BOOK OF ABSTRACTS

POSTER CONTRIBUTIONS

BEYONDC WORKSHOP 2023

KICKOFF MEETING 2.0

CAMPUS UNIVERSITY OF VIENNA

27 & 28 MARCH 2023

INHALT

1. NO-SIGNALLING CONSTRAINS QUANTUM COMPUTATION WITH INDEFINITE CAUSAL STRUCTURE

LUCA APADULA

Quantum processes with indefinite causal structure emerge when we wonder which are the most general evolutions, allowed by quantum theory, of a set of local systems which are not assumed to be in any particular causal order. These processes can be described within the framework of higher-order quantum theory which, starting from considering maps from quantum transformations to quantum transformations, recursively constructs a hierarchy of quantum maps of increasingly higher order. In this work, we develop a formalism for quantum computation with indefinite causal structures; namely we characterize the computational structure of higher order quantum maps. Taking an axiomatic approach, the rules of this computation are identified as the most general compositions of higher order maps which are compatible with the mathematical structure of quantum theory. We provide a mathematical characterization of the admissible composition for arbitrary higher order quantum maps. We prove that these rules, which have a computational and information-theoretic nature, are determined by the more physical notion of the signalling relations between the quantum systems of the higher order quantum maps.

2. OPTIMAL FORAGING STRATEGIES CAN BE LEARNED AND OUTPERFORM LÉVY WALKS

LUKAS FIDERER

Lévy walks and other theoretical models of optimal foraging have been successfully used to describe real-world data, attracting attention in several fields such as economy, physics, ecology, and evolutionary biology. However, it remains unclear in most cases which strategies maximize foraging efficiency and whether such strategies can be learned by living organisms. To address these questions, we model foragers as reinforcement learning agents. We first prove theoretically that maximizing rewards in our reinforcement learning model is equivalent to optimizing foraging efficiency. We then show with numerical experiments that our agents learn foraging strategies which outperform the efficiency of known strategies such as Lévy walks.

3. REINFORCEMENT LEARNING AND DECISION MAKING VIA SINGLE-PHOTON QUANTUM WALKS

FULVIO FLAMINI

Variational quantum algorithms represent a promising approach to quantum machine learning. Here, we present a variational approach to quantize projective simulation (PS), a reinforcement learning model aimed at interpretable artificial intelligence. Decision making in

PS is modeled as a random walk on a graph describing the agent's memory. To implement the quantized model, we consider quantum walks of single photons in a lattice of tunable Mach-Zehnder interferometers. We propose variational algorithms tailored to reinforcement learning tasks, and we show, using an example from transfer learning, that the quantized PS learning model can outperform its classical counterpart. We also discuss the role of quantum interference for training and decision making, paving the way for realizations of interpretable quantum learning agents.

4. PRECISION SPECTROSCOPY AND QUANTUM INFORMATION WITH TRAPPED MOLECULAR IONS

BRANDON FUREY

We aim to demonstrate the creation of superpositions of rotational states in a diatomic molecular ion built using a combination of microwaves and stimulated Raman transitions driven by two beams from an optical frequency comb. This could pave the way for certain quantum error correction codes which use a trapped molecule as the basis for a logical qubit.

5. HACKING QUANTUM KEY DISTRIBUTION BASED ON QUANTUM DOTS

FRANCESCO GIORGINO

Quantum Key Distribution (QKD) allows two remote parties to establish a private key over a public channel, assuming only the validity of quantum theory. While the security of QKD is in principle guaranteed by the uncertainty principle, real-world quantum systems are vulnerable to \textit{side-channel} attacks exploiting the internal structure of classical or quantum devices [1, 2]. Recently, there has been growing interest in the implementation of QKD with quantum dot single-photon sources, thanks to their high brightness and low multiphoton emission. Here, we show that unlike their weak coherent state counterparts, these new sources are vulnerable to Trojan Horse-type attacks exploiting the inherent setup structure of phonon-assisted excitation. The adversary introduces weak coherent pulses in the source setup and analyses the signal performing a Beam Splitting Attack [3]. We highlight that standard countermeasures such as Decoy States [4] to probe channel losses and auxiliary detectors to monitor the incoming signal are not applicable in this scenario without lowering the secure key rate. We experimentally implement the attack on a setup based on InAs/InGaAs/GaAs dots, emitting in telecommunication C-band and excited via phonon assisted excitation [5].

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[2] N. Gisin, S. Fasel, B. Kraus et al., Phys. Rev. A 73, 022320 (2006).
[3] Bennett, C.H., Bessette, F., Brassard, G. et al. J. Cryptology 5, 3–28 (1992).
[4] Hoi-Kwong Lo, Xiongfeng Ma, and Kai Chen, Phys. Rev. Lett. 94, 230504 (2005).
[5] M. Cosacchi, F. Ungar et al., Phys. Rev. Lett. 123, 017403 (2019).

6. ACCESSING INACCESSIBLE INFORMATION VIA QUANTUM INDISTINGUISHABILITY

SEBASTIAN HORVAT

We present an information-theoretic task that consists in learning an apparently perfectly isolated bit of information by merely spatially translating the object that encodes it. We show that the task can be solved with the use of independently prepared indistinguishable particles, but cannot be solved with distinguishable ones, unless they are entangled. Our results thus corroborate the view that the entanglement that seems to be necessarily present in systems comprised of indistinguishable particles is more than a mere representational artefact and can indeed be used as a resource for information processing. Apart from its foundational merit, our results are of practical importance for cryptography.

7. CONSTANT DEPTH CODE DEFORMATIONS IN THE PARITY ARCHITECTURE

ANETTE MESSINGER

We present a protocol to encode and decode arbitrary quantum states in the parity architecture with constant circuit depth using measurements, local nearest-neighbor and single-qubit operations only. While this procedure typically requires a quadratic overhead of simultaneous qubit measurements, it allows for a simple and low-depth implementation of logical multi-qubit gates in the parity encoding via code deformation. We discuss how such encoding and decoding schemes can be used to flexibly change the size and shape of the underlying code to enable a more efficient implementation of quantum gates or algorithms. We apply the new findings to the QAOA which leads to a constant depth implementation using local gates at the same optimization performance as the standard, potentially non-local, QAOA approach without the parity encoding. Furthermore, we show that our method can reduce the depth of implementing the quantum Fourier transform by a factor of two when allowing measurements.

8. SOLVING RANK CONSTRAINED QUANTUM SEMIDEFINITE PROGRAMS IN POLYNOMIAL TIME

JOSHUA MORRIS

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.

9. TOWARDS OPTICALLY INTEGRATED TRAPPED ION QUANTUM COMPUTING

MARCO SCHMAUSER

Trapped ion quantum computers are known to be large and complex experiments. One of the reasons for this is that light guidance between lasers and ions is done mainly by free-beam optics, which means that the overall system requires a lot of space and is susceptible to drifts and vibrations. The only way to make such a system compact and scalable is to increasingly integrate functionality, in this specific case optical elements, from external components directly into the ion trap. To solve this problem, a method has been developed to write single-mode and polarization-maintaining waveguides directly into quartz glass using ultrashort laser pulses. These light guides can be tuned to a specific wavelength, ranging from UV to near infrared. The next step is to realize an ion trap with such integrated waveguides. In this context, the approach of a microstructured trap is pursued, which allows for a scalable trap architecture and is compatible with industrial production. In parallel, an integrated cryogenic quantum computing system is being built to enable fast trap changes and additionally investigate the light delivery to the trap chip.

10. CLASSICAL-QUANTUM COMBS, THEIR MIN-ENTROPY AND THEIR MEASUREMENT-BASED APPLICATIONS QUANTUM INFORMATION WITH TRAPPED-ION BASED QUDITS

ISAAC SMITH

Learning a hidden property of a quantum system typically requires a series of interactions. In this work, we consider a formalisation of such multi-round learning processes that uses a generalisation of classical-quantum states called classical-quantum combs. Here, "classical" refers to a random variable encoding the hidden property to be learnt, and "quantum" refers to the quantum comb describing the behaviour of the system. By using the quantum combs formalism, the optimal strategy for learning the hidden property can be quantified via the comb min-entropy (Chiribella and Ebler, NJP, 2016). With such a tool on hand, we focus attention on an array of combs derived from measurement-based quantum computation (MBQC) and related applications. Specifically, we describe a known blind quantum computation (BQC) protocol using the combs formalism and thereby leverage the min-entropy to provide a proof of single-shot security for multiple rounds of the protocol, extending the existing result in the literature. Furthermore, we introduce novel connections between MBQC and quantum causal models and quantum causal inference, which allows for the use of the min-entropy to quantify the optimal strategy for causal discovery. We consider further operationally motivated examples, including one associated to learning a quantum reference frame.

11. PROCESSING QUANTUM INFORMATION WITH TRAPPED-ION BASED QUDITS

PETER TIRLER

In the current stage of its evolution, Quantum Information Processing is following the precedent set by classical computing and generally encodes information in binary form, thus relying on so-called qubits. For many of the systems used to process this quantum information, this is however a rather artificial constraint, limiting the Hilbert space available for computation and introducing leakage errors that slip through the most common error correction schemes. Going from qubits to qudits, non-binary logical base states, to leverage a larger Hilbert space for computation is therefore one path towards building more powerful and reliable Quantum Information Processors that can be used to solve real-world problems. We use trapped Calcium ions to encode information in higher-dimensional qudits up to d = 7, demonstrate comparable performance to a qubit-based processor and set out to build a new experimental setup dedicated exclusively to QIP with trapped Calcium qudits.

12. STATE-DEPENDENT FORCE SPECTROSCOPY FOR TRAPPED IONS

STEFAN WALSER

Optical trapping and laser cooling are techniques that founded a revolution of quantum experiments in which atoms and molecules are manipulated using optical forces. A particularly useful technique are optical tweezers. Certain trapped ions are an excellent basis for high precision spectroscopic experiments due to the available electronic structure for state preparation and read-out. In this project we aim to combine state-dependent optical tweezers to manipulate the motional modes of an ion crystal with quantum logic spectroscopy. We plan to co-trap a 40Ca+ logic ion with a molecular ion which is inaccessible to standard spectroscopic techniques in ion traps. Applying a state-dependent force on the molecular ion, the overall trapping potential is modified. This consequently changes the frequency of the ion’s common motional mode, which can be measured via the logic ion. Thereby we realize a quantum non-demolition measurement of the molecule’s internal vibrational and rotational states.

13. ALL-OPTICAL READOUT OF A SUPERCONDUCTING QUBIT

THOMAS WERNER

Superconducting circuits are promising candidates for future quantum computing applications. Since one needs millions of these circuits to overcome standards set by classical devices, the control and readout of each individual circuit becomes increasingly important. Current experimental realizations rely on multiple coaxial cables per circuit. The amount of microwave lines will pose a great challenge for dilution refrigerators. One way to deal with this challenge is to substitute the microwave coaxial lines with optical fibers and to use an electro-optic transducer to convert microwave and optical fields into each other at millikelvin temperatures. My poster will show how we read out a Transmon using infrared radiation at the fiber input of a dilution fridge, a converter at its mixing chamber and an optical heterodyne setup at its output. I will compare our results of three different types of readout for the same qubit, going from all-mw, to mw-to-optics, to all-optical readout.

14. QUANTUM SIMULATION WITH 2D ION CRYSTALS

ARTEM ZHDANOV

Our project aims to move trapped ions quantum simulation platform beyond 1D chains while maintaining a full control on a single ion level. Making 2D ion crystals immediately unlocks the possibility of simulation of spin lattices, a challenging model to simulate using linear strings. To reach this goal we use custom designed monolithic Paul trap, which is capable of maintaining tens of calcium ions in a stable stationary crystal configurations. With this poster, I would like to give an overview of our project, the main advantages and obstacles of our approach and the results achieved so far on our way to 2D quantum simulation.