International Workshop on Quantum Tomography (IWQT)

量子层析国际研讨会

30 July – 03 August 2018

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

Workshop website: http://iwqt.datahub.top

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 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 (Xinjiangwancheng Stop，新江湾城站)

Campus guide

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)

★ Conference venue (Physics Research Building 物理科研楼大报告厅)

▲ Lunch place

Conference Dinner: 金时代顺风大酒店（四平路店），杨浦区四平路 2500 号东方商厦 5 楼（近黄兴路，五角场地铁站 2 号口），021-55097717/55097718

Shuttle Bus Info

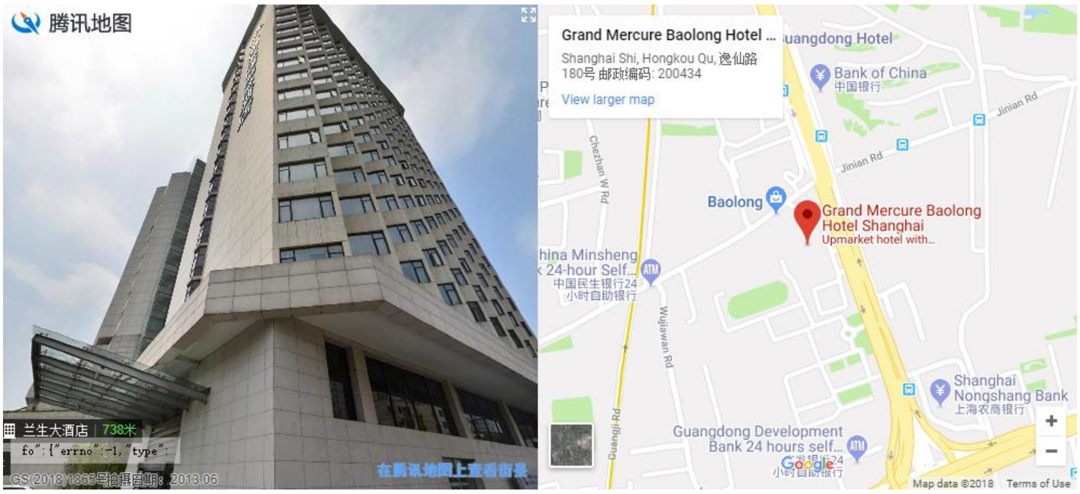
Note: We have a bus provided between the Conference Venue and Baolong Hotel.

	Tuesday	Wednesday	Thursday	Friday
Baolong-Fudan	8:00	8:30	8:30	8:30
Fudan-Baolong	17:30	18:30	14:00	17:30

Baolong-Conference Dinner	Thursday 18:00
Conference Dinner-Baolong	Thursday 21:00

Accommodation

- [Baolong Hotel（宝隆宾馆）]
  Address: No. 180 Yixian Road, Hongkou District, Shanghai（上海市虹口区逸仙路 180 号）
  Phone: (021) 35059666
  About 21 mins to Fudan University (Jiangwan New Campus) by car



- [Qingyun Hotel（卿云宾馆）]
  Address: No. 220 Handan Road, Yangpu District, Shanghai（上海市杨浦区邯郸路 220 号）
  Phone: (021) 65642249
  About 18 mins to Fudan University (Jiangwan New Campus) by car
- [Yanyuan Hotel（燕园宾馆）]
  Address: No. 270 Zhengtong Road, Yangpu District, Shanghai （上海市杨浦区政通路 270 号）
  Phone: 400-688-6687
  About 15 mins to Fudan University (Jiangwan New Campus) by car
- [Fuxuan Hotel（复宣宾馆）]
  Address: No. 400 Guoding Road, Yangpu District, Shanghai（上海市杨浦区国定路 400 号）
  Phone: (021) 55589518
  About 20 mins to Fudan University (Jiangwan New Campus) by car

Introduction to the Workshop

Following the successful series of workshops on quantum tomography held in CQT, Singapore (2011) and Fields Institute, Toronto (2013), we are pleased to announce another one at Fudan University in Shanghai this summer.

Over the past few years, quantum tomography has become an indispensable component of quantum information science. New results and new challenges are popping up from time to time. So, it is now a good time to gather experts and students together to discuss new results, new ideas, as well as major challenges in quantum tomography. This workshop may hopefully serve as a good platform to achieve this goal. The main interests of the workshop include (but not limited to)

- Characterization of fault-tolerant devices
- Quantum tomography of many-body states
- Efficient verification of multipartite states
- Precision measurements
- Experimental tomography
- Other related topics

Invited speakers:

Animesh Datta (University of Warwick, UK)

Jiangfeng Du (University of Science and Technology of China)

Jens Eisert (Free University of Berlin, Germany)

Berge Englert (National University of Singapore, Singapore)

Chris Ferrie (University of Technology Sydney, Australia)

Masahito Hayashi (Nagoya University, Japan)

Zhibo Hou (University of Science and Technology of China)

Zdenek Hradil (Palacky University Olomouc, Czech Republic)

Xiaojun Jia (Shanxi University, China)

Matthias Kleinmann (University of Siegen, Germany)

Richard Kueng (California Institute of Technology, USA)

Xin-Qi Li (Tianjin University, China)

Chao-Yang Lu (University of Science and Technology of China)

Dawei Lu (Southern University of Science and Technology, China)

Shunlong Luo (Academy of Mathematics and System Sciences, CAS, China)

Hui Khoon Ng (Yale-NUS College, Singapore)

Luis Sanchez-Soto (Max Planck Institut für die Physik des Lichts, Germany)

Barry Sanders (University of Calgary, Canada)

Guo-Yong Xiang (University of Science and Technology of China)

Peng Xue (Beijing Computational Science Research Center, China)

Nengkun Yu (University of Technology Sydney, Australia)

Scientific Program (Overview)

<table>
<tr><th rowspan="2">Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><th>30-Jul</th><th>31-Jul</th><th>1-Aug</th><th>2-Aug</th><th>3-Aug</th></tr>
<tr><td>08:00-08:50</td><td></td><td>Registration
(Conference Venue)</td><td></td><td></td><td></td></tr>
<tr><td>08:50-09:00</td><td></td><td>Opening</td><td></td><td></td><td></td></tr>
<tr><td>09:00-09:35</td><td></td><td>Berge Englert</td><td>Jiangfeng Du (presented by Ya Wang)</td><td>Matthias Kleinmann</td><td>Shunlong Luo</td></tr>
<tr><td>09:35-10:10</td><td></td><td>Dawei Lu</td><td>Luis Sanchez-Soto</td><td>Nengkun Yu</td><td>Masahito Hayashi</td></tr>
<tr><td>10:10-10:50</td><td></td><td colspan="4">Coffee & Tea</td></tr>
<tr><td>10:50-11:25</td><td></td><td>Jens Eisert</td><td>Animesh Datta</td><td>Xin-Qi Li</td><td>Chao-Yang Lu</td></tr>
<tr><td>11:25-12:00</td><td></td><td>Richard Kueng</td><td>Hui Khoon Ng</td><td>Xiaojun Jia</td><td>Lukas Knips</td></tr>
<tr><td>12:00-14:00</td><td></td><td colspan="4">Lunch</td></tr>
<tr><td>14:00-14:35</td><td rowspan="7">Registration
(Baolong Hotel)</td><td>Peng Xue</td><td>Barry Sanders</td><td rowspan="6">Free Afternoon</td><td>Zdenek Hradil</td></tr>
<tr><td>14:35-15:10</td><td>Guo-Yong Xiang</td><td>Chris Ferrie</td><td>Zhibo Hou</td></tr>
<tr><td>15:10-15:40</td><td colspan="2">Coffee & Tea</td><td>Coffee & Tea</td></tr>
<tr><td>15:40-16:00</td><td>Yong Siah Teo</td><td>Yin Cai</td><td>Qiang Zeng</td></tr>
<tr><td>16:00-16:20</td><td>Ulrich Seyfarth</td><td>Rui Han</td><td>Struchalin Gleb</td></tr>
<tr><td>16:20-16:40</td><td>Heng Shen</td><td rowspan="2">Poster Session</td><td>Aonan Zhang</td></tr>
<tr><td></td><td></td><td>Conference Dinner (18:30)</td><td>Closing Remarks</td></tr>
</table>

Long talk: 35 mins (30 + 5)
Short talk: 20 mins (17 + 3)

Detailed Program

31 July (Tuesday)

Time		
08:00-08:50	Registration (**Conference Venue**)	
08:50-09:00	Opening: Huangjun Zhu	
09:00-09:35	Berge Englert	Quantum Mechanics vs Local Hidden Variables --- A Bayesian View
09:35-10:10	Dawei Lu	Tomography is Necessary for Universal Entanglement Detection with Single-Copy Observables
10:10-10:50	Coffee & Tea	
10:50-11:25	Jens Eisert	Exploiting structure in optical quantum gate and many-body tomography
11:25-12:00	Richard Kueng	Recovering quantum gates from few average gate fidelities
12:00-14:00	Lunch	
14:00-14:35	Peng Xue	Topological properties in parity-time-symmetric quantum walks
14:35-15:10	Guo-Yong Xiang	Deterministic realization of collective measurements via photonic quantum walks
15:10-15:40	Coffee & Tea	
15:40-16:00	Yong Siah Teo	Bayesian error regions in quantum parameter estimation
16:00-16:20	Ulrich Seyfarth	Valuable quantum states of the SU(1,1) interferometer and their Majorana representations
16:20-16:40	Heng Shen	Observing the quantum interference and entanglement of electron-nuclear system and trapped ions on Bloch sphere by Wigner distribution

01 August (Wednesday)

Time		
08:00-08:50		
08:50-09:00		
09:00-09:35	Jiangfeng Du (presented by Ya Wang)	Diamond spin magnetometry and its application
09:35-10:10	Luis Sanchez-Soto	Compressed sensing of vortex beams
10:10-10:50	Coffee & Tea	
10:50-11:25	Animesh Datta	Verification of quantum computation and simulation
11:25-12:00	Hui Khoon Ng	Randomized benchmarking does not measure average infidelity
12:00-14:00	Lunch	
14:00-14:35	Barry Sanders	Reinforcement learning for hard quantum metrology and control
14:35-15:10	Chris Ferrie	Self-guided quantum learning
15:10-15:40	Coffee & Tea	
15:40-16:00	Yin Cai	Multimode Entanglement and Quantum-enhanced Frequency Metrology with an Optical Frequency Comb
16:00-16:20	Rui Han	Efficient sampling of quantum states using the complex Wishart distributions
	Poster Session	

02 August (Thursday)

Time		
08:00-08:50		
08:50-09:00		
09:00-09:35	Matthias Kleinmann	Towards a conclusive verification of bipartite bound entanglement
09:35-10:10	Nengkun Yu	Entanglement verification, with or without tomography
10:10-10:50	Coffee & Tea	
10:50-11:25	Xin-Qi Li	Direct measurement of the quantum state of photons in a cavity
11:25-12:00	Xiaojun Jia	Generation and manipulation of continuous variable non-classical states
12:00-14:00	Lunch	
14:00-14:35	Free Afternoon	
14:35-15:10		
15:10-15:40		
15:40-16:00		
16:00-16:20		
16:20-16:40		
	Conference Dinner (18:30)	

Conference Dinner: 金时代顺风大酒店（四平路店），杨浦区四平路 2500 号东方商厦 5 楼（近黄兴路，五角场地铁站 2 号口），021-55097717/55097718

03 August (Friday)

Time		
08:00-08:50		
08:50-09:00		
09:00-09:35	Shunlong Luo	Fisher Information: From Parameter Estimation to Quantum Coherence
09:35-10:10	Masahito Hayashi	Attaining the ultimate precision limit in quantum state estimation
10:10-10:50	Coffee & Tea	
10:50-11:25	Chao-Yang Lu	High-performance boson sampling using solid-state single photons
11:25-12:00	Lukas Knips	Quantum State Tomography with Reduced Effort and for Finite Statistics
12:00-14:00	Lunch	
14:00-14:35	Zdenek Hradil	Quantum tomography and super-resolution: two opposite faces of quantum metrology
14:35-15:10	Zhibo Hou	Heisenberg-limit control-enhanced sequential scheme for general quantum parameter estimation
15:10-15:40	Coffee & Tea	
15:40-16:00	Qiang Zeng	Experimental High-Dimensional Einstein-Podolsky-Rosen Steering
16:00-16:20	Struchalin Gleb	Adaptive quantum tomography of high-dimensional bipartite systems
16:20-16:40	Aonan Zhang	Adaptive tomography of qubits: Purity versus statistical fluctuations
	Closing Remarks: Huangjun Zhu	

Abstracts of the talks

31 July (Tuesday)

Quantum Mechanics vs Local Hidden Variables --- A Bayesian View

Berge Englert
Centre for Quantum Technologies and Department of Physics, National University of Singapore; and MajuLab, Singapore

The data of four recent experiments --- conducted in Delft, Vienna, Boulder, and Munich with the aim of refuting nonquantum hidden-variables alternatives to the quantum-mechanical description --- are evaluated from a Bayesian perspective of what constitutes evidence in statistical data. It is found that each of the experiments provides strong, or very strong, evidence in favor of quantum mechanics and against the nonquantum alternatives. This Bayesian analysis supplements the previous non-Bayesian ones, which refuted the alternatives on the basis of small p-values, but could not support quantum mechanics.

Tomography is Necessary for Universal Entanglement Detection with Single-Copy Observables

Dawei Lu
Southern University of Science and Technology, China

Entanglement, one of the central mysteries of quantum mechanics, plays an essential role in numerous tasks of quantum information science. A natural question of both theoretical and experimental importance is whether universal entanglement detection can be accomplished without full state tomography. We prove a no-go theorem that rules out this possibility for nonadaptive schemes that employ single copy measurements only. We also examine a previously implemented experiment [H. Park et al., Phys. Rev. Lett. 105, 230404 (2010)], which claimed to detect entanglement of two-qubit states via adaptive single copy measurements without full state tomography. In contrast, our simulation and experiment both support the opposite conclusion that the protocol, indeed, leads to full state tomography, which supplements our no-go theorem. These results reveal a fundamental limit of single-copy measurements in entanglement detection and provide a general framework of the detection of other interesting

properties of quantum states, such as the positivity of partial transpose and the k-symmetric extendibility.

Exploiting structure in optical quantum gate and many-body tomography

Jens Eisert
Free University of Berlin, Germany

arXiv:1803.00572 [quant-ph]

Recovering quantum gates from few average gate fidelities

Richard Kueng
California Institute of Technology, USA

Characterizing quantum processes is a key task for the development of quantum technologies, especially at the noisy intermediate scale of today's devices. One method for characterizing processes is randomized benchmarking, which is robust against state preparation and measurement (SPAM) errors. A complementing approach asks for full tomographic knowledge. Compressed sensing techniques achieve full tomography of quantum channels essentially at optimal resource efficiency. We attempt to combine the favorable features of both worlds: For multi-qubit unitary gates, we provide a practical (full) tomography method that works with an essentially optimal number of average gate fidelities measured with respect to random Clifford unitaries.

Topological properties in parity-time-symmetric quantum walks

Peng Xue
Beijing Computational Science Research Center, China

The study of non-Hermitian systems with parity-time (PT) symmetry is a rapidly developing frontier in recent years. Experimentally, PT-symmetric systems have been realized in classical optics by balancing gain and loss, which holds great promise for novel optical devices and networks. Here we report the first experimental realization of passive PT-symmetric quantum dynamics for single photons by temporally alternating photon losses in the quantum walk (QW) interferometers. The ability to impose PT symmetry allows us to realize and investigate Floquet topological phases driven by PT-symmetric QWs. We observe topological edge states between regions with different bulk topological properties and confirm the robustness of these edge states with respect to PT-symmetry-preserving perturbations and PT-symmetry-breaking static disorder. Our results pave the way for realizing quantum mechanical PT-synthetic devices and augur exciting possibilities for exploring topological properties of non-Hermitian systems using discrete-time QWs.

Deterministic realization of collective measurements via photonic quantum walks

Guo-Yong Xiang

University of Science & Technology of China

Collective measurements on identically prepared quantum systems can extract more information than local measurements, thereby enhancing information-processing efficiency. Although this nonclassical phenomenon has been known for two decades, it has remained a challenging task to demonstrate the advantage of collective measurements in experiments. Here, we introduce a general recipe for performing deterministic collective measurements on two identically prepared qubits based on quantum walks. Using photonic quantum walks, we realize experimentally an optimized collective measurement with fidelity 0.9946 without post selection. As an application, we achieve the highest tomographic efficiency in qubit state tomography to date. Our work offers an effective recipe for beating the precision limit of local measurements in quantum state tomography and metrology. In addition, our study opens an avenue for harvesting the power of collective measurements in quantum information processing and for exploring the intriguing physics behind this power.

Bayesian error regions in quantum parameter estimation

Yong Siah Teo

Seoul National University, South Korea

I shall summarize some recent developments in employing Bayesian error regions as error certifications for point estimators in a general convex parameter estimation setting, which includes quantum-state tomography. First, asymptotic analytical approximations to Bayesian error regions for sufficiently large data sample size are introduced to efficiently compute the two principal region qualities, size and credibility, that reflects error information of an experimentally obtained point estimator. The positive performance of these approximations are studied with qubit and qutrit tomography. Next, adaptive methods are established to optimize the so-called region accuracy of Bayesian region estimators relative to the true parameter, which is a ``frequentist"-flavored concept that generalizes the accuracy of a point estimator. These adaptive methods are region-analogs of those that achieve the quantum Fisher information for point estimators.

Valuable quantum states of the SU(1,1) interferometer and their Majorana representations

Ulrich Seyfarth

Max Planck Institute for the Science of Light, Germany

It is well-known, that the SU(1,1) interferometer dwarfs the usual SU(2) interferometer in the context of phase sensitivity. But apart from this point, the set of valuable quantum states should be examinated. In analogy to the case of SU(2) which seems to be extensively discussed, we study here the SU(1,1) case. Therefore, several types of states of the SU(1,1) interferometer are discussed. This includes SU(1,1) NOON states and SU(1,1) squeezed states. Corresponding Majorana representations are constructed as well.

Observing the quantum interference and entanglement of electron-nuclear system and trapped ions on Bloch sphere by Wigner distribution

Heng Shen

University of Oxford, UK

We present the experimental reconstruction of the Wigner function of a two-level electron spin and electron-nuclear spin system in diamond. This spherical Wigner function contains the same information as the density matrix for any spin- j system. As an example, we experimentally measure the Wigner function of a single qubit undergoing a nearly pure dephasing process. The extracted fidelities of spin state at different time points show the same decay rate as dephasing process, which agrees with theoretical prediction. We also experimentally extended this methods to two qubit system including electron-nuclear spins, and trapped ions. Our method can be applied straightforwardly to multi-atom systems for measuring the Wigner function of their collective spin state.

01 August (Wednesday)

Diamond spin magnetometry and its application

Jiangfeng Du
University of Science and Technology of China

The sensitive measurement of the nanoscale magnetic signal brings the widely applied magnetic resonance into a new regime, the nanoscale magnetic resonance spectroscopy and imaging. In this talk I will present our recent advancement [1-5] in this area using a nanoscale diamond spin sensor and discuss its potential towards a practical tool in single molecule spectroscopy and imaging.

[1] Fei Kong, Pengju Zhao, Xiangyu Ye, Zhecheng Wang, Zhuoyang Qin, Pei Yu, Jihu Su, Fazhan Shi, and Jiangfeng Du. *Zero-field electron spin resonance spectroscopy on nanoscale*, Nature Communications, in press (2018)
[2] Xing Rong, Mengqi Wang, Jianpei Geng, Xi Qin, Maosen Guo, Man Jiao, Yijin Xie, Pengfei Wang, Pu Huang, Fazhan Shi, Yi-Fu Cai, Chongwen Zou & Jiangfeng Du. *Searching for an exotic spin-dependent interaction with a single electron-spin quantum sensor*. Nature Communications, 9:739 (2018)
[3] Wenchao Ma, Longwen Zhou, Qi Zhang, Min Li, Chunyang Cheng, Jianpei Geng, Xing Rong, Fazhan Shi, Jiangbin Gong, and Jiangfeng Du. *Experimental Observation of a Generalized Thouless Pump with a Single Spin*, Phys. Rev. Lett., 120, 120501 (2018)
[4] Kebiao Xu, Tianyu Xie, Zhaokai Li, Xiangkun Xu, Mengqi Wang, Xiangyu Ye, Fei Kong, Jianpei Geng, Changkui Duan, Fazhan Shi,and Jiangfeng Du. *Experimental Adiabatic Quantum Factorization under Ambient Conditions Based on a Solid-State Single Spin System*, Phys. Rev. Lett., 118, 130504 (2017)
[5] Wenchao Ma, Bin Chen, Ying Liu, Mengqi Wang, Xiangyu Ye, Fei Kong, Fazhan Shi, Shao-Ming Fei, and Jiangfeng Du. *Experimental Demonstration of Uncertainty Relations for the Triple Components of Angular Momentum*, Phys. Rev. Lett., 118, 180402 (2017)

Compressed sensing of vortex beams

Luis Sanchez-Soto
Max Planck Institut für die Physik des Lichts, Germany

In this talk I will present recent experimental results of compressed sensing using single photons carrying orbital angular momentum. I will also show how adaptive techniques can be employed to deal with states of any unknown rank.

Verification of quantum computation and simulation

Animesh Datta
University of Warwick, UK

Ensuring that a quantum device operates as expected, even in the presence of errors and imperfections, is a vital step in their fruitful use. This is often achieved by performing quantum tomography of states, process, and measurements. In the context of quantum computation or simulation, this strategy is unfortunately not scalable. We present a scalable method that provides confidence in the output of a quantum computer or simulator based on the outcomes of a certain number of 'traps'. The traps are computations that can be performed efficiently classically and are chosen so as to be sensitive to all possible errors or imperfections. We show how this strategy can be used to verify quantum supremacy. We also present some recent results on how such a method can be implemented with no spatial and minimal temporal overheads.

Randomized benchmarking does not measure average infidelity

Hui Khoon Ng
Yale-NUS College, and CQT, NUS, Singapore

Randomized benchmarking (RB) is a popular procedure used to gauge the performance of a set of gates useful for quantum information processing (QIP). Recently, Proctor et al. [PRL 119, 130502 (2017)] demonstrated a practically relevant example where the RB measurements give a number r very different from the actual average gate-set infidelity \epsilon, despite past theoretical assurances that the two should be equal. Here, we derive formulas for \epsilon, and for r from the RB protocol, in a manner permitting easy comparison of the two. We show that r is not equal to \epsilon, i.e., RB does not measure average infidelity, and, in fact, neither one bounds the other. We give several examples, all plausible in real experiments, to illustrate the differences in \epsilon and r. Many recent papers on experimental implementations of QIP have claimed the ability to perform high-fidelity gates because they demonstrated small r values using RB. Our analysis shows that such a conclusion cannot be drawn from RB alone.

This is based on work by Jiaan Qi (Dept Physics, NUS) and HKN (arXiv:1805.10622).

Reinforcement learning for hard quantum metrology and control

Barry Sanders
University of Calgary, Canada

We develop reinforcement learning as a robust tool for classical and quantum metrology and control, and our approach is valuable if the model or training sets are insufficient to deliverable sufficient fidelity for quantum control or sufficient precision for quantum metrology.

Self-guided quantum learning

Chris Ferrie
University of Technology Sydney, Australia

I'll present new approaches to the problems of quantum state and process tomography wherein no data post-processing is required. The problem is translated into one of optimisation and an iterative, adaptive solution is proposed. When the protocol ends, the experiment has guided itself to the correct solution.

Multimode Entanglement and Quantum-enhanced Frequency Metrology with an Optical Frequency Comb

Yin Cai
Xi'an Jiaotong University, China

Multimode entanglement is an essential resource for quantum information processing and quantum metrology. Here we demonstrate an optical on-demand, reconfigurable multimode entangled state, using an intrinsically multimode quantum resource and a homodyne detection apparatus. Without altering either the initial squeezing source or experimental architecture, we realize the construction of thirteen cluster states of various sizes and connectivities as well as the implementation of a secret sharing protocol. In the end, using our squeezing resource, we will exhibit an quantum spectrometer with a sensitivity beyond quantum limit.

Efficient sampling of quantum states using the complex Wishart distributions

Rui Han

Centre for Quantum Technologies, National University of Singapore, Singapore

High-quality random samples of quantum states are extremely useful for a variety of applications; they are, in particular, needed in Bayesian methods for estimating quantum states or selected properties of quantum states. Unfortunately, the standard algorithms for sampling in accordance with a given target distribution are expensive (in CPU time) and usually yield correlated samples as generated from a random walk in the high-dimensional quantum state space. In addition, the algorithms are often impractical for systems that contains more than just a few qubits. As a remedy, we introduce yet another algorithm that can reliably, and with good efficiency, produce a random sample of quantum states in any dimension, and with no correlation among subsequent entries into the sample. Our novel method consists of two steps: First, we produce a CPU-cheap large reference sample from a fitting complex Wishart distribution that mimics the target distribution as well as possible. Second, we reject or accept entries in the reference sample such that the remaining smaller sample is in accordance with the target sample. The acceptance rate – the yield of the second step – is many orders magnitude larger than that for a uniform sample as reference. We illustrate the method with examples for sampling quantum states for single qubits, single qutrits, qubit pairs and qubit quartets, for which the quantum state space is 3-, 8-, 15-, and 255-dimensional, respectively.

02 August (Thursday)

Towards a conclusive verification of bipartite bound entanglement

Matthias Kleinmann
Univeristät Siegen, Germany

Bipartite bound entangled states form a class of states with a small volume within the state space. Also, this class of states is particularly difficult prepare experimentally, because bound entangled states are both, entangled and mixed. Yet another challenge is the verification that such a preparation was successful, since all states compatible with the data have to be verified to be bound entangled. In this talk I will present a method to find states which are most suitable for preparation and verification and I detail the statistical methods for verifying that the experimental state was indeed bound entangled.

Entanglement verification, with or without tomography

Nengkun Yu
Centre for Quantum Software and Information, University of Technology Sydney, Australia

In this paper, we study this problem of certifying entanglement without tomography in the constrain that only single copy measurements can be applied. This task is formulate as a membership problem related to a dividing quantum state space, therefore, related to the geometric structure of state space. We show that universal entanglement detection among all states can never be accomplished without full state tomography. Moreover, we show that almost all multipartite correlation, include genuine entanglement detection, entanglement depth verification, requires full state tomography. However, universal entanglement detection among pure states can be much more efficient, even we only allow local measurements. Almost optimal local measurement scheme for detecting pure states entanglement is provided.

Direct measurement of the quantum state of photons in a cavity

Xin-Qi Li
Tianjin University, China

We propose a scheme to measure the quantum state of photons in a cavity. The proposal is based on the concept of quantum weak values and applies equally well to both the solid-state circuit and atomic cavity quantum electrodynamics (QED) systems. The proposed scheme allows us to access directly the superposition components in Fock state basis, rather than the Wigner function as usual in phase space. Moreover, the separate access feature held in the direct scheme does not require a global reconstruction for the quantum state, which provides a particular advantage beyond the conventional method of quantum state tomography.

Generation and manipulation of continuous variable non-classical states

Xiaojun Jia

State Key Laboratory of Quantum Optics Quantum Optics Devices,

Institute of Opto-Electronics, Shanxi University, Taiyuan

030006, P. R. China

Continuous variables (CVs) entangled state of light is one of the essential quantum resources in quantum information science and technology. We have designed and built an efficient and compact light source of entangled state, a wedged type-II KTP crystal inside the Nondegenerate Optical Parametric Amplifier (NOPA) is used for implementing frequency-down-conversion of the pump field to generate the optical entangled state and achieving the dispersion compensation between the pump and the subharmonic waves. The EPR entangled state of light with quantum correlations of 8.4 dB for both amplitude and phase quadratures are experimentally produced by this NOPA. On the other hand, it is crucial for realization of quantum information networks to establish entanglement among multiple space-separated quantum memories and then at a user-controlled moment to transfer the stored entanglement to quantum channels for distribution and conveyance of information. We realize an experimental demonstration on generation, storage and transfer of deterministic quantum entanglement among three spatially separated atomic ensembles. The off-line prepared multipartite entanglement of optical modes is mapped into three distant atomic ensembles to establish entanglement of atomic spin waves. Then the stored atomic entanglement is transferred into a tripartite quadrature entangled state of light, which is space-separated and can be dynamically allocated to three quantum channels for conveying quantum information.

03 August (Friday)

Fisher Information: From Parameter Estimation to Quantum Coherence

Shunlong Luo
Academy of Mathematics and Systems Science, Chinese Academy of Sciences, China

The notion of Fisher information originated from statistics and have permeated into information and physics. It plays a crucial role in both foundations and practices of quantum metrology. In this talk, we review various aspects of classical as well as quantum Fisher information, illustrate their use in quantum measurement and quantum coherence.

Attaining the ultimate precision limit in quantum state estimation

Masahito Hayashi
Nagoya University, Japan

We derive a bound on the precision of quantum state estimation for finite dimensional systems, and prove its attainability in the generic case where the spectrum is non-degenerate. Our results hold under an assumption called local asymptotic covariance, which is weaker than unbiasedness or local unbiasedness. The derivation is based on an analysis of the limiting distribution of the estimator's deviation from the true value of the parameter, and takes advantage of quantum local asymptotic normality, a useful asymptotic characterization of identically prepared states by Gaussian states of continuous variable systems. We first prove our results for the mean square error of a special class of models, called D-invariant, and then extend the results to arbitrary models, generic cost functions, and global state estimation, where the unknown parameter is not restricted to a local neighbourhood of the true value. The extension includes a treatment of nuisance parameters, namely parameters that are not of interest to the experimenter but nevertheless affect the estimation. As an illustration of the general approach, we provide the optimal estimation strategies for the joint measurement of two qubit observables, for the estimation of qubit states in the presence of amplitude damping noise, and for noisy multiphase estimation.

High-performance boson sampling using solid-state single photons

Chao-Yang Lu

University of Science and Technology of China, Hefei, P.R. China

cylu@ustc.edu.cn

Abstract: We develop single-photon sources that simultaneously combines high purity, efficiency, and indistinguishability. We demonstrate entanglement among ten single photons. We construct high-performance multi-photon boson sampling machines to race against classical computers.

Boson sampling is considered as a strong candidate to demonstrate the "quantum advantage / supremacy" over classical computers. However, previous proof-of-principle experiments suffered from small photon number and low sampling rates owing to the inefficiencies of the single-photon sources and multi-port optical interferometers. In this talk, I will report two routes towards building Boson Sampling machines with many photons.

In the first path, we developed SPDC two-photon source with simultaneously a collection efficiency of ~70% and an indistinguishability of ~91% between independent photons. With this, we demonstrate genuine entanglement of ten photons [1]. Very recently, we managed to observe 12-photon entanglement using a novel SPDC source. Such a platform will provide enabling technologies for teleportation of multiple properties of photons [2] and efficient scattershot boson sampling.

In the second path, using a QD-micropillar, we produced single photons with high purity (>99%), near-unity indistinguishability for >1000 photons [3], and high extraction efficiency [4]—all combined in a single device compatibly and simultaneously. We build 3-, 4-, and 5-bosonsampling machines which runs >24,000 times faster than all the previous experiments, and for the first time reaches a complexity about 100 times faster than the first electronic computer (ENIAC) and transistorized computer (TRADIC) [5,6]. We are currently increasing the rate by optimizing the single-photon system efficiency to near unity, background-free resonance fluorescence, and using improved schemes such as boson sampling with photon loss [7], with the hope of achieving 20-photon boson sampling in the near term.

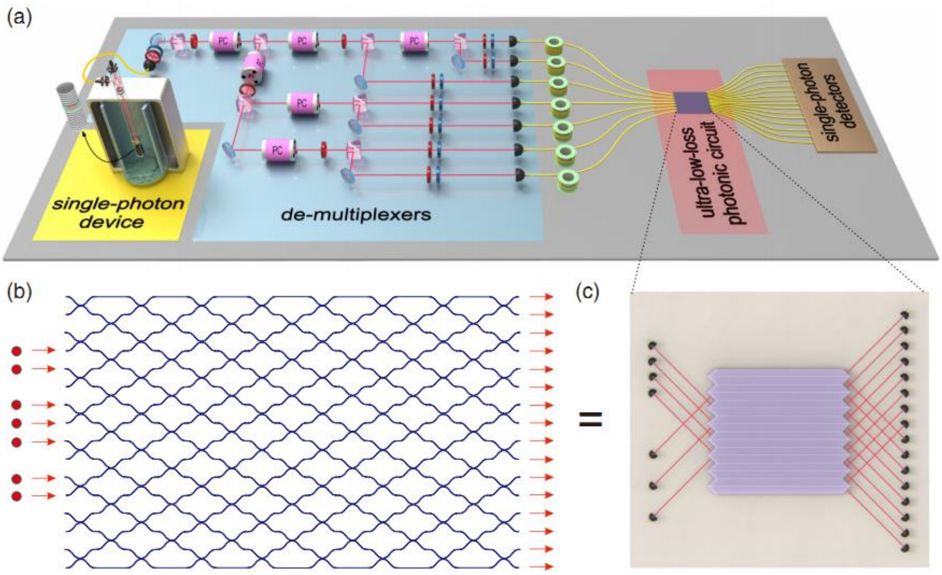


Figure 1: Experimental setup for boson sampling with 7 input single photons into an ultra-low-loss 16*16 interferometer. Quantum dot single photon extraction (system) efficiency is 82% (34%). Photon indistinguishability 94% (90%) at time separation of 13 ns (15 μs). Three-photon count rate ~80 KHz.

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Quantum State Tomography with Reduced Effort and for Finite Statistics

Lukas Knips

LMU & MPQ, Munich, Germany

Quantum state tomography became a powerful tool for fully determining unknown multiqubit states. However, it is demanding in terms of the experimental effort as well as the subsequent data evaluation. In this talk, we will review our endeavor to reduce the requirements inside and outside the laboratory. Permutationally invariant (PI) tomography allows to reduce the exponential scaling of full state tomography to polynomial scaling for states which are PI or close to the PI subspace. Combining this approach with compressed sensing allows to further reduce the experimental requirements significantly. After data recording, its evaluation poses the next challenge. Common tools for obtaining physical density matrices can lead to a systematic underestimation of the state fidelity and overestimation of its entanglement. We will also discuss the finite statistics effects, which lead to a characteristic distribution of eigenvalues. This not only allows to investigate systematic errors in state preparation or evaluation, but enables to distinguish physically significant contributions from mere noise.

Quantum tomography and super-resolution: two opposite faces of quantum metrology

Zdenek Hradil
Department of Optics, Palacky University, Czech Republic

Quantum information technologies have recorded an enormous progress within the recent decades. They have developed from the early stages of thought experiments into nowadays almost ready-to-use applications. The quantum state is not an observable and as such it cannot be measured in the traditional sense of this word. Information encoded in a quantum state may be portrayed by various ways yielding the most complete and detailed picture of the quantum object available. On the other hand due to the statistical nature of quantum effects the information coded in quantum state cannot be recovered with an arbitrary precision. Tomography and super-resolution are two opposite faces of quantum strategies for quantum inspired metrology. Mathematical framework is given by Max-Lik tomography and fundamental limits upon the quantum resolution- Quantum Fisher Information, as will be demonstrated on several examples of optical detection. The spatial resolution of any imaging device is restricted by diffraction, which causes a sharp point on the object to blur into a finite-sized point-spread function, which hinders to distinguish two neighbourhood points - an effect known as Rayleigh curse. The same problem can be reconsidered from the perspective of quantum estimation theory. Here the constraints on resolution are more fundamental and correspond to the so called Fisher information and Cramer-Rao lower bound (CRLB) for parameter estimation. When only light intensity at the image plane is measured on the basis of all the traditional techniques such as CCD detection, the Fisher information falls to zero as the separation between two sources decreases in accordance with Rayleigh curse. Surprisingly, as has been predicted theoretically and demonstrated experimentally the Quantum Fisher Information calculated for optimal measurement remains constant implying that the Rayleigh limit is subsidiary to the problem and super-resolution is achievable. However, this problem should be considered from the broader perspective of the multi-parameter CRLB for simultaneously estimating parameters such as centroid position, relative distance and brightness of the sources. For the general case of unequally bright sources, the amount of information one can gain about the separation falls to zero, but there is always an improvement in comparison with the intensity detection.

Heisenberg-limit control-enhanced sequential scheme for general quantum parameter estimation

Zhibo Hou
University of Science and Technology of China

Quantum metrology can in principle achieve precisions beyond the shot-noise limit. In practice, however, preparing many-body entangled states for the standard entangled parallel scheme in quantum metrology are extremely challenging. The entanglement-free sequential scheme provides an alternative possibility, which can achieve the same precision as the entangled parallel scheme under commuting dynamics. For noncommuting dynamics, however, the direct sequential scheme in general can not achieve the same precision as the entangled scheme. Here by adding optimal quantum controls in the sequential scheme we realize a scalable scheme of quantum metrology that can achieve the same precision as the entangled scheme under general noncommuting unitary dynamics. We implement up to eight controls in experiments, which can achieve the same precision as the 8-photon NOON state in the entangled scheme. Our work demonstrates the control-enhanced recipe for achieving the Heisenberg precision under general noncommuting dynamics, and opens the avenue for harvesting the power of quantum control in quantum metrology.

Experimental High-Dimensional Einstein-Podolsky-Rosen Steering

Qiang Zeng
Beijing Institute of Technology, China

Steering nonlocality is the fundamental property of quantum mechanics, which has been widely demonstrated in some systems with qubits. Recently, theoretical works have shown that the high-dimensional (HD) steering effect exhibits novel and important features, such as noise suppression, which appear promising for potential application in quantum information processing (QIP). However, experimental observation of these HD properties remains a great challenge to date. In this work, we demonstrate the HD steering effect by encoding with orbital angular momentum photons for the first time. More importantly, we have quantitatively certified the noise-suppression phenomenon in the HD steering effect by introducing a tunable isotropic noise. We believe our results represent a significant advance of the nonlocal steering study and have direct benefits for QIP applications with superior capacity and reliability.

Adaptive quantum tomography of high-dimensional bipartite systems

Struchalin Gleb

Faculty of Physics, M. V. Lomonosov Moscow State University, Quantum Technologies Centre, Russia

There are two main goals in protocol development for quantum tomography. The first one is to find protocols with minimal number of measurement operators (e.g. minimal qubit tomography based on tetrahedron geometry [1]). The second objective is to construct protocols that achieve a certain level of accuracy faster (compared by the number of measured input states) than others, or equivalently give more accurate estimation for the same number of measured copies of the true state. The present work considers the latter case. Adaptive measurements have recently been shown to significantly improve accuracy of quantum state and process tomography. There exist various adaptive schemes for measurement selection demonstrating different flexibility and computational simplicity. By flexibility we mean that a protocol can be easily tailored to use only some subset of available measurements. The flexibility becomes important when the system of interest is multipartite, because in this case all measurements are divided into two classes: general measurements and factorized measurements (according to a tensor product structure of the system Hilbert space). Factorized measurements carried out on the subsystems independently are relatively simple to implement in experiments, so a protocol, limited to factorized measurements only, is highly desirable. In our opinion there is a lack of flexible and computationally fast protocols for high-dimensional state tomography. For example, Bayesian optimal experimental design is a versatile approach with high reconstruction accuracy, but it is computationally involved. A prominent class of computationally fast protocols are protocols that include measurements in the eigenbasis of the current estimate [2]. The problem is that the eigenbasis will almost certainly contain entangled vectors, and therefore these protocols require general type of measurements, which is a severe experimental limitation. There is no straightforward generalization of these protocols which use factorized measurements only. We present a novel adaptive protocol, which is computationally fast and requires only factorized measurements [3]. We provide arguments that measurements having nearly zero outcome probability for nearly pure states (more precisely, the probability should be less than the minimal eigenvalue of the true state) are necessary to qualitatively improve the estimation accuracy compared to non-adaptive protocols. Therefore the main idea of our protocol is to find vectors to project on that are simultaneously orthogonal to several eigenvectors of the current estimator. We mainly consider a case of bipartite systems with two identical parts, however some results are applicable for general multipartite systems. We investigate the estimation accuracy of the proposed protocol both in numerical simulations and real experiments for the states with dimension up to 36. The experiments are carried out with spatial states of photon pairs produced by a spontaneous parametric down conversion process. In experiments we compare the performance of our protocol with non-adaptive random measurements. In simulations, protocols based on measurements in the eigenbasis are also used for comparison. We use a maximum likelihood estimation (MLE) for data processing, however, our protocol is independent of the choice of a statistical estimation procedure. We observe an improvement of reconstruction accuracy for our protocol, compared to the non-adaptive random measurements both in simulations and in real experiments.

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Adaptive tomography of qubits: Purity versus statistical fluctuations

Aonan Zhang

Nanjing University, China

Reliable and efficient characterization for quantum systems is a central task and fundamental issue in quantum information science. Here we investigate a procedure for adaptive qubit state tomography which achieves O(1/N) scaling in accuracy for large N. We analyze the performance of the adaptive protocol on the characterization of pure, highly mixed and nearly-pure states, and clarify how the purity of the state and the statistical fluctuations of measurement outcomes affect the tomography accuracy. Our results highlight the unique behavior of nearly-pure states in quantum state tomography.

List of posters

P1. Amandeep Singh, *Experimental Classification of Tripartite Entanglement Without Prior Information on an NMR Quantum Information Processor*

P2. Yuanlong Wang, *Quantum Hamiltonian Identification*

P3. Qi Yu, *Filtering for a Class of Quantum Systems with Classical Stochastic Disturbance*

P4. Shengli Zhang, *Photon catalysis acting as noiseless linear amplification and its application in coherence enhancement*

P5. Daekun Ahn, *Adaptive Compressed Sensing without any A Priori Information*

P6. Yanwu Gu, *Bell experiments and Bayesian inference*

P7. Jun Yan Sim, *Optimal error regions and optimal error intervals for quantum process estimation*

P8. Jiaan Qi, *Randomized Benchmarking does not measure average infidelity*

P9. Xu-dan Chai, *Tomographic reconstruction of multi-qubit states*

P10. Chenrui Zhang, *Direct Measurement of the Two-dimension Quantum Wavefunction via Strong Measurement*

P11. Shihao Zhang, *Characterization of microwave graph states for simulating quantum computation and information processing*

P12. Tong-jun Liu, *Experimental certification of Mermin steering in tripartite GHZ states*

P13. Jie Xie, *Experimental Device-independent Test of Quantum Measurements*

P14. Keren Li, *Implementing the Gradient algorithm on the Quantum Simulator*

Abstracts of the posters

P1. Experimental Classification of Tripartite Entanglement Without Prior Information on an NMR Quantum Information Processor

Amandeep Singh
Indian Institute of Science Education and Research Mohali, India

We experimentally implement a recently proposed scheme for tripartite entanglement detection on a spin ensemble using NMR. The protocol not only detects multipartite entanglement but also classifies it into six inequivalent classes of three-qubit entangled states. Measurements of only four observables suffice to experimentally differentiate between the six classes. Experimental realization is achieved on a three-qubit NMR quantum information processor, by mapping the desired observables onto Pauli's z-operator.

P2. Quantum Hamiltonian Identification

Yuanlong Wang
University of New South Wales at Canberra, Australia

Quantum Hamiltonian identification is important for characterizing the dynamics of quantum systems, calibrating quantum devices and achieving precise quantum control. In this paper, an effective two-step optimization (TSO) quantum Hamiltonian identification algorithm is developed within the framework of quantum process tomography. In the identification method, different probe states are inputted into quantum systems and the output states are estimated using the quantum state tomography protocol via linear regression estimation. The system time-independent Hamiltonian is reconstructed based on the experimental data for the output states. The Hamiltonian identification method has computational complexity $O(d^6)$ where d is the dimension of the system Hamiltonian. An error upper bound $O(d^3/\sqrt{N})$ is also established, where N is the resource number for the tomography of each output state, and several numerical examples demonstrate the effectiveness of the proposed TSO Hamiltonian identification method.

P3. Filtering for a Class of Quantum Systems with Classical Stochastic Disturbance

Qi Yu
University of New South Wales, Australia

We present filtering equations for a class of hybrid quantum-classical systems where a quantum optical cavity system is continuously disturbed by a classical linear stochastic process. A quantum cavity system is employed to describe the classical stochastic process as an analog. The initial `hybrid' quantum-classical system consisting of both a classical signal and a quantum cavity system is then modeled by a combined quantum system with two quantum cavity systems. The stochastic master equations (SME), or filtering equations, are then derived using quantum probability theory. A quantum extended Kalman filter (QEKF) method is adopted as a convenient solution to this filtering problem. The effectiveness of both SME and QEKF methods is demonstrated by applying them to an optical cavity system.

P4. Photon catalysis acting as noiseless linear amplification and its application in coherence enhancement

Shengli Zhang
Beijing Key Laboratory of Nanophotonics & Ultrafine Optoelectronic Systems, School of Physics, Beijing Institute of Technology, China

Photon catalysis is an intriguing quantum mechanical operation during which no photon is added to or subtracted from the relevant optical system. However, we prove that photon catalysis is in essence equivalent to a simpler but more efficient noiseless linear amplifier. This provides a simple and zero-energy-input method for enhancing quantum coherence. We show that the coherence enhancement holds both for coherent state and two-mode squeezed vacuum (TMSV) state. For TMSV state, biside photon catalysis is shown to be equivalent to two times of single-side photon catalysis and two times of photon catalysis do not provide substantial enhancement in quantum coherence, compared with single-side catalysis. We further extend our investigation to the performance of coherence enhancement with more realistic scheme of photon catalysis where heralded approximated single photon state and on-off detector are exploited. Moreover, we investigate the influence of imperfect photon detector and the result shows that amplification effect of photon catalysis is insensitive to detector inefficiency. Finally, we apply the coherence measure to quantum illumination and the same trend of performance improvement as coherence enhancement is identified in practical quantum target detection.

P5. Adaptive Compressed Sensing without any A Priori Information

Daekun Ahn

Seoul National University, South Korea

We establish a novel adaptive compressed sensing scheme that reconstructs any unknown rank-deficient quantum state, using few optimal measurement outcomes without any prior information, in contrast with the standard compressed sensing philosophy that requires both the knowledge that quantum state is at most of rank-r, which is much smaller than D (r-sparse assumption), and a target state to validate the reconstruction.

P6. Bell experiments and Bayesian inference

Yanwu Gu

National University of Singapore, Singapore

Based on Einstein's local realism, Bell developed a local hidden variable theory (LHV) and derived an inequality which constrains the correlations in measurement outcomes from two distant observers. He also pointed out that this inequality could be violated by measurement outcomes of entangled quantum states. Indeed, violations of Bell's inequality were found in a series of experiments (including some recent loophole-free Bell experiments). However, the probabilities that enter the Bell's inequality are approximated by relative frequencies which may violate the no-signaling constraints. So some other statistical evidence is useful for ruling out LHV. In frequentist statistics, hypothesis testing about LHV could be performed. If a low p-value is obtained, local realism is rejected. However, the interpretation of p-values is controversial, and p-values can't provide evidence in favor of a hypothesis. Here we use the relative belief ratio (RBR) as a measure for statistical evidence, which is the ratio between posterior probability and prior probability. If the RBR of a region or a model is larger than 1, the data provide evidence in favor of it. Otherwise, it's evidence against. We sampled probabilities in both QM and LHV. These samples are classified into three regions: (1) QM only, (2) LHV only, (3) overlap. Then we simulated some Bell experiments and used the mock data to ensure there is no bias favoring QM in our method. We analyzed data from several loophole-free Bell experiments. By maximum likelihood estimation we characterized experimental parameters. Our model gave very low prior probability and posterior probability close to 1 for the “QM only” region, which is very strong evidence in favor of QM and against LHV. Our study provides a new approach to analyzing Bell experiments.

P7. Optimal error regions and optimal error intervals for quantum process estimation

Jun Yan Sim
Centre for Quantum Technologies, Singapore

Quantum process estimation is the procedure of reconstructing an unknown quantum channel from observed data. In this work, we construct optimal error regions for quantum process estimation as a supplement for the maximum-likelihood estimator. We also construct optimal error intervals for the estimation of properties of quantum process. To construct the optimal error regions and optimal error intervals, we employ the Hamiltonian Monte Carlo method to generate random samples of quantum channel. We developed a parameterization of quantum channel which is essential in the Hamiltonian Monte Carlo method. We illustrate our methods with examples on single-qubit channel.

P8. Randomized Benchmarking does not measure average infidelity

Jiaan Qi
National University of Singapore, Singapore

One important aspect in Fault-tolerant quantum computing is to determine the properties of noise processes, which is modeled by quantum channels. A class of protocols known as Randomized Benchmarking is used by many experimentalist to measure the average fidelity of quantum gates. In this poster, we first analyzed this protocol, gave an intuitive derivation of the decay rate, and show that it does not in general measure average fidelity as intended. We also derived a formula for the average infidelity that is easy to compare with the RB number, and show that they are different quantities indeed. We provided a possible mechanism that could cause underestimation of the noise by using a perturbative approach. Above follows from my recent work arXiv:1805.10622 [quant-ph]. Alternative use of the RB protocol is also explored, specifically, we show that it is possible to use a extension of RB to detect properties like complete positiveness of the quantum channels.

P9. Tomographic reconstruction of multi-qubit states

Xu-dan Chai
Beijing Institute of Technology, China

Quantum state tomography (QST)is of crucial importance in assessing the quality of quantum information processing devices. Tomography fundamentally requires both experimental and data processing recourses, which increase exponentially with number of qubits. To enhance the tomography efficiency, we develop target approaches to character an unknown quantum state with fewer identical copies of states. We demonstrate how the Phaselift performed in the tomography of the polarization photonic qubits system with Nestrov. Numerically, we simulate multi-qubits entangled stats tomography, specially for the three special entangled state including Greenberger-Horne-Zeilinger (GHZ) state, W-class sate and cluster state. Meaningfully, we find that, due to the special entanglement- the W-class states, Nestrov algorithm outperforms the W-class state especially for larger qubit cases. Furthermore, compared to the CVX algorithm, the Nestrov algorithm turns out to be more practically advisable specially for larger qubits states tomography. Furthermore we make the tomography on the time-bin entangled states via compressed sensing and self-guided method. It shows that the phaselift is more efficient for larger number of qubits tomography while self-guided is more precise for small number of qubits cases.

P10. Direct Measurement of the Two-dimension Quantum Wavefunction via Strong Measurement

Chenrui Zhang
University of Science and Technology of China

Wavefuncion is the foundation of quantum theory, which is assumed to give a complete description of a quantum system. For a long time, wavefunction is introduced as an abstract element of the theory and physicists look at it with a pragmatic attitude. The situation, however, is somewhat changed when Lundeen et al. report the direct measurement of the quantum wavefunction via weak measurement, which gives the wavefunction a clearly operational definition. The weak measurement method requires sequential measurement of conjugate observables position and momentum with the position measurement is weak enough. The

wavefunction is directly obtained by measuring the weak value. Surprisingly, the recent research shows that performing sequential strong measurements realizes the same target, in which case the higher precision and accuracy are given. Here we report the direct measurement of the two-dimension transverse wavefunction of photons via strong measurement, in particular the wavefunction of photons carrying orbit angular momentum is first shown. As an important application, the measurement of two-dimensional objects. The results presented here will not only deepen our understanding of abstract wavefunction but also have significant applications in quantum information processing and quantum imaging.

P11. Characterization of microwave graph states for simulating quantum computation and information processing

Shihao Zhang

Beijing Institute of Technology, China

With the development of insightful classical descriptions that capture much or all of the essential physics of the system in question, impressive progress has been made in the area of classically simulating quantum systems in recent years. By establishing a mapping between the detection of intensities of classical signals output from an appropriate designed circuit and the correlation measurements outcomes in the quantum photonic experiments, we implement a series of experiments with a different number of receiving antenna and signal channel to simulate the 4-, 8-, 14- and 16-qubit graph states correspondingly via reproducing the probability distribution predicted in quantum theory. Then we employ the state tomography techniques and entanglement witness operators to characterize these constructed microwave graph states (MGS) by analog with quantum experimental settings. This scalable and reliable system can serve as a test-bed to simulate certain quantum computation based on intermediate-sized quantum systems, such as measurement-based quantum computing, fault-tolerant measurement and demonstrate topological properties of specific quantum many-body systems.

P12. Experimental certification of Mermin steering in tripartite GHZ states

Tong-jun Liu

Nanjing University of Posts and Telecommunications, China

Einstein-Podolsky-Rosen (EPR) steering is intermediate between entanglement and Bell nonlocality in the hierarchical structure of quantum nonlocality. The violation of Mermin steering inequality certifies the presence of EPR steering in tripartite systems. We presented an experimental generation of three-photon entangled states. The fidelity of our GHZ state was 87.25 ± 0.03% through quantum state tomography. To verify the entanglement, the Mermin steering inequality[1] was measured, up to 3.50 ± 0.05, which was much higher than 2, the classical bound. In addition, a class of GHZ-like states was generated to characterize the entanglement source.

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P13. Experimental Device-independent Test of Quantum Measurements

Jie Xie

Nanjing University, China

The certification of a theoretical model for quantum measurements is of vital importance in quantum information tasks. However, such certification usually relies on extra assumptions on the state-generating devices. Recently, the device-independent (DI) way of testing quantum measurements has been introduced and fully characterize the set of input-output correlation compatible with any qubit measurement. Here we implement two kinds of qubit measurements, symmetric informationally complete (SIC) measurements and mutually unbiased bases (MUBs) with practical photonic apparatus, and test the observed measurement statistics in the DI way with both theoretical hypotheses and reconstructed measurements given by quantum detector tomography. Furthermore, we characterize the detectors by taking the DI test as an additional condition of tomography. Our results highlight the tightness and validity of the test, and foreshadow novel tomography protocols inspired by DI tests.

P14. Implementing the Gradient algorithm on the Quantum Simulator

Keren Li

Tsinghua University, China

Gradient descent method, as one of the major methods in numerical optimization, is the key ingredient in many machine learning algorithms. As one of the most fundamental way to solve the optimization problems, it promises the function value to move along the direction of steepest descent. For the vast resource consumption when dealing with high-dimensional problems, a quantum version of this iterative optimization algorithm has been proposed recently[arXiv:1612.01789]. Here, we develop this protocol and implement it on a quantum simulator with limited resource. A prototypical experiment was shown with a 4-qubit Nuclear Magnetic Resonance quantum processor, which demonstrated the optimization process iteratively. Experimentally, the iterative point converged to the local minimum with an fidelity all above 94\% via full-state tomography. Moreover, our method can be employed to a multidimensional scaling problem, showing the capability to exponentially outperform with its classical counterparts. With the onrushing tendency of machine learning and quantum information, our work provide an alternative to the high-dimensional optimization problem and a subroutine for future-practical quantum computers.

List of Participants

Name	Affiliation	Country
Amandeep Singh	Indian Institute of Science Education and Research Mohali	India
Animesh Datta	University of Warwick	UK
Aonan Zhang	Nanjing University	China
Barry Sanders	University of Calgary	Canada
Berge Englert	Centre for Quantum Technologies and Department of Physics, National University of Singapore; and MajuLab	Singapore
Chao-Yang Lu	University of Science and Technology of China	China
Chengjie Zhang	Soochow University	China
Chenrui Zhang	University of Science and Technology of China	China
Chenxi Liu	Nanjing University of Posts and Telecommunications	China
Chris Ferrie	University of Technology Sydney	Australia
Daekun Ahn	Seoul National University	South Korea
Dawei Lu	Southern University of Science and Technology	China
Feng Tian	Beijing Institute of Technology	China
Guo-Yong Xiang	University of Science and Technology of China	China
Hai Li	Shandong Technology and Business University	China
Haiping Li	Beijing Institute of Technology	China
Hao Dai	Academy of Mathematics and System Sciences, CAS	China
Hao Yuan	Anhui University	China
Heng Shen	University of Oxford	UK
Hui Khoon Ng	Yale-NUS College, and the Centre for Quantum Technologies, NUS	Singapore
Jens Eisert	Free University of Berlin	Germany
Jiaan Qi	National University of Singapore	Singapore
Jian Li	Nanjing University of Posts and Telecommunications	China
Jiangfeng Du	University of Science and Technology of China	China
Jie Sun	Huazhong University of Science and Technology	China

Jie Xie	Nanjing University	China
Juju Hu	Jiangxi Normal University	China
Jun-Feng Tang	University of Science and Technology of China	China
Keren Li	Tsinghua University	China
Lei Li	China University of Petroleum (East China)	China
Lingshan Xu	Yanbian University	China
Luis Sanchez-Soto	Max Planck Institut für die Physik des Lichts	Germany
Lukas Knips	LMU & MPQ, Munich	Germany
Masahito Hayashi	Nagoya University	Japan
Matthias Kleinmann	Universität Siegen, Germany	Germany
Ming Li	China University of Petroleum	China
Mingyang Shen	Yanbian University	China
Nan Li	Academy of Mathematics and Systems Science, CAS	China
Nengkun Yu	Centre for Quantum Software and Information University of Technology Sydney	Australia
Peng Xue	Beijing Computational Science Research Center	China
Penghui Yao	Nanjing University	China
Qi Yu	University of New South Wales	Australia
Qian Yu	Yanbian University	China
Qiang Zeng	Beijing institute of technology	China
Qin Wang	Nanjing University of Posts & Telecommunications	China
Qingbin Luo	Hubei University for Nationalities	China
Richard Kueng	California Institute of Technology	USA
Rui Han	Centre for Quantum Technologies, National University of Singapore	Singapore
Shengli Zhang	Beijing Key Laboratory of Nanophotonics & Ultrafine Optoelectronic Systems, School of Physics, Beijing Institute of Technology	China
Shihao Ma	Changzhou Institute of Technology	China
Shihao Zhang	Beijing Institute of Technology	China
Shuangshuang Fu	University of Science and Technology Beijing	China

Shunlong Luo	Academy of Mathematics and Systems Science, CAS	China
Shu-Qian Shen	China University of Petroleum	China
Sim Jun Yan	Centre for Quantum Technologies	Singapore
Struchalin Gleb	Faculty of Physics, M. V. Lomonosov Moscow State University, Quantum Technologies Centre	Russia
Tian Feng	Beijing Institute of Technology	China
Tianhai Zeng	Beijing Institute of Technology	China
Tong-Jun Liu	Nanjing University of Posts and Telecommunications	China
Ulrich Seyfarth	Max Planck Institute for the Science of Light	Germany
Wen-Li Yu	Shandong Technology and Business University	China
Xiangdong Zhang	Beijing Institute of Technology	China
Xiaojun Jia	Shanxi University	China
Xiaoming Zhang	City University of Hong Kong	China
Xinlei Yong	Yanbian University	China
Xin-Qi Li	Tianjin University	China
Xinyu Chen	Nanjing University	China
Xu-dan Chai	Beijing Institute of Technology	China
Yali Tian	Shanxi University	China
Yanwu Gu	National University of Singapore	Singapore
Ye-Chao Liu	Beijing Institute of Technology	China
Yong Siah Teo	Seoul National University	South Korea
Yimin Wang	Army Engineering University	China
Yin Cai	Xi'an Jiaotong University	China
Yinghua Ji	Jiangxi Normal University	China
Yiping Lu	Centre for Quantum Technologies, National University of Singapore	Singapore
Yuan Sun	Academy of Mathematics and System Sciences, CAS	China
Yuanlong Wang	University of New South Wales at Canberra	Australia
Yue Zhang	Academy of Mathematics and System Sciences, CAS	China
Yuli Dong	Soochow University	China

Yuxia Zhang	Beijing Institute of Technology University	China
Zdenek Hradil	Department of Optics, Palacky University	Czech Republic
Zhan Zheng	Zhejiang University of Technology	China
Zhaoqi Wu	Nanchang University	China
Zhibo Hou	University of Science and Technology of China	China
Zhichao Zhang	Beijing Institute of Technology	China
Zhijin Ke	University of Science and Technology of China	China

复旦大学

Fudan University