key part of scaling, which for optical fields requires trap chips with integrated optical waveguides. I will describe integrated chips which we have designed, which may allow a significant speed-up of multi-qubit operations. Looking towards further scaling, many apparent challenges appear to lie in the use of radio-frequency traps, including power-dissipation and the need to co-align microscopically varying potentials. I will describe how this might be mitigated using micro-fabricated arrays of Penning traps [2], which would also provide a powerful tool for implementing trapped-ion quantum simulation on a variety of two-dimensional lattices.

[1] V. Negnevitsky, M. Marinelli et al. Nature 563, 527–531 (2018)
[2] S. Jain et al. arXiv:1812.06755 (2018)

Scalable quantum computing with Majorana Zero Modes

Torsten Karzig
Microsoft, USA

I'll present a quick overview of the concept of topological quantum computation and discuss designs for scalable quantum computers composed of qubits encoded in aggregates of four or more Majorana zero modes. Quantum information can be manipulated according to a measurement-only protocol, which is facilitated by tunable couplings between Majorana zero modes and nearby semiconductor quantum dots. I'll, in particular, discuss the stability of such topological qubits and the corresponding qubit operations.

Quantum simulations in integrated photonics

Anthony Laing
University of Bristol, UK

Modelling the dynamics of quantum mechanical systems, including molecules, is generally intractable to classical computational techniques. Such computational overheads may be overcome by utilising quantum simulation techniques, in which a well-controlled quantum system is programmed to mimic the quantum behaviour of another. Recent progress in integrated photonics has seen the advent of high fidelity on-chip processing of photonic quantum information and fully programmable circuitry to establish devices that are universal for linear optics. Progress has also been made in the integration of photon sources and single photon detection. Together with high speed and low loss photonic switches, a versatile class of photonic quantum simulators becomes a realistic prospect. It is hoped that the demands on error correction for specialised quantum simulators could be much lower than those for universal digital quantum simulators. Here we report experimental demonstrations of quantum photonics as a simulation platform for molecular quantum dynamical behaviour. Using the analogy of optical modes in miniaturised waveguides for vibrational modes and single photons for quantised vibrational excitations, we show how to simulate the dynamics of any molecular system in the standard harmonic approximation model. Progress in integrated quantum photonics is also discussed.

Quantum information processing and programmable quantum simulations using Rydberg atom arrays

Mikhail Lukin
Harvard University, USA

We describe the recent advances involving programmable, coherent manipulation of quantum many-body systems using atom arrays excited into Rydberg states. Prospects for realization and testing quantum algorithms using this approach will be discussed.

The status of Majorana based quantum information processing.

Charlie Markus
NBI Copenhagen, Denmark

Ion-trap based quantum computing - Pushing towards fault-tolerance

Thomas Monz
Alpine Quantum Technologies and Universität Innsbruck, Austria

The ion-trap architecture is one of the most promising architectures to realize a scalable quantum computing. In this presentation I will provide a status-update on the ion-trap based quantum computer in Innsbruck: from genuine 16 particle entanglement, via scalable benchmarking demonstrated on up to 10 qubits, to novel methods for theorists to manipulate our quantum computer - in the near future potentially even from their laptop.

From many-body physics to quantum information with Rydberg atoms

Hannes Pilcher
Harvard University, USA

Photonic Quantum Information and Quantum Computing

Lee Rozema
University of Vienna, Austria

The promise of quantum computation and cryptography has led to a race develop practical new quantum technologies, and has spurred on research to efficiently create, detect, and manipulate delicate quantum systems. Photonics has traditionally been a testbed for quantum protocols given the relative ease with which one can create "pretty good" entangled states. Much current research is focused on engineering quantum photonic systems to enable the production and manipulation of larger and higher-quality quantum states suitable for quantum computation. This talk will review our groups progress towards these goals using linear-optics, and introduce our early results characterizing the non-linear response of graphene nanoplasmonic devices with a view towards single-photon level interaction.

Benchmarking NISQ Devices.

Sarah Sheldon
IBM, USA

As the field marches towards quantum advantage with near-term quantum processors, it becomes imperative to characterize, verify, and validate performance. An outstanding scientific challenge in the community is a scalable set of metrics or experiments which can shed light on the usability of a device for near-term algorithms. Moreover, it becomes critical to explore techniques to extend the computational reach of noisy systems, be it through understanding underlying non-idealities, or more efficient circuit compilation. In this talk I will review the work we are doing at IBM to develop a NISQ device and our recent results.

Prospects for Quantum Information Processing

Matthias Troyer
ETH Zürich, Switzerland and Microsoft, USA

Entanglement Stabilization of Superconducting Qubits using Parity Detection and Real-Time Feedback

Andreas Wallraff
Department of Physics, ETH Zurich, Switzerland

Fault tolerant quantum computing relies on the ability to detect and correct errors. In quantum error correction codes this can be achieved by protectively measuring multi-qubit parity operators and subsequently conditioning operations on the observed error syndrome. We experimentally demonstrate the use of an ancillary qubit to repeatedly measure the ZZ and XX parity operators of two data qubits projecting their joint state into a well-defined parity subspace. By applying up to 12 cycles of feedback operations conditioned on the outcome of individual parity measurements we realize real-time stabilization of Bell state with a constant fidelity of up to 74 %. In contrast, when performing the protocol using Pauli frame updates, we observe a continuing decrease in fidelity from cycle to cycle. The ability to stabilize parity over multiple rounds of feedback with no reduction in fidelity provides strong evidence for the feasibility of executing stabilizer codes on timescales much longer than the intrinsic coherence times of the constituent qubits.

[1] C. Kragl und Andersen et al., arXiv:1902.06946 (2019)

This research was performed in a collaboration between Christian Kraglund Andersen, Ants Remm, Stefania Balasiu, Sebastian Krinner, Johannes Heinsoo, Jean-Claude Besse, Mihai Gabureac, Andreas Wallraff, and Christopher Eichler.

Outlook for Chemistry Simulation on Near Term Quantum Computers

Nathan Wiebe
Microsoft, USA

Recent advances in super conducting qubits have opened the possibility of large quantum devices that may offer a tangible quantum advantage relative to classical computers. This potential has raised excitement surrounding the possibility that important problems in chemistry and material science may also be simulated on near term quantum devices. In this talk I will discuss state of the art simulation results and address the question of whether interesting problems in chemistry and material science are likely to be addressable in near term quantum computers. I will then discuss the potential of performing these quantum simulations using quantum error correction and conclude that while some simulation problems seem out of reach for near-term superconducting quantum devices that some problems in material science may one day be within reach.

Quantum computation and simulation with quantum dots – “spins-inside”.

Xiao Xue
Technische Universiteit, Nederlands

In this talk, I will present our vision of a large-scale spin-based quantum processor, and ongoing work to realize this vision in the group of Lieven Vandersypen [1].

First, we have developed a ’N+1’ method to efficiently tune up a linear eight quantum dot array –a ’Qubyte’- into the single electron regime. Combined with virtual gates and video rate data acquisition, we show that we are able to systematically add quantum dots one by one without influencing existing dots [2]. We applied the virtual gates method to a 2X2 array, to obtain full tunability of all the chemical potentials and tunnel couplings [3]. Such a tunable artificial Fermion lattice allowed us to probe phenomena in condensed matter physics that have not been observed before, such as Nagaoka ferromagnetism [unpublished].

Second, we demonstrated a programmable two-qubit system in silicon quantum dots. We can create all Bell states with 85-90% fidelities, and implement simple quantum algorithms [4]. Single-qubit gate fidelities are characterized by randomized benchmarking, giving average fidelities of 98.8% and 92.2% for each qubit. We developed a new method called character randomized benchmarking to characterize two-qubit behaviour. We show a 92.0% fidelity of a two-qubit CPhase gate and negligible crosstalk between the two qubits [5].

Third, we observed strong coupling between a single spin and a single microwave photon in a cavity, which paves the way towards coupling two local registers at a distance [6]. The on-chip resonator can also be used for gate-based dispersive readout [7], removing the need for a charge sensor.

Finally, we have explored the possibility of operating spin qubits at 1-4K, offering potential integration with classical electronics at cryo temperature [8].

[1] L. M. K. Vandersypen, et al., npj Quantum Information 3, 34 (2017).
[2] C. Volk, A. M. J. Zwerver, et al., arXiv: 1901.00426.
[3] U. Mukhopadhyay, J. P. Dehollain, et al., Appl. Phys. Lett. 112, 183505 (2018).
[4] T. F. Watson, et al., Nature 555, 633 (2018).
[5] X. Xue, et al., arXiv: 1811.04002.
[6] N. Samkharadze, G. Zheng, et al., Science 359, 1123 (2018).
[7] G. Zheng, et al., arXiv: 1901.00687.
[8] L. Petit, et al., Phys. Rev. Lett. 121, 076801 (2018).

Ideal Projective Measurements have Infinite Resource Costs

Guryanova Yelena
IQOQI, Vienna, Austria

We show that it is impossible to perform ideal projective measurements on quantum systems using finite resources. We identify three fundamental features of ideal projective measurements and show that when limited by finite resources only one of these features can hold. Our framework is general enough to accommodate any system and pointer models, and their corresponding Hamiltonians. For a pointer that perfectly reproduces the statistics of the system, we provide tight analytic expressions for the energy cost of performing the measurement in terms of the dimension of the systems, as well as the protocol that effects this measurement. The associated cost may be broken down into two parts. Fist, the cost of preparing the pointer in a suitable state, and second, cost of a global interaction between the system and pointer in order to correlate them. Our results show, that, even under the assumpotion that the interaction ca be controlled perfecty, achieving perfect correlation in infinitely expensive.

Physically motivated ansatz for variational quantum algorithms

Herasymenko Yaroslav
Leiden University, Netherlands

One of the most natural and promising applications for a quantum computer is the simulation of quantum systems. In particular, one is typically interested in the low-energy behavior of such systems, which prevents the need to extract the exponentially large amount of information stored on a quantum resister. One method to study such systems is the Variation Quantum Eigensolver. In this approach, the system state is parametrized by externally tunable angles, and explores some sub manifold of the larger Hilbert space, minimizing the energy of the state. This raises an interesting problem of parametrizing only the relevant part of the Hilbert space in the most efficient way possible, to allow us to look for low energy wave functions with fewer quantum resources. In this project, we address this question by presenting a family of natural ansatze for quantum states, along with some general tools to analyze other ansatze.

Optimizing Quantum Error Correction Codes with Reinforcement Learning

Pulsen Natrup Hendrik
University of Innsbruck, Austria

Quantum error correction is widely thought to be the key to fault-tolerant quantum computation. However, determining the most suited encoding for unknown error channels or specific laboratory setups is highly challenging. Here, we present a reinforcement learning (RL) framework for optimizing and fault-tolerantly adapting quantum error correction codes. We consider a RL agent tasked with modifying a quantum memory until a desired logical error rate is reached. Using efficient simulations of a surface code quantum memory with about 70 physical qubits, we demonstrate that such a RL agent can determine near-optimal solutions, in terms of the number of physical qubits, for various error models of interest.

Moreover, the proposed scheme can be employed both for off-line simulations with specified noise models and for on-line optimization for arbitrary, unknown noise. In particular, we discuss how a learning algorithm trained on a simulated environment can transfer its experience to physical setups for further optimization under real conditions, capitalizing on the strength of RL. Maintaining the option to switch from one scenario to another, we can train a learning algorithm on fast simulations with modelled environments before optimizing the code under laboratory conditions.

Quantum heuristics for near-term devices

Tura, Jordi
Max-Planck-Institut für Quantenoptik, Deutschland

In this work we present a method to build a quantum circuit to heuristically minimize the energy of a quantum Hamiltonian under a set of restrictions, such as having a limited number of gates of a given type. The algorithm is based on an adaptive algorithmic cooling procedure, aided by some classical optimization. Algorithms for the so-called NISQ (noisy, intermediate-scale quantum) devices have become an intensive field of research, and in our work we focus on the following directions: first, we benchmark the performance of the algorithm in for a number of qubits $N > 50$, thus going beyond the limits of classical simulation; second, we take into consideration and study the effect of different noise models; and third, we take into account the statistical noise arising from estimating expectation values of operators, thus giving realistic estimates for the number of measurements and actual runtime of the algorithm. Furthermore, the principles our procedure is based upon can be easily exported to specific experimental platforms, where only a restricted subset of operations is typically available, and coherence time is limited.

Poster Presentations

1. **Solid-state electron spin lifetime limited by phononic vacuum modes**
   Astner, Thomas
2. **Many-body States Preparation on Rydberg Lattice Gases via Optimal Control**
   Cui, Jian
3. **Designing ground states of Hopfield networks for quantum state preparation**
   Clemens, Dlaska
4. **Optimal QAOA-Sequences for the LHZ architecture**
   Ender Kilian
5. **Photonic architecture for reinforcement learning**
   Flamini, Fulvio
6. **Rapid counter-diabatic sweeps in lattice gauge adiabatic quantum computing** Hartmann, Andreas
7. **Spin Ensembles in Quantum Solids**
   Kanagin, Andrew
8. **Digital Quantum Simulation, Trotter Errors, and Quantum Chaos of the Kicked Top**
   Olsacher, Tobias
9. **On-demand Semiconductor Source of Entangled Photons Which Simultaneously Has High Fidelity, Efficiency, and Indistinguishability**
   Jian Qin
10. **High-efficiency multiphoton boson sampling**
    Jian Qin
11. **Quantum advantage of the decision-making process using a small-scale trapped-ion processor**
    Sriarunothai Theeraphot
12. **Direct measure of genuine tripartite entanglement independent from bipartite constructions**
    Ziane, Mustapha

Solid-state electron spin lifetime limited by phononic vacuum modes

Astner, Thomas
VCQ, Atominstitut, TU-Wien, Austria

The negatively charged nitrogen-vacancy (NV) center in diamond has attracted significant attention for possible applications in quantum information tasks. It possesses long lifetimes (T1) and spin-phase coherence times (T2) even at room temperature. In hybrid architectures robust coupling between remote ensembles demonstrated that these spin species may open the opportunity for solid-state quantum information transfer [1]. To exploit all features of this spin system, sound knowledge of spin-environment interaction is necessary.

In the solid-state environment, the most fundamental process by which an excited spin ensemble transfers energy to the surrounding is governed by longitudinal relaxation processes. These processes are usually driven by spin-phonon interaction. Here we show a method to study the longitudinal spin-lattice relaxation of large ensembles of NV spins in diamond in the low temperature limit where quantum effects become relevant. Our experiment is based on a cavity quantum electrodynamics framework, where we use a novel 3D lumped element resonator [2]. The spin ensemble is in the strong coupling regime and in the experiment, we measure the spin-lattice relaxation below the single phonon limit. There quantum fluctuations become important and provide the ultimate upper bound for T1 [4]. Remarkably, we find that the low phononic density of states at the NV transition frequency enables the spin polarization to survive over macroscopic timescales of up to 8h [3].

We additionally present a theoretical model that describes the direct spin phonon coupling mechanism and calculate the relaxation rate ab initio based on density functional theory.

[1] T. Astner, S. Nevlacsil, et. al.; Phys. Rev. Lett. **118**, 140502 (2017)
[2] A. Angerer, T. Astner, et. al.; Appl. Phys. Lett. **109**, 089901 (2016)
[3] T. Astner, J. Gugler, et. al.; Nature Mat. **17**, 313-317 (2018)

Many-body States Preparation on Rydberg Lattice Gases via Optimal Control

Cui, Jian
Institute of Quantum Control, Forschungszentrum Juelich, Germany

We present optimal control protocols to prepare different many-body quantum states of Rydberg atoms in optical lattices or optical tweezers. Specifically, we show how to prepare highly ordered many-body ground states, GHZ states as well as thermal equilibrium states, within sufficiently short experimental times minimizing detrimental decoherence effects. For the GHZ states, we optimized a Fisher information detection protocol to experimentally verify the multipartite entanglement of the prepared states based only on standard measurement techniques. Realistic experimental constraints and imperfections are taken into account by our optimization procedure making it applicable to ongoing experiments. Our results suggest that it is possible to realize GHZ states with more than 20 qubits and thermal states with a wide range of effective temperatures based on current experimental technology.

Designing ground states of Hopfield networks for quantum state preparation

Clemens, Dlaska
University of Innsbruck, Institute for Theoretical Physics, Austria

We present a protocol to store a polynomial number of arbitrary bit strings, encoded as spin configuration's, in the approximately degenerate low-energy manifold of an all-to-all connected sing spin glass. The interactive protocol is inspired by machine learning techniques utilizing k-local Hopfield networks trained with-local Hebbian learning and unlearning. The trained Hamiltonians the basis of a quantum state preparation scheme to create quantum many-body superpositions with tenable squared amplitudes using resources available in near term experiments. We find that the number of configurations that can be stored in the ground states, and thus turned into superposition, scales with the k-locality of the Icing interaction.

Optimal QAOA-Sequences for the LHZ architecture

Ender Kilian
University of Innsbruck, Institute for Theoretical Physics, Austria

The quantum approximate optimization algorithm (QAOA) is a variation algorithm to find approximate solutions of combinatorial optimization problems. Many hard optimization problems can be mapped to all-to-all connected spin-models. However, interactions present in any physical system are quasi-local. The LHZ architecture [1] enables the implementation of fully connected Ising Hamiltonians, with only quasi-local interactions. Using this architecture for digital quantum computation further simplifies the physical realization. Moreover, this allows full parallelization of QAOA for arbitrary all-to-all connected problem graphs, independent of the system size. Even though hybrid quantum-classical algorithms are very promising for near-term applications, there is no clear understanding of their performance. The additional degrees of freedom introduced by the LHZ architecture allow for more flexibility in the QAOA protocol, which we use to investigate quantum optimizers. With projective simulation [2] as a reinforcement-learning framework we want to learn optimal QAOA protocols and their dependence on different families of problems.

[1] doi:10.1126/sciadv.1500838
[2] doi:10.1038/srep00400

Photonic architecture for reinforcement learning

Flamini, Fulvio
University of Innsbruck, Institute for Theoretical Physics, Austria

The last decade has seen an unprecedented growth in two seemingly distant fields, artificial intelligence and quantum technologies, whose common goal is to boost current computing capabilities. At the same time, large effort is being devoted to the development of neuromorphic processors that are inspired by neuro-biological systems. A key question, then, is to what extent one can take advantage of their state of the art to design a learning agent that is apt to be tested in a foreseeable future. In this work we take up this challenge within the framework of projective simulation, a recently introduced learning model that is designed from an inherently physical perspective. In this context, we present the blueprint for a photonic implementation of projective simulation that is effective in solving standard problems in reinforcement learning. We numerically investigate its operation both in ideal and in imperfect experimental conditions, showing how realistic levels of noise can be even beneficial during the learning process. The proposed architecture, based on single-photon evolution on a mesh of tunable beam splitters, is simple, scalable and a first integration in a movable system appears to be within the reach of near-term technology.

Rapid counter-diabatic sweeps in lattice gauge adiabatic quantum computing

Hartmann, Andreas
University of Innsbruck, Institute for Theoretical Physics, Austria

We present a coherent counter-diabatic quantum protocol to prepare ground states in the lattice gauge mapping of all-to-all Ising models (LHZ) with considerably enhanced final ground state fidelity compared to a quantum annealing protocol. We make use of a variational method to find approximate counter-diabatic Hamiltonians that has recently been introduced by Sels and Polkovnikov [Proc. Natl. Acad. Sci. 114, 3909 (2017)]. The resulting additional terms in our protocol are time-dependent local on-site y-magnetic fields. These additional Hamiltonian terms do not increase the minimal energy gap, but instead compensate for the Berry curvature. A single free parameter is introduced which is optimized via classical updates. The protocol consists only of local and nearest-neighbour terms which makes it attractive for implementations in near term experiments.

Spin Ensembles in Quantum Solids

Kanagin, Andrew
VCQ, Atominstitut, TU-Wien, Austria

Spin technologies are a prime candidate to usher in the next quantum revolution. They offer an ideal system which can be used to study and implement quantum physics. Isolated they are an ideal quantum memory; interacting with each other they are the basis for many body physics. While placed in the correct environment they can be employed as ultra-sensitive sensors. We propose building a new solid-state spin system based on impurity spins isolated in spin-0 (quantum) solids. These spin-0 solids offer a uniquely soft environment, creating less stress and pressure induced inhomogeneous broadening on the chosen impurities. Relatively large densities of impurities can be achieved which can enable one to build quantum memories for superconducting quantum information circuits. Our initial choice of impurities will be rubidium, which has a hyperfine splitting capable of being addressed by superconducting coplanar waveguides, while the spin-0 solid will be made out molecular hydrogen (H2). Para-hydrogen, one of the two species of molecular hydrogen has been shown in recent years to be an extremely good candidate for isolating spins at large impurity densities.

Digital Quantum Simulation, Trotter Errors, and Quantum Chaos of the Kicked Top

Olsacher, Tobias
University of Innsbruck, Institute for Theoretical Physics, Austria

At my poster I present recent results from Lukas M. Sieberer et al.; “Digital Quantum Simulation, Trotter Errors, and Quantum Chaos of the Kicked Top (arXiv:1812.05876)”.

In this work Trotter errors in digital quantum simulation of collective spin systems are connected to the quantum-chaotic behaviour of the kicked top. For such a digital quantum simulation a range of Trotter steps is found where Trotter errors can be controlled for up to arbitrary long times. This regime corresponds to regular motion of the kicked top. For larger Trotter steps chaotic dynamics of the kicked top leads to proliferation of Trotter errors. Similar results have been obtained by M. Heyl et al., “Quantum localization bounds Trotter errors in digital quantum simulation”; (arXiv:1806.11123) for the case of a one-dimensional interacting spin-1/2 system. For the kicked top this phenomenon can be studied in different experimental realizations ranging from single atomic spins to trapped-ion systems. These platforms thus enable in-depth studies of Trotter errors and their relation to signatures of quantum chaos, including the growth of out-of-time-ordered correlators.

On-demand Semiconductor Source of Entangled Photons Which Simultaneously Has High Fidelity, Efficiency, and Indistinguishability

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An outstanding goal in quantum optics and scalable photonic quantum technology is to develop a source that each time emits one and only one entangled photon pair with simultaneously high entanglement fidelity, extraction efficiency, and photon indistinguishability. By coherent two-photon excitation of a single InGaAs quantum dot coupled to a circular Bragg grating bullseye cavity with broadband high Purcell factor up to 11.3, we generate entangled photon pairs with a state fidelity of 0.90(1), pair generation rate of 0.59(1), pair extraction efficiency of 0.62(6), and photon indistinguishability of 0.90(1) simultaneously.

High-efficiency multiphoton boson sampling

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Boson sampling is considered as a strong candidate to demonstrate ‘quantum computational supremacy’ over classical computers. However, previous proof-of- principle experiments suffered from small photon number and low sampling rates owing to the inefficiencies of the single-photon sources and multiport optical interferometers. Here, we develop two central components for high-performance boson sampling: robust multiphoton interferometers with 99% transmission rate and actively demultiplexed single-photon sources based on a quantum dot–micropillar with simultaneously high efficiency, purity and indistinguishability. We implement and validate three-, four- and five-photon boson sampling, and achieve sampling rates of

4.96 kHz, 151 Hz and 4 Hz, respectively, which are over 24,000 times faster than previous experiments. Our architecture can be scaled up for a larger number of photons and with higher sampling rates to compete with classical computers, and might provide experimental evidence against the extended Church–Turing thesis.

Quantum advantage of the decision-making process using a small-scale trapped-ion processor

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We demonstrate a proof-of-concept experiment for speeding up reinforcement learning by implementing the decision-making process on a freely programmable quantum computer. The scheme follows a model for learning agents based on projective simulation [1,3]. The 2-qubit trapped-ion quantum processor used here is coherently controlled solely by radio-frequency radiation. Hyperfine-states of 171Yb+ ions exposed to a magnetic-field gradient serve as qubits. This small-scale processor is sufficient to demonstrate the main features of quantum projective simulation, and gives a quadratic speed-up of the deliberation time in computational complexity over its classical counterpart. Furthermore, an error model successfully describes small deviations of the measured results from the theoretical simulation. The demonstration of the quantum speed-up highlights the potential of quantum-enhanced learning agents for autonomous machines in a rapidly changing environment.

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Direct measure of genuine tripartite entanglement independent from bipartite constructions

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A new and direct measure (without bipartite measures) of genuine entanglement in tripartite systems based on the volume of the negative part of the Wigner function is proposed. We analyze comparatively this quantity and the different types of entanglement present in two major classes (GHZ and W classes) formed in the coherent state basis