QWORLD

QUANTUM SCIENCE DAYS

Program & List of Talks

All aspects of quantum information science and technology

The first scientific meeting organized by QWorld | June 1-2, 2021, Online

It is our pleasure to introduce the first Quantum Science Days, a scientific meeting organized by QWorld (Association) to provide opportunities for researchers at all levels working on all aspects of quantum information science and technologies to present their work. For this first edition, we received many excellent submissions, and we are happy and excited to have a program of 26 contributed talks over two days. We are also honored to have five distinguished speakers. We hope that you find the meeting to be a place to meet with other researchers around the world, and we also hope that it provides a stimulating environment that can help you advance your research.

We especially thank James Wootton (IBM Zurich), Alba Cervera Lierta (University of Toronto), Barry Sanders (University of Calgary), Tracy E. Northup (University of Innsbruck), and Menno Veldhorst (QuTech and Kavli Institute of Nanoscience) for honoring our event with their speech. We are very thankful to every author for submitting their work to the first edition of Quantum Science Days.

This event would not be possible without Ilke Ercan (TU Delft), Aeysha Khalique (QPakistan & National University of Sciences and Technology, Islamabad), and Andras Palyi (QHungary & Budapest University of Technology and Economics) who generously devoted their time to serve on the program committee. We thank each of them for their significant contributions.

We cannot thank Agnieszka Wolska (QWorld) enough for her great effort in preparing this booklet, as well as taking care of our event page, advertisements, and all graphical materials. We thank Andrei Voicu Tomut (QRomania) for preparing and taking care of our Discord server.

More than 500 people have registered for our event. We are very grateful to each of them for showing us such a huge appreciation.

Sumeet Khatri (Louisiana State University)
Co-chair of the program committee
Abuzer Yakaryilmaz (QWorld & University of Latvia)
Co-chair of the program committee
Chair of the organizing committee

Program

JUNE 1

Session 1 Abuzer Yakaryilmaz

10:00 (GMT) | Opening
10:05 (GMT) | **James Wootton, Quantum procedural generation**
11:00 (GMT) | Multi-qubit quantum finite automata using structured photons by Stephen Z. D. Plachta (21)
11:20 (GMT) | Implementing quantum finite automata algorithms on noisy devices by Utku Birkan (19, QIntern)
11:40 (GMT) | Tunable trade-off between quantum and classical computation via non-unitary Zeno-like dynamics by Aurél Gábris (10)
12:00 (GMT) | Universal notion of classicality based on ontological framework by Shubhayan Sarkar (17)

12:20 – 12:50 | Break (30 min.)

Session 2 Aeysha Khalique & Sumeet Khatri

12:50 (GMT) | Introducing QResearch by Zoltán Zimborás
13:10 (GMT) | The landscape of academic literature in quantum technologies by Zeki Seskir (1)
13:30 (GMT) | A computer science-oriented approach to introduce quantum computing to a new audience by Irina Heinz (11, QIntern)
13:50 (GMT) | Comparing quantum software development kits for introductory level education by Marija Šćekić (25)
14:10 (GMT) | Physical analysis of quantum circuits using python by Zeynep Pelin Yıldırım (14, QIntern)
14:30 (GMT) | Hybrid quantum variational algorithm for simulating open quantum systems with near-term devices by Hossein Davoodi Yeganeh (2)
14:50 (GMT) | Space-efficient binary optimization for variational computing by Adam Glos (13)

15:10 – 15:40 | Break (30 min.)

Session 3 Sumeet Khatri & Aeysha Khalique

15:40 (GMT) | Infeasible space reduction for QAOA through encoding change by Ludmila Botelho (20)
16:00 (GMT) | **Alba Cervera Lierta, The meta-variational quantum eigensolver**
17:00 (GMT) | **Barry Sanders, Quantum computing for data science**

Program

JUNE 2

Session 1 Zoltán Zimborás

10:00 (GMT) | **Tracy E. Northup, Quantum networks based on trapped-ion quantum computers**
11:00 (GMT) | MIMO Terahertz quantum key distribution by Neel Kanth Kundu (6)
11:20 (GMT) | Bell nonlocality is not sufficient for the security of standard device-independent quantum key distribution protocols by Máté Farkas (15)
11:40 (GMT) | Sequential sharing of genuine EPR steering by multiple observers by Shashank Gupta (7)
12:00 (GMT) | Resource analysis for quantum-aided Byzantine agreement by Zoltán Guba (9, QIntern)

12:20 – 12:50 | Break (30 min.)

Session 2 Andras Palyi

12:50 (GMT) | **Menno Veldhorst, Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits**
13:50 (GMT) | Crosstalk analysis for single-qubit and two-qubit gates in spin qubit arrays by Irina Heinz (12)
14:10 (GMT) | Nuclear spin readout in a cavity-coupled hybrid quantum dot-donor system by Jonas Mielke (16)
14:30 (GMT) | A singlet triplet hole spin qubit in planar Ge by Daniel Jirovec (8)
14:50 (GMT) | Spin shuttling in a silicon double quantum dot by Florian Ginzel (4)

15:10 – 15:40 | Break (30 min.)

Session 3 Ilke Ercan

15:40 (GMT) | Natural heavy-hole flopping mode qubit in germanium by Philipp M. Mutter (3)
16:00 (GMT) | Driving-assisted open quantum transport in qubit networks by Donny Dwiputra (26)
16:20 (GMT) | Polaron formation in a spin chain by measurement-induced imaginary Zeeman field by Pavlo Pyshkin (5)
16:40 (GMT) | Switching between relaxation hotspots and coldspots in disordered spin qubits by Amin Hosseinkhani (18)
17:00 (GMT) | Quantum state tomography as a numerical optimization problem by Niklas Rohling (22)
17:20 (GMT) | Cheap readout error mitigation on expensive NISQ devices by Akos Budai (23)
17:40 (GMT) | Fermion sampling: a robust quantum computational advantage scheme using fermionic linear optics and magic input states by Zoltán Zimborás (24)

Invited speakers

James Wootton (IBM Zurich)

Quantum procedural generation

Abstract:

Quantum computation is an emerging technology that promises to be a powerful tool in many areas. Though some years likely still remain until significant quantum advantage is demonstrated, the development of the technology has led to a range of valuable resources. These include publicly available prototype quantum hardware, advanced simulators for small quantum programs and programming frameworks to test and develop quantum software. In this talk we show that these resources are sufficient to provide the first useful results in the field of procedural generation [1,2].

Ref:
[1] https://dl.acm.org/doi/10.1145/3402942.3409600
[2] https://ieeexplore.ieee.org/document/9231571

Dr. James Wootton

is part of IBM Quantum, based at IBM Research – Zurich. He has worked for over a decade on quantum error correction, and has also been involved in multiple educational and outreach activities. He now focusses on helping people new to the field of quantum computing tackle interesting research questions.

See the recording of the talk on YouTube >>

Invited speakers

Alba Cervera Lierta (University of Toronto)

The meta-variational quantum eigensolver

Abstract:

In this talk, I will present the meta-VQE, an algorithm capable to learn the ground state energy profile of a parametrized Hamiltonian. By training the meta-VQE with a few data points, it delivers an initial circuit parametrization that can be used to compute the ground state energy of any parametrization of the Hamiltonian within a certain trust region. We test this algorithm with a XXZ spin chain, an electronic H4 Hamiltonian and a single-transmon quantum simulation. In all cases, the meta-VQE is able to learn the shape of the energy functional and, in some cases, resulted in improved accuracy in comparison to individual VQE optimization. The meta-VQE algorithm introduces both a gain in efficiency for parametrized Hamiltonians, in terms of the number of optimizations, and a good starting point for the quantum circuit parameters for individual optimizations. The proposed algorithm can be readily mixed with other improvements in the field of variational algorithms to shorten the distance between the current state-of-the-art and applications with quantum advantage. I will also review the features of Tequila, a quantum software package for the rapid development of quantum algorithms.

Ref:
https://arxiv.org/abs/2009.13545 (Meta-VQE),
https://iopscience.iop.org/article/10.1088/2058-9565/abe567 (Tequila paper),
https://github.com/aspuru-guzik-group/tequila (Tequila),
https://github.com/aspuru-guzik-group/tequila-tutorials (tequila tutorials),
https://arxiv.org/abs/2101.08448 (NISQ review)

Alba Cervera-Lierta

did her PhD at the University of Barcelona, where she studied a physics degree and an MSc in particle physics. Her background is quantum information, multipartite entanglement and quantum computation. She is currently a Postdoctoral fellow at the MatterLab (Alán Aspuru-Guzik group) at the University of Toronto. She currently works on near-term quantum algorithms, the development of computational tools for quantum computation and high-dimensional quantum physics.

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Invited speakers

Barry Sanders (University of Calgary)

Quantum computing for data science

Abstract:
I provide a perspective on the development of quantum computing for data science, including a dive into state-of-the-art for both hardware and algorithms.

Barry Sanders
is a professor and Director of the Institute for Quantum Science and Technology at the University of Calgary, Lead of the Quantum Alberta consortium, part-time Distinguished Professor at the University of Science and Technology of China and part-time VAJRA professor at the Raman Research Instiute in India. He is a Fellow of the Royal Society of Canada, of the Institute of Physics, of the American Physical Society and of the Optical Society of America.

See the recording of the talk on YouTube >>

Invited speakers

Tracy E. Northup (University of Innsbruck)

Quantum networks based on trapped-ion quantum computers

Abstract:

Entanglement-based quantum networks hold out the promise of new capabilities for secure communication, distributed quantum computing, and interconnected quantum sensors [1,2]. However, only a handful of elementary quantum networks have been realized to date. Trapped ions are among the most promising platforms for quantum information science, and I will review the state of the art in linking together trapped-ion quantum computers [3-5]. Optical cavities provide efficient quantum interfaces between ions and photons [6-9]; I will present ongoing work to link two cavity-coupled ion traps in Innsbruck across a 400 m fiber channel. We will then consider how to extend such links to multi-node networks.

Ref:
[1] H. J. Kimble, Nature 453, 1023 (2008)
[2] S. Wehner, D. Elkouss, and R. Hanson, Science 362, eaam9288 (2018)
[3] D. L. Moehring, P. Maunz, S. Olmschenk, K. C. Younge, D. N. Matsukevich, L.-M. Duan, and C. Monroe, Nature 449, 68 (2007)
[4] D. Hucul, I. V. Inlek, G. Vittorini, C. Crocker, S. Debnath, S. M. Clark, and C. Monroe, Nat. Phys. 11, 37 (2015)
[5] L. J. Stephenson, D. P. Nadlinger, B. C. Nichol, S. An, P. Drmota, T. G. Ballance, K. Thirumalai, J. F. Goodwin, D. M. Lucas, and C. J. Ballance, High-Rate, Phys. Rev. Lett. 124, 110501 (2020)
[6] A. Stute, B. Casabone, P. Schindler, T. Monz, P. O. Schmidt, B. Brandstätter, T. E. Northup, and R. Blatt, Nature 485, 482 (2012)
[7] B. Casabone, K. Friebe, B. Brandstätter, K. Schüppert, R. Blatt, and T. E. Northup, Phys. Rev. Lett. 114, 023602 (2015)
[8] M. Meraner, A. Mazloom, V. Krutyanskiy, V. Krcmarsky, J. Schupp, D. Fioretto, P. Sekatski, T. E. Northup, N. Sangouard, and B. P. Lanyon, Phys. Rev. A 102, 052614 (2020)
[9] J. Schupp, V. Krcmarsky, V. Krutyanskiy, M. Meraner, T. E. Northup, and B. P. Lanyon, arXiv:2105.02121 (2021)

Tracy Northup

is the Ingeborg Hochmair Professor of Experimental Physics at the University of Innsbruck, Austria. Her research explores quantum interfaces between light and matter, focusing on trapped-ion and cavity-based interfaces for quantum networks and quantum optomechanics. She received her PhD from the California Institute of Technology in 2008 and then held an appointment as a postdoctoral scholar at the University of Innsbruck, where she was the recipient of a Marie Curie International Incoming Fellowship and an Elise Richter Fellowship. She became an assistant professor at the University of Innsbruck in 2015 and has been a full professor since 2017. In 2016, she received the START Prize, the highest Austrian award for young scientists, from the Austrian Science Fund.

See the recording of the talk on YouTube >>

Invited speakers

Menno Veldhorst
(QuTech and Kavli Institute of Nanoscience)

Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits

Abstract:

Our approach toward scalable quantum technology departs from the transistor, the most replicated structure made by mankind [1,2]. We define qubits on the spin states of electrons and holes in silicon and germanium quantum dots. In this talk I will present our recent results in increasing the qubit quality and quantity. First, we show that even a single hole can be coherently controlled [3]. By exploiting the strong spin-orbit interaction of holes we obtain fast qubit operation with gate fidelities of 99.99%, setting new benchmarks for quantum dot systems. Furthermore, through dynamical decoupling we obtain record coherence times for holes and by applying this technique as a band filter we are able to measure the transversal hyperfine interaction with nuclear spins. Second, we demonstrate that quantum dot qubits and control electronics can be operated in the same temperature regime [4,5]. In addition, we show that qubits can be realized using a fully-industrial 300 mm wafer process. These together define a key step toward integrated quantum circuits [1]. Third, we construct a 2×2 quantum dot array and show qubit coupling in two dimensions [6,7]. We obtain universal control and demonstrate coherent execution of a quantum circuit that entangles and disentangles all four qubits. Finally, I will present our strategies to overcome qubit-to-qubit variations, aiming to build quantum systems with fewer control lines than number of qubits [8], targeting to achieve a quantum advantage with the same materials and techniques that enabled todays information age.

Ref:
[1] Vandersypen et al. npj Quantum Information 2017
[2] Scappucci et al. Nature Reviews Materials 2020
[3] Hendrickx et al. Nature Communications 2020
[4] Petit et al. Nature 2020
[5] Xue et al. Nature 2021
[6] van Riggelen et al. APL 2021
[7] Hendrickx et al. Nature 2021
[8] Li et al. Science Advances 2018

Menno Veldhorst

is group leader at QuTech, the lead of the QuTech Academy, and portfolio director at the extension school of the TU Delft. Veldhorst received his PhD cum laude at the University of Twente (in the groups of prof. A. Brinkman and prof. H. Hilgenkamp). He performed his postdoctoral research at the University of New South Wales in the group of prof. A. Dzurak, where he demonstrated single and two-qubit logic in silicon, mentioned as one of the top ten breakthroughs in physics in 2015 by Physics World. His group at QuTech introduced planar germanium qubits, demonstrated universal logic with silicon above one Kelvin, and realized four-qubit logic with quantum dots. He has published more than 60 papers, including 18 publications in the Science and Nature journals. For his contributions to silicon and germanium quantum technology he received the Nicholas Kurti Science Prize and he is listed as a visionary in the MIT Technology Review list 35 innovators under 35. As lead QuTech Academy, Veldhorst develops massive online courses (MOOCs) on quantum technology, which have attracted already over 80.000 students.

See the recording of the talk on YouTube >>

List of Talks

[In their submitted order]

1. The landscape of academic literature in quantum technologies

See the recording >>

Zeki Seskir (METU Physics Department)*

In this study, we investigated the academic literature on quantum technologies (QT) using bibliometric tools. We used a set of 49,823 articles obtained from the Web of Science (WoS) database using a search query constructed through expert opinion. Analysis of this revealed that QT is deeply rooted in physics, and the majority of the articles are published in physics journals. Keyword analysis revealed that the literature could be clustered into three distinct sets, which are (i) quantum communication/cryptography, (ii) quantum computation, and (iii) physical realizations of quantum systems. We performed a burst analysis that showed the emergence and fading away of certain key concepts in the literature. This is followed by co-citation analysis on the „highly cited" articles provided by the WoS, using these we devised a set of core corpus of 34 publications. Comparing the most highly cited articles in this set with respect to the initial set we found that there is a clear difference in most cited subjects. Finally, we performed co-citation analyses on country and organization levels to find the central nodes in the literature. Overall, the analyses of the datasets allowed us to cluster the literature into three distinct sets, construct the core corpus of the academic literature in QT, and to identify the key players on country and organization levels, thus offering insight into the current state of the field. Search queries and access to figures are provided in the appendix.

2. Hybrid quantum variational algorithm for simulating open quantum systems with near-term devices

See the recording >>

Mahmoud Mahdian and Hossein Davoodi Yeganeh (University of Tabriz)*

Hybrid quantum-classical (HQC) algorithms make it possible to use near-term quantum devices supported by classical computational resources by useful control schemes. In this paper, we develop an HQC algorithm using an efficient variational optimization approach to simulate open system dynamics under the Noisy-Intermediate Scale Quantum computer. Using the time-dependent variational principle (TDVP) method and extending it to McLachlan TDVP for density matrix which involves minimization of Frobenius norm of the error, we apply the unitary quantum circuit to obtain the time evolution of the open quantum system in the Lindblad formalism. Finally, we illustrate the use of our methods with detailed examples which are in good agreement with analytical calculations.

3. Natural heavy-hole flopping mode qubit in germanium

Philipp M. Mutter and Guido Burkard (University of Konstanz)*

Flopping mode qubits in double quantum dots (DQDs) allow for coherent spin-photon hybridization and fast qubit gates when coupled to either an alternating external or a quantized cavity electric field. To achieve this, however, electronic systems rely on synthetic spin-orbit interaction (SOI) by means of a magnetic field gradient as a coupling mechanism. Here we theoretically show that this challenging experimental setup can be avoided in heavy-hole (HH) systems in germanium (Ge) by utilizing the sizable cubic Rashba SOI. We argue that the resulting natural flopping mode qubit possesses highly tunable spin coupling strengths that allow for qubit gate times in the nanosecond range when the system is designed to function in an optimal operation mode which we quantify.

4. Spin shuttling in a silicon double quantum dot

See the recording >>

Florian Ginzel, Adam R. Mills, Jason R. Petta, and Guido Burkard*
(University of Konstanz; Princeton University)

The transport of quantum information between different nodes of the device is crucial for a quantum processor. In the context of spin qubits, this can be realized by coherent electron spin shuttling between quantum dots. Here we theoretically study a minimal version of spin shuttling between two quantum dots (QDs) occupied by one electron [1]. We analyze the possibilities and limitations of spin transport during a detuning sweep in a silicon double QD. This research is motivated by recent experimental progress [2-4]. Spin-orbit interaction and an inhomogeneous magnetic field play an important role for spin shuttling and are included in our model. Interactions that couple the position, spin and valley degrees of freedom open avoided crossings in the spectrum allowing for diabatic transitions and interfering paths. The outcomes of single and repeated spin shuttling protocols are explored by means of numerical simulations and an approximate analytic model based on the Landau-Zener model. We find that fast high-fidelity spin-shuttling is feasible for optimal choices of parameters or protected by constructive interference.

[1] Ginzel et al., Phys. Rev. B 102, 195418 (2020)
[2] T. Fujita et al., npj Quantum Information 3, 22 (2017)
[3] A. R. Mills et al., Nature Communs 10, 1063 (2019)
[4] J. Yoneda et al., https://arxiv.org/abs/2008.04020 (2020)

5. Polaron formation in a spin chain by measurement-induced imaginary Zeeman field

See the recording >>

Pavlo Pyshkin, E. Ya. Sherman, and Lian-Ao Wu (University of the Basque Country)*

We present a high-rate projective measurement-based approach for controlling non-unitary evolution of a quantum chain of interacting spins. In this approach, we demonstrate that local measurement of a single external spin coupled to the chain can produce a spin polaron, which remains stable after the end of the measurement. This stability results from the fact that the Hilbert space of the chain contains a subspace of non-decaying states, stable during the nonunitary evolution. These states determine the resulting final state of the chain and long-term shape of the polaron. In addition to formation of the spin polarons, the presented measurement protocol can be used for distillation of non-decaying states from an initial superposition or mixture.

6. MIMO Terahertz quantum key distribution

See the recording >>

Neel Kanth Kundu, Soumya P. Dash, Matthew R. McKay, and Ranjan K. Mallik*
(The Hong Kong University of Science and Technology; Indian Institute of Technology Bhubaneswar; Indian Institute of Technology Delhi)

We propose a multiple-input multiple-output (MIMO) quantum key distribution (QKD) scheme for improving the secret key rates and increasing the maximum transmission distance for terahertz (THz) frequency range applications operating at room temperature. We propose a transmit beamforming and receive combining scheme that converts the rank-r MIMO channel between Alice and Bob into r parallel lossy quantum channels whose transmittances depend on the non-zero singular values of the MIMO channel. The MIMO transmission scheme provides a multiplexing gain of r, along with a beamforming and array gain equal to the product of the number of transmit and receive antennas. This improves the secret key rate and extends the maximum transmission distance. Our simulation results show that multiple antennas are necessary to overcome the high free-space path loss at THz frequencies. Positive key rates are achievable in the 10–30 THz frequency range that can be used for both indoor and outdoor QKD applications for beyond fifth generation ultra-secure wireless communications systems.

7. Sequential sharing of genuine EPR steering by multiple observers

Shashank Gupta (S. N. Bose National Centre for Basic Sciences)

We investigate the possibility of multiple use of a single copy of three-qubit state for detecting genuine tripartite Einstein-Podolsky--Rosen (EPR) steering. A pure three-qubit state of either the Greenberger-Horne-Zeilinger (GHZ)-type or W-type is shared between two fixed observers in two wings and a sequence of multiple observers in the third wing who perform unsharp or non-projective measurements. The measurement settings of each of the multiple observers in the third wing is independent and uncorrelated with the measurement settings and outcomes of the previous observers. In such set-up, we investigate all possible types of $(2 \longrightarrow 1)$ and $(1 \longrightarrow 2)$ genuine tripartite EPR steering. For each case, we obtain an upper limit on the number of observers on the third wing who can demonstrate genuine EPR steering through the quantum violation of an appropriate tripartite steering inequality. We show that the GHZ state allows for a higher number of observers compared to that for W states. Additionally, $(1 \longrightarrow 2)$ genuine steering is possible for a larger range of the sharpness parameters compared to that for the $(2 \longrightarrow 1)$ genuine steering cases.

8. A singlet triplet hole spin qubit in planar Ge

Daniel Jirovec (IST Austria) et al.*

See the recording >>

Spin qubits are considered to be among the most promising candidates for building a quantum processor. GroupIV hole spin qubits have moved into the focus of interest due to the ease of operation and compatibility with Si technology. In addition, Ge offers the option for monolithic superconductor-semiconductor integration. Here we demonstrate a hole spin qubit operating at fields below 10 mT, the critical field of Al, by exploiting the large out-of-plane hole g-factors in planar Ge and by encoding the qubit into the singlet-triplet states of a double quantum dot. We observe electrically controlled g-factor-difference-driven and exchange-driven rotations with tunable frequencies exceeding 100 MHz and dephasing times of 1 μs which we extend beyond 150 μs with echo techniques. These results demonstrate that Ge hole singlet-triplet qubits are competing with state-of-the art GaAs and Si singlet-triplet qubits. In addition, their rotation frequencies and coherence are on par with Ge single spin qubits, but they can be operated at much lower fields underlining their potential for on chip integration with superconducting technologies. *(arXiv:2011.13755)*

9. Resource analysis for quantum-aided Byzantine agreement

Zoltán Guba, István Finta, Ákos Budai, Lóránt Farkas, Zoltán Zimborás, and András Pályi (Budapest University of Technology and Economics; Nokia Bell Labs; Óbuda University; Wigner Research Centre for Physics)*

See the recording >>

In distributed computing, a byzantine fault is a condition where a component behaves inconsistently, showing different symptoms to different components of the system. Consensus among the correct components can be reached by appropriately crafted communication protocols, even in the presence of byzantine faults. Quantum-aided protocols built upon distributed entangled quantum states are worth considering, as they are more resilient than traditional ones. Based on earlier ideas, here we introduce a parameter-dependent family of quantum-aided weak broadcast protocols, and prove their security. We analyze the resource requirements as functions of the protocol parameters, and locate the parameter range where these requirements are minimal. Hence, our work illustrates the engineering aspects of future deployments of such protocols in practice. Following earlier work demonstrating the suitability of noisy intermediate-scale quantum (NISQ) devices for the study of quantum networks, we show how to prepare our resource quantum state on publicly available IBM quantum computers. We outline follow-up tasks toward practical quantum-aided byzantine fault tolerance.

10. Tunable trade-off between quantum and classical computation via non-unitary Zeno-like dynamics

See the recording >>

Pavlo V. Pyshkin, Aurél Gábris, Da-Wei Luo, Jian-Qiang You, and Lian-Ao Wu (University of the Basque Country; Czech Technical University in Prague; Wigner Research Centre for Physics; Stevens Institute of Technology; Zhejiang University; Basque Foundation for Science)*

We propose and analyze a measurement-based non-unitary variant of the continuous time Grover search algorithm. We derive tight analytical lower bounds on its efficiency for arbitrary database sizes and measurement parameters. We study the behaviour of the algorithm subject to Oracle errors, and find that it outperforms the standard algorithm for several values of such errors. Our analysis is based on deriving a non-hermitian effective description of the algorithm, yielding also a deeper insight into components responsible for the quantum and the classical operation of the protocol.

11. A Computer Science-Oriented Approach to Introduce Quantum Computing to a New Audience

See the recording >>

Özlem Salehi, Zeki Seskir, and İlknur Tepe (IITiS PAN; METU Physics Department; QWorld)*

Contribution: In this study, an alternative educational approach for introducing quantum computing to a wider audience is highlighted. The proposed methodology considers quantum computing as a generalized probability theory rather than a field emanating from physics and utilizes quantum programming as an educational tool to reinforce the learning process.

Background: Quantum computing is a topic mainly rooted in physics, and it has been gaining rapid popularity in recent years. A need for extending the educational reach to groups outside of physics has also been becoming a necessity.

Intended outcomes: This study aims to inform academics and organizations interested in introducing quantum computing to a diverse group of participants on an educational approach. It is intended that the proposed methodology would facilitate people from diverse backgrounds to enter the field.

Application design: The introductory quantum physics content is bypassed and the quantum computing concepts are introduced through linear algebra instead. Quantum programming tasks are prepared in line with the content. Pre/post-test design method and Likert scale satisfaction surveys are utilized to measure knowledge acquisition and to evaluate the perception of the learning process by the participants.

Findings: Conducted pre/post-test design survey shows that there is a statistically significant increase in the basic knowledge levels of the participants on quantum computing concepts. Furthermore, no significant difference in the gain scores is observed between the participants from different STEM-related educational backgrounds. The majority of the participants were satisfied and provided positive feedback.

12. Crosstalk analysis for single-qubit and two-qubit gates in spin qubit arrays

See the recording >>

Irina Heinz and Guido Burkard (University of Konstanz)*

Scaling up spin qubit systems requires high-fidelity single-qubit and two-qubit gates. Gate fidelities exceeding 98% were already demonstrated in silicon based single and double quantum dots, whereas for the realization of larger qubit arrays crosstalk effects on neighboring qubits must be taken into account. We analyze qubit fidelities impacted by crosstalk when performing single-qubit and two-qubit operations on neighbor qubits with a simple Heisenberg model. Furthermore we propose conditions for driving fields to robustly synchronize Rabi oscillations and avoid crosstalk effects. In our analysis we also consider next to nearest neighbor crosstalk and show that double synchronization leads to a restricted choice for the driving field strength, exchange interaction, and thus gate time. Considering realistic experimental conditions we propose a set of parameter values to perform a nearly crosstalk-free CNOT gate and so open up the pathway to scalable quantum computing devices.

13. Space-efficient binary optimization for variational computing

See the recording >>

Adam Glos, Aleksandra Krawiec, and Zoltan Zimboras (Polish Academy of Sciences; Wigner Research Centre for Physics; BME-MTA Lendulet Quantum Information Theory Research Group)*

In the era of Noisy Intermediate-Scale Quantum (NISQ) computers it is crucial to design quantum algorithms which do not require many qubits or deep circuits. Unfortunately, the most well-known quantum algorithms are too demanding to be run on currently available quantum devices. Moreover, even the state-of-the-art algorithms developed for the NISQ era often suffer from high space complexity requirements for particular problem classes. In this paper, we show that it is possible to greatly reduce the number of qubits needed for the Traveling Salesman Problem (TSP), a paradigmatic optimization task, at the cost of having deeper variational circuits. While the focus is on this particular problem, we claim that the approach can be generalized for other problems where the standard bit-encoding is highly inefficient. Finally, we also propose encoding schemes which smoothly interpolate between the qubit-efficient and the circuit depth-efficient models. All the proposed encodings remain efficient to implement within the Quantum Approximate Optimization Algorithm framework.

14. Physical analysis of quantum circuits using python

See the recording >>

Zeynep Pelin Yıldırım, Ahmed Asaf Toprakçı, Samantha van Rijs*, and İlke Ercan (Boğaziçi University; Bilkent University; Technical University of Delft)*

Physical analysis of quantum circuits provides important insights into the performance efficiency of these emerging computing systems. In order to better understand the physical constraints imposed on these circuits, we need simple yet effective tools to study the impact of circuit parameters as well as external conditions. During the QIntern 2020 research program, we developed python codes to study the physics of solid state quantum circuits under best case scenarios. In this work, we present our ongoing research on physical circuit analysis of these quantum systems under non-idealized conditions. We illustrate the impact of temperature change and other noise factors on the behaviour of structures such as quantronium and fluxonium circuits. In order to provide a basis for comparison on the physics of different qubit circuits, we also illustrate an analysis of Nitrogen-Vacancy (NV) center qubits. Our work provides a comprehensive bottom-up discussion on the realization of qubits as well as physical limitations imposed on these systems. We also illustrate the powerful tools python provides to develop effective analyses.

15. Bell nonlocality is not sufficient for the security of standard device-independent quantum key distribution protocols

See the recording >>

Máté Farkas, Maria Balanzó-Juandó, Karol Łukanowski, Jan Kołodyński, and Antonio Acín (ICFO)*

Device-independent quantum key distribution is a secure quantum cryptographic paradigm that allows two honest users to establish a secret key, while putting minimal trust in their devices. Most of the existing protocols have the following structure: first, a bipartite nonlocal quantum state is distributed between the honest users, who perform local projective measurements to establish nonlocal correlations. Then, they announce the implemented measurements and extract a secure key by post-processing their measurement outcomes. We show that no protocol of this form allows for establishing a secret key when implemented on certain entangled nonlocal states, namely on a range of entangled two-qubit Werner states. To prove this result, we introduce a technique for upper-bounding the asymptotic key rate of device-independent quantum key distribution protocols, based on a simple eavesdropping attack. Our results imply that either different tools — such as different reconciliation techniques or non-projective measurements — are needed for device-independent quantum key distribution in the large-noise regime, or Bell nonlocality is not sufficient for this task.

16. Nuclear spin readout in a cavity-coupled hybrid quantum dot-donor system

See the recording >>

Jonas Mielke, Jason R. Petta, and Guido Burkard (University of Konstanz)*

Nuclear spins show long coherence times and are well isolated from the environment, which are properties making them promising for quantum information applications. However, these same qualities make the readout of nuclear spin qubits challenging. Here, we present a method for nuclear spin readout by probing the transmission of a microwave resonator. We consider a flopping mode spin qubit [1,2] formed by a single electron in a hybrid quantum dot-donor architecture subjected to a homogeneous magnetic field and a transverse magnetic field gradient. This qubit interacts with a microwave resonator via the electric dipole coupling allowing for strong spin photon coupling [3,4]. In our scenario, the electron spin interacts with a 31P defect nuclear spin via the hyperfine interaction. Our theoretical investigation demonstrates a 31P nuclear spin state dependent shift of the absorption resonance representing the signature for strong spin-photon coupling that can be resolved in contemporary experiments and thus allows for nuclear spin readout.

[1] Benito et al., Phys. Rev. B 100, 125430 (2019)
[2] Croot et al., Phys. Rev. Research 2, 012006 (2020)
[3] Mi et al., Nature 555, 599 (2018)
[4] Benito et al., Phys. Rev. B 96, 235434 (2017)

17. Universal notion of classicality based on ontological framework

Shubhayan Sarkar (Center for Theoretical Physics of the Polish Academy of Sciences)*

See the recording >>

Existence of physical reality in the classical world is a well-established fact from day-to-day observations. However, within quantum theory, it is not straightforward to reach such a conclusion. A framework to analyse how observations can be described using some physical states of reality in a theory independent way was recently developed, known as ontological framework. Different principles when imposed on the ontological level give rise to different observations in physical experiments. Using the ontological framework, we formulate a novel notion of classicality termed „universal classicality" which is based upon the physical principles that in classical theories pure states are physical states of reality and every projective measurement just observes the state of the system. We construct a communication task in which the success probability is bounded from above for ontological models satisfying the notion of universal classicality. Contrary to previous notions of classicality which either required systems of dimension strictly greater than two or at least three preparations, a violation of „universal classicality" can be observed using just a pair of qubits and a pair of incompatible measurements. We further show that violations of previously known notions of classicality such as preparation non-contexuality and Bell's local causality is a violation of universal classicality.

18. Switching between relaxation hotspots and coldspots in disordered spin qubits

Amin Hosseinkhani and Guido Burkard (University of Konstanz)*

See the recording >>

We develop a valley-dependent envelope function theory that can describe the effects of arbitrary configurations of interface steps and miscuts on the qubit relaxation time. For a given interface roughness, we show how our theory can be used to find the valley--dependent dipole matrix elements, the valley splitting, and the spin-valley coupling as a function of the electromagnetic fields in a Si/SiGe quantum dot spin qubit. We demonstrate that our theory can quantitatively reproduce and explain the result of experimental measurements for the spin relaxation time with only a minimal set of free parameters. Investigating the sample dependence of spin relaxation, we find that at certain conditions for a disordered quantum dot, the spin-valley coupling vanishes. This, in turn, completely blocks the valley-induced qubit decay. We show that the presence of interface steps can in general give rise to a strongly anisotropic behavior of the spin relaxation time. Remarkably, by properly tuning the gate-induced out-of-plane electric field, it is possible to turn the spin-valley hotspot into a "coldspot" at which the relaxation time is significantly prolonged and where the spin relaxation time is additionally first-order insensitive to the fluctuations of the magnetic field. This electrical tunability enables on-demand fast qubit reset and initialization that is critical for many quantum algorithms and error correction schemes. We, therefore, argue that the valley degree of freedom can be used as an advantage for Si spin qubits.

19. Implementing quantum finite automata algorithms on noisy devices

See the recording >>

Utku Birkan, Özlem Salehi, Viktor Olejar, Cem Nurlu, and Abuzer Yakaryılmaz*
(Middle East Technical University; Özyeğin University; P.J. Šafárik University in Košice; Boğaziçi University; University of Latvia; QWorld)

Quantum finite automata (QFAs) literature offers an alternative mathematical model for studying quantum systems with finite memory. As a superiority of quantum computing, QFAs have been shown exponentially more succinct on certain problems such as MODp = {a^j | j ≡ 0 mod p}, where p is a prime number. In this paper we present improved circuit based implementations for QFA algorithms recognizing the MODp problem using the Qiskit framework. We focus on the case p=11 and provide a 3 qubit implementation for the MOD11 problem reducing the total number of required gates using alternative approaches. We run the circuits on real IBM quantum devices but due to the limitation of the real quantum devices in the NISQ era, the results are heavily affected by the noise. This limitation reveals once again the need for algorithms using less amount of resources. Consequently, we consider an alternative 3 qubit implementation which works better in practice, and we obtain promising results even for the problem MOD31.

20. Infeasible space reduction for QAOA through encoding change

See the recording >>

Ludmila Botelho, Adam Glos, Akash Kundu, Jaros law Adam Miszczak, Ozlem Salehi, and Zoltan Zimboras (Polish Academy of Sciences; Wigner Research Center for Physics; BME-MTA Lendulet Quantum Information Theory Research Group)*

In the era of Noisy Intermediate-Scale Quantum (NISQ) computing, the design of space-efficient and fault-tolerant quantum algorithms is inevitable. Considering the problems defined over permutations, the straightforward approaches are infeasible in terms of space and have undesirable impacts on heuristic NISQ era algorithms such as Quantum Approximate Optimization Algorithm (QAOA). Besides the issues related to space efficiency, it becomes harder to reach the optimal solutions as the feasible solutions constitute only a small fraction of the whole space. Addressing these issues, we propose Encoding-Changing Quantum Approximate Optimization Algorithm (EC-QAOA) method for decreasing the quantum memory requirements of the QAOA approach. We demonstrate the effectiveness of the proposed method through the Travelling Salesman Problem. We show that the proposed approach enables quantum error mitigation using mid-circuit measurements. Furthermore, we compare the performance of the proposed method with the existing approaches by numerical studies.

21. Multi-qubit quantum finite automata using structured photons

See the recording >>

Stephen Z. D. Plachta, Markus Hiekkamäki, Abuzer Yakaryılmaz, and Robert Fickler (Tampere University; University of Latvia; QWorld)*

Finite automata (FA) are fundamental computational devices that make binary decisions (yes or no) using their finite memories (states) after reading a given input once, symbol by symbol. We use up to four qubits, formed from superpositions of Laguerre-Gaussian (LG) modes encoded on heralded single photons, as a quantum finite automaton (QFA). We demonstrate exponential state efficiency compared to classical finite automata when answering the prime number promise problem.

22. Quantum state tomography as a numerical optimization problem

See the recording >>

*Violeta N. Ivanova-Rohling, Guido Burkard, and Niklas Rohling**
(University of Konstanz; Bulgarian Academy of Sciences)

Quantum state tomography (QST) is the process of finding an estimate for the density matrix of a quantum system performing measurements on several copies of the state of the system. QST is an essential yet time-consuming tool for the verification of a quantum device. Consequently, finding the set of measurements which allows for QST in the fastest way while reaching the desired precision is of high practical relevance. For a few scenarios, analytical solutions to this problem are known, e.g. for non-degenerate projective measurements, the eigenbases of the optimal set of measurement operators form a complete set of mutually unbiased bases (MUBs), which is known to exist for Hilbert spaces of prime-power dimension [1]; for measuring one qubit in a set of N qubits, the optimal choice for a QST measurement scheme is a set of mutually unbiased subspaces (MUSs), which can be constructed from a complete set of MUBs [2]. Here, we extend the latter result to the qubit-qutrit system of dimension six where no complete set of MUBs is known. Such a system is realized in a nitrogen-vacancy center in diamond by the N-14 nuclear spin-1 (qutrit) and two electronic states (qubit). We formulate the search for the fastest QST measurement scheme as a high-dimensional optimization problem and numerically obtain a solution whose deviations from a set of MUSs are so small that they are without practical relevance [3]. Our numerical approach is applicable to many situations where no analytical expression of the optimal QST scheme is known.
This work was partially supported by the Zukunftskoleg (University of Konstanz) and the Bulgarian National Science Fund under the contract No KP-06-PM 32/8.

[1] W. K. Wootters and B. D. Fields, Ann. Phys. 191, 363 (1989).
[2] B. G. Bodmann and J. I. Haas, Proc. Amer. Math. Soc. 146, 2601 (2018).
[3] V. N. Ivanova-Rohling, G. Burkard, and N. Rohling, arXiv:2012.14494.

23. Cheap readout error mitigation on expensive NISQ devices

See the recording >>

Akos Budai, Zoltan Zimboras, and Andras Palyi (Budapest University of Technology and Economics; Hungary Academy of Sciences; Nokia Bell Labs)*

Readout error mitigation (REM) is an efficient tool to improve the functionality of Noisy Intermediate-Scale Quantum (NISQ) devices. In most superconducting prototype quantum computers, the readout error dominates the errors of individual gates. The level of improvement gained by 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.

24. Fermion sampling: a robust quantum computational advantage scheme using fermionic linear optics and magic input states

See the recording >>

Michał Oszmaniec, Ninnat Dangniam, Mauro E.S. Morales, and Zoltán Zimborás (Polish Academy of Sciences; University of Technology Sydney; Wigner Research Centre for Physics; MTA-BME Lendulet Quantum Information Theory Research Group; Budapest University of Technology and Economics)*

Fermionic Linear Optics (FLO) is a restricted model of quantum computation which in its original form is known to be efficiently classically simulable. We show that, when initialized with suitable input states, FLO circuits can be used to demonstrate quantum computational advantage with strong hardness guarantees. Based on this, we propose a quantum advantage scheme which is a fermionic analogue of Boson Sampling: Fermion Sampling with magic input states. We consider in parallel two classes of circuits: particle-number conserving (passive) FLO and active FLO that preserves only fermionic parity and is closely related to Matchgate circuits introduced by Valiant. Mathematically, these classes of circuits can be understood as fermionic representations of the Lie groups U(d) and SO(2d). This observation allows us to prove our main technical results. We first show anticoncentration for probabilities in random FLO circuits of both kinds. Moreover, we prove robust average-case hardness of computation of probabilities. To achieve this, we adapt the worst-to-average-case reduction based on Cayley transform, introduced recently by Movassagh, to representations of low-dimensional Lie groups. Taken together, these findings provide hardness guarantees comparable to the paradigm of Random Circuit Sampling. Importantly, our scheme has also a potential for experimental realization. Both passive and active FLO circuits are relevant for quantum chemistry and many-body physics and have been already implemented in proof-of-principle experiments with superconducting qubit architectures. Preparation of the desired quantum input states can be obtained by a simple quantum circuit acting independently on disjoint blocks of four qubits and using 3 entangling gates per block. We also argue that due to the structured nature of FLO circuits, they can be efficiently certified.

25. Comparing quantum software development kits for introductory level education

See the recording >>

Marija Šćekić and Abuzer Yakaryılmaz (Mediterranean University; University of Latvia; QWorld)*

We initiate a study to overview and compare quantum software development kits (QSDKs) in terms of their usability for introductory level quantum education. In this work, we focus on Qiskit, ProjectQ, Cirq, and Forest. For comparison, we define six tasks based on QWorld's introductory tutorial called Bronze. We implement each task on these QSDKs. Besides, we check how easy it is to install them. According to our preliminary results, not every QSDK comes as a stand-alone python package. This may create certain installation and execution problems. Visualization of quantum circuits may be poor or fail in some cases. For the rest of the tasks, all QSDKs are good to work with.

26. Driving-assisted open quantum transport in qubit networks

See the recording >>

Donny Dwiputra, Jusak S. Kosasih, Albertus Sulaiman, and Freddy P. Zen*
(Institut Teknologi Bandung; Indonesian Center for Theoretical and Mathematical Physics; Badan Pengkajian dan Penerapan Teknologi)

We determine the characteristic of dissipative quantum transport in a coupled qubit network in the presence of on-site and off-diagonal external driving. The work is a generalization of the dephasing-assisted quantum transport where noise is beneficial to the transport efficiency. Using Floquet-Magnus expansion extended to Markovian open systems, we analytically derive transport efficiency and compare it to exact numerical results. We find that periodic driving may increase the efficiency at frequencies near the coupling rate. On the other hand, at some other frequencies the transport may be suppressed. We then propose the enhancement mechanism as the ramification of interplay between driving frequency, dissipative, and trapping rates.

27. Introducing QResearch

See the recording >>

Zoltán Zimborás and Adam Glos (QWorld)*

In this talk, we present the activities of QResearch, the research arm of QWorld. Several types of QResearch programs are organized throughout the year, these include the different Study Groups, Research Groups, and the QIntern program. We provide the details of each of these programs, and, finally, discuss how students and researchers - either members of QWorld or not - can take part in these.

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Yakaryılmaz is partially supported by ERDF project Nr. 1.1.1.5/19/A/005 "Quantum computers with constant memory"

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The booklet is prepared by Agnieszka Wolska (2021)