Quantum Science and Technology Mini-Symposium
Room 208 W - Session QS1-TuM

Quantum Simulations and Quantum-Inspired Technologies

Moderators: Andre Schleife, University of Illinois at Urbana-Champaign, **Sisira Kanhirathingal**, Rigetti Computing

8:00am **QS1-TuM-1 Quantum Simulation of Spin-Current Autocorrelation Function***, **Yi-Ting Lee,*** University of Illinois at Urbana Champaign*; Bibek Pokharel,* IBM, T.J. Watson Research Center*; Arnab Banerjee,* Purdue University*; Andre Schleife,* University of Illinois at Urbana-Champaign*; Jeffrey Cohn,* IBM Almaden Research Center

Understanding spin dynamics has long intrigued physicists, as it plays a vital role in revealing the characteristics of quantum magnets, with potential applications in spintronic devices and spin qubits. Evaluating the dynamical properties of large spin systems is often challenging for classical computers due to the exponential growth in memory requirements. Since Hamiltonian dynamics can be efficiently simulated using quantum circuits, the evaluation of time-dependent properties has generated significant interest within the quantum computing community.

While time-dependent magnetization and the one-time dynamical structure factor have been simulated on quantum computers before, there has been no simulation of the spin-current autocorrelation function (ACF). The one-time spin-current ACF can be used to identify the diffusion behavior of spin systems and is directly related to their coherence properties and device performance. In this research, we first consider the spin-1/2 XXZ Heisenberg model as it serves as the framework for studying magnetic interaction.

Here, we introduce a simple yet efficient direct measurement scheme for evaluating the one-time spin-current ACF. Unlike the standard Hadamard test, our method eliminates the need for control gates with ancilla qubits and reduces the number of required circuits by a factor of N, where N is the number of qubits. We demonstrate the circuit design and measurement protocol and validate it through a quantum experiment on the *ibm_marrakesh* hardware. In the 20-qubit experiment with the Néel state, we achieve excellent agreement with the numerical results for both the real and imaginary parts, highlighting the effectiveness of our method. Moreover, we present a design for measuring the two-time spin-current ACF and demonstrate good agreement between statevector-simulated results and numerical results, further showcasing the utility of our approach. Furthermore, our method can be potentially extended to measure any ACF, benefiting the study of spin dynamics.

This work is supported by Taiwan UIUC scholarship, and we acknowledge support by the IBM Illinois Discovery Accelerator Institute and the IBM Externship Program. This work made use of the Illinois Campus Cluster, a computing resource that is operated by the Illinois Campus Cluster Program in conjunction with the National Center for Supercomputing Applications and which is supported by funds from UIUC. The research at IBM and Purdue is supported by National Quantum Initiative Science Research Centers, Quantum Science Center, managed by ORNL for the US-DOE.

8:15am **QS1-TuM-2 Quashing Logical Errors with Multimode Quantum Error Correction***, Nick Frattini, Dany Lachance-Quirion,* ***Matthew Hamer****, Marc-Antoine Lemonde,* Nord Quantique, Canada

Quantum error correction (QEC) is essential for fault-tolerant quantum computing, ensuring that logical informationremains protected from physical noise during the execution of quantum algorithms. Traditional QEC strategies achieve this by redundantly encoding logical qubits across many physical qubits, incurring significant hardware overhead. At Nord Quantique, we leverage the large Hilbert space of quantum oscillators to perform QEC within a single physical system, offering a potentially more hardware-efficient path to fault-tolerant quantum computing.

Among such bosonic codes, grid codes are particularly promising, as they encode discrete-variable logical information in translationally invariant lattices in phase space. Recent experimental demonstrations in superconducting circuits have validated this approach with single-mode grid codes, enabling QEC that helps more than it hurts. A key challenge in these demonstrations were the silent logical errors induced by auxiliary control systems (e.g., transmons). One promising avenue to circumvent this for FTQC are multi-mode grid codes, where auxiliary errors may move the state outside of the logical space rather than inducing silent logical errors.

In this talk, we will present our experimental resultsalong two axes toward FTQC: gates for single-mode grid qubits, and QEC for two-mode grid qubits. For the two-mode so-called tesseract code, we will demonstrate its enhanced features by leveraging mid-circuit measurement outcomes to suppress logical decay in a hardware-efficient architecture.These results validate Nord Quantique's vision of multimode grid codes as a promising pathway toward FTQC.

8:30am **QS1-TuM-3 Quantum Information Processing Stack: From Bottom to Top and Back***, **Sophia Economou,*** Virginia Tech **INVITED**

Quantum processors have become quite large and sophisticated machines over the last several years, with many tech companies racing to develop the first quantum computer of practical utility. While the progress has been impressive, quantum processors still face significant hurdles such as short coherence times and high error rates. They are not yet able to compete with classical information processing technologies in solving problems of practical interest. I will discuss my group's contributions across the quantum information processing stack, from the control of quantum hardware to quantum algorithm development and back.

9:00am **QS1-TuM-5 Quantum Simulation of Condensed Matter Using Trotterized Entanglement Renormalization***, **Thomas Barthel,*** Duke University

Strongly-correlated quantum matter can be simulated with tensor network states. A very interesting approach, motivated by real-space renormalization group, is the multi-scale entanglement renormalization ansatz (MERA). While MERA has various advantages over alternative tensor network methods, it has relatively high classical computation costs, which limits the attainable approximation accuracy [1]. To avoid the classically expensive contractions of high-order tensors, we have developed a variational quantum eigensolver (VQE) based on MERA and tensor Trotterization [2]. Due to its causal structure and noise-resilience, the MERA VQE can be implemented on noisy intermediate-scale (NISQ) devices and still describe large physical systems. The number of required qubits is system-size independent and only grows logarithmically when using quantum amplitude estimation to speed up gradient evaluations. Translation invariance can be used to make computation costs square-logarithmic in the system size and describe the thermodynamic limit. Results of benchmark simulations for various critical spin models and algorithmic phase diagrams substantiate a quantum advantage [3] and we have proven the absence of barren plateaus [4-6]. I will report on first experimental tests on ion-trap devices, which clearly demonstrate a continuous quantum phase transition. Using a new holographic tomography scheme, we were also able to resolve for the first time the transition from area-law to log-area law scaling of subsystem entanglement entropies when approaching criticality [7].

[1] "Scaling of contraction costs for entanglement renormalization algorithms including tensor Trotterization and variational Monte Carlo", arXiv:2407.21006, PRB 111, 045104 (2025)
[2] "A quantum-classical eigensolver using multiscale entanglement renormalization", arXiv:2108.13401, PRR 5, 033141 (2023)
[3] "Convergence and quantum advantage of Trotterized MERA for strongly-correlated systems", arXiv:2303.08910, Quantum 9, 1631 (2025)
[4] "Absence of barren plateaus and scaling of gradients in the energy optimization of isometric tensor network states", arXiv:2304.00161, Commun. Math. Phys. 406, 86 (2025)
[5] "Isometric tensor network optimization for extensive Hamiltonians is free of barren plateaus", arXiv:2304.14320, PRA 109, L050402 (2024)
[6] "Equivalence of cost concentration and gradient vanishing for quantum circuits: An elementary proof in the Riemannian formulation", arXiv:2402.07883, Quantum Sci. Technol. 9, 045039 (2024)
[7] "Probing entanglement scaling across a quantum phase transition on a quantum computer", arXiv:2412.18602

9:15am **QS1-TuM-6 Reducing the Resources Required by ADAPT-VQE Using Coupled Exchange Operators and Improved Subroutines***, **Mafalda Francisco Ramôa da Costa Alves,*** Virginia Tech, Portugal*; Sophia Economou, Edwin Barnes, Nicholas Mayhall, Panagiotis Anastasiou,* Virginia Tech*; Luis Santos,* INESC TEC, Portugal

Adaptive variational quantum algorithms arguably offer the best prospects for quantum advantage in the NISQ era. Since the inception of the first such algorithm, ADAPT-VQE, many improvements have appeared in the literature. We propose two modifications to the algorithm: (i) a Hessian recycling protocol, where the approximate second derivatives of the cost function obtained by quasi-Newton optimizers flow from one iteration to the next, and (ii) a novel operator pool, the Coupled Exchange Operator (CEO) pool, where the elements are linear combinations of qubit excitations. We show that unitaries generated by CEOs can be implemented with low two-qubit gate counts - in particular, they can be implemented with as many or fewer CNOTs as those generated by only one of the constituent qubit excitations.We combine these two improvements with others previously proposed in the literature to create the most cost- and hardware-efficient version of ADAPT-VQE to date. We use the resulting algorithm on a range of molecular systems, and assess the cost of executing it on hardware. We show a dramatic reduction of these quantum resources compared to prior versions of the algorithm and find that our state-of-the-art CEO-ADAPT-VQE outperforms UCCSD, the most widely regarded static VQE ansatz, in all relevant metrics.We further compare the algorithm to state-of-the-art static ansatze and observe that all those with a comparable CNOT count to ADAPT-VQE require a measurement overhead of the order of 10^5 for small (12 qubit) molecules. This goes against the common belief that the adaptive ansatz construction incurs a measurement overhead - thanks to ADAPT-VQE-specific cost optimizations and the favorable cost landscape the algorithm naturally generates, the measurement costs are actually decreased.

9:30am **QS1-TuM-7 Floquet-ADAPT-VQE: A Quantum Algorithm to Simulate Non-Equilibrium Physics in Periodically Driven Systems***,* ***Abhishek Kumar****, Karunya Shirali, Nicholas J. Mayhall, Sophia E. Economou, Edwin Barnes,* Virginia Tech

Non-equilibrium many-body quantum systems exhibit many fascinating phenomena absent in equilibrium systems, but simulating them on classical computers is challenging. We propose a hybrid quantum-classical algorithm, Floquet-ADAPT-VQE, to simulate the non-equilibrium physics of periodically driven quantum systems. We utilize the Floquet-Hilbert space, a composition of auxiliary and physical spaces, to transform the Hamiltonian into a time-independent form. We define a cost function based on the square of the shifted extended Floquet Hamiltonian and show how to prepare Floquet eigenstates using Floquet-ADAPT-VQE. We also obtain a suitable auxiliary initial state whose squared Floquet energy is independent of the number of auxiliary qubits as well as the driving frequency, which leads to better convergence with fewer ADAPT iterations. Additionally, we provide a framework to calculate the time-dependent expectation value of observables in the Floquet state with fixed-depth quantum circuit. We demonstrate our algorithm by performing numerical simulations on a periodically driven XYZ model with a magnetic field. We also explore potential applications of our algorithm for studying various non-equilibrium phenomena in periodically driven systems.

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