BOOK OF ABSTRACTS

INVITED SPEAKERS

BEYONDC CONFERENCE 2022

FRONTIERS OF QUANTUM INFORMATION SCIENCE

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INVITED SPEAKERS

1. ANTONIO ACÍN

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NETWORK QUANTUM INFORMATION PROCESSING

Small quantum networks consisting of several nodes sharing entangled states are within reach with current and near-term technologies. They offer new possibilities for quantum information processing beyond what achievable in standard point-to-point configurations. In this talk, quantum networks are considered in the device-independent scenario where devices are seen as quantum back boxes processing classical information. We first show how the characterization of correlations in quantum networks is related to the study of causal networks. We then present several results illustrating the possibilities these networks offer in the foundations of quantum physics or for the development of quantum information technologies. In the first case, we show how real quantum theory can be falsified in a small network consisting of three observers in an entanglement swapping configuration. In the second, we discuss a scheme to self-test any pure entangled state.

2. MARKUS ASPELMEYER

University of Vienna

EXPLORING THE FRONTIERS OF GRAVITY IN QUANTUM EXPERIMENTS

3. STEPHEN BARTLETT

University of Sydney

MAKING QUANTUM ERROR CORRECTION PRACTICAL

Quantum error correction offers a pathway to large-scale quantum computing with noisy devices, but the resource overheads for error correction (both numbers of physical qubits and amount of time spent on error correction) can be astronomical. I'll describe a number of innovations that may make quantum error correction practical. Rather than viewing error correction as a type of quantum algorithm running on generic hardware, we take a co-design approach to integrate the quantum code together with the full hardware stack to work together. Tailored codes can respond better to the relevant noise model of the system. Highly-efficient quantum logic operations are possible by exploiting code properties and possible hardware advantages such as long-range gates. Efficient decoders can exploit the flow of information through the stack and reduce both latency and hardware requirements. Combined together, these ideas can improve performance, reduce overheads, and bring fault-tolerant quantum computing closer to reality.

4. RAINER BLATT

University of Innsbruck

QUANTUM COMPUTATION AND QUANTUM SIMULATION WITH STRINGS OF TRAPPED CA+ IONS

The state-of-the-art of the Innsbruck trapped-ion quantum computer [1] is briefly reviewed. We present an overview on the available quantum toolbox and discuss the scalability of the approach. With up to 50 fully controlled ion qubits we perform quantum simulations investigating quantum transport [2] and emerging hydrodynamics features [3]. Employing the quantum toolbox for entanglement-enhanced Ramsey interferometry, we find optimal parameters for quantum metrology [4]. Quantum computers can be protected from noise by encoding the logical quantum information redundantly into multiple qubits using error-correcting codes. Manipulating logical quantum states by imperfect operations requires that all operations on the quantum register obey a fault-tolerant circuit design to avoid spreading uncontrolled errors. We demonstrate a fault-tolerant universal set of gates on two logical qubits in the trapped-ion quantum computer [5].

[1] I. Pogorelov et al., PRX Quantum 2, 020343 (2021) [2] C. Maier et al., Phys. Rev. Lett. 122, 050501 (2019) [3] M. K. Joshi et al., Science 376, 720 (2022) [4] C. D. Marciniak et al., Nature 603, 604 (2022) [5] L. Postler et al., Nature 605, 675 (2022)

5. FERNANDO BRANDÃO

California Institute of Technology / Amazon Web Services

6. HANS J. BRIEGEL

University of Innsbruck

7. HARRY BUHRMAN

University of Amsterdam

QUANTUM FINE-GRAINED COMPLEXITY

One of the major challenges in computer science is to establish lower bounds on the resources, usually time, that are needed to solve computational problems. This holds in particular for computational problems that appear in practise. One way towards dealing with this situation is the study of fine-grained complexity where we use special reductions to prove time lower bounds for many diverse problems based on the conjectured hardness of some key problems. For example, computing the edit distance between two strings, a problem that has a practical interest when determining the genetic distance between species based on their DNA, has an algorithm that takes O(n^2) time. Using a fine-grained reduction, it can be shown that faster algorithms for edit distance also imply a faster algorithm for the Boolean Satisfiability (SAT) problem (that is believed to not exist). This is evidence that the current edit distance algorithms are optimal. Another problem, besides SAT, that is used as a basis for these reductions is the 3SUM problem. The situation in the quantum regime is no better; almost all known lower bounds for quantum algorithms are defined in terms of query complexity, which doesn't help much for problems for which the best-known algorithms take super-linear time. Therefore, employing fine-grained reductions in the quantum setting seems a natural way forward. However, translating the classical fine-grained reductions directly into the quantum regime is not always possible for various reasons. In this talk, I will present some recent results in which we circumvent these challenges and prove quantum time lower bounds for some problems in BQP conditioned on the conjectured quantum hardness of for example SAT (and its variants) and the 3SUM problem. This is based on joint work with Bruno Loff, Florian Speelman, and Subhasree Patro.

8. MARKO CETINA

Duke University

QUANTUM COMPUTING WITH ION CHAINS

9. ANTONIO CORCOLES-GONZALEZ

IBM Research

CHARTING A CONTINUOUS PATH TOWARDS FAULT TOLERANCE AT SCALE

Several physical platforms for quantum information processing have experienced tremendous advances in recent years in terms of size and quality. However, large scale fault tolerant quantum computing remains out of reach with today's current qubit counts and noise. Fortunately, recent error mitigation techniques provide an alternative approach to deal with noise and offer a competitive path for quantum computations. With mitigation, we trade off time (in the form of circuit count) to correct errors using probabilistic error cancellation. Although the overhead is exponential, we expect it to be competitive with comparable classical techniques with modest improvements in device performance. In this talk I will give some insights on the challenging overheads required by current quantum error correction approaches and some of their shortcomings, and will discuss how error mitigation techniques, novel hardware developments, and new quantum error correcting codes will help bridge the gap between the state-of-the-art today and fault tolerant quantum computing at scale.

10. SOPHIA ECONOMOU

Virginia Tech

EFFICIENTLY CREATING AND USING ENTANGLEMENT FOR QUANTUM TECHNOLOGIES

I will describe efficient protocols for the creation of entangled photonic graph states and entangling gates of nuclear spins in quantum defect centers, with a focus on quantum repeater applications. I will also highlight some of our recent results in quantum simulation algorithms for NISQ processors and beyond.

11. JENS EISERT

Freie Universität Berlin

A SINGLE T-GATE MAKES QUANTUM DISTRIBUTION LEARNING HARD

There has been substantial excitement recently in identifying tasks for which quantum devices could possibly outperform classical devices. Indeed, identifying scenarios for which the classical analogue is outperformed is at the heart of the activities of the SFB. Recent experimental implementations on random circuit sampling have provided strong evidence that quantum devices can outperform classical computers on paradigmatic tasks [1]. Also, quantum simulators seem to reach regimes out of scope for classical computers. These developments invite further studies to see what further applications of quantum devices could be found. Notions of quantum-assisted machine learning are seen as candidates for this. In this talk, we will have a look at such notions of quantum-assisted machine learning, driven by the hope that quantum algorithms could fare better than classical ones in instances of learning tasks. These advantages could refer to computational speedups, but also to better generalization and other figures of merit. We will discuss the comparative power of classical and quantum learners for generative modelling within the probably approximately correct framework, for which we prove a separation between the quantum and classical settings [2,3]. In the light of new findings on the PAC learnability of the output distributions of local quantum circuits, we will discuss how much structure is actually expected to be required to hope for quantum advantages in quantum-assisted machine learning [4]. We prove that the injection of a single T-gate into Clifford circuits renders the task of learning evaluators from samples infeasible in polynomial time. This is in stark contrast to the case of Clifford circuits for which we provide an efficient learning algorithm based on Gaussian elimination [5]. This work will provide a roadmap of what next steps are to be taken for work in quantum machine learning, and will flesh out the potential and limitations of quantum probabilistic modelling, and the extent to which one can hope such algorithms to contribute to the main themes of the SFB.

[1] Computational advantage of quantum random sampling, D. Hangleiter, J. Eisert, review for Rev. Mod. Phys., arXiv:2206.04079 (2022). [2] On the quantum versus classical learnability of discrete distributions, R. Sweke, J.-P. Seifert, D. Hangleiter, J. Eisert, Quantum 5, 417 (2021). [3] A super-polynomial quantum-classical separation for density modelling, N. Pirnay, R. Sweke, J. Eisert, and J.-P. Seifert, in preparation (2022). [4] Learnability of the output distributions of local quantum circuits, M. Hinsche, M. Ioannou, A. Nietner, J. Haferkamp, Y. Quek, D. Hangleiter, J.-P. Seifert, J. Eisert, R. Sweke, arXiv:2110.05517 (2021). [5] A single T-gate makes distribution learning hard, M. Hinsche, M. Ioannou, A. Nietner, J. Haferkamp, Y. Quek, D. Hangleiter, J.-P. Seifert, J. Eisert, R. Sweke, arXiv:2207.03140 (2022).

12. JOSEPH EMERSON

University of Waterloo

THE ROLE OF RANDOMIZED COMPILING FOR QUANTUM COMPUTING: FROM NISQ TO QEC

I will give an overview of the theoretical underpinnings and recent experimental results exploring how, when and why randomized compiling can improve NISQ performance, stabilize error mitigation and improve the predictability and performance of quantum error correcting codes.

13. GERHARD KIRCHMAIR

University of Innsbruck

COHERENT CONTROL OF MULTI-QUBIT DARK STATES IN WAVEGUIDE QUANTUM ELECTRODYNAMICS

14. DIETRICH LEIBFRIED

National Institute of Standards and Technology

TOWARD LARGE SCALE AND FAULT TOLERANCE WITH TRAPPED IONS

In this talk, possible pathways to fault-tolerant large-scale quantum information processors based on trapped ions are presented. The envisioned machines would incorporate millions of qubits, feature operation errors on physical qubits of order 10-4 and memory coherence times on the order of hours. Qubit connectivity with sufficiently low crosstalk is achieved by moving ions around in a large array of traps and executing operations on small groups of ions that are sufficiently isolated from all other qubits and the environment. [1] Fault-tolerant execution of complex algorithms is facilitated by extensive use of "helper qubits" that serve to cool the motion, initialize internal states, and read out error syndromes without compromising computational qubits in the algorithm substantially. While building a machine of this scale is currently out of reach, present efforts can inform this vision and the performance of many necessary components can be demonstrated in separate proof-of-principle experiments in dedicated, smaller scale setups. Relevant experiments at NIST and in other laboratories will be discussed. [1] D. J. Wineland et al., J. Res. Nat. Inst. Stand. Technol. 103, 259 (1998).

15. MIKHAIL LUKIN

Harvard University

EXPLORING NEW SCIENTIFIC FRONTIERS WITH PROGRAMMABLE ATOM ARRAYS

We will discuss the recent advances involving programmable, coherent manipulation of quantum many-body systems using neutral atom arrays excited into Rydberg states, allowing the control over 200 qubits in two dimensions. These systems can be used for realization and probing of exotic quantum phases of matter and exploration of their non-equilibrium dynamics. Recent advances involving the realization and probing of quantum spin liquid states - the exotic topological states of matter have thus far evaded direct experimental detection and the observation of quantum speedup for solving optimization problems will be described. In addition, the realization of novel quantum processing architecture based on dynamically reconfigurable entanglement and the steps towards quantum error correction will be discussed. Finally, we will discuss prospects for using these techniques for realization of large-scale quantum processors.

16. SABRINA MANISCALCO

University of Helsinki / Algorithmiq

UNLOCKING PRACTICAL QUANTUM ADVANTAGE WITH NEAR-TERM QUANTUM COMPUTERS

Today's quantum computers are imperfect. They are made of dozens of qubits that can be prepared in highly non-classical states but, being very sensitive to noise, their ability to preserve quantum properties is very limited. Noise not only arises from the interaction with the external environment, but encompasses all the imperfections in the sophisticated quantum hardware and control system. This is why, despite the discovery of algorithms that in principle would allow us to simulate interesting and currently intractable problems in chemistry and materials, applications to industrially relevant problems seem out-of-reach. Therefore, several quantum computing players are shifting their attention away from near-term quantum computers and towards fault-tolerant devices.In this talk I will show that, contrarily to what is largely believed, quantum algorithms on near-term quantum computers can lead to quantum advantage already now. The key ingredient to unlock quantum advantage in noisy devices is the use of informationally complete generalised measurements (IC POVMs) [1,2]. Our results show how our hybrid variational quantum-classical algorithms using IC data allow for unprecedented noise attenuation [3], execution time reduction [1,2], and efficient ansatz generation. The combination of these three achievements makes current quantum computers able to show quantum advantage for quantum chemistry problems in the very near future.

[1] G. García-Pérez et al., PRX Quantum 2, 040342 (2021) [2] A. Glos et al., arXiv:2208.07817 [3] G.García-Pérez et al., arXiv:2207.01360

17. CHARLES M. MARCUS

Niels Bohr Institute, University of Copenhagen

HYBRID MATERIALS: TOPOLOGICAL SUPERCONDUCTIVITY AND BEYOND

18. KLAUS MØLMER

Niels Bohr Institute, University of Copenhagen

FLYING AND STATIONARY QUBITS – CHALLENGES AND OPPORTUNITIES

With the scaling of quantum technologies to many separate material quantum components, we may have recourse to couple these systems by quantum radiation of light, microwaves or phonons. In future optical quantum processors, we may, conversely, need to manipulate the quantum states of radiation pulses by their interaction with non-linear stationary quantum components. While several physical processes have been proposed and already demonstrated for these tasks, there are rather fundamental obstacles to, e.g., merely interchange flying and stationary qubits in circuits for quantum computing. These obstacles include the general multimode character of propagating fields and the duration and spatial extent of useful light and microwave pulses. The talk will review methods to deal theoretically with these obstacles, and it will present examples of new, unforeseen, possibilities for preparation and manipulation "on the fly" of quantum states of light and matter.

19. TRACY NORTHUP

ENTANGLEMENT OF TRAPPED-ION QUBITS SEPARATED BY 230 M

Entanglement-based quantum networks hold out the promise of new capabilities for secure communication, distributed quantum computing, and interconnected quantum sensors. However, only a handful of elementary quantum networks have been realized to date. I will present recent results from our prototype network, in which two calcium ions are entangled with one another over a distance of 230 m, via a 510(2) m optical fiber channel linking two buildings. The ion-ion entanglement is based on ion-photon entanglement mediated by coherent Raman processes in optical cavities. I will discuss the advantages of trapped ions for quantum networks and the role that cavities play as quantum interfaces between light and matter. After examining the key metrics of fidelity and success probability, we will consider how this work may be extended in the future to long-distance networks of entangled quantum processors.

20. RENATO RENNER

ETH Zurich

FROM QUANTUM CRYPTOGRAPHY TO BLACK HOLES

At first sight, cryptography has little to do with gravity. Nonetheless, quantum information-theoretic concepts that have been developed in the context of quantum cryptography are becoming increasingly popular for (theoretical) investigations of black holes. On closer inspection, this is not that surprising. In both areas of research, we have to deal with potentially highly complex quantum systems, namely the “eavesdropper” and the “black hole interior”, which have basically no known structure. In this talk, I will show how modern tools from quantum cryptography allow us to analyse such structureless systems and thus gain insights into the physics of black holes.

21. HELMUT RITSCH

University of Innsbruck

MINIMALISTIC NANO-OPTICAL DEVICES USING DIPOLE COUPLED QUANTUM EMITTERS

Subwavelength arrays of quantum emitters feature unique and largely designable nonlinear optical properties. In particular, absorption and emission properties of nanoscopic ring structures offer unique possibilities. As striking example, we identify a sub-wavelength sized ring of exactly 9 identical dipoles with an extra identical emitter with a extra loss channel at the center as the most efficient antenna configuration to direct incoming photons to the center without reemission. The enhancement is most pronounced a given resonance frequency but still stays visible for broadband light absorption. For very tiny structures below a tenth of a wavelength a full quantum description exhibits a larger enhancement than predicted from a classical dipole approximation. The origin of the effect lies in the appearance of a collective dark state with dominant center occupation. By special design of the center absorber one can harness the same efficiency enhancement also at different wavelengths and for other geometric structures. On the one hand this could be the basis of a new generation of highly efficient and selective nano antennas while on the other hand it could be an important piece towards understanding the surprising efficiency of natural light harvesting molecules. Adding gain in nano ring systems allows to design minimalistic classical as well as non-classical light sources.

22. JÖRG SCHMIEDMAYER

TU Wien

EMERGENT QUANTUM SIMULATORS

Quantum Simulation promises insight into quantum physics problems which are beyond the ability to calculate with conventional methods. Quantum simulators can be built either using a 'digital' Trotter decomposition of the problem or by directly building the Hamiltonian in the lab and performing 'analogue' experiments. I will present here a different approach, by which the model to simulate emerges naturally from a completely different microscopic Hamiltonian. I will illustrate this in the example of the emergence of the Sine-Gordon quantum field theory from the microscopic description of two tunnel coupled super fluids [1] and in the emergence of Pauli blocking in an weakly interacting bose gas [2]. Special emphasis will be put on how to verify such emergent quantum simulators and how to characterize them. Thereby I will present two tools: High order correlation functions and their factorization [1], the evaluation of the quantum effective action and the momentum dependence of propagators and vertices (running couplings, renormalization of mass etc ..) of the emerging quantum field theory [3] and quantum field tomography that points to a new way to read out quantum simulators [4]. Together they establish general methods to analyse quantum systems through experiments and thus represents a crucial ingredient towards the implementation and verification of quantum simulators. As an example, I will report on the progress towards measuring area laws of mutual information [5] and entanglement entropy in a quantum simulation of n continuous QFT.

Work performed in collaboration with the groups of Th. Gasenzer und J. Berges (Heidelberg), Jens Eisert (FU Berlin) and E. Demler (Harvard). Supported by the DFG-FWF: SFB ISOQUANT: and the EU: ERC-AdG QuantumRelax

[1] T. Schweigler et al., Nature 545, 323 (2017), arXiv:1505.03126 [3] F. Cataldine et al. arXiv:2111.13647[3] T. Zache et al. Phys. Rev. X 10, 011020 (2020) [4] M. Gluza et al., Communication Physics 3, 12 (2020) [5] M. Tajil et al., arXiv:2206.10563

23. FABIO SCIARRINO

University of Rome

EXPERIMENTAL PHOTONIC TESTS ON QUANTUM CAUSALITY

24. FRANK VERSTRAETE

Ghent University

QUANTUM SIMULATION: BOUNDARY CONDITIONS, DUALITIES AND CONTINUUM LIMITS

25. IAN WALMSLEY

Imperial College London

BUILDING QUANTUM MACHINES OUT OF LIGHT

Hybrid light-matter networks offer the promise for delivering robust quantum information processing technologies, from sensor arrays to quantum simulators. I will discuss some approaches to demonstrating quantum advantage using photons, as well as applications of quantum memories in network source coding.

26. ANTON ZEILINGER

The Austrian Academy of Sciences (ÖAW)

FROM CURIOSITY ABOUT QUANTUM FOUNDATIONS TO THE ROOTS OF QUANTUM TECHNOLOGY

Early experiments on quantum foundations were motivated essentially by curiosity. There was no awareness that this opened up the avenue to quantum information. The experiments I will discuss go from neutron interferometry via three-photon entanglement, and entanglement swapping to recent path identity results based on a seminal and long overlooked paper by Wang, Zou, and Mandel. I will also argue that experiments on the foundations continue to be a fascinating field.