MON 2: Quantum Control

Time: Monday 14:15–16:15 Location: ZHG002

MON 2.1 Mon 14:15 ZHG002

Quantum control by fast driving — •Sandro Wimberger — Department of Mathematical, Physical and Computer Sciences, Parma University — INFN, Sezione Milano-Bicocca, Parma group

We present a scheme for the systematic design of quantum control protocols based on shortcuts to adiabaticity. To fight decoherence, the adiabatic dynamics is accelerated by introducing high-frequency modulations in the control Hamiltonian, which mimic a time-dependent counterdiabatic correction. We present several applications for the high-fidelity realization of quantum state transfers and quantum gates based on effective counterdiabatic driving, in platforms ranging from superconducting circuits to Rydberg atoms [1]. We briefly sketch as well related ideas to control many-body interactions [2] and evolution errors by compensating terms in the Hamiltonian [3].

[1] F. Petiziol, F. Mintert, S. Wimberger, EPL 145, 15001 (2024); [2] S. Dengis, S. Wimberger, P. Schlagheck, PRA 111, L031301 (2025); [3] M. Delvecchio, F. Petiziol, E. Arimondo, S. Wimberger, PRA 105, 042431 (2022)

MON 2.2 Mon 14:30 ZHG002

Model predictive quantum control: A modular strategy for improving efficiency of quantum control — Eya Guizani and •Julian Berberich — Institute for Systems Theory and Automatic Control, University of Stuttgart, Germany

Model predictive control (MPC) is one of the most successful modern control methods. It relies on repeatedly solving a finite-horizon optimal control problem and applying the beginning piece of the optimal input. In this contribution, we explore the application of MPC for closed quantum systems governed by finite-dimensional Hamiltonian dynamics. Multiple MPC schemes are proposed to address different problem formulations, allowing us to trade off computational complexity with performance while retaining systems-theoretic guarantees on stability and convergence. Numerical experiments benchmark the performance of these formulations against competing approaches. Our results demonstrate the flexibility of MPC and its ability to achieve high performance in quantum optimal control problems.

MON 2.3 Mon 14:45 ZHG002

Optimization of algorithm-specific resource states for trotterized quantum dynamics and universal quantum computation — •Thierry N. Kaldenbach[1,2], Isaac D. Smith[2], Hendrik Poulsen Nautrup[2], Matthias Heller[3,4], and Hans J. Briegel[2] — [1]Institute of Materials Research, German Aerospace Center (DLR), Cologne, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, Austria — [3]Fraunhofer Institute for Computer Graphics Research IGD, Darmstadt, Germany — [4]Interactive Graphics Systems Group, Technical University of Darmstadt, Germany

The direct compilation of algorithm-specific graph states in measurement-based quantum computation (MBQC) potentially leads to resource reductions in terms of circuit depth, entangling gates, and sometimes even the number of qubits. In this work, we extend previous studies on algorithm-tailored graph states to periodic sequences of Pauli rotations, which commonly appear in, e.g., trotterized quantum dynamics. We also use our approach to derive universal resource states from generating sets of Pauli unitaries, whose structure relates to the anticommutation pattern of the set. In addition, we implement a significantly enhanced annealing-based algorithm to find optimal resource states within local-Clifford MBQC. We demonstrate and compare both of our technique based on examples from quantum chemistry, binary optimization, and universal quantum computation. In particular, we showcase how graph states tailored for specific observables can lead to qubit reductions beyond the Z2 symmetries exploited in qubit tapering.

MON 2.4 Mon 15:00 ZHG002

Lower bounds for the Trotter error — •Alexander Hahn[1], Paul Hartung[2], Daniel Burgarth[2,1], Paolo Facchi[3,4], and Kazuya Yuasa[5] — [1]Center for Engineered Quantum Systems, Macquarie University, 2109 NSW, Australia — [2]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany — [3]Dipartimento di Fisica, Università di Bari, I-70126 Bari, Italy — [4]Istituto Nazionale di Fisica Nucleare, Sezione di Bari, I-70126 Bari, Italy — [5]Department of Physics, Waseda University, Tokyo 169-8555, Japan

In analog and digital simulations of practically relevant quantum systems, the target dynamics can only be implemented approximately. The Trotter product formula is the most common approximation scheme as it is a generic method which allows tuning accuracy. The Trotter simulation precision will always be inexact for noncommuting operators, but it is currently unknown what the minimum possible error is. This is an important quantity because upper bounds for the Trotter error are known to often be vast overestimates. Here we present explicit lower bounds on the error, in norm and on states, allowing to derive minimum resource requirements. Numerical comparison with the true error shows that our bounds offer accurate and tight estimates.

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MON 2.5 Mon 15:15 ZHG002

Riemannian quantum circuit optimization based on matrix product operators — •Isabel Nha Minh Le[1,2], Shuo Sun[1,2], and Christian B. Mendl[1,2,3] — [1]Technical University of Munich, School of Computation, Information and Technology, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Technical University of Munich, Institute for Advanced Study, 85748 Garching, Germany

We significantly enhance the simulation accuracy of initial Trotter circuits for Hamiltonian simulation of quantum systems by integrating first-order Riemannian optimization with tensor network methods. Unlike previous approaches, our method imposes no symmetry assumptions, such as translational invariance, on the quantum systems. This technique is scalable to large systems through the use of a matrix product operator representation of the reference time evolution propagator. Our optimization routine is applied to various spin chains and fermionic systems described by the transverse-field Ising Hamiltonian, the Heisenberg Hamiltonian, and the spinful Fermi-Hubbard Hamiltonian. In these cases, our approach achieves a relative error improvement of up to four orders of magnitude for systems of 50 qubits. Furthermore, we demonstrate the versatility of our method by applying it to molecular systems, specifically lithium hydride, achieving an error improvement of up to eight orders of magnitude. This proof of concept highlights the potential of our approach for broader applications in quantum simulations.

MON 2.6 Mon 15:30 ZHG002

Counterdiabatic driving for random gap Landau-Zener (LZ) transitions — •Georgios Theologou[1], Mikkel F. Andersen[2,3], and Sandro Wimberger[4,5] — [1]ITP, Universität Heidelberg — [2]Department of Physics, University of Otago — [3]Dodd-Walls Centre for Photonic and Quantum Technologies — [4]Department of Mathematical, Physical and Computer Sciences, Parma University — [5]INFN, Sezione Milano-Bicocca, Parma group

The LZ model describes a two-level quantum system governed by a time-dependent Hamiltonian which undergoes an avoided crossing. In the adiabatic limit, the transition probability $\mathcal{P}_{\rm LZ}$ vanishes. To enforce an adiabatic evolution at arbitrary speed, an auxiliary control field $H_{\rm CD} = f_{\rm CD}\boldsymbol{\sigma}$ can be reverse-engineered, such that the full Hamiltonian $H + H_{\rm CD}$ drives the states transitionlessly. In the LZ case, $f_{\rm CD}$ takes the form of a Lorentzian pulse centered at the crossing, and the matrix $\boldsymbol{\sigma}$ is determined by the orthogonality of $H_{\rm CD}$ with $H_{\rm LZ}$ and $\dot{H}_{\rm LZ}$. Our aim is to construct a single $H_{\rm GCD}$ that controls an ensemble of LZ-type Hamiltonians with a distribution of energy gaps. For a single realization, the evolution is not any more adiabatic nor the final transition probability is zero. $H_{\rm GCD}$ can be optimized to minimize the expectation value of a given cost function. We consider the effect of different sweeps and prefactors $f_{\rm CD}$. We found a systematic trade-off between instantaneous adiabaticity and the final transition probability. As an analytically solvable limit, we examine the LZ model in the presence of a $\delta(t)$ potential and the connection to the minimization of the corresponding non-adiabatic probablity $\mathcal{P}_{\rm LZD}$.

MON 2.7 Mon 15:45 ZHG002

Spectral Control of a Noisy Quantum Emitter with Opti-

cal Pulses — •Kilian Unterguggenberger[1], Alok Gokhale[1], Aleksei Tsarapkin[1,2], Wentao Zhang[2], Katja Höflich[1,2], Herbert Fotso[3], Tommaso Pregnolato[1,2], Laura Orphal-Kobin[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH), Berlin, Germany — [3]University at Buffalo SUNY, Buffalo, USA

Indistinguishability of single photons gives rise to quantum interference, making it an essential ingredient for quantum information processing. Optimizing single-photon sources for indistinguishability represents an ongoing technological challenge. Solid-state emitters for instance typically exhibit inhomogenous frequency broadening due to charge noise. Current mitigation strategies such as feedback loops or post-selection introduce a large experimental overhead or drastically reduce the usable photon rate. In this work, we demonstrate a conceptually simple and efficient all-optical spectral control protocol on a nitrogen vacancy center in diamond. We observe that periodic excitation by optical π-pulses during the excited state lifetime reduces the emitter linewidth almost to the lifetime limit. Half of the spectral weight can be shifted to a target frequency selected by the pulse carrier frequency. The protocol [Fotso et al., PRL 116, 033603 (2016)] was proposed for the universal two-level system, rendering our approach applicable to a wide range of atomic and solid-state single-photon sources. Our work establishes a promising new avenue towards scalable sources of indistinguishable single photons.

MON 2.8 Mon 16:00 ZHG002

Coherent Control of a Carbon-13 nuclear spin proximal to a Tin-Vacancy Center in Diamond — •Jeremias Resch[1], Ioannis Karapatzakis[1], Philipp Fuchs[2], Marcel Schrodin[1], Michael Kieschnick[3], Julia Heupel[4], Mohamed Elshorbagy[1], Luis Kussi[1], Christoph Sürgers[1], Cyril Popov[4], Jan Meijer[3], Christoph Becher[2], Wolfgang Wernsdorfer[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität des Saarlands — [3]Universität Leipzig — [4]Universität Kassel

Robust quantum networks require an interface between photons and long-lived spin degrees of freedom. Due to its strong spin-orbit splitting, the Tin-Vacancy center electron spin possesses long spin lifetimes and has been shown to be able to be coherently controlled with high fidelity. In order to store information longer than the communication time between two nodes, even more long-lived nuclear spin degrees need to be coherently addressed. For high fidelity control of both electron and nuclear spin, the use of microwave fields is required. Recent work has shown the manipulation using aluminum wire bonds and on-chip gold waveguides. Both methods suffer from Ohmic losses in the microwave line, restricting coherence through heat induction. To overcome this challenge, we fabricate a superconducting coplanar waveguide made from Niobium on a diamond membrane through all-optical lithography. Using this, we demonstrate initialization of a single carbon-13 spin by optical pumping, perform high fidelity coherent manipulation, randomized benchmarking, and achieve a coherence time up to 1.3s.