Mini-Workshop on Quantum Verification

量子验证研讨会

16 August – 18 August 2019

Video Conference Room, Department of Physics, Fudan University,

Shanghai, China

Organizers:

- Huangjun Zhu (zhuhuangjun@fudan.edu.cn), Fudan University
- Jiangwei Shang (jiangwei.shang@bit.edu.cn), Beijing Institute of Technology

Secretary:

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

Sponsored by:

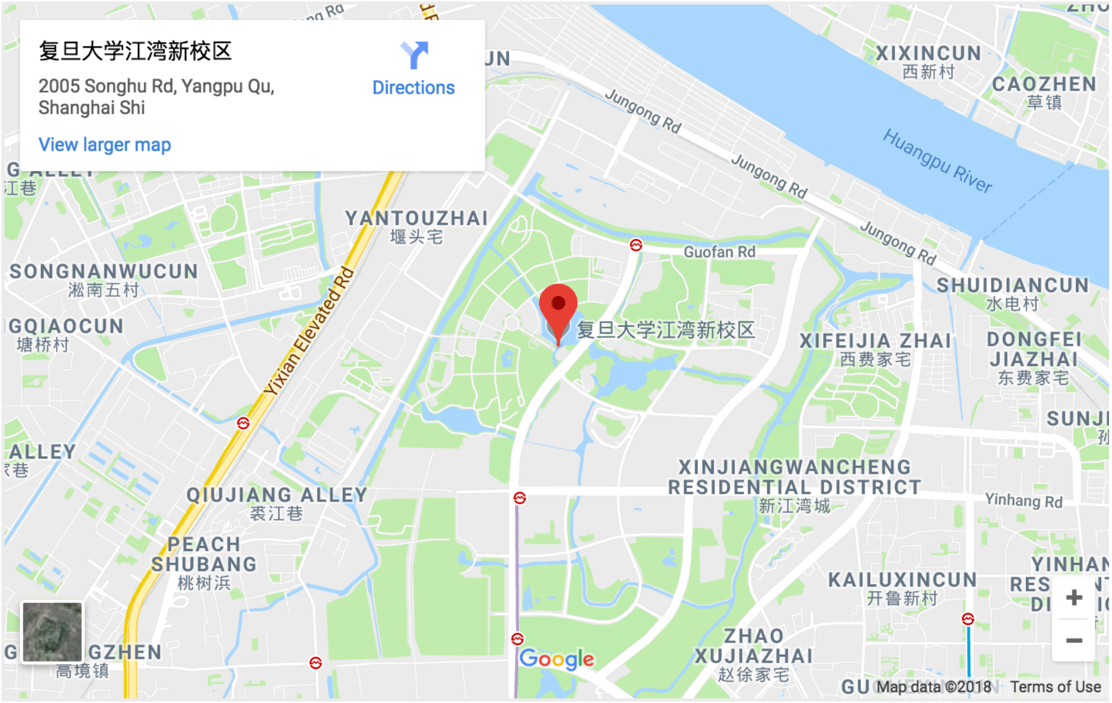
- Fudan University
- State Key Laboratory of Surface Physics
- Beijing Institute of Technology
- Key Laboratory of Advanced Optoelectronic Quantum Architecture and Measurement, Ministry of Education

Workshop website: http://www.physics.fudan.edu.cn/tps/outreach/mwqv/

➤ http://www.physics.fudan.edu.cn/tps/outreach/mwqv/

Venue

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



Transportation

- From Pudong Ariport to Fudan University (Jiangwan New Campus)
  By Taxi: About 160 yuan and 68 mins
- From Hongqiao Ariport 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 (Xinjiangwancheng Stop，新江湾城站)

Scientific Program (Overview)

Time	Thursday 15-Aug	Friday 16-Aug	Saturday 17-Aug	Sunday 18-Aug
08:50-09:00		Opening		Free discussion
09:00-09:40		Masahito Hayashi	Animesh Datta	
09:40-10:05		Kun Wang	Bin Cheng	
10:05-11:00		Registration, Coffee & Tea		
11:00-11:25		Zihao Li	Group discussion	
11:25-11:50		Ye-Chao Liu		
12:00-14:00		Lunch		
14:00-14:40		Zhaohui Wei	Tomoyuki Morimae	
14:40-15:05		Yun-Guang Han	Yadong Wu	
15:05-16:00	Registration (Ramada Hotel Shanghai Wujiaochang)	Coffee & Tea		
16:00-16:25		Thinh Le	You Zhou	
16:25-16:50		Geng Chen	Hao Xu	
		Conference Dinner (18:30)		

Long talk : 40 mins (35+5) 4
Short talk : 25 mins (20+5) 10
Posters can be set up during the morning coffee & tea break on 16 Aug.

➤ http://www.physics.fudan.edu.cn/tps/outreach/mwqv/

Detailed Program

16 August (Friday)

Time		
8:50-09:00	Opening: Huangjun Zhu	
09:00-09:40	Masahito Hayashi	Hypothesis testing and verification of quantum entangled state
09:40-10:05	Kun Wang	Optimal Verification of Two-Qubit Pure States
10:05-11:00	Registration, Coffee & Tea	
11:00-11:25	Zihao Li	Optimal Verification of Greenberger-Horne-Zeilinger States
11:25-11:50	Ye-Chao Liu	Efficient verification of Dicke states
12:00-14:00	Lunch	
14:00-14:40	Zhaohui Wei	An Analytic Semi-device-independent Entanglement Quantification for Bipartite
14:40-15:05	Yun-Guang Han	Self-testing of three-qubit states
15:05-16:00	Coffee & Tea	
16:00-16:25	Thinh Le	Quantum state verification with realistic noisy devices
16:25-16:50	Geng Chen	Experimental optimal and robust verification of entangled state
18:30	Conference Dinner	

17 August (Saturday)

Time		
08:50-09:00		
09:00-09:40	Animesh Datta	Accrediting outputs of noisy intermediate-scale quantum computing devices
09:40-10:05	Bin Cheng	Experimental Cryptographic Verification for Near-Term Quantum Cloud Computing
10:05-11:00	Coffee & Tea	
11:00-11:50	Group discussion	
12:00-14:00	Lunch	
14:00-14:40	Tomoyuki Morimae	Post-hoc verification of quantum computing
14:40-15:05	Yadong Wu	Efficient verification of bosonic quantum channels via benchmarking
15:05-16:00	Coffee & Tea	
16:00-16:25	You Zhou	Efficient detection of multipartite entanglement structure
16:25-16:50	Hao Xu	Unruh Quantum Otto heat engine with level degeneracy

18 August (Sunday)

Time	
08:00-16:50	**Free discussion**

- http://www.physics.fudan.edu.cn/tps/outreach/mwqv/

Shuttle Bus Info

Note: We have a bus provided between the Conference Venue and Ramada Shanghai Wujiaochang.

	Friday	Saturday		
Ramada-Fudan	8:30	8:30		
Fudan-Ramada		17:15		

Fudan -Conference Dinner	Friday 18:00
Conference Dinner- Ramada	Friday 20:30

Abstracts of the talks

16 Aug (Friday)

Hypothesis testing and verification of quantum entangled state

Masahito Hayashi
Nagoya University, Japan

Recently, verification of quantum entangled state attracts much attention in the relation with verification of measurement-based quantum computer. However, the origin of this topic can be back to hypothesis testing of quantum entangled state, which was studied in 2006-2009 as follows. M. Hayashi, K. Matsumoto, and Y. Tsuda, "A study of LOCC-detection of a maximally entangled state using hypothesis testing," Journal of Physics A: Mathematical and General, Vol.39 14427-14446 (2006); DOI 10.1088/0305-4470/39/46/013.M. Hayashi, B.-S. Shi, A. Tomita, K. Matsumoto, Y. Tsuda, and Y.-K. Jiang, "Hypothesis testing for an entangled state produced by spontaneous parametric down conversion," Physical Review A, Vol.74, 062321 (2006). M. Hayashi, A. Tomita, and K. Matsumoto, "Statistical analysis of testing of an entangled state based on the Poisson distribution framework," New Journal of Physics, Vol.10, 043029, (2008)M. Hayashi, "Group theoretical study of LOCC-detection of maximally entangled state using hypothesis testing," New Journal of Physics, Vol.11, No.4, 043028 (2009) (57pp); DOI 10.1088/1367-2630/11/4/043028At that time, the relation with Fisher information was discussed. In this talk, we explain these old results and focus on the relation between them and the recent results, which was triggered by the following paper.

Optimal Verification of Two-Qubit Pure States

Kun Wang
Shenzhen Institute for Quantum Science and Engineering, Southern University of Science and Technology, China

In a recent work [Phys. Rev. Lett. 120, 170502 (2018)], Pallister et al. proposed an optimal strategy to verify non-maximally entangled two-qubit pure states under the constraint that the accessible measurements being locally projective and non-adaptive. Their nice result leads naturally to the question: What is the optimal strategy among general LOCC measurements? In this Letter, we answer this problem completely for two-qubit pure states. To be specific, we give the optimal strategy for each of the following available classes of measurements: (i) local operations and one-way classical communication (one-way LOCC) measurements; (ii) local operations and two-way classical communication (two-way LOCC) measurements; and (iii) separable measurements. Surprisingly, our results reveal that for the two-qubit pure state verification problem, two-way LOCC measurements remarkably outperforms one-way LOCC measurements and has the same power as the separable measurements.

Optimal Verification of Greenberger-Horne-Zeilinger States

Zihao Li

Fudan University, China

GHZ states are canonical examples of quantum states with genuine multipartite entanglement. They play key roles both in quantum information processing and foundational studies. For real-world applications, it is crucial to verify these states with high precision using limited resources. Here we present optimal protocols for verifying GHZ states based on local projective measurements. These protocols provide a highly efficient way for fidelity estimation and entanglement detection as well. By virtue of adaptive local projective measurements, our protocols can also be generalized to GHZ-like states with high efficiency.

Efficient verification of Dicke states

Ye-Chao Liu

Beijing Institute of Technology, China

Among various multipartite entangled states, Dicke states stand out because their entanglement is maximally persistent and robust under particle losses. Although much attention has been attracted for their potential applications in quantum information processing and foundational studies, the characterization of Dicke states remains as a challenging task in experiments. Here, we propose efficient and practical protocols for verifying arbitrary n-qubit Dicke states in both adaptive and nonadaptive ways. Our protocols require only two distinct settings based on Pauli measurements besides permutations of the qubits. To achieve infidelity \$\epsilon\$ and confidence level \$1-\delta\$, the total number of tests required is only \$O(n\epsilon^{-1}\ln\delta^{-1})\$. This performance is much more efficient than all known protocols based on local measurements, including quantum state tomography and direct fidelity estimation, and is comparable to the best global strategy. Our protocols are readily applicable with current experimental techniques and are able to verify Dicke states of hundreds of qubits.

An Analytic Semi-device-independent Entanglement Quantification for Bipartite

Zhaohui Wei
Tsinghua, China

We define a property called nondegeneracy for Bell inequalities, which describes the situation that in a Bell setting, if a Bell inequality and involved local measurements are chosen and fixed, any quantum state with a given dimension and its orthogonal quantum state cannot violate the inequality remarkably at the same time. We prove that for an arbitrary quantum dimension, based on the measurement statistics only, we can give an analytic lower bound for the entanglement of formation of the unknown bipartite quantum state by choosing a proper nondegenerate Bell inequality, making the whole process semi-device-independent. We provide specific examples to demonstrate the existence of nondegeneracy and applications of our approach.

Self-testing of three-qubit states

Yunguang Han
Fudan University, China

Self-testing refers to a device-independent way to uniquely identify the state and the measurement for uncharacterized quantum device. We present here several results of self-testing three-qubit states. The first one is self-testing W state using only two-body correlations. Then we proposed self-testing scheme for a large family of symmetric three-qubit states, namely the superposition of W state and GHZ state. We first propose and analytically prove self-testing criterion for a special symmetric state which with equal coefficients of the canonical basis, by designing subsystem self-testing of partially and maximally entangled state simultaneously. Then we demonstrate for the general case, the states can be self-tested using numerical analysis by the swap method combining semi-definite programing (SDP) in a high precision.

Quantum state verification with realistic noisy devices

Thinh Le
Centre for Quantum Technologies, Singapore

Quantum state verification is an efficient class of quantum protocol for verifying a certain state preparation device. Much of its recent interest lie in the simplicity (local, nonadaptive and noncollective measurements) and efficiency as compared to quantum state tomography, Bell test or fidelity estimation protocols. We ask the question: what would happen to such protocols if our implementation of the measurements are noisy in practice? This lead to a generalized version of the original quantum state verification task and introduces another parameter. The type I error probability or false positive into the problem. We derive optimal protocol for such scenarios given several class of allowed measurements. In terms of number of repetitions, as expected there is a nontrivial gap between the optimal protocol with general entangled measurements and that with separable measurements. Moreover, when restrict to the class of separable measurements, the optimal protocol using separable measurement performs as well as that where the separable measurements commute with the ideal state. For the latter class of verification protocols, we provide an analytic proof of optimality.

Experimental optimal and robust verification of entangled state

Geng Chen

Key Lab of Quantum Information, University of Science and Technology of China, China

The initialization of a quantum system into a certain state is a crucial aspect of quantum information science. While a variety of measurement strategies have been developed to characterize how well the system is initialized, for a given one, there is in general a trade-off between its efficiency and the accessible information of the quantum state.
Conventional quantum state tomography can characterize unknown states by reconstructing the density matrix; however, its exponentially expensive postprocessing is likely to produce a deviate result. Alternatively, quantum state verification provides a technique to quantify the prepared state with significantly fewer measurements, especially for quantum entangled states. Here, we experimentally implement an optimal verification of entangled states with local measurements, where the estimated infidelity is inversely proportional to the number of measurements. The utilized strategy is tolerant of the impurity of realistic states, hence being highly robust in a practical sense. Even more valuable, our method only requires local measurements, which incurs only a small constant-factor (<2.5) penalty compared to the globally optimal strategy requiring nonlocal measurements.

17 Aug (Saturday)

Accrediting outputs of noisy intermediate-scale quantum computing devices

Animesh Datta
University of Warwick, UK

We present an accreditation protocol for the outputs of noisy intermediate-scale quantum devices. By testing entire circuits rather than individual gates, our accreditation protocol can provide an upper-bound on the variation distance between noisy and noiseless probability distribution of the outputs of the target circuit of interest. Our accreditation protocol requires implementation of quantum circuits no larger than the target circuit, therefore it is practical in the near term and scalable in the long term. Inspired by trap-based protocols for the verification of quantum computations, our accreditation protocol assumes that noise in single-qubit gates is bounded (but potentially gate-dependent) in diamond norm. We allow for arbitrary spatial and temporal correlations in the noise affecting state preparation, measurements and two-qubit gates.

Experimental Cryptographic Verification for Near-Term Quantum Cloud Computing

Bin Cheng
Southern University of Science and Technology, China

Recently, there are more and more organizations offering quantum-cloud services, where any client can access a quantum computer remotely through the internet. In the near future, these cloud servers may claim to offer quantum computing power out of reach of classical devices. An important task is to make sure that there is a real quantum computer running, instead of a simulation by a classical device. Here we explore the applicability of a cryptographic verification scheme that avoids the need of implementing a full quantum algorithm or requiring the clients to communicate with quantum resources. In this scheme, the client encodes a secret string in a scrambled IQP (instantaneous quantum polynomial) circuit sent to the quantum cloud in the form of classical message, and verify the computation by checking the probability bias of a class of output strings generated by the server. We provided a theoretical extension and implemented the scheme on a 5-qubit NMR quantum processor in the laboratory and a 5-qubit and 16-qubit processors of the IBM quantum cloud. We found that the experimental results of the NMR processor can be verified by the scheme with about 2.5% error, after noise compensation by standard techniques. However, the fidelity of the IBM quantum cloud is currently too low to pass the test (about 42% error). This verification scheme shall become practical when servers claim to offer quantum-computing resources that can achieve quantum supremacy.

Post-hoc verification of quantum computing

Tomoyuki Morimae
Kyoto University, Japan

I explain a protocol of verifying quantum computing in such a way that the correctness of the result can be verified at any later time. The verifier needs only the ability of single-qubit measurements in X and Z basis. [Fitzsimons, Hajdusek, and TM, PRL 120, 040501 (2018)]

Efficient verification of bosonic quantum channels via benchmarking

Yadong Wu
University of Calgary, Canada

We aim to devise feasible, efficient verification schemes for bosonic channels. To this end, we construct an average-fidelity witness that yields a tight lower bound for average fidelity plus a general framework for verifying optimal quantum channels. For both multi-mode unitary Gaussian channels and single-mode amplification channels, we present experimentally feasible average-fidelity witnesses and reliable verification schemes, for which sample complexity scales polynomially with respect to all channel specification parameters. Our verification scheme provides an approach to benchmark the performance of bosonic channels on a set of Gaussian-distributed coherent states by employing only two-mode squeezed vacuum states and local homodyne detections. Our results demonstrate how to perform feasible tests of quantum components designed for continuous-variable quantum information processing.

Efficient detection of multipartite entanglement structure

You Zhou
Institute for Interdisciplinary Information Sciences, Tsinghua University, China

Recently, there are tremendous developments on the number of controllable qubits in several quantum computing systems. For these implementations, it is crucial to determine the entanglement structure of the prepared multipartite quantum state as a basis for further information processing tasks. In reality, evaluation of a multipartite state is in general a very challenging task owing to the exponential increase of the Hilbert space with respect to the number of system components. In this work, we propose a systematic method using very few local measurements to detect multipartite entanglement structures based on the graph state---one of the most important classes of quantum states for quantum information processing. Thanks to the close connection between the Schmidt coefficient and quantum entropy in graph states, we develop a family of efficient witness operators to detect the entanglement between subsystems under any partitions and hence the entanglement intactness. We show that the number of local measurements equals to the chromatic number of the underlying graph, which is a constant number, independent of the number of qubits. In reality, the optimization problem involved in the witnesses can be challenging with large system size. For several widely-used graph states, such as 1-D and 2-D cluster states and the Greenberger-Horne-Zeilinger state, by taking advantage of the area law of entanglement entropy, we derive analytical solutions for the witnesses, which only employ two local measurements. Our method offers a standard tool for entanglement structure detection to benchmark multipartite quantum systems.

Unruh Quantum Otto heat engine with level degeneracy

Hao Xu

Institute for Quantum Science and Engineering, Department of Physics, Southern University of Science and Technology, China

We investigate the Unruh quantum Otto heat engine with level degeneracy. An effectively two-level system, where the ground state is non-degenerate and the excited state is n-fold degenerate, is acting as the working substance, and the vacuum of massless free scalar field serves as a thermal bath via the Unruh effect. We calculate the heat and work at each step of the Unruh quantum Otto cycle and study the features of the heat engine. The efficiency of the heat engine depends only on the excited energy values of the two-level system, not on its level degeneracy. However, the degeneracy acts as a kind of thermodynamic resource and helps us to extract more work than in the non-degenerate case. The extractable work has a finite upper bound, corresponding to $n\rightarrow \infty$.

Abstracts of the posters

P1. Distillation of 20.5dB strongly squeezed single mode quantum entanglement state with realistic photon subtraction

ShengLi Zhang

BeiJing Institute of Technology, China

Entanglement distillation is an efficient method for retrieving entanglement of higher quality from large amounts of weakly entangled states. Up till now, almost all the result on distillation of continuous variable entanglement considered weak squeezed entanglement. Recently, single mode squeezing at 15dB is available in experiment. This enlightens us to consider the strong-squeezing effect and its impacts to state-of-art distillation scheme. We show an effective distillation scheme with photon subtraction and local on-line squeezer.

P2.Zero-tradeoff multi-parameter estimation from multiple Heisenberg uncertainty relations

Zhibo Hou

University of Science and Technology of China, China

High precision parameter estimation is one of the main driving force 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. It is a wide belief that tradeoffs are unavoidable for the estimation of multiple parameters whose generators do not commute with each other. Here by relating the precision limit directly to the Heisenberg uncertainty relation we show that to achieve the highest precisions for multiple parameters simultaneously is fundamentally equivalent to saturate multiple Heisenberg uncertainty relations at the same time. Guided by this insight, we experimentally demonstrate that, contrary to the wide belief, the highest precisions for the estimation of all three parameters in SU(2) operators can be achieved simultaneously. With eight optimally designed controls, we achieve a 13.8 dB improvement over the shot-noise limit. Our work not only deepens the connection between quantum metrology and the Heisenberg uncertainty relation, but also marks a crucial step towards achieving the ultimate precision of multi-parameter quantum estimation, which has wide implications in magnetometry, quantum gyroscope, quantum reference frame alignment, etc.

P3.2-Photon Quantum state reconstruction via two dimensional quantum walk

Chai Xudan

Center for quantum technology research, China

Quantum state tomography is to uniquely determined the density matrix of the system according to the measurement data. Its efficiency is mainly limited by that the requirement of the setup increases exponentially with the number of qubits. Here we report a new method to recover the 2-photon quantum states by only one static measurement. This static measurement is realized by 2-photon quantum walk in our work, which brings new sparsity into the initial state and by this we can handle the quantum system in a bigger Herbert space. We numerically simulate 2-photon quantum walk and measure the correlation measurement among the outputs. We use a self-guided algorithm to reconstruct the density of matrix both for 2-photon pure and mixed sates. The method we use shows high accuracy and efficient for the pure and mixed states tomography especially for the low-rank state recovery.

List of Participants

Name	Affiliation	country
Animesh Datta	University of Warwick	UK
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Huangjun Zhu	Fudan University	China
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Tomoyuki Morimae	Kyoto University	Japan
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Yunguang Han	Fudan University	China
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Zihao Li	Fudan University	China

复旦大学

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