FM 36: Quantum Computation: Benchmarking and Certification

Time: Tuesday 14:00–16:15 Location: 2006

Invited Talk FM 36.1 Tue 14:00 2006

Building Trust — •Elham Kashefi — University of Edinburgh & CNRS, Sorbonne Universite

Over the next decades we will see a state of flux as quantum technologies become part of the mainstream computing and communicating landscape. In the meantime we can expect to see quantum devices with high variability in terms of architectures and capacities. Adopting and applying such a highly variable and novel technology is both costly and risky as this quantum approach has an acute verification and validation problem:

On the one hand, since classical computations cannot scale up to the computational power of quantum mechanics, verifying the correctness of a quantum-mediated computation is challenging; on the other hand, the underlying quantum structure resists classical certification analysis.

This talk provides an overview of all different approaches to quantum certification, ranging from advanced tomographic tools such as compressed sensing, to fidelity estimation and witnessing and the verification of arbitrary quantum computations in an interactive fashion.

FM 36.2 Tue 14:30 2006

Benchmarking quantum computers with Qiskit Ignis — •James Wootton — IBM Research - Zurich

There are many ways that imperfections can arise in a quantum computation. It is important to assess what these do to our qubits, how they affect our ability to run programs with the devices, and how to mitigate their effects. Many different methods have been developed to do this, from the randomized benchmarking that focuses on single gates to the quantum volume that characterizes entire devices. This talk will introduce some of these methods, and show how they can be used in practice.

FM 36.3 Tue 14:45 2006

Certifying the building blocks of quantum computers from Bell's theorem — •Jean-Daniel Bancal[1,2], Pavel Sekatski[2], and Nicolas Sangouard[2] — [1]Department of Applied Physics, University of Geneva, 1211 Geneva, Switzerland — [2]Quantum Optics Theory Group, Universität Basel, CH-4056 Basel, Switzerland

Quantum computers hold great promises, but as their experimental realization concretizes it becomes clear that, like most quantum technologies, they are sensitive to implementation imperfections. Due to their large spectrum of possible application, device-independent certification schemes are needed to guarantee their proper working and certify their results. Recently, it was shown that practical imperfections do not constitute a fundamental barrier to this goal: black-box certification is in principle possible [see e.g. B. W. Reichard et al., Nature 496, 456 (2013)]. Realistic recipe that could be used in today's experiments were however not provided. Here, we present a framework for the device-independent certification of quantum channels that is inherently noise-tolerant. We show that it provides a generic tool for a bottom-up certification of quantum computers and technologies. We certify building blocks such as multi-qubit gates, quantum memories, quantum converters, Bell state measurements, quantum instruments, etc. Our test validates the capability of an imperfect device to be used in a larger quantum technology device, independently of its actual implementation and of the purpose for which it is used. This brings device-independent certification to the scope of currently available devices.

FM 36.4 Tue 15:00 2006

Sample complexity of device-independently certified "quantum supremacy" — •Dominik Hangleiter[1], Martin Kliesch[2], Jens Eisert[1], and Christian Gogolin[3] — [1]FU Berlin, Berlin — [2]Heinrich-Heine-Universität, Düsseldorf — [3]Universität Köln, Köln

Results on the hardness of approximate sampling are seen as important stepping stones towards a convincing demonstration of the superior computational power of quantum devices. The most prominent suggestions for such experiments include boson sampling, IQP circuit sampling, and universal random circuit sampling. A key challenge for any such demonstration is to certify the correct implementation. For all these examples, and in fact for all sufficiently flat distributions, we show that any non-interactive certification from classical samples and a description of the target distribution requires exponentially many uses of the device. It is an ironic twist of our results that the same property that is a central ingredient for the approximate hardness results, prohibits sample-efficient certification: namely, that the sampling distributions, as random variables depending on the random unitaries defining the problem instances, have small second moments.

FM 36.5 Tue 15:15 2006

Self-Consistent Calibration of Quantum Gate Sets — Pascal Cerfontaine, •René Otten, and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

The precise and automated calibration of quantum gates is a key requirement for building a reliable quantum computer. Unlike errors from decoherence, systematic errors can in principle be completely removed by tuning experimental parameters. In this talk, we present an iterative calibration routine which can remove systematic gate errors on several qubits. A central ingredient is the construction of pulse sequences that extract independent indicators for every linearly independent error generator. We show that decoherence errors only moderately degrade the achievable infidelity due to systematic errors. Furthermore, we investigate the convergence properties of our approach by performing simulations for a specific qubit encoded in a pair of electron spins. Our results indicate that a gate set with 230 gate parameters can be calibrated in about ten iterations, after which incoherent errors limit the gate fidelity.

FM 36.6 Tue 15:30 2006

Gate set tomography via tensor completion — •Raphael Brieger[1], Ingo Roth[2], and Martin Kliesch[1] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany

Flexible characterization techniques that quantify and identify unwanted noise are crucial in the development of accurate quantum gates. Such techniques must work under realistic assumptions on the state-preparations and measurements available in NISQ devices. Gate set tomography (GST) has been proposed as a technique that simultaneously extracts tomographic information on an entire set of quantum gates, the state preparation and the measurements under minimal assumptions. We argue that the problem of reconstructing the gate set can naturally be cast as the problem of completing a translation-invariant matrix product state (MPS) from the knowledge of some of its entries. Such structured completion problems can be studied using the mathematical framework of compressed sensing. Extending recent results from the compressed sensing literature, we develop a new approach to the GST data processing task. We show numerically that an MPS completion algorithm can be used for the reconstruction of gate sets. Potential advantages of this approach are the ability to include physicality and low-rank constraints as well as prior knowledge on the gate implementations. Our approach is a promising first step towards more scalable GST schemes amenable to theoretical guarantees building on rigorous results available for MPS completion algorithms.

FM 36.7 Tue 15:45 2006

Mitigation of readout noise by classical post-processing based on Quantum Detector Tomography — Filip Maciejewski[1], Michał Oszmaniec[2], and •Zoltán Zimborás[3] — [1]University of Warsaw, Faculty of Physics, Ludwika Pasteura 5, 02-093 Warszawa, Poland — [2]National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdansk, Wita Stwosza 57, 80-308 Gdansk, Poland — [3]Wigner Research Centre for Physics H-1525 Budapest, P.O.Box 49, Hungary

We propose a simple scheme to reduce readout errors in experiments on quantum systems with finite number of measurement outcomes. Our method relies on performing classical post-processing which is preceded by Quantum Detector Tomography, i.e., the reconstruction of a Positive-Operator Valued Measure describing the given quantum measurement device. If the measurement device is affected only by an invertible classical noise, it is possible to correct the outcome statistics of future experiments performed on the same device. We provide a characterization of readout noise occurring in IBM and Rigetti quantum devices and observe a good agreement with this noise model, which suggests that classical noise might be a dominant form of noise for superconducting transmon qubits. Moreover, we analyze the influence of the presence of coherent errors on and finite statistics on the performence of our correction procedure. We also test our scheme experimentally on the IBM 5-qubit device and observe a significant improvement of results for the implementation of a number of algorithms and other quantum information processing tasks.

FM 36.8 Tue 16:00 2006

Blind tomography via sparse de-mixing — •Ingo Roth, Jadwiga Wilkens, Dominik Hangleiter, and Jens Eisert — Freie Universität, Berlin, Germany

The envisioned applications of quantum technologies require to achieve an enourmous precision in engineering its individual components. This is why efficient and flexible methods for extracting information about quantum devices from measurements are crucial. One important task is to fully determine a quantum state from the measured data, e.g. in order to improve devices for state preparation. Experimental schemes for quantum state tomography typically require measurement devices that are calibrated to a high precision. At the same time, the precision of the measurement's calibration ultimately relies on an accurate state preparation creating a vicious cycle. In this work, we develop the framework of blind tomography which breaks this vicious cycle using only very mild and generic structure assumptions. We propose a scheme allowing for incomplete knowledge of the measurement device during the tomography of a low-rank quantum state. The scheme simultaneously determines both the device's calibration and the quantum state with minimal resources and efficient classical post-processing. Building on recent techniques from the field of compressed sensing, we derive algorithmic strategies for blind tomography and provide analytical performance guarantees. We further demonstrate the performance of our scheme in numerical simulations.