QI 6: Quantum Computing and Algorithms II

Time: Wednesday 10:45–12:45 Location: H3

Invited Talk QI 6.1 Wed 10:45 H3

Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator — •Alexander Grimm — Paul Scherrer Institute, Villigen, Switzerland

Quantum two-level systems are routinely used to encode qubits, but tend to be inherently fragile leading to errors in the encoded information. Quantum error correction (QEC) addresses this challenge by encoding effective qubits into more complex quantum systems.

A qubit that is intrinsically protected against a subset of quantum errors can be encoded into superpositions of two opposite-phase oscillations in a resonator, so-called Schrödinger-cat states. This "cat qubit" has the potential to significantly reduce the complexity of QEC. However, the practical operation of a cat qubit faces several challenges: The oscillations are highly excited states of the resonator and need to be stabilized in order to maintain the protection. At the same time, the system has to be compatible with fast gate operations and an efficient measurement of the encoded information.

In this talk, I will review some key concepts of QEC and situate our approach within the field. Then, I will present recent experimental results on the stabilization and operation of an error-protected cat qubit through the interplay between Kerr nonlinearity and single-mode squeezing in a superconducting microwave resonator. I will conclude with an outlook on different applied and fundamental research directions enabled by this experiment.

Invited Talk QI 6.2 Wed 11:15 H3

The 3rd quantum revolution: Quantum Algorithmic Experiments. — •Dorit Aharonov — Hebrew University of Jerusalem, Israel

Following the second quantum revolution, which had completely undermined how we think of algorithms, the last decade gave birth to a third quantum revolution - which has changed the way we think of physical experiments. I will demonstrate this with some examples of how quantum computational ideas such as quantum error correction and quantum algorithms can be used to enhance conventional quantum experiments, to achieve increased efficiency and precision in sensing, metrology, and more. I will then describe my recent attempt together with Jordan Cotler and Xiaoliang Qi to generalize these developments and provide a universal mathematical model for quantum experiments, which we call Quantum algorithmic measurements (QUALMs). In this framework, we show that certain experimental tasks (such as determining the time reversal symmetry of a many body quantum system), can be performed exponentially more efficiently if enhanced with even simple quantum computational abilities. Improvements on our initial protocols were recently implemented experimentally on Google's Sycamore. These and other results which I will mention, suggest that quantum experiments constitute a new playground in which quantum-computational advantages can be exhibited.

QI 6.3 Wed 11:45 H3

Dynamical subset sampling of quantum error correcting circuits — •Sascha Heussen[1,2], Manuel Rispler[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]Institute for Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich, 52428 Jülich, Germany

Quantum error correcting stabilizer codes enable protection of quantum information against errors during storage and processing. Efficiently simulating faulty gate operations poses numerical challenges beyond circuit depth or large numbers of qubits. More efficient simulation of non-deterministic quantum error correcting protocols, such as Shor-type error correction or flag-qubit based fault-tolerant circuits where intermediate measurements and classical feedback determine the actual circuit sequence to perform the protocol, becomes feasible via dynamical subset sampling. As an importance sampling technique, dynamical subset sampling allows to effectively make use of computational resources to only sample the most relevant sequences of quantum circuits in order to estimate a protocol's logical failure rate with well-defined error bars instead of post-selecting on classical measurement data. We outline the method along with two examples that demonstrate its capabilities to reach a given target variance on the logical failure rate with five orders of magnitude fewer samples than Monte Carlo simulation. Our method naturally allows for efficient simulation of realistic multi-parameter noise models describing faulty quantum processor architectures, e.g. based on trapped ions.

QI 6.4 Wed 12:00 H3

Pauli channels can be estimated from syndrome measurements in quantum error correction — •Thomas Wagner, Dagmar Bruss, Hermann Kampermann, and Martin Kliesch — Heinrich-Heine-Universität Düsseldorf

Large scale quantum computation requires quantum error correction. The performance can be significantly improved if detailed information about the noise is available, allowing to optimize both codes and decoders. It has been proposed to estimate error parameters from the syndrome measurements done anyway during quantum error correction. While these measurements preserve the encoded quantum state, it is currently not clear how much information about the noise can be extracted in this way. So far, apart from the limit of vanishing error rates, rigorous results have only been established for some specific codes.

In this work, we rigorously resolve the question for arbitrary stabilizer codes. We prove that a surprisingly high amount of information can be extracted from the syndromes. The main result is that a stabilizer code can be used to estimate Pauli channels with correlations across a number of qubits given by the pure distance. This result does not rely on the limit of low error rates, and applies even if high weight errors occur frequently. Our proof combines Boolean Fourier analysis, combinatorics, elementary algebraic geometry and iterated Schur complements. It is our hope that this work opens up interesting applications, such as the online adaptation of a decoder to time-varying noise.

QI 6.5 Wed 12:15 H3

Cheap Readout Error Mitigation on Expensive NISQ devices — •Ákos Budai[1,2,3], András Pályi[1,3], and Zoltán Zimborás[2,3] — [1]Department of Theoretical Physics and MTA-BME Exotic Quantum Phases Research Group, Budapest University of Technology and Economics, Hungary — [2]Wigner RCP, Hungarian Academy of Sciences — [3]Nokia Bell Labs, (Budapest, Hungary)

Noisy Intermediate-Scale Quantum (NISQ) devices are already available today for public use. These prototype quantum processors do not have enough qubits needed for implementing useful quantum error correction codes. Instead, different error mitigation schemes turned out to be efficient tools for improving the functionality of NISQ devices. In most superconducting prototype quantum computers, the readout error dominates the errors of individual gates. The level of improvement gained by readout error mitigation (REM) depends on the error probabilities and number of shots available. In this work, we quantify the efficiency of REM for a specific simple quantum protocol (parameter estimation), and combine analytical and numerical techniques to find the optimal division of available shots between the REM task and the quantum protocol itself. This task is of direct financial relevance, since certain quantum computer providers bill after the number of shots executed.

QI 6.6 Wed 12:30 H3

Microwave individual qubit addressing of $^{9}Be^{+}$ in a two-ion crystal — •Hardik Mendpara[1,2], Markus Duwe[1,2], Nicolas Pulido[1,2], Amado Bautista[1,2], Giorgio Zarantonello[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100,38116 Braunschweig — [3]National Institute of Standards and Technology, Boulder, Colorado 80303

Single-qubit rotations and two-qubit entangling gates form a universal set of quantum operations capable of implementing any quantum algorithm. With multiple trapped ions, a key prerequisite for single-qubit rotations is the capability to reliably address individual qubits. Instead of the more wide-spread laser based approach, we implement quantum operations using microwaves. In this work, we report on microwave individual-ion addressing, and on the implementation of randomized benchmarking [1]. Together with the entangling gate, this enables controlled sequences of single- and two-qubit gates [2]. This makes it possible to perform benchmarking algorithms to better characterize the performance of two-qubit entangling gates [3,4].

[1] U. Warring *et al.*, Phys. Rev. Lett. **110**,173002 (2013)
[2] G. Zarantonello *et al.*, Phys. Rev. Lett. **123**, 260503 (2019)
[3] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)
[4] J. Gaebler *et al.*, Phys. Rev. Lett. **109**, 179902 (2012)