Workshop on Modern Trends in Quantum Theory

Monday, 23 May 2022 - Friday, 27 May 2022

Faculty of Nuclear Sciences and Physical Engineering

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

CAAS CENTRE OF ADVANCED APPLIED SCIENCES

Book of Abstracts

The Workshop on Modern Trends in Quantum Theory is organized by the Centre of Advanced Applied Sciences (CAAS). Its aim is to bring together close scientific collaborators of the sub-programs Geometry and Spectral Properties of Quantum Systems, and Quantum Optics and Quantum Information of the Theory Group of CAAS.

Accessing the venue

The address of the workshop venue is:

Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague
Břehová 7 115 19 Praha 1

Location (mapy.cz)
Location (Google maps)

The closest metro/tram stop is called *Staroměstská*. Alternatively you can take a tram to *Malostranská* and cross the river on foot. It is recommended to have tickets bought in advance, however, some trams are equipped with vending machines on board. Tickets can also be bought via the mobile app PID lítáčka, and vending machines are available at every metro station and certain tram stops. The mobile app will also advise you on which type of ticket to buy and plan your route. Using the mobile app is highly recommended if you have a mobile internet plan.

Inside the building

The talks will be held in Lecture hall 103, on the 2nd floor of the building. The poster session will be held in the Atrium in the souterrain.

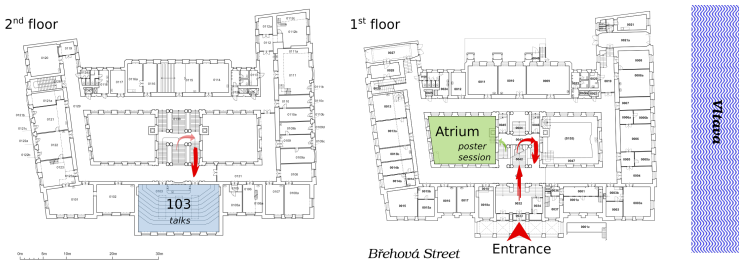

Figure 1: floor map

Acknowledgements

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Contents

Talk / **28**

Iterated nonlinear quantum protocols: theory and practice

Author: Tamás Kiss[1]

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Nonlinear evolution is not a usual phenomenon in quantum physics. It is possible to define a time-evolution for an ensemble of equally prepared systems in a somewhat unusual way: take N systems, apply an entangling unitary transformation, measure all but one of the systems and, depending on the measurement results, keep or throw away the remaining system. This procedure applied to the whole ensemble results in a new ensemble, the state of which being a nonlinear transformation of the initial quantum state.
We present some properties of the possible dynamics for one- and two-qubit systems without and with noise. We report on the realization of a couple of steps for two of the protocols in optical experiments. Furthermore, we discuss possible applications.

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Generalized bulk-edge correspondance at positive temperature

Author: Horia Cornean[1]

[1] *University in Aalborg, Denmark*

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By extending the gauge covariant magnetic perturbation theory to operators defined on half planes, we prove that for general 2d random ergodic magnetic Schrödinger operators the celebrated bulk-edge correspondence is just a particular case of a much more general paradigm, which also includes the theory of diamagnetic currents and of Landau diamagnetism. Our main result is encapsulated in a formula, which states that the derivative of a large class of bulk partition functions with respect to the external constant magnetic field, equals the expectation of a corresponding edge distribution function of the velocity component which is parallel to the edge. Neither spectral gaps, nor mobility gaps, nor topological arguments are required. The equality between the bulk and edge indices, as stated by the conventional bulk-boundary correspondence, is obtained as a corollary of our purely analytical arguments by imposing a gap condition and by taking a "zero temperature" limit.

This is joint work with S. Teufel and M. Moscolari.

Talk / **23**

Dimensional Reduction of Gauge Theories and Quantum Simulations

Author: Saverio Pascazio[1]

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We derive and discuss one- and two-dimensional models for classical electromagnetism by making use of Hadamard's method of descent. Low-dimensional electromagnetism is conceived as a specialization of the higher dimensional one, in which the fields are uniform along the additional spatial directions. We then consider two-dimensional models for a charged spin-1/2 particle, both in the free case and in the presence of the electromagnetic field, by applying the same reduction technique. The basic properties of these theories, as well as their relation with existing models for two-dimensional matter, are discussed. We focus on the relevance of these findings for the quantum simulation of (lattice) gauge theories.

Talk / 12

Fermionic walkers driven out of equilibrium

Author: Alain Joye[1]

[1] *Université Grenoble Alpes, Grenoble*

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We consider a discrete-time non-Hamiltonian dynamics of a quantum system consisting of a finite sample locally coupled to several infinite reservoirs of fermions with a translation symmetry. In this setup, we compute the asymptotic state, fluxes of fermions into the different reservoirs, as well as the entropy production rate of the dynamics.
This is joint work with S. Andréys and R. Raquépas.

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KAM stability of quantum symmetries

Author: Paolo Facchi[1]

Co-authors: Hiromichi Nakazato ; Daniel Burgarth ; Saverio Pascazio ; Kazuya Yuasa

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We show that for any finite-dimensional quantum systems the conserved quantities can be characterized by their robustness to small perturbations: for fragile symmetries, small perturbations can lead to large deviations over long times, while for robust symmetries, their expectation values remain close to their initial values for all times. This is in analogy with the celebrated Kolmogorov-Arnold-Moser theorem in classical mechanics.

Talk / 10

Geometric realizations of boundaries of infinite trees

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We discuss the construction of the trace operator defined on Sobolev spaces over a class of infinite trees based on an identification of the abstract boundary with an Euclidean domain. This can be used to study coupling problems between objects of different dimensions. Joint work with Kiyan Naderi (Oldenburg).

Talk / 2

Quantum state preparation and dynamical symmetries: Coherent laser-induced preparation of multipartite W- and GHZ-quantum states and their interconversion.

Author: Gernot Alber[1]

Co-authors: Thorsten Haase [2]; Vladimir Stojanovic [2]

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Coherent laser-induced excitation processes based on timescale hierarchies offer interesting perspectives for the controlled and deterministic preparation of entangled multipartite quantum states. Greenberger-Horne-Zeilinger (GHZ) and W-states are prominent examples of such multipartite quantum states which constitute valuable resources for quantum information processing. Motivated by current experimental efforts aiming at the controlled preparation and interconversion of these quantum states in neutral-atom systems in the Rydberg-blockade regime, we explore the theoretical potential of Lie-algebraic methods and dynamical symmetries for achieving state preparation and inverconversion between these important classes of multipartite quantum states. It is demonstrated that these dynamical symmetry-based methods provide promising theoretical approaches for exploring and optimizing laser pulse sequences capable of achieving these state preparation and interconversion tasks efficiently [1]. Thus, these methods constitute powerful theoretical alternatives to other nowadays frequently used approaches, such as the ones based on Lewis-Riesenfeld invariants [2].

[1] Th. Haase, G. Alber, V. Stojanovic, Phys. Rev. A 103, 032427 (2021)
'Conversion from W to Greenberger-Horne-Zeilinger States in the Rydberg-Blockade Regime of Neutral-Atom Systems: Dynamical-Symmetry-Based Approach'.
[2] H. R. Lewis, W. B. Riesenfeld, J. Math. Phys. 10, 1458 (1969)
'An Exact Quantum Theory of the Time-Dependent Harmonic Oscillator and of a Charged Particle in a Time-Dependent Electromagnetic Field'.

Talk / 13

Towards Morse theory of dispersion relations

Author: Gregory Berkolaiko[1]

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The question of optimizing an eigenvalue of a family of self-adjoint operators that depends on a set of parameters arises in diverse areas of mathematical physics. Among the particular motivations for this talk are the Floquet-Bloch decomposition of the Schroedinger operator on a periodic structure, nodal count statistics of eigenfunctions of quantum graphs, conical points in potential energy surfaces in quantum chemistry and the minimal spectral partitions of domains. In each of these problems one seeks to identify and/or count the critical points
of the eigenvalue with a given label (say, the third lowest) over the parameter space which is often known and simple, such as a torus.

Classical Morse theory is a set of tools connecting the number of critical points of a smooth function on a manifold to the topological invariants of this manifold. However, the eigenvalues are not smooth due to presence of eigenvalue multiplicities or diabolical points". We rectify this problem for eigenvalues of generic families of finite-dimensional operators. The correctMorse indices" of the problematic diabolical points turn out to be universal: they depend only on the total multiplicity at the diabolical point and on the relative position of the eigenvalue of interest in the eigenvalue group.

Based on a joint work with I.Zelenko.

Talk / **14**

Can one hear a real symmetric matrix?

Author: Uzy Smilansky[1]

[1] *Weizmann Institute of Science, Rehovot*

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The question asked in the title is addressed from two points of view:

First, we show that providing enough (term to be explained) spectral data, suffices to reconstruct uniquely generic (term to be explained) matrices. The method is well defined but requires somewhat cumbersome computations.

Second, restricting the attention to banded matrices with band-width much smaller than the dimension, one can provide more spectral data than the number of unknown matrix elements.

We make use of this redundancy to reconstruct generic banded matrices in a much more straightforward fashion where the "cumbersome computations"can be skipped over.

Explicit criteria for a matrix to be in the non-generic set are provided.

Talk / **7**

Aspects of time in quantum mechanics

Author: Stephen M. Barnett[1]

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Time in quantum mechanics, especially the non-relativistic theory has privileged position in that unlike the Cartesian coordinates it is a parameter rather than an operator. Moreover, it is a parameter over which we have no control: time passes and our quantum systems evolve. Yet the theory is essentially time-symmetric (as is most of the rest of physics) so there is a sense in which "time-reversed"
quantum theory should have a meaning. This is indeed the case and I shall present such a retrodictive (as opposed to predictive) theory, which is linked to the conventional approach by Bayes' theorem. The theory brings with it surprises, some of which I shall demonstrate. These include unconventional explanations for classic quantum optics experiments and novel devices designed using retrodictive reasoning including the possibility of information processing in the past! If time permits I shall also introduce the principle of devices utilising indefinite causal order, in which there is an advantage to be had by employing physical operations in a superposition of temporal orders.

Talk / **9**

On the excess charge for bosonic atomic systems

Author: Rafael Benguria[1]

[1] *Pontificia Universidad Católica de Chile*

Corresponding Author: rafael.benguria@gmail.com

In this talk I will present some new results on the excess charge for bosonic systems.

Poster / 30

Nonlinear squeezing and its decoherence

Author: Vojtěch Kala[1]

Co-authors: Radim Filip [1]; Petr Marek [1]

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Corresponding Author: vojtech.kala@gmail.com

Nonlinear squeezing is an important feature for universal quantum computing, that in principle enables universal control of a continuous variable system [1]. Simultaneously, it is a subject to current experimental effort [2,3,4]. We show its behaviour under decoherence and possibilities of protection by Gaussian operations [4]. Therefore, our results can enhance the ability to detect the nonlinear squeezing.
[1] Seth Lloyd et al., PRL 82, 1784 (1999)
[2] Shunya Konno, et al., Phys. Rev. Applied 15, 024024 (2021)
[3] Francesco Albarelli, et al., PRA 98, 052350 (2018)
[4] Yu Zheng, et al., PRX Quantum 2, 010327 (2021)
[5] Vojtěch Kala, Petr Marek, Radim Filip, arXiv:2107.06036 [quant-ph]

Poster / 26

Measurement disturbance tradeoffs in three-qubit unsupervised quantum classification

Authors: Hector Spencer-Wood[1]; John Jeffers[2]; Sarah Croke[1]

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[2] *University of Strathclyde*

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We consider measurement disturbance tradeoffs in quantum machine learning protocols which seek to learn about quantum data. We study the simplest example of a binary classification task, in the unsupervised regime. Specifically, we investigate how a classification of two qubits, that can each be in one of two unknown states, affects our ability to perform a subsequent classification on three qubits when a third is added. Surprisingly, we find a range of strategies in which a non-trivial first classification does not affect the success rate of the second classification. There is, however, a non-trivial measurement disturbance tradeoff between the success rate of the first and second classifications, and we fully characterise this tradeoff analytically.

Poster / **29**

Benchmarking quantum computers using quantum state matching of qubits

Authors: Adrian Ortega[1]; Orsolya Kálmán[1]; Tamás Kiss[1]

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We present our advances on the implementation of a measurement-induced nonlinear protocol for quantum state matching using some commercially available quantum computers. Using this implementation, we present a benchmark that detects quantitatively the device specific errors. In contrast to current benchmarks trends, our circuit is a non-random deep circuit. Among the devices analyzed, we discuss briefly which are more promising.

Poster / **25**

Quantum local time

Author: Václav Potoček[1]

Co-author: Václav Zatloukal

[1] *FNSPE, CTU in Prague*

The trajectory of a quantum particle during unitary evolution between its preparation and a later measurement can not be studied without measuring the particle, but measurement disturbs the state and the statistics of the measurement outcomes no longer pertain to the original evolution. We show how using path integral methods a sensible quasi-probability can be assigned to the event of passing multiple points along the trajectory, or to entire trajectories, in a position- and time-discrete system. We show that by extension of the weak measurement protocol this quantity is actually experimentally measurable with asymptotically zero disturbance. Joint, conditional, marginal quasiprobabilities can be defined consistently, and reduce to familiar probabilities in scenarios where a standard measurement is possible. We use this to define a quantum version of local time, a random variable studied in random processes, and illustrate by practical examples. By asking the probability of this being zero at the initial node of a discrete time quantum walk on a graph, for example, we introduce a new notion of weak recurrence and weak Pólya number, which we calculate for the Hadamard walk. The result is different, both in meaning and in value, from two related quantities studied by Grünbaum et al. (2013) and Štefaňák et al. (2008). Nevertheless, the results and methods in their current form are usable for any time-discrete quantum system in a Hilbert space spanned by a countable preferred basis.

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Applications of quantum computers in quantum chemistry

Authors: Ludvík Cigna[1]; Martin Štefaňák[2]

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Quantum computing has received a lot of attention recently, and specifically its application in quantum chemistry looks very promising. This research project summarizes the most important methods used in calculating the electronic structure of a chemical system on quantum computers. This includes the formulation of the problem in first and second quantization and the use of classical computational methods of quantum chemistry, starting with the Born-Oppenheimer approximation.
In particular, attention is paid to the Hartree-Fock method, from which more advanced approaches follow. Next, methods for mapping fermions to qubits are discussed and extra space is given to the Bravyi-Kitaev transform. This is then exploited in two quantum algorithms suitable for determining the ground state.
The first is an algorithm for phase estimation. Within this, two methods for simulating the Hamiltonian are described, namely the so-called Trotterization and qubitization. The second is a variational algorithm for energy estimation suitable already for NISQ computers.
Finally, the aim of the research project will be to demonstrate the derived methods on examples of simple molecules.

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On the steady and asymptotic subspaces of open quantum systems

Author: DANIELE AMATO[1]

[1] *University of Bari*

The evolution of an open quantum system is described by a quantum channel, i.e. a completely positive trace-preserving map. Under the Markovian approximation, the continuous dynamics of an open quantum system is given by a semigroup with a Gorini-Kossakowski-Lindblad-Sudarshan (GKLS) generator. In this poster we will discuss several constraints for the number of steady and asymptotic states of quantum channels and Markovian continuous evolutions. Joint work with Paolo Facchi.

Poster / 34

Disorder-free localization in quantum walks

Author: Iskender Yalcinkaya[1]

Co-authors: Baris Cakmak [2]; Goktug Karpat [3]; Shane P. Kelly [4]; Burcin Danaci [5]; A. Levent Subasi [6]

[1] *Czech Technical University in Prague*

[2] *Bahçeşehir University*

[3] *Izmir University of Economics*

[4] *Johannes Gutenberg University of Mainz*

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[6] *Istanbul Tecehnical University*

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The localization phenomenon usually happens due to the existence of disorder in a medium. Nevertheless, specific quantum systems allow dynamical localization solely due to internal interactions. We study a discrete-time quantum walker which exhibits disorder-free localization. The quantum walker moves on a one-dimensional lattice and interacts with on-site spins by coherently rotating them around a given axis at each step. Since the spins do not have their dynamics, the system poses the local spin components along the rotation axis as many conserved moments. When the interaction is weak, the spread of the walker shows subdiffusive behavior, having downscaled ballistic

tails in the evolving probability distribution at intermediate time scales. However, as the interaction gets stronger, the walker gets exponentially localized in the complete absence of disorder in both lattice and initial state. Using a matrix-product-state ansatz, we investigate the relaxation and entanglement dynamics of the on-site spins due to their coupling with the quantum walker. Surprisingly, even in the delocalized regime, entanglement growth and relaxation occur slowly, unlike the majority of the other models displaying a localization transition.

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Quantum walk based state transfer algorithms on the complete M-partite graph

Authors: Martin Štefaňák[1]; Stanislav Skoupý[2]

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We introduce the general scheme of discrete-time quantum walk algorithm for the search and state transfer algorithm based on discrete-time quantum walk. We prove that adding a loop to each vertex improves success probability of the search algorithm on a complete M-partite graph in the limit of a large graph. We show that the state transfer algorithm performs perfect state transfer between sender and receiver in the case when their are in different partitions of the graph. However, the state transfer algorithm fails to achieve perfect state transfer when sender and receiver are in the same partition of the graph. We propose modification of the state transfer algorithm by adding switch of evolution operator during teh run of algorithm. We show that state transfer algorithm with active switch performs perfect state transfer in all cases of relative position of sender and receiver on the complete M-partite graph.

Poster / **37**

Hearing the shape of a quantum boundary condition

Authors: Giuliano Angelone[1]; Paolo Facchi[2]; Giuseppe Marmo[3]

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[2] *University of Bari, Italy and INFN Italy*

[3] *Università degli studi di Napoli*

We study the isospectrality problem for a free quantum particle confined in a ring with a junction. By characterizing the energy spectrum in terms of a spectral function, we classify all the possible self-adjoint realizations. The latter turn out to be divided in two classes, which are discerned by the action of parity.

Main reference: G. Angelone, P. Facchi and G. Marmo, *Hearing the shape of a quantum boundary condition*, arXiv: 204.10248 [quant-ph] (2022), https://arxiv.org/abs/2204.10248.

Poster / **36**

Quantum graphs with preferred orientation coupling

Author: Jiří Lipovský[1]

Co-authors: Marzieh Baradaran [1]; Pavel Exner [2]

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In the presented poster, known results on the spectral properties of quantum graphs with preferred orientation coupling are reviewed. Special attention is paid to the recent result on magnetic ring chains with preferred orientation coupling.

Poster / **22**

Small angle asymptotics for Robin Laplacians on infinite circular cones

Authors: Konstantin Pankrashkin[1]; Marco Vogel[1]

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For $\varepsilon > 0$ and $n \in \mathbb{N}$ consider the infinite cone $\Omega_\varepsilon := \{(x_1, x') \in (0,\infty) \times \mathbb{R}^n : |x'| < \varepsilon x_1\}$ and the operator Q_ε^α acting as the Laplacian $u \mapsto -\Delta u$ on Ω_ε with the Robin boundary condition $\partial_\nu u = \alpha u$ at $\partial\Omega_\varepsilon$, where ∂_ν is the outward normal derivative and $\alpha > 0$. It is known from numerous earlier works that the essential spectrum of Q_ε^α is $[-\alpha^2, +\infty)$ and that the discrete spectrum is finite for $n = 1$ and infinite for $n \geq 2$, but the behavior of individual eigenvalues with respect to the geometric parameter ε was only addressed for $n = 1$ so far. In the present work we consider arbitrary $n \geq 2$ and look at the spectral asymptotics as ε becomes small, i.e. as the cone becomes "sharp" and collapses to its central axis. Our main result is as follows: if $n \geq 2$, $\alpha > 0$ and $j \in \mathbb{N}$ are fixed, then the jth eigenvalue $E_j(Q_\varepsilon^\alpha)$ of Q_ε^α behaves as $E_j(Q_\varepsilon^\alpha) = -\frac{n^2\alpha^2}{(2j+n-2)^2\,\varepsilon^2} + O\left(\frac{1}{\varepsilon}\right)$ as $\varepsilon \to 0^+$.

Poster / **38**

Quantum estimation with driven quantum walk

Author: Shivani Singh[1]

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Using quantum Fisher information (QFI), we will show that parameter estimation with a driven discrete-time quantum walk (QW) provides a better bound over the attainable precision when compared to standard QW. Here, we are studying the quantum estimation of the phase parameter of the evolution operator. With this study, we can also show that QW set-up can be used to reduce the variance in the phase estimation of Mach-Zender interferometer for a fixed number of measurements.

Poster / **39**

Asymptotic trapping in coined Grover flip-flop quantum walks on general graphs with dynamical percolation

Authors: Jan Mareš[1]; Jaroslav Novotný[2]; Martin Štefaňák[3]; Igor Jex[4]

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It is known from previous works that discrete flip-flop quantum walks with the Grover coin on finite graphs can exhibit the phenomenon of asymptotic trapping, where the walker can evade a sink introduced in the graph indefinitely with non-zero probability. This interference phenomenon is caused by so-called trapped states –eigenstates of the walk with limited support, i.e. with zero coefficients for some positions in the graph. It is also known that some of these states remain present in the asymptotic dynamics of the walk after disruption by dynamical percolation –random closing and re-opening of edges in the graph at each time step. In this work we extend a recipe for construction of a basis of the trapped states subspace available previously for finite simple 3-regular planar graphs to all finite simple graphs. We also provide new insights into the role of the position of the sink and its relation to the initial position of the walker, we give general advice how some changes of the graph influence transport, and we support the above by presenting several closed-form formulas for the asymptotic transport probability in dependence on parameters describing the graph.

Poster / **40**

Robust quantum search algorithm via non-unitary Zeno-like dynamics

Authors: Pavlo Pyshkin[1]; Aurél Gábris[2]; Da-Wei Luo[3]; J. Q. You[4]; Lian-Ao Wu[1]

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We propose and analyze a non-unitary variant of the continuous time Grover search algorithm based on frequent Zeno-type measurements. We show that the algorithm scales similarly to the pure quantum version by deriving tight analytical lower bounds on its efficiency for arbitrary database sizes and measurement parameters. We study the behavior of the algorithm subject to noise, and find that under certain oracle and operational errors our measurement-based algorithm outperforms the standard algorithm, showing robustness against these noises.

Poster / **41**

Incremental Learning of Quantum Generative Adversarial Networks

Authors: Artem Kandaurov[1]; Aurél Gábris[1]; Ivo Petr[1]

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Machine learning field has shown incredible impact on many kinds of optimization problems. Recently the power of machine learning was applied to speed up the quantum states preparation. Although approximation with quantum generative adversarial networks is one of the fastest ways to prepare a generic quantum state, training time for such models is still significant and can easily impair quantum advantage. This thesis explores incremental learning of quantum generative adversarial networks for the quantum states preparation problem and introduces learning use cases reducing the training time.

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Asymptotic synchronization and phase-locking in qubit networks

Authors: Daniel Štěrba[1]; Igor Jex[1]; Jaroslav Novotný[2]

[1] *FNSPE CTU in Prague*

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The work concerns asymptotic synchronization and phase-locking in qubit networks undergoing Markovian evolution described by the GKSL master equation with normal Lindblad operators. For a two-qubit system, all synchronization and phase-locking mechanisms within the given framework are obtained and classified, using solely analytic methods. In the case of synchronization, the results are generalized to qubit networks, n-qubit systems with bipartite interactions. It is shown how the two-qubit synchronization-enforcing Lindblad operators can be used to synchronize an arbitrarily large qubit network via construction of a suitable Lindbladian. Selected properties of the synchronization and phase-locking mechanisms are discussed.

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Angle and angular momentum – new twist for an old pair

Author: Zdeněk Hradil[1]

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Reaching ultimate performance of quantum technologies requires the use of detection at quantum limits and access to all resources of the underlying physical system. We establish a full quantum analogy between the pair of angular momentum and exponential angular variable, and the structure of canonically conjugate position and momentum. This includes the notion of optimal simultaneous measurement of the angular momentum and angular variable, the identification of Einstein-Podolsky-Rosen-like variables and states, and finally a phase-space representation of quantum states. Our construction is based on close interconnection of the three concepts and may serve as a template for the treatment of other observables. This theory also provides a new testbed for implementation of quantum technologies combining discrete and continuous quantum variables.

Talk / 5

A Ionization Model

Author: Raffaele Carlone[1]

Co-authors: L. Tentarelli ; M. Correggi ; M. Falconi ; M. Olivieri ; W. Borrelli

[1] *Università "Federico II" di Napoli*

In the first part we will describe the dynamics of a quantum particle coupled to bosonic fields, in the quasi-classical regime. In this case, the fields are very intense and the corresponding degrees of freedom can be treated semiclassically. We prove that in such a regime the effective dynamics for the quantum particles is approximated by
the one generated by a time-dependent point interaction, i.e., a singular time-dependent perturbation of the Laplacian supported in a point. As a by-product, we also show that the unitary dynamics of a time-dependent point interaction can be approximated in strong operator topology by the one generated by time-dependent Schrödinger operators with suitably rescaled regular potentials.Then we analyze the ionization problem for the effective model. First, we prove global well-posedness of the associated Cauchy problem under general assumptions on the potential and on the initial datum. Then, for a monochromatic periodic potential (which also satisfies a suitable no-resonance condition) we investigate the asymptotic behavior of the survival probability of a bound state of the time-independent problem.

Talk / 8

100 years of complementarity

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Einstein in 1905, in his explanation of the photoelectric effect, postulated that light, the quintessential wave, had to possess particle-like properties. In the course of 1923-24, de Broglie, analyzing electron scattering from metal surfaces, postulated that electrons, the quintessential particles, must possess wave-like properties. In 1928, Bohr made the first attempt to reconcile the two viewpoints and introduced the concept of complementarity (or, in a more restricted sense, wave-particle duality), and thus the by now nearly 100 years history of complementarity has started.

We begin with a brief overview of the history of quantitative complementarity relations. A particle going through an interferometer can exhibit wave-like or particle-like properties. The first quantitative duality relation was obtained by Greenberger and Yasin [1], between the strictly single-partite properties: predictability $P = |\rho_{11} - \rho_{22}|$ and visibility $V = 2|\rho_{12}|$ and has the form

$$\mathrm{P}^2 + V^2 \leq 1. \qquad (1)$$

In a seminal study of the two-path interferometer, Englert introduced detectors into the interferometer arms and defined the path distinguishability, D, as the discrimination probability of the path detector states [2]. He derived a relation between this type of path information and the visibility $V = 2|\rho_{12}|$ of the interference pattern, in the form

$$\mathrm{D}^2 + V^2 \leq 1. \qquad (2)$$

In a follow-up [3], Englert and Bergou showed that D is a joint property of the system and the meter to be clearly distinguished from predictability, which is a strictly single partite property. They showed that (2) corresponds to the so-called which-way sorting (post-selection) of the measurement data. They also introduced the quantum erasure sorting, which led to the duality relation $P^2 + C^2 \leq 1$, where the coherence C is a joint property of the system and detectors. Most importantly, they conjectured that D should be related to an entanglement measure. Taking up this conjecture, the complete bipartite (particle-meter) complementarity relation, connecting complementarity, i.e., visibility of the interference pattern, V, and path predictability, P, to entanglement, was found in [4], in the form of a *triality relation*,

$$P^2 + C^2 + V^2 \leq 1. \qquad (3)$$

Here C is the concurrence, emerging naturally as part of the completeness relation for a bipartite system. In [5], this *triality relation* was further generalized to multi-path (n-path) interferometers. These works completed the research on quantitative complementarity and brought the Bohr-Einstein debate to a very satisfying closure. In particular, Eq. (3), which is a triality relation, displays explicitly that entanglement is the genuinely quantum contribution with no classical counterpart, whereas visibility, quantifying wave-like behavior, and predictability, quantifying particle-like behavior, can be regarded as classical contribution.

In all of the works discussed above, the l_2 measure of coherence was employed. Recently, however, a resource theory of quantum coherence was developed and two new coherence measures were introduced [6]. The l_1 measure is the trace distance, the entropic measure is the entropic distance of a given state to the nearest incoherent state. In the second part of the talk we present our recent results for multi-path interferometers, employing the new measures. Using these measures, we derived entropic and l_1 based duality relations for multi-path interferometers [7, 8]. The l_1 based duality relation for n-path interferometers is

$$\left(\frac{C+D-\frac{n-2}{n-1}}{\frac{\sqrt{n}}{n=1}}\right)^2 + \left(\frac{C-D}{\sqrt{\frac{n}{n-1}}}\right)^2 \leq 1, \quad C, D > 0, \qquad (4)$$

where C is the l_1 measure of coherence, generalizing the visibility V. To close, we will present recent results generalizing duality relations to finite groups [9], recent entropic duality relations [10], and discuss recent developments, showing that relations like Eq. (1) can be derived from intrinsic properties of quantum states, without referring to measurements [11, 12].

References
[1] D. M. Greenberger and A. Yasin, ”Simultaneous wave and particle knowledge in a neutron interferometer,”Phys. Lett. A
128, 391 (1988).
[2] B.-G. Englert, ”Fringe Visibility and Which-Way Information: An Inequality,”Phys. Rev. Lett. 77, 2154 (1996).
[3] B.-G. Englert and J. A. Bergou, ”Quantitative quantum erasure,”Opt. Commun. 179, 337 (2000).
[4] M. Jakob and J. A. Bergou, ”Quantitative complementarity relations in bipartite systems: Entanglement as a physical
reality,”Opt. Commun. 283, 827 (2010) [also as arxiv:0302075].
[5] M. Jakob and J. A. Bergou, ”Complementarity and entanglement in bipartite qudit systems,”Phys. Rev. A 76, 052107
(2007).
[6] T. Baumgratz, M. Cramer, Tand M. B. Plenio, ”Quantifying Coherence,”Phys. Rev. Lett. 113, 140401 (2014).
[7] E. Bagan, J. A. Bergou, S. S. Cottrell, and M. Hillery, ”Relations between Coherence and Path Information,”Phys. Rev.
Lett. 116, 160406 (2016).
[8] E. Bagan, J. Calsamiglia, J. A. Bergou, and M. Hillery, ”Duality Games and Operational Duality Relations,”Phys. Rev.
Lett. 120, 050402 (2016).
[9] E. Bagan, J. Calsamiglia, J. A. Bergou, and M. Hillery, ”A generalized wave-particle duality relation for finite groups,”
Journal of Physics A: Math. Theor. 51, 414015 (2018).
[10] E. Bagan, J. A. Bergou, and M. Hillery, ”Wave-particle duality relations based on entropic bounds for which-way information,”Phys. Rev. A 102, 022224 (2020).
[11] X. L¨u, ”Quantitative wave-particle duality as quantum state discrimination”, Phys. Rev. A 102, 02201 (2020).
[12] X. L¨u, ”Duality of path distinguishability and quantum coherence”, Phys. Lett. A 397, 127259 (2021).

Talk / 18

Divisibility of quantum processes and stroboscopic simulations of quantum dynamics

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The concept of divisibility of dynamical maps will be used to introduce an analogous concept for quantum channels by analyzing the simulability of channels by means of dynamical maps. In particular, this is addressed for Lindblad divisible, completely positive divisible and positive divisible dynamical maps. The corresponding L-divisible, CP-divisible and P-divisible subsets of channels are characterized and visualized for the case of qubit channels. We will discuss their mutual relations. Motivated by the analogy between the channel divisibility and the integer factorization we will further
address the question of strictly n-divisible channels. In particular, we will explain that , surprisingly, divisible channels are also infinitely divisible ones.

Talk / **19**

The Riemann Zeta Function and Quantum Mechanics

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The Riemann zeta function ζ plays a crucial role in number theory as well as physics. Indeed, the distribution of primes is intimately connected to the non-trivial zeros of this function. We briefly summarize the essential properties of the Riemann zeta function and then present a quantum mechanical system which when measured appropriately yields ζ. We emphasize that for the representation in terms of a Dirichlet series interference [1] suffices to obtain ζ. However, in order to create ζ along the critical line where the non-trivial zeros are located we need two entangled quantum systems [2]. In this way entanglement may be considered the quantum analogue of the analytical continuation of complex analysis. We also analyze the Newton flows [3, 4] of ζ as well as of the closely related function ξ. Both provide additional insight [5] into the Riemann hypothesis.

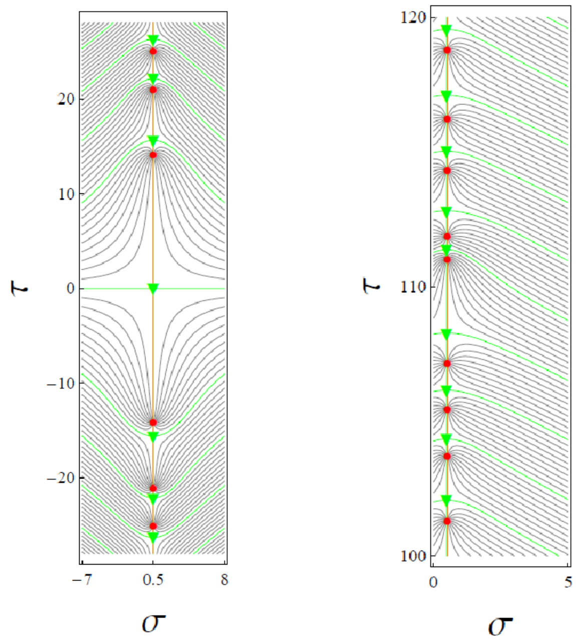

Figure 2: Lines of constant phase of the function ξ

[1] R. Mack, J. P. Dahl, H. Moya-Cessa, W.T. Strunz, R. Walser, and W. P. Schleich, Riemann ζ-function from wave packet dynamics, Phys. Rev. A. 82, 032119 (2010).
[2] C. Feiler and W.P. Schleich, Entanglement and analytical continuation: an intimate relation told by the Riemann zeta function, New J. Phys. 15, 063009 (2013).
[3] J. Neuberger, C. Feiler, H. Maier, and W.P. Schleich, Newton flow of the Riemann zeta function: Separatrices control the appearance of zeros, New J. Phys. 16, 103023 (2014).
[4] J.W. Neuberger, C. Feiler, H. Maier, and W.P. Schleich, The Riemann hypothesis illuminated by the Newton flow of ζ.� Phys. Scr. 90, 108015 (2015).
[5] W.P. Schleich, I. Bezděková, M.B. Kim, P.C. Abbott, H. Maier, H.Montgomery, and J.W. Neuberger, Equivalent formulations of the Riemann hypothesis based on lines of constant phase, Phys. Scr. 93, 065201 (2018).

Talk / **4**

Application of quantum and microwave graphs in investigations of spectral invariants and non-Weyl systems

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We introduce a new spectral invariant: the generalized Euler characteristic $\mathcal{E}$ [1]. The commonly used Euler characteristic i.e., the difference between the number of vertices $|V|$ and edges $|E|$ is the most important topological characteristic of a graph. However, to describe spectral properties of differential equations with mixed Dirichlet and Neumann vertex conditions it is necessary to introduce a new spectral invariant, the generalized Euler characteristic is $\mathcal{E} = |V| - |V_D| - |V|$, with $|V_D|$ denoting the number of Dirichlet vertices. We demonstrate theoretically and experimentally that the generalized Euler characteristic $\mathcal{E}$ of quantum and microwave graphs [2] can be determined from small sets of the lowest eigen-frequencies. We discuss a relationship between the generalized Euler characteristic of the original graph $\mathcal{E}_o$ which was split at vertices into two disconnected subgraphs $i = 1, 2$ and their generalized Euler characteristics $\mathcal{E}_i$.

Another important characteristic of a quantum graph is the average density of resonances, $\rho = (L/\pi)$, where L denotes the length of the graph. This is a robust measure. It does not depend on the number of vertices in a graph and holds also for most of the boundary conditions at the vertices. Graphs obeying this characteristic are called Weyl graphs. Using microwave graphs (networks) that simulate quantum graphs we show that there exist graphs, called non-Weyl graphs, that do not adhere to this characteristic [3]. For standard coupling conditions we demonstrate that the transition from a Weyl graph to a non-Weyl graph occurs if we introduce a balanced vertex. A vertex is called balanced if the numbers of infinite leads and internal edges meeting at a vertex are the same.

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References:

[1]. M. Ławniczak, P. Kurasov, S. Bauch, M. Białous, A. Akhshani, and L. Sirko, A new spectral invariant for quantum graphs, Scientific Reports 11, 15342 (2021).
[2]. O. Hul, S. Bauch, P. Pakoński, N. Savytskyy, K. Życzkowski, and L. Sirko, Experimental simulation of quantum graphs by microwave networks, Phys. Rev. E 69, 056205 (2004).
[3]. M. Ławniczak, J. Lipovský, and L. Sirko, Non-Weyl Microwave Graphs, Phys. Rev. Lett. 122, 140503 (2019).

Talk / 33

Quantum optics and information science in multi-dimensional photonics networks

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Quantum technologies promise a change of paradigm for many fields of application, for example in communication systems, in high-performance computing and simulation of quantum systems, as well as in sensor technology. They can shift the boundaries of today's systems and devices beyond classical limits and seemingly fundamental limitations.

Photonic systems, which comprise multiple optical modes as well as many nonclassical light quantum states of light, have been investigated intensively in various theoretical proposals over the last decades. However, their implementation requires advanced setups of high complexity, which poses a considerable challenge on the experimental side, and stimulate the demand for novel theoretical approaches. The realization of controlled quantum network structures and demonstration of innovative concepts is key for many applications in quantum optics and quantum information science. Here we present different approaches to overcome current limitations for the implementation of multi-dimensional quantum networks.