QSim Poster List

Session 1: Tuesday, August 5, 2025

[2] Zhi-Yuan Wei (University of Maryland), Tao Shi (Institute of Theoretical Physics, CAS), Ignacio Cirac (Max Planck Institute for Quantum Optics) and Eugene Demler (ETH Zurich).

Kondo impurity in an attractive Fermi-Hubbard bath: Equilibrium and dynamics.

Presenter: Zhi-Yuan Wei

Abstract: We investigate the equilibrium and dynamical properties of a Kondo impurity coupled to either 1D or 2D superconductors, modeled by the attractive Fermi-Hubbard model. For the ground state, we find the singlet-doublet phase transition and π-phase shifts of the SC order parameter. For dynamics, first, we consider spin dynamics following an abrupt connection of the polarized impurity to the 2D bath. We find rapid relaxation of impurity polarization and directional emission of a magnetization pulse, which becomes damped as it propagates into the bulk. Then, we analyze transport between two SC leads coupled through the impurity at finite bias voltage. We uncover four distinct regimes in the transient dynamics and transport properties: (I) the AC Josephson effect regime; (II) dynamical competition between charge-density-wave (CDW) and SC orders with transient Kondo correlations; (III) the coexistence of AC and DC currents facilitated by partial Kondo screening and dynamical stabilization of the SC order; (IV) DC Kondo transport regime modified by the SC order. Regime II exhibits a dynamical transition from SC to CDW order that locally restores the U(1) symmetry. We argue that our findings for regime IV provide a theoretical explanation for the experimentally observed anomalous enhancement of DC conductance and suppression of the AC Josephson current.

Keywords: Nonequilibrium dynamics, Fermi-Hubbard model, Magnetic quantum impurity, Superfluid/superconductivity

[5] Siddharth Chander (University of Illinois Urbana Champaign).

Comparative Analysis of Quantum Approximate Optimization Algorithms for Solving the Travelling Salesperson Problem.

Presenter: Siddharth Chander

Abstract: The Quantum Approximate Optimization Algorithm (QAOA) was developed to tackle combinatorial optimization problems, such as the Travelling Salesman Problem (TSP), by approximating solutions through quantum mechanics. QAOA utilizes a unitary transformation to prepare a quantum state that encodes a potential solution, with the parameters of the unitary optimized by a classical optimizer. This study evaluates QAOA's performance on the NP-hard TSP, comparing the standard version of the algorithm from Farhi and an enhancement, Warm-Start QAOA, to a classical solver. The TSP seeks the shortest possible route that visits a set of cities, a problem that is amenable to quantum formulation using platforms like Qiskit. Warm-Start QAOA initializes the algorithm's parameters based on a solution to a relaxed version of the problem, offering potential improvements in optimization efficiency. By comparing these quantum algorithms to a classical solver, we provide a comprehensive assessment of their performance across key metrics, including route quality, execution time, and scalability. Through this analysis, we highlight the relative strengths and weaknesses of QAOA and its warm-start variant for solving the TSP, alongside the classical approach, offering insights into their potential for route optimization and practical applications in real-world settings. We conclude that, while the classical solver significantly outperforms QAOA and warm-start QAOA at smaller-scale problem cases, warm-Start QAOA has the potential to yield advantages at a larger scale when run on NISQ-era noisy hardware.

Keywords: Quantum Approximate Optimization Algorithm (QAOA), Warm-Start QAOA, Travelling Salesman Problem (TSP), Quantum Computing, Noisy Intermediate-Scale Quantum (NISQ), Hybrid Quantum-Classical Optimization, IBM Qiskit, Route Optimization

[6] Jaka Vodeb (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich), Jean-Yves Desaules (Institute of Science and Technology Austria (ISTA)), Andrew Hallam (University of Leeds), Andrea Rava (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich; RWTH Aachen University), Gregor Humar (Department of Complex Matter, Jožef Stefan Institute; Department of Physics, University of Ljubljana), Dennis Wilsch (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich), Fengping Jin (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich), Madita Willsch (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich;), Kristel Michielsen (Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich) and Zlatko Papic (University of Leeds).

Stirring the false vacuum via interacting quantized bubbles on a 5,564-qubit quantum annealer.

Presenter: Gregor Humar

Abstract: False vacuum decay—the transition from a metastable quantum state to a true vacuum state—plays an important role in quantum feld theory and non-equilibrium phenomena such as phase transitions and dynamical metastability. The non-perturbative nature of false vacuum decay and the limited experimental access to this process make it challenging to study, leaving several open questions regarding how true vacuum bubbles form, move and interact. Here we observe quantized bubble formation in real time, a key feature of false vacuum decay dynamics, using a quantum annealer with 5,564 superconducting fux qubits. We develop an efective model that captures both initial bubble creation and subsequent interactions, and remains accurate under dissipation. The annealer reveals coherent scaling laws in the driven many-body dynamics for more than 1,000 intrinsic qubit time units. This work provides a method for investigating false vacuum dynamics of large quantum systems in quantum annealers.

Keywords: quantum simulation, quantum many-body physics, false vacuum decay

[8] Abhishek Jamunkar (Centre for Quantum Technologies, National University of Singapore), Zilong Chen (Centre for Quantum Technologies, National University of Singapore), Tong-Yan Xia (Centre for Quantum Technologies, National University of Singapore), Vasu Dev (Centre for Quantum Technologies, National University of Singapore), Kai Xiang Lee (Centre for Quantum Technologies, National University of Singapore), Jinyu Zhou (Centre for Quantum Technologies, National University of Singapore), Vincent Mancois (Centre for Quantum Technologies, Nanyang Technological University), Jintao Yang (Centre for Quantum Technologies, National University of Singapore), Thanh Nguyen (Centre for Quantum Technologies, National University of Singapore), Ng Boon Long (Centre for Quantum Technologies, National University of Singapore), Kelvin Lim (Centre for Quantum Technologies, Nanyang Technological University), Zhengjiang Li (Centre for Quantum Technologies, Nanyang Technological University), Mujahid Aliyu (Centre for Quantum Technologies, National University of Singapore) and David Wilkowski (Centre for Quantum Technologies, Nanyang Technological University).

Toward Digital and Analogue Quantum Processors Using Neutral Atom Arrays.

Presenter: Abhishek Jamunkar

Abstract: We have started an ambitious project aiming to build digital and analogue quantum processor prototypes that should be delivered in 2029. During the period 2025-2027, six equivalent experimental machines will be mounted using neutral atoms tweezer array techniques. Our objective will be to have more than 200 atoms arranged in a defect-free lattice with state-of-the-art performances in term of lifetime, loading rate, robustness, and control of the phase and amplitude of the addressing lasers. After 2027, each experimental platform will be used to develop the prototypes in a parallel approach. We aim to achieve > 99.9% and > 99% single and two qubit gate fidelity, respectively. Error-correction codes should be implemented to reduce further the error rate.

Keywords: Ultracold gases, Nanophotonics, Quantum Sensing, Quantum simulations, Quantum Computer

[9] Isabel Nha Minh Le (Technical University of Munich), Shuo Sun (Technical University of Munich) and Christian B. Mendl (Technical University of Munich).

Riemannian quantum circuit optimization based on matrix product operators.

Presenter: Isabel Nha Minh Le

Abstract: 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.

Keywords: quantum circuits, quantum circuit compression, quantum circuit optimization, Hamiltonian simulation, tensor networks, quantum-classical hybrid method, differential geometry

[12] Jaka Vodeb (Jozef Stefan Institute), Dennis Willsch (Julich Research Centre), Kristel Michielsen (Julich Research Centre), Jacek Dziarmaga (Jagiellonian University, Institute of Theoretical Physics), Marek Rams (Jagiellonian University, Institute of Theoretical Physics) and Francis Jr. Bayocboc (Jagiellonian University, Institute of Theoretical Physics).

From Critical Dynamics to Coarsening: Bias-Tuned Quantum Phase Transitions on a 2400 Qubit Coherent Annealer.

Presenter: Jaka Vodeb

Abstract: In this work, we explore the dynamics of quantum phase transitions and domain formation in a programmable quantum annealing platform based on a new, coherence-optimized version of the D-Wave quantum annealer, utilizing over 2400 qubits. By leveraging enhanced coherence times and control capabilities, we systematically investigate the role of externally applied symmetry-breaking fields on quantum dynamics across critical points in two qualitatively different systems: a one-dimensional (1D) chain and a two-dimensional (2D) square lattice.Our study reveals a clear dynamical crossover from the Kibble–Zurek (KZ) regime to adiabatic evolution, governed by the presence of a weak bias field. In the 1D chain, we benchmark our results against known analytical predictions and numerical tensor network simulations, finding excellent agreement in both the scaling of excitation suppression and the bias-controlled restoration of adiabaticity, consistent with the theoretical framework proposed in Rams et al [Physical Review Letters, 123(13), p.130603]. The critical bias strength required to bypass the freeze-out region scales in accordance with KZ theory modified by susceptibility divergence at the critical point, enabling us to tune the evolution between defect-generating and adiabatic regimes. Extending this analysis to more complex geometries, we observe a qualitatively similar crossover in the 2D square lattice. In particular, in the 2D lattice, we are able to track domain formation and post-critical coarsening with high spatial resolution. By quenching the system into the ordered phase under a symmetry-breaking bias, we observe the curvature and volume-driven dynamics of domain walls and demonstrate the influence of bias on the size distribution of domains. This behavior is characteristic of model A dynamics for systems with a non-conserved order parameter and is consistent with both classical and quantum coarsening theory. Strikingly, we find that the coarsening dynamics observed on the quantum annealer quantitatively match tensor network simulations based on projected entangled pair states and matrix-product-state methods, reinforcing the utility of the annealer as a reliable platform for simulating out-of-equilibrium many-body quantum systems. Altogether, our findings establish that coherent quantum annealing hardware can successfully emulate non-equilibrium quantum dynamics beyond the standard Kibble–Zurek picture, offering new opportunities to study universality, quantum coarsening, and phase ordering kinetics across different spatial dimensions. This work lays the groundwork for future exploration of collective dynamics in programmable quantum systems, especially in the presence of tunable disorder, long-range interactions, and metastable quantum phases.

Keywords: Quantum Phase Transition, Quantum Annealing, Coherent Dynamics, Non-equilibrium Dynamics, Post-critical Dynamics, One-dimensional Systems, Two-dimensional Systems, Kibble-Zurek mechanism, Adiabatic Evolution, Symmetry Breaking Bias, Tensor Networks, Projected Entangled Pair States, Matrix Product States, Quantum Coarsening, Model A Dynamics

[13] Goksu Toga (North Carolina State University), Abhishek Samlodia (Syracuse University) and Alexander Kemper (North Carolina State University).

Accessing fast scrambling with nearest neighbor interactions.

Presenter: Goksu Toga

Abstract: In this talk, we introduce the Hyperbolic Ising model, which is a mixed field Ising model that lives in the discretization of the AdS_2 space. Through the calculation of infinite and finite temperature OTOCs, we show that this model can be classified as a fast scrambler, and it saturates the bound on chaos, making this model maximally chaotic. Our model is easily simulatable on the current NISQ hardware using both gate-based and analog quantum computers. To demonstrate the application on gate-based computers, we simulate this model on IBM quantum hardware and measure OTOCs using randomized measurement protocols. We further sketch out the necessary setup for analog simulations using Rydberg arrays. Our results indicate that contrary to the common belief it is possible to achieve fast scrambling behavior in local models with carefully designed interactions motivated from holography. This provides us with models to study fast scrambling on quantum computers without worrying about the computational cost of simulating all-to-all or long-range interacting models while emphasizing the effects that a curved background can have on the dynamics of the model.

Keywords: Fast Scrambling, Quantum Simulation, Many-body quantum chaos

[15] Roeland Wiersema (Flatiron Institute), Yuxuan Zhang (University of Toronto), Juan Carrasquilla (ETH Zurich), Lukasz Cincio (Los Alamos National Lab) and Yong-Baek Kim (University of Toronto).

Scalable quantum dynamics compilation via quantum machine learning.

Presenter: Roeland Wiersema

Abstract: Quantum dynamics compilation is an important task for improving quantum simulation efficiency: It aims to synthesize multi-qubit target dynamics into a circuit consisting of as few elementary gates as possible. Compared to deterministic methods such as Trotterization, variational quantum compilation (VQC) methods employ variational optimization to reduce gate costs while maintaining high accuracy. In this work, we explore the potential of a VQC scheme by making use of out-of-distribution generalization results in quantum machine learning (QML): By learning the action of a given many-body dynamics on a small data set of product states, we can obtain a unitary circuit that generalizes to highly entangled states such as the Haar random states. The efficiency in training allows us to use tensor network methods to compress such time-evolved product states by exploiting their low entanglement features. Our approach exceeds state-of-the-art compilation results in both system size and accuracy in one dimension (1D). For the first time, we extend VQC to systems on two-dimensional (2D) strips with a quasi-1D treatment, demonstrating a significant resource advantage over standard Trotterization methods, highlighting the method's promise for advancing quantum simulation tasks on near-term quantum processors.

Keywords: variational compilation, circuit compression, tensor networks

[16] Jue Xu (University of Hong Kong), Chu Zhao (Tsinghua University), Junyu Fan (International Quantum Academy) and Qi Zhao (University of Hong Kong).

Exponentially Decaying Quantum Simulation Error with Noisy Devices.

Presenter: Jue Xu

Abstract: Quantum simulation is a promising way toward practical quantum advantage, but noise in current quantum hardware poses a significant obstacle. We theoretically and numerically revealed that not only the physical error but also the algorithmic error in a single Trotter step decreases exponentially with the circuit depth. In particular, according to our results, we derive the optimal number of Trotter steps and the noise requirement to guarantee total simulation precision. At last, we demonstrate that our improved error analysis leads to significant resource-saving for fault-tolerant Trotter simulation. By addressing these aspects, this work systematically characterizes the robustness of Trotter simulation errors in noisy quantum devices and paves the way toward practical quantum advantage.

Keywords: quantum simulation, Trotter error, noisy circuit, NISQ, fault-tolerant

[18] Philipp Westhoff (Ludwig-Maximilians Universität München), Sebastian Paeckel (Ludwig-Maximilians Universität München) and Mattia Moroder (Trinity College Dublin).

Fast and direct preparation of a genuine lattice BEC via the quantum Mpemba effect.

Presenter: Philipp Westhoff

Abstract: Short abstract (Please note that the long abstract, which includes figures and references, is attached together with the paper in the PDF "long_abstract_and_paper_Mattia_Moroder.pdf")

Preparing high-fidelity Bose-Einstein condensates (BEC) is the key first step toward generating highly entangled states in the quantum simulators based on ultracold atoms in optical lattices. In this talk, I will present an efficient method for dissipatively preparing a BEC directly on a lattice, replacing the currently used slow, two-stage procedure prone to environment-induced decoherence and heating. The protocol drives the lattice subsystem into a non-equilibrium steady state exhibiting a lattice analog of a true BEC, with depletion controllable via the dissipation strength. A symmetry-based Mpemba effect allows analytical identification of simple, experimentally realizable initial states that converge exponentially faster than random ones. Additionally, I show how combining superfluid immersion with lattice shaking enables tuning the momentum of the prepared BEC. Theoretical predictions are confirmed by matrix-product state simulations, which quantify the speedups and fidelities achieved. This protocol offers a powerful tool for significantly enhancing the preparation of highly entangled states in analog quantum simulators.

Keywords: dissipative state preparation, quantum Mpemba effect, ultracold atoms in optical lattices, Bose-Einstein condensate (BEC)

[23] Mingyu Kang (Duke University).

Noise-robust analog quantum simulation of noisy quantum systems.

Presenter: Mingyu Kang

Abstract: This abstract suggests a path towards quantum advantage in simulating models of quantum phenomena in Nature, extended from our recent review [1] and experimental quantum simulation [2].

Open quantum systems are widely used to model physical, chemical, biological, and material systems. When characterizing quantum phenomena, a more detailed and accurate open quantum system model can be constructed at the cost of requiring a larger computational cost. For an example of energy transfer in molecular systems, starting from a model consisting of electronic states, vibrational modes are incorporated to account for the quantum nature of the environment, followed by the inclusion of the dissipation of vibrational modes. A characterization of the dissipation as mixed Gaussian relaxation and non-Gaussian dephasing adds crucial detail for understanding the long-time behavior of the quantum system.

In the context of analog quantum simulation, I would like to share the perspective that the intrinsic noise of the quantum simulator can serve as a resource for simulating the dissipative component of the target quantum phenomena. This would require precise characterization of noise mechanisms in both the quantum simulator hardware and the open quantum system to be simulated. In Ref.~[1], we perform numerical simulations of the expected performance of noisy trapped-ion simulators, which leads to the conclusion that the noise level of the trapped-ion system needs to be reduced by roughly two orders of magnitude from the state-of-the-art in order to achieve a quantum advantage in simulating linear vibronic coupling models. However, the experimental results for simulating the spin-boson model in Ref.~[2] already achieve high accuracy, even though the evolution time of the quantum simulator is comparable to the time scale of the hardware noise. This is because the motional dephasing noise, a leading error source that is characterized and mitigated for high-fidelity two-qubit gates, is essentially injected and used as an ingredient for simulating the dephasing of the bath oscillator. Indeed, vibrational dephasing, together with vibrational relaxation, is known to be a significant decoherence mechanism in condensed-phase molecular dynamics, which leads to the study of the open quantum Rabi model with mixed bosonic relaxation and dephasing.

A more detailed characterization of a quantum system leads to a more accurate prediction and control of its behavior, which applies to both the quantum simulator hardware and the quantum phenomena in Nature. Robustness to noise in analog quantum simulation is naturally achieved by using the inherent noise of the quantum simulator hardware to simulate the dissipative mechanisms. This approach could pave the way for near-term quantum advantage as well as inspire theoretical exploration of novel open quantum system models, with broad applicability across physical, chemical, and biological systems.

[1] M. Kang, H. Nuomin, S. N. Chowdhury, J. L. Yuly, K. Sun, J. Whitlow, J. Valdiviezo, Z. Zhang, P. Zhang, D. N. Beratan, and K. R. Brown, Seeking a quantum advantage with trapped-ion quantum simulations of condensed-phase chemical dynamics, Nat. Rev. Chem. 8, 340-358 (2024)

[2] K. Sun, M. Kang, H. Nuomin, G. Schwartz, D. N. Beratan, K. R. Brown, and J. Kim, Quantum simulation of spin-boson models with structured bath, arXiv:2405.14624, In Press, Nat. Comm.

Keywords: robust quantum simulation, analog quantum simulation, open quantum system, quantum advantage, trapped ions

[25] Matteo D'Anna (ETH Zurich), Yuxuan Zhang (Vector Institute), Roeland Wiersema (Flatiron Institute) and Juan Carrasquilla (ETH Zurich).

Circuit compilation for quantum dynamics of 2D systems with Pauli propagation.

Presenter: Matteo D'Anna

Abstract: As quantum processors progress toward practical utility, the need for efficient compilation algorithms grows. In particular, simulating real-time dynamics with limited quantum resources requires the compression of accurate, deep circuits into shallow, hardware-friendly forms (that retain the high levels of accuracy). We present a variational approach for compiling deep time evolution operators into optimized shallower ansaetze using the Pauli propagation framework. Our method minimizes a fidelity-based cost function over special classes of ensembles of product states, that relate to the Hilbert-Schmidt cost by some out-of-distribution bound from the literature. By avoiding reliance on global Haar randomness (required for computing the Hilbert-Schmidt cost) and leveraging locally scrambled distributions, we achieve scalable circuit compression suited for near-term architectures, especially systems with connectivities more challenging that 1D.

This formulation allows us to replace standard simulation techniques, such as Trotterization, with a variational strategy tailored to reduce circuit depth. Our method is particularly well suited to 2D quantum systems, where hardware limitations make traditional approaches impractical. The compression technique introduced here thus opens the door to high-fidelity dynamical simulation on near-term quantum devices.

Numerical results show that our approach can enhance dynamics simulations for current hardware and in the future. In general our circuits implement the dynamics orders of magnitude more accurately than Trotterization, and do so by using identical resources. We demonstrate this in an experimental setup, where we simulate the dynamics of a cloud of hard-core bosons on a lattice using Quantinuum's H1 quantum chip. We show that by applying our compressed ansatz multiple times it's possible to track the exact dynamics for much longer times than what would have been possible with standard Trotterization. Additionally, we can tackle the compression of large 2D systems, as we perform the compression for the dynamics of the transverse field Ising model on a 30x30 lattice.

Keywords: 2D dynamics, Circuit compression, Circuit compilation, Pauli propagation, Variational optimization

[26] Adrian Skasberg Aasen (Universität Heidelberg), Andras Di Giovanni (Karlsruher Institut für Technologie), Hannes Rotzinger (Karlsruher Institut für Technologie), Alexey Ustinov (Karlsruher Institut für Technologie) and Martin Gärttner (Friedrich-Schiller-University Jena).

Mitigation of correlated readout errors without randomized measurements.

Presenter: Adrian Skasberg Aasen

Abstract: Quantum simulation, the study of strongly correlated quantum matter using synthetic quantum systems, has been the most successful application of quantum computers to date. It often requires determining observables with high precision, for example when studying critical phenomena near quantum phase transitions. Thus, readout errors must be carefully characterized and mitigated in data post-processing, using scalable and noise-model agnostic protocols. We present a readout error mitigation protocol that uses only single-qubit Pauli measurements and avoids experimentally challenging randomized measurements. The proposed approach captures a very broad class of correlated noise models and is scalable to large qubit systems. It is based on a complete and efficient characterization of few-qubit correlated positive operator-valued measures (POVMs), using overlapping detector tomography. To assess the effectiveness of the protocol, observables are extracted from simulations involving up to 100 qubits employing readout errors obtained from experiments with superconducting qubits.

Keywords: Readout error mitigation, Correlated errors, Overlapping tomography, Quantum detector tomography, Quantum state tomography

[27] Niccolo Baldelli (Barcelona Supercomputing Center).

Classical and Quantum simulation of Deconfined Quantum critical points in one-dimensional systems.

Presenter: Niccolò Baldelli

Abstract: Deconfined quantum critical points (DQCP) are exotic phase transitions not predicted by the Landau-Ginzburg symmetry-breaking paradigm. In particular, they are associated with a one-point gap closing between distinct locally ordered phases, thus to a continuous phase transition. This is in stark contrast with standard symmetry-breaking theories that predict a first-order phase transition between locally ordered phases. While predicted more than 20 years ago, the precise identification of systems showing DQCPs has been elusive due to the fine tuning of parameters needed to identify them. In this talk, we will present precise Tensor Networks calculations unveiling the presence of such transitions in one-dimensional bosons and fermionic systems. Moreover, we will show how a system with such physics can be implemented in a quantum simulator with ultracold will finally discuss the possibility of implementing a measurement protocol via a quench between the two phases connected by a DQCP.

Keywords: Quantum phase transition, Deconfined Quantum Criticality, Uniform MPS, Cold Atoms, Hubbard physics, Low-dimensional physics, Bosonization

[28] Yingkang Cao (University of Maryland, College Park), Suying Liu (University of Maryland, College Park), Haowei Deng (University of Maryland, College Park), Zihan Xia (University of Southern California), Xiaodi Wu (University of Maryland, College Park) and Yuxin Wang (University of Maryland, College Park).

Robust analog quantum simulators by quantum error-detecting codes.

Presenter: Yingkang Cao

Abstract: Achieving noise resilience is an outstanding challenge in Hamiltonian-based quantum computation. To this end, energy-gap protection provides a promising approach, where the desired quantum dynamics are encoded into the ground space of a penalty Hamiltonian that suppresses unwanted noise processes. However, existing approaches either explicitly require high-weight penalty terms that are not directly accessible in current hardware, or utilize non-commuting 2-local Hamiltonians, which typically leads to an exponentially small energy gap. In this work, we provide a general recipe for designing error-resilient Hamiltonian simulations, making use of an excited encoding subspace stabilized by solely 2-local commuting Hamiltonians. Our results thus overcome a no-go theorem previously derived for ground-space encoding that prevents noise suppression schemes with such Hamiltonians. Importantly, our method is scalable as it only requires penalty terms that scale polynomially with system size. To illustrate the utility of our approach, we further apply this method to a variety of 1- and 2-dimensional many-body spin models, potentially extending the duration of high-fidelity simulation by orders of magnitude in current hardware.

Keywords: Analog quantum simulation, Quantum error suppression, Energy-gap protection

[32] Lucia Vilchez-Estevez (University of Oxford and Phasecraft Ltd.), Raul A. Santos (Phasecraft Ltd.), Sabrina Yue Wang (Phasecraft Ltd.) and Filippo Maria Gambetta (Phasecraft Ltd.).

Extracting the spin excitation spectrum of a fermionic system using a quantum processor.

Presenter: Filippo Maria Gambetta

Abstract: Understanding low-energy excitations in fermionic systems is crucial for their characterization. They determine the response of the system to external weak perturbations, its dynamical correlation functions, and provide mechanisms for the emergence of exotic phases of matter. In this work, we study the spin excitation spectra of the 1D Fermi-Hubbard model using a digital quantum processor. Introducing a protocol that is naturally suited for simulation on quantum computers, we recover the retarded spin Green's function from the time evolution of simple observables after a specific quantum quench. We exploit the robustness of the protocol to perturbations of the initial state to minimize the quantum resources required for the initial state preparation, and to allocate the majority of them to a Trotterized time-dynamics simulation. This, combined with the intrinsic resilience to noise of the protocol, allows us to accurately reconstruct the spin excitation spectrum for large instances of the 1D Fermi-Hubbard model without making use of expensive error mitigation techniques, using up to 30 qubits of an IBM Heron r2 device.

Keywords: quantum simulation, time-dynamics simulation, quantum quench, Fermi-Hubbard model, spectroscopy, dynamical structure factor, low-energy excitations

[33] Nik Gjonbalaj (Harvard University), Rahul Sahay (Harvard University) and Susanne Yelin (Harvard University).

Shortcuts to Analog Preparation of Non-Equilibrium Quantum Lakes.

Presenter: Nik Gjonbalaj

Abstract: The dynamical preparation of exotic many-body quantum states is a persistent goal of analog quantum simulation, often limited by experimental coherence times. Recently, it was shown that fast, non-adiabatic Hamiltonian parameter sweeps can create finite-size ``lakes'' of quantum order in certain settings, independent of what is present in the ground state phase diagram. Here, we show that going further out of equilibrium via external driving can substantially accelerate the preparation of these quantum lakes. Concretely, when lakes can be prepared, existing counterdiabatic driving techniques -- originally designed to target the ground state -- instead naturally target the lakes state. We demonstrate this both for an illustrative single qutrit and a model of a Z2 Rydberg quantum spin liquid. In the latter case, we construct experimental drive sequences that accelerate preparation by almost an order of magnitude at fixed laser power. We conclude by using a Landau-Ginzburg model to provide a semi-classical picture for how our method accelerates state preparation.

Keywords: Analog state preparation, Counterdiabatic driving, Quantum spin liquids, Non-equilibrium states

[34] Mafalda Ramôa (Virginia Tech), Panagiotis Anastasiou (Virginia Tech), Luis P. Santos (INESC TEC, INL, University of Minho), Edwin Barnes (Virginia Tech), Nicholas Mayhall (Virginia Tech) and Sophia Economou (Virginia Tech).

Status and Prospects of VQE for Quantum Simulation.

Presenter: Mafalda Ramôa

Abstract: In this work, we discuss and compare leading proposals of ansatze for the electronic structure problem. Our main contribution is a comparison of key viability metrics: The CNOT count and measurement costs required to achieve a chemically accurate solution. We consider our novel CEO-ADAPT-VQE algorithm as well as several static VQEs: k-UpCCGSD, QNP, tUPS, oo-tUPS and pp-tUPS.

From the comprehensive set of ansatze we simulated, ADAPT-VQE markedly appears as the most viable approach, with other ansatze either failing to reach chemical accuracy or requiring a prohibitive number of measurements - five orders of magnitude larger than required by ADAPT-VQE, including all costs incurred throughout the adaptive ansatz construction.

This surprising result contradicts the common belief that the adaptive ansatz construction incurs a measurement overhead: The optimization perks enjoyed by ADAPT-VQE easily compensate for any additional measurements required by the adaptive protocol.

Keywords: VQE, NISQ, ADAPT-VQE, Electronic structure, Adaptive ansatz, Ansatz

[35] Edward Chen (IBM Quantum), Senrui Chen (University of Chicago), Laurin Fischer (IBM Quantum), Andrew Eddins (IBM Quantum), Luke Govia (IBM Quantum), Brad Mitchell (IBM Quantum), Andre He (IBM Quantum), Youngseok Kim (IBM Quantum), Liang Jiang (University of Chicago) and Alireza Seif (IBM Quantum).

Disambiguating Pauli noise in quantum computers.

Presenter: Senrui Chen

Abstract: Understanding noise in quantum computers is crucial for processing quantum information. However, fundamental limitations prevent us from uniquely identifying the noise model affecting a quantum processor. This raises the question of whether these limitations impact our ability to predict noisy dynamics and mitigate errors. Here, we show, both theoretically and experimentally, that when learnable degrees of freedom are self-consistently characterized, the unlearnable (gauge) degrees of freedom do not impact predictions of noisy dynamics or error mitigation. We use the recently introduced framework of Pauli gate set learning to efficiently and self-consistently characterize and mitigate noise of a complete gate set, including state preparation, measurements, and two-qubit entangling gates. We validate our approach through experiments with up to 92 qubits and show that while the gauge choice does not affect error-mitigated observable values, optimizing it reduces sampling overhead. Our findings address a longstanding issue involving the ambiguities in characterizing quantum noise.

Keywords: entanglement, quantum walks, error mitigation, noise learning, gauge models

[39] Yuto Morohoshi (The University of Osaka), Akimoto Nakayama (The University of Osaka), Hidetaka Manabe (The University of Osaka) and Kosuke Mitarai (The University of Osaka).

Learning Functions of Hamiltonians with Hamiltonian Fourier Features.

Presenter: Yuto Morohoshi

Abstract: We propose and experimentally demonstrate a quantum machine learning task that is provably easy for quantum computers and arguably hard for classical ones.

The task involves predicting quantities of the form $\mathrm{Tr}[f(H)\rho]$, where f is an unknown function, given descriptions of H and ρ.

Using a Fourier-based feature map of Hamiltonians and linear regression, we theoretically establish the learnability and demonstrate it on a superconducting device with up to 40 qubits.

Our results provide a machine learning task with practical relevance, provable quantum easiness, and near-term feasibility.

Keywords: Quantum Simulation, Quantum Machine Learning, Product Formula, NISQ

[40] Minsoo Kim (Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea) and Changhun Oh (Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea).

Exponential Quantum Learning Advantage with Vanishingly Small Entanglement.

Presenter: Minsoo Kim

Abstract: Quantum learning has emerged as a promising application of quantum technology that offers a quantum advantage.

It is established that the use of quantum memory can exponentially reduce sample complexity for learning a quantum channel.

However, in the proposed scheme, the preparation of maximally entangled states is necessary to realize the exponential advantage.

In this work, we demonstrate that this exponential advantage in Pauli channel learning can still be attained using input states with vanishingly small entanglement.

We construct an explicit input state with inverse-polynomial entanglement that enables the learning task to be completed with only polynomial sample complexity.

Additionally, we show that if the number of ancilla qubits is constrained, exponential sample complexity is necessary even for partial channel parameter learning.

Our results establish how quantum resources can affect the sample complexity in quantum channel learning.

Keywords: Quantum Learning, Quantum Advantage, Pauli Channel Learning

[41] Eduard J. Braun (Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany), Moritz Hornung (Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany), Sebastian Geier (Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany), Titus Franz (Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str.1, Garching D-85748, Germany), Gerhard Zürn (Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany) and Matthias Weidemüller (Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany).

Observation of hysteresis in a disordered Heisenberg quantum spin system.

Presenter: Eduard J. Braun

Abstract: Disorder plays an important role for the dynamics and the equilibrium properties of complex quantum systems. A paradigmatic model for exploring disordered and frustrated quantum spin systems are quantum spin glasses. Classical spin glasses are typically characterised by a temperature-dependent splitting between two different susceptibilities, which are referred to as zero-field cooled (ZFC) and field-cooled (FC). However, these cannot be measured directly in an isolated quantum system as they involve tuning of the temperature of an external bath coupled to the system. In this contribution we introduce analogues of these susceptibility measurements, tailored for isolated quantum spin systems. We denote them as zero-field annealing (ZFA) and field annealing (FA). We implement these protocols on a Rydberg atom quantum simulator to probe the phase structure of a dipolar-interacting Heisenberg spin model as a function of both energy and disorder. We observe a significant splitting between ZFA and FA susceptibilities in the strongly disordered regime at low energies, indicating multiple equilibrium states. This raises questions about the nature of this regime and its potential connection to a spin glass phase. Generally, the ZFA and FA protocols provide a novel framework for exploring energy-dependent equilibrium properties and hysteresis in isolated quantum many-body systems.

Keywords: Quantum Simulation, Many-body physics, Spin glass physics, Disorder and frustration, Dipolar interacting systems, Hysteresis

[44] Gennaro Zanfardino (Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno), Stefano Paesani (NNF Quantum Computing Programme, Niels Bohr Institute, University of Copenhagen), Luca Leuzzi (Institute of Nanotechnology of the National Research Council of Italy, CNR-NANOTEC, Rome), Raffaele Santagati (Quantum Lab, Boehringer Ingelheim, 55218 Ingelheim am Rhein, Germany), Fabrizio Illuminati (Institute of Nanotechnology of the National Research Council of Italy, CNR-NANOTEC), Giancarlo Ruocco (Center for Life Nano- & Neuro-Science, Italian Institute of Technology, IIT, Rome) and Marco Leonetti (Institute of Nanotechnology of the National Research Council of Italy, CNR-NANOTEC, Rome).

Photonic realization of a Hopfield associative memory by multiphoton entanglement and interference.

Presenter: Gennaro Zanfardino

Abstract: In this talk we will discuss a recently discovered connection [1] between multiphoton quantum interference—a key component of emerging photonic quantum technologies—and Hopfield-like Hamiltonian models associated with classical neural networks, which are paradigmatic models of associative memory and machine learning in systems of artificial intelligence. A major challenge in this context is that simulating the dynamics of fully connected networks with multi-neuronal synaptic couplings requires a computational time that scales super-extensively with the number of neurons, typically scaling with M, the average per neuron connectivity index.

Analog photonic computation offers a promising path to drastically reduce this computational cost as pointed out in a previous study [2] in which incoherent classical light was used to simulate a 2-body Hopfield model. In order to generalize this correspondence to the multi-synaptic, large-storage regime, an additional mechanism is required in the proposed photonic architecture for energy measurement: the use of entangled photons and interferometry.

Specifically, we demonstrate that a system composed of N_p indistinguishable photons in superposition over M field modes, combined with a controlled array of M binary phase-shifters and a linear-optical interferometer, produces output photon statistics that can be described by a p-body Hopfield Hamiltonian. This Hamiltonian involves M Ising-like neurons (with states ±1), where the interaction order is given by p = 2N_p.

Hopfield models are characterized by two key parameters: the temperature T, and the storage load α, defined as the number of stored patterns per neuron. These models exhibit three distinct phases: the retrieval phase (low T, low α), the glassy phase (low T, high α), and the paramagnetic phase, which emerges at sufficiently high T. In our proposed photonic implementation, both of these parameters can be experimentally controlled, enabling the exploration of the different phases of the system.

We performed a detailed study of the generalized 4-body Hopfield model arising from our design. We show that it undergoes a transition from a memory retrieval phase to a memory blackout (spin-glass) regime as the number of stored patterns increases.

Our mapping provides a new avenue toward the implementation and investigation of disordered and complex classical systems via efficient photonic quantum simulators. Conversely, it allows for the interpretation of structured photonic systems through the lens of classical spin Hamiltonians.

References

[1] G. Zanfardino, S. Paesani, L. Leuzzi, R. Santagati, F. Illuminati, G. Ruocco, and M. Leonetti, Multiphoton quantum simulation of the generalized Hopfield memory model, doi.org/10.48550/arXiv.2504.00111 (Doi of the proposed work).

[2] M. Leonetti, E. Hormann, L. Leuzzi, G. Parisi, and G. Ruocco, Optical computation of a spin glass dynamics with tuneable complexity, Proceedings of the National Academy of Sciences 118, e2015207118 (2021).

Keywords: Hopfield model, Spinglass Hamiltonian, Multiphotonic Interference, Quantum Coherence

[45] Andrew Osborne (Princeton University), Ciro Salcedo (Princeton University) and Andrew Houck (Princeton University).

Glued tree lattices with only compact localized states .

Presenter: Ciro Salcedo

Abstract: Flat band physics is a central theme in modern condensed matter physics. By constructing a tight–binding single particle system that has vanishing momentum dispersion in one or more bands, and subsequently including more particles and interactions, it is possible to study physics in strongly interacting regimes. Inspired by the glued trees that first arose in one of the few known examples of quantum supremacy, we define and analyze two infinite families of tight binding single particle Bose–Hubbard models that have only flat bands, and only compact localized states despite having any nonnegative number of translation symmetries. The first class of model that we introduce is constructed by replacing a sufficiently large fraction of the edges in a generic countable graph with glued trees modified to have complex hoppings. The second class arises from thinking of complex weighted glued trees as rhombi that can then be used to tile two dimensional space, giving rise to the familiar dice lattice and infinitely many generalizations thereof, of which some are Euclidian while others are hyperbolic.

Keywords: Localization, Lattices, Aharonov-Bohm caging, flat bands

[48] Oskar Leimkuhler (University of California, Berkeley) and K. Birgitta Whaley (University of California, Berkeley).

Exponential quantum speedups in quantum chemistry with linear depth.

Presenter: Oskar Leimkuhler

Abstract: We prove classical simulation hardness, assuming non-collapse of the polynomial hierarchy, for quantum circuit families with applications in near-term chemical ground state estimation. The proof exploits a connection to particle number conserving matchgate circuits with fermionic magic state inputs, which are shown to be universal for quantum computation under post-selection, and are therefore not classically simulable in the worst case, in either the strong (multiplicative) or weak (sampling) sense. We apply this result to quantum multi-reference methods designed for near-term hardware by ruling out certain dequantization strategies for computing the off-diagonal matrix elements. We demonstrate these quantum speedups for two choices of reference state that incorporate both static and dynamic correlations to model the electronic eigenstates of molecular systems: orbital-rotated matrix product states, which are preparable in linear depth, and unitary coupled-cluster with single and double excitations. In each case we discuss the implications for achieving exponential quantum advantage in quantum chemistry on near-term hardware.

Keywords: Quantum algorithms, Near-term, Electronic structure, Complexity theory, Tensor networks

[49] Samuele Piccinelli (IBM Research Zurich), Francesco Tacchino (IBM Research Zurich), Alberto Baiardi (IBM Research Zurich), Max Rossmannek (IBM Research Zurich), Almudena Carrera Vazquez (IBM Research Zurich), Ivano Tavernelli (IBM Research Zurich), Antonio Mezzacapo (IBM Research US), Mario Motta (IBM Research US), William Kirby (IBM Research US), Kunal Sharma (IBM Research US) and Javier Robledo Moreno (IBM Research US).

Improved sample-based quantum diagonalization via randomized Hamiltonian simulation.

Presenter: Samuele Piccinelli

Abstract: Quantum computing has emerged as a new computing paradigm capable of solving problems that have unfavorable scaling on classical computers. Quantum chemistry represents one of the main and most impactful avenues for applications of these new machines. However, the current landscape of algorithms suffers from a fundamental roadblock created by the trade-off between the limited resources of today's noisy quantum hardware and algorithmic performance guarantees. In this work, we introduce an algorithm that allows this trade-off to be flexibly adjusted based on the available resources, offering both theoretical robustness and practical compatibility with near-term hardware. Our approach, based on a combination of Hamiltonian simulation via qDRIFT and the recently introduced scheme of sample-based quantum diagonalization, paves the way for enabling efficient quantum chemistry simulations on quantum computers and Krylov-based quantum diagonalization approaches for chemistry.

Keywords: Quantum simulations, Quantum chemistry, Sample-based quantum diagonalization

[51] Christopher Kang (University of Chicago) and Yuan Su (Microsoft Quantum).

Quantum matrix arithmetics with Hamiltonian evolution.

Presenter: Christopher Kang

Abstract: The efficient implementation of matrix arithmetic operations underpins the speedups of many quantum algorithms. We develop methods to perform quantum matrix arithmetics, with the result encoded in the off-diagonal blocks of a Hamiltonian, using Hamiltonian evolutions of input operators. This covers matrix multiplication, matrix addition, matrix inversion, Hermitian conjugation, fractional scaling, integer scaling, complex phase scaling, and singular value transformation.

We show how to coherently reconstruct the Hamiltonian block encoding, so that matrix arithmetic operations can be composed one after another. Consequently, our methods require at most 2 ancilla qubits throughout the entire quantum computation, in contrast to the standard approach that necessitates fresh ancillas at each step. We also develop an overlap estimation algorithm to extract classical properties of Hamiltonian block encoded operators, with complexity matching the well known Hadmard test, at no extra cost of qubit.

When applied to quantum simulation, our methods inherit the commutator scaling from the Lie-Trotter-Suzuki formulas, while leveraging the power of matrix arithmetics to reduce the cost of each Trotter step.

To illustrate this feature, we describe a quantum circuit for simulating the doubly factorized tensor hypercontracted electronic structure Hamiltonian, with total gate complexity $\alpha_{\text{comm},\eta}^{1+o(1)}n_Rn_Cn_Bn$. Our dependence on the rank n_R, copies n_C, base size n_B and spin orbitals n matches qubitization in the double factorization case. Our $\alpha_{\text{comm},\eta}$ is always lower than the normalization factor α of qubitization, and can be substantially lower when the number of particles η is small or the coefficient tensors are nearly orthogonal. We achieve this using 1 single ancilla qubit.

Keywords: Quantum simulation, Quantum algorithm, Lie group commutator product formula, Quantum singular value transformation

[53] Niall Robertson (IBM Quantum), Bibek Pokharel (IBM Quantum), Bryce Fuller (IBM Quantum), Eric Switzer (NIST), Oles Shtanko (IBM Quantum), Mirko Amico (IBM Quantum), Adam Byrne (IBM Quantum), Andrea D'Urbano (IBM Quantum), Salome Hayes-Shuptar (IBM Quantum), Albert Akhriev (IBM Quantum), Nathan Keenan (IBM Quantum), Sergey Bravyi (IBM Quantum) and Sergiy Zhuk (IBM Quantum).

Tensor Network enhanced Dynamic Multiproduct Formulas.

Presenter: Bibek Pokharel

Abstract: Tensor networks and quantum computation are two of the most powerful tools for the simulation of quantum many-body systems. Rather than viewing them as competing approaches, here we consider how these two methods can work in tandem. We introduce a novel algorithm that combines tensor networks and quantum computation to produce results that are more accurate than what could be achieved by either method used in isolation. Our algorithm is based on multiproduct formulas (MPF) - a technique that linearly combines Trotter product formulas to reduce algorithmic error. Our algorithm uses a quantum computer to calculate the expectation values and tensor networks to calculate the coefficients used in the linear combination. We present a detailed error analysis of the algorithm and demonstrate the full workflow on a one-dimensional quantum simulation problem on 50 qubits using two IBM quantum computers: ibm_torino and ibm_kyiv.

Keywords: Tensor Networks, Dynamics, Quantum-centric supercomputing

[54] Bharath Sambasivam (Virginia Tech), Kyle Sherbert (Virginia Tech), Karunya Shirali (Virginia Tech), Nicholas J. Mayhall (Virginia Tech), Edwin Barnes (Virginia Tech) and Sophia E. Economou (Virginia Tech).

Efficient variational low-temperature Gibbs state preparation without entropy measurements.

Presenter: Bharath Sambasivam

Abstract: Preparing Gibbs states, which describe systems in equilibrium at finite temperature, is of great importance, particularly at low temperatures. In this work, we propose a new method– TEPID-ADAPT– that prepares the thermal Gibbs state of a given Hamiltonian at low temperatures using a variational method that is partially adaptive and uses a minimal number of ancillary qubits. We achieve this using a truncated, parametrized eigenspectrum of the Hamiltonian. Beyond preparing Gibbs states, this approach also straightforwardly gives us access to the truncated low-energy eigenspectrum of the Hamiltonian, making it also a method that prepares excited states simultaneously. As a result of this, we are also able to prepare thermal states at any lower temperature of the same Hamiltonian without further optimization.

Keywords: Gibbs states, excited states, fixed-depth dynamics, ADAPT-VQE

[57] Alexander Schuckert (University of Maryland), Eleanor Crane (Massachusetts Institute of Technology), Alexey Gorshkov (University of Maryland), Mohammad Hafezi (University of Maryland) and Michael Gullans (University of Maryland).

Fermion-qubit fault-tolerant quantum computing.

Presenter: Alexander Schuckert

Abstract: Simulating the dynamics of electrons and other fermionic particles in quantum chemistry, material science, and high-energy physics is one of the most promising applications of fault-tolerant quantum computers. However, the overhead in mapping time evolution under fermionic Hamiltonians to qubit gates renders this endeavor challenging. We introduce fermion-qubit fault-tolerant quantum computing, a framework which removes this overhead altogether. Using native fermionic operations we first construct a repetition code which corrects phase errors only. We then engineer a fermionic color code which corrects for both phase and loss errors. We show how to realize a universal fermionic gate set in this code, including transversal Clifford gates. Interfacing with qubit color codes we realize qubit-fermion fault-tolerant computation, which allows for qubit-controlled fermionic time evolution, a crucial subroutine in state-of-the-art quantum algorithms for simulating fermions. We show how our framework can be implemented in neutral atoms, overcoming the apparent inability of neutral atoms to implement non-number-conserving gates by introducing a neutral-atom braiding gate using photodissociation of bosonic molecules. As an application, we consider the fermionic fast Fourier transform, an important subroutine for simulating crystalline materials, finding an exponential improvement in circuit depth from O(N) to O(log(N)) with respect to lattice site number N and a linear improvement from O(N^2) to O(Nlog(N)) in Clifford gate complexity compared to state-of-the-art qubit-only approaches. Our work opens the door to fermion-qubit fault-tolerant quantum computation in platforms with native fermions such as neutral atoms, quantum dots and donors in silicon, with applications in quantum chemistry, material science, and high-energy physics.

Keywords: Fault-tolerant quantum simulation, Logical fermions, Quantum error correction, Fermionic quantum computing, Materials Simulation, Quantum Chemistry, Neutral atoms, Quantum dots, Tweezer arrays

[58] Eugen Coroi (Korea Advanced Institute of Science and Technology (KAIST)) and Changhun Oh (Korea Advanced Institute of Science and Technology (KAIST)).

Exponential advantage in continuous-variable quantum state learning.

Presenter: Eugen Coroi

Abstract: We consider the task of learning quantum states in bosonic continuous-variable (CV) systems. We present a concrete experimentally feasible protocol that utilizes entangled measurements and reflected states to enable efficient learning of the characteristic function of CV quantum states with a sample complexity independent of the number of modes n. We then prove that any general adaptive learning scheme without entangled measurements requires a sample complexity that is exponential in n to accomplish the same task, demonstrating an exponential advantage provided by entangled measurements. Remarkably, we also prove that any general adaptive entanglement-assisted scheme also requires an exponential sample complexity if access to reflected states is prohibited. Hence, we establish a rigorous exponential advantage from entangled measurements and access to reflected states in learning CV quantum states.

Keywords: continuous-variable systems, CV systems, quantum learning, quantum learning theory, state learning, quantum state learning, CV state learning, exponential advantage

[59] Jungsoo Hong (SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University, Suwon 16419, Republic of Korea), Seong Ho Kim (Department of Chemistry, Ulsan National Institute of Science and Technology, Ulsan, 44919, Republic of Korea), Seung Kyu Min (Department of Chemistry, Ulsan National Institute of Science and Technology, Ulsan, 44919, Republic of Korea) and Joonsuk Huh (Department of Chemistry, Yonsei University, Seoul 03722, Republic of Korea).

Qubit-oscillator hybrid quantum simulator for conical intersection with multilevel nonlinear couplings: a case study of uracil cation.

Presenter: Jungsoo Hong

Abstract: Simulating the nonadiabatic dynamics of molecules is crucial for understanding photochemical processes, including nonradiative and ultrafast dissipation. However, it becomes classically intractable as system size increases due to the exponential scaling of vibrational modes. While linear vibronic coupling (LVC) models offer simplification, we provide numerical evidence that they are insufficient for accurately capturing the complex dynamics of the uracil cation, particularly involving its anharmonic potentials and three-state conical intersections. To address this challenge, we propose a quantum simulation approach mapping the nonadiabatic dynamics of the uracil cation, including its nonlinear potentials and multi-level couplings, onto a qubit-oscillator hybrid quantum system. We integrate generalized quantum signal processing (GQSP) within this architecture, utilizing it as a key subroutine to generate the nonlinear bosonic phase gates required to simulate dynamics on anharmonic potentials. We numerically demonstrate the construction of these potentials for the uracil cation and validate our quantum approach via comparative analysis against a classical method on a toy model. This work presents a framework for leveraging qubit-oscillator systems and GQSP to simulate complex, anharmonic potential molecular dynamics beyond the reach of classical methods.

Keywords: quantum computational chemisty, vibronic coupling, conical intersection, quantum signal processing

[60] Francesco Cesa (IQOQI Innsbruck), Hannes Pichler (IQOQI Innsbruck) and Hannes Bernien (IQOQI Innsbruck).
Fast and Error-Correctable Quantum RAM.

Presenter: Francesco Cesa
Abstract. Quantum devices can process data in a fundamentally different way than classical computers, promising breakthrough capabilities across several fields of science, e.g. in the simulation of quantum systems. To leverage this potential, many algorithms require the aid of a quantum Random Access Memory (QRAM), i.e. a module capable of efficiently loading datasets (both classical and quantum) onto the quantum processor. However, a realisation of this fundamental building block is still outstanding, since existing proposals require prohibitively many resources for reliable implementations, or are not compatible with current architectures. Moreover, present approaches cannot be scaled-up, as they do not allow for efficient quantum error-correction. Here we develop a QRAM design, that enables fast and robust QRAM calls, naturally allows for fault-tolerant and error-corrected operation, and can be integrated on present hardware. Our proposal employs a special quantum resource state that is consumed during the QRAM call: we discuss how it can be assembled and processed efficiently in a dedicated module. Concretely, we provide detailed blueprints and quantitative estimations for modern neutral-atom processors, demonstrating that high-fidelity QRAM queries can be implemented at rates compatible with the fault-tolerant computational clock-time. Our work places a long missing, fundamental component of quantum computers within reach of currently available technology; this opens the door to algorithms featuring practical quantum advantage, including search or oracular problems, quantum chemistry and machine learning. ArXiv link: https://arxiv.org/html/2503.19172v1

Keywords: Quantum Random Access Memory, Quantum Error Correction, Fault tolerance, Quantum Simulation, Neutral Atoms

[61] Leon Rullkötter (Fraunhofer IAO), Bharadwaj Chowdary Mummaneni (Fraunhofer IAO) and Sebastian Weber (University of Stuttgart).

Resource-efficient Variational Block-Encoding (VBE).

Presenter: Leon Rullkötter

Abstract: Block-encoding operators are one of the essential components in algorithms based on Quantum Signal Processing. Their complexity largely determines the overall complexity of the full algorithm. Using variational methods we aim to compile block-encoding unitaries with near-optimal resource requirements for a large range of input matrices. We find that the number of variational parameters in the parameterized quantum circuit approaches the number of free parameters in the input matrices, depending whether they are real, complex and/or hermitian. Additionally, symmetries present in the input matrix can be incorporated into the ansatz circuit, reducing the parameter count further. While determining variational block-encodings ceases to be computational feasible for large system sizes, the constructed operators can be used as components of larger block-encodings via linear combination of variational block-encodings.

Keywords: Block-Encoding, Variational compilation, Symmetic Quantum Circuits, Hamiltonian Simulation, Quantum Signal Processing

[63] Stefano Reale (QuTech and Kavli Institute of Nanoscience), Daniel Jirovec (QuTech and Kavli Institute of Nanoscience), Pablo C. Fariña (QuTech and Kavli Institute of Nanoscience), Xin Zhang (QuTech and Kavli Institute of Nanoscience), Elizaveta Morozova (QuTech and Kavli Institute of Nanoscience), Sander L. de Snoo (QuTech and Kavli Institute of Nanoscience), Stefan D. Oosterhout (Netherlands Organisation for Applied Scientific Research (TNO)), Menno Veldhorst (QuTech and Kavli Institute of Nanoscience) and Lieven M. K. Vandersypen (QuTech and Kavli Institute of Nanoscience).

Beam-splitter interferometry for many-body spectroscopy in a quantum dot ladder.

Presenter: Stefano Reale

Abstract: Gate-defined semiconductor quantum dot arrays are a promising platform for digital and analog quantum simulations due to their scalability and precise control capabilities [1]. Recent advancements have enabled the engineering of interacting spin systems expected to exhibit signatures of complex many-body states [2]. However, characterizing the energy spectrum of such systems is challenging, since interactions give rise to many-body eigenstates that are far more complex than the simple spin-flip excitations that define the computational (Zeeman) basis. Here we demonstrate a time-domain spectroscopic technique that provides a one-to-one mapping from computational basis states prepared in the non-interacting regime to the many-body regime. We initialize quantum superpositions through Landau-Zener transitions at spin-orbit-induced anticrossings in Ge/SiGe quantum dots, then adiabatically evolve these states into the interacting regime and back, realizing a protocol similar to many-body Ramsey interferometry [3]. This approach allows us to selectively probe the energy states in the interacting regime and reconstruct the spectrum of a chain of up to 8 spins in a gate-defined Ge/SiGe quantum dot ladder. To our knowledge, this work presents the first comprehensive spectroscopic characterization of many-body states in a semiconductor quantum dot array of this scale, advancing our ability to study quantum phases of matter in scalable solid-state platforms.

[1] Hensgens, T., Fujita, T., Janssen, L. et al., Nature 548, 70–73 (2017).

[2] Appel, M.H., Ghorbal, A., Shofer, N. et al., Nature Physics 21, 368–373 (2025).

[3] Roberts, G., Vrajitoarea, A., Saxberg, B., et al., Science Advances 10, eado1069 (2024).

Keywords: Semiconductor quantum dots, Many-body spectroscopy, Interacting spin systems, Spin-orbit coupling, Solid-state quantum systems

[67] Ka-Wa Yip (Northeastern University), Kubra Yeter-Aydeniz (The Mitre Corporation) and Sijia Dong (Northeastern University).

Variational Quantum Annealing for Quantum Chemistry.

Presenter: Ka-Wa Yip

Abstract: We introduce a variational quantum annealing (VarQA) algorithm for electronic structure theory, in which we use the quantum annealer as a sampler and prepare an ansatz state through its statistics. We also introduce a strategy called the "digitizer" for searching the space of variational parameters efficiently. We demonstrate the effectiveness of VarQA by evaluating the ground-state potential energy surface

for molecules with up to 20 spin orbitals as well as an excited-state potential energy surface. This approach resembles the workings of the quantum Boltzmann Machines (QBMs), but is generalized to handle distributions beyond the Boltzmann distribution.

In VarQA, with the number of required logical qubits equal to the number of spin orbitals, a fully connected Ising Hamiltonian can be readily implemented in a large-scale quantum annealer as a scalable ansatz for electronic structure calculations.

Keywords: Many-body physics in quantum simulators, Analog quantum simulation, Adiabatic quantum computation, Quantum Annealing, Quantum Chemistry

[69] Yuxin Wang (Joint Center for Quantum Information and Computer Science, University of Maryland), Jacob Bringewatt (Harvard University), Alireza Seif (IBM Quantum), Anthony Brady (NIST/University of Maryland), Changhun Oh (Korea Advanced Institute of Science and Technology) and Alexey Gorshkov (NIST/University of Maryland).

Exponential entanglement advantage in sensing correlated noise.

Presenter: Yuxin Wang

Abstract: In this work, we propose a new form of exponential quantum advantage in the context of sensing correlated noise. Specifically, we focus on the problem of estimating parameters associated with Lindblad dephasing dynamics, and show that entanglement can lead to an exponential enhancement in the sensitivity (as quantified via quantum Fisher information of the sensor state) for estimating a small parameter characterizing the deviation of system Lindbladians from a class of maximally correlated dephasing dynamics. This result stands in stark contrast with previously studied scenarios of sensing uncorrelated dephasing noise, where one can prove that entanglement does not lead to an advantage in the signal-to-noise ratio. Our work thus opens a novel pathway towards achieving entanglement-based sensing advantage, which may find applications in characterizing decoherence dynamics of near-term quantum devices. Further, our approach provides a potential quantum-enhanced probe of many-body correlated phases by measuring noise generated by a sensing target. We also discuss realization of our protocol using near-term quantum hardware.

Keywords: Quantum sensing, Quantum noise estimation, Entanglement advantage, Correlation-function measurement

[70] Sangwoo Jeon (Agency for Defense Development) and Changhun Oh (Korea Advanced Institute of Science and Technology).

Unitary channel certification.

Presenter: Sangwoo Jeon

Abstract: Certifying the correct functioning of quantum processes is essential for achieving fault-tolerant quantum information processing. In this work, we address the unitary channel certification problem, which provides the fundamental hardness in quantum process certification. We show that for the worst-case unitary channels, certification requires exponentially many queries. On the other hand, we show that for the average-case unitary channel, certification can be accomplished within a constant number of queries. This exponential gap provides the foundation of efficient channel certification toward fault tolerance.

Keywords: Quantum process certification, Quantum algorithm, Unitary channel

[75] Seung Park (Institute for Convergence Research and Education in Advanced Technology, Yonsei University), Dongkeun Lee (Division of National Supercomputing, Korea Institute of Science and Tecshnology Information), Jeongho Bang (Institute for Convergence Research and Education in Advanced Technology, Yonsei University), Hoon Ryu (Department of Artificial Intelligence Engineering, Kumoh National Institute of Technology) and Kyunghyun Baek (Institute for Convergence Research and Education in Advanced Technology, Yonsei University).

Subspace Variational Quantum Simulation with Fidelity Lower Bounds.

Presenter: Seung Park

Abstract: We propose an algorithm to simulate the time evolution of a subspace based on the iterative variational method. This algorithm compresses the Trotter circuit into a shorter-depth parameterized quantum circuit (PQC) by optimizing fidelities between time-evolved basis and PQC-prepared states in our target subspace. We also provide the worst-case performance of our algorithm for arbitrary initial states in subspace via lower bounds on the fidelities.

Keywords: Trotterization, Quantum Simulation, Variational Quantum Algorithm, Subspace Time Evolution, Fidelity Lower Bound

[78] Yuki Koizumi (The University of Tokyo), Kaito Wada (Keio University), Wataru Mizukami (Osaka University) and Nobuyuki Yoshioka (The University of Tokyo).

Faster Quantum Algorithm for Multiple Observables Estimation in Fermionic Problem.

Presenter: Nobuyuki Yoshioka

Abstract: Achieving quantum advantage in efficiently estimating collective properties of quantum many-body systems remains a fundamental goal in quantum computing. While the quantum gradient estimation (QGE) algorithm has been shown to achieve doubly quantum enhancement in the precision and the number of observables to be estimated under an adaptive scheme, it remains unclear whether one benefits in practical applications such as quantum many-body simulation. In this work, we present a generalized framework of the adaptive QGE algorithm and further propose two variants which enable us to estimate the collective properties of fermionic systems using the smallest cost among existing quantum algorithms. The first method utilizes the symmetry inherent in the target state to speed up the process of encoding the information of observables into the phase of a probe system, and the second method successfully incorporates a parallel scheme of observable estimation with the adaptive strategy. We show that our proposal offers quadratic speedup compared with the prior QGE algorithm in the task of partial tomography without additional space complexity. Furthermore, we provide numerical demonstrations that, for the problem of estimating the 2-local reduced density matrix, our proposals improve the number of calls to the state-preparation oracle of the target state by a factor of 100 for the nitrogenase FeMo cofactor and by a factor of 500 for the Fermi-Hubbard model of 100 sites. Our work paves the way towards universal quantum enhancement for practitioners of quantum computation.

Keywords: Quantum Algorithm, Heisenberg limit, partial tomography, QSVT, many-body problem

[79] Qiang Miao (Duke University), Tianyi Wang (Duke University), Kenneth Brown (Duke University), Thomas Barthel (Duke University) and Marko Cetina (Duke University).

Probing Entanglement Scaling Across a Quantum Phase Transition on a Quantum Computer.

Presenter: Qiang Miao

Abstract: The investigation of strongly-correlated quantum matter is difficult due to the curse of dimensionality and intricate entanglement structures. These challenges are particularly pronounced in the vicinity of continuous quantum phase transitions, where quantum fluctuations manifest across all length scales. While quantum simulators give controlled access to a number of strongly correlated systems, the study of critical phenomena has been hampered by finite-size effects arising from diverging correlation lengths. Moreover, the experimental investigation of entanglement in many-body systems has been hindered by limitations in measurement protocols. To address these challenges, we employ the multiscale entanglement renormalization ansatz (MERA) and implement a holographic scheme for subsystem tomography on a fully-connected trapped-ion quantum computer. Our method accurately represents infinite systems and long-range correlations with few qubits, facilitating the efficient extraction of observables and entanglement properties, even at criticality. We observe a quantum phase transition with spontaneous symmetry breaking and reveal the evolution of entanglement properties across the critical point. For the first time, we demonstrate log-law scaling of subsystem entanglement entropies at criticality on a digital quantum computer. This achievement highlights the potential of MERA for the investigation of strongly-correlated many-body systems on quantum computers.

Keywords: Entanglement entropy, Quantum phase transition, Trapped-ion quantum computer, Tensor network state

[82] Hyeonjun Yeo (Department of Physics and Astronomy, Seoul National University), Kabgyun Jeong (Research Institute of Mathematics, Seoul National University) and Hyunchul Nha (Department of Physics, Texas A & M University at Qatar).

Quantum Entanglement in Rydberg Atom Arrays.

Presenter: Kabgyun Jeong

Abstract: Characterizing quantum transitions across different quantum phases is of crucial importance in many-body physics. This is usually addressed in terms of order parameters using physical quantities such as magnetization in spin-chain systems. We here propose entanglement-based order parameters that manifest different quantum phases providing insight into quantum correlation among constituent parts in strongly correlated systems. Our approach thereby offers a valuable tool to look into many-body physics across quantum phase transitions both theoretically and experimentally. As an illustration we investigate quantum entanglement for the array of Rydberg atoms in 2D optical tweezer arrays by employing concurrence as an entanglement quantifier while our proposal can be applied to any measure of entanglement. We also present an experimentally accessible method to witness phase transitions in the Rydberg atom array.

Keywords: Quantum simulation, Quantum entanglement, Rydberg atom arrays

[87] Eric Switzer (National Institute of Standards and Technology), Niall Robertson (IBM Quantum, IBM Research Europe), Nathan Keenan (IBM Quantum, IBM Research Europe), Ángel Rodríguez (Centro de Física de Materiales CFM/MPC (CSIC-UPV/EHU)), Andrea D'Urbano (IBM Quantum, IBM Research Europe), Bibek Pokharel (IBM T.J. Watson Research Center), Talat S. Rahman (University of Central Florida), Oles Shtanko (IBM T.J. Watson Research Center), Sergiy Zhuk (IBM Quantum, IBM Research Europe) and Nicolás Lorente (Donostia International Physics Center; Centro de Física de Materiales CFM/MPC (CSIC-UPV/EHU)).

Two-dimensional Discrete Time Crystals with Anisotropic Heisenberg Coupling.

Presenter: Eric D. Switzer

Abstract: Discrete time crystals (DTCs) represent a striking example of non-equilibrium quantum phases, characterized by robust subharmonic oscillations that spontaneously break discrete time-translation symmetry. We demonstrate a two-dimensional DTC with variable anisotropic Heisenberg interactions in a driven quantum many-body system, realized on the IBM Fez superconducting processor using 144 qubits on a decorated heavy-hexagon lattice. We observe clear evidence of DTC behavior and demonstrate that the polarized initial state displays long-lived oscillations, reflecting weak ergodicity breaking reminiscent of many-body scars. To support and validate our hardware experiments, we perform classical simulations using both Matrix Product States and two-dimensional tensor network states for small system sizes and specific low-entanglement regimes. We also utilize a novel noisy signal recovery method to extract high-precision noiseless collective observables from hardware measurements. Our results highlight how periodic driving, disorder, and quantum correlations stabilize exotic non-equilibrium phases in realistic quantum systems.

Keywords: discrete time crystal, non-equilibrium quantum phase, many-body scars, matrix product states, two-dimensional tensor network states, superconducting processor

[89] Masanori Hanada (Queen Mary University of London).

Exponential Speedup in Digital Quantum Simulation of Non-Abelian Gauge Theories.

Presenter: Jad Halimeh

Abstract: Nearly two decades after the seminal work by Byrnes and Yamamoto, a scalable digital quantum simulation protocol for non-Abelian gauge theories, such as QCD, in more than one spatial dimension has remained elusive. Most approaches have focused on the Kogut-Susskind formulation, yet all known protocols to date suffer from exponentially growing costs (specifically, circuit depth and the number of classical input parameters) in terms of the number of qubits. This makes practical simulation of physically relevant regimes infeasible, even with fault-tolerant universal quantum computers.

In this talk, we present a class of digital quantum simulation protocols that achieve an exponential speedup in resource efficiency. Our approach is based on the orbifold lattice Hamiltonian, a generalization that encompasses the Kogut-Susskind Hamiltonian as a special case. The resulting quantum circuits are remarkably simple and written down by hand; they can be constructed explicitly using only CNOT gates and single-qubit rotations whose numbers are proportional to the lattice volume. Our protocol is universally applicable to SU(N) gauge theories in arbitrary spatial dimensions and with arbitrary matter content. These results mark a substantial step forward toward feasible quantum simulation of non-Abelian gauge dynamics, with potential implications for high-energy physics, quantum field theory, and beyond.

Reference: 2011.06576 [hep-th], 2401.12045 [hep-th], 2411.13161 [quant-ph], and three papers to appear

Keywords: Quantum Simulations, Quantum Field Theory, Quantum Chromodynamics, Quantum Gravity

[92] Zain Hamid Saleem (Mathematics and Computer Science Division, Argonne National Laboratory, Lemont, IL), Anil Shaji (School of Physics, IISER Thiruvananthapuram, Kerala, India), Anjala Mullaparambil Babu (School of Physics and Applied Physics Southern Illinois University Carbondale), Da-Wei Luo (Center for Quantum Science and Engineering and Department of Physics,Stevens Institute of Technology,New Jersey), Quinn Langfitt (Department of Computer Science, Northwestern University, Evanston, IL), Ting Yu (Center for Quantum Science and Engineering and Department of Physics,Stevens Institute of Technology,New Jersey) and Stephen Gray (Center for Nanoscale Materials, Argonne National Laboratory, Lemont, IL).

Quantum Fisher Information and the Curvature of Entanglement.

Presenter: Anjala Mullaparambil Babu

Abstract: We explore the relationship between quantum Fisher information (QFI) and the second derivative of concurrence with respect to the coupling between two qubits, referred to as the curvature of entanglement (CoE). For a two-qubit quantum probe used to estimate the coupling constant appearing in a simple interaction Hamiltonian, we show that at certain times CoE = −QFI; these times can be associated with the concurrence, viewed as a function of the coupling parameter, being a maximum. We examine the time evolution of the concurrence of the eigenstates of the symmetric logarithmic derivative and show that, for both initially separable and initially entangled states, simple product measurements suffice to saturate the quantum Cram´er-Rao bound when CoE = −QFI, while otherwise, in general, entangled measurements are required giving an operational significance to the points in time when CoE = −QFI.

Keywords: Quantum metrology, Quantum sensing, Quantum Cramer-Rao bound, Quantum Fisher Information, Entanglement, Concurrence

[96] Dominik Hahn (Oxford University), Ryan Sweke (African Institute for Mathematical Sciences, South Africa), Abhinav Deshpande (BM Quantum, IBM Research – Almaden, San Jose) and Oles Shtanko (IBM Quantum, IBM Thomas J. Watson Research Center, Yorktown Height).

Quantum Gibbs Sampling with Local Circuits.

Presenter: Dominik Hahn

Abstract: State preparation is a foundational task in the simulation of quantum many-body systems. Recently, specific classes of quasilocal Lindbladian operators have been proposed that drive systems toward Gibbs states al long times. In this talk, I will demonstrate an implementation of that dynamics on near-term quantum devices.

To achieve this, I show that a truncation of the jump operators to strictly local terms introduces controllable and well-characterized errors. This locality enables a Trotterization approach to simulate the Lindbladian dynamics via quantum circuits. I further demonstrate that these circuits can be compiled with moderate gate overhead, making them feasible for implementation on current noisy intermediate-scale quantum (NISQ) hardware.

Finally, I present numerical results that explore the robustness of this method under realistic noise models and discuss the trade-offs between convergence time, gate cost, and accuracy in achieving thermal states.

Keywords: Thermal state preparation, Quantum Gibbs sampling, Quantum simulation

[97] Sivaprasad Omanakuttan (JP Morgan Chase), Zichang He (JP Morgan Chase), Zhiwei Zhang (JP Morgan Chase), Tianyi Hao (JP Morgan Chase), Arman Babakhani (JP Morgan Chase), Shouvanik Chakrabarti (JP Morgan Chase), Dylan Herman (JP Morgan Chase), Joseph Sullivan (JP Morgan Chase), Michael Perlin (JP Morgan Chase), Ruslan Shaydulin (JP Morgan Chase), Marco Pistoia (JP Morgan Chase) and Sami Boulebnane (JP Morgan Chase).

Threshold for Fault-tolerant Quantum Advantage with the Quantum Approximate Optimization Algorithm.

Presenter: Shouvanik Chakrabarti

Abstract: Hamiltonian evolution is one of the most common primitives in quantum algorithms. For example, optimal quantum algorithm for linear systems relies on adiabatic evolution with a continuously varying Hamiltonian. Consequently, careful compilation of Hamiltonian evolution circuits can dramatically reduce the resource requirements of quantum algorithms, impacting the threshold for quantum advantage. In this work, we compile and analyze the Quantum Approximate Optimization Algorithm (QAOA) combined with Amplitude Amplification (AA) applied to random 8-SAT at the satisfiability threshold. Our compilation involves careful optimization of circuits for Hamiltonian simulation, which may be of independent interest. We use the analytical scaling of the time-to-solution for QAOA identified by PRX Quantum 5, 030348 (2024) and find that with QAOA depth p=623, QAOA+AA achieves a crossover with state-of-the-art classical heuristics at 179 variables and 14.99 hours of runtime when executed on a surface-code-based fault-tolerant quantum computer with 73.91 million physical qubits, a physical error rate of 10−3, and a 1 μs code cycle time. Notably, we allow the classical solver to be parallelized as long as its total energy consumption is equal to that required for decoding in the surface code. We further show that this restriction on classical solver energy consumption can be relaxed given optimistic but plausible reductions in physical error rates and fault-tolerance overheads, enabling a crossover of 2.94 hours using 8.88 million physical qubits against a classical solver running on a supercomputer with 725,760 CPU cores. These findings support the hypothesis that large-scale fault-tolerant quantum computers will be useful for optimization based on Hamiltonian evolution.

Keywords: QAOA, Random Satisfiability, Surface Code, Fault Tolerant Quantum Computation, Fault Tolerant compilation

[98] Stefano Barison (Institute of Physics, Ecole Polytechnique Federale de Lausanne (EPFL)), Javier Robledo Moreno (IBM Quantum, IBM T. J. Watson Research Center) and Mario Motta (IBM Quantum, IBM T. J. Watson Research Center).

Quantum-centric computation of molecular excited states with extended sample-based quantum diagonalization.

Presenter: Javier Robledo Moreno

Abstract: The quantum simulation of molecular electronic structure is an important application of quantum devices. Recent developments have demonstrated that quantum devices can be effectively combined with classical supercomputing resources in the context of the sample-based quantum diagonalization (SQD) algorithm. This allowed the largest electronic structure quantum simulation to date (77 qubits) and opened near-term devices to practical use cases in chemistry toward the hundred-qubit mark. However, the description of many important physical and chemical properties of those systems, such as photo-absorption/-emission, requires a treatment that goes beyond the ground state alone. In this work, we extend the SQD algorithm to determine low-lying molecular excited states. The extended-SQD method improves over the original SQD method in accuracy, at the cost of an additional computational step. It also improves over quantum subspace expansion based on single and double electronic excitations, a widespread approach to excited states on pre-fault-tolerant quantum devices, in both accuracy and efficiency. The extended SQD method is used to compute the first singlet (S1) and triplet (T1) excited states of the nitrogen molecule with a correlation-consistent basis set, and the ground- and excited-state properties of the [2Fe-2S] cluster

Keywords: Quantum Simulation, Quantum Chemistry, Excited States

[105] Evan Borras (University of New Mexico) and Milad Marvian (University of New Mexico).

Towards Optimal Lindbladian Simulation.

Presenter: Evan Borras

Abstract: Quantum simulation has emerged as a key application of quantum computing, with significant progress made in algorithms for simulating both closed and open quantum systems. The simulation of open quantum systems, particularly those governed by the Lindblad master equation, has received attention recently with the current state-of-the-art algorithms having an input model query complexity of O(Tpolylog(T/ε)), where T and ε are the requested time and precision of the simulation respectively. For Hamiltonian simulation it has been show that the optimal Hamiltonian query complexity is O(T + log(1/ε)), additive in nature between the two parameter, but for Lindbladian simulation this question remains open. In this work we provide evidence that the additive complexity of O(T + log(1/ε)) is reachable for the Lindbladian simulation problem by constructing a novel quantum algorithm achieving this query complexity for a large class of Lindbladians.

Keywords: Quantum simulation, Quantum algorithms, Open Quantum Systems

[113] William Kirby (IBM Quantum), Roel Van Beeumen (Lawrence Berkeley National Laboratory), Daan Camps (Lawrence Berkeley National Laboratory), Anirban Chowdhury (IBM Quantum), Katherine Klymko (Lawrence Berkeley National Laboratory) and Yizhi Shen (Lawrence Berkeley National Laboratory).

Quantum Krylov Algorithm for Szegö Quadrature.

Presenter: William Kirby

Abstract: We present a quantum algorithm to evaluate matrix elements of functions of unitary operators. The method is based on using the quantum computer to calculate nodes and weights comprising a quadrature rule, which can then be used to approximate matrix elements of any desired function of a fixed unitary operator between a fixed pair of states. The unitary operator could approximate a time evolution, opening the door to applications like estimating properties of Hamiltonian spectra and Gibbs states, but more generally could be any operator implementable via a quantum circuit. While the pair of states identifying the matrix element must be known a priori, once the quadrature rule is constructed it can be used to approximate the matrix element for any function of the unitary, with only the accuracy of the approximation depending on the choice of unitary. We expect this algorithm to be useful as a subroutine in other quantum algorithms, much like quantum signal processing or the quantum eigenvalue transformation of unitaries.

Keywords: quantum Krylov algorithms, numerical quadrature, quantum numerical linear algebra, quantum signal processing

[116] Alan Duriez (IBM Research), Pamela Carvalho (IBM Research), Marco Antonio Barroca (IBM Research), Federico Zipoli (IBM Research), Ben Jaderberg (IBM Quantum), Rodrigo Barros Ferreira (IBM Research), Kunal Sharma (IBM Quantum), Antonio Mezzacapo (IBM Quantum), Benjamin Wunsch (IBM Research) and Mathias Steiner (IBM Research).

A sample-based quantum diagonalization framework for periodic solids.

Presenter: Alan Duriez

Abstract: State-of-the-art techniques in computational materials science often fail to capture many-body interactions in periodic systems. One particular application is the electronic structure problem, where established approaches such as Density Functional Theory are applied to predict experimental results. In this contribution, we present a sample-based quantum diagonalization (SQD) workflow for simulating the electronic ground state of periodic materials, and for predicting their band gaps. We obtain a fermionic Hamiltonian for crystalline solids by first projecting the electronic density obtained by density functional theory onto a localized basis set and then adding interaction parameters obtained by a self-consistent field theory. We then build an approximation of the system's ground-state wavefunction with the local unitary cluster Jastrow (LUCJ) ansatz. By sampling the quantum circuit and classically diagonalizing the Hamiltonian in the resulting configuration subspace, we predict the band gap energy of representative materials and obtain agreement with experimental results. The predicted bandgaps were obtained from calculations using 38 and 46 qubits, performed on a superconducting quantum processor, with minimal error-mitigation overhead. Our self-consistent approach offers a scalable pathway for utility-scale quantum simulation of materials.

Keywords: material science, quantum simulation, quantum computing

[124] Jiaqi Leng (University of California, Berkeley), Zhiyan Ding (University of California, Berkeley), Zherui Chen (University of California, Berkeley) and Lin Lin (University of California, Berkeley).

Operator-Level Quantum Acceleration of Non-Logconcave Sampling.

Presenter: Jiaqi Leng

Abstract: Sampling from distributions in the form $\sigma \propto e^{-\beta V}$ is a fundamental task in physics, chemistry, biology, computer science, and statistics. In general settings where V is nonconvex (i.e., non-logconcave sampling), classical approaches such as Langevin dynamics are known to struggle. Despite the progress in quantum algorithms for accelerating discrete Markov chains over the past two decades, a quantum counterpart for accelerating Langevin dynamics has remained elusive. We introduce the first quantum algorithm that accelerates Langevin dynamics for general continuous potentials with provable speedups. Instead of attempting to solve the Langevin stochastic differential equation or the underlying Fokker--Planck equation on a quantum computer, our method encodes the target Gibbs measure into the amplitudes of a quantum state. This encoded Gibbs state is characterized as the kernel of a specially constructed block matrix, which is closely related to the Witten Laplacian operator. Building on this framework, we also develop the first quantum algorithm that accelerates the classical replica exchange dynamics, a widely used classical technique beyond Langevin dynamics for sampling from rugged energy landscapes.

Keywords: Quantum algorithms, Non-logconcave sampling, Gibbs sampling, Ground state preparation, Quantum numerical linear algebra

[131] Yi Zhu (Harvard University), Haley Nguyen (Harvard University), Charles Staub (Harvard University), Bob Bao (Harvard University) and Giulia Semeghini (Harvard University).

A mixed-species quantum simulator.

Presenter: Yi Zhu

Abstract: We present our ongoing efforts toward creating a continuously reloaded, programmable neutral atom array based on a mixture of Rb and Yb. Single-species atom arrays have recently enabled exciting applications in quantum information, simulation, and metrology. The addition of a second atomic species opens new possibilities for implementing selective qubit control, engineering asymmetric inter- and intra-species Rydberg interactions, and exploring novel architectures for quantum simulation. Additionally, continuous replenishment of both atomic species is central to improving scalability and circuit depths, while decreasing cycle times. We present progress toward realizing this new quantum platform and discuss its applications to quantum simulation—from simulating lattice gauge theories to exploring fermionic models.

Keywords: atom array, dual-species, continuous reloading, Yb-Rb

[133] Zecheng Li (The Pennsylvania State University) and Chunhao Wang (Penn State University).

Improved Quantum Simulation of Time-Dependent Hamiltonians with Simpler Discrete-Clock Constructions.

Presenter: Zecheng Li

Abstract: In this paper, we present a proof-of-concept quantum algorithm for simulating time-dependent Hamiltonian evolution with discrete-clock constructions. Our algorithm reduces the simulation problem to simulating a time-independent Hamiltonian in a larger space by a discrete clock Hamiltonian construction, which was first explored in this application by Watkins, Wiebe, Roggero, and Lee [PRX Quantum, 2024]. We improve the dependence on evolution time and precision of the simulation algorithm compared with the previous work based on a simpler discrete-clock construction. In addition, the complexity matches the state-of-the-art simulation algorithms using other approaches. To achieve this improvement, we use Duhamel's principle to treat the clock and system Hamiltonians separately and exploit properties of Gaussian quadrature to reduce the simulation cost. Our approach demonstrates that time-dependent Hamiltonian simulation can be as efficient in a simpler framework and hence provides a new angle to model and simulate time-dependent systems.

Keywords: Time-dependent Hamiltonian simulation, clock construction, Gaussian quadrature, Duhamel's principle

[150] Gaurav Gyawali (Cornell University), Henry Shackleton (Massachusetts Institute of Technology), Zhu-Xi Luo (Georgia Tech) and Michael Lawler (Binghamton University).

Emergent coding phases and hardware-tailored quantum codes.

Presenter: Michael Lawler

Abstract: Some quantum codes, with the surface code as a prominent example, arose from models of physical systems. Yet it is the opposite problem of finding codes to correct errors in physical systems, which is a central problem of quantum information theory. The quantum capacity theorem sheds light on this problem. Viewing the noise produced by a quantum computer over a short enough time interval as a quantum channel, there exists an optimal state which maximizes the coherent information for ``one use'' of the channel. The theorem guarantees that this optimal state provides the information required to build a code that can send quantum information perfectly through the channel, provided we have access to multiple uses of the channel. Using periodically applied error correction that decodes and corrects errors disrupting these optimal states can, therefore, allow information to propagate indefinitely through the channel. We show that this implies the optimal state defines a coding phase. We explore these ideas in the context of a quantum channel model related to quantum circuits, which we call the open random unitary model (ORUM). It replaces two-qubit unitaries with depolarizing channels associated with averaging such unitaries, and replaces measurements with single-qubit dephasing channels. Through numerical optimization, we find that the ORUM hosts three coding phases: the ``maximally mixed code'' phase, a ``Z_2 code'' phase (where ORUM's $U(1)$ gauge symmetry is broken down to Z_2), and a no-coding phase where information is lost. These phases exhibit first-order transitions between them and converge at a novel zero capacity multi-critical point. Though the quantum capacity theorem asserts the existence of a code defined by these optimal states, we introduce two practical error correction procedures and study how they alter the ideal phase diagram found from the study of a single time step. Carrying out our optimization procedure on current noisy devices could provide a systematic way to construct quantum codes for robust computation.

Keywords: Coding Phases, Noise Model, Hardware-Tailored Codes, Quantum Capacity

[155] Nikolay Gnezdilov (Dartmouth College), Hugo Perrin (University of Strasbourg), Thibault Scoquart (Karlsruhe Institute of Technology) and Andrei Pavlov (Karlsruhe Institute of Technology).

Dynamic thermalization on noisy quantum hardware.

Presenter: Nikolay Gnezdilov

Abstract: Emulating thermal observables on a digital quantum computer is essential for quantum simulation of many-body physics. However, thermalization typically requires a large system size due to incorporating a thermal bath, whilst limited resources of near-term digital quantum processors allow for simulating relatively small systems. We show that thermal observables and fluctuations may be obtained for a small closed system without a thermal bath. Thermal observables occur upon classically averaging quantum mechanical observables over randomized variants of their time evolution that run independently on a digital quantum processor. Using an IBM quantum computer, we experimentally find thermal occupation probabilities with finite positive and negative temperatures defined by the initial state's energy. Averaging over random evolutions facilitates error mitigation, with the noise contributing to the temperature in the simulated observables. This result fosters probing the dynamical emergence of equilibrium properties of matter at finite temperatures on noisy intermediate-scale quantum hardware.

Keywords: Quantum simulation, Thermalization, State preparation, Quantum many-body dynamics

[168] Arman Duha (Oklahoma State University), Samuel Begg (The University of Texas at Dallas) and Thomas Bilitewski (Oklahoma State University).

Nonequilibrium Universality of a Squeezing Phase Transition.

Presenter: Arman Duha

Abstract: We investigate phase transitions in the nonequilibrium dynamics of power-law interacting spin-1/2 bilayer XXZ models, which have recently been shown to allow generation of entanglement in the form of two-mode squeezing. We find a transition between a phase characterized by Heisenberg limited squeezing and a

partially collective phase. We identify universal scaling of the squeezing dynamics in terms of system parameters and a divergent time-scale, establishing these as distinct dynamical phases. Our work demonstrates a novel dynamical phase transition with potential applications in quantum sensing and quantum simulation in cold-atomic, molecular or Rydberg platforms.

Keywords: Dynamical Phase Transition, Spin Squeezing, Floquet Engineering, Entanglement Production, Quantum-Enhanced Sensing

[182] Daniel Mark (MIT), Federica Surace (Trinity College Dublin), Thomas Schuster (Caltech), Adam Shaw (Stanford University), Wenjie Gong (MIT), Soonwon Choi (MIT) and Manuel Endres (Caltech).

High-energy plasma dynamics and memory effects in a 60-atom lattice gauge quantum simulator.

Presenter: Daniel Mark

Abstract: We use a 60-atom Rydberg quantum simulator to experimentally investigate a lattice gauge theory of quantum electrodynamics in one spatial dimension. We report several experimental surprises in its dynamics: despite the quench being at infinite temperature, correlations propagate ballistically to long distances, and there are short-range correlations that do not reach thermal equilibrium within experimental timescales. Our observations are simply explained in terms of plasma oscillations arising from pair production in response to electric fields. This description yields a number of physical insights, including new families of many-body scars and a method to visualize the many-body dynamics with Wigner distributions. We also identify an interference mechanism which results in a long memory of clustering of charged particles, an effect which is not present in the continuum field theory. Our work discovers a common, gauge-theoretic origin to many dynamical phenomena in Rydberg blockaded systems, resolving existing questions and expanding the phenomenology, and hint at the possibilities for discoveries from detailed quantum simulations of lattice gauge theories.

Keywords: Lattice gauge theory, Nonequilibrium quantum dynamics, Rydberg atom array

Session 2: Thursday, August 7, 2025

[62] Mohammed Alghadeer (University of Oxford), Shuxiang Cao (University of Oxford), Simone D. Fasciati (University of Oxford), Michele Piscitelli (University of Oxford), Mustafa Bakr (University of Oxford) and Peter J. Leek (University of Oxford).

Scalable Superconducting Quantum Lattice with Low Crosstalk.

Presenter: Mohammed Alghadeer

Abstract: Realizing large-scale superconducting quantum circuits containing individually addressable, high-coherence qubits remains a significant hardware challenge toward utility-scale quantum computing (1,2). Efforts to scale up these systems are hindered by technical challenges including Josephson junction fabrication yield, precise frequency targeting, and quantum crosstalk. As the number of qubits increases, spurious modes and residual inter-qubit interactions can degrade performance and reduce the fidelity of quantum operation. Overcoming these limitations requires scalable architectures that minimize parasitic couplings while maintaining robust connectivity. Scalable two-dimensional (2D) lattice architectures enable the implementation of logical operations using quantum error-correction codes (3–5), such as the surface code6, and the simulation of 2D lattice Hamiltonian, including the Bose–Hubbard mode (l7), in condensed matter8,9 and atomic physics10. While increasing qubit counts is crucial for realizing practical applications, scaling superconducting qubits currently introduces significant obstacles related to maintaining overall device performance and integrating high connectivity without introducing additional errors in gate operations (11). Although significant efforts have been made to improve fabrication techniques (12–15) and minimize hardware requirements (16,17), scaling superconducting qubits using simplified architectures is crucial to mitigate fabrication defects (18–20) and reduce hardware overhead (21). Ultimately, a practical superconducting quantum computer must integrate a large number of physical qubits with robust connectivity and fast, high-fidelity gates for fault-tolerant protocols (18).

In this work, we present the characterization of a 4x4 square lattice of fixed frequency transmon qubits with nearest-neighbour capacitive coupling, demonstrating low crosstalk and single-qubit gate errors across the device. We realize this device in a tileable 3D-integrated circuit architecture (22) which has previously been shown to support high coherence and low crosstalk23, and is expected to maintain performance at larger scales due to its simplicity and the use of off-chip inductive shunting to eliminate spurious enclosure modes (24). Each qubit is capacitively coupled through the substrate to a readout resonator positioned on the opposite side of the chip, featuring a tileable unit cell (see Fig. 1 (a)). This approach enables individual qubit control and readout in a compact lattice architecture (see Fig. 1 (b) and (c)). We implement off-chip inductive shunting on the device enclosure to mitigate box-mediated residual crosstalk originating from parasitic enclosure modes23,24. Each qubit is capacitively coupled to its four nearest neighbors via lithographically patterned capacitive arms, facilitating interactions characterized by exchange energy rates Ji, j between each pair of qubits (see Fig. 1 (b)). We will discuss the design and fabrication process of the device, and show measurements of qubit coherence, single and two-qubit gates, and inter-qubit couplings across the lattice.

[71] Tianfeng Feng (University of Hong Kong), Jue Xu (University of Hong Kong), Wenjun Yu (University of Hong Kong), Zekun Ye (Nanjing University), Penghui Yao (Nanjing University) and Qi Zhao (University of Hong Kong).

Distributed Quantum Simulation.

Presenter: Jue Xu

Abstract: Quantum simulation is a promising pathway toward practical quantum advantage by simulating large-scale quantum systems. In this work, we propose communication-efficient distributed quantum simulation protocols by exploring three quantum simulation algorithms, including the product formula, the truncated Taylor series, and the quantum signal processing over a quantum network. Our protocols are further shown to be optimal by deriving a lower bound on the quantum communication complexity for distributed quantum simulations with respect to evolution time and the number of distributed quantum processing units. Additionally, our distributed techniques go beyond quantum simulation and are applied to distributed versions of Grover's algorithms and quantum phase estimation. Our work not only paves the way for achieving a practical quantum advantage by scalable quantum simulation but also enlightens the design of more general distributed architectures across various physical systems for quantum computation.

Keywords: quantum simulation, quantum communication, quantum algorithms, quantum network

[106] Abhinav Muraleedharan (University of Toronto) and Nathan Wiebe (University of Toronto).

Simulating Time Dependent and Nonlinear Classical Oscillator Systems through Nonlinear Schrödingerization.

Presenter: Abhinav Muraleedharan

Abstract: We present quantum algorithms for simulating the dynamics of a broad class of classical oscillator systems containing 2^n coupled oscillators (Eg: 2^nn masses coupled by springs), including those with time-dependent forces, time- varying stiffness matrices, and weak nonlinear interactions. We achieve this generalization of the Harmonic oscillator simulation algorithm through an ap- proach that we call “Nonlinear Schrödingerization”, which involves reduction of the dynamical system to a nonlinear Schrödinger equation and then reduced to a time-independent Schrodinger Equation through perturbative techniques. The linearization of the equation is performed using a new approach that al- lows us to approximate the dynamics of a nonlinear Schrödinger equation as a linear Schrödinger equation in a higher dimensional space. This allows us to then use the Hamiltonian Simulation framework to simulate the resulting system’s dynamics. When the properties of the classical dynamical systems can be efficiently queried, and when the initial state can be efficiently pre- pared, the complexity of our quantum algorithm is polynomial in n, and almost linear in evolution time for most dynamical systems. Our work significantly extends the applicability of quantum algorithms to simulate the dynamics of non-conservative and nonlinear classical systems, addressing key limitations in previous approaches.

Keywords: Quantum Simulation, Differential Equations, Nonlinear Differential Equations

[109] Abhinav Deshpande (IBM), Marcel Hinsche (FU Berlin), Sona Najafi (IBM), Kunal Sharma (IBM), Ryan Sweke (IBM) and Christa Zoufal (IBM).

Dynamic parameterized quantum circuits: expressive and barren-plateau free.

Presenter: Abhinav Deshpande

Abstract: Classical optimization of parameterized quantum circuits is a widely studied methodology for the preparation of complex quantum states, as well as the solution of machine learning and optimization problems. However, it is well known that many proposed parameterized quantum circuit architectures suffer from drawbacks which limit their utility, such as their classical simulability or the hardness of optimization due to a problem known as "barren plateaus". We propose and study a class of dynamic parameterized quantum circuit architectures. These are parameterized circuits containing intermediate measurements and feedforward operations. In particular, we show that these architectures:

1. Provably do not suffer from barren plateaus.

2. Are expressive enough to describe arbitrarily deep unitary quantum circuits.

3. Are competitive with state of the art methods for the preparation of ground states and facilitate the representation of nontrivial thermal states. These features make the proposed architectures promising candidates for a variety of applications.

Keywords: variational quantum algorithms, barren plateaus, quantum optimization

[132] Ahmet Burak Catli (University of Toronto), Sophia Simon (University of Toronto) and Nathan Wiebe (University of Toronto).

Exponentially Better Bounds for Quantum Optimization via Dynamical Simulation.

Presenter: Sophia Simon

Abstract: We provide several quantum algorithms for continuous optimization that do not require any gradient estimation. Instead, we encode the optimization problem into the dynamics of a physical system and coherently simulate the time evolution. This allows us, in certain cases, to obtain exponentially better query upper bounds relative to the best known upper bounds for gradient-based optimization schemes which utilize quantum computers only for the evaluation of gradients. Our first two algorithms can find local optima of a differentiable function $f: \mathbb{R}^N \rightarrow \mathbb{R}$ by simulating either classical or quantum dynamics with friction via a time-dependent Hamiltonian. We show that these methods require $O(N^2\kappa^2/h_x^2\epsilon)$ queries to a phase oracle to find an ϵ-approximate local optimum of a locally quadratic objective function, where κ is the condition number of the Hessian matrix and h_x is the discretization spacing. In contrast, we show that gradient-based methods require $O(N^{3/2}(1/\epsilon)^{\kappa \log(3)/4})$ queries. Our third algorithm can find the global optimum of f by preparing a classical low-temperature thermal state via simulation of the classical Liouvillian operator associated with the Nosé Hamiltonian. We use results from the quantum thermodynamics literature to bound the thermalization time for the discrete system. Additionally, we analyze barren plateau effects that commonly plague quantum optimization algorithms and observe that our approach is vastly less sensitive to this problem than standard gradient-based optimization. Our results suggests that these dynamical optimization approaches may be far more scalable for future quantum machine learning, optimization and variational experiments than was widely believed.

Keywords: Continuous Optimization, Quantum Algorithms, Quantum Simulation, Gradient Descent

[134] Siddharth Hariprakash (BlueQubit Inc), Vincent Su (BlueQubit Inc), Mohammed Zuhair Mullath (BlueQubit Inc) and Hrant Gharibyan (BlueQubit Inc).

Benchmarking Coefficient based Sparse Pauli Dynamics Simulators for Utility-Scale Quantum Experiments.

Presenter: Siddharth Hariprakash

Abstract: This paper presents a novel and conceptually simple benchmarking protocol for evaluating the applicability of coefficient-based Sparse Pauli Dynamics (CSPD) simulation methods for quantum simulation. Notably, such techniques have generated excitement for their ability to unlock accurate estimates of utility-scale quantum circuits with over 100 qubits as demonstrated in [BGC23, BcvacC25]. Our methodology provides a resource-efficient approach to determine whether CSPD is suitable for specific quantum problems by analyzing convergence patterns of observable expectation values with a constraint on computational resources. We show that by combining the numerical dependence of the expectation values on the coefficient threshold δ with the scaling of the runtime with δ, one can easily extrapolate whether CSPD provides a reliable estimate for the quantum simulation problem at hand. We apply our methodology to the class of circuits used in the IBM utility-scale kicked Ising model experiment performed in [K+23]. We provide further analytical and numerical insight into the mathematical structure of CSPD. Specifically we study the distributions of the coefficients of the evolved observables in the Pauli basis as well as the growth in the number of Pauli operators required to represent the evolved observables. We use these results to place place practical bounds on the maximum number of Pauli operators present at any given step in the evolution as a function of δ, which ties directly to the memory and runtime requirements of CSPD. All expectation value and runtime results are generated using functionality available in our platform, offering the first comprehensive benchmarking toolset for understanding the practical limitations of this powerful classical simulation approach.

Keywords: Quantum Computing, Classical Simulation, Observable Expectation Values, Benchmarking

[137] Ye Ma (UCSB) and Murphy Niu (Department of Computer Science, UCSB).

MoSAIC: A Framework for Knitting Error Mitigation via Spatio-Temporal Noise Scopes.

Presenter: Ye Ma

Abstract: This work introduces MoSAIC, a novel quantum error mitigation framework that uniquely combines Probabilistic Error Cancellation (PEC) with circuit partitioning methods to significantly improve scalability and effectively mitigate correlated errors in quantum circuits. By decomposing large quantum circuits into smaller, manageable sub-circuits, MoSAIC confines errors within local noise scopes. Each sub-circuit undergoes targeted error recovery, substantially reducing sampling overhead compared to traditional methods. Extensive numerical experiments, including a detailed study on 8-qubit fixed-point Grover search circuit and 3x3 qubit Ising model, demonstrate MoSAIC's performance in handling correlated errors and scaling efficiently to deeper, more complex quantum circuits.

Keywords: Quantum Error Mitigation, Probabilistic Error Cancellation, Circuit Knitting, Correlated Error

[138] Faisal Alam (University of Illinois at Urbana-Champaign) and Bryan Clark (University of Illinois at Urbana-Champaign).

Learning dynamic quantum circuits for efficient state preparation.

Presenter: Faisal Alam

Abstract: Dynamic quantum circuits (DQCs) incorporate mid-circuit measurements and gates conditioned on these measurement outcomes. DQCs can prepare certain long-range entangled states in constant depth, making them a promising route to preparing complex quantum states on devices with a limited coherence time. Almost all constructions of DQCs for state preparation have been formulated analytically, relying on special structure in the target states. In this work, we approach the problem of state preparation variationally, developing scalable tensor network algorithms which find high-fidelity DQC preparations for generic states. We apply our algorithms to critical states, random matrix product states, and subset states. We consider both DQCs with a fixed number of ancillae and those with an extensive number of ancillae. Even in the few ancillae regime, the DQCs discovered by our algorithms consistently prepare states with lower infidelity than a static quantum circuit of the same depth. Notably, we observe constant fidelity gains across system sizes and circuit depths. For DQCs with an extensive number of ancillae, we introduce scalable methods for decoding measurement outcomes, including a neural network decoder and a real-time decoding protocol. Our work demonstrates the power of an algorithmic approach to generating dynamic circuits, broadening their scope of applications to new areas of quantum computing.

Keywords: dynamic quantum circuits, state preparation, measurement and feedforward, long range entanglement

[139] Suying Liu (University of Maryland, College Park), Xiaodi Wu (University of Maryland, College Park) and Murphy Yuezhen Niu (University of California, Santa Barbara).

Optimal and Robust Quantum Hamiltonian Learning through Parallelization.

Presenter: Suying Liu

Abstract: Learning the underlying Hamiltonian of a quantum system is essential for accurate simulation of many-body dynamics, improving quantum device fidelity, and enabling quantum-enhanced sensing. While quantum metrology methods focus on achieving Heisenberg-limited precision for few-qubit systems, and general Hamiltonian learning addresses broader classes of unknown Hamiltonian models, both approaches are often impractical or inefficient in realistic scenarios where the Hamiltonian structure is predetermined by the device architecture. In this work, we address two key challenges in realistic Hamiltonian learning: leveraging prior structural knowledge to reduce learning costs and ensuring robustness against decoherence and time-dependent coherent errors. We introduce a fully robust learning algorithm tailored for parallel-learnable Hamiltonians, inspired by the structure of physical platforms such as Rydberg atom arrays and superconducting qubit systems. Our method achieves a quadratic speedup in sample complexity relative to the number of parameters, reaches the Heisenberg limit, and matches the asymptotic lower bound for estimating all-to-all connected Hamiltonians. Besides, we provide a comprehensive experimental proposal and corresponding numerical simulations on Rydberg atom quantum simulators for practical, high-precision Hamiltonian learning in the NISQ era.

Keywords: Robust quantum metrology, Hamiltonian learning, Quantum simulation verification

[140] Nadie Litenn (Brandeis University), Tianci Zhou (Virginia Tech) and Brian Swingle (Brandeis University).

Scrambling Dynamics with Imperfections in a Solvable Model.

Presenter: Nadie LiTenn

Abstract: We study how probes of quantum scrambling dynamics respond to two kinds of imperfections --- unequal forward and backward evolutions and decoherence --- in a solvable Brownian circuit model. We calculate a ``renormalized'' out-of-time-order correlator (ROTOC) in the model with N qubits, and we show that the ROTOC is controlled by an effective probability distribution in the weight space which obeys a system of N non-linear equations of motion that can be easily solved numerically for large system sizes which are beyond the reach of exact methods. Moreover, for an operator initially concentrated on weight one $w_0=1$, we provide an exact solution to the equations in the thermodynamic limit of many qubits that is valid for all times, all non-vanishing perturbation strengths $p\gtrsim 1/\sqrt{N}$, and all decoherence strengths. We also show that a generic initial condition $w_0 >1$ leads to a metastable state that eventually collapses to the $w_0=1$ case after a lifetime $\sim \log(N/w_0)$. Our results highlight situations where it is still possible to extract the unperturbed chaos exponent even in the presence of imperfections, and we comment on the applications of our results to existing experiments with nuclear spins and to future scrambling experiments.

Keywords: Out of time order correlator, Quantum chaos, Information scrambling, Brownian circuit, Noise, Imperfection, Decoherence, Localization

[144] Ayushi Dubal (Department of Computer Sciences, University of Wisconsin-Madison, Madison, WI 53706), David Kremer (IBM Quantum, IBM T.J. Watson Research Center, Yorktown Heights, NY 10598), Simon Martiel (IBM Quantum, IBM France Lab, Saclay, France), Victor Villar (IBM Quantum, IBM T.J. Watson Research Center, Yorktown Heights, NY 10598), Derek Wang (IBM Quantum, IBM T.J. Watson Research Center, Yorktown Heights, NY 10598) and Juan Cruz-Benito (IBM Quantum, IBM T.J. Watson Research Center, Yorktown Heights, NY 10598).

Optimization of Hamiltonian Simulation Circuits with Reinforcement Learning.

Presenter: Ayushi Dubal

Abstract: Simulating quantum Hamiltonians is a cornerstone application for near-term quantum devices. However, compiling these circuits efficiently remains a significant challenge due to architectural constraints and the sparsity and structure of simulation workloads. In this work, we present a reinforcement learning-based compilation framework specifically designed for Hamiltonian simulation circuits composed of Pauli networks - sequences of Clifford gates and arbitrary-angle Pauli rotations. Unlike traditional heuristic methods, which often struggle with connectivity-induced local optima, our approach uses Proximal Policy Optimization (PPO) to learn globally optimal synthesis strategies that are architecture-aware and parameter-preserving.

We demonstrate our method on the HamLib Benchpress benchmark suite, which includes circuits from quantum chemistry, condensed matter, and high-energy physics. Our RL-based compiler achieves up to 4× shallower circuits and up to 60% reduction in 2-qubit gates compared to standard tools like Qiskit and Rustiq. The method scales to circuits with over 80k 2-qubit gates in under two minutes of runtime. This result shows that structure-aware, learning-based compilation can enable large-scale, exact Hamiltonian simulation on today's quantum hardware.

Keywords: Hamiltonian Simulation, Quantum Compilation, Reinforcement Learning

[145] Zhenning Liu (University of Maryland, College Park), Xiantao Li (Department of Mathematics, Pennsylvania State University), Chunhao Wang (Department of Computer Science and Engineering, Pennsylvania State University) and Jin-Peng Liu (Yau Mathematical Sciences Center, Tsinghua University). ***Toward end-to-end quantum simulation for protein dynamics.***

Presenter: Zhenning Liu

Abstract: Modeling and simulating the protein folding process overall remains a grand challenge in computational biology. We systematically investigate end-to-end quantum algorithms for simulating various protein dynamics with effects, such as mechanical forces or stochastic noises. A major focus is the read-in of system settings for simulation, for which we discuss (i) efficient quantum algorithms to prepare initial states—whether for ensemble or single-state simulations, in particular, the first efficient procedure for preparing Gaussian pseudo-random amplitude states, and (ii) the first efficient loading of the connectivity matrices of the protein structure. For the read-out stage, our algorithms estimate a range of classical observables, including energy, low-frequency vibrational modes, density of states, displacement correlations, and optimal control parameters. Between these stages, we simulate the dynamic evolution of the protein system, by using normal mode models—such as Gaussian network models (GNM) and all-atom normal mode models. In addition, we conduct classical numerical experiments focused on accurately estimating the density of states and applying optimal control to facilitate conformational changes. These experiments serve to validate our claims regarding potential quantum speedups. Overall, our study demonstrates that quantum simulation of protein dynamics represents a robust, end-to-end application for both early-stage and fully fault-tolerant quantum computing.

Keywords: applications of quantum simulation, molecular dynamics, fault-tolerant quantum simulation algorithms, near-term quantum simulation algorithms, computational biology

[146] Nazli Ugur Koyluoglu (Harvard University), Johannes Feldmeier (Harvard University), Nishad Maskara (Harvard University), Alexandra Geim (Harvard University), Simon Evered (Harvard University), Sophie Li (Harvard University), Dolev Bluvstein (Harvard University), Tom Manovitz (Harvard University), Muqing Xu (Harvard University), Sepehr Ebadi (Massachusetts Institute of Technology; Harvard University), Hengyun Zhou (Harvard University; QuEra Computing), Vladan Vuletic (Massachusetts Institute of Technology), Markus Greiner (Harvard University) and Mikhail Lukin (Harvard University).

Floquet engineering of multi-body interactions in periodically driven Rydberg atom arrays.

Presenter: Nazli Ugur Koyluoglu

Abstract: A key challenge of programmable quantum simulation is expanding the class of many-body Hamiltonians that can be realized on current devices. In particular, realizing complex many-body phenomena such as dynamical lattice gauge theories (LGTs) requires implementation of multi-body interactions that are typically not directly available in natural Hamiltonians. We introduce and analyze a novel Hamiltonian engineering technique based on time-dependent control. Our approach leverages controlled perturbations around periodic many-body trajectories as a resource for operator spreading, and uses these time-evolved operators as a basis to realize a broad class of complex multi-body interactions with tunable coefficients. We apply this framework to the neutral atom array platform, to engineer dynamics within the constrained "Rydberg-blockaded" subspace in two settings. First, we show how blockade-consistent exchange interactions on a one-dimensional chain can be engineered, enabling exploration of novel phases with emergent particle number conservation and interesting dynamics of multi-partite entanglement. Second, we demonstrate our ability to implement multi-body ring-exchange interactions in a two-dimensional setting, and present a realistic proposal for investigating unexplored regimes in non-equilibrium dynamics of 2D LGTs.

Keywords: Floquet engineering, multi-body interactions, Rydberg atom arrays, Rydberg blockade, periodic driving, quantum simulation, multi-partite entanglement, Luttinger liquid, lattice gauge theories

[151] Jeffery Yu (University of Maryland, College Park), Yuan Liu (North Carolina State University), Sho Sugiura (Blocq Inc), Troy Van Voorhis (Massachusetts Institute of Technology) and Sina Zeytinoglu (NTT Research, Inc.).

Clifford circuit based heuristic optimization of fermion-to-qubit mappings.

Presenter: Jeffery Yu

Abstract: Simulation of interacting fermionic Hamiltonians is one of the most promising applications of quantum computers. However, the feasibility of analysing fermionic systems with a quantum computer hinges on the efficiency of fermion-to-qubit mappings that encode non-local fermionic degrees of freedom in local qubit degrees of freedom. While recent works have highlighted the importance of designing fermion-to-qubit mappings that are tailored to specific problem Hamiltonians, the methods proposed so far are either restricted to a narrow class of mappings or they use computationally expensive and unscalable brute-force search algorithms. Here, we address this challenge by designing a heuristic numerical optimization framework for fermion-to-qubit mappings. To this end,we first translate the fermion-to-qubit map-ping problem to a Clifford circuit optimization problem, and then use simulated annealing to optimize the average Pauli weight of the problem Hamiltonian. For all fermionic Hamiltonians we have considered, the numerically optimized mappings outperform their conventional counterparts, including ternary-tree-based mappings that are known to be optimal for single creation and annihilation operators.We find that our optimized mappings yield be-tween 15% to 40% improvements on the aver-age Pauli weight when the simulation Hamiltonian has an intermediate level of complexity.Most remarkably, the optimized mappings improve the average Pauli weight for 6×6 nearest-neighbor hopping and Hubbard models by more1than 40% and 20%, respectively. Surprisingly,we also find specific interaction Hamiltonians for which the optimized mapping outperform any ternary-tree-based mapping. Our results establish heuristic numerical optimization as an effective method for obtaining mappings tailored for specific fermionic Hamiltonian.

Keywords: fermion-to-qubit mapping, Jordan-Wigner transformation, Bravyi-Kitaev transformation, Clifford optimization, electronic structure, simulated annealing

[152] Hisham Amer (Virginia Tech), Kyle Sherbert (Virginia Tech), Nicholas Mayhall (Virginia Tech), Edwin Barnes (Virginia Tech) and Sophia Economou (Virginia Tech).

Experimental demonstration of state preparation for quantum simulation algorithms using optimal control.

Presenter: Hisham Amer

Abstract: We experimentally demonstrate how our pulse-based quantum simulation framework can reduce both error mitigation overhead and the runtime of near-term algorithms by several orders of magnitude, placing them well within the capabilities and coherence times of current devices. We test our approach on IBM's superconducting devices. First, we experimentally demonstrate the concept of the minimum evolution time of a state preparation procedure and how it hinges upon a device's accessible set of control parameters. This involves a square shape discretization of our pulse ansatz, where through control of pulse phase and amplitude we experimentally prepare the multiqubit ground state of molecular Hydrogen to chemical accuracy. Additionally, we demonstrate more elaborate pulse-ansatz shaping schemes with both fixed and adaptive pools of pulse shapes. This involves using a pulse basis of Fourier-modes to experimentally prepare the ground states of both molecular Hydrogen and Lithium Hydride at bond lengths 2 and 4 Angstroms respectively, lengths that are harder to solve for. We run these experiments with no error mitigation or suppression beyond simple readout error mitigation, in under 15 and 121 nanoseconds, around a quarter and a third of the gate times of a single X-gate and CNOT respectively.

Keywords: near term algorithms, experimental, IBM devices, superconducting platforms, quantum utility, Scaling, chemical accuracy, quantum optimal control, pulse level, ground state preparation, molecular simulation, compact ansatz, variational

[153] Donghwa Ji (Collage of Liberal Studies, Seoul National University.), Junseo Lee (Quantum AI Team, Norma Inc.), Myeongjin Shin (KAIST), Ilkwon Sohn (Korea Institute of Science and Technology Information) and Kabgyun Jeong (Seoul National University).

A Quantum Neural Network Approach to Estimating Quantum Uncommon Information Bounds.

Presenter: Kabgyun Jeong

Abstract: In classical information theory, uncommon information refers to the amount of information not shared between two messages. Extending this concept to the quantum domain, quantum uncommon information (QUI) is defined as the amount of information needed to exchange two quantum states. While the value of uncommon information can be precisely calculated in the classical case, a direct method for computing QUI is not yet known. Current research has focused on establishing upper and lower bounds for QUI. In this paper, we propose a method for estimating the bounds of QUI using quantum neural networks.

Keywords: Quantum uncommon information, Quantum Machine Learning, QDVR representation

[156] Brandon Friend (University of Arizona, Department of Physics) and Sean Fleming (University of Arizona, Department of Physics).

Quantum Computing of A Nuclear Lattice Model.

Presenter: Brandon Friend

Abstract: We simulate the Helium-4 nucleus on a 2×2×2 lattice using three qubits per nucleon, extending previous work that used a two-dimensional 2×2 lattice to simulate systems of three or fewer nucleons. We map the Hamiltonian from pionless effective field theory onto a quantum computer by discretizing space onto the lattice. With the position of one nucleon fixed, the system can be simulated using only nine qubits. We apply the Variational Quantum Eigensolver (VQE), in a classical simulation of the quantum circuit, to prepare the approximate ground state and extract the binding energy of the nucleus. Despite the compact representation using nine qubits, the simulation produces a bound state with a binding energy of the correct order of magnitude. However, due to approximations and limited resolution, the computed binding energy does not quantitatively match classical calculations and experimental observations.

Keywords: Quantum simulation, Nuclear physics, Nuclear Lattice, Variational Quantum Eigensolver (VQE), Quantum computing, Pionless effective field theory, Quantum circuit simulation, Ground state preparation, Binding energy calculation

[157] Vaibhav Sharma (Rice University), Kaden R.A. Hazzard (Rice University), Sayak Guha Roy (Rice University), Jad C Halimeh (Ludwig Maximilian University of Munich), Kaidi Xu (Max Planck Institute of Quantum Optics) and Umberto Borla (Max Planck Institute of Quantum Optics).

Dynamical production of mesons and tetraquarks from locally exciting a Z2 lattice gauge theory.

Presenter: Vaibhav Sharma

Abstract: Quantum simulation of lattice gauge theories is an important avenue to gain insights into both particle physics phenomena and constrained quantum many-body dynamics. There is a growing interest in probing analogs of high energy collision phenomena in lattice gauge theories that can be implemented on current quantum simulators. Motivated by this, we characterize the bound excitations that originate from a local high energy excitation in a 1D Z2 lattice gauge theory. We focus on a simple, experimentally accessible setting that does not require preparation of colliding wavepackets and isolates the effects of gauge field confinement strength and initial state energy on the nature of propagating excitations. We find that without resonant particle production, the dynamics is characterized by the propagation of a superposition of differently sized mesons. The average meson length is systematically controlled by the gauge field confinement strength and the initial excitation's energy. The mesons oscillate in time and get spatially filtered out as longer mesons propagate slower. In the presence of resonant particle production, we find parameter regimes where the initial excitation produces four particle bound states that are long lived. We call these tetraquark states. We show that the bound tetraquarks simply emerge from an interplay of linear gauge confinement and resonant pair-production of particles in a gauge theory.

Keywords: Quantum simulation, Lattice gauge theory, Quantum many-body dynamics, Non-equilibrium dynamics

[158] Dengimowei Alabintei (University of Maryland) and Nii Attoh-Okine (University of Maryland).

HYBRID QUANTUM NEURAL NETWORK AND SHAPELY ADDITIVE EXPLANATIONS IN RAIL TRACK GEOMETRY DEFECT PREDICTION.

Presenter: Dengimowei Alabintei

Abstract: This study applies quantum machine learning, which brings together quantum computing and machine learning, for predictive maintenance in the railroad industry. Rail companies invest substantially in their networks to achieve their objective of a safe and efficient railroad. However, derailments caused by track geometry defects pose significant risks to this objective. Issues such as profile deviations and alignment irregularities often lead to train derailments, which can disrupt operations and increase repair costs. Therefore, there is a need for predictive strategies. To address this challenge, this research develops a quantum neural network (QNN) to predict track profile and alignment defects based on subsurface conditions, utilizing data obtained from Ground-penetrating Radar (GPR), which includes the ballast fouling index, ballast thickness index, layer roughness index, and moisture likelihood index. The developed QNN consists of a ZZ feature map layer and an EfficientSU2 ansatz layer, trained using the COBYLA and LBFGS optimizers. Additionally, a classical neural network (CNN) was developed to establish a baseline for comparison. Furthermore, Shapley Additive Explanations (SHAP) were employed to analyze the QNN's decision-making process, ensuring interpretability for practical applications. The study's findings indicate that the QNN, trained with the COBYLA optimizer, outperformed the CNN in predicting alignment defects, while the CNN performed better for the left profile. Both models exhibited similar results for the right profile. SHAP analysis revealed that the layer roughness index and ballast fouling index were the most influential factors in predicting defects in track geometry, followed by the ballast thickness index, with the moisture likelihood index being less significant. These results align with engineering principles, confirming the model's suitable performance. This work demonstrates that QNNs can improve predictive maintenance, with SHAP providing a clear understanding of the model's predictions for industry use.

Keywords: Quantum Machine Learning, Quantum Neural Networks, Rail Infrastructure, Shapely Additive Explanations

[159] Boseon Kim (Korea Institute of Science and Technology Information), Ilkwon Sohn (Korea Institute of Science and Technology Information), Wooyeong Song (Korea Institute of Science and Technology Information), Kwangil Bae (Korea Institute of Science and Technology Information) and Wonhyuk Lee (Korea Institute of Science and Technology Information).

A Reliable Extrapolation-based Error Mitigation Framework for Structured Quantum Algorithms.

Presenter: Boseon Kim

Abstract: Quantum error mitigation is a crucial technique for suppressing errors especially in noisy intermediate-scale quantum devices, enabling more reliable quantum computation without the overhead of full error correction. Zero-Noise Extrapolation (ZNE), which we mainly consider in this work, is one of prominent quantum error mitigation methods. For algorithms with deep circuits - such as iterative quantum algorithms involving multiple oracle calls - ZNE's effectiveness is significantly degraded under high noise. Extrapolation based on such low-fidelity data often yields inaccurate estimates and requires substantial overhead. In this study, we propose a lightweight, extrapolation-based error mitigation framework tailored for structured quantum algorithms composed of repeating operational blocks. The proposed method characterizes the error of the repeated unit operation block, rather than the full algorithm, using shallow circuits. Extrapolation is used to estimate the block fidelity, followed by a reconstruction of the mitigated success probability. We validate our method via simulations of a 6-qubit Grover's algorithm on IBM's Aer simulator and a modeled 127-qubit Eagle processor. Our results, particularly those from Aer simulator, demonstrate that the unit block's error follows a highly consistent exponential decay. This allows our technique to achieve robust error mitigation, overcoming the limitations of conventional ZNE which is often compromised by statistically unreliable data from near-random behavior under heavy noise.

Keywords: Noisy Intermediate Scale Quantum Computing, Quantum error mitigation, Zero Noise Extrapolation

[160] Anthony Ciavarella (LBNL), Siddharth Hariprakash (UC Berkeley), Christian Bauer (LBNL) and Jad Halimeh (Max Planck Institute of Quantum Optics).

Truncation Uncertainties for Accurate Quantum Simulations of Gauge Theories.

Presenter: Anthony Ciavarella

Abstract: The encoding of lattice gauge theories onto quantum computers requires a discretization of the gauge field's Hilbert space on each link. In the electric basis, Hilbert space fragmentation limits the excitation of large electric fields. This is used to develop formalism for estimating the size of truncation errors in the electric basis. Generically, the truncation error falls off as a factorial of the field truncation. Examples of this formalism are applied to the Schwinger model and a pure U(1) lattice gauge theory. For reasonable choices of parameters, we improve on previous error estimates by several orders of magnitude.

Keywords: quantum simulation, lattice gauge theory, resource estimation

[161] Mikel Palmero (University of the Basque Country), Miguel Ángel Simón (University of the Basque Country) and Dario Poletti (Singapore University of Technology and Design).

Towards macroscopic cat-state generation by quantum control techniques .

Abstract: High fidelity generation of highly entangled states of many particles gets prohibitively complicated as the size of the system grows, as shown by previous experimental attempts. A common strategy to generate such entangled states is by initializing the system in an easily achivable ground state, e.g. in the presence of a strong magnetic field, and slowly ramping down that field to adiabatically drive the system to the desired state. The increasing amount of energy levels, with decreasing energy gaps, makes the traditional strategy too slow to adiabatically follow, triggering the decohering effect of noises.

In this work, we study a realistic N-ion Dicke model (up to 10 ions) in the presence of dissipative noise. We follow a quantum control strategy based in the shortcut to adiabaticity technique called Fast Quasi-Adiabatic (FAQUAD) to minimise the driving time and boost the maximum fidelities that can be reached for the desired cat state. FAQUAD allows for a seminumerical approach, an important feature when tackling such complex systems, and test it for increasingly refined versions of the protocol, proving its clear advantage compared to simple adiabatic ramp-downs, and even to previous engineered alternatives. We also combine the FAQUAD protocol with a dynamical decoupling strategy to minimize the effect of the decoherence along the driving.

Following the same flexible FAQUAD strategy, current works attempts to boost the performance of quantum circuits based on the Digital-Analog Quantum Simulator (DAQC) paradigm. DAQC partially digitizes a quantum circuit, reducing the circuit depth of a fully digital algorithm, but also the system size of a fully analog simulator. This approach tries to improve the fidelity of current NISQ-era devices by minimizing the error introduced by noisy gates at the cost of driving relatively small Hamiltonians in time. The precise control of the analog parts is thus still a necessity, and FAQUAD has all the necessary ingredients to help in this task.

Keywords: Dissipative many-body systems, Quantum control, DAQC

[162] David Kreplin (Fraunhofer IPA) and Marco Roth (Fraunhofer IPA).

Quantum Phase Estimation on Quantum Hardware.

Presenter: David Kreplin

Abstract: Quantum Phase Estimation (QPE) remains one of the most promising techniques for achieving quantum advantage, particularly in the determination of ground-state energies. Recent advances have significantly lowered the qubit and circuit depth requirements by leveraging the Hadamard test in combination with controlled Hamiltonian time evolution [1].

In this work, we demonstrate a single-ancilla variant of QPE on current quantum hardware using the Quantum Complex Exponential Least Squares (QCELS) algorithm [2]. We evaluate its performance across different small Hamiltonians and observe remarkable robustness against finite-sampling noise and hardware-induced errors, achieving high precision even on NISQ-era devices.

We demonstrate a successful implementation of the algorithm on IBM quantum computers. We obtain the ground-state energies of the hydrogen molecule on hardware below chemical accuracy across its full dissociation profile, starting solely from the Hartree-Fock reference state. These results position QCELS as a highly promising candidate for near-term hardware realization of quantum phase estimation.

[1] Lin, Lin, and Yu Tong. "Heisenberg-limited ground-state energy estimation for early fault-tolerant quantum computers." PRX quantum 3.1 (2022): 010318.

[2] Ding, Zhiyan, and Lin Lin. "Even shorter quantum circuit for phase estimation on early fault-tolerant quantum computers with applications to ground-state energy estimation." PRX quantum 4.2 (2023): 020331.

Keywords: Quantum Phase Estimation, Hadamard Test, Quantum Hardware, NISQ Hardware

[163] Siddhant Midha (Princeton University) and Sarang Gopalakrishnan (Princeton University).

Learning about the dynamics of open quantum systems through emitted radiation.

Presenter: Siddhant Midha

Abstract: We investigate radiation metrology--—the problem of inferring the dynamics of a Markovian open quantum system by continuously monitoring the radiation it emits into its environment. Unlike conventional quantum metrology, which typically relies on repeated state preparation, radiation metrology offers a route to achieving Heisenberg-limited precision without such repetition. Leveraging connections with matrix product state techniques, we derive compact analytical expressions for the ultimate precision bounds, as measured by the quantum Fisher information. We analyze how this precision scales with time and particle number, particularly in the vicinity of dissipative phase transitions. Additionally, we propose protocols for engineering optimal open quantum sensors and discuss the practical challenges of accessing the full quantum Fisher information in experimental settings.

Keywords: open quantum systems, fisher information, metrology, dynamics

[164] Filippo Della Chiara (Universita' di Bologna), Martina Nibbi (Technical University of Munich), Yizhi Shen (Lawrence Berkeley National Laboratory) and Roel Van Beeumen (Lawrence Berkeley National Laboratory).

E*xplicit and compact block encodings of spin Hamiltonians through efficient Dicke states preparation.*

Presenter: Martina Nibbi

Abstract: Block encoding is a key component in many quantum algorithms, particularly those based on Quantum Singular Value Transformation (QSVT). Its efficient construction remains, however, a challenging task, especially when explicit circuit implementations are needed. The current state-of-the-art approach relies on the Linear Combination of Unitaries (LCU) decomposition of the target matrix, but its practical use is limited by the high gate overhead of the SELECT oracle, which typically requires complex multi-controlled operations.

In this work, we introduce the "Fast One-Qubit Control Select" LCU variant (FOQCS-LCU), a novel scheme that leverages the check matrix formalism to implement the SELECT oracle using only n CNOT and n controlled-Z gates, along with a linear number of ancilla qubits. In addition, we exploit problem structure to reduce the cost of the state preparation oracle by designing a family of efficient Dicke state preparation routines. We apply our method to construct explicit block encoding circuits for representative spin models, including Heisenberg and spin glass Hamiltonians, and provide detailed, non-asymptotic gate counts. Numerical benchmarks confirm that FOQCS-LCU yields CNOT savings of over an order of magnitude compared to standard LCU implementations. These results pave the way for scalable block encodings of structured operators across a broader class of quantum systems.

Keywords: Block encoding, Qubitization, Dicke states, Spin models, Structure-aware algorithms, Quantum algorithms, Quantum simulation

[165] Wenxuan Zhang (National University of Singapore), Bo Xing (Massachusetts Institute of Technology), Xiansong Xu (Singapore University of Technology and Design) and Dario Poletti (Singapore University of Technology and Design).

Paths towards time evolution with larger neural-network quantum states.

Presenter: Bo Xing

Abstract: In recent years, the neural-network quantum states (NNQS) method has been investigated to study the ground state and the time evolution of many-body quantum systems [1]. We expand on the investigation and consider a quantum quench from the paramagnetic to the antiferromagnetic phase in the tilted Ising model. We show that the projected time-dependent variational Monte Carlo (p-tVMC) method [2] performs better, for our case, than evolving the equation of motion for the neural network parameters [1]. We also show that p-tVMC is amenable to techniques like K-FAC [3], minSR [4-5], and SOO[6], thus allowing us to study larger systems.

Keywords: Quantum Machine Learning, Neural-Networks quantum states, Projected time-dependent variational Monte Carlo

[166] Yipei Zhang (UC Berkeley), Philippe Lewalle (UC Berkeley), Tathagata Karmakar (UC Berkeley), K. Birgitta Whaley (UC Berkeley) and Alain Sarlette (INRIA).

The Quantum Zeno Dragging: A Versatile Tool for Quantum Control & Computation.

Presenter: Yipei Zhang

Abstract: The quantum Zeno effect is typically described in terms of a measurement freezing a quantum system's dynamics. We here consider instead measurement-driven "Zeno dragging" control and algorithm, implemented by an evolving measurement or dissipator. We analyze the condition under which multi-channel Zeno dragging dynamics converges to a target subspace. We then illustrate how this Zeno dragging dynamics can be used to solve Boolean satisfiability problems (k-SAT) with arbitrary measurement strength. We also present numerical evidence indicating the advantageous of heralded dynamics with feedback. Finally, we show how optimal dragging schedules affect the performance of our protocols.

Keywords: Quantum Measurement, Quantum Algorithm, Quantum Control

[167] Niclas Schillo (Fraunhofer IAO, University of Stuttgart IAT), Thomas Wellens (Fraunhofer IAF) and Andreas Sturm (Fraunhofer IAO).
Efficient Quantum Circuit Implementation for Linear Combinations of Pauli Strings Using Anticommuting Transformations.

Presenter: Niclas Schillo

Abstract: We present a novel method for the efficient implementation of quantum circuits for linear combinations of pairwise commuting Pauli strings. Although conventional linear combination of unitaries (LCU) methods can implement sums of pairwise commuting Pauli strings, they often incur significant resource costs. In this work, we propose a technique that transforms sets of pairwise commuting Pauli strings into sets of anti-commuting Pauli strings, which are inherently unitary. This transformation enables the direct and efficient implementation of the resulting unitary operators in certain cases, without requiring ancillary qubits, while only causing local changes in phase. To address the phase differences introduced by this transformation, we employ a logarithmic-size ancilla register to apply the necessary corrections. Through specific examples, we demonstrate that our approach achieves a quadratic reduction in the CNOT gate count compared to standard LCU implementations, while maintaining the same ancilla qubit requirements. We also present examples from quantum chemistry to illustrate the practical benefits of our method.

Keywords: Quantum algorithms, Linear Combination of Unitaries (LCU), Block encoding, Quantum chemistry

[169] Abdullah Kazi (University of Mumbai) and Mahnoor Fatima (State University of New York at Stony Brook).
Exploring Dynamic Circuits through Gibbs Free Energy Calculations via Variational Quantum Algorithms.

Presenter: Mahnoor Fatima

Abstract: Dynamic circuits represent a significant shift in quantum algorithm design by enabling mid-circuit measurements, conditional operations, and classical-quantum feedback during execution. In this work, we leverage the power of dynamic circuits to variationally estimate the Gibbs Free Energy of quantum systems, focusing on the Transverse Field Ising Model (TFIM). Utilizing Qiskit's dynamic capabilities, we implement variational quantum Gibbs state preparation, incorporate swap tests with mid-circuit resets. Our implementation achieves high-fidelity ground state approximation with efficient circuit depth management, demonstrating the potential of dynamic circuits for near-term quantum thermodynamic calculations.

Keywords: Dynamic circuits, Gibbs state, Quantum algorithms

[170] Grace Sommers (Princeton University), Michael Foss-Feig (Quantinuum), David Hayes (Quantinuum), David Huse (Princeton University) and Michael Gullans (Joint Center for Quantum Information and Computer Science, NIST/University of Maryland, College Park).
Observation of a Fault Tolerance Threshold with Concatenated Codes.

Presenter: Grace Sommers
Abstract: We introduce a fault-tolerant protocol for code concatenation using a butterfly network architecture with high noise thresholds and low ancilla overhead to allow implementation on current devices. We develop a probability passing decoder using tensor networks that applies Bayesian updates to the marginal error probabilities after each layer of checks, achieving a state preparation threshold of $e_c \approx 0.089$ for erasure errors, and ≈ 0.015 for unheralded noise. We implement our state preparation protocol on ion-trap hardware with added noise to demonstrate the threshold behavior in a real quantum device. We further theoretically test the performance of our scheme as a quantum memory and for universal quantum computation through the preparation of low-noise magic states for state distillation and T-gate injection.

Keywords: quantum error correction, fault tolerance, phase transitions

[171] Philipp Schleich (Department of Computer Science, University of Toronto; Vector Institute for Artificial Intelligence), Tyler Kharazi (Department of Chemistry and Berkeley Quantum Information and Computation Center, University of California, Berkeley), Xiangyu Li (Pacific Northwest National Laboratory), Jin-Peng Liu (Tsinghua University; Yanqi Lake Beijing Institute of Mathematical Sciences and Applications), Alán Aspuru-Guzik (Department of Computer Science, University of Toronto; Vector Institute for Artificial Intelligence) and Nathan Wiebe (Department of Computer Science, University of Toronto; PNNL; Canadian Institute for Advanced Studies). ***Arbitrary Boundary Conditions and Constraints in Quantum Algorithms for Differential Equations via Penalty Projections.***

Presenter: Xiangyu Li

Abstract: Complicated boundary conditions are essential to accurately describe phenomena arising in nature and engineering. Recently, the investigation of a potential speedup through quantum algorithms in simulating the governing ordinary and partial differential equations of such phenomena has gained increasing attention.
We design an efficient quantum algorithms for solving differential equations with arbitrary boundary conditions. Specifically, we propose an approach to enforce arbitrary boundary conditions and constraints through adding a penalty projection to the governing equations. Assuming a fast-forwardable representation of the projection to ensure an efficient interaction picture simulation, the cost of to enforce the constraints is at most $O(\log\lambda)$ in the strength of the penalty λ in the gate complexity; in the worst case, this goes as $O([t^2\|v(0)\|^2\|A_0\| + \|b\|_{L^1[0;t]}^2)]/\varepsilon)$, for precision ε and a dynamical system $\frac{d}{dt} v(t) = A_0(t) v(t) + b(t)$ with negative semidefinite $A_0(t)$ of size $n^d\times n^d$. E.g., for the heat equation, this leads to a gate complexity overhead of $\widetilde O(d\log n + \log t)$.
We show constraint error bounds for the penalty approach and provide validating numerical experiments, and estimate the circuit complexity using the Linear Combination of Hamiltonian Simulation.

Keywords: Arbitrary Boundary Conditions, Quantum Algorithms, Differential Equations, Penalty Projections

[172] Chanung Park (Seoul National University) and Dohun Kim (Seoul National University).

Investigating valley effects in Si/SiGe quantum dots for spin qubit applications.

Presenter: Chanung Park
Abstract: Silicon quantum dots are a promising platform for realizing spin qubits, offering long coherence times and compatibility with existing semiconductor technologies. However, the conduction band of silicon contains multiple nearly degenerate valley states, which can couple to spin and orbital dynamics. This complicates qubit operation by affecting energy levels, tunneling rates, and state coherence.
In this work, we investigate how valley transitions arise in Si/SiGe quantum dots through quantum dynamics simulation. By incorporating valley physics into the model, we examine how the factors such as quantum dot geometry, inter-dot coupling, and valley characteristics influence qubit behavior, and we investigate the mechanisms of valley transitions and their impact on Pauli Spin Blockade (PSB)-based parity readout experiments. Experimentally observed features, including closely spaced Rabi frequencies, variations in exchange coupling, and ramp-rate dependence, are successfully reproduced and interpreted within this framework. Additionally, we explore how quantum dot positioning impacts the tunability of valley states.
These findings deepen our understanding of valley-related effects in silicon quantum dots and suggest that, with further investigation, tuning and control of valley states may become a viable pathway for improving spin qubit performance.

Keywords: silicon quantum dot, spin qubit, valley splitting, parity readout measurement

[174] Gabriele Calliari (Universität Innsbruck & IQOQI), Robert Ott (Universität Innsbruck & IQOQI), Hannes Pichler (Universität Innsbruck & IQOQI) and Torsten V. Zache (Universität Innsbruck & IQOQI).
Field digitization scaling in a Z_N symmetric model.

Presenter: Gabriele Calliari

Abstract: The simulation of quantum field theories, both classical and quantum, requires regularization of infinitely many degrees of freedom. However, in the context of field digitization (FD) -- a truncation of the local fields to N discrete values -- a comprehensive framework to obtain continuum results is currently missing. Here, we propose to analyze FD by interpreting the parameter N as a coupling in the renormalization group (RG) sense. As a first example, we investigate the two-dimensional classical N-state clock model as a Z_N FD of the U(1)-symmetric XY-model. Using effective field theory, we employ the RG to derive generalized scaling hypotheses involving the FD parameter N, which allows us to relate data obtained for different N-regularized models in a procedure that we term "field digitization scaling" (FDS). Using numerical tensor-network calculations at finite bond dimension \chi, we further uncover an unconventional universal cross-over around a low-temperature phase transition induced by finite N, demonstrating that FDS can be extended to describe the interplay of \chi and N. Finally, we analytically prove that our calculations for the 2D classical-statistical Z_N clock model are directly related to the quantum physics in the ground state of a (2+1)D Z_N lattice gauge theory which serves as a FD of compact quantum electrodynamics. Our study thus paves the way for applications of FDS to quantum simulations of more complex models in higher spatial dimensions, where it could serve as a tool to analyze the continuum limit of digitized quantum field theories.

Keywords: quantum simulation, quantum field theory, tensor networks, lattice gauge theory, field digitization scaling

[175] Joana Fraxanet Morales (IBM).
Real-Time Dynamics in a (2+1)-D Gauge Theory: The Stringy Nature on a Superconducting Quantum Simulator.

Presenter: Joana Fraxanet Morales

Abstract: Understanding the confinement mechanism in gauge theories and the universality of effective string-like descriptions of gauge flux tubes remains a fundamental challenge in modern physics. We probe string modes of motion with dynamical matter in a digital quantum simulation of a (2+1)-dimensional gauge theory using a superconducting quantum processor with up to 144 qubits, stretching the hardware capabilities with quantum-circuit depths comprising up to 192 two-qubit layers. We realize the Z2-Higgs model through an optimized embedding into a heavy-hex superconducting qubit architecture, directly mapping matter and gauge fields to vertex and link superconducting qubits, respectively. Using the structure of local gauge symmetries, we implement a comprehensive suite of error suppression, mitigation, and correction strategies to enable real-time observation and manipulation of electric strings connecting dynamical charges. Our results resolve a dynamical hierarchy of longitudinal oscillations and transverse bending at the end points of the string, which are precursors to hadronization and rotational spectra of mesons. We further explore multi-string processes, observing the fragmentation and recombination of strings. The experimental design supports 300,000 measurement shots per circuit, totaling 600,000 shots per time step, enabling high-fidelity statistics. We employ extensive tensor network simulations using the basis update and Galerkin method to predict large-scale real-time dynamics and validate our error-aware protocols. This work establishes a milestone for probing non-perturbative gauge dynamics via superconducting quantum simulation and elucidates the real-time behavior of confining strings.

Keywords: lattice gauge theories, string dynamics, quantum simulation, superconducting quantum processor

[177] Margaret Lockwood (Pacific Northwest National Lab), Connah Johnson (Pacific Northwest National Lab), Nathan Wiebe (University of Toronto), Johannes Mülmenstädt (Pacific Northwest National Lab), Jaehun Chun (Pacific Northwest National Lab), Xiaolong Yin (Colorado School of Mines), Gregory Schenter (Pacific Northwest National Lab), Margaret Cheung (Pacific Northwest National Lab) and Xiang-Yu Li (Pacific Northwest National Lab). ***Quantum Computing for Coupled Metabolic Dissipative Reaction-Diffusion Processes.***

Presenter: Margaret Lockwood

Abstract: Cell models described by biochemical equations require extensive classical computing resources, which currently limit the system size and spatiotemporal scale of simulations. The number of possible reaction terms among species grows exponentially and perhaps more significantly, reaction rates are not believed to be computable in polynomial time on a classical computer. In this work we propose using a quantum computer to simultaneously compute these rates while computing the spatiotemporal dynamical evolution of systems relevant in cell modeling to offer the potential of increased predictive capabilities, better resource estimation, and understanding of essential cell processes, like metabolic reactions. To demonstrate the utility of quantum computing in cell modeling research, we formulate a general framework for the reaction-diffusion model with arbitrary S-species of interacting concentrations with higher order terms, and use the two-species third-order Gierer-Meinhardt reaction-diffusion model, a set of coupled nonlinear dissipative differential equations as a benchmark case for numerical simulation. Through theoretical error-bound analysis and numerical simulation, we show that the Carleman-linearization method is suitable with small relative error compared the Runge-Kutta 4th order approximation for the majority of biologically relevant parameter regimes. We perform error and complexity analysis of quantum linear system algorithms applied to the linearized system, which indicate potential quantum advantage. We aim to present a generalized framework to overcome time, spatial, system size constraints in preparation for intensive whole-cell modeling efforts. Our scheme, albeit a relatively generic case in metabolic systems, can be extended to other systems involving ``coupled reaction-diffusion'' phenomena such as coalescence of nanodroplets and nanoparticle attachment due to thermal motion.

Keywords: quantum algorithms, biophysics, reaction-diffusion, Carleman Linearization

[178] Andrew Stasiuk (MIT), Garrett Heller (MIT), Lance Berkey (MIT), Bo Xing (MIT) and Paola Cappellaro (MIT). ***Anomalous Diffusion in a Percolating Disordered Dipolar Spin Ensemble.***

Presenter: Andrew Stasiuk

Abstract: Emergent hydrodynamics (EHD) bridges short-time unitarity with late-time thermodynamics, whereby universal transport phenomena dictate the manner and speed of transport and thermalization. Typical non-integrable systems with few conserved local quantities are expected to be diffusive. In contrast, strongly disordered systems which admit phases such as many-body localization, are predicted to inhibit thermalization and thus slow dynamical transport. Disordered systems represent a uniquely poised platform to probe the quantum-to-classical transition and the emergence of irreversible thermodynamics from the underlying unitary structure. Here, we study a strongly disordered nuclear spin ensemble, using local measurements enabled by the disordered-state technique. We observe an apparent phase transition into a sub-diffusive regime, which we model as a random walk on the emergent fractal structure of percolating network in the dipolar spin ensemble. Our novel theoretical model provides a framework for characterizing the emergence of thermalization in closed quantum systems, even in the presence of strong disorder.

Keywords: Emergent Hydrodynamics, Strong Disorder, Percolation, Localization

[179] Sojeong Park (KAIST) and Changhun Oh (KAIST).

Efficiently Simulating Lossy Boson Sampling and Noisy IQP Sampling Using MPS with Tunable Accuracy.

Presenter: Sojeong park

Abstract: Demonstrating quantum advantage through sampling problems such as boson sampling and instantaneous quantum polynomial-time (IQP) sampling requires understanding how noise affects their classical simulability. While these problems are believed to be classically intractable in the ideal case, realistic experiments are imperfect, and the boundary between classically tractable and intractable regimes remains unclear.
In this work, we generalize the matrix product state (MPS) approach, which was initially applied to Gaussian boson sampling (GBS), to simulate lossy single-photon Fock state boson sampling and noisy IQP sampling. This simulation method is significantly efficient than the matrix product operator approach. Additionally, unlike previous methods that rely on fixed approximations to nearby classically simulable inputs, our MPS-based algorithm supports all loss rates and allows tunable accuracy depending on computational resources.
We propose a unified MPS simulation framework that is efficient and advantageous than previous approaches. This work provides a practical tool for analyzing the classical simulability of noisy quantum sampling experiments.

Keywords: lossy boson sampling, noisy IQP sampling, classical simulation, matrix product state, entanglement Renyi entropy

[180] Jiwon Heo (KAIST), Sojeong Park (KAIST) and Changhun Oh (KAIST).
Classical simulation of quantum circuits with noisy magic inputs.

Presenter: Jiwon Heo

Abstract: Utilizing magic states lies at the forefront of both theoretical and experimental quantum computing fields, owing to their pivotal role in achieving quantum supremacy and implementing universal fault-tolerant architectures. Despite their promise, the practical realization remains constrained by physical errors in real experimental environments. In this work, we demonstrate the impact of noises on magic states and their computational power, by introducing a novel classical simulation algorithm.
Building upon a unifying framework applicable to diverse universal quantum computing platforms, we outline the general problem setting and detail our simulation strategy. We then demonstrate the versatility of our approach through applications to both qubit-based systems and fermionic linear-optical architectures. Finally, we present numerical results that elucidate the scaling of computational resources required by the algorithm, so that we provide practical insights into the interplay between error rates and simulation complexity.

Keywords: Classical simulation, Noisy quantum circuit, Magic state

[181] Robert Ott (Innsbruck University), Torsten Zache (Innsbruck University), Nishad Maskara (Harvard University), Mikhail Lukin (Harvard University), Peter Zoller (Univ of Innsbruck) and Hannes Pichler (University of Innsbruck).

Probing Topological Entanglement on Large Scales.
Presenter: Robert Ott

Abstract: Topologically ordered quantum matter exhibits intriguing long-range patterns of entanglement, which reveal themselves in subsystem entropies. However, measuring such entropies, which can be used to certify topological order, on large partitions is challenging and becomes practically unfeasible for large systems.
We propose a protocol based on local adiabatic deformations of the Hamiltonian which extracts the universal features of long-range topological entanglement from measurements on small subsystems of finite size, trading an exponential number of measurements against a polynomial-time evolution. Our protocol is general and readily applicable to various quantum simulation architectures. We apply our

method to various string-net models representing both Abelian and non-Abelian topologically ordered phases and illustrate its application to neutral atom tweezer arrays with numerical simulations.

Keywords: Quantum Simulation, Topological Order, Rydberg Atom Arrays, Entanglement Structures, Quantum Many-body Physics

[183] Sooryansh Asthana (Indian Institute of Technology Bombay), Yeshma Ibrahim (Indian Institute of Technology Bombay), Norman Tze Wei Koo (University of Chicago) and Sai Vinjanampathy (Indian Institute of Technology Bombay).
Unifying Theory for Robust Quantum Sensors.

Presenter: Yeshma Ibrahim

Abstract: Enhanced metrological performance requires the use of highly entangled states. This understanding has prompted researchers to study the nature of distributions from which one can sample random quantum states that are metrologically useful. Permutationally invariant states have emerged as a promising candidate in this context. In this work, we advance a unifying theory of quantum-enhanced metrology in terms of the orbits of the Lie group generated by the Hamiltonians. Our theory explains why permutationally invariant sensors and conventional Ramsey interferometric protocols operate beyond the standard quantum limit. Moreover, it provides a novel approach in designing robust quantum sensors that bypass the need for fine-tuning or other complex, measurement-specific constructions.

Keywords: Quantum Metrology, Quantum Entanglement, Random Quantum States, Dynamical Lie Algebra

[184] Ilyoun Na (Department of Physics, University of California, Berkeley), Jack Kemp (Department of Physics, Harvard University), Sinead Griffin (Materials Sciences Division, Lawrence Berkeley National Laboratory) and Yang Peng (Department of Physics and Astronomy, California State University, Northridge).
Engineering micromotion in Floquet prethermalization via space-time symmetries.

Presenter: Ilyoun Na

Abstract: We present a systematic framework for Floquet prethermalization under strong resonant driving, emphasizing the pivotal role of dynamical space-time symmetries. Our approach demonstrates how dynamical space-time symmetries map onto the projective static symmetry group of the prethermal Hamiltonian governing the prethermal regime. We introduce techniques for detecting dynamical symmetries through the time evolution of local observables, facilitating a detailed analysis of micromotion within each period and surpassing the limitations of conventional stroboscopic Floquet prethermal dynamics. To implement this framework, we present a prethermal protocol that preserves order-two dynamical symmetry in a spin-ladder model, confirming the predicted relationships between the expectation values of local observables at distinct temporal points in the Floquet cycle, linked by this symmetry.

Keywords: Non-equilibrium quantum dynamics, Dynamical space-time symmetries, Projective symmetry groups, Symmetry detection via time evolution, Floquet prethermalization, Micromotion analysis

[185] Timothy Mooney (Joint Center for Quantum Information and Computer Science and Joint Quantum Institute), Dong Yuan (Tsinghua University and Joint Institute for Laboratory Astrophysics), Chao Yin (University of Colorado, Boulder), Adam Ehrenberg (Joint Center for Quantum Information and Computer Science and Joint Quantum Institute), Christopher Baldwin (Michigan State University), Andrew Childs (Joint Center for Quantum

Information and Computer Science and University of Maryland, College Park) and Alexey Gorshkov (Joint Center for Quantum Information and Computer Science and Joint Quantum Institute).
Time Independence Does Not Limit Information Flow.

Presenter: Timothy Mooney

Abstract: While the impact of locality restrictions on quantum dynamics and algorithmic complexity has been well studied in the general case of time-dependent Hamiltonians, the capabilities of time-independent protocols are less well understood. We investigate two settings that seem to suggest that time-independent protocols can propagate information at the same speed as time-dependent ones. First, we present and analyze two optimal time-independent state-transfer protocols for free-particle systems, which utilize continuous-time single-particle quantum walks with hopping strength decaying as a power law. We rigorously prove and numerically confirm that our protocols achieve quantum state transfer, with controllable error over an arbitrarily long distance in any spatial dimension, at the speed limits set by the free-particle Lieb-Robinson bounds. This shows that time independence does not limit information flow for long-range free-particle Hamiltonians. Next, using clock constructions, we show that the light cone for time-independent Hamiltonians, as captured by Lieb-Robinson bounds, is the same as that for time-dependent systems when local ancillas are allowed. More specifically, we develop time-independent protocols for approximate quantum state transfer with the same run-times as their corresponding time-dependent protocols. Given any piecewise-continuous Hamiltonian, our construction gives a time-independent Hamiltonian that implements its dynamics in the same time, up to error ε, at the cost of introducing a number of local ancilla qubits for each data qubit that is polylogarithmic in the number of qubits, the norm of the Hamiltonian and its derivative (if it exists), the run time, and 1/ε. In both cases, this gives time-independent protocols with the same optimal light-cone-saturating run-times as their time-dependent counterparts.

Keywords: Lieb Robinson Bounds, Light Cones, Time Independence, Clock Constructions

[186] Gyungmin Cho (Seoul National University) and Dohun Kim (Seoul National University).
Entanglement-enhanced randomized measurement in noisy quantum devices.

Presenter: Gyungmin Cho

Abstract: Quantum hardware is advancing rapidly across various platforms, yet implementing large-scale quantum error correction (QEC) remains challenging. As hardware continues to improve, there is a growing need to identify potential applications on noisy quantum devices that can leverage these enhancements. With this motivation, we explore the advantages of shallow measurements over (non-entangling) single-qubit measurements for learning various properties of a quantum state. While previous studies have examined this subject, they have primarily focused on specific problems. Here, by developing a new theoretical framework, we demonstrate how shallow measurements can benefit in diverse scenarios. Despite the additional errors from two-qubit gates in shallow measurements, we experimentally validated improvements compared to single-qubit measurements in applications like derandomization, common randomized measurements, and machine learning up to 40 qubits and 46 layers of two-qubit gates, respectively. As a result, we show that hardware improvements, even before QEC, could broaden the range of feasible applications.

Keywords: Randomized measurement, Classical shadow, Machine learning

[187] Jaehun Jeong (College of Liberal Studies, Seoul National University, Seoul 08826, Korea), Donghwa Ji (College of Liberal Studies, Seoul National University, Seoul 08826, Korea) and Kabgyun Jeong (Research Institute of Mathematics, Seoul National University, Seoul 08826, Korea).
Finding Optimal Structure of Parameterized Quantum Circuits for the Quantum Policy Gradient via Mutual Information-Based Expressivity Measure.

Presenters: Jaehun Jeong and Kabgyun Jeong

Abstract: Quantum computing is widely predicted to fundamentally transform the whole data processing pipeline, yet current difficulties of the practical implementation due to noise-related issues provide us with a little access to the quantum resources. In this Noisy Intermediate-Scale Quantum (NISQ) era, hybrid quantum-classical approaches have gained prominence, with parameterized quantum circuits (PQCs) serving as a central component across various quantum algorithms such as VQE, QAOA, and increasingly in quantum machine learning tasks. Thanks to their tunable nature, PQCs can be much further expanded to the Quantum Reinforcement Learning regime, too, especially to Quantum Policy Gradient (QPG) framework. While prior works on quantum policy gradient have largely focused on porting classical RL pipelines to quantum circuits, they often overlook the representational analysis on PQCs in QPG. It is a well established fact that PQC-based learning is susceptible to Barren Plateaus, and also referring to the classical perspective of bias-variance tradeoff, choosing a circuit with appropriate expressivity becomes much more crucial issue. Existing expressivity measure—such as the Haar expressivity gap (informally speaking) and Effective Dimension—offer some assessment criterion to us, but fail to account for the action-driven dynamical nature of reinforcement learning, where policy structure must align closely with reward distributions. In this work, we propose a new mutual-information-based expressivity measure (MIBEM) tailored for quantum policy gradient settings. MIBEM is designed to capture how effectively a PQC internalize reward-relevant structure in its action distributions. We analyze the behavior of MIBEM in comparison with existing measures across various Ansatz design, including Haar-random 2-designs, hardware-efficient circuits, and Instantaneous Quantum Polynomial (IQP) circuits. Through empirical evaluation, we would demonstrate that MIBEM captures a more structured and reward-aligned characterization of PQC and offers a principled approach for detecting plateau section or early stopping via utilizing it as a criteria of deciding the learning convergence.

Keywords: Parameterized Quantum Circuit, Quantum Reinforcement Learning, Quantum Policy Gradient, Mutual Information, Instantaneous Quantum Polynomial

[188] Dolly Nambi (Louisiana State University), Kabir Khanna (University of Massachusetts Amherst), Andrew Allocca (Louisiana State University), Tom Iadecola (Iowa State University), Ciaran Hickey (University College, Dublin), Romain Vasseur (University of Geneva) and Justin Wilson (Louisiana State University).

Post-Selected Criticality of Measurement-Induced Phase Transitions.

Presenter: Dolly Nambi

Abstract: We investigate the post-selected critical properties of measurement-induced phase transitions (MIPTs) in two distinct models: a monitored random quantum circuit and a random tensor network. The monitored random quantum circuit comprises of two-qubit Haar-random gates and post-selective projective measurements, where qubits are consistently projected onto their ground state. The random tensor network model is constructed from a projected entangled pair state (PEPS) wavefunction, in which qutrits are gradually projected onto the ground state by reducing the bond dimension of the entangled pair states.
Both models exhibit a novel transition from area-law to volume-law entanglement scaling. Our numerical results provide strong evidence that these post-selected systems share the same universal critical behavior, which is distinct from the universality class of MIPTs with non-selective measurements. These findings offer deeper insights into the role of post-selection in quantum dynamics and entanglement structure.

Keywords: Measurement- Induced Phase Transition, Post-selected Universality, Random Quantum Circuits, Random Tensor Networks

[189] Kang Yisoo (KAIST), Junseo Lee (NORMA) and Kabgyun Jeong (Seoul National University). ***Constructing Quantum Error Correcting code with Wang tiling.***

Presenter: Yisoo Kang

Abstract: Wang tiling is an aperiodic method of tiling the plane using unit squares with colored edges, where adjacent tiles must match in color. While at first glance Wang tilings and quantum error correction may seem unrelated, we have explored their connection and found that Wang tiling can serve as a new framework for constructing quantum error-correcting codes (QECCs), particularly under the conditions of indistinguishability and recoverability.
There have been earlier attempts to construct QECCs using Penrose tilings, another form of aperiodic tiling. Our investigation shows that Wang tiling offers an alternative and potentially advantageous method for code construction. We propose a comparison between quantum error correcting codes based on Wang and Penrose tilings, focusing on practical metrics such as code distance, fault-tolerance, and physical implementability.
Looking forward, we aim to generalize this approach to a broader class of aperiodic tilings, seeking a unified framework where the aperiodicity of the tiling naturally contributes to the non-local properties required for robust quantum error correction.

Keywords: Wang tiling, connection between WT and QECC, generalize to aperiodic tiling

[190] Matthew Molinelli (Princeton University), Joshua Wang (Princeton University), Jeronimo Martinez (Princeton University), Rhine Samajdar (Princeton University) and Andrew Houck (Princeton University). ***Quantum simulation of Bose-Hubbard ladders on superconducting qubits.***

Presenter: Matthew Molinelli

Abstract: Superconducting qubits provide a promising platform for quantum simulation due to their natural implementation of the Bose-Hubbard Hamiltonian and flexibility in tuning system parameters. In these systems, the combination of onsite interactions and interference effects from synthetic magnetic fields gives rise to interesting quantum many body dynamics and phases. Ladders built from coupled one-dimensional chains are among the simplest lattices where effects from a magnetic field can be observed; in addition, their reduced dimensionality maximizes the impact of onsite interactions [1]. Within a single device, a combination of fixed and tunable qubit couplings allows precise control over the ratio of hoppings along the parallel and perpendicular edges of the ladder. Additionally, changing the sign of the hopping implements a synthetic magnetic field equivalent to 0 or pi flux threaded through each plaquette of the ladder. The tunability of both hopping and flux enables access of various quantum many body phases and correlations. Here, we present the design and implementation of a ladder realized with superconducting qubits and demonstrate control over the Hamiltonian parameters necessary to explore these fascinating quantum phases.
[1] Xiang, ZC., Huang, K., Zhang, YR. et al. Simulating Chern insulators on a superconducting quantum processor. Nat Commun 14, 5433 (2023). https://doi.org/10.1038/s41467-023-41230-9

Keywords: analog quantum simulation, Bose-Hubbard, superconducting

[191] Pegah Mohammadipour (The Pennsylvania State University) and Xiantao Li (The Pennsylvania State University).
Polynomial Extrapolation for Physical Noise and Step-Size Error Mitigation in Lindblad Simulation.

Presenter: Pegah Mohammadipour

Abstract: Polynomial extrapolation has emerged as one of the most effective classical post-processing techniques for boosting quantum accuracy without increasing circuit depth. In this work, we dissect two complementary applications of extrapolation in open quantum dynamics: one mitigates physical noise through zero-noise extrapolation, and the other suppresses algorithmic error via step-size extrapolation. Each method is analyzed through the lens of bias–variance tradeoffs and yields concrete resource estimates for reliable near-term quantum simulation.

In the first part, we develop a theoretical foundation for zero-noise extrapolation (ZNE), revealing how Richardson and least-squares polynomial methods behave under general Lindblad-type noise. We derive bias bounds for non-polynomial error channels and prove that, with Chebyshev nodes or regression-based fits, the variance inflation due to shot noise can be tamed. The result: to reach error ε, one needs only

$$
\Omega\bigl(\log(1/\varepsilon)\bigr) \text{ circuits}, \quad \text{each with } \Omega(\varepsilon^{-2-\delta}) \text{ samples}.
$$

We further propose a protocol for mitigating physical and algorithmic error simultaneously using a single extrapolation axis.

In the second part, we tackle step-size extrapolation for Lindblad integrators. Performing a backward-error analysis on two first-order quantum algorithms, we establish the smoothness of the function

$$
f_\tau(T) := \operatorname{Tr}[\rho_\tau(T)\,O],
$$

the expectation value of an observable O after simulating time-T evolution using step size τ. This enables Richardson extrapolation in τ, and we show that the number of required time steps scales only logarithmically in ε^{-1}, while the maximum circuit depth drops exponentially—from $\mathcal{O}(T^2/\varepsilon)$ to $\mathcal{O}(T^2 \log(1/\varepsilon))$—without increasing quantum resource overhead.

Together, these studies chart a rigorous, resource-aware roadmap for error mitigation in noisy quantum simulations of open systems—revealing how a modest number of well-chosen circuits can substitute for deeper, noisier ones.

This work is based on two of our papers:

Pegah Mohammadipour and Xiantao Li. “Direct Analysis of Zero-Noise Extrapolation: Polynomial Methods, Error Bounds, and Simultaneous Physical-Algorithmic Error Mitigation”. In: arXiv preprint arXiv:2502.20673 (2025). doi: 10.48550/arXiv.2502.20673

Pegah Mohammadipour and Xiantao Li. "Reducing Circuit Depth in Lindblad Simulation via Step-Size Extrapolation". Preprint

Keywords: Open quantum systems, Lindblad dynamics, Quantum simulation, Zero-noise extrapolation, Step-size extrapolation, Richardson extrapolation, Algorithmic error mitigation, Quantum error mitigation, Trotter-Suzuki decomposition, Bias-variance tradeoff, Sampling complexity, Circuit depth reduction, Near-term quantum devices (NISQ), Expectation value estimation

[192] Debopriyo Biswas (Duke University), Yichao Yu (Duke University), Vivian Ni Zhang (Duke University), Bahaa Harraz (Duke University), Keqin Yan (Duke University), Goksu Toga (North Carolina State University), Krishnanand Karthikeyan (Virginia Tech), Gong Cheng (Virginia Tech), Chunjun Cao (Virginia Tech), Alexander Kemper (North Carolina State University), Alexander Kozhanov (Duke University), Crystal Noel (Duke University) and Christopher Monroe (Duke University).

Programmable Trapped Ion Systems for Quantum Simulations of Quantum Gravity and Chaos.

Presenter: Debopriyo Biswas

Abstract: Trapped ion quantum computers feature high connectivity and gate fidelity with universal control—making them ideal for exploring quantum information dynamics relevant to quantum gravity and chaos. Here, we present plans and progress towards experiments on a programmable trapped ion system based on 171Yb+ ion qubits. Our apparatus uses a Sandia chip-trap in a room temperature vacuum chamber and tightly focused 355-nm Raman beams to individually control qubits in a 13-ion chain.
Using our system in the digital gate-mode, we plan to implement a holographic tensor network code named HaPPY code, encoding bulk logical degrees of freedom into boundary physical qubits [1]. The logical information and how it relates to the physical boundary is analogous to the AdS/CFT correspondence of holographic duality. Starting with two entangled logical holographic codes and tuning the amount of entanglement, we can study changes to the quantum extremal surfaces (QES) by measuring the boundary qubits' entropy. The QES, which is affected by bulk geometry and entanglement, is expected to increase as the amount of entanglement increases.
We also present progress towards a digital-analog hybrid toolset for studies of fast information scrambling, which is a hallmark of chaos. We plan to implement the recently proposed hyperbolic Ising model [2], which uses only local interactions unlike other well-known fast scramblers like the SYK model. We present simulations of the Ising interactions in a trapped ion chain by tuning the amplitudes and frequencies of the Raman beams in the analog simulation mode. The measurement of out-of-time-correlators (OTOCs), which indicate fast scrambling, is carried out by digital gates. Together, these experiments represent new directions in simulating gravitational phenomena and quantum information dynamics on near-term quantum hardware.
References:
1.Cao, ChunJun, et al. "Quantum Lego expansion pack: Enumerators from tensor networks." PRX Quantum 5.3 (2024): 030313.
2.Toga, G. C., Samlodia, A., & Kemper, A. F. (2025). Fast Scrambling in the Hyperbolic Ising Model. arXiv preprint arXiv:2503.00114.

Keywords: quantum computing, trapped ions, quantum gravity, chaotic systems, fast information scrambling, holographic code

[193] Premjith Thekkeppatt (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam), Digvijay (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam), Klaasjan van Druten (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam) and Florian Schreck (Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam). ***Confinement-induced stabilization of a resonantly interacting Bose-Fermi mixture.***

Presenter: Klaasjan van Druten

Abstract: We demonstrate the stabilizing effect of confinement to lower dimension of a resonantly interacting Bose-Fermi gas mixture near quantum degeneracy. Specifically, we work with a mixture of ultracold neutral 87Rb atoms (bosons) and 87Sr atoms (fermions). The two-body scattering properties of this mixture in the ultracold regime (submicrokelvin temperatures) were previously determined in our group [1,2], and it was found that the interspecies s-wave scattering length is very nearly resonant (a~1400 Bohr radii). In previous experiments, this mixture suffered from strong losses at high densities (near quantum degeneracy). This was attributed to three-body recombination, as this is expected to limit the lifetime (in three dimensions, 3D) for near-resonant two-body interactions, scaling as a^4 [3]. We find that the losses are strongly suppressed when applying an additional 1D optical lattice to bring the mixture from a 3D optical trap to the quasi-2D trapping regime [4,5]. The resonantly interacting mixture was observed to have a long lifetime, up to hundreds of milliseconds, when the motion is confined to 2D. Our immediate goal is now to create weakly bound RbSr molecules from the demonstrated stable starting point, for instance using confinement-induced resonance [6]. This is the next step towards creating open-shell ultracold heteronuclear ground-state RbSr molecules, having both a significant electric and magnetic dipole moment. Further, our results suggest promising opportunities to study the properties of this novel Bose-Fermi quantum gas mixture, both in 2D and in 1D, and also in the (Mott) insulator regime when confined by a 3D optical lattice. Our results highlight the 87Rb-87Sr quantum gas mixture as an appealing and

promising platform for studying quantum many-body effects, precision measurement [7], quantum chemistry, quantum computation, and quantum simulation.
[1] A. Ciamei, et al., Phys. Chem. Chem. Phys 20, 26221 (2018)
[2] V. Barbé et al., Nat. Phys.14, 881 (2018)
[3] P.O. Fedichev, M.W. Reynolds and G.V. Shlyapnikov, Phys Rev. Lett. 77, 2921 (1996)
[4] D.S. Petrov, M. Holtzmann and G.V. Shlyapnikov, Phys. Rev. Lett 84, 2551 (2000)
[5] A. Görlitz et al, Phys. Rev. Lett. 87, 130402 (2001)
[6] L. Oghittu et al., arXiv:2506.02579 (2025)
[7] P. Thekkepatt, Digvijay, A. Urech, F. Schreck and K. van Druten, arXiv:2504.11242 (2025)

Keywords: Quantum gases, Bose-Fermi mixtures, Few-body interactions, Low-dimensional systems, Ultracold molecules

[194] Elliot Eklund (University of Sydney), Patrick Sinnott (University of Sydney), Arkin Tikku (University of Sydney), William J. Huggins (Google Quantum AI), Guang Hao Low (Google Quantum AI), Dominic W. Berry (Google Quantum AI), Ryan Babbush (Google Quantum AI) and Ivan Kassal (University of Sydney).
End-to-End Simulation of Chemical Dynamics on a Quantum Computer.

Presenter: Patrick Sinnott

Abstract: Computer simulations of chemical dynamics are a powerful means for understanding chemical processes. However, classical computers struggle to simulate many types of chemical processes, especially those involving non-adiabatic dynamics, where the Born-Oppenheimer approximation breaks down. Although quantum computers could simulate quantum-chemical dynamics more efficiently than classical computers, there is currently no complete quantum algorithm to calculate dynamical observables to within a known error. Here, we present an end-to-end quantum algorithm for simulating chemical dynamics that avoids all uncontrolled approximations, including the Born-Oppenheimer approximation and pseudopotentials, by explicitly treating the nuclei and the electrons on an equal footing. To do so, the full nuclear-electronic wavefunction is simulated on a real-space grid in first quantization, including all algorithmic steps: initial-state preparation, time evolution using qubitization, and measurement of chemically relevant observables such as reaction yields and rates. We identify photochemistry as a likely early application of our algorithm and perform end-to-end resource estimates for simulating non-adiabatic dynamics of photo-excited molecules on fault-tolerant quantum computers.

Keywords: Chemical dynamics, Quantum simulation, Quantum algorithms, Resource estimate, Photochemistry

[195] Kushagra Mehta (University of Maryland), Samarth Sriram (University of Maryland) and Avik Dutt (University of Maryland).
Simulating Quantum Dynamics of Two-Mode Driven Dissipative Nonlinear Oscillators .

Presenter: Kushagra Mehta

Abstract: We simulate the dynamics of single and coupled nonlinear quantum oscillators under coherent interactions and engineered drive and dissipation. In particular, we investigate a single Rayleigh–van der Pol (RvdP) and a pair of coupled van der Pol oscillators (vdP). Starting from a Schrödinger cat state, evolved under the Kerr and squeezing Hamiltonians along with appropriate dissipators, we find that the Wigner negativities vanish rapidly, preventing sustained quantum behavior. To further explore exotic quantum phenomena, we then turn to a pair of coupled vdP oscillators and analyze signatures such as entanglement, amplitude death and oscillation death. Recent work in literature has claimed the generation of “squeezed” states in the quantum analog of the amplitude death phase; however, our rigorous theory and simulations reveal the lack of nonclassical squeezing in these parameter regimes, both in the single-mode and two-mode version. We instead confirm that by probing the

deep quantum regime, such a system can show genuine quantum squeezing and thus exhibit noise below the standard quantum limit. We also quantify Gaussian entanglement and purity through these squeezed and anti-squeezed covariances. Finally, we study the phenomenon of oscillation death and show significant deviation of the quantum models from the classical and noisy classical models in the steady state. We anticipate that these phase transitions and nonclassical states generated through quantum analogs of well-known classical models can have implications for quantum technologies such as sensing, metrology, and simulation of driven-dissipative dynamical systems.

Keywords: Squeezing, Entanglement, Nonlinear Dynamics, Driven-Dissipative Systems

[196] Christopher Kane (University of Maryland College Park), Siddharth Hariprakash (University of California Berkeley), Neel Modi (University of California Berkeley), Michael Kreshchuk (Phase Craft) and Christian Bauer (Lawrence Berkeley National Laboratory).

Two Advances in Lattice Field Theory: Algorithm-Dependent Continuum Limit Costs and Block Encoding Methods.

Presenter: Christopher Kane

Abstract: We present two advances in lattice field theory simulation. First, we address a critical but often overlooked challenge: approximate time evolution errors can spoil the continuum limit. We develop the Statistically-Bounded Time Evolution (SBTE) protocol to answer: "For a given time evolution algorithm, what additional computational cost is required to ensure time evolution errors have negligible impact on the continuum limit relative to statistical precision?" This protocol provides a general framework applicable to any quantum algorithm, offering an alternative to more complex renormalization procedures. Applying SBTE to Product Formula (Trotter) and Quantum Signal Processing (QSP) algorithms, we find that the additional cost can be significant for Trotter but is always negligible for QSP.
Second, we introduce new block-encoding methods for scalar field theory Hamiltonians. Beyond the standard Linear Combination of Unitaries (LCU) approach, we show that QSP techniques—including Quantum Singular Value Transformation (QSVT)—can efficiently implement block encodings with improved asymptotic scaling in qubits per bosonic mode. We also present LOVE-LCU (Linear Operators Via Exponentiation and LCU), which outperforms other methods for operators up to ~12 qubits, highlighting the practical importance of concrete circuit constructions over asymptotic comparisons.
These contributions address complementary challenges in making quantum lattice field theory simulations more reliable and efficient.

Keywords: lattice gauge theory, Hamiltonian simulation, block encoding techniques

[197] Twesh Upadhyaya (Joint Center for Quantum Information and Computer Science, University of Maryland), Zacharie Van Herstraeten (DIENS, École Normale Supérieure, PSL University, CNRS, INRIA), Jack Davis (DIENS, École Normale Supérieure, PSL University, CNRS, INRIA), Oliver Hahn (The University of Tokyo), Nikolaos Koukoulekidis (Duke Quantum Center, Duke University) and Ulysse Chabaud (DIENS, École Normale Supérieure, PSL University, CNRS, INRIA).

Majorization theory for quasiprobabilities.

Presenter: Twesh Upadhyaya

Abstract: Majorization theory is a powerful mathematical tool to compare the disorder in distributions, with wide-ranging applications in many fields including mathematics, physics, information theory, and economics. While majorization theory typically focuses on probability distributions, quasiprobability distributions provide a pivotal framework for advancing our understanding of quantum mechanics, quantum information and signal processing. Here, we introduce a notion of majorization for continuous quasiprobability distributions over infinite

measure spaces. Generalizing a theorem by Hardy, Littlewood and Pólya, we prove the equivalence of four definitions for both majorization and relative majorization in this setting. We give several applications of our results in the context of quantum resource theories, obtaining new families of resource monotones and no-goes for quantum state conversion. Our results provide a general formalism for assessing the disorder of integrable functions over infinite measure spaces using majorization theory.

Keywords: Quantum Information Theory, Majorization, Quasiprobabilities, Quantum Resource Theories

[198] Shreyan Ganguly (Dartmouth College), Linta Joseph (Dartmouth College) and Chandrasekhar Ramanathan (Dartmouth College).
Effectiveness of time-reversal protocols in solid-state spin-based quantum simulators.

Presenter: Shreyan Ganguly

Abstract: Time-reversal plays an important role in the field of quantum simulations by enabling the measurement of Out-of-Time-Ordered-Correlators (OTOC-s), which themselves can be used for probing important aspects in the domain of quantum information such as information scrambling effects and verification protocols. Development of effective time-reversal protocols allows more precise measurements of OTOC-s. In this work, we investigate the effectiveness of such time-reversal protocols for a nuclear spin (NMR) based quantum simulator (where time reversal is implemented by engineering “effective Hamiltonians” via application of a periodic train of radiofrequency (RF) pulses). For such platforms (which allow global/local control), the Hamiltonian engineering is implemented over discrete time intervals. Analytic schemes like Average Hamiltonian Theory (AHT)/Floquet theory are employed for precisely designing the control protocols for this process. This work involves the elucidation of the effects of imperfections in the pulse sequences (such as finite pulse effects) which introduce errors in the simulation process itself. We employ Average Hamiltonian Theory in conjugation with the F-Matrix formalism to analytically evaluate these error terms and study their effects for a specific pulse sequence (that can generate highly correlated spin states and hence lead to high quality OTOC measurements). This allows us to obtain bounds for the controllability of the engineered Hamiltonian. The effectiveness of the engineered Hamiltonian (for time reversal purposes) is experimentally studied by measuring the Loschmidt echo fidelity. This allows us to set a benchmark for the performance of the time-reversal protocol and opens up possibilities for testing the sensitivity of these engineered Hamiltonains to perturbations.

Keywords: Time reversal, Out-of-Time-Ordered-Correlators, Hamiltonian Engineering, Quantum Control, Loschmidt echo fidelity

[199] Hanqing Liu (University of Maryland), Austin Hulse (Duke University) and Iman Marvian (Duke University).
Unitary Designs from Random Symmetric Quantum Circuits.

Presenter: Hanqing Liu

Abstract: In this work, we study distributions of unitaries generated by random quantum circuits containing only symmetry-respecting gates. We develop a unified approach applicable to all symmetry groups and obtain an equation that determines the exact design properties of such distributions. It has been recently shown that the locality of gates imposes various constraints on realizable unitaries, which in general, significantly depend on the symmetry under consideration. These constraints typically include restrictions on the relative phases between sectors with inequivalent irreducible representations of the symmetry. We call a set of symmetric gates semi-universal if they realize all unitaries that respect the symmetry, up to such restrictions. For instance, while 2-qubit gates are semi-universal for Z_2, U(1), and SU(2) symmetries in qubit systems, SU(d) symmetry with d>=3 requires 3-qudit gates for semi-universality. Failure of semi-universality precludes the distribution generated by the random circuits from being even a 2-design for the Haar distribution over symmetry-respecting unitaries. On the other hand, when semi-universality holds, under mild conditions, satisfied by U(1) and SU(2) for example, the

distribution becomes a t-design for t growing polynomially with the number of qudits, where the degree is determined by the locality of gates. More generally, we present a simple linear equation that determines the maximum integer t_max for which the uniform distribution of unitaries generated by the circuits is a t-design for all t<=t_max. Notably, for U(1), SU(2) and cyclic groups, we determine the exact value of t_max as a function of the number of qubits and locality of the gates, and for SU(d), we determine the exact value of t_max for up to 4-qudit gates.

Keywords: Unitary design, Symmetric quantum circuits, Semi-universality

[200] Sreevardhan Atyam (University of Illinois, Urbana-Champaign), Anitej Chanda (University of Illinois, Urbana-Champaign), Aniket Deshpande (University of Illinois, Urbana-Champaign), Qizhao Huang (University of Illinois, Urbana-Champaign) and Edgar Solomonik (University of Illinois, Urbana-Champaign).
Approximating Tensor Contractions with Annealed Importance Sampling.

Presenters: Sreevardhan Atyam and Aniket Deshpande

Abstract: Tensor network contractions form the computational backbone of quantum simulations in condensed matter physics, quantum chemistry, and beyond. However, they quickly become computationally prohibitive as system size increases.
We present an Annealed Importance Sampling (AIS)-based algorithm, implemented with single-site Glauber dynamics, which offers a promising approach to efficiently approximate these high-dimensional contractions. Here, we systematically compare AIS-based sampling against uniform sampling strategies across a 3×3 lattice tensor network, highlighting regimes where AIS yields significant improvements in accuracy, particularly as the contraction becomes increasingly challenging. Our numerical results demonstrate clear advantages of AIS in terms of convergence, suggesting substantial potential for scalable and resource-efficient simulation of quantum systems. This work provides a foundation for implementing AIS-based tensor contraction methods towards simulating complex quantum systems.
Our AIS methodology is applicable to various quantum information tasks, such as simulating quantum circuits and contracting tensor networks arising in specific condensed matter systems.

Keywords: Tensor Networks, Tensor Contractions, Annealed Importance Sampling, Glauber Dynamics, Quantum Simulation

[201] Aditya K. Rao (University of Toronto), Jenny R. Moore (University of Toronto), Grier M. Jones (University of Toronto) and Hans-Arno Jacobsen (University of Toronto).
Scaling the Local Unitary Cluster Jastrow Ansatz with Distributed Quantum Computing.

Presenters: Aditya K. Rao and Jenny R. Moore

Abstract: In quantum chemistry, one of the key problems is solving for the ground state energy of a molecular Hamiltonian, revealing properties useful in areas such as material science and drug discovery. Classically, higher accuracy methods are computationally expensive, scaling exponentially with the number of electrons. The local unitary cluster Jastrow (LUCJ) Ansatz is a popular quantum alternative, but limited by the number of qubits per quantum processor unit (QPU), restricting the size of the complete active space (CAS) and/or the complexity of the chemical systems studied. Leveraging circuit knitting and distributed quantum computing (DQC) can negate this limitation by distributing LUCJ across multiple QPUs. Partitioning LUCJ by its alpha and beta spin-orbitals achieves two smaller Ansätze that can be run independently, increasing the total number of qubits available. Here, we demonstrate this by distributing the heavy-hex and all-to-all connectivity implementations of the LUCJ Ansatz with local operations (LO). So far, our results are scaling well both in terms of sampling overhead and chemical accuracy, with the distributed LUCJ achieving near exact agreement with the original LUCJ in systems such as diatomics and hydrogen chains. This method has potential scalability beyond 100 qubits per device. This allows

the electronic structure of larger, more complex, systems with real world applications to be studied, thereby pushing the boundaries of quantum chemistry beyond classical limitations.

Keywords: Local unitary cluster Jastrow, Distributed quantum computing, Quantum-centric supercomputing, Electronic structure theory, Circuit knitting, Quantum chemistry, Quantum algorithms, Quantum computing

[202] Aditya K. Rao (University of Toronto), Jenny R. Moore (University of Toronto), Grier Jones (University of Toronto) and Hans-Arno Jacobsen (University of Toronto).
Near-term Quantum Algorithms and Error Correction for Molecular Property Predicitions.

Presenters: Aditya K. Rao and Jenny R. Moore

Abstract: Chemical applications using near-term quantum algorithms, such as those related to the distributed quantum computing (DQC) and quantum machine learning (QML), have proven to be capable means of predicting molecular properties in the age of noisy-intermediate scale quantum (NISQ) devices. Our research has focused on the application and benchmarking of quantum error mitigation approaches, coupled with these algorithms, to study the prediction accuracy and possibility of a quantum advantage. Our previous work, with respect to DQC on NISQ devices, has shown that quantum error mitigation can scale algorithms to multiple quantum devices and is crucial for applications related to quantum chemistry. Our current work explores the partitioning of existing algorithms as well as the development of novel QML algorithms for applications related to catalyst discovery and drug design and for understanding the trainability, expressibility, and generalization capabilities of various models.

Keywords: Quantum machine learning, Middleware, Distributed quantum computing, Quantum chemistry, Quantum computing, Quantum algorithms

[203] Lev H. Kendrick (Harvard University), Anant Kale (Harvard University), Youqi Gang (Harvard University), Alexander D. Deters (Harvard University), Muqing Xu (Harvard University), Chunhan Feng (Simons Foundation (Flatiron Institute)), Shiwei Zhang (Simons Foundation (Flatiron Institute)), Martin Lebrat (Harvard University), Aaron W. Young (Harvard University) and Markus Greiner (Harvard University).
Emergent physics at ultralow temperatures in a Fermi-Hubbard quantum simulator.

Presenter: Youqi Gang

Abstract: The Fermi-Hubbard model is a fundamental model in the understanding of strongly correlated electron systems. Despite its simplicity, its phase diagram at low temperatures and finite doping remains a challenge for standard computational methods and is a subject of ongoing investigation. Ultracold fermionic atoms in optical lattices offer a pristine realization of the Hubbard model, yet the accessible temperature has been too high to address many open questions. Here, we demonstrate a several-fold reduction in temperature by adiabatically transforming a low-entropy product state of ~300 atoms into a correlated final state. This enables us to study previously inaccessible regimes of the phase diagram. We observe a line of thermodynamic anomalies separating the low- and high-doping regimes, known as a Widom line. Lattice modulation spectroscopy reveals a suppression of low-energy spectral weight in the low-doping regime, which is non-uniform in the Brillouin zone, indicative of a pseudogap. In addition, we observe a region of enhanced rotational symmetry breaking that may indicate a state of fluctuating stripes. This work demonstrates the utility of quantum simulation in addressing frontier problems in correlated electron physics.

Keywords: Quantum Simulation, Many-body Physics, Optical Lattices

[204] Nothando Khumalo (UCLA), Aman Mehta (UCLA), William Munizzi (UCLA) and Prineha Narang (UCLA).
Entanglement and Magic Dynamics in Ingleton Violating Circuits.

Presenter: Nothando Khumalo

Abstract: Entropy vectors offer a useful tool for classifying quantum states according to their entanglement structure. For certain classes of states, such as stabilizer states or holographic states, the space of allowed entropy vectors is defined by a set of entropy inequalities those states must satisfy. While successful research has associated specific inequalities to classes of states, at low qubit number, very little is known about the dynamics of entropy vectors or about the entanglement transition between different classes of states. In this work, we present a machine learning approach to studying entropy vector dynamics and entropy inequality violation. One notable inequality, the Ingleton inequality, is satisfied by states whose entanglement and correlations can be captured by linear coding solutions. We employ our machine learning approach to identify rare Ingleton-violating states in the Hilbert space, and construct explicit circuits to prepare those states from the computational basis. Additionally we investigate the role of non-local magic, a key indicator of classical intractability in quantum systems, in driving violations of the Ingleton inequality. Our results provide new tools and insights for analyzing the dynamics of quantum resources, as well as characterizing the relationship between entanglement and magic in the context of entropy inequalities.

Keywords: Quantum, Machine Learning, Algorithms, Information theory, Simulation, Quantum Networks, Entanglement, Magic

Learning measurement-induced phase transitions using attention

Presenter: Hyejin Kim

Abstract: Measurement-induced phase transition (MIPT) is a hallmark of monitored quantum dynamics but remains challenging to observe experimentally due to reliance on post-selection or classical simulation. We introduce a scalable, data-centric approach using the Quantum Attention Network (QuAN), an attention-based architecture that learns directly from measurement data without post-selection. By analyzing dynamics generated by unitaries and weak measurements, we show QuAN can detect MIPTs via two complementary tasks: (1) distinguishing trajectories from different initial states ("learnability transition") and (2) classifying phases from a single initial state ("phase recognition"). The latter requires orders of magnitude fewer samples and is robust to realistic noise. Attention scores confirm that QuAN focuses on the tail of the Born probability distribution, providing physical interpretability. Our results establish a practical framework for detecting MIPTs on near-term quantum hardware and demonstrate the utility of attention-based models in learning complex quantum phenomena.