QI 34: Quantum Control I

Time: Thursday 14:30–16:30 Location: HS II

QI 34.1 Thu 14:30 HS II

Controlling Many-Body Quantum Chaos — •Lukas Beringer[1], Mathias Steinhuber[1], Juan Diego Urbina[1], Klaus Richter[1], and Steven Tomsovic[1,2] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics and Astronomy, Washington State University, Pullman, WA USA

Controlling chaos is a well-established technique that leverages the exponential sensitivity of classical chaotic systems for efficient control. This concept has been generalized to single-particle quantum systems [1] and, more recently, extended to bosonic many-body quantum systems described by the Bose-Hubbard model [2]. In direct analogy to the classical paradigm, a localized quantum state can be transported along a specific trajectory to a desired target state. In the latter context, this approach reduces to time-dependent control of the chemical potentials, making it suitable for implementation in optical lattice experiments. Highlighted potential applications are rapid, customizable state preparation and stabilization of quantum many-body scars in one-, two-, and three-dimensional lattices. Recent progress includes potential applications to large time-crystal platforms and preparation protocols for entangled states, such as cat-like states.

[1] S. Tomsovic, J. D. Urbina, and Klaus Richter, Controlling Quantum Chaos: Optimal Coherent Targeting, PRL 130.2 (2023): 020201.

[2] L. Beringer, M. Steinhuber, J. D. Urbina, K. Richter, S. Tomsovic, Controlling many-body quantum chaos: Bose-Hubbard systems, New J. Phys (2024): 26 073002.

QI 34.2 Thu 14:45 HS II

Distance to unreachability and quantum speed limits — •Marco Wiedmann and Daniel Burgarth — Friedrich-Alexander Universität Erlangen-Nürnberg

Quantum speed limits provide a fundamental lower bound on how fast quantum systems can evolve towards a given target. This is particularly interesting for applications in quantum control, where decoherence limits the time available to the experimentalist. We present lower bounds on the time needed to implement any given unitary operation in a given control system. The bound crucially depends on the size of the minimal perturbation to the control system that renders the target operation unreachable. Further, we extend the result to the use case of analogue quantum simulation by bounding the minimal time needed to simulate a given Hamiltonian time evolution in the worst case.

QI 34.3 Thu 15:00 HS II

Classical surrogates of quantum control landscapes — •Martino Calzavara[1,2], Tommaso Calarco[1,2,3], and Felix Motzoi[1,2] — [1]Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Straße, 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Since the introduction of the GRAPE algorithm for efficiently computing fidelity gradients, piecewise-constant controls have become a widely adopted ansatz for studying Quantum Optimal Control problems. The time evolution for this class of time-dependent Hamiltonians can be represented as a Parametrized Quantum Circuit, allowing us to analyze the properties of the fidelity as a function of the control pulses - the so-called Quantum Control Landscape - by employing concepts and techniques borrowed from Quantum Machine Learning (QML) and Variational Quantum Algorithms (VQA). Among these techniques are classical surrogate models, which represent the output of a quantum circuit as a linear combination of non-linear feature maps, providing valuable insights into the representational power of QML models and the structure of VQA landscapes. In this work, we employ classical surrogate models as a theoretical tool to investigate the properties of Quantum Control Landscapes, and to learn approximate representations of such landscapes using supervised learning.

QI 34.4 Thu 15:15 HS II

Neural-network-based preparation of quantum state families: Theory and experiment — Hector Hutin[1], •Pavlo Bilous[2], Florian Marquardt[2,3], and Benjamin Huard[1] — [1]Ecole Normale Supérieure de Lyon, CNRS, Laboratoire de Physique, 69342 Lyon, France — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [3]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Fast preparation of quantum states is a crucial ingredient for scaling up quantum computing devices. Along with the established techniques like GRadient Ascent Pulse Engineering (GRAPE), the neural-network (NN) methods are being increasingly employed for this task. However, using a NN for preparation of a fixed single quantum state implies a very slow training from scratch once a different quantum state is required.

We present a way to teach a NN quantum state preparation for a continuous family of states instead of a single state. Once trained on a random selection from the family, the NN is able to predict control signals for *any* quantum state from the family. Building up on the original theoretical proposal from Ref. [1], we introduced further theoretical developments and demonstrated the method experimentally for Schrödinger cat states [2]. The method can be useful e.g. for implementation of parametrized quantum gates requiring fast switching between quantum states.

[1] F. Sauvage and F. Mintert, Phys. Rev. Lett. 129, 050507 (2022).

[2] H. Hutin, P. Bilous et. al. arxiv.org:2409.05557 (2024).

QI 34.5 Thu 15:30 HS II

Dissipative preparation of few-particle fractional Chern insulators — •Luis Calvin Steinfadt, Francesco Petiziol, and André Eckardt — TU Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, Berlin 10623, Germany

Fractional Chern insulators (FCIs) are lattice analogs of fractional quantum Hall systems, where the interplay of particle interactions and topological effects leads to the emergence of interesting many-body phenomena, such as long-range entanglement and anyonic excitations. These features make such systems of significant interest, especially due to their potential for quantum information technology. The purpose of investigating FCIs in a clean and controllable setting motivates efforts toward their realization in quantum simulations. Key difficulties in this context are implementing the relevant Hamiltonian through quantum simulation schemes and also driving the system toward the correlated FCI ground state. We explore the use of reservoir engineering, as can be realized in superconducting circuits, to stabilize the FCI ground state of the Harper-Hofstadter-Hubbard model. In particular, we consider realizations of the Hamiltonian based on Floquet engineering, as experimentally realized in quantum gas microscopes [1] and superconducting qubits [2]. It has been shown that these ingredients can be successfully combined to effectively prepare target Floquet states [3]. Here, they are applied to prepare small-scale bosonic Laughlin states.

[1] J. Léonard et al., Nature 619, 495-499 (2023)

[2] C. Wang et al., Science 384, 579-584 (2024)

[3] F. Petiziol, A. Eckardt, Phys. Rev. Lett. 129, 233601 (2022)

QI 34.6 Thu 15:45 HS II

Platonic dynamical decoupling for multi-spin systems — •Colin Read, Eduardo Serrano-Ensástiga, and John Martin — University of Liège, Liège, Belgium

In the NISQ era, where quantum information processing is hindered by the decoherence and dissipation of elementary quantum systems, developing new protocols to extend the lifetime of quantum states is of considerable practical and theoretical importance. A prominent method, called dynamical decoupling, uses a carefully designed sequence of pulses applied to a quantum system, such as a qudit, to suppress the coupling Hamiltonian between the system and its environment, thereby mitigating dissipation.

In this work, we design decoupling sequences composed solely of SU(2) operations and based on the tetrehedral, octahedral and icosahedral point groups, which we call Platonic sequences. We use a generalization of the Majorana representation for operators to develop a simple framework for establishing the decoupling properties of each sequence, whose potential application is demonstrated for many relevant quantum systems, such as spin ensembles and large atomic spins, and which are highly robust to both finite-duration pulses and systematic control errors.

QI 34.7 Thu 16:00 HS II

Robust composite Molmer-Sorensen gate — •Kaloyan Zlatanov, Svetoslav Ivanov, and Nikolay Vitanov — Center for Quantum Technologies, Sofia, Bulgaria

The Mølmer-Sørensen (MS) gate is a two-qubit rotational gate in ion traps that is highly valued due to its ability to preserve the motional state of the ions. However, its fidelity is obstructed by errors affecting the motion of the ions as well as the rotation of the qubits. In this work, we propose an amplitude-modulated composite MS gate which features fidelity which is robust to gate timing, detuning and coupling errors.

QI 34.8 Thu 16:15 HS II

The Sub-harmonic Driving Theory and Its Applications — •Longxiang Huang[1,2], Jacquelin Luneau[1,2], Stefan Filipp[1,2,3], Peter Rabl[1,2,3], and Klaus Liegener[1,2] — [1]Technical University of Munich, Department of Physics, Garching, Germany — [2]Walther-Meißner-Institut, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

Nonlinear processes have gained significant attention in physics. In parametrically driven pendulums, sub-harmonic oscillations have revealed steady-state solutions at integer multiples of the driving frequency. Conversely, anharmonic oscillators driven at fractions of frequency will oscillate, a phenomenon known as sub-harmonic driving. In this talk, we extend this concept into the quantum realm. Starting from a general quantum system driven by multiples of a singular tone, we employ Floquet theory and degenerate perturbation theory. By this, we obtain an effective Hamiltonian within a degenerate two-level subspace, demonstrating n-th order sub-harmonic oscillations. We test this framework on transmon qubits and predict resonant frequency shifts and Rabi rates, improving previous results relying on the rotating wave approximation (RWA). Additionally, our analysis is valid in regimes where RWA fails, allowing us to study, e.g., fluxonium qubits: higher-order contributions result in frequency shifts and Rabi rates that align closely with experimental results at large driving amplitudes. Furthermore, this framework can be applied to other systems, such as the two-photon Raman transition in trapped ions and Rydberg atoms and the three-photon excitation in quantum dots.