Cornell Quantum Day (November 9, 2023)
Book of Abstracts

Speaker: Hyejin Kim
Advisor(s): Eun-Ah Kim
Affiliation: Cornell University
Title: Attention to Quantum Complexity
Abstract: Random quantum circuit holds a particular interest due to the non-trivial growth in complexity of the state with the increase in circuit depth. Various metrics have been proposed to characterize this quantum complexity, such as conventional entanglement entropy and linear cross-entropy benchmarks (XEB). As both of these methods require formidable amounts of quantum data or even large-scale classical simulations for estimation, the need for an efficient alternative approach arises to detect complexity given a limited amount of data. We turn to the notion of K-design, which invites one to look into higher moments of the bit string distribution. While the rigorous estimation of the moments would also require large amounts of data, it ought to be possible to learn partial information relevant for higher moments, in principle. Using the self-attention mechanism to learn aspects of higher moments, we design and train quantum attention networks (QAN) to learn increasing complexity. We show that QAN can learn past anti-concentration on simulated data. Application of QAN on experimental data shows how QAN can learn in the presence of real noise. Our results show an exciting prospect of using QAN to learn quantum complexity beyond the limits of manually specified functions.

Speaker: Keiran Lewellen
Advisor(s): Debanjan Chowdhury
Affiliation: Cornell University
Title: Tracking thermal evolution of quantum many-body states using variational shadow tomography
Abstract: An important task in the field of quantum simulation is the preparation of ground states given a generic local Hamiltonian. While this is quantumly hard in general, a recently proposed class of quantum "cooling" algorithms holds promise for a large subset of Hamiltonians. They work by replicating the way Nature prepares ground states – using a "bath" to cool the system. However, while such algorithms eventually prepare a target thermal state, they provide no efficient mechanism to track the thermal evolution of the system towards that target. To solve this problem we propose the Variational Quantum Thermometry (VQT) algorithm, which utilizes the power of shadow tomography along with a physically-motivated reinterpretation of variational autoencoders. We demonstrate the success of this algorithm both for predicting the temperatures of thermal states and for tracking the thermal evolution of quantum cooling algorithms with and without noise.

Speaker: Haoran Lu
Advisor(s): Valla Fatemi
Affiliation: Cornell University
Title: Detection and manipulation of Andreev Spin Qubits
Abstract: A weak link between two superconductors will create discrete states within the superconducting gap. When the link is short, the even-parity electrons on the weak link will form a high dispersing two-level system called Andreev pair states. We focus on the region where the weak

link is long enough to form a few sub bands, and spin-orbital coupling separates the degenerate odd-parity spin states, enabling detecting and manipulating them individually. This type of hybrid platform, Andreev spin qubit (ASQ) has only recently been developed and is still under exploration. The large energy separation between the ground sub band and the higher bands, long lifetime and compact spatial structure offered by ASQ makes it a good candidate for quantum computing. In today's talk, we will mainly focus on the background of ASQ as well as how we tune the analog control gate to detect spin states, how we achieve qubit drive and how we measure its qubit lifetime.

Speaker: Dhrumil Patel
Advisor(s): Mark M. Wilde
Affiliation: Cornell University
Title: Wave Matrix Lindbladization as an Approach for Simulating Markovian Quantum Dynamics
Abstract: We investigate the problem of simulating open system dynamics governed by the well-known Lindblad master equation. In order to do so, we introduce an input model in which Lindblad operators are encoded into pure quantum states, called program states, and we also introduce a method, called wave matrix Lindbladization, for simulating Lindbladian evolution by means of interacting the system of interest with these program states. We begin by focusing on a simple case in which the Lindbladian consists of only one Lindblad operator and a Hamiltonian. Thereafter, we extend the method to simulating general Lindbladians and other cases in which a Lindblad operator is expressed as a linear combination or a polynomial of the operators encoded into the program states. We propose quantum algorithms for all these cases and also investigate their sample complexity, i.e., the number of program states needed to simulate a given Lindbladian evolution approximately. Finally, we demonstrate that our quantum algorithms provide an efficient route for simulating Lindbladian evolution relative to full tomography of encoded operators, by proving that the sample complexity for tomography is dependent on the dimension of the system, whereas the sample complexity of wave matrix Lindbladization is dimension independent.

Speaker: Saahil Patel & Daniel Koch
Affiliation: AFRL/RITQ
Title: Quantum Algorithms Research at AFRL
Abstract: Saahil will present his latest Quantum Machine Learning (QML) research, covering recent work with quantum data compression and putting it into context with quantum communication channels. Compression of quantum data allows us to utilize and transmit data using fewer qubits. Simulating transmission of quantum data through noisy communication channels allows us to study quantum state degradation and robustness of certain quantum states to various sources of noise. Some preliminary results will show how we can potentially use Variational Quantum algorithms (VQA) to learn and account for noise in these communication channels. Then, Dr. Koch will discuss his recent work using Amplitude Amplification (Amp. Amp.) to solve combinatorial optimization problems such as QUBO (quadratic unconstrained binary optimization). The most common framework for Amp. Amp. involves 'oracle' operations which separate all 2^N basis states of a Hilbert Space into two groups: "marked" and "unmarked". These oracle operations are powerful for computational means, leading to the typical quadratic speedup of Amp. Amp. as originally proposed by Grover. However, they are also very circuit depth costly, which has led Dr. Koch to investigate alternative NISQ-friendly oracle operations and their use for solving QUBO (and beyond) problems.

Speaker: Chris Richardson
Affiliation: Laboratory for Physical Sciences
Title: Epitaxial nitride thin films for superconducting quantum circuits

Abstract: Epitaxial superconducting thin films with potential to improve high-fidelity superconducting qubits will be presented. Through a structure-first approach, Plasma Assisted Molecular Beam Epitaxy (PAMBE) is used to grow niobium titanium nitride alloys (NbxTi1-xN) and wide bandgap nitride (AlN) superconductors directly on sapphire wafers. This combination of nitride materials provides sufficient degrees of freedom that synthesis of an epitaxial Josephson junction may be possible. Growth results of NbxTi1-xN films on c-plane sapphire substrates, and initial trilayer NbTiN/AlN/NbTiN (superconductor-insulator-superconductor) Josephson junction structures on sapphire will be presented along with structural analysis and microwave measurements.

Speaker: Hamim Mahmud Rivy
Advisor(s): Karan Mehta
Affiliation: Cornell University
Title: A Cryogenic Trapped-Ion Apparatus For Integrated Optical Control

Abstract: Although trapped ions offer a promising platform for practical quantum computing, scaling the optical system required for control imposes is a major challenge. Here, I will describe optical and electrical characterization of an ion trap device with integrated optics intended to implement a standing-wave-wave laser cooling scheme with $^{40}Ca^{+}$ ions. The trap device was fabricated in a commercial foundry and Si_3N_4 and Al_2O_3 waveguides were integrated to deliver red and UV wavelengths respectively to control the ion. Also, an overview of the apparatus development for the cryogenic trapped ion system will be given. The apparatus development includes the development of trap device packaging, cryogenic system, compact acousto-optic modulator system, magneto optical trap, and electronic control system.

Speaker: Alen Senanian
Advisor(s): Peter McMahon
Affiliation: Cornell University
Title: Signal classification using measurement back-action in a continuous-variable quantum reservoir computing experiment.
Abstract:

Speaker: Kunal Sharma
Title: Effect of non-unital noise on random circuit sampling
Abstract: In this work, drawing inspiration from the type of noise present in real hardware, we study the output distribution of random quantum circuits under practical non-unital noise sources with constant noise rates. We show that even in the presence of unital sources like the depolarizing channel, the distribution, under the combined noise channel, never resembles a maximally entropic distribution at any depth. To show this, we prove that the output distribution of such circuits never anticoncentrates — meaning it is never too "flat" — regardless of the depth of the circuit. This is in stark contrast to the behavior of noiseless random quantum circuits or those with only unital noise, both of which anticoncentrate at sufficiently large depths. As consequences, our results have interesting algorithmic implications on both the hardness and easiness of noisy random circuit sampling, since anticoncentration is a critical property exploited by both state-of-the-art classical hardness and easiness results.

Speaker: Qin Xu
Advisor(s): Greg Fuchs

Title: Strong photon-magnon coupling using a lithographically defined organic ferrimagnet

Abstract: We demonstrate a cavity-magnonic system composed of a superconducting microwave resonator coupled to a magnon mode hosted by the organic-based ferrimagnet vanadium tetracyanoethylene ($V[TCNE]_x$). This work is motivated by the challenge of scalably integrating a low-damping magnetic system with planar superconducting circuits. We take advantage of the properties of $V[TCNE]_x$, which has ultra-low intrinsic damping, can be grown at low processing temperatures on arbitrary substrates, and can be patterned via electron beam lithography. Our devices operate in the strong coupling regime, with a cooperativity exceeding 1000 for coupling between the Kittel mode and the resonator mode at T~0.4 K, suitable for scalable quantum circuit integration. Higher-order magnon modes are also observed with much narrower linewidths than the Kittel mode. This work paves the way for high-cooperativity hybrid quantum devices in which magnonic circuits can be designed and fabricated as easily as electrical wires.

Speaker: Zhou Yang
Advisor: Chao-Ming Jian
Title: Tapestry of dualities in decohered quantum error correction codes and a bound on error threshold

Abstract: Quantum error correction (QEC) codes protect quantum information from noises and errors that inevitably occur in near-term quantum computing platforms. An important measure of the performance of the QEC codes is the error threshold. We argue that the error threshold belongs to a family of decoherence-induced phase transitions (DIPT) of the QEC codes, which are signaled by the singularities of the Rényi entropies of the code after decoherence caused by the errors. For a large class of QEC codes, namely the Calderbank-Shor-Steane (CSS) codes, we find a mapping between the Rényi entropies caused by the Pauli errors and a pair of disordered classical $\mathbb{Z}_2$ spin models. The two classical models are related to one another by a Kramers-Wannier-like duality. The DIPTs correspond to critical points of these classical models. Moreover, we find an additional duality between bit-flip (X) and phase (Z) errors for the Rényi entropies with Rényi index R = 2, 3. An intricate tapestry of dualities is thus woven with the aforementioned elements. For CSS codes with a symmetry between the X- and Z-stabilizers, we show that the R = 2, 3 dualities become self-dualities, which strongly constrain the critical points of the DIPTs with R = 2, 3. Utilizing these self-dualities, we further obtain a generic upper bound on the error threshold for this class of CSS symmetric codes, which includes the 2d toric code, Haah’s code, etc.