52nd Symposium on Mathematical Physics

Channels, Maps, and All That

June 14–17, 2021

Institute of Physics, Nicholaus Copernicus University in Toruń
Toruń, Poland

BOOK OF ABSTRACTS

Toruń, 2021

Dedicated to the memory of Andrzej Kossakowski, 1938–2021

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The quantum mechanics canonically associated to free probability

Co-authors: Tarek Hamdi and Yun Gang Lu

It is now known that each classical random variable has a canonical quantum decomposition in terms of creation, annihilation and preservation (CAP) operators satisfying commutation relations uniquely determined by their Jacobi coefficients or their multi–dimensional extensions. Symmetric classical random variables also have a canonically conjugated moments and the two are intertwined by a generalization, to arbitrary random variables, of the Gauss–Fourier transform. Thus every classical random variable determines its own quantum mechanics.
Usual QM corresponds to the Gaussian–Poisson class.
Quadratic QM corresponds to the 3 non–standard classes of Meixner measures.
According to the information complexity index for probability measures on $\mathbb{R}$, the semi–circle–arcsine class has a lower complexity index than the above mentioned 5 classes. Thus it is interesting to investigate how does the QM associated to these probability measures look like. I will discuss the solution of this problem in the case of the semi–circle law. It turns out that in this case the canonically conjugate moment is given by the Hilbert transform with respect to the semi–circle measure. This allows to express the momentum evolution and the free evolution (generated by kinetic energy) in terms, respectively, of Bessel functions and of confluent hypergeometric series.

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Mixing indistinguishable systems leads to a quantum Gibbs paradox

The classical Gibbs paradox concerns the entropy change upon mixing two gases. Whether an observer assigns an entropy increase to the process depends on their ability to distinguish the gases. A resolution is that an "ignorant" observer, who cannot distinguish the gases, has no way of extracting work by mixing them. Moving the thought experiment into the quantum realm, we reveal new and surprising behaviour: the ignorant observer can extract work from mixing different gases, even if the gases cannot be directly distinguished. Moreover, in the macroscopic limit, the quantum case diverges from the classical ideal gas: as much work can be extracted as if the gases were fully distinguishable. We show that the ignorant observer assigns more microstates to the system than found by naive counting in semiclassical statistical mechanics. This demonstrates the importance of accounting for the level of knowledge of an observer, and its implications for genuinely quantum modifications to thermodynamics.

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Trajectory-based GKLS equation and its energetics

Given a trajectory described by a time-dependent density matrix of an arbitrary open quantum system, we formulate a universal GKSL dynamical equation describing the given dynamics. Using this framework we introduce methods to speed up the dynamics of a driven open quantum system along any trajectory of interest. This framework generalizes counterdiabatic driving to open quantum processes. We next analyze the obtained dynamical equation from an energy perspective, which provides an unambiguous formulation of heat and work in quantum systems based on the dissipated energy and the energy assigned to the coherent part of the dynamics.

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Self-testing within the stabilizer formalism

Self-testing is a device-independent method for certification of entangled quantum states and measurements performed on them. In this talk I will review our recent results on self-testing that are formulated within the stabilizer formalism known for instance for its use in quantum error correction. In particular, I will demonstrate how it can be used to derive scalable Bell inequalities for the graph states and prove self-testing statements for them. I will then show how the stabilizer formalism can be used to self-test not only entangled states but also genuinely entangled subspaces in multiqubit Hilbert spaces. I will finally discuss possible generalizations to composite quantum systems of local dimension higher than two. This talk is based on [1, 2, 3, 4].

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Mitigating Detection Crosstalk Errors with Local Unitaries

In this work, we show that readout errors originated from multiple detectors that may contain both detection crosstalk and local noise can be mitigated via quantum detector tomography. We present a mitigation protocol that applies local unitaries before a detection event and a classical post-processing with measurement outcomes. The mitigation protocol can lead a measurement readout error to a percent region.

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Asymptotic transport properties in open quantum spin chains

We consider spin chains of arbitrary length with XX interactions, weakly coupled to thermal baths through their end spins. We derive the master equation in the so-called global approach and present an analytic study of the transport properties of its unique stationary state.

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Quantifying necessary quantum resources for nonlocality

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Nonlocality is one of the most important resources for quantum information protocols. The observation of nonlocal correlations in a Bell experiment is the result of appropriately chosen measurements and quantum states. We quantify the minimal purity to achieve a certain Bell value for any Bell operator. Since purity is the most fundamental resource of a quantum state, this enables us also to quantify the necessary coherence, discord, and entanglement for a given violation of two-qubit correlation inequalities. Our results shine new light on the CHSH inequality by showing that for a fixed Bell violation an increase in the measurement resources does not always lead to a decrease of the minimal state resources.

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Eternal Adiabaticity and KAM-Stability

Co-authors: Paolo Facchi, Hiromichi Nakazato, Saverio Pascazio, Kazuya Yuasa

We develop approximations to a perturbed quantum dynamics beyond the standard approximation based on quantum Zeno dynamics and adiabatic elimination. The effective generators describing the approximate evolutions are endowed with the same block structure as the unperturbed part of the generator, and their adiabatic error is "eternal" — it does not accumulate over time. We show how this gives rise to Schrieffer-Wolff generators in open systems. When considering conserved quantities of an unperturbed system, these approximations provide an version of the celebrated Kolmogorov-Arnold-Moser (KAM) theorem in classical mechanics for finite dimensional quantum dynamics.
[Based on Phys. Rev. Lett. 126, 150401 (2021) and Phys. Rev. A 103, 032214 (2021).]

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The "thermodynamic reverse bound" and the role of retrodiction in statistical mechanics

In this talk, I will present some recent work about the role that statistical retrodiction and the theory of approximate reversibility play in statistical mechanics, in particular, fluctuation relations and the second law of thermodynamics, for classical and quantum systems.

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Quantum Darwinism and classical objectivity: A collision model viewpoint

Understanding how a quantum system exchanges information or energy with its surroundings and how this can lead to a classically objective state is a ubiquitous problem. Quantum Darwinism, and the more stringent spectrum broadcast structures, provide a framework to understand how specific information is redundantly encoded across the environmental degrees of freedom resulting in classical objectivity. Various tools have been employed to study the phenomenon of quantum Darwinism and in this talk I will focus on one such technique, namely collision models, which are particularly well suited to the task. Their simple structure endows them with great flexibility to probe the limitations of the Darwinistic framework which we will explore in simple spin-systems.

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Quantum operations with indefinite direction of time

The standard operational framework of quantum theory is time-asymmetric. This asymmetry reflects the capabilities of ordinary agents, who are able to deterministically pre-select the states of quantum systems, but not to deterministically post-select the outcomes of quantum measurements. However, the fundamental dynamics of quantum particles is time-symmetric, and is compatible with a broader class of operations where pre-selections and post-selections are combined in general ways that do not presuppose a definite direction of time. In this talk I introduce a framework for quantum operations with indefinite time direction, providing an example, called the quantum time flip, where an unknown, time-symmetric process is accessed in a coherent superposition of two alternative time directions. In certain information-theoretic tasks, a hypothetical agent with access to the quantum flip can in principle outperform all agents who operate in a definite time direction.

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No purification ontology, no quantum paradoxes

It is almost universally believed that in quantum theory the two following statements hold: 1) all transformations are achieved by a unitary interaction followed by a von Neumann measurement; 2) all mixed states are marginals of pure entangled states. I name this doctrine the dogma of purification ontology. The source of the dogma is the original von Neumann axiomatisation of the theory, which largely relies on the Schrödinger equation as a postulate, which holds in a nonrelativistic context, and whose operator version holds only in free quantum field theory, but no longer in the interacting theory. In the present paper I prove that both ontologies of unitarity and state purity are unfalsifiable, even in principle, and therefore axiomatically spurious. I propose instead a minimal four-postulate axiomatisation: 1) associate a Hilbert space $\mathcal{H}_A$ to each system A; 2) compose two systems by the tensor product rule $\mathcal{H}_{AB} = \mathcal{H}_A \otimes \mathcal{H}_B$; 3) associate a transformation from system A to B to a quantum operation, i.e. to a completely positive trace-non-increasing map between the trace-class operators of A and B; 4) (Born rule) evaluate all joint probabilities through that of a special type of quantum operation: the state preparation. I then conclude that quantum paradoxes — such as the Schrödinger-cat's, and, most relevantly, the information paradox — are originated only by the dogma of purification ontology, and they are no longer paradoxes of the theory in the minimal formulation. For the same reason, most interpretations of the theory (e.g. many-world, relational, Darwinism, transactional, von Neumann-Wigner, time-symmetric, ...) interpret the same dogma, not the strict theory stripped of the spurious postulates.

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Dissipative Quantum Chaos in Floquet Systems

Dissipative Quantum Chaos is an emerging theory with the agenda to relate open quantum and classical dissipative systems and eventually provide us with a tool to determine whether the evolution of an open system is "chaotic" or "regular". Spectral properties of generators of quantum Markovian evolution are important in this respect. So far the emphasis was put on generators of the Gorini-Kossakowski-Sudarshan−Lindblad (GKS-L) form. Universal features were fund and some new concept, like Complex Spacing Ration, were developed by using the GKS-L framework. However, stationary GKS-L generators do not provide a straightforward way to semiclassical chaotic regime; therefore it is hard to relate open quantum and dissipative classical system with chaotic dynamics. In this talk, I address another type of generator, the so-called Redfield generators, which emerge in the Floquet-Markov theory and allows for a semiclassical transition. I use a driven Duffing oscillator as a model to illustrate spectral properties of Redfield generators.

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Discrete phase space techniques in quantum spin chains

Phase space techniques provide an alternative way to do quantum physics bringing new insights and simplicity in some cases. The talk covers some of the advances in relating these techniques to the study of many-body systems which can be considered as toy models to the study of more general relations to quantum correlations.

The Wigner function formalism from quantum optics, is applied via Wootters' discrete Wigner function, to detect quantum phase transitions in critical spin systems. A general formula relating the phase space techniques and the thermodynamical quantities of spin models, is derived then applied to single, bipartite and multipartite systems governed by the XY and the XXZ models. The approach allows to introduce a novel way to represent, detect, and distinguish first-, second- and infinite-order quantum phase transitions.

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Quantum Markov Semigroups on a One-Mode Fock Space: Irreducibility and Normal Invariant States

We consider the most general Gaussian quantum Markov semigroup on a one-mode Fock space, discuss its construction from the generalized GKSL representation of the generator. We prove the known explicit formula on Weyl operators, characterize irreducibility and its equivalence to a Hormander type condition on commutators and establish necessary and sufficient conditions for existence and uniqueness of normal invariant states.

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Taking the temperature of a pure quantum state

Co-authors: Mark T. Mitchison, Archak Purkayastha, Marlon Brenes, Alessandro Silva

Temperature is a deceptively simple concept that still raises deep questions at the forefront of quantum physics research. The observation of thermalisation in completely isolated quantum systems, such as cold-atom quantum simulators, implies that a temperature can be assigned even to individual, pure quantum states. Here, we propose a scheme to measure the temperature of such pure states through quantum interference. Our proposal involves interferometry of an auxiliary qubit probe, which is prepared in a superposition state and subsequently undergoes decoherence due to weak coupling with a closed, thermalised many-body system. Using only a few basic assumptions about chaotic quantum systems — namely, the eigenstate thermalisation hypothesis and the emergence of hydrodynamics at long times — we show that the qubit undergoes pure exponential decoherence at a rate that depends on the temperature of its surroundings. We verify our predictions by numerical experiments on a quantum spin chain that thermalises after absorbing energy from a periodic drive. Our work provides a general method to measure the temperature of isolated, strongly interacting systems under minimal assumptions.

arXiv:2103.16601 [quant-ph]

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Free versus Bound Entanglement: Machine learning tackling a NP-hard problem

Entanglement detection in high dimensional systems is a NP-hard problem. In particular, if the PPT criterion fails one cannot be sure that the state is not bound entangled. The first question we want to answer is if those states are rare? Typically bound entangled states are constructed by designing — via human intuition — dedicated entanglement witnesses. The problem is that a successful witness is typically not successful for another bound entangled state. Machine learning (ML) algorithms are designed to handle huge data sets and to find previously unknown correlations in the data. We consider a large set of magically symmetric states, convex combinations of Bell states which form a simplex. For those states we apply human designed entanglement witnesses that are revealing interesting families of states, however, those are not finding many bound entangled states. Based on a new result, namely that there are upper and lower bounds to entanglement witnesses [2] and exploiting the magical symmetry, we find a large volume of bound entangled states (more than separable states) [1]. Interestingly, ML algorithms reveal that this set of bound entangled states has a strong substructure that is very different to the free or separable states. This opens a novel road to find and characterize bound entanglement towards solving the long-standing problem of what the existence of bound entanglement is implying.

In the second part of the talk we show that entanglement witnesses based on unextendible Mutually Unbiased Bases (MUBs) are more powerful in detection entanglement than extendible MUBs and exhibit a strong dependence on the dimensions [3], revealing for the first time the usefulness of unextendible MUBs in quantum information theory.

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No-signalling assamblages beyond quantum mechanics: when quantum theory can generate extremal points in a post-quantum framework

It is well known that in the language of no-signaling boxes — consistent families of probabilites representing measurement correlations — the following three sets: local deterministic, quantum and no-signalling constitute the increasing sequence with strict inclusions (see [1]). Moreover the outer set of no-signalling boxes has no nontrivial (i.e not local deterministic) extremal points that are generated by measurement on quantum states [2]. This fact significantly complicates all quantum information security protocols potentially robust against attacks of more powerful, post-quantum adversaries (see [3]).

In the case of no-signalling assamblages which attracted attention recently, the strict inclusion of the three analogous sets is also true execept bipartite case [4]. However, the issue of extremality, potentially vital to information security, has not been studied yet.

Here we present results that fill gaps in the above picture. First, it turns out that even in the sequential measurement scenario there is no chance for nontrivial quantumly generated extremal point in the set of no-signalling boxes. Second, somewhat surprisingly, such a no-go theorem turns out to no longer hold for no-signalling assamblages [5].

This is for the first time when quantum mechanics is observed to be powerful enough to produce points that are extremal in some post-quantum framework. The new concept of the inflexibility of assamblages with pure quantum elements plays here an important role.

We also study the boundary of the no-signalling assamblages [6]. In analogy to quantum entanglement theory we define and study the edge of the set of assamblages. We found that here quantum mechanics can produce edge assamblages via measurements on at most rank-two 3-qubit states as opposed to rank five for the edge of the 3-qubit quantum entanglement set.

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Memory effects and the efficiency of bio-molecular switches

Co-authors: Giovanni Spaventa, Martin B. Plenio

Quantum resource theory formulations of thermodynamics offer a versatile tool for the study of fundamental limitations to the efficiency of physical processes, independently of the microscopic details governing their dynamics. Despite the ubiquitous presence of non-Markovian dynamics in open quantum systems at the nanoscale, rigorous proofs of their beneficial effects on the efficiency of quantum dynamical processes at the bio-molecular level have not been reported yet. Here we combine the resource theory of athermality with concepts from the theory of divisibility classes for quantum channels, to prove that memory effects can increase the efficiency of photoisomerization to levels that are not achievable under a purely Markovian (i.e. memoryless) evolution. This provides rigorous evidence that memory effects can be a useful resource in biological quantum dynamics, and, more generally, quantum thermodynamics at the nanoscale.

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Quasi-inversion of quantum channels

Given a quantum channel E, we introduce the concept of its quasi-inverse as a completely positive trace-preserving map E^{qi} which when composed with E increases its average input-output fidelity in an optimal way. The channel E^{qi} comes as close as possible to the inverse of a quantum channel. We give a complete solution for qubit channels and provide quite a few illustrative examples in higher dimensions.

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Universal constraint for relaxation rates for quantum dynamical semigroup: Physical manifestation of completely positive condition

We discuss general properties of relaxation rates for any completely positive dynamical semigroup. We find an interesting constraint for relaxation rates which universally holds in fairly large and physically interesting classes, e.g., weak coupling regime and entropy non-decreasing evolutions, and conjecture that this is universally hold for any quantum dynamical semigroups. Due to this universality, our constraint reflects the physical manifestation of completely positive condition.

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Storage capacity and learning capability of quantum neural networks

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We study the storage capacity of quantum neural networks (QNNs) described as completely positive trace preserving (CPTP) maps, which act on an N-dimensional Hilbert space. We demonstrate that QNNs can store up to N linearly independent pure states and provide the structure of the corresponding maps. While the storage capacity of a classical Hopfield network scales linearly with the number of neurons, we show that QNNs can store an exponential number of linearly independent states. We estimate, employing the, so called, Gardner program, the relative volume of CPTP maps with M stationary states. The volume decreases exponentially with M and shrinks to zero for $M \geq N + 1$. We generalize our results to QNNs storing mixed states as well as input-output relations for feed-forward QNNs. Our approach opens the path to relate storage properties of QNNs to the quantum properties of the input-output states. This paper is dedicated to the memory of Peter Wittek.

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Recovering entanglement through spatial deformation of identical particle wave functions

We consider two initially separated and entangled identical qubits subject to two independent noise channels. Three typical models are studied: amplitude damping, phase damping and depolarizing channels. After a given interaction time, a procedure is applied which first deforms the spatial wave functions of the qubits to make them overlap and then performs spatially localized operations and classical communication (sLOCC). We find that this procedure allows for recovering quantum correlations spoiled by the environment. A general behavior occurs: the higher the spatial indistinguishability achieved via deformation, the larger the amount of recovered entanglement.

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Diffusive limit of non-Markovian quantum jumps

We solve two long-standing problems for stochastic descriptions of open quantum system dynamics. First, we find the classical stochastic processes corresponding to non-Markovian quantum state diffusion and non-Markovian quantum jumps in projective Hilbert space. Second, we show that the diffusive limit of non-Markovian quantum jumps can be taken on the projective Hilbert space in such a way that it coincides with non-Markovian quantum state diffusion. However, the very same limit taken on the Hilbert space leads to a completely new diffusive unraveling, which we call non-Markovian quantum diffusion. Further, we expand the applicability of non-Markovian quantum jumps and non-Markovian quantum diffusion by using a kernel smoothing technique allowing a significant simplification in their use. Lastly, we demonstrate the applicability of our results by studying a driven dissipative two level atom in a non-Markovian regime using all of the three methods.

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Learning to measure: A new adaptive approach to extract information in quantum algorithms for near-term quantum computers

Just like their classical counterparts, quantum algorithms require a set of inputs, provided for example as real numbers, and a list of operations to be performed on some reference initial state. Unlike classical computers, however, information is stored in a quantum processor in the form of a wavefunction, thus requiring special procedures to read out the final results. In fact, it is in general neither possible nor convenient to fully reconstruct this quantum state, so that useful insights must be extracted by performing specific observations.

Unfortunately, the number of measurements required for many popular applications is known to grow unsustainably large with the size of the system, even when only partial information is needed. This is for example the case for the so-called Variational Quantum Eigensolver, which is based on the reconstruction of average energies. Here we propose a scheme to tackle this problem.

We employ a generalised class of quantum measurements that can be iteratively adapted to minimize the number of times the target quantum state should be prepared and observed. As the algorithm proceeds, it reuses previous measurement outcomes to adjust its own settings and increase the accuracy of subsequent runs. We make the most out of every sample by combining all data produced while fine-tuning the measurement into a single, highly accurate estimate of the energy, thus decreasing the expected runtime by several orders of magnitude. Furthermore, all the measurement data contain complete information about the state: once collected, they can be reused again and again to calculate other properties of the system without additional costs.

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Groupoids, channels, and probabilities

Scwhinger's approach to quantum mechanics has been described in terms of groupoids [2]. While the mathematical definition of groupoid in terms of small categories may be considered rather far-fetched, a simple example of groupoid is given by any term-diagram of energy levels and transitions available in any text-book on spectroscopy. In this talk we will give a pedagogical description of a concrete representation of groupoids for a finite-level quantum system. We will consider states and channels for bipartite systems from the perspective of quantum conditional probability. We shall also briefly consider quantum tomography from the view-point of groupoids.

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On the relation between time local and non-local master equations

We analyse an open quantum system dynamics corresponding to commutative, diagonalizable dynamical maps in the damping basis representation. An explicit connection between the local and non-local generators is given. What is more, our approach gives some insights into the occurence of different dephasing terms in both equations. The Redfield-like approximation is investigated, with the focus on the preservation or occurrence of divisibility in the sense of positive or completely positive maps under this approximation.

Nina Megier, Andrea Smirne, Bassano Vacchini, New J. Phys. **22** 083011 (2020).

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Quantum capacity of bosonic dephasing channel

Most of the analysis on communication rate through quantum channels is restricted to the cases of Gaussian channels. That is while there is an increasing pressure to go beyond the Gaussian channels paradigm for many essential tasks in quantum information. Here we focus on a continuous-variable dephasing channel, which is a notable example of a non-Gaussian quantum channel. By proper use of channel properties, we show that the optimal input state is diagonal in the Fock basis with a distribution that is a discrete version of a Gaussian distribution.

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Markovian approximation for the dynamics of correlated initial system-reservoir states

We consider the typical open system setup, where a finite system S interacts with a reservoir R modelled by a field of thermal oscillators. The reservoir correlation function is assumed to decay polynomially in time. In contrast to the typical setup, we draw the initial states from a large class in which S and R can be correlated. We show that the reduced dynamics of S is approximated as follows: Take the initially correlated, full SR state and reduce it to the S alone (trace out R), then apply a Markovian semigroup (acting on S alone) to that reduced state. The difference between the true reduced dynamics and its Markovian approximation is small in the SR coupling constant, for all times (no weak coupling scaling necessary). Under generic conditions, the generator of the approximating Markovian semigroup is the usual Davies generator, which is of the Gorini-Kossakowski-Lindblad-Sudarshan form and generates a CPTP dynamical semigroup. Our approach is based on recent advances in the resonance theory of open system dynamics and is mathematically rigorous.

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Markovianization with approximate unitary designs

Memoryless processes are ubiquitous in nature, in contrast with the mathematics of open systems theory, which states that non-Markovian processes should be the norm. This discrepancy is usually addressed by subjectively making the environment forgetful. Here we prove that there are physical non-Markovian processes that with high probability look highly Markovian for all orders of correlations; we call this phenomenon *Markovianization*. Formally, we show that when a quantum process has dynamics given by an approximate unitary design, a large deviation bound on the size of non-Markovian memory is implied. We exemplify our result employing an efficient construction of an approximate unitary circuit design using only two-qubit interactions, showing how seemingly simple systems can speedily become forgetful. Conversely, since the process is closed, it should be possible to detect the underlying non-Markovian effects. However, for these processes, observing non-Markovian signatures would require highly entangling resources and hence be a difficult task.

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Open Quantum Random Walks and Quantum Markov chains on Trees

This talk is devoted to Quantum Markov Chains (QMC) associated with Open Quantum Random Walks (OQRW) on trees. We present a transition operator of QMC associated by OQRW and our investigation leads to the detection of the phase transition phenomena within the proposed scheme.

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Quantum correlations in PT-symmetric systems

We study the dynamics of correlations in a setup to observe PT-symmetric physics: a pair of coupled oscillators, subject to gain and losses. Starting from a coherent state, quantum correlations (QC) are created, despite the system being driven only incoherently, and can survive indefinitely. Both total and QCs exhibit different scalings of their long-time behavior in the PT-broken/unbroken phase and at the exceptional point (EP). In particular, PT symmetry breaking is accompanied by non-zero stationary Qcs which can explained in terms of entropy balance. The EP emerges as the most classical configuration, as classical correlations diverge while QCs vanish.

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Bound states of artificial atoms in open and closed waveguides

An excited atom in free space decays towards its ground state through spontaneous emission. Boundary conditions and artificial dimensional reduction drastically modify this picture, enhancing or inhibiting decay, and displaying a plethora of interesting interference effects.

We consider N artificial atoms, approximated as two-level quantum emitters, coupled to a linear guided mode, in a quasi-one-dimensional configuration. We focus on the single- and double-excitation sectors, and explore the relaxation towards bound states for resonant values of the interatomic distance, the generation of entanglement, and the phenomenon of correlated emission.

We also study closed waveguides, in which photon wavenumbers and frequencies are discretized, and characterize the stable states in which one excitation is steadily shared between the field and one or two emitters.

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Informational steady-states and conditional entropy production in continuously monitored systems

I will put forth a unifying formalism for the description of the thermodynamics of continuously monitored systems, where measurements are only performed on the environment connected to a system. I will show, in particular, that the conditional and unconditional entropy production, which quantify the degree of irreversibility of the open system's dynamics, are related to each other by the Holevo quantity. This, in turn, can be further split into an information gain rate and loss rate, which provide conditions for the existence of informational steady-states, i.e. stationary states of a conditional dynamics that are maintained owing to the unbroken acquisition of information. I will illustrate the applicability of our framework through several examples, including the modelling of a recent experiment in the field of cavity optomechanics.

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Controllability of infinite dimensional quantum systems based on Quantum Graphs

The development of quantum information processing and quantum computation goes hand in hand with the ability of addressing and manipulating quantum systems. Quantum Control Theory has provided a successful framework, both theoretical and experimental, to design and develop the control of such systems. In particular, for finite dimensional quantum systems or finite dimensional approximations to them. The theory for infinite dimensional systems is much less developed.

In this talk I propose a scheme of infinite dimensional quantum control on quantum graphs based on interacting with the system by changing the self-adjoint boundary conditions. I will show the existence of solutions of the time-dependent Schrödinger equation, the stability of the solutions and the (approximate) controllability of the state of a quantum system by modifying the boundary conditions on generic quantum graphs.

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Open quantum systems on NISQ computers

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The numerical solution of Markovian master equations can be approached through the unravelling into a corresponding stochastic Schroedinger equation. Here we describe how to implement the simulation of such a stochastic Schroedinger equation on a noisy Intermediate-scale quantum computer. As a proof on concept we show how to simulate the unravelling of various single-qubit and two-qubit master equations on IBMQ hardware.

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Correlation-Picture Approach to Open-Quantum-System Dynamics

We introduce a dynamical picture, referred to as correlation picture, which connects a correlated bipartite state to its uncorrelated counterpart. This picture allows us to derive an exact dynamical equation for a general open-system dynamics with system-environment correlations included. This exact dynamics is in the form of a Lindblad-like equation even in the presence of initial system-environment correlations. For explicit calculations, we also develop a weak-correlation expansion that allows us to introduce systematic perturbative approximations. This expansion provides approximate master equations that can feature advantages over existing weak-coupling techniques. As a special case, we derive a Markovian master equation, which is different from existing approaches. We compare our equations with corresponding standard weak-coupling equations using two examples, for which our correlation-picture formalism is more accurate or as accurate as the weak-coupling equations.

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Strong coupling thermodynamics of open quantum systems

I will suggest a thermodynamic framework for open quantum systems in contact with a thermal reservoir. In this approach, the first and second laws are obtained for arbitrary system-reservoir coupling strengths, and including both factorized and correlated initial conditions. This is achieved by adapting the thermodynamic properties to the generally strong coupling regime, approaching the ones defined for equilibrium, and their standard weak-coupling counterparts as appropriate limits. Moreover, they can be inferred from measurements involving only system observables, so no controlled reservoirs are required. Finally, a thermodynamic signature of non-Markovianity will be presented in the form of a positive entropy production rate.

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Copositive maps as entanglement witnesses

Co-authors: C. Marconi, A. Aloy, J. Tura

We demonstrate that the characterization of entanglement in symmetric bipartite states in arbitrary dimensions, admits a dual representation in terms of copositive matrices and associated linear maps. Of particular interest are exceptional copositive matrices which do not admit a decomposition as the sum of a positive semidefinite matrix (PSD) and a symmetric, entry-wise non-negative matrix (NN) and lead to nondecomposable entanglement witnesses. We illustrate our results by constructing families of generic symmetric bound entangled states whose detection and certification is normally NP-hard, and disclose the generic structure of symmetric bipartite states.

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Exploring the Limits of Open Quantum Dynamics: Motivation, Results from Toy Models to Applications

Co-authors: Frederik vom Ende and Gunther Dirr

Which quantum states can be reached by coherently controlling n-level quantum systems coupled to a thermal bath in a switchable Markovian way? We address reachable sets of coherently controllable open quantum systems with switchable coupling to a thermal bath of temperature T. — The core problem reduces to a toy model of studying points in the standard simplex allowing for two types of controls: (i) permutations within the simplex, (ii) contractions by a dissipative semigroup. By illustration, we put the problem into context and show how toy-model solutions pertain to the reachable set of the original controlled Markovian quantum system. Beyond the case $T = 0$ (amplitude damping) we present results for $0 < T < \infty$ using methods of d-majorisation.

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Rate-operator quantum jumps: continuous-measurement interpretation and non-Markovian dynamics

Stochastic methods with quantum jumps are routinely used to describe open quantum system dynamics, both for the advantage they provide from a computational point of view, and for their insight into fundamental topics, such as the role of measurements in quantum mechanics and the description of non-Markovian memory effects. In this talk, I will present a recently introduced quantum-jump approach, which is based on the definition of a non-linear rate operator and hence named rate-operator quantum jumps (ROQJ). I will first show that ROQJ is associated with a systematic continuous-measurement interpretation for a wide class of dynamics, including a set of master equations with negative decay rates, where the standard Monte Carlo wave function (MCWF) approach to quantum jumps does not apply. I will then discuss how ROQJ can be extended to deal with general non-Markovian evolutions, going beyond the current non-Markovian generalizations of MCWF, and how it helps clarify the different types of memory effects that arise within the context of quantum jumps.

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Dynamical phase transition in dissipative quantum dynamics

Phase transitions in equilibrium systems are prime examples where nonanalytical behaviour of physical quantities upon paramter change occurs. Dynamical phase transitions (DPT) refer to non-equilibrium situations, where certain observables display nonsmooth dynamics under real-time evolution. We here report the discovery of a DPT in dissipative quantum dynamics [1]. We find that a famous model from quantum optics, the damped and driven Dicke model, generically displays DPTs in the presence of dissipation. By employing an expansion of the time evolved quantum state for large system size, we are able to compute the relevant observables in an exact way and explain the origin of the nonanalyticities. Relations to the large deviation theory of a classical stochastic process are shown. This insight allows us to propose a scheme for measurement of the DPT in a cavity-QED setup, which crucially exploits correlations between the system and its environment.

[1] Valentin Link and Walter T. Strunz, Phys. Rev. Lett. **125**, 143602 (2020).

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Non-Markovianity and information backflow in terms of entropic quantities

We point out that the approach to quantum non-Markovianity focusing on information backflow between system and environment can be naturally extended to consider general divergences. including in particular a regularized version of relative entropy, termed telescopic relative entropy. We show that in this framework distinguishability revivals are upper bounded and conditioned by the formation of correlations and changes in the environment. In this framework it appears in particular that the square root of the Jensen-Shannon divergence is a very natural quantifier of information backflow. We illustrate our findings by means of examples, comparing with the trace distance approach.

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There is only one time

Co-authors: Caterina Foti, Alessandro Coppo, Giulio Barni, Alessandro Cuccoli

We draw a picture of physical systems that allows us to recognize what “time” is by requiring consistency with the way that time enters the fundamental laws of Physics. Elements of the picture are two non-interacting and yet entangled quantum systems, one of which acting as a clock. The setting is based on the Page and Wootters mechanism, with tools from large-N quantum approaches. Starting from an overall quantum description, we derive not only the Schrödinger equation but also, when in an entirely classical picture, the Hamilton equations of motion. This work shows that there is not a “quantum time”, possibly opposed to a “classical” one; there is only one time, and it is a manifestation of entanglement.

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On complexities for quantum compound systems

In order to discuss the efficiency of information transmission of the quantum communication processes consistently, we consider the entropy type functional and the mutual entropy type functional with respect to the initial state and the quantum communication channel. In this study, the mutual entropy type measures are constructed by the compound state between the initial and final systems. In this paper, we modify the compound state and examine the entropy functional and the mutual entropy functional defined by the modified compound states by means of the initial state and the completely positive channel to study the efficiency of information transmission of the quantum communication processes.

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Quantum Scrambling of Observable Algebras

In this talk I'll describe an algebraic/geometrical notion of quantum scrambling for generalized quantum subsystems described by a $*$-closed subalgebra of operators evolving through a unitary channel. This approach comprises and vastly extends the notions of operator entanglement and of coherence generating power. Typicality results as well as dynamical fluctuations bounds can be established for quantum chaotic systems.

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Probabilistic storing of quantum dynamics

The goal of quantum learning is to store the quantum dynamics in quantum memory and retrieve its action when needed. In this talk I will report on general limitations of probabilistic quantum learning of general unitary gates, and analyze the noise-robustness of the optimal learning protocol for the case of phase gates. The connections to programmable quantum processors and port-based teleportation schemes will be discussed.