Q 57: Open Quantum Systems III

Time: Thursday 14:30–16:30 Location: P 4

Q 57.1 Thu 14:30 P 4

Non-unitarity maximizing unraveling of open quantum dynamics — •Ruben Daraban, Fabrizio Salas-Ramirez, and Johannes Schachenmayer — University of Strasbourg

The dynamics of many-body quantum states in open systems is commonly numerically simulated by unraveling the density matrix into pure-state trajectories. In this work, we introduce a new unraveling strategy that can adaptively minimize the averaged entanglement in the trajectory states. This enables a more efficient classical representation of trajectories using matrix product decompositions. Our new approach is denoted non-unitarity maximizing unraveling (NUMU). It relies on the idea that adaptively maximizing the averaged non-unitarity of a set of Kraus operators leads to a more efficient trajectory entanglement destruction. Compared to other adaptive entanglement lowering algorithms, NUMU is computationally inexpensive. We demonstrate its utility in large-scale simulations with random quantum circuits. NUMU lowers runtimes in practical calculations, and it also provides new insight on the question of classical simulability of quantum dynamics. We show that for the quantum circuits considered here, unraveling methods are much less efficient than full matrix product density operator simulations, hinting to a still large potential for finding more advanced adaptive unraveling schemes.

Q 57.2 Thu 14:45 P 4

Deterministic Quantum Jump (DQJ) Method for Weakly Dissipative Systems — •Marcus Meschede[1] and Ludwig Mathey[1,2] — [1]Center for Optical Quantum Technologies and Institute for Quantum Physics, University of Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

Simulating large open quantum systems is computationally expensive due to the complexity scaling of the density matrix formalism. Instead of time evolving the total density matrix, Quantum jump methods approximate the evolution through a statistical ensemble of quantum jump trajectories. In this work, we propose the Deterministic Quantum Jump (DQJ) method for the weak dissipation limit of the Lindblad master equation. In DQJ, quantum jumps are deterministically placed on a suitable jump time grid. For time evolutions in which the probability of trajectories with few jumps dominate higher order jump trajectories N, we show that the infidelity of the DQJ method with the true evolution can scale with $\propto 1/N^4$ in the number of trajectories. This drastically outperforms the Standard Quantum jump (SQJ) method, scaling with $\propto 1/N$. We demonstrate the improved scaling on the evolution of a system of coupled qubits as well as on the the spectrum of a Kerr-anharmonic oscillator. Generally, our DQJ method is suitable to all systems in which quantities are sensitive to weak coupling to the environment. In particular, it is native to the field of quantum computing, e.g. cQED setups, in which the weak coupling to the environment is crucial in evaluating quantum protocols.

Q 57.3 Thu 15:00 P 4

Stable Quantum Trajectories for Pseudo-Lindblad Equations — •Lorenz Wanckel and André Eckardt — Technical University of Berlin, Institute for Physics and Astronomy

In open quantum systems beyond the ultraweak coupling regime, master equations such as the Redfield equation, which are not of Lindblad but of pseudo-Lindblad form, are often used. This prevents the application of the standard Monte Carlo wave-function unraveling introduced by Dalibard et al. The Pseudo-Lindblad Quantum Trajectory (PLQT) approach, introduced by Becker et al., provides an unraveling of pseudo-Lindblad equations without the need to enlarge the Hilbert space, but it exhibits inherent long-time instabilities due to exponentially growing fluctuations. We present a stabilized PLQT algorithm that suppresses these fluctuations, thereby enabling reliable simulations up to and including the steady state.

Q 57.4 Thu 15:15 P 4

Open quantum system dynamics with semi-group influence matrices — •Valentin Link[1], Hong-Hao Tu[2], and Walter Strunz[3] — [1]Institut für Physik und Astronomie, Technische Universität Berlin, 10623, Berlin, Germany — [2]Faculty of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, 80333 München, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062, Dresden, Germany

Approaching the long-time dynamics of non-Markovian open quantum systems presents a challenging task when the bath is strongly coupled. Recent proposals address this problem by representing temporal correlations encoded in the environmental influence matrix in terms of a compressed matrix product operator (MPO). I present a highly efficient algorithm to generate such an MPO form, utilizing infinite tensor-network methods. The resulting uniform MPO representation defines a dynamical semigroup in a reduced auxiliary space, allowing us to directly target long evolution times. I demonstrate the capabilities of this approach for computing dynamical quantities in spin-boson and single-impurity Anderson models.

[1] V. Link, H. H. Tu, W. T. Strunz, Phys. Rev. Lett. 132, 200403 (2024) [2] M. Sonner, V. Link, D. A. Abanin, Phys. Rev. Lett. 135, 170402 (2025)

Q 57.5 Thu 15:30 P 4

A witness of superluminal signalling in quantum theory and its modifications. — •Aritro Mukherjee — University of Duisburg-Essen

Linearity of the master equations in quantum theory and in many of its proposed modifications is often taken to guarantee the absence of superluminal signalling, thereby preserving causality. However, in many scenarios, master equations are not always available in a closed analytic form, limiting the applicability of this argument. To address this, we first introduce a general operational witness for detecting superluminal signalling which does not rely on explicit knowledge of a master equation and is easily assessed when analytical methods are not available. Furthermore, applying this witness reveals a surprising result: even linear master equations can permit superluminal signalling unless a specific locality condition is satsfied by the master equations. Hence we show that linearity of the corresponding master equations is not sufficient towards preserving causality. In contrast, the witness we propose provides a necessary and sufficient criterion for ruling out superluminal signalling in full generality. Ref: arXiv:2410.08844 / Phys. Rev. A 112, 062202 (2025)

Q 57.6 Thu 15:45 P 4

Perturbative and non-perturbative continuous similarity transformations for Lindbladians — •Lea Lenke and Kai Phillip Schmidt — FAU Erlangen-Nürnberg

We study the Lindbladian of the dissipative transverse field Ising chain by continuous similarity transformations (CSTs). The latter are the two flow equation methods pcst^{++} and directly evaluated enhanced perturbative continuous unitary transformations (deepCUTs) which both generate effective block-diagonal operators. The first method, pcst^{++}, is a generalization of the method of perturbative continuous unitary transformations (pCUTs) to non-Hermitian operators like the Lindbladian and multiple quasiparticle types. The second method, deepCUT, uses a perturbative truncation scheme to generate a non-perturbative expansion of the effective operator. We apply the same generator as in the definition of the pcst^{++} to generalize deepCUT to non-Hermitian operators. We apply both methods to the Lindbladian describing the dissipative transverse field Ising chain. In the subsequent treatment of the obtained effective Lindbladian, we take advantage of its block-diagonal structure and perform a linked-cluster expansion obtaining results that are valid in the thermodynamic limit.

Q 57.7 Thu 16:00 P 4

Recursive perturbation approach to time-convolutionless master equations: Explicit construction of generalized Lindblad generators for arbitrary open systems — •Alessandra Colla[1,2,3], Heinz Peter Breuer[3,4], and Giulio Gasbarri[5,6] — [1]Dipartimento di Fisica Aldo Pontremoli, Università degli Studi di Milano, Via Celoria 16, I-20133 Milan, ItalyDipartimento di Fisica *Aldo Pontremoli*, Università degli Studi di Milano, Via Celoria 16, I-20133 Milan, Italy — [2]INFN, Sezione di Milano, Via Celoria 16, I-20133 Milan, Italy — [3]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [4]EUCOR Centre for Quantum Science and Quantum Computing,University

of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [5]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen 57068, Germany — [6]Física Teòrica: Informació i Fenòmens Quàntics, Department de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain

We present a recursive perturbative expansion for the time-convolutionless (TCL) generator of an open quantum system that preserves a generalized Lindblad-like structure at every order, assuming only an initially uncorrelated system*environment state. The generator is cast in a canonical, minimal-dissipation form that uniquely splits coherent (Hamiltonian) and dissipative contributions

Q 57.8 Thu 16:15 P 4

Artificial discovery of lattice models for wave transport — •Jonas Landgraf[1,2], Clara Wanjura[1], Vittorio Peano[1], and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]University of Erlangen-Nuremberg

Wave transport devices, such as amplifiers, frequency converters, and nonreciprocal devices, are essential for modern communication, signal processing, and sensing applications. Of particular interest are traveling wave setups, which offer excellent gain and bandwidth properties. So far, the conceptual design of those devices has relied on human ingenuity. This makes it difficult and time-consuming to explore the full design space under a variety of constraints and target functionalities. In our work, we present a method that automates this challenge. By optimizing the discrete and continuous parameters of periodic coupled-mode lattices, our approach identifies the simplest lattices that achieve the target transport functionality, and we apply it to discover new schemes for directional amplifiers, isolators, and frequency demultiplexers. Leveraging automated symbolic regression tools, we find closed analytical expressions that facilitate the discovery of generalizable construction rules. Moreover, we utilize important conceptual connections between the device transport properties and non-Hermitian topology. The resulting structures can be implemented on a variety of platforms, including microwave, optical, and optomechanical systems. Our approach opens the door to extensions like the artificial discovery of lattice models with desired properties in higher dimensions or with nonlinear interactions.