International Workshop on Quantum Characterization, Verification, and Validation (IWQCVV)

量子刻画与验证国际研讨会

23-25 August, 2023

Department of Physics (C108), Fudan University, Shanghai, China

Organizers:

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- Ms. Xinli Yan (yanxinli@fudan.edu.cn), Fudan University

Sponsored by:

- Fudan University
- State Key Laboratory of Surface Physics
- Key Laboratory for Information Science of Electromagnetic Waves, Ministry of Education
- Beijing Institute of Technology
- Key Laboratory of Advanced Optoelectronic Quantum Architecture and Measurement, Ministry of Education

Workshop website: http://iwqcvv2023.top/

Venue

Department of Physics (C108), Fudan University (Jiangwan New Campus), 2005 Songhu Rd, Yangpu District, Shanghai, China
复旦大学物理系(C108)，上海市杨浦区淞沪路 2005 号复旦大学江湾新校区

Transportation

- From Pudong Airport to Fudan University (Jiangwan New Campus)
  By Taxi: About 160 yuan and 68 mins
- From Hongqiao Airport to Fudan University (Jiangwan New Campus)
  By Taxi: About 116 yuan and 55 mins
- Bus No.1201 (Fudan University Jiangwan Campus Stop)
- Bus No.168 (Fudan University Jiangwan Campus Stop)
- Bus No.538 (Songhu Road Yinxing Road Stop)
- Subway Line 10 (Guofan Road Station，国帆路站)
- To Blinq Hotel: Subway Line 10 (Xinjiangwancheng Station，新江湾城站)

Invited Speakers

Animesh Datta	University of Warwick
Barry Sanders	University of Calgary
Da-Wei Wang	Zhejiang University
Dengke Qu	Southeast University
Dong Liu	Tsinghua University
Geng Chen	University of Science and Technology of China
Guo-Yong Xiang	University of Science and Technology of China
Haidong Yuan	The Chinese University of Hong Kong
He Lu	Shandong University
Hsin-Yuan Huang	Caltech
Hui Khoon Ng	National University of Singapore
Jens Eisert	Freie Universität Berlin
Lijian Zhang	Nanjing University
Nana Liu	Shanghai Jiao Tong University
Qi Zhao	The University of Hong Kong
Shunlong Luo	The Academy of Mathematics and System Science, CAS
Shuo Yang	Tsinghua University
Soonwon Choi	MIT
Tomoyuki Morimae	Kyoto University
Valerio Scarani	National University of Singapore
Xiao-Dong Yu	Shandong University
Xin Wang	Hong Kong University of Science and Technology (Guangzhou)
Xiaosong Ma	Nanjing University
Xiongfeng Ma	Tsinghua University
Yanhong Xiao	Shanxi University
Yoshifumi Nakata	Kyoto University
Yuxiang Yang	The University of Hong Kong
Zhaohui Wei	Tsinghua University
Zhengfeng Ji	Tsinghua University
Zhibo Hou	University of Science and Technology of China

Scientific Program (Overview)

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<tr><td>09:40-10:15</td><td></td><td>Zhengfeng Ji</td><td>Geng Chen</td><td>Guo-Yong Xiang</td></tr>
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<tr><td>11:55-14:00</td><td></td><td colspan="3">Lunch</td></tr>
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<tr><td>15:10-15:45</td><td rowspan="5">Registration (Blinq Hotel Shanghai Wujiaochang)</td><td>Yoshifumi Nakata</td><td>Dong Liu</td><td>Jens Eisert *</td></tr>
<tr><td>15:45-16:20</td><td>Coffee break</td><td>Zhibo Hou</td><td>Coffee break</td></tr>
<tr><td>16:20-16:55</td><td>Tomoyuki Morimae *</td><td rowspan="3">Poster Session</td><td>Animesh Datta *</td></tr>
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***** **:** online talk
35 min (30+5) for each talk
Posters can be set up during the morning coffee break on 24 Aug.

Zoom Meeting

- Meeting ID: 849 2058 3467
- Passcode: 876888

Live Streaming

Accommodation Info & Shuttle Bus

Blinq Hotel 上海五角场博邻酒店

1258 Yinhang Road, Yangpu District, Shanghai (about 500m from Xinjiangwancheng Station on Line 10)

上海市杨浦区殷行路 1258 号（距 10 号线新江湾城站约 500 米）

Phone: +86(021)65888865

About 1.6 km from the conference venue (Department of Physics, Jiangwan New Campus, Fudan University). Conference check-in starts in this hotel on the afternoon of 22 Aug.

Note: We have a bus provided between the Conference Venue and Blinq Hotel Shanghai Wujiaochang in the morning.

	Wednesday	Thursday	Friday
Blinq-Fudan	8:00	8:00	8:00

Fudan -Conference **Banquet**	Thursday 18:15

Detailed Program

23 August (Wednesday)

Time	Talk Info	
08:30-09:05	Barry Sanders	Kittens, cats and compasses: superposing coherent states for quantum sensing, quantum communication, quantum computing and quantum fun
09:05-09:40	Xiongfeng Ma	Practical means to calibrate quantum gates
09:40-10:15	Zhengfeng Ji	IQP Sampling and Verifiable Quantum Advantage: Stabilizer Scheme and Classical Security
10:15-10:45	Registration, Coffee break	
10:45-11:20	Zhaohui Wei	All pure bipartite entangled states can be semi-self-tested with only one measurement setting on each party
11:20-11:55	Hsin-Yuan Huang	Learning many-body Hamiltonians with Heisenberg-limited scaling
11:55-14:00	Lunch	
14:00-14:35	Valerio Scarani	Dynamics-based certification
14:35-15:10	Xiaosong Ma	Integrated quantum photonics for quantum network and entangled state verifications
15:10-15:45	Yoshifumi Nakata	Quantum error correction by low-depth random Clifford circuits
15:45-16:20	Coffee break	
16:20-16:55	Tomoyuki Morimae	Quantum commitments and signatures without one-way functions
16:55-17:30	Xin Wang	Quantum Phase Processing for Eigen-information Processing and Quantum Machine Learning
17:30-18:05	Xiao-Dong Yu	A complete hierarchy for the pure state marginal problem in quantum mechanics

24 August (Thursday)

Time	Talk Info	
08:30-09:05	Shunlong Luo	Fisher Information: From Metrology to Asymmetry, Coherence, and Uncertainty
09:05-09:40	Haidong Yuan	Information geometry under hierarchical quantum measurement
09:40-10:15	Geng Chen	A new quantum resource: Quantum causal order
10:15-10:45	Registration, Coffee break	
10:45-11:20	Yuxiang Yang	Fully optimized quantum metrology: ultimate precision and optimal protocols
11:20-11:55	Qi Zhao	Hamiltonian simulation by compensating Trotter error with linear combination of unitary operations
11:55-14:00	Lunch	
14:00-14:35	Yanhong Xiao	Simplified multiparameter atomic sensor by machine learning
14:35-15:10	Hui Khoon Ng	Quantum computing with noisy components
15:10-15:45	Dong Liu	Noise-resilient circuit design and benchmarking strategy based on periodic unitary circuit
15:45-16:20	Zhibo Hou	Minimum-consumption state discrimination with global optimal adaptive measurements
16:20-18:05	Coffee break and Poster Session	

Banquet (18:30): The shuttle bus to the banquet departs at 18:15.

25 August (Friday)

Time	Talk Info	
08:30-09:05	Lijian Zhang	Direct characterization of quantum systems: efficiency and precision
09:05-09:40	Soonwon Choi	Toolbox for Analog Quantum Simulators
09:40-10:15	Guo-Yong Xiang	Precision limit of quantum multi-parameter measurement
10:15-10:45	Registration, Coffee break	
10:45-11:20	Shuo Yang	Scalable Quantum State Tomography with Locally Purified Density Operators and Local Measurements
11:20-11:55	He Lu	Experimental Shadow Tomography on Quantum Optical System
11:55-14:00	Lunch	
14:00-14:35	Dawei Wang	Quantum Induced Coherence Light Detection and Ranging
14:35-15:10	Nana Liu	Analog quantum simulation of partial differential equations
15:10-15:45	Jens Eisert	Exploiting randomness in benchmarking beyond randomized benchmarking
15:45-16:20	Coffee break	
16:20-16:55	Animesh Datta	Quantum accreditation of digital and analogue computers and simulators
16:55-17:30	Dengke Qu	Experimental investigate of state-independent contextuality

Talk Abstracts

23 August (Wednesday)

Barry Sanders, University of Calgary

Title: Kittens, cats and compasses: superposing coherent states for quantum sensing, quantum communication, quantum computing and quantum fun

Abstract: Glauber coherent states are semiclassical in the sense that that follow classical harmonic-oscillator dynamics and are minimum uncertanity states. A superposition of two macroscopically distinct coherent states is a Schrödinger cat state (alive and dead in superposition) and a kitten if not macroscopically distinct. Superposing two-and multi-mode coherent states in an entangled coherent state. Geometric intuition arises through quasiprobability representations, allowing us to talk about superposing coherent states on a line (relevant to boson qubits) and on a circle (e.g. compass states also relevant to bosonic qubits). I present this potted history followed by our proposal for making a nuclear cat state.

Xiongfeng Ma, Tsinghua University

Title: Practical means to calibrate quantum gates

Abstract: Advancements in controllable quantum systems require efficient multi-qubit gate characterization for high-fidelity quantum computing. Randomized benchmarking, while effective, faces challenges due to its complicated implementation of multi-qubit twirling gates. In this talk, I will present two protocols — character-cycle and character-average benchmarking—that use local twirling gates to estimate the process fidelity of individual multi-qubit operations. These two protocols can characterize a large class of quantum gates, including the Clifford group and its locally transformed variants, which forms a universal quantum gate set. Following the same idea, we further study the benchmarking protocols for classically replaceable unitary operations. We propose a systematic method to construct a twirling group for benchmarking a classical replaceable unitary operation. We show that our construction is optimal for some Z-basis gates like CCZ in the scope of classically replaceable unitary operations. As an additional result, we prove the optimality of Pauli twirling in turning a channel into a Pauli channel and, meanwhile, in Clifford gate benchmarking.

Zhengfeng Ji, Tsinghua University

Title: IQP Sampling and Verifiable Quantum Advantage: Stabilizer Scheme and Classical Security

Abstract: Sampling problems demonstrating beyond classical computing power with noisy intermediate-scale quantum (NISQ) devices have been experimentally realized. In those realizations, however, our trust that the quantum devices faithfully solve the claimed sampling problems is usually limited to simulations of smaller-scale instances and is, therefore, indirect. The problem of verifiable quantum advantage aims to resolve this critical issue and provides us with greater confidence in a claimed advantage. Instantaneous quantum polynomial-time (IQP) sampling has been proposed to achieve beyond classical capabilities with a verifiable scheme based on quadratic-residue codes (QRC). Unfortunately, this verification scheme was recently broken by an attack proposed by Kahanamoku-Meyer. In this work, we revive IQP-based verifiable quantum advantage by making two major contributions. Firstly, we introduce a family of IQP sampling protocols called the stabilizer scheme, which builds on results linking IQP circuits, the stabilizer formalism, coding theory, and an efficient characterization of IQP circuit correlation functions. This construction extends the scope of existing IQP-based schemes while maintaining their simplicity and verifiability. Secondly, we introduce the Hidden Structured Code (HSC) problem as a well-defined mathematical challenge that underlies the stabilizer scheme. To assess classical security, we explore a class of attacks based on secret extraction, including the Kahanamoku-Meyer's attack as a special case. We provide evidence of the security of the stabilizer scheme, assuming the hardness of the HSC problem. We also point out that the vulnerability observed in the original QRC scheme is primarily attributed to inappropriate parameter choices, which can be naturally rectified with proper parameter settings.

Zhaohui Wei, Tsinghua University

Title: All pure bipartite entangled states can be semi-self-tested with only one measurement setting on each party

Abstract: It has been known that all bipartite pure quantum states can be self-tested, i.e., any such state can be certified completely by initially measuring both subsystems of this state by proper local quantum measurements and subsequently verifying that the correlation between the measurement choices and the outcomes satisfies a specific condition. In such a protocol, a key feature is that the conclusion can still be reliable even if involved quantum measurements are untrusted, where quantum nonlocality is crucial and plays a central role, and this means that each party has to conduct at least two different quantum measurements to produce a desirable correlation. Here, we prove that when the underlying Hilbert space dimension is known beforehand, an arbitrary $d * d$ bipartite pure state can be certified completely (up to local unitary transformations) by a certain correlation generated by a single measurement setting on each party, where each measurement yields only 3d or even d+1 outcomes. Notably,

our protocols do not involve any quantum nonlocality. We believe that our result may provide us a remarkable convenience when certifying bipartite pure quantum states in quantum labs.

Hsin-Yuan Huang (Robert), Caltech

Title: Learning many-body Hamiltonians with Heisenberg-limited scaling

Abstract： Learning a many-body Hamiltonian from its dynamics is a fundamental problem in physics. In this work, we propose the first algorithm to achieve the Heisenberg limit for learning an interacting N-qubit local Hamiltonian. After a total evolution time of $O(1/\epsilon)$, the proposed algorithm can efficiently estimate any parameter in the N-qubit Hamiltonian to ϵ-error with high probability. The proposed algorithm is robust against state preparation and measurement error, does not require eigenstates or thermal states, and only uses polylog$(1/\epsilon)$ experiments. In contrast, the best previous algorithms, such as recent works using gradient-based optimization or polynomial interpolation, require a total evolution time of $O(1/\epsilon^2)$ and $O(1/\epsilon^2)$ experiments. Our algorithm uses ideas from quantum simulation to decouple the unknown N-qubit Hamiltonian H into noninteracting patches and learns H using a quantum-enhanced divide-and-conquer approach. We prove a matching lower bound to establish the asymptotic optimality of our algorithm.

Valerio Scarani, National University of Singapore

Title: Dynamics-based certification

Abstract: This talk will describe a new class of witness of quantum features (Wigner negativity entanglement) based on the knowledge of the dynamics of the system. Initially conceived by Tsirelson for one harmonic oscillator, the technique has been extended both to discrete systems and to other Hamiltonians; and can be used to detect entanglement in the case of composite systems.

Xiaosong Ma, Nanjing University

Title: Integrated quantum photonics for quantum network and entangled state verifications

Abstract: Quantum technology employs the ‘spooky’ phenomena of quantum physics such as superposition, randomness and entanglement to process information in a novel way. Quantum photonics provides a promising path for both delivering quantum-enhanced technologies and exploring fundamental physics. In this talk, I will introduce our recent endeavors in developing functional nodes for quantum information processing based on integrated optics architecture and their potential applications in a metropolitan fiber network.

In the second part, I will talk about our recent work on quantum state verifications in high dimensions as well as using feed-forward technique.

Yoshifumi Nakata, Kyoto University

Title: Quantum error correction by low-depth random Clifford circuits

Abstract: Quantum random code is a quantum error correcting code (QECC) generated by a random quantum circuit and is known to have high performance of correcting various noises. While it was originally proposed as a theoretical technique, recent developments have opened the possibility of realizing it by near-term quantum devices. In this work, we show that QECCs generated by one-dimensional log-depth random Clifford circuits have high performance against stochastic Pauli noise. The result is obtained by constructing an efficient tensor-network decoder for the codes. The combination of efficient encoding, decoding and high performance against stochastic Pauli noise may indicate that such codes are good candidates for near-term quantum memories.

Xin Wang, Hong Kong University of Science and Technology (Guangzhou)

Title: Quantum Phase Processing for Eigen-information Processing and Quantum Machine Learning

Abstract: Quantum computing can provide speedups in solving many problems as the evolution of a quantum system is described by a unitary operator in an exponentially large Hilbert space. Such unitary operators change the phase of their eigenstates and make quantum algorithms fundamentally different from their classical counterparts. Based on this unique principle of quantum computing, we develop a new algorithmic toolbox ``quantum phase processing" that can directly apply arbitrary trigonometric transformations to eigenphases of a unitary operator. The quantum phase processing circuit is constructed simply, consisting of single-qubit rotations and controlled-unitaries, typically using only one ancilla qubit. Besides the capability of phase transformation, quantum phase processing can extract the eigen-information of quantum systems by measuring the ancilla qubit. Quantum phase processing complements another powerful framework known as quantum singular value transformation and leads to more intuitive and efficient quantum algorithms for solving problems that are particularly phase-related. We exploit the power of our method by investigating a plethora of applications in quantum phase estimation, Hamiltonian simulation, entanglement spectroscopy and quantum entropies estimation. For quantum machine learning, we also prove that single-qubit quantum neural networks can approximate any univariate function by mapping the model to a partial Fourier series. We notably establish the exact correlations between the parameters of the trainable gates and the Fourier coefficients, resolving an open problem on the universal approximation property of quantum neural networks. This talk is based on arXiv:2205.07848 (NeurIPS 2022) and arXiv:2209.14278 (AQIS 2023 Talk).

Tomoyuki Morimae, Kyoto University

Title: Quantum commitments and signatures without one-way functions

Abstract: In the classical world, the existence of commitments is equivalent to the existence of one-way functions. In the quantum setting, on the other hand, commitments are not known to imply one-way functions, but all known constructions of quantum commitments use at least one-way functions. Are one-way functions really necessary for commitments in the quantum world? In this work, we show that non-interactive quantum commitments (for classical messages) with computational hiding and statistical binding exist if pseudorandom quantum states exist. Pseudorandom quantum states are sets of quantum states that are efficiently generated but their polynomially many copies are computationally indistinguishable from the same number of copies of Haar random states (Ji, Liu, and Song, CRYPTO 2018). It is known that pseudorandom quantum states exist even if BQP = QMA (relative to a quantum oracle) (Kretschmer, TQC 2021), which means that pseudorandom quantum states can exist even if no quantum-secure classical cryptographic primitive exists. Our result therefore shows that quantum commitments can exist even if no quantum-secure classical cryptographic primitive exists. In particular, quantum commitments can exist even if no quantum-secure one-way function exists. In this work, we also consider digital signatures, which are other fundamental primitives in cryptography. We show that one-time secure digital signatures with quantum public keys exist if pseudorandom quantum states exist. In the classical setting, the existence of digital signatures is equivalent to the existence of one-way functions. Our result, on the other hand, shows that quantum signatures can exist even if no quantum-secure classical cryptographic primitive (including quantum-secure one-way functions) exists.

Xiao-Dong Yu, Shandong University

Title: A complete hierarchy for the pure state marginal problem in quantum mechanics

Abstract: Clarifying the relation between the whole and its parts is crucial for many problems in science. In quantum mechanics, this question manifests itself in the quantum marginal problem, which asks whether there is a global pure quantum state for some given marginals. This problem arises in many contexts, ranging from quantum chemistry to entanglement theory and quantum error correcting codes. In this paper, we prove a correspondence of the marginal problem to the separability problem. Based on this, we describe a sequence of semidefinite programs which can decide whether some given marginals are compatible with some pure global quantum state. As an application, we prove that the existence of multiparticle absolutely maximally entangled states for a given dimension is equivalent to the separability of an explicitly given two-party quantum state. Finally, we show that the existence of quantum codes with given parameters can also be interpreted as a marginal problem, hence, our complete hierarchy can also be used.

24 August (Thursday)

Shunlong Luo, Chinese Academy of Sciences

Title: Fisher Information: From Metrology to Asymmetry, Coherence, and Uncertainty

Abstract: The notation of Fisher information arises from statistical inference and is now playing an increasingly important and instrumental role in many fields such as statistics, mathematics, physics, and information. In particular, it plays a crucial role in the emergent field of quantum metrology. In this talk, we first present various aspects of Fisher information, and then focus on the Wigner-Yanase skew information (which is the first version of quantum Fisher information) and illustrate its applications in quantifying asymmetry, coherence and quantum uncertainty.

Haidong Yuan, The Chinese University of Hong Kong

Title: Information geometry under hierarchical quantum measurement

Abstract: In most quantum technologies, measurements need to be performed on the parametrized quantum states to transform the quantum information to classical information. The measurements, however, inevitably distort the information. The characterization of this discrepancy is an important subject in quantum information science, which plays a key role in understanding the difference between the structures of quantum and classical informations. Here we analyze the difference in terms of the Fisher information metric and present a framework that can provide analytical bounds on the discrepancy under hierarchy quantum measurements. Specifically, we present a set of analytical bounds on the difference between the quantum and classical Fisher information metric under hierarchy p-local quantum measurements, which are measurements that can be performed collectively on at most p copies of quantum states.

Geng Chen, University of Science and Technology of China

Title: A new quantum resource: Quantum causal order

Abstract: This talk will give an introduction to quantum causal order and its application in quantum information processing. Especially, a recently published work on quantum metrology will be presented, which implements a quantum causal order scheme with a hybrid optical system and achieves a precision attaining super-Heisenberg limit.

Yuxiang Yang, The University of Hong Kong

Title: Fully optimized quantum metrology: ultimate precision and optimal protocols

Abstract: One of the main quests in quantum metrology is to attain the ultimate precision to limit with given resources, where the resources are not only of the number of queries, but more importantly of the allowed strategies. With the same number of queries, the restrictions on the strategies constrain the achievable precision. In this talk, I will introduce a systematic framework to identify the ultimate precision limit of different families of strategies, including the parallel, the sequential and the indefinite-causal-order strategies, and provide an efficient algorithm that determines an optimal strategy within the family of strategies under consideration. Within this framework, we can show there exists a strict hierarchy of the precision limits for different families of strategies.

Qi Zhao, The University of Hong Kong

Title: Hamiltonian simulation by compensating Trotter error with linear combination of unitary operations

Abstract: Trotter and linear-combination-of unitary (LCU) are two popular Hamiltonian simulation methods. We propose Hamiltonian simulation algorithms using LCU to compensate Trotter error, which enjoy both of their advent ages. By adding few gates after the Kth-order Trotter formula, we realize a better time scaling than 2Kth-order Trotter. Our first algorithm exponentially improves the accuracy scaling of the Kth-order Trotter formula. In the second algorithm, we consider the detailed structure of Hamiltonians and construct LCU for Trotter errors with commutator scaling. Consequently, for lattice Hamiltonians, the algorithm enjoys almost linear system-size dependence and quadratically improves the accuracy of the Kth-order Trotter.

Yanhong Xiao, Shanxi University

Title: Simplified multiparameter atomic sensor by machine learning

Abstract: We propose a novel paradigm for vector atomic magnetometry based on machine learning. Unlike conventional schemes where one measured signal explicitly connects to one parameter, here we encode the three-dimensional magnetic-field information in the set of four simultaneously acquired signals, i.e., the oscillating optical rotation signal's harmonics of a frequency modulated laser beam traversing the atomic sample. The map between the recorded signals and the vectorial field information is established through a pre-trained deep neural network. We demonstrate experimentally a single-shot all-optical vector atomic magnetometer,

with a simple scalar-magnetometer design employing only one elliptically-polarized laser beam and no additional coils. Magnetic field amplitude sensitivities of about 100 fT/sqrt(Hz) and angular sensitivities of about 100-200 μrad/sqrt(Hz) (for a magnetic field of about 140 nT) are derived from the neural network. Our approach can reduce the complexity of the architecture of vector magnetometers, and may shed light on the general design of multiparameter sensing.

Hui Khoon Ng, National University of Singapore

Title: Quantum computing with noisy components

Abstract: Quantum computation with near-future devices will remain limited by the noise in the physical components. The only way forward, to get to large-scale and useful quantum computers, is be through active error correction and fault-tolerant methods. I will discuss some aspects of this, touching on the current status of the subject, and areas worth of further exploration.

Dong Liu, Tsinghua University

Title: Noise-resilient circuit design and benchmarking strategy based on periodic unitary circuit

Abstract: Noise presents a significant challenge to the scalability of quantum computation, necessitating a comprehensive understanding and effective correction mechanisms. This study introduces a two-pronged approach based on a periodic unitary circuits addressing there needs in the Noisy Intermediate-Scale Quantum (NISQ) era. Firstly, an innovative noise-resilient circuit design strategy for control-free phase estimation is developed, reducing phase estimation error considerably by identifying and mitigating benign noise types. Through the use of a randomized compiling protocol, generic noise is transformed into stochastic Pauli noise, paving the way for quantum phase estimation in the pre-fault-tolerant quantum computing era. Secondly, we propose a novel method of Channel Spectrum Benchmarking (CSB) to overcome the limitations of current benchmarking techniques. CSB infers the noise properties of target gates from their noisy channel eigenvalues, allowing for benchmarking of universal gates and scalability to many-qubits systems. It provides direct noise information for both native gates and circuit fragments, thereby aiding the calibration of global entangling gates and key modules in quantum algorithms. Our finding suggests the significant potential of this dual strategy for developing robust quantum processors and optimizing quantum error mitigation in the NISQ era.

Zhibo Hou, University of Science and Technology of China

Title: Minimum-consumption state discrimination with global optimal adaptive measurements

Abstract: Discriminating non-orthogonal quantum states for a fixed admissible error rate is a reliable starting point for many quantum information processing tasks. The key request is to minimize the average resource consumption. By subtly using the updated posterior probability, here we develop a general global optimal adaptive (GOA) approach, which applies to any error rate requirement, any prior probability, and any measurement restrictions. Under local measurement restrictions, we achieve a global optimal adaptive local (GOAL) strategy, which is much more efficient than the previous global optimal fixed local projective (GOFP) method and serves as a local bound. When incorporating the more efficient two-copy collective measurements, we obtain a global optimal adaptive collective (GOAC) strategy to further beat the local bound. We experimentally realize out GOAC method and demonstrate its efficiency advantages over GOAL and GOFP. By exploiting the power of both adaptivity and collective measurements, out work marks an important step in minimum-consumption quantum state discrimination.

25 August (Friday)

Lijian Zhang, Nanjing University

Title: Direct characterization of quantum systems: efficiency and precision

Abstract: Direct tomography of quantum systems using weak measurements has several advantages compared to the standard quantum tomography in terms of reduced experimental and algorithmic complexities. In this talk I will present our recent works on the resource efficient scheme for the direct characterization of multi-particle entangled quantum states, as well as the direct characterization of quantum measurement. The characterization precision and the way to improve it are also discussed.

Soonwon Choi, MIT

Title: Toolbox for Analog Quantum Simulators

Abstract: Analog quantum simulation is one of the most promising applications of existing quantum technologies. In this talk, we will present novel methods for improving the utility of present-day quantum simulators. These methods include high-precision benchmarking and advanced measurement techniques. Our benchmarking protocol allows estimating the many-body fidelities of small or intermediate-size quantum systems, and we will present experimental demonstrations of the technique. Then, we will introduce a simple, universal measurement protocol for extracting arbitrary physical properties of quantum states obtained from experiments. Our protocol leverages the information scrambling that occurs in natural quench dynamics of generic quantum systems, providing a scalable and efficient solution for measuring observables that are otherwise not directly accessible. We will illustrate the power of our approach with several examples.

Guo-Yong Xiang， USTC

Title: Precision limit of quantum multi-parameter measurement

Abstract: High precision parameter estimation is one of the main driving forces for science and technology. For the estimation of a single parameter, the fundamental limit, as well as the protocols to achieve it, have been extensively studied. However, for practical applications such as imaging and spectroscopy, there are typically multiple parameters, for which the fundamental limits remain elusive. Usually, the trade-offs are unavoidable for the estimation of multiple parameters whose generators do not commute with each other. In this talk, I will introduce our recent works on multi-parameter quantum estimation and its applications.

Shuo Yang, Tsinghua University

Title: Scalable Quantum State Tomography with Locally Purified Density Operators and Loc al Measurements

Abstract: Understanding quantum systems holds significant importance for assessing the performance of quantum hardware and software, as well as exploring quantum control and quantum sensing. An efficient representation of quantum states enables realizing quantum state tomography with minimal measurements. In this study, we propose a new approach to state tomography that uses tensor network representations of mixed states through locally purified density operators and employs a classical optimization algorithm requiring only local measurements. Through numerical simulations of one-dimensional pure and mixed states and two-dimensional random tensor network states up to size 8x8, we demonstrate the efficiency, accuracy, and robustness of our proposed methods. Experiments on the IBM Quantum platform complement these numerical simulations. Our study opens new avenues in quantum state tomography for two-dimensional systems using tensor network formalism.

He Lu, Shandong University

Title: Experimental Shadow Tomography on Quantum Optical System

Abstract: Quantum optical system is a promising route in quantum information science. The exponentially growing complexity of multiphoton entangled states significantly empowers the applications in quantum information science, yet limits the ability to fully characterize it by means of standard quantum tomography. Shadow tomography provides a scalable and practical approach to characterize large-scale quantum states. We experimentally explore the feasibility of the shadow tomography in the realistic scenario with a finite number of measurements and noisy operations. We prepare a four-qubit GHZ state and show how to estimate expectation values of multiple observables and Hamiltonian. We compare the strategies with uniform, biased, and derandomized classical shadows to conventional ones that sequentially measures each state function exploiting either importance sampling or observable grouping. We next demonstrate the estimation of nonlinear functions using classical shadows and analyze the entanglement of the prepared quantum state. Our experiment verifies the efficacy of exploiting (derandomized) classical shadows and sheds light on efficient quantum computing with noisy intermediate-scale quantum hardware. The shadow tomography requires complex unitary operations applied on the prepared states before the projective measurements. Replacing the unitary operations and projective measurements with positive operator valued measures (POVMs) significantly alleviates the complexity of experimental settings, making it capable to extract complete informations for tomography in single experimental run. We propose to demonstrate POVM on polarization degree of freedom of photonic qubit with a single metasurface optical chip instead of conventional bulky optical assemblies. Specifically, we design and fabricate a metasurface to perform shadow tomography with octahedron POVM, and show its superiority in estimation of observables. Moreover, we combine the shadow

estimation and a self-learning algorithm to efficiently and accurately reconstruct the underlying quantum states, which exhibits advantages in terms of fewer number of measurements required, high accuracy of the estimation and robustness against optical loss.

Da-Wei Wang, Zhejiang University

Title: Quantum Induced Coherence Light Detection and Ranging

Abstract: Quantum illumination has been proposed and demonstrated to improve the signal-to-noise ratio (SNR) in light detection and ranging (LiDAR). When relying on coincidence detection, such a quantum LiDAR is limited by the response time of the detector and suffers from jamming noise. Inspired by the Zou-Wang-Mandel experiments, we design, construct and validate a quantum induced coherence (QuIC)LiDAR which is inherently immune to ambient and jamming noises. In traditional LiDAR the direct detection of the reflected probe photons suffers from deteriorating SNR for increasing background noise. In (QuIC)LiDAR we circumvent this obstacle by only detecting the entangled reference photons, whose single-photon interference fringes are sued to obtain the distance of the object, while the reflected probe photons are used to erase path information of the reference photons. In consequence, the noise accompanying the reflected probe light has no effect on the detected signal/ We demonstrate such noise resilience with both LED and laser light to mimic the background noise and jamming attack. The proposed method paves a new way of battling noise in precise quantum electromagnetic sensing and ranging.

Nana Liu, Shanghai Jiao Tong University

Title: Analog Quantum Simulation of Partial Differential Equations

Abstract: Quantum simulators were originally proposed to be helpful for simulating one partial differential equation (PDE) in particular – Schrodinger’s equation. If quantum simulators can be useful for simulating Schrodinger’s equation, it is hoped that they may also be helpful for simulating other PDEs. As with large-scale quantum systems, classical methods for other high-dimensional and large-scale PDEs often suffer from the curse-of-dimensionality (costs scale exponentially in the dimension D of the PDE), which a quantum treatment might in certain cases be able to mitigate. To enable simulation of PDEs on quantum devices that obey Schrodinger’s equations, it is crucial to first develop good methods for mapping other PDEs onto Schrodinger’s equations. In this talk, I will introduce the notion of Schrodingerisation: a procedure for transforming non-Schrodinger PDEs into a Schrodinger-form. This simple methodology can be used directly on analog or continuous quantum degrees of freedom – called qumodes, and not only on qubits. This continuous representation can be more natural for PDEs since, unlike most computational methods, one does not need to discretise the PDE first. In this

way, we can directly map D-dimensional linear PDEs onto a (D + 1)-qumode quantum system where analog Hamiltonian simulation on (D + 1) qumodes can be used. I show how this method can be applied to linear PDEs, certain nonlinear PDEs, nonlinear ODEs and also linear PDEs with random coefficients, which is important in uncertainty quantification.

Jens Eisert, Freie Universität Berlin

Title: Exploiting randomness in benchmarking beyond randomized benchmarking

Abstract: Quantum computers and simulators promise to solve problems beyond the means of classical computers. Quantum simulators specifically may provide new insights into strongly-correlated condensed-matter problems that are hard to obtain from classical supercomputers. Early on, it became clear that quantum simulators may reach regimes for which the best known classical algorithms are challenged in keeping up with existing large-scale quantum simulators. The promises of the field - challenging as they may be in their own right - can only be fulfilled if the components work well and if the entire prescription is operating as anticipated. For this reason, questions of benchmarking and certification are moving into the center of attention.
We will put such questions into the center of this talk, making basically two points: First, we make the point that known, efficiently trackable dynamics can be a powerful tool to be used in benchmarking. Hamiltonian learning can help in assessing analog quantum simulators. Possibly more importantly, randomness can be a tool the range of applicability of which can go substantially beyond that of randomized benchmarking. Starting from a general and comprehensive mathematical framework of randomized benchmarking, we will show that suitable randomized sequences can deliver the same quantum data input for a wealth of classical post-processing techniques, giving rise to noise channel tomography, Pauli channel learning, randomized benchmarking without end gates or cross-talk tomography. Shadow estimation can be made robust and based on shallow circuits. We will end the talk on the note that sophisticated benchmarking schemes may often require sophisticated classical post-processing, but not necessarily sophisticated measurements in experiments.

Animesh Datta, University of Warwick

Title: Quantum accreditation of digital and analogue computers and simulators

Abstract: Quantum acceleration provides an upper bound on the correctness of the outputs of arbitrary sized noisy quantum computers. It requires implementation of quantum circuits no larger than the target circuits, and is therefore practical in the near term and scalable in the long term. It tests entire circuits rather than individual gates and allows for arbitrary spatial and temporal correlations in the noise affecting state preparation, measurements and two-qubit gates. It has been demonstrated experimentally and extended to analogue quantum simulators.

Dengke Qu, Southest University

Title: Experimental investigate of state-independent contextuality

Abstract: Experimental Investigation of State-Independent Contextuality: Contextuality is a phenomenon at the heart of quantum mechanics that differs from classical behavior and has been recently identified as a resource in quantum information processing. Experimental demonstration of contextuality is thus an important goal. We experimentally demonstrate a test of state-independent contextuality in a four-dimensional Hilbert space with single photons and violate the inequality by at least 387 standard deviations. Despite imperfections and possible measurement disturbances, our results cannot be explained by non-contextual models. We also provide a theoretical analysis of a test of contextuality with a coherent light field and show how the definitions affect the emergence of non-classical correlations. Our result sheds new light on the conflict between quantum and classical physics.

Poster Abstracts

P1. Purity enhances criteria for correlated quantum network states

Zhenpeng Xu
Anhui University, China

Quantum networks are of high interest nowadays. In short, it is the way how quantum sources distribute particles to different parties in the network. Based on whether the sources are classically correlated or not, a quantum network is called correlated quantum network (CQN) or independent quantum network (IQN). Bundles of tools have been developed recently to determine whether a given quantum state or correlation can arise from IQN or not. In comparison, tools for CQN are rare. We propose a systematic approach based on purity to prompt well-known techniques for IQN to work for CQN. With this approach, we came up with criteria which work even simultaneously for networks with different kinds of topology. We also show that this approach can be further improved with more information, e.g., the exact noise model.

P2. Many-body quantum sensing with separable initial states

Jing Yang
Nordic Institute of Theoretical Physics

Quantum many-body interactions can lead to entanglement between different parities and therefore can be employed to enhance the precision of quantum sensing. Nevertheless, up to date, to reach the so-called Heisenberg limit, the present many-body sensing protocols requires to prepare the initial state in a highly entanglement, which experimentally either may be not feasible or cost too much time to prepare. In this work, we propose to prepare the sensor in separable state or the ground state of the sensing Hamiltonian. We analyse how local control operation can enhance the precision for a quantum many-body sensor.

P3. Realizing Non-physical Maps via Generalized Density Matrix Exponentiation

Zhenhuan Liu
Tsinghua University, China

Quantum physics offers advantages over its classical counterpart by allowing more general operations. Nevertheless, valid quantum operations are subject to the basic principles of quantum physics, specifically, the requirements of being completely positive and trace-preserving. However, non-physical maps also play vital roles in quantum information science and the fundamental study of quantum physics. Unfortunately, there are currently no effective methods to physically realize these non-physical maps. To address this limitation, we introduce the generalized density matrix exponentiation (GDME) algorithm, which leverages quantum memory, sequentially inputted states, and adjustable joint Hamiltonian evolution. GDME enables the physical realization of any Hermitian-preserving map by encoding its output into a quantum process. We thoroughly analyze the performance of GDME, including its sample complexity and robustness, and prove its optimality in certain cases. GDME, when combined with algorithms like Hadamard test and quantum phase estimation, can extract information or even generate states from the output of non-physical maps, facilitating various applications. By realizing positive, but not completely positive maps, GDME provides exponential advantages in entanglement detection and quantification compared with single-copy methods. Furthermore, GDME facilitates the recovery of noiseless quantum states from multiple copies of noisy states by realizing the inverse map of a noise channel, thus provides a new paradigm for managing quantum errors. GDME has potential to be an important protocol for quantum state benchmarking and a fundamental building block for large-scale quantum algorithms.

P4. Noise-Resilient Phase Estimation with Randomized Compiling

Yanwu Gu

Beijing Academy of Quantum Information Sciences, China

We develop an error mitigation method for the control-free phase estimation. We prove a theorem that under the first-order correction, the phases of a unitary operator are immune to the noise channels with only Hermitian Kraus operators, and therefore, certain benign types of noise for phase estimation are identified. By further incorporating the randomized compiling protocol, we can convert the generic noise in the phase estimation circuits into stochastic Pauli noise, which satisfies the condition of our theorem. Thus, we achieve a noise-resilient phase estimation without any quantum resource overhead. The simulated experiments show that our method can significantly reduce the estimation error of the phases by up to 2 orders of magnitude. Our method paves the way for the utilization of quantum phase estimation before the advent of fault-tolerant quantum computers.

P5. Predictive Modelling of A Quantum Process with Neural Networks

Yan Zhu

The University of Hong Kong, China

Complete characterization of an unknown quantum process can be achieved by process tomography and Hamiltonian learning. However, learning an unknown quantum process from its incomplete measurement data is an open problem. In this paper, we develop the first neural network algorithm for emulating the behavior of an unknown quantum process applied on a certain ensemble of input states, by learning from the classical information of a few input-output sample pairs. After training, this neural model can be used to predict the measurement statistics of a set of measurements of interest performed on the output state corresponding to any input in the state ensemble. Besides learning a quantum gate or quantum circuit, our model can also be applied for learning a quantum dynamical evolution and predicting the measurement statistics on the time-evolving state, which enables fast classical emulation of a long-time quantum evolution. We show satisfactory numerical results using our neural network model for various exotic quantum processes in quantum computing, quantum many-body physics and quantum optics.

P6. Flexible Learning of Quantum States with Generative Query Neural Networks

Yadong Wu

The University of Hong Kong, China

Deep neural networks are a powerful tool for characterizing quantum states. Existing networks are typically trained with experimental data gathered from the quantum state that needs to be characterized. But is it possible to train a neural network offline, on a different set of states? Here we introduce a network that can be trained with classically simulated data from a fiducial set of states and measurements, and can later be used to characterize quantum states that share structural similarities with the fiducial states. With little guidance of quantum physics, the network builds its own data-driven representation of a quantum state, and then uses it to predict the outcome statistics of quantum measurements that have not been performed yet. The state representations produced by the network can also be used for tasks beyond the prediction of outcome statistics, including clustering of quantum states and identification of different phases of matter.

P7. Classical Verification of Quantum Measurement for Computational Basis and XY-plane Basis

Qingshan Xu
Jinan University, China

Recent advances in quantum technologies raise the urgent need of verifying the correct functionality of quantum device. Certifying the correctness of quantum device in a fully classical manner is an important research branch. In this paper, we present a measurement protocol that allows a classical verifier interacts with an efficient quantum prover to verify the computational basis or the XY-plane basis measurement on a quantum state. With the help of two adaptive hardcore bit properties of noisy trapdoor claw-free family, the security of measurement protocol is proved, which is under quantum hardness of the learning with error. The security characterizes the distance between the output distribution of measurement protocol and the distribution obtained by measuring certain quantum state in the designated basis, with or without the presence of honest behavior of the prover. Moreover, exploiting the measurement protocol, we present two device-noise-independent verification protocols of graph states and a classical verification protocol of delegated quantum computing whose soundness is 0.5757.

P8. The Non-equilibrium Cost of Accurate Information Processing

Fei Meng
City University of Hong Kong, China

Accurate information processing is crucial both in technology and in nature. To achieve it, any information processing system needs an initial supply of resources away from thermal equilibrium. Here we establish a fundamental limit on the accuracy achievable with a given amount of nonequilibrium resources. The limit applies to arbitrary information processing tasks and arbitrary information processing systems subject to the laws of quantum mechanics. It is easily computable and is expressed in terms of an entropic quantity, which we name the reverse entropy, associated to a time reversal of the information processing task under consideration. The limit is achievable for all deterministic classical computations and for all their quantum extensions. As an application, we establish the optimal tradeoff between nonequilibrium and accuracy for the fundamental tasks of storing, transmitting, cloning, and erasing information. Our results set a target for the design of new devices approaching the ultimate efficiency limit, and provide a framework for demonstrating thermodynamical advantages of quantum devices over their classical counterparts.

P9. Unified Direct Parameter Estimation via Quantum Reservoirs

Yinfei Li

Beijing Institute of Technology, China

Parameter estimation is an indispensable task in various applications of quantum information processing. To predict parameters in the post-processing stage, it is inherent to first perceive the quantum state with a measurement protocol and store the information acquired. In this work, we propose a general framework for constructing classical approximations of arbitrary quantum states with quantum reservoir networks. A key advantage of our method is that only a single local measurement setting is required for estimating arbitrary parameters, while most of the previous methods need exponentially increasing number of measurement settings. To estimate M parameters simultaneously, the size of the classical approximation scales as lnM. Moreover, this estimation scheme is extendable to higher-dimensional as well as hybrid systems, which makes it exceptionally generic. Both linear and nonlinear functions can be estimated efficiently by our scheme, and we support our theoretical findings with extensive numerical simulations.

P10. Coupler-Free Gain-Assisted Excitation of Surface Plasmon Polaritons

Muqaddar Abbas

Xi'an Jiaotong University, China

We suggest a scheme for coupler-free excitation of Surface Plasmon Polariton (SPP) based on electromagnetically induced transparency (EIT) in an asymmetric semiconductor quantum well (SQW) system. Usually a coupler is used to avoid a momentum mismatch between light and SPP. However, due to the inherent quantum feature of asymmetric SQW, SPP is excited directly from free space light without any coupler. For SPP, the three-layer structure is considered to have a top transparent layer, a middle layer of thin metallic film, and a bottom layer of semiconductor material. The bottom layer consists of asymmetric SQWs. It is found that if the permittivity of the asymmetric SQWs medium is less than unity, which can be met for negative probe detuning, then momentum matches occur at a specific resonance angle. In order to compensate for the losses, we introduce gains into our system by incorporating the system parameters. The transfer matrix method is used to estimate the reflectivity and field enhancement spectrum of the probe field. The results of our model can bring more degrees of freedom for enhancing the SPP and have potential applications in photovoltaic devices, Plasmon technology, and biosensors.

P11. Corrupted Sensing Quantum State Tomography

Mengru Ma
Beijing Institute of Technology, China

We consider a critical problem in characterizing quantum systems, the simultaneous reconstruction of structured quantum states and structured noise. By using experimentally friendly Pauli measurements and simple convex optimization algorithms, we propose methods for quantum state tomography based on the signal recovery technique known as corrupted sensing. With no priori information of structured quantum states and structured corruption, we investigate the reconstruction as well as the stability of the algorithm. We numerically demonstrate the power of our algorithm by assuming Gaussian sparse noise and Poisson sparse noise for five-qubit low rank state tomography. In particular, our approach can achieve the high quality of the recovery with incomplete sets of measurements and is also suitable for performance improvement of large quantum systems. We envisage that the techniques of corrupted sensing can become a practical tool that greatly reduces the cost and computational effort for quantum tomography in noisy intermediate-scale quantum systems.

P12. Maxwell demon and Einstein-Podolsky-Rosen Steering

Meng-jun Hu
Beijing Academy of Quantum Information Sciences, China

The study of Maxwell demon and quantum entanglement is of importance not only because of its foundational meaning in physics but also due to its potential applications in quantum information. Previous research mainly focus on thermodynamics by taking account of quantum correlations. Here we consider from the opposite perspective, and ask whether or not quantum non-locality correlation can be simulated by doing work. The Maxwell demon-assistant Einstein-Podolsky-Rosen (EPR) steering is proposed, which implies a new-type loophole. The apply of the Landauer's erasure principle suggests that the only way to close this loophole during steering task is by continuously monitoring the heat fluctuation of local environment by participant. We construct a quantum circuit model of Maxwell demon-assistant EPR steering, which can be demonstrated by current programmable quantum processors, e.g., superconducting quantum computers. Based on this quantum circuit model, we obtain quantitative formula describing the relation between energy dissipation due to work of the demon and quantum non-locality correlation. The result obtained is of great physical interest because it provides a new way to explore and understand the relation between quantum non-locality, information and thermodynamics.

P13. Robust and Efficient Verification of Blind Measurement-Based Quantum Computation

Zihao Li
Fudan University, China

Blind quantum computation (BQC) is a secure quantum computation method that protects the privacy of clients. Measurement-based quantum computation (MBQC) is a promising approach for realizing BQC. To obtain reliable results in blind MBQC, it is crucial to verify whether the resource graph states are accurately prepared in the adversarial scenario. However, previous verification protocols for this task are too resource consuming or noise susceptible to be applied in practice. Here, we propose a robust and efficient protocol for verifying arbitrary graph states with any prime local dimension in the adversarial scenario, which leads to a robust and efficient protocol for verifying blind MBQC. Our protocol requires only local Pauli measurements and is thus easy to realize with current technologies. Nevertheless, it can achieve the optimal scaling behaviors with respect to the system size and the target precision as quantified by the infidelity and significance level, which has never been achieved before. Notably, our protocol can exponentially enhance the scaling behavior with the significance level.

P14. Algorithm for Evaluating Distance-based Entanglement Measures

Yixuan Hu
Beijing Institute of Technology, China

Quantifying entanglement in quantum systems is an important yet challenging task due to its NP-hard nature. In this work, we propose an efficient algorithm for evaluating distance-based entanglement measures. Our approach builds on Gilbert's algorithm for convex optimization, providing a reliable upper bound on the entanglement of a given arbitrary state. We demonstrate the effectiveness of our algorithm by applying it to various examples, such as calculating the squared Bures metric of entanglement as well as the relative entropy of entanglement for GHZ states, W states, Horodecki states, and chessboard states. These results demonstrate that our algorithm is a versatile and accurate tool that can quickly provide reliable upper bounds for entanglement measures.

P15. Experimental Quantum State Measurement with Classical Shadows

Ting Zhang
Shandong University, China

A crucial subroutine for various quantum computing and communication algorithms is to efficiently extract different classical properties of quantum states. In a notable recent theoretical work by Huang, Kueng, and Preskill~[Nature Phys.16, 1050 (2020)], a thrifty scheme showed how to project the quantum state into classical shadows and simultaneously predict M different functions of a state with only $mc O(log_2 M)$ measurements, independent of the system size and saturating the information-theoretical limit. Here, we experimentally explore the feasibility of the scheme in the realistic scenario with a finite number of measurements and noisy operations. We prepare a four-qubit GHZ state and show how to estimate expectation values of multiple observables and Hamiltonians. We compare the measurement strategies with uniform, biased, and derandomized classical shadows to conventional ones that sequentially measure each state function exploiting either importance sampling or observable grouping. We next demonstrate the estimation of nonlinear functions using classical shadows and analyze the entanglement of the prepared quantum state. Our experiment verifies the efficacy of exploiting (derandomized) classical shadows and sheds light on efficient quantum computing with noisy intermediate-scale quantum hardware.

P16. Scalable Quantum State Tomography with Locally Purified Density Operators and Local Measurements

Yuchen Guo
Tsinghua University, China

Understanding quantum systems holds significant importance for assessing the performance of quantum hardware and software, as well as exploring quantum control and quantum sensing. An efficient representation of quantum states enables realizing quantum state tomography with minimal measurements. In this study, we propose a new approach to state tomography that uses tensor network representations of mixed states through locally purified density operators and employs a classical optimization algorithm requiring only local measurements. Through numerical simulations of one-dimensional pure and mixed states and two-dimensional random tensor network states up to size 8×8, we demonstrate the efficiency, accuracy, and robustness of our proposed methods. Experiments on the IBM Quantum platform complement these numerical simulations. Our study opens new avenues in quantum state tomography for two-dimensional systems using tensor network formalism.

P17. Estimation from a Few Shot Randomized Measurement

Gongchu Li

University of Science and Technology, China

Many nonlinear properties are essential in the quantum information process and can be effectively predicted from randomized measurement. Now, robustness to channel and measurement errors and prediction efficiency is under the spotlight. They are always on different ends of a scale: a gain of robustness is always at the cost of efficiency, and an efficient method needs a precise setup. We put forward a new method to predict nonlinear properties called few-shot randomized measurement, which can be proven efficient and robust. Only a few shots are needed, and prediction from the limited resources is robust to both channel and measurement errors. We demonstrate the method in predicting two nonlinear properties — purity and mixed state entanglement in the experiment.

P18. Robust Verification of Entangled States under Noisy Measurements

Lan Zhang

Beijing Institute of Technology, China

In this work, we provide a systematic assessment of the performance of quantum state verification (QSV) protocols. Here we loosen the restrictions of standard quantum state verification protocols, to make the whole process valid under noisy condition, with the cost of efficiency. Then we find some special noise models are available for our new definition of QSV. and develop a universal performance measure for QSV protocols in the case where the measurements are noisy

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P19. Experimental Verification of Entangled States in the Adversarial Scenario

Wenhao Zhang

School of physics and optoelectronic engineering

Efficient verification of entangled states is crucial to many applications in quantum information processing. This problem is particularly important in the adversarial scenario in which the malicious source may cheat the client. However, traditional tomographic approaches and standard quantum state verification (QSV) protocols are not applicable in the adversarial scenario even if efficiency is not a concern. Here we demonstrate a defensive QSV protocol tailored to the adversarial scenario via a high-speed preparation-and-measurement apparatus, with which each system can be controlled and measured in a flexible way. Our experimental results clearly show that standard QSV protocols may significantly overestimate the fidelity and lead to an erroneous conclusion. In sharp contrast, the defensive QSV protocol can provide a reliable certificate for the fidelity at comparable high efficiency even under malicious attacks. Furthermore, our protocol is robust to imperfections in state preparation, which is crucial to practical applications, but has not received sufficient attention.

P20. Tradeoff between Coherence and Mixedness and Their Evolution under Quantum Noise Channels

Yuanhong Tao

Zhejiang University of Science and Technology, China

Generally quantum processes tend to mix the pure input states and degrade the original coherence. Such processes display exactly the trade-offs between the coherence and the mixedness. In this paper, we present trade-offs between the coherence measures (l2 norm of coherence, coherence via skew information, geometric measure of coherence) and the mixedness (normalized linear entropy mixedness, geometric measure of mixedness, mixedness via skew information). The evolution of these trade-offs are also investigated under four quantum noise channels: the bit flip, phase flip, depolarizing and amplitude damping channels.

P21. Robust and Efficient Hamiltonian Learning

Wenjun Yu

The University of Hong Kong, China

With the fast development of quantum technology, the sizes of both digital and analog quantum systems increase drastically. In order to have better control and understanding of the quantum hardware, an important task is to characterize the interaction, i.e., to learn the Hamiltonian, which determines both static and dynamic properties of the system. Conventional Hamiltonian learning methods either require costly process tomography or adopt impractical assumptions, such as prior information on the Hamiltonian structure and the ground or thermal states of the system. In this work, we present a robust and efficient Hamiltonian learning method that circumvents these limitations based only on mild assumptions. The proposed method can efficiently learn any Hamiltonian that is sparse on the Pauli basis using only short-time dynamics and local operations without any information on the Hamiltonian or preparing any eigenstates or thermal states. The method has a scalable

complexity and a vanishing failure probability regarding the qubit number. Meanwhile, it performs robustly given the presence of state preparation and measurement errors and resiliently against a certain amount of circuit and shot noise. We numerically test the scaling and the estimation accuracy of the method for transverse field Ising Hamiltonian with random interaction strengths and molecular Hamiltonians, both with varying sizes and manually added noise. All these results verify the robustness and efficacy of the method, paving the way for a systematic understanding of the dynamics of large quantum systems.

P22. Lattice Gauge Theory and Topological Quantum Error Correction with Quantum Deviations in the State Preparation and Error Detection

Yuanchen Zhao
Tsinghua University, China

Quantum deviations or coherent noise are a typical type of noise when implementing gate operations in quantum computers, and their impact on the performance of quantum error correction (QEC) is still elusive. Here, we consider the topological surface code, with both stochastic noise and coherent noise on the multi-qubit entanglement gates during stabilizer measurements in both initial state preparation and error detection. We map a multi-round error detection protocol to a three-dimensional statistical mechanical model consisting of Z2 gauge interactions and relate the error threshold to its phase transition point. Specifically, two error thresholds are identified distinguishing different error correction performances. Below a finite error threshold, in stark contrast to the case with only stochastic errors, unidentifiable measurement errors can cause the failure of QEC in the large code distance limit. This problem can only be fixed at the perfect initial state preparation point. For a finite or small code with distance d, we find that if the preparation error rate is below a crossover scale proportional to 1/log d, the logical errors can still be suppressed. We conclude that this type of unavoidable coherent noise has a significant impact on QEC performance, and becomes increasingly detrimental as the code distance increases.

P23. Efficient Estimation of Multipartite Quantum Coherence

Qiming Ding
Peking University, China

Quantification of coherence lies at the heart of quantum information processing and fundamental physics. Exact evaluation of coherence measures generally needs a full reconstruction of the density matrix, which becomes intractable for large-scale multipartite systems. Here, we propose a systematic theoretical approach to efficiently estimating lower and upper bounds of coherence in multipartite states. Under the stabilizer formalism, the lower bound is determined by the spectrum estimation method with a small number of measurements, and the upper bound is determined by a single measurement. We verify our theory with a four-qubit optical quantum system. We experimentally implement various multiqubit entangled states, including the Greenberger-Horne-Zeilinger state, the cluster state, and the W state, and show how their coherences are efficiently inferred from measuring a few observables.

P24. Measurement-Device-Independent Verification of Quantum States

Xinyu Xu
University of Science and Technology of China, China

Efficient and reliable verification of quantum states is central to quantum information processing applications. In realistic, however, measurement devices can be imperfect or untrusted, which limits the application of standard QSV protocols. Here, we propose the measurement-device-independent QSV (MDI-QSV). With the help of trusted quantum inputs, we provide a systematical approach to design MDI-QSV strategies for a given bipartite state. We quantitatively investigate the number of required measurements in these strategies, and find that it has an optimal scaling with the required accuracy and confidence level similar to the standard QSV where trusted measurement devices are available.
Therefore, our results provide a sample-efficient method for quantum state verification in the measurement-device-independent scenario, and is feasible with current technology.

P25. Magic of Quantum Hypergraph States

Junjie Chen
Tsinghua University, China

Magic, or nonstabilizerness, characterizes the deviation of a quantum state from the set of stabilizer states and plays a fundamental role from quantum state complexity to universal fault-tolerant quantum computing. However, analytical or even numerical characterizations of magic are very challenging, especially in the multi-qubit system, even with a moderate qubit number. Here we systemically and analytically investigate the magic resource of archetypal multipartite quantum states -- quantum hypergraph states, which can be generated by multi-qubit Controlled-phase gates encoded by hypergraphs. We first give the magic formula in terms of the stabilizer Rényi-α entropies for general quantum hypergraph states and prove the magic cannot reach the maximal value, if the average degree of the corresponding hypergraph is constant. Then we investigate the statistical behaviors of random hypergraph states and prove the concentration result that typically random hypergraph states can reach the maximal magic. This also suggests an efficient way to generate maximal magic states with random diagonal circuits. Finally, we study some highly symmetric hypergraph states with permutation-symmetry, such as the one whose associated hypergraph is 3-complete, i.e., any three vertices are connected by a hyperedge. Counterintuitively, such states can only possess constant or even exponentially small magic for $\alpha \geq 2$. Our study advances the understanding of multipartite quantum magic and could lead to applications in quantum computing and quantum many-body physics.

P26. Experimental Investigation of Quantum Correlations in a Two-Qutrit Spin System

Yue Fu

Beijing Institute of Technology, China

We report an experimental investigation of quantum correlations in a two-qutrit spin system in a single nitrogen-vacancy center in diamond at room temperatures. Quantum entanglement between two qutrits was observed at room temperature, and the existence of nonclassical correlations beyond entanglement in the qutrit case has been revealed. Our work demonstrates the potential of the NV centers as the multiqutrit system to execute quantum information tasks and provides a powerful experimental platform for studying the fundamental physics of high-dimensional quantum systems in the future.

P27. A Geometric Perspective of Quantum Noise Dynamics and Robust Quantum Control

Xiuhao Deng

Southern University of Science and Technology, China

Coupling to noise makes quantum systems ’applications difficult. While scientists can easily scale up the number of qubits, interference of noise on larger and larger quantum systems becomes a major challenge. In this presentation, I will introduce a geometric perspective of the dynamics of quantum systems affected by noise and propose a universal framework for studying the errors accumulated by noise. This theoretical framework is the Quantum Erroneous Evolution Diagram (QEED). Then, I will introduce some interesting properties and applications of this theoretical framework, including how to analyze the sensitivity of a system to noise or parameter changes, and how to construct arbitrary control pulses and universal dynamically-corrected quantum gates and gate sequences to perform powerful quantum control against general noise. Gate fidelities up to 99.999% over a broad range of noise strengths are demonstrated via numerical simulations on realistic models of quantum dots and transmon qubits.

P28. Performance analysis of multi-shot shadow estimation

You Zhou and Qing Liu

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Shadow estimation is an efficient method for predicting many observables of a quantum state with a statistical guarantee. In the multi-shot scenario, one performs projective measurement on the sequentially prepared state for K times under the same unitary evolution, and repeats this procedure for M rounds of random sampled unitary, which results in MK times measurements in total. Here we analyze the performance of shadow estimation in this multi-shot scenario, which is characterized by the variance of estimating the expectation value of some observable O. We find that in addition to the shadow-norm $\|\mathbf{O}\|_{\mathbf{shadow}}$ introduced in [Huang et.al. Nat. Phys. 2020], the variance is also related to another norm, and we denote it as the cross-shadow-norm $\|\mathbf{O}\|_{\mathbf{Xshadow}}$. For both random Pauli and Clifford measurements, we analyze and show the upper bounds of $\|\mathbf{O}\|_{\mathbf{Xshadow}}$. In particular, we figure out the exact variance formula of Pauli observables for random Pauli measurements. Our work gives theoretical guidance for the application of multi-shot shadow estimation.

List of Participants

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