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BOOK OF ABSTRACTS

Presented in alphabetical order

INVITED SPEAKERS

Borhan Ahmadi

International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk, Poland

Nonreciprocal Quantum Batteries

Nonreciprocity, arising from the breaking of time-reversal symmetry, has become a fundamental tool in diverse quantum technology applications. It enables directional flow of signals and efficient noise suppression, constituting a key element in the architecture of current quantum information and computing systems. Here we explore its potential in optimizing the charging dynamics of a quantum battery. By introducing nonreciprocity through reservoir engineering during the charging process, we induce a directed energy flow from the quantum charger to the battery, resulting in a substantial increase in energy accumulation. Despite local dissipation, the nonreciprocal approach demonstrates a fourfold increase in battery energy compared to conventional charger-battery systems. This effect is observed in the stationary limit and remains applicable even in overdamped coupling regimes, eliminating the need for precise temporal control over evolution parameters. Our result can be extended to a chiral network of quantum nodes, serving as a multi-cell quantum battery system to enhance storage capacity. The proposed approach is straightforward to implement using current state-of-the-art quantum circuits, both in photonics and superconducting quantum systems. In a broader context, the concept of nonreciprocal charging has significant implications for sensing, energy capture, and storage technologies or studying quantum thermodynamics.

Link to the paper:
https://doi.org/10.1103/PhysRevLett.132.210402

Anna Erika Elisabeth Andersson

Heriot-Watt University, Edinburgh, United Kingdom

Quantum cryptography beyond quantum key distribution: variants of quantum oblivious transfer

Modern cryptography is more than sending secret messages, and quantum cryptography is more than quantum key distribution. One example is oblivious transfer, which is interesting partly because it can be used to implement secure multiparty computation. We discuss a protocol for quantum XOR oblivious transfer, and how non-interactive quantum oblivious transfer protocols can be "reversed", so that oblivious transfer is still implemented from a sender to a receiver, but so that it is the receiver who sends a quantum state to the sender, who measures it, instead of the other way round. This is useful when one party can only prepare and send quantum states, and the other party can only measure them, which is often the case in practical quantum communication systems. Both the “original” XOR oblivious transfer protocol and its reversed version have been implemented optically. We also discuss how quantum random access codes can be connected with quantum oblivious transfer.

Erik Aurell

KTH Royal Institute of Technology, Sweden

Average entanglement entropy of a subsystem in a constrained pure Gaussian state ensemble

More than 30 years ago Don Page showed that a small subsystem of a larger random pure state is with high probability maximally mixed, and also conjectured the form of the average entanglement entropy when the subsystem is not small. I will consider the same type of problem when the random pure state is constrained by given marginals, and is also assumed to be Gaussian. I will show an analogous proposition as Page’s, in that the small subsystem is almost surely in a maximum-entropy Gaussian state, given the constraints. The statement is arrived at by computing the average of the subsystem reduced density matrix to power x for all positive integers x, and then analytically continuing to $x = 1$. I will then discuss the extension to when the subsystem is not small, and the resulting corrections to the maximum-entropy state. Finally, I will discuss this constrained random Gaussian state as a model of Hawking radiation, and what light it can shed on Hawking’s information paradox.
This is joint work with Lucas Hackl and Mario Kieburg, building on earlier work with Pawel Horodecki and Robert Jonsson, published as Phys. Rev. Lett. **133**(6) 060202 (2024).

Konrad Banaszek

University of Warsaw, Poland / Quantum Optical Technologies Sp. z o.o., Poland

From multimode quantum information to optical communication in space

A powerful technique to implement quantum information protocols in the temporal degree of freedom of optical fields is quantum pulse gating (QPG). The QPG technique can also be used to remove noise from optical signals to the extent that is out of reach for conventional methods. This contribution will present results of an activity funded by the European Space Agency and carried out by Quantum Optical Technologies Sp. z o.o., Poland in cooperation with Universität Paderborn, Germany, to study the potential of QPG filtering for quantum and classical communication in space scenarios.

Charles Bennett

IBM, Research Division, USA

Can we reason about our place in the universe without defining "us?"

Modern cosmology has revived interest in some early 20th century puzzles that had seemed to be more in the realm of unanswerable philosophy than science: the Boltzmann's brain problem of whether we might be merely rare statistical fluctuations in an old dead universe rather than inhabitants of a thriving young one, and the Wigner's friend problem, of what it feels like to be inside an unobserved quantum superposition. Algorithmic information theory, by computerizing the Occam's razor paradigm, offers a way of sidestepping these questions' otherwise daunting subjectivity.

Michael Berry

University of Bristol, United Kingdom

Geometric phases old and new

The waves that describe systems in quantum physics can carry information about how their environment has been altered, for example by forces acting on them. This effect is the geometric phase. It occurs in the optics of polarised light, where it goes back to the 1820s; it influences wave interference; and it provides insight into the spin-statistics relation for identical quantum particles. The underlying mathematics is geometric: parallel transport, explaining how falling cats turn, and how to park a car. Associated with the geometric phase are the curvature and metric 2-forms. Incorporating the back-reaction of the geometric phase on the dynamics of the changing environment exposes an unsolved problem: how can a system be separated from a slowly-varying environment? The concept has a tangled history.

Kay Brandner

School of Physics and Astronomy, University of Nottingham, UK

Dynamics of Open Quantum Systems in the Weak-Memory Regime: A Mathematical Framework Beyond the Markov Approximation

Memory effects are ubiquitous in open quantum systems. They emerge from retarded interactions between the system of interest and its environment, which can usually not be directly observed or controlled. On the mathematical level, this process gives rise to time evolution equations that are non-local in time, such as the Nakajima–Zwanzig equation, which can be derived systematically with projection operator techniques. If the characteristic time scales of observable and environmental degrees of freedom are sharply separated, locality in time can be restored through the standard Markov approximation. We show that this approach can be rigorously extended to a well-defined weak-memory regime, where the relevant time scales can be of comparable order of magnitude. We further derive explicit bounds on the error of the local approximation and a convergent perturbation scheme for its systematic construction. Being applicable to any autonomous setting with a finite-dimensional Hilbert space, our theory provides a unifying framework for the description of weak but significant memory effects in open quantum systems.

Link to the papers:
https://doi.org/10.1103/PhysRevLett.134.037101
https://doi.org/10.1103/PhysRevE.111.014137

Łukasz Cywiński

Institute of Physics, Polish Academy of Sciences, Poland

Towards scalable quantum computer based on silicon quantum dots

Classical computers are made from semiconductors, but semiconductor-based architectures for quantum computers are still less developed than those based on superconducting circuits, trapped ions, or neutral atoms. I will try to convince you that there are good reasons to still pursue the "semiconductor path" to quantum computers, and discuss challenges that need to be overcome on this path. I will also discuss what kinds of interesting physical problems from solid state physics and open quantum system physics one can grapple with, while contributing to a somewhat "engineering-like" task of building a scalable quantum computer. Special attention will be given to recent progress of coherent shuttling of spin qubits over distances of hundreds of nanometers. Achieving such shuttling over 10 micron distance will clear one major obstacle for scalability of quantum dot based quantum computers.

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Tomasz Dietl

International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Poland

Understanding of Quantum Hall Effects in Topological Quantum Wells

Experimental results for HgTe and (Hg,Mn)Te topological quantum wells accumulated in Würzburg and other places, including Warsaw [1,2], point to a surprisingly short topological protection length in the regime of the quantum spin Hall effect and to an exceptionally wide quantum Hall plateau corresponding to the uppermost hole Landau level. I will show that residual acceptor states that pin the Fermi level in the topological gap, also account for efficient scattering between helical edge channels [3,4]. The presence of holes bound to acceptors explains quantitatively experimental findings, providing that non-scalar terms in the electron-hole exchange, as well as the Kondo and Luttinger effects, are taken into account [4] together with the formation of bound magnetic polarons in the case of (Hg,Mn)Te [4,5]. At the same time, resonant acceptor states in the gapless situation pin the Fermi level and lead to an unexpectedly large hole and electron mobility in the 2D and 3D cases, respectively. I will also discuss the relevance of our findings to other topological systems like WTe2 and InAs/(Ga,In)Sb and quantum wells of topological crystalline insulators [6]. Finally, I will address the prospect of Cr- and V-doped HgTe quantum wells [7,8] for observations and applications of the quantum anomalous Hall effect.

References:

1. I. Yahniuk, S. S. Krishtopenko, G. Grabecki, B. Jouault, C. Consejo, W. Desrat, M. Majewicz, A. M. Kadykov, K. E. Spirin, V. I. Gavrilenko, N. N. Mikhailov, S. A. Dvoretsky, D. B. But, F. Teppe, J. Wróbel, G. Cywiński, S. Kret, T. Dietl, W. Knap, Magnetotransport in inverted HgTe quantum wells, npj Quantum Materials 4, 13 (2019).

2. I. Yahniuk, A. Kazakov, B. Jouault, S. S. Krishtopenko, S. Kret, G. Grabecki, G. Cywiński, N. N. Mikhailov, S. A. Dvoretskii, J. Przybytek,V. I. Gavrilenko, F. Teppe, T. Dietl, W. Knap, HgTe quantum wells for QHE metrology under soft cryomagnetic conditions: permanent magnets and liquid 4He temperatures, arXiv:2111.07581.

3. T. Dietl, Effects of charge dopants in quantum spin Hall materials, Phys. Rev. Lett. 130, 086202 (2023).

4. T. Dietl, Quantitative theory of backscattering in topological HgTe and (Hg,Mn)Te quantum wells: Acceptor states, Kondo effect, precessional dephasing, and bound magnetic polaron, Phys. Rev. B 107, 085421 (2023).

5. D. Bugajewski, T. Dietl, Role of magnetic doping in topological HgTe and application of the Gram-Schmidt method for computing impurity states in quantum wells, Semicond. Sci. Technol. 40, 015006 (2025).

6. A. Kazakov, V. V. Volobuev, Ch. W. Cho, B. A. Piot, Z. Adamus, T. Wojciechowski, T. Wojtowicz, G. Springholz, T. Dietl, Topological phase diagram and quantum magnetotransport effects in (Pb,Sn)Se quantum wells with magnetic barriers (Pb,Eu)Se,

arXiv:2501.02302.

7. C. Śliwa, T. Dietl, Tight-binding theory of spin-spin interactions, Curie temperatures, and quantum Hall effects in topological (Hg,Cr)Te in comparison to non-topological (Zn,Cr)Te, and (Ga,Mn)N, Phys. Rev. B 110, 165201 (2024).

8. G. Cuono, C. Autieri, T. Dietl, CdTe and HgTe doped with V, Cr, and Mn — prospects for the quantum anomalous Hall effect, Phys. Rev. B 110, 165112 (2024).

Zbigniew Ficek

Quantum Optics and Engineering Division, Institute of Physics, University of Zielona Góra, Poland

Creation and conversion of correlations in a system of coupled bosonic modes

Various types of correlations can exist inside quantum systems and their presence may influence on the process of the generation and transfer of coherence and entanglement between different parts of the sys- tem. In this presentation we will address this problem and consider a continuous variable Gaussian system composed of two bosonic modes a and b, which can be coupled through fundamentally dissimilar physical processes, the linear (beamsplitter) type interaction or/and the nonlinear (parametric down conversion) interaction [1]. We include decoherence (damping) expected for modes interacting with their environments. The down-conversion process is known to entangle modes being in classical states [2, 3], and the beam splitter interaction is known to generate entanglement only if the modes are in nonclassical states [4]. Coherence and entanglement are determined by different kinds of correlations that the coherence is described by the mutual (bipartite) one-photon or first-order correlation function a†b , whereas entanglement requires a nonzero mutual two-photon correlation function ab . We will discuss in details how the creation of these mutual correlation functions depends on the state of the modes including vacuum, thermal and single-mode squeezed states and whether these two type of correlations can simultaneously exist in the system. A deeper issue we investigate is to establish how nonzero mutual correlation functions are generated through the coupling processes, whether the correlations are created simply by a transfer of population from one mode to another or are converted from other processes induced in the system, such as creation of population from the vacuum.

References:

1. J. J. Slim, et al., Nature 627, 767 (2024).

2. M. J. Collett and C.W. Gardiner, Phys. Rev. A 30, 1386 (1984).

3. P. Lahteenmki, G. S. Paraoanu, J. Hassel, and P. J. Hakonen, Nat. Commun. 7:12548 doi: 10.1038/ncomms12548 (2016).

4. M. S. Kim, W. Son, V. Buzek and P. L. Knight, Phys. Rev. A. 65, 032323 (2002).

Robert Fickler

Tampere University, Finland

Spin-Orbit Quantum Frequency Conversion

Quantum frequency conversion (QFC) is the nonlinear optical process of coherently changing the color of a single photon while preserving its quantum state. Applications of QFC are many, including single-photon detection and the interfacing of photons with quantum memories, both extremely important for current quantum technologies. In this work, we present a spin-orbit quantum frequency converter, a device that not only converts a single photon in the telecom regime to a visible photon, but it also transfers the quantum information from the polarization degree of freedom (spin angular momentum) to the spatial phase profile of the photon (orbital angular momentum). We show that such a spin-orbit QFC is possible by driving the nonlinear process with a classical light field that is non-separable in the polarization and spatial degrees of freedom, a feature that is necessary for the coherence of the QFC process. We do so by converting one out of a pair of polarization-entangled photons, showing that the preservation of the entanglement (non-local) in the final two-photon state is conditioned upon the classical non-separability (local) of the driving field.

Nicolas Gisin

Université de Genève, Switzerland

Three ways beyond Bell inequalities

The violation of Bell inequalities is arguably the most profound discovery of 20th century science. After the Nobel prize of 2022, the great enterprise, as John Bell used to say, is not over. Here we present 3 ways beyond Bell inequalities:

1. Network non-locality, i.e. non-locality in (quantum) networks with independent sources. In this context no inputs are necessary, opening entirely new aspects of non-locality.
2. Search for hidden influences, i.e. a still possible local explanation of quantum correlations, based on supraluminal influences.
3. Entanglement in joint measurements. Entanglement between subsystems is by now pretty well studied. However, entanglement plays also a crucial role in joint measurements.

Khrystyna Gnatenko

Ivan Franko National University of Lviv, Ukraine

Detection of properties of multi-qubit quantum states corresponding to networks with quantum programming

We examine the quantum states of spin systems corresponding to weighted and directed graphs G(V,E). The relation of the quantum properties with the characteristics of the corresponding graphs has been found [1,2]. We have obtained that the velocity of quantum evolution depends on the sum of the weighted degrees of the graph's nodes, where the weights in G(V,E) are squared. The curvature of quantum graph states depends on the sum of the weighted degrees of nodes in graphs constructed by raising the weights in G(V,E) to the second and fourth powers, and on the sum of the products of the weights of edges forming squares in graph. The torsion depends on the sum of the products of edge weights forming triangular subgraphs. Quantum protocols for detection graph properties have been constructed and realized on IBM's quantum computers [1]. In addition the entanglement of the quantum states corresponding to networks has been examined. It is found that the geometric measure of entanglement of a qubit with other qubits in the graph state depends on the weights of the incoming and outgoing arcs connected to the vertex representing the qubit, as well as on the indegree and outdegree of this vertex in the graph [2].

References:

1. Kh. P. Gnatenko, European Phys J Plus Vol. 140, 241 (2025).

2. Kh. P. Gnatenko, Phys. Lett. A. Vol. 521. Art. 129815. 5 p (2024)

Link to article:
https://link.springer.com/article/10.1140/epjp/s13360-025-06172-9

Jarosław Korbicz

Center for Theoretical Physics PAS, Poland

Decoherence from the light bending interaction

We analyse a decoherence effect, caused by the gravitational interaction between a massive body and the electromagnetic field. Assuming a quantum version of the light bending interaction, we show that it leads to decoherence of the mass if the light is not observed. Using the extreme weakness of the gravitational coupling, we derive explicitly the decoherence lengthscales for general states of the central mass and for both thermal and coherent light. Predictably, the effect is very faint for anything but hugely energetic light, however from the fundamental point of view of co-existence of both gravitation and quantum theories, it is there. Since effectively the studied system is a quantum optomechanical system, we hope our results, properly rescaled, will be also useful in optomechanics.

Link to article:
https://arxiv.org/abs/2502.18079

Maciej Lewenstein

ICFO Barcelona, Spain

QI@ICFO-QOT

In my talk I will start first with a short presentation of the very recent Quantum Information activities in the Quantum Optics Group at ICFO. I will mention activities in Quantum Thermodynamics [1,2,3], widely understood Quantum Metrology [4,5], various faces of Witnessing Quantumness [6-10]. We will make a short digression on "Karolism" [11], and our work on Quantum Simulations [12,13]. The important part of the talk will be devoted to the question how to employ Bell inequalities as a tool to probe quantum chaos.

References:

1. Anubhav Kumar Srivastava, Utso Bhattacharya, Maciej Lewenstein, and Marcin Płodzień, Topological quantum thermometry, arXiv:2311.14524, resubmission to Phys. Rev. Lett.

2. Brij Mohan, Rajeev Gangwar, Tanmoy Pandit, Mohit Lal Bera, Maciej Lewenstein, and Manabendra Nath Bera, Coherent Heat Transfer Leads to Genuine Quantum Enhancement in Performances of Continuous Engines, arXiv:2404.05799, ???

3. Jin-Fu Chen, Kshiti Sneh Rai, Patrick Emonts, Donato Farina, Marcin Płodzień, Przemyslaw Grzybowski, Maciej Lewenstein, and Jordi Tura, Boosting thermalization of classical and quantum many-body systems, submitted to Phys. Rev. X, arXiv:2411.03420.

4. Adriano Macarone-Palmieri, Leonardo Zambrano, Maciej Lewenstein, Antonio Acin, Donato Farina, Deep Neural Network-assisted improvement of quantum compressed sensing tomography, arXiv:2405.10052, resubmitted to Phys. Rev. Res.

5. J. O. de Almeida, M. Lewenstein, and M. Skotiniotis, Collective super-resolving measurements for mixed bosonic states, submitted to Phys. Rev. X Quantum, arXiv:2110.00986, resubmitted?

6. Marcin Płodzień, Sambunath Ds, Maciej Lewenstein, Christina Psaroudaki, and Katarzyna Roszak, Harnessing spin-qubit decoherence to probe strongly-interacting quantum systems, resubmission to PRE or PRB, arXiv:2410.22003.

7. Guillem Müller-Rigat, Albert Aloy, Maciej Lewenstein, Matteo Fadel, Jordi Tura, Three-outcome multipartite Bell inequalities: applications to dimension witnessing and spin-nematic squeezing in many-body systems, arXiv:2406.12823, under review in Phys. Rev. X Quantum

8. A. Tononi and M. Lewenstein, Temporal Bell inequalities in a many-body system, arXiv:2409.17290, response in preparation, Rep. Prog. Phys. and Quant. Sci. Tech.

9. Giacomo Franceschetto, Marcin Płodzień, Maciej Lewenstein, Antonio Acín, and Pere Mujal, Harnessing quantum back-action for time-series processing, submission to Phys.

Rev. Lett., arXiv:2411.03979

10. Albert Aloy, Guillem Müller-Rigat, Maciej Lewenstein, Jordi Tura, and Matteo Fadel, Bell inequalities as a tool to probe quantum chaos, arXiv:2406.11791, resubmitted to Phys. Rev. Lett.

11. Marcin Płodzień, Maciej Lewenstein, and Jan Chwedeńczuk, Many-body quantum resources of graph states, arXiv:2410.12487, submission to special issue ROPP.

12. Emanuele Gaz, Pavel P. Popov, Guy Pardo, Maciej Lewenstein, Philipp Hauke and Erez Zohar, Quantum Simulation of non-Abelian Lattice Gauge Theories: a variational approach to D8, ???, arXiv:2501.17863, submitted to Phys. Rev. X Quantum.

13. Pavel P. Popov, Joana Fraxanet, Luca Barbiero, and Maciej Lewenstein, Geometrical frustration, power law tunneling and non-local gauge fields from scattered light, submitted to Phys. Rev. Lett., arXiv:2502.04330.

Karol Ławniczak

University of Lodz, Faculty of Physics and Applied Informatics, Departament of Theoretical Physics, Poland

Quantum selective measurement as a nonlinear evolution

In this lecture, we interpret the deterministic aspect of the quantum selective measurement process as a nonlinear evolution employing the formalism of quasilinear evolution introduced in refs. [1] and [2]. Specifically, we replace the projection of the quantum state with a nonlinear von Neumann equation that satisfies the quasi-linearity property, which ensures the exclusion of superluminal signalling [1]. Notably, quasilinear evolutions asymptotically lead to states consistent with those obtained via the standard state-update formula. We illustrate our approach with low-dimensional examples.
Joint work with Jakub Rembieliński.

References:

1. Jakub Rembieliński and Paweł Caban, Nonlinear evolution and signalling, Phys.Rev.Research 2 (2020) 012027

2. Jakub Rembieliński and Paweł Caban, Nonlinear extension of the quantum dynamical semigroup, Quantum 5, (2021) 420;

Klaus Mølmer

Københavns Universitet, Denmark

The state of monitored quantum systems – more than meets the eye

From about 1980 and onwards, a variety of single quantum systems has become subject to experimental investigation in laboratories, and stochastic Schrödinger and master equations were developed to describe the behavior of continuously monitored systems. While these approaches were derived from the usual rules of quantum mechanics, their adaption to different situations shed new light on the rules themselves. In the talk, I shall show recent examples of how asking purely practical and quantitative questions leads to more foundational insights and provides genuinely new elements to our understanding of quantum states and quantum evolution. And the same insights yield stronger "shut-up-and-calculate" analyses for quantum sensing and metrology.

Giovanna Morigi

Universität des Saarlandes, Germany

Search as (quantum) selforganized process

Efficient retrieval of information is a core operation in the world wide web, is essential for the sustainance of living organism, and is a paradigm for optimization algorithms. Inspired by the food search dynamics of living organisms, we discuss a search on a graph with multiple constraints where the dynamics is a selforganized process resulting from the interplay of coherent dynamics and Gaussian noise. We show that Gaussian noise can be beneficial to the search dynamics leading to significantly faster convergence to the optimal solution. We then analyse how these concepts can be extended to quantum searches, cast in terms of spatial searches on a graph and discuss whether and when the efficiency of noise-assisted quantum searches can outperform the one of unitary protocols.

Marek Mozrzymas

Institute of Theoretical Physics, University of Wrocław, Poland

From port-based teleportation to Frobenius reciprocity theorem: partially reduced irreducible representations and their applications

In this lecture, we present the connection of two concepts as induced representation and partially reduced irreducible representations (PRIR) appear in the context of port-based teleportation protocols. Namely, for a given finite group Gwith arbitrary subgroup H, we consider a particular case of matrix irreducible representations, whose restriction to the subgroup H, as a matrix representation of H, is completely reduced to diagonal block form with an irreducible representation of Hin the blocks. The basic properties of such representations are given. Then as an application of this concept, we show that the spectrum of the port-based teleportation operator acting on n systems is connected in a very simple way with the spectrum of the corresponding Jucys-Murphy operator for the symmetric group S(n−1) S(n). This shows on the technical level relation between teleporation and one of the basic objects from the point of view of the representation theory of the symmetric group. This shows a deep connection between the central object describing properties of deterministic PBT schemes and objects appearing naturally in the abstract representation theory of the symmetric group. In particular, we present a new expression for the eigenvalues of the Jucys-Murphy operators based on the irreducible characters of the symmetric group. As an additional but not trivial result, we give also purely matrix proof of the Frobenius reciprocity theorem for characters with explicit construction of the unitary matrix that realizes the reduction of the natural basis of induced representation to the reduced one.

Marcin Nowakowski

Gdańsk University of Technology, Poland

Topological Observers in Generalized Spaces - Observability in Quantum Physics and Quantum AI

In both quantum physics and artificial intelligence, the role of the observer remains foundational yet elusive. There is no consensus on the definition of observers. In this talk we will present a concept of an internal observer and the hierarchy of observers [1] drawing inspiration from the advancements in abstract algebraic topology, with their generalization to topological observers [2].
At the heart of our proposal is the idea that an observer can be modeled as an n-dimensional hypercube equipped with a homotopical structure. Such a "homotopical observer" probes both internal and external degrees of freedom of a quantum system via topological compositions, with its observational power intrinsically bounded by the hypercube's homotopy order n. In effect, this observer can resolve all internal spaces of a quantum system up to the nth homotopy. Now consider a quantum structure with internal degrees of freedom (compared to classical scales), either in terms of internal spaces, higher symmetries, or resolution of extended structures at high energies. Viewing these systems from "the inside" requires an observer model that can sense these internal spaces topologically. This is where our model of a homotopical observer becomes relevant. A concrete realization of such a model can be given in terms of extended Topological Quantum Field Theories TQFTs, where internal spaces of a system are realized via paths between paths as higher cobordisms [6] extending the lower-level structures of entangled quantum histories [3-5]. A computational realization of higher homotopy spaces can be found in [7]. An n-hypercube can interact with such spaces via topological compositions. The external boundary states that we started off with could be the entire external universe or even a particle (as seen from the external view). Its internal structure can only be sensed by a homotopical observer. Our framework not only reframes quantum measurement as a topological interaction but also establishes a bridge to quantum AI models capable of genuine internal "representations".

References:
1. M. Nowakowski, Towards Physics of Internal Observers: Exploring the Roles of External and Internal Observers (2023), arXiv:2304.01677.

2. M. Nowakowski, X. Arsiwalla, M. Mohseni, M. Czachor, Topological Observers in Generalized Spaces, In preparation.

3. M. Nowakowski, E. Cohen, P. Horodecki, Entangled histories versus the two-state-vector formalism: Towards a better understanding of quantum temporal correlations. Phys. Rev. A 98 (2018), p.032312.

4. M. Nowakowski, Quantum Entanglement in Time. AIP Conf. Proc. 1841 (2017), p. 020007.

5. I. Paiva, M. Nowakowski, E. Cohen, Dynamical nonlocality in quantum time via modular operators, Phys. Rev. A 105 (2022), p. 042207.

6. J. Lurie. On the classification of topological field theories. In: Current developments in mathematics, 2008, International Press of Boston, pp. 129–280 (2009)

7. X. D. Arsiwalla, X.D., Gorard, J. Pregeometric Spaces from Wolfram Model Rewriting Systems as Homotopy Types. Int J Theor Phys 63, 83 (2024).

Matteo Paris

University of Milan, Italy

Information scrambling in quantum metrology

We discuss the use of information scrambling to improve precision and mitigate the effects of sloppiness and incompatibility in single- and multi-parameter quantum metrology, encompassing both stepwise and joint estimation strategies.

Saverio Pascazio

Università degli Studi di Bari, Italy

Statistical mechanics of multipartite entanglement

Multipartite entanglement of a system of n qubits can be characterized in terms of the bipartite purity distribution function over all balanced bipartitions. We look for maximally multipartite entangled states whose purity is minimal for all bipartitions and reformulate this optimization problem into a statistical mechanics problem. For a given subsystem, purity can always be minimized by assuming an appropriate (pure) state. When considering many subsystems, the requirement that purity be minimal for all of them can generate conflicts and frustration. This highlights an interesting link between frustration and multipartite entanglement.

Martin Plenio

Ulm University, Germany

The Thermodynamic Costs of Pure Dephasing in Quantum Heat Engines: Quasistatic Efficiency at Finite Power

Quantum heat engines are commonly believed to achieve their optimal efficiency only when operated quasi-statically. When running at finite power, however, they suffer effective friction due to the generation of coherences and transitions between energy eigenstates. It was noted that it is possible to increase the power of a quantum heat engine using external control schemes or suitable dephasing noise. Here, we investigate the thermodynamic cost associated with dephasing noise schemes using both numerical and analytical methods. Our findings unveil that the observed gain in power is generally not free of thermodynamic costs, as it involves energy costs of the control fields or heat flows between thermal and dephasing baths. These contributions must be duly accounted for when determining the engine's overall efficiency. Interestingly, we identify a particular working regime where these costs become negligible, demonstrating that quantum heat engines can be operated at any power with an efficiency per cycle that approaches arbitrarily closely that under quasistatic operation.

References:

https://arxiv.org/abs/2312.05375

Zbigniew Puchała

Institute of Theoretical and Applied Informatics, Polish Academy of Sciences, Poland

Advances in Discrimination and Certification of Quantum Operations and Measurements

This talk explores recent progress in distinguishing and certifying quantum operations and measurements. We discuss key results from three studies: (1) establishing bounds on the success probability of distinguishing unknown quantum operations, (2) local certification of unitary quantum channels with optimal strategies, and (3) discrimination of von Neumann measurements with and without classical descriptions. These findings contribute to the development of robust quantum technologies by improving our understanding of the fundamental limits of quantum discrimination and certification.

Gniewomir Sarbicki

Nicolaus Copernicus University in Toruń, Poland

Entanglement detection by randomised measurements

We discuss the possibilities of entanglement detection in terms of data gathered in the randomised measurement scheme, when values of n-point correlations are averaged w.r. to the Haar measure of local unitary groups. We show the local invariants accessible to estimate in such scheme for subsequent values of n and discuss the entanglement criteria expressible in terms of it.

Pragya Shukla

Department of Physics, Indian Institute of Technology, Kharagpur, India

Many body quantum state ensembles: a complexity parameter formulation

The entanglement analysis of a pure state of a many body quantum system requires a prior information about its state matrix, obtained in principle by solving the Hamiltonian matrix. The missing information due to complexity of the many body interactions however renders it necessary to consider an ensemble of Hamiltonians and thereby an ensemble for each eigenstate. This in turn leaves a statistical description of the entanglement measures as the only option. For an ensemble to appropriately represent a many body Hamiltonian, the ensemble parameters must be determined from the system parameters. A variation of the latter is therefore expected to manifest in variation of the the ensemble for each eigenstate and thereby their entanglement aspects. We theoretically analyze the effect of varying system conditions on the eigenstates of a wide range of Hamiltonians and derive a common mathematical formulation for the bipartite entanglement statistics. As the system information in the formulation enters through a single functional of the ensemble parameters, this implies the analogy of statistics for different eigenstate ensembles (non-ergodic type) if they share the same complexity parameter and thereby reveals a deep web of connection underlying among quantum states of different Hamiltonians (with same global symmetry class). Besides revealing universality among non-ergodic states, the information is also relevant for quantum state engineering e.g. how to achieve a Haar random state starting from a random non-ergodic state.

Link to articles:

1. https://arxiv.org/abs/2503.01989
2. https://iopscience.iop.org/article/10.1088/1751-8121/acd9fe

Janine Splettstösser

Chalmers University of Technology, Gothenburg, Sweden

Bounds on noise in quantum transport of fermions and bosons

When implementing a task in a small-scale quantum system, it is typically highly relevant to achieve high precision, namely a high signal-to-noise ratio. This holds also true in quantum transport settings, where a task to be achieved could for example be to produce a steady current, possibly from a temperature bias or a time-dependent drive.
Here, I will present results for bounds on the achievable precision or the "acceptable" noise of generic transport currents, which we find from scattering theory for quantum transport. This includes the noise of charge currents, energy currents (which could for example be of interest when investigating cooling), or entropy currents and entropy production. These currents are produced by possibly large potential or temperature biases or even by nonthermal distributions in the contacts. We put the achieved bounds in context with known relations for classical or close-to equilibrium relations, such as the fluctuation-dissipation theorem and the thermodynamic or uncertainty relations. The advantage of using scattering theory compared to typically employed perturbative approaches in the coupling, is that we can fully account for quantum effects. We demonstrate how constraints on fluctuations depend on whether power is produced or dissipated. We also show to which extent fermionic systems have the advantage of higher precision than bosonic systems depending on reflection probabilities and bandwidth of the conductor.

References:

1. Didrik Palmqvist, Ludovico Tesser, Janine Splettstoesser: Kinetic uncertainty relations for quantum transport. arXiv:2410.10793 (2024)

2. Ludovico Tesser, Janine Splettstoesser: Out-of-Equilibrium Fluctuation-Dissipation Bounds. Phys. Rev. Lett. 132, 186304 (2024)

Marcin Syperek

Wrocław University of Science and Technology, Poland

Deterministically fabricated semiconductor quantum dot-based single-photon source for on-chip and telecom applications

Optically triggered self-assembled semiconductor quantum dots (QDs) are quasi-zero-dimensional structures that generate non-classical photon states on demand. These photons, or flying qubits, are crucial for quantum photonics devices that may transform information processing and enable advancements in quantum-secured communication and computation. This presentation outlines a method for fabricating single quantum dot (QD) photon sources using a scalable and deterministic approach. The InAs/InP QDs emit photons at approximately 1550 nm, making them suitable for silica optical fiber networks within the telecom band. The device leverages the Purcell effect, necessitating precise placement of QDs in relation to a microcavity's optical mode. This arrangement enhances photon extraction efficiency, increases spontaneous emission, and improves quantum statistics. The fabrication process combines far-field optical imaging of QD emissions in the near-infrared with electron beam lithography for cavity production, resulting in a relatively high yield of devices. By employing a deterministic method for creating cavity-coupled single-photon sources, it becomes feasible to develop more complex systems. The device can be precisely integrated with a photonic platform to form a quantum-integrated photonic chip. This integration can be achieved using a pick-and-place technique through micro-transfer printing, enabling the combination of various material platforms. An example of this process is the hybrid integration of a one-dimensional InP nanocavity with self-assembled InAs/InP quantum dots on a SiN-based photonic platform.

Link to article:
https://www.nature.com/articles/s41467-024-47551-7

Volodymyr Tkachuk

Ivan Franko National University of Lviv, Ukraine

Entanglement in Quantum Hypergraph States and Its Quantification on a Quantum Computer

A detailed classification of multipartite entanglement types in hypergraph states remains an open problem. Here, we focus on bipartite entanglement, specifically the entanglement of a single qubit (spin) with the rest of the system in a hypergraph state. In this case, the measure of entanglement is fully determined by the expectation value of the spin. We find that even in the bipartite case, explicitly calculating the entanglement measure of one qubit (spin) with the rest of the hypergraph state presents a nontrivial combinatorial problem. Notably, such a problem does not arise for ordinary graph states. The hypergraph state is generated using a unitary evolution operator containing a Hamiltonian with three-, four-, and higher-order spin interactions. We propose a quantum algorithm that overcomes the combinatorial challenges and enables the calculation of the entanglement measure of a single qubit with the rest of the system in a quantum hypergraph state. This quantum algorithm is implemented on IBM quantum computers for selected hypergraphs. The results of quantum computations show good agreement with theoretical predictions.

Patrycja Tulewicz

Institute of Spintronics and Quantum Information, Faculty of Physics and Astronomy, Adam Mickiewicz University, Poland

Resource-Efficient Quantum Correlation Measurement: A Multicopy Neural Network Approach for Practical Applications

In my talk, I will present a new method for measuring quantum correlation in multiparticle systems by integrating multi-copy experimental techniques with advanced artificial intelligence techniques. Our new method significantly reduces the number of measurements compared to conventional quantum state tomography with improved accuracy and opens new perspectives for efficient quantum characterization.
I will discuss an experimental implementation of the algorithm on IBM quantum processors, where we successfully measured Bell negativity and non-locality of Werner and Horodecki states in the presence of real depolarization noise and amplitude suppression. Our approach uses SHAP analysis to identify the optimal set of measurements for training neural networks and determining entanglement witnesses. This reduces the number of measurements required and improves robustness to noise.
The presentation will also be extended to include a demonstration of real-world applications of the multicopy estimation (MCE) approach in distributed quantum computing (DQC). I will show the applicability of this method to the observation of entanglement behavior in DQC as a potential benchmark for DQC networks.

Acknowledgements:
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Link to article:

https://doi.org/10.48550/arXiv.2411.05745

Anton Zeilinger

Institute for Quantum Optics and Quantum Information – Vienna (IQOQI-Vienna) of the Austrian Academy of Sciences, Austria

Schrödinger's cat is never dead and alive

At the occasion of the centenary of Heisenberg on Helgoland I will discuss some of the conceptual issues with quantum mechanics along the lines of Heisenberg's view.

Wojciech Żurek

Los Alamos National Laboratory

Decoherence and Quantum Darwinism

Decoherence shows how the openness of quantum systems—interaction with their environment—suppresses flagrant manifestations of quantumness. Einselection accounts for the emergence of preferred quasi-classical *pointer states*. Quantum Darwinism goes beyond decoherence. It posits that the information acquired by the monitoring environment responsible for decoherence is disseminated, in many copies, in the environment, and thus becomes accessible to observers. This indirect nature of the acquisition of information by observers who use the environment as a communication channel is the mechanism through which objective classical reality emerges from the quantum substrate: States of the systems of interest are not subjected to direct measurements (hence, not perturbed) by the agents acquiring information about them. Thus, they can exist unaffected by the information gained by observers.

Karol Życzkowski

Jagiellonian University, Cracow, Poland / Center for Theoretical Physics, Polish Academy of Science, Warsaw, Poland

Discrete dynamics in the set of quantum measurements

As any discrete dynamics in classical simplex Δ_N can be described by a stochastic matrix, $p' = Sp$, we introduce an analogous dynamics in the space of quantum measurements, often referred to as positive operator-valued measurement (POVM). Such a measurement is defined by set of positive operators, $P_j = P_j^\dagger \geq 0$, summing to identity. Transformations in the set of quantum measurements can be described by blockwise stochastic matrices, composed of positive blocks that sum column wise to identity, and the notion of sequential product of matrices. Such transformations correspond to a sequence of quantum measurements.

Imposing additionally the dual condition that the sum of blocks in each row is equal to identity we arrive at blockwise bistochastic matrices, sometimes called quantum magic squares. Analyzing their dynamical properties, we formulate a quantum analog of the

Ostrowski description of the classical Birkhoff polytope and introduce the notion of majorization between quantum measurements. Our framework provides a dynamical characterization of the set of blockwise bistochastic matrices and establishes a resource theory in the set of quantum measurements.
Joint work with Albert Rico (Barcelona), Moises Moran (Ankara) and Shmuel Fridland (Chicago).

POSTER PRESENTERS

Aaqib Ali

University of Bari Aldo Moro, Italy

Optimized Error Filtration for Noise Mitigation in Quantum Systems

Error filtration is a hardware-based noise mitigation technique that leverages auxiliary qubits and entangling gates to suppress errors in quantum systems. While both the signal and ancillary qubits are susceptible to local noise, constructive interference—sometimes combined with post-selection—enables a reduction in the noise affecting the signal qubit. In this work, we identify the optimal entangling unitary gates that maximize interference effectiveness. Beginning with a universal gate set, we refine these gates through gradient descent or stochastic optimization of relevant functionals. We further analyze the resilience of our optimized scheme under realistic conditions, considering the impact of noise in ancillary qubits and cross-talk between qubits. Despite these imperfections, our findings indicate that increasing the number of ancilla qubits enhances the protection of quantum information. To evaluate the performance of our method, we benchmark it against key metrics relevant to different quantum applications, including F_e, $\mathcal{I}_Q$ (for quantum sensing), and CHSH value (for cryptographic tasks), using one, two, and three ancillary qubits. Additionally, for configurations with one and two ancillas, we derive explicit analytical expressions for the optimal unitary operations based on an ansatz approach. Finally, we compare our approach with the recently proposed Superposed Quantum Error Mitigation (SQEM) method, which relies on superposition of causal orders. Our results show that, across a broad range of noise strengths, our error filtration technique can outperform SQEM in both effectiveness and robustness, making it a promising strategy for improving the reliability of near-term quantum devices.

Link to article:
https://doi.org/10.48550/arXiv.2409.01398

Bihalan Bhattacharya

Nicolaus Copernicus University in Toruń, Poland

Qubit Schwarz maps with diagonal unitary and orthogonal symmetries

I shall discuss Schwarz maps in this presentation and analyze the relationship between positivity, operator Schwarz inequality and complete positivity of a linear unital map. Next I shall discuss complete characterization of a class of unital qubit Schwarz maps with diagonal unitary and orthogonal symmetries. Such maps have already found a lot of applications in quantum information theory. M. D. Choi provided the first example of a Schwarz map which is not completely positive and it falls in this class. As a case study I shall also analyze the Schwarz property of Pauli maps.

Link to article:
J. Phys. A: Math. Theor. 57, 395202 (2024)

Rafał Bistroń, Marcin Rudziński

Jagiellonian University, Cracow, Poland

Benchmarking quantum devices beyond classical capabilities

Rapid development of quantum computing technology has led to a wide variety of sophisticated quantum devices. Benchmarking these systems becomes crucial for understanding their capabilities and paving the way for future advancements. The Quantum Volume (QV) test is one of the most widely used benchmarks for evaluating quantum computer performance due to its architecture independence. However, as the number of qubits in a quantum device grows, the test faces a significant limitation: classical simulation of the quantum circuit, which is indispensable for evaluating QV, becomes computationally impractical. In this work, we propose modifications of the QV test that allow for direct determination of the most probable outcomes (heavy output subspace) of a quantum circuit, eliminating the need for expensive classical simulations. This approach resolves the scalability problem of the Quantum Volume test beyond classical computational capabilities.

Link to article:
https://arxiv.org/abs/2502.02575

Wojciech Bruzda

Center for Theoretical Physics, Polish Academy of Sciences (CFT PAN), Poland

Quantum Circuits for High-Dimensional Absolutely Maximally Entangled States

Absolutely maximally entangled (AME) states of multipartite quantum systems exhibit maximal entanglement across all possible bipartitions. These states lead to teleportation protocols that surpass standard teleportation schemes, determine quantum error correction codes and can be used to test performance of current term quantum processors. Several AME states can be constructed from graph states using minimal quantum resources. However, there exist other constructions that depart from the stabilizer formalism. In this work, we present explicit quantum circuits to generate exemplary non-stabilizer AME states of four subsystems with four, six, and eight levels each and analyze their capabilities to perform quantum information tasks.

Link to article:
https://arxiv.org/abs/2504.05394

Paweł Cieśliński

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Conservation of coherence and entanglement under quantum reference frame transformations

Recent work on quantum reference frames (QRFs) has demonstrated that superposition and entanglement depend on the choice of QRF, such that either one can increase or decrease under a change of QRF. Given their utility in quantum information processing, it is important to understand how a mere change of perspective can produce or reduce these resources. Here we show that QRF transformations are $\mathcal{C}$-preserving incoherent operations and find trade-offs between entanglement and subsystem $\mathcal{C}$ under these transformations. We prove an exact conservation theorem for two pairs of measures and a weaker trade-off for any possible pairs of measures. Finally, we discuss the implications of this interplay for quantum information protocols, clarifying some misconceptions about non-locality and Hilbert space factorization.

Link to article:
https://arxiv.org/abs/2406.19448

Piotr Dulian

Centre for Quantum Optical Technologies, Centre of New Technologies, University of Warsaw

QMetro++ - Python package for large scale quantum metrology

QMetro++ - is a Python package providing a set of tools for determining quantum estimation protocols maximising $\mathcal{I}_Q$ (QFI). Optimization can be performed for an arbitrary arrangement of input states, probe channels, noise correlations, control operations and measurements called strategy. The use of tensor networks and iterative see-saw algorithm allows for efficient optimization even in the regime of large number of channel uses ($N \approx 100$). Additionally, package comes with implementation of the recently developed methods for computing fundamental upper bounds on QFI which help in assessing the optimality of the obtained results. All functionalities are wrapped up in a user-friendly interface which enables to define strategies at various levels of detail.

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Karol Horodecki

Faculty of Mathematics, Physics and Informatics, University of Gdańsk, Poland

Bound on repeated key for all key correlated states

Quantum key repeater is the backbone of the future Quantum Internet. It is an open problem for an arbitrary mixed bipartite state shared between stations of a quantum key repeater, how much of the key can be generated between its two end-nodes. We place a novel bound on quantum key repeater rate, which uses relative entropy distance from, in general, entangled quantum states. It allows us to generalize bound on key repeaters of M. Christandl and R. Ferrara [Phys. Rev. Lett. 119, 220506]. The bound, albeit not tighter, holds for a more general class of states. In turn, we show that the repeated key of the so called key-correlated states can exceed twice the one-way distillable entanglement at most by twice the max-relative entropy of entanglement of its attacked version. We also provide a non-trivial upper bound on the amount of private randomness of a generic independent bit.

Link to article:
https://arxiv.org/abs/2206.00993

Ryszard Kukulski

IT4 Innovations National Supercomputing Center, Czech Republic

Quantum key distribution based on indefinite causal order

Quantum computing is one of the most important branches of modern cryptology. The potential of quantum cryptanalysis is considered the greatest threat to classical cryptographic algorithms. On the other hand, quantum computing also enables the construction of quantum key distribution (QKD) protocols that cannot be easily eavesdropped upon. This unique feature makes QKD protocols of great interest to the entire cryptographic community.
In this work, we present a novel two-party QKD protocol based on indefinite causal order. The core idea is that participants guess the order of certain quantum operations with reasonably high security. When the communication is not eavesdropped, then in each single step the probability of reading the correct state by both side (Alice and Bob) exceeds 85.35

Link to article:
to be published/Authors list: Ryszard Kukulski, Mateusz Leśniak, Paulina Lewandowska, Grzegorz Rajchel-Mieldzioć, and Michał Wroński

André Hernandes Alves Malavazi

International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk, Poland

Two-time weak measurement protocol for ergotropy protection in open quantum batteries

Quantum batteries are emerging as highly efficient energy storage devices that can exceed classical performance limits. Although there have been significant advancements in controlling these systems, challenges remain in stabilizing stored energy and minimizing losses due to inevitable environmental interaction. In this paper, we propose a protocol that employs selective weak measurements to protect quantum states from such influence and mitigate battery discharging, that is feasible in state-of-the-art technologies. We establish thermodynamic constraints that allow this method to be implemented without disrupting the overall energy and ergotropy balance of the system, i.e., with no extra net recharging. Our findings demonstrate that appropriately chosen measurement intensity can reduce unwanted discharging effects, thereby preserving ergotropy and improving the stability of quantum batteries. We illustrate the protocol with single and two-qubit systems and establish the generalization for N-cell batteries. Additionally, we explore how weak measurements influence the coherent and incoherent components of ergotropy, providing new insights into the practical application of quantum coherence in energy storage technologies.

Link to article:
https://arxiv.org/abs/2411.16633

Moein Naseri

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Scalable Noisy Quantum Circuits for Biased Noise Qubits

In this work, we consider biased-noise qubits affected only by bit-flip errors, which is motivated by existing systems of stabilized cat qubits. This property allows us to design a class of noisy Hadamard-tests involving entangling and certain non-Clifford gates, which can be conducted reliably with only a polynomial overhead in algorithm repetitions. On the flip side we also found classical algorithms able to efficiently simulate both the noisy and noiseless versions of our specific variants of Hadamard test. We propose to use these algorithms as a simple benchmark of the biasness of the noise at the scale of large circuits. The bias being checked on a full computational task, it makes our benchmark sensitive to crosstalk or time-correlated errors, which are usually invisible from individual gate tomography. For realistic noise models, phase-flip will not be negligible, but in the Pauli-Twirling approximation, we show that our benchmark could check the correctness of circuits containing up to 10^6 gates, several orders of magnitudes larger than circuits not exploiting a noise-bias. Our benchmark is applicable for an arbitrary noise-bias, beyond Pauli models.

Link to article:
https://arxiv.org/abs/2305.02045

Yasser Omar

IST, ULisbon & PQI – Portuguese Quantum Institute, Portugal

Towards Energetic Quantum Advantage in Trapped-Ion Quantum Computation

The question of the energetic efficiency of quantum computers has gained some attention only recently. A precise understanding of the resources required to operate a quantum computer with a targeted computational performance and how the energy requirements can impact the scalability is still missing. In this work, one implementation of the quantum Fourier transform (QFT) algorithm in a trapped ion setup was studied. The main focus was to obtain a theoretical characterization of the energetic costs of quantum computation. The energetic cost of the experiment was estimated by analyzing the components of the setup and the steps involved in a quantum computation, from the cooling and preparation of the ions to the implementation of the algorithm and readout of the result. A potential scaling of the energetic costs was argued and used to find a possible threshold for an energetic quantum advantage against state-of-the-art classical supercomputers.

Vivek Pandey

Nicolaus Copernicus University in Toruń, Poland

Fundamental limitations on the recoverability of quantum processes

Quantum information processing and computing tasks can be understood as quantum networks, comprising quantum states and channels and possible physical transformations on them. It is hence pertinent to estimate the change in informational content of quantum processes due to physical transformations they undergo. The physical transformations of quantum states are described by quantum channels, while the transformations of quantum channels are described by quantum superchannels. In this work, we determine fundamental limitations on how well the physical transformation on quantum channels can be undone or reversed, which are of crucial interest to design and benchmark quantum information and computation devices. In particular, we refine (strengthen) the quantum data processing inequality for quantum channels under the action of quantum superchannels. We identify a class of quantum superchannels, which appears to be the superchannel analogue of subunital quantum channels, under the action of which the entropy of an arbitrary quantum channel is nondecreasing. We also provide a refined inequality for the entropy change of quantum channels under the action of an arbitrary quantum superchannel.

Link to article:
https://arxiv.org/abs/2403.12947

Łukasz Pawela

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Quantum-aware Transformer model for state classification

Entanglement is a fundamental feature of quantum mechanics, playing a crucial role in quantum information processing. However, classifying entangled states, particularly in the mixed-state regime, remains a challenging problem, especially as system dimensions increase. In this work, we focus on bipartite quantum states and present a data-driven approach to entanglement classification using transformer-based neural networks. Our dataset consists of a diverse set of bipartite states, including pure separable states, Werner entangled states, general entangled states, and maximally entangled states. We pretrain the transformer in an unsupervised fashion by masking elements of vectorized Hermitian matrix representations of quantum states, allowing the model to learn structural properties of quantum density matrices. This approach enables the model to generalize entanglement characteristics across different classes of states. Once trained, our method achieves near-perfect classification accuracy, effectively distinguishing between separable and entangled states. Compared to previous Machine Learning, our method successfully adapts transformers for quantum state analysis, demonstrating their ability to systematically identify entanglement in bipartite systems. These results highlight the potential of modern machine learning techniques in automating entanglement detection and classification, bridging the gap between quantum information theory and artificial intelligence.

Link to article:
https://arxiv.org/abs/2502.21055

Sumit Rout

International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk, Poland

Non-local correlations enhance classical channel in minimal prepare and measure scenario

Although no-signalling correlations cannot increase the Shannon capacity of classical channels, they can nonetheless provide significant advantages in various classical communication tasks. In this work, we consider a minimal bipartite prepare-and-measure scenario where Bob has no input, and Alice is restricted to bounded classical communication. For every communication task within this setting, we construct a Bell-type inequality that witnesses the advantage of sharing non-classical correlations. We further explore distinct families of communication tasks that reveal the operational utility of non-local correlations. As a noteworthy case, we identify a family of tasks where Hardy-type correlations outperform any strategy relying solely on shared randomness.

Abhyoudai Sajeevkumar Shaleena

International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk, Poland

A semi-analytical optimization of Bell inequalities in a tripartite scenario.

We have developed a semi-analytical optimization for finding the tight bounds for Bell inequalities in tripartite case corre-sponding to the $4 \times 4 \times 2$ scenario. Given a quantum state (or equivalently the correlation tensor T), our method could provide an insight into witnessing nonlocality and the upper bound to the corresponding B442 inequality can be obtained just from optimizing eigenvalues of a matrix U = T T T over polar and azimuthal angles corresponding to two orthonormal vectors C±. Moreover, we have used the optimization to witness nonlocality for certain family of states arising from a three body decay. Finally, we provided a construction of a no-signalling box that saturates the algebraic bound of B442.

Marek Sawerwain*, Joanna Wiśniewska, Roman Gielerak

University of Zielona Góra, Poland

FredLib: The Fredholm determinant for Schmidt decomposition of quantum continuous registers

In the field of quantum computing, particularly for finite states, the Schmidt decomposition has many applications, including the characterization of entanglement, as it allows for an easy demonstration of the relationship between entanglement and von Neumann entropy. This decomposition is also used in the problem of state purification. Moreover, numerical computations related to the Schmidt decomposition for finite states within small systems do not pose a challenge. However, for continuous and infinite quantum states, direct techniques for computing the Schmidt decomposition cannot naturally be applied. Therefore, in this work, we propose using a computational technique based on the Fredholm determinant along with appropriate quadratures. This approach enables the determination of the Schmidt decomposition as well as, for example, the computation of von Neumann entropy for continuous states. The implementation of the necessary quadratures and computational procedures has been carried out using the Python programming language and the NumPy package, making it relatively easy to perform calculations using the developed procedures.

*poster presenter

Leonard Sikorski

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Quantification of the energy consumption of entanglement distribution

One of the main tasks of quantum information technologies is generating, manipulating, and using quantum resources. Prominent examples of such resources are quantum entanglement and key secure against quantum adversary, which are planned to be used in future quantum networks, e.g., for distributed quantum computing and secret communication, respectively. In these networks, quantum resources will be distributed via technologically advanced devices modelled with CPTP maps aka quantum channels. This process is expected to involve energy consumption both due to technological imperfections but also due to fundamental phenomena. The consumption takes place during both passing input to the channel and the distillation of imperfect resources taken from the channel's output to its almost perfect form required for coherent processing of information. For this reason, we propose estimating and minimizing this consumption as one of the important tasks on the way to resource aware quantum information processing. We therefore establish a quantitative study of energy expenditure in producing quantum resources via quantum channels. We distinguish technological and fundamental energy costs. Technological cost depends on hardware; hence, it is not a fixed quantity. We then focus mostly on the fundamental one. We establish a paradigm for quantifying the minimal, i.e., unavoidable fundamental energy consumption in creating a maximally resourceful state expressed in units of Jule per Rbit (energy invested while distributing a unit of resource). We explore this paradigm in the case of quantum entanglement. We derive a lower bound on the fundamental energetic cost of the standard entanglement distribution procedures (taking maximally entangled states as input to the channels). Hence, under the contemporary design, we provide a quantitative estimate (a lower bound) of the inevitable energy consumption in future quantum networks. We also compare energy performance of the first three entanglement distillation protocols in the case of distribution of quantum entanglement encoded in the polarization of photons. Fundamentally these protocols require energy by many orders of magnitude higher than the proposed lower bound on energy consumption, stemming from entanglement irreversibility.

Maciej Stankiewicz

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SVTest: general purpose software for testing weakly random sources with exemplary application to seismic data analysis enabling quantum amplification

Generating private randomness is essential for numerous applications ranging from security proofs to online banking. Consequently, the capacity of quantum devices to amplify the privacy of a weak source of randomness, in cases unattainable by classical methods, constitutes a practical advantage. One of the theoretical models of such weak sources are the so-called Santha-Vazirani (SV) sources; however, finding natural sources satisfying the SV model is a paramount challenge. In this article, we take three significant steps on the way to simplify this hard task. We begin with an in-depth analysis of the mathematical background for estimating the quality of a weak randomness source by providing a set of axioms that systematize the possible approaches to such estimation. We then develop software (SVTest) to estimate the parameter characterizing the source's randomness. The software is general-purpose, i.e., it can test the randomness of any target sequence of bits. Later, we apply the software to test seismic events (earthquakes and local noise) as potential sources of randomness. Our results demonstrate that seismic phenomena are possible sources of randomness, depending on the choice of discretization. Therefore, our work provides strong evidence of the potential of geophysical phenomena as a source of cryptographic resources, building an unprecedented bridge between both fields.

Link to article:
https://doi.org/10.48550/arXiv.2504.06899

Alexander Streltsov

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Advances in entanglement catalysis

Entanglement is a fundamental resource in quantum information processing, yet understanding its manipulation and transformation remains a challenge. Many tasks rely on highly entangled pure states, but obtaining such states is often challenging due to the presence of noise. Typically, entanglement manipulation procedures involving asymptotically many copies of a state are considered to overcome this problem. These procedures allow for distilling highly entangled pure states from noisy states, which enables a wide range of applications, such as quantum teleportation and quantum cryptography. When it comes to manipulating entangled quantum systems on a single copy level, using entangled states as catalysts can significantly broaden the range of achievable transformations. Similar to the concept of catalysis in chemistry, the entangled catalyst is returned unchanged at the end of the state manipulation procedure. Our results demonstrate that despite

the apparent conceptual differences between the asymptotic and catalytic settings, they are actually strongly connected and fully equivalent for all distillable states. Our methods rely on the analysis of many-copy entanglement manipulation procedures which may establish correlations between different copies. As an important consequence, we demonstrate that using an entangled catalyst cannot enhance the asymptotic singlet distillation rate of a distillable quantum state. Our findings provide a comprehensive understanding of the capabilities and limitations of both catalytic and asymptotic state transformations of entangled states, and highlight the importance of correlations in these processes.

Link to article:
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.133.250201

Gerardo Suarez

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Modeling Quantum Environments with QuTiP

This poster explores the powerful connection between power spectrums, correlation functions, and spectral densities within the framework of open quantum systems. Leveraging the capabilities of QuTiP and its new environment class, we demonstrate how to efficiently calculate and analyze these fundamental quantities for open quantum systems and the role they play in different levels of approximation for open system dynamics.

References:

1. Neill Lambert, Eric Giguère, Paul Menczel, Boxi Li, Patrick Hopf, Gerardo Suárez, Marc Gali, Jake Lishman, Rushiraj Gadhvi, Rochisha Agarwal, Asier Galicia, Nathan Shammah, Paul Nation, J. R. Johansson, Shahnawaz Ahmed, Simon Cross, Alexander Pitchford, & Franco Nori. (2024). QuTiP 5: The Quantum Toolbox in Python.

2. Suárez, G., Łobejko, M., & Horodecki, M. (2024). Dynamics of the nonequilibrium spin-boson model: A benchmark of master equations and their validity. Physical Review A, 110(4).

3. Hideaki Takahashi, Samuel Rudge, Christoph Kaspar, Michael Thoss, Raffaele Borrelli; High accuracy exponential decomposition of bath correlation functions for arbitrary and structured spectral densities: Emerging methodologies and new approaches. J. Chem. Phys. 28 May 2024; 160 (20)

Abdelmalek Taoutioui

Faculty of Mathematics, Physics and Informatics, University of Gdańsk, Poland

Certifying asymmetry in the configuration of three qubits

We consider a scenario where Alice uses an untrusted device to prepare a qubit state from a set of three possible states and sends it to Bob. Bob then probes the state using an uncharacterized measurement device. In this setup, we prove that an asymmetric configuration of the Bloch vectors associated with the qubit trine states can be certified. To achieve this, we construct a linear functional Q on the observed measurement probabilities based on a biased version of the dimension witness I_3. Specifically, the witness Q is defined as the sum of three biased I_3 functionals that capture the relative angles between the Bloch vectors of our asymmetric target trine states. We compute a bound on this witness Q that holds for any mirror-symmetric configuration of the Bloch vectors of the prepared trine states. Additionally, we provide the overall maximum value of the witness, which is reached by preparing a specific set of trine states, which we call target states. The difference between the above mirror-symmetric witness value and the overall maximum witness value defines a witness gap, which can only be zero if the Bloch vectors of the target trine states possess a mirror-symmetric configuration. This latter gap is used as a measure of the degree of asymmetry of the target trine states. By optimising over the witness gap, we discovered that the most asymmetric three-qubit configuration forms a scalene right triangle inscribed within the great circle of the Bloch sphere. In addition to the theoretical analysis, we implemented our prepare-and-measure scenario on IBMQ devices and observed a violation of the mirror-symmetric witness bound for the most asymmetric target, thereby confirming the asymmetric configuration of target trine states

Gianluigi Tartaglione

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Geometric measure of nonlocality

We introduce a geometric characterisation of Bell nonlocality with the aim of providing its bona fide geometric quantification depending only on the intrinsic properties of quantum states operators on Hilbert space. We discuss the basic axiomatic structure that is needed for a meaningful geometric characterisation and quantification of Bell nonlocality in Hilbert space by defining the set of local states, i.e., the states that do not violate Bell inequalities (the so-called free states), and the set of free operations, i.e. the transformations that do not create the nonlocality resource, which includes local operations and shared randomness. We then introduce the geometric measures of Bell nonlocality, based either on the relative entropy or on the distance from the set of local states. We investigate and compare three different geometric measures, each one defined according to the three distinguished contractive metrics on the set of quantum states, namely the trace, the Bures, and the Hellinger distance. For completeness, we also discuss the ge-

ometric measures defined according to the non-contractive Hilbert Schmidt metric. We compute explicitly the different geometric measures for some specific classes of quantum states, including two-qubit Werner states, Bell-diagonal states, and Bell-diagonal states at fixed convexity, and we compare them with the corresponding geometric measures of entanglement, finding some relevant relations.

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Towards violation of Bell inequalities by position measurements for Dirac particles

The natural extension of hidden variables to the realm of relativistic physics would be a hypothetical theory in which trajectories (i) exists, consistent with a local hidden variable (LHV) model, and (ii) remains subluminally. Interestingly, the simplest inequality arising from these assumptions in the bipartite case is satisfied by the Dirac equation [1]. This suggests that its dynamics could, in principle, be simulated by LHV theories with causal (i.e., subluminal) trajectories. Motivated by this, we aim to explicitly refute LHV theories for the Dirac equation, drawing an analogy to similar results established for the Schrödinger equation [2]. In this work, we present evidence supporting such a refutation and outline steps towards its quantitative assessment [1].

References:

1. A. Tonipe, T. Miller, A. Zampeli, M. Eckstein, and P. Horodecki, (2025), in preparation.

2. J. Kiukas and R. F. Werner, Journal of Mathematical Physics 51 (2010), 10.1063/1.3447736.

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The role of entanglement in the excitation of a three-level atom by a propagating two-photon light

We considered the problem of optimal excitation of a three-level atom of ladder configuration by propagating light in the two-photon state. The applied atom-light interaction model is based on the Wigner-Weisskopf approximation. Thus the model is formulated within the following assumptions: a flat coupling constant, rotating wave approximation, and the extension of the lower limit of integration over frequency to minus infinity. We analyze the probability of two-photon absorption by the atom using the analytical formula determined in that was obtained by making use of quantum trajectories. We characterized the properties of the optimal two-photon state that excites an atom perfectly, i.e. with probability equal to one. The spectro-temporal shape of the optimal state of light is determined by the lifetimes of the atomic states, with the degree of photonic entanglement in the optimal state depending on the lifetime ratio. In consequence, two distinct interaction regimes can be identified in which the entanglement of the input state of light has a qualitatively different impact. We show that photon entanglement plays a fundamental role in the optimal excitation of a system by two-photon light. As the optimal states may be challenging to prepare in general, we compare the results with those obtained for photon pairs that can be generated in the laboratory. We optimize the parameters of these two-photon light states to achieve the maximum probability of two-photon absorption for the atomic system. We present the role of entanglement and resonances in the atom excitation process, and show how destructive and constructive light interference affects excitation of the atom.

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