THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

DEPARTMENT OF APPLIED MATHEMATICS
應 用 數 學 系

2025 IEEE International Conference on Quantum Control, Computing and Learning (IEEE qCCL2025)

The Hong Kong Polytechnic University

June 25 - 28, 2025

IEEE Advancing Technology for Humanity · The Hong Kong Polytechnic University 香港理工大學 · Physical Society of Hong Kong 香港物理學會 · IEEE Hong Kong 香港 · International Year of Quantum Science and Technology · RIQT Research Institute for Quantum Technology · Department of Applied Mathematics 應用數學系 · 国盾量子 QuantumCTek

The aim and scope of the conference

This conference will convene leading experts and researchers from a diverse array of scientific disciplines. Attendees will have the opportunity to share their latest research findings and delve into the most cutting-edge developments in the field of quantum technologies. This event also serves as a valuable platform for fostering scientific collaboration and academic exchange among colleagues across quantum control, computing, and learning communities.

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Schedule

Day 1 (Wednesday, June 25, 2025)

Pre-conference workshop (**Z205**) Chaired by Hailan Ma	
Keynote talk	
14:00-15:00	Guo-Yong Xiang Control-enhanced Quantum Precision Measurement
Contributed talks	
15:00-15:40	Xiaoting Wang Fixed-point Quantum Continuous Search Algorithm with Optimal Query Complexity
15:40-16:00	Coffee Break [1]
16:00-16:40	Weichao Liang Parameter Estimation for Quantum Stochastic Systems
16:40-17:20	Xiaodong Yang Quantum Robust Control in Complex Noisy Environments and Large-scale Qubit
17:20-18:00	Shuixin Xiao Quantum Tomography: Theory, Algorithm Design, and Experimental Validation

1. Coffee Break, Lunch, & Reception Dinner are provided to all registered attendees, including plenary speakers, keynote speakers, invited speakers, registered attendees, local organizers, and student helpers.

Day 2 (Thursday, June 26, 2025)

08:00 - 8:45	Registration (**Z205**)	
08:45 - 9:00	Opening Address and Group Photo (**Z205**)	
Plenary Talk (**Z205**)		
09:00 - 10:00	Pierre Rouchon Quantum Feedback Engineering, Bosonic Codes and Quantum Error Correction	
10:00 -10:30	Coffee Break	
Keynote Talks (**Z205**)		
10:30-11:15	Christiane Koch Training Schrödinger's Cat: A Physicist's Perspective on Quantum Control	
11:15-12:00	Mile Gu Introducing Quantization^2: Quantum-Enhanced Quantization in Predictive Modelling and its operational Benefits in Near Future Devices	
12:00-13:30	Lunch (Communal Staff Restaurant, 4/F, Communal Building)	
13:30-15:30	Parallel Sessions	
	Session 1A (**Z205**)	Session 1B (**Z207**) Invited session (Chair: Yanan Liu)
15:30 -16:30	Coffee Break	
16:30 -18:30	Parallel Sessions	
	Session 2A (**Z205**)	Session 2B (**Z207**)

Day 3 (Friday, June 27, 2025)

Plenary Talk (**Z205**)	
09:00 -10:00	Howard Wiseman Quantum State Smoothing: Theory and Experiments
10:00 -10:30	Coffee Break
Keynote Talks (**Z205**)	
10:30-11:15	Joonhee Choi Benchmarking and Noise Learning in Large-Scale Quantum Devices
11:15-12:00	Yuerui (Larry) Lu 2D Quantum Materials for Next-generation Quantum Photonic Devices
12:00-13:30	Lunch (Communal Staff Restaurant, 4/F, Communal Building)
13:30-15:30	Parallel Sessions Session 3A (**Z205**) Award Session: Best Paper Finalist Session 3B (**Z207**)
15:30-16:00	Coffee Break
16:00-18:00	Parallel Sessions Session 4A (**Z205**) Hong Kong Session Session 4B (**Z207**)
19:00-21:00	Conference Banquet SJ Cuisine, 2/F, Harbour Crystal Centre, Tsim Sha Tsui

Day 4 (Saturday, June 28, 2025)

Plenary Talk (**Z205**)	
09:00 -10:00	Chaoyang Lu From Science-for-QC to QC-for-Science
10:00 -10:30	Coffee Break
Keynote Talks (**Z205**)	
10:30 -11:15	Hidehiro Yonezawa Development of Optical Quantum Computer at RIKEN
11:15 -12:00	Xiongfeng Ma Hybrid Quantum-Classical Optimization of LOCC-Assisted Circuits for Scalable Entanglement Generation
12:00 -13:30	Lunch (Communal Staff Restaurant, 4/F, Communal Building)
13:30 -15:30	Parallel Sessions Session 5A (**Z205**) Invited session (Chair: Qi Zhao) Session 5B (**Z207**)
15:30 -16:00	Coffee Break
16:00 -18:00	Session 6 (**Z205**)

Parallel Session Details

Session 1A (13:30-15:30, June 26, Venue: Z205)

Yuanzheng Paul Tan, Yung Szen Yap, Patrick Bore, Rangga Perdana Budoyo, Long Nguyen, Kun Hee Park and Rainer Dumke	Effects of White Noise on Superconducting Qubit Control Pulses
Ruikang Liang and Gong Cheng	An Approach to Control Design for 2-level Quantum Ensemble Systems
Ritik Sareen, Yule Mayevsky-Mattiaccio, Akram Youssry Mohamed and Alberto Peruzzo	Graybox Quantum System Identification and Control
Zigui Zhang and Zibo Miao	Robust Control Landscape for Parameterized Quantum Gate against Time-varying Noise
Henrik Glavind Clausen and Rafal Wisniewski	Receding Horizon Control for Quantum Metrology with Continuous Measurements
Andreas Deutschmann-Olek	Optimal Splitting of Bose-Einstein Condensates

Session 1B (13:30-15:30, June 26, Venue: Z207)

Hailan Ma, Ian R. Petersen and Daoyi Dong	Adaptive Quantum Autoencoders with Mixed Reference States
Mingxuan Liu, Valerio Scarani, Alexia Auffèves and Kiarn Laverick	A Retrodictive Approach to Quantum State Smoothing
Nicolas Mousset and Nina Amini	Decomposition of the Hilbert Space of a Continuous Quantum Dynamical Semigroup
Qi Yu, Kiarn Laverick, Daoyi Dong and Howard Wiseman	Estimation of Quantum States and Dynamical Parameters Given Past and Future Information
Shan Ma, Yuchen Xiong, Lihan Zhou and Shibei Xue	Real Matrices Larger than a Complex Matrix: Applications to Gaussian Quantum Information Processing
Yanan Liu, Areeya Chantasri, Hongting Song and Howard Wiseman	Imperfection Analyses for Random-Telegraph-Noise Mitigation Using Spectator Qubits

Session 2A (16:30-18:30, June 26, Venue: Z205)

Raul Santos and Servaas Kokkelmans	Designing the C_k Phase Gate Family for the Rydberg Atom Architecture through the Magnus Expansion
Zhihui Peng	Generation and Control of Non-classical Microwave Photon/Phonon Fields
Yuanzheng Paul Tan, Christoph Hufnagel, Stefano Carrazza and Rainer Dumke	Routine Qubit Calibration in a Compute Cluster Environment Using Qibocal
Ying Zheng, Jianwei Zhang, Yiting Chen, Shengnan Miao, Wenxin Shi, Shuotian Chen, Haijun Chen and Lijun Wang	Efficient Isotope-selective Ablation Loading of a One-Dimensional Ion Crystal into a Four-rod Electrode Trap
Snehal Mandal, Biplab Biswas, Ayan Kumar Ghosh and Bhupendra N Dev	Spectral Characterization of a Superconducting Transmon Qubit with Fourier Transform Noise Spectroscopy
Zhaokai Li	Experimental Quantum Reservoir Computing with Spin Systems

Session 2B (16:30-18:30, June 26, Venue: Z207)

Qiushi Liu and Yuxiang Yang	Heisenberg-limited Quantum Metrology without Ancilla
Xiang Li, Yong Wang, Lijun Liu, Yiguang Hong and Shuming Cheng	Quantum State Tomography via Kirkwood-Dirac Quasiprobability
Hongzhen Chen, Lingna Wang and Haidong Yuan	Simultaneous Measurement of Multiple Incompatible Observables and Tradeoff in Multiparameter Quantum Estimation
Apoorva Patel	Limitations of Quantum Advantage in Unsupervised Machine Learning
Andrew Tanggara, Mile Gu and Kishor Bharti	Strategic Codes: The Universal Spatio-temporal Framework for Quantum Error-Correction
Xiao-Dao Lin, Hsi-Ming Chang, Jhih-Shih You and Hsiu-Chuan Hsu	Quantum Error Mitigation via Autoencoder Neural Networks

<u>Session 3A</u> (13:30-15:30, June 27, Venue: Z205)

Adam Wesolowski and Karim Essafi	Benchmark of the Full and Reduced Effective Resistance Kernel for Molecular Classification
Yuting Zhu, Guangpu Wu and Shibei Xue	Quantum Coupled-giant-cavity Gyroscopes under Strict Braided Topologics
Aoi Fujimoto, Hiroyuki Ichihara and Rina Kanamoto	Optomechanical Cooling in the Unresolved Sideband Regime Using Coherent Feedback Control
Weichao Liang	Feedback Stabilization of Perturbed Quantum Systems via Reduced Filters
Mirko Legnini and Julian Berberich	Robust Feedback-based Quantum Optimization: Analysis of Coherent Control Errors
Shuixin Xiao, Yuanlong Wang, Zhibo Hou, Guo-Yong Xiang, Ian Petersen and Daoyi Dong	Collective Quantum State Tomography: Closed-form and Numerical Solutions, and Validation

<u>Session 3B</u> (13:30-15:30, June 27, Venue: Z207)

Sourav Dutta, Aditya Jain and Prabha Mandayam	Smallest Quantum Codes for Amplitude Damping Noise
Kin Tung Michael Ho, Yuk Lung Lawrence Ho, Shang Yu, Kin Lai Michelle Ho, Ronghan Zhang, Zexuan Wang, Giin Yu Amy Tan and Po-Heng Lee	Photonic Quantum Computing for RNA Structure and Gene Regulation
Jasper Postema and Servaas Kokkelmans	Existence and Characterisation of Bivariate Bicycle Codes
Yiying Chen, Peidong Wang and Zizhu Wang	Extending Causal Control: A Parallel Serial Switch and its Device-Independent Certification
Chengran Yang, Marta Florida Llinas, Mile Gu and Thomas Elliott	Dimension Reduction in Quantum Sampling of Stochastic Processes
Hongbin Song, Guofeng Zhang and Hidehiro Yonezawa	Strong Quantum Entanglement in Non-Gaussian Quantum States

Session 4A (16:00-18:00, June 27, Venue: Z205)

Giulio Chiribella	Learning Quantum Systems with Deep Neural Networks
Jeff Ou	Noise Reduction in Quantum Amplifiers by Feedback
Haidong Yuan	Precision Limits and Tradeoffs for Multi-Parameter Quantum Metrology

Session 4B (16:00-18:00, June 27, Venue: Z207)

Wilfred Wan Kei Lin	Quantum Medicine in Drug Discovery and Pharmacology
Julian Berberich, Daniel Fink, Daniel Pranjic, Christian Tutschku and Christian Holm	Training Robust and Generalizable Quantum Models
Oliver Chapman and David P. Tew	Reinforcement Learning for Quantum Chemistry State Preparation
Xuan Ye and Xiaoting Wang	Enhancing Quantum Error Mitigation via Graph-Based Learning Structures
Nahid Binandeh Dehaghani, A. Pedro Aguiar and Rafal Wisniewski	Optimizing Maximally Entangled State Generation via Pontryagin's Principle
Jayne Thompson, Paul Riechers, Andrew Garner, Thomas Elliott and Mile Gu	Energetic Advantages for Quantum Agents in Online Execution of Complex Strategies

Session 5A (13:30-15:30, June 28, Venue: Z205)

Xingjian Zhang, Zhaokai Pan and Guoding Liu	Unconditional Quantum Magic Advantage in Shallow Circuit Computation
Dong An, Akwum Onwunta and Gengzhi Yang	Fast-Forwarding Quantum Algorithms for Linear Dissipative Differential Equations
Yukun Zhang, Yusen Wu and Xiao Yuan	A Dequantized Algorithm for the Guided Local Hamiltonian Problem
Zhong-Xia Shang, Naixu Guo, Dong An and Qi Zhao	Design Nearly Optimal Quantum Algorithm for Linear Differential Equations via Lindbladians
Nikita Guseynov, Xiajie Huang and Nana Liu	Efficient Explicit Gate Construction of Block-Encoding for Hamiltonians Needed for Simulating Partial Differential Equations
Ya-Dong Wu, Yan Zhu, Giulio Chiribella and Nana Liu	Efficient Learning of Continuous-Variable Quantum States

Session 5B (13:30-15:30, June 28, Venue: Z207)

Nirupam Basak and Goutam Paul	Multiparty Quantum Secret Sharing under Noisy Scenario
Yuusei Tateyama and Yuzuru Kato	Quantum Circuit Learning for Sparse Identification of Quantum Hamiltonian Dynamics
Pankaj Agrawal, Abhisek Panda and Chandan Datta	Local Filtering and Quantumness
Yu-Juan Sun and Wei-Min Zhang	Quantum Memory Circuit for Ion Channel Dynamics in the Nervous System
Junjing Xing, Yunlong Xiao and Yuqi Li	Communication with Embezzling Catalysts
Hanxiao Tao, Jiaqi Hu and Rebing Wu	On the Expressivity of Quantum Machine Learning Models at the Physical Level

Session 6 (16:00-18:00, June 28, Venue: Z205)

Huiqi Xue and Xiu-Hao Deng	Quantum Control Robustness Landscapes
Yiwei Chen, Chen Jiang, Yong Liu, Hongye Su, Xiaomin Hu and Yu Pan	A Compact Upconversion Single-Photon Imager for Full-Range and Accurate 3-D Imaging
Yunyan Lee, Rebbecca Thien, Ian Petersen and Daoyi Dong	Quantum Coherent Systems for Ground-State Problems
Harish S. Bhat	Second-Order Adjoint Method for Quantum Optimal Control
Sofiane Chalal and Nina Amini	Unravelling Mean-field Lindblad Equation
Chen Jiang, Yixin Xuan, Shuai Wan, Biheng Liu, Xiaomin Hu, Chunhua Dong, Qinmin Yang and Yu Pan	Frequency-locked Si3N4 Microring for Doppler Frequency Shift Detection

Poster Information

No.	Authors	Title
1	Hélène Canot, Philippe Durand and Emmanuel Frenod	Attempt to Predict Violent Meteoric Phenomena Using a Quantum Neural Approach.
2	Ronghan Zhang, Zexuan Wang, Kin Tung Michael Ho, Nigel J.D. Graham, Giin-Yu Amy Tan and Po-Heng Henry Lee	Application of the Harrow-Hassidim-Lloyd (HHL) Algorithm for Simulating a Novel Renewable Energy Production Pathway in Bioenergy Systems
3	Robert De Keijzer, Luke Visser, Oliver Tse and Servaas Kokkelmans	Fidelity-Enhanced Variational Quantum Optimal Control
4	Klemens Katterbauer, Saleh Komies and Pranay Asthana	Quantum Feedback Networks for Enhancing Reservoir Water Control Management
5	Saleh Komies	Advancing Quantum-Enhanced Spectroscopy for Real-Time Characterization in Oil and Gas
6	Rebing Wu and Gong Cheng	Robustly Realizable Quantum Gates
7	Chunlin Yang, Hongmei Yao, Zexian Li, Zhaobing Fan, Guofeng Zhang and Jianshe Liu	Improved Sparse Structured Block Encoding with Low Subnormalization
8	Ximing Wang, Chengran Yang and Mile Gu	Variational Quantum Circuit Decoupling
9	Shibdas Roy	Efficient Learning of Arbitrary Single-Copy Quantum States
10	Anumita Mukhopadhyay, Shibdas Roy and Arun Kumar Pati	Unitality Conditions on Subsystems in Quantum Dynamics
11	Noureddine Rochdi, Rachdi Ahl Laamara and Mohamed Bennai	Digitized Quantum Rabi model in Deep Strong Coupling Regime
12	Varun Puram, K.M. George and Johnson Thomas	Block Encoding of Non-Unitary Matrices into Quantum Framework
13	Maël Bompais, Nina Amini and Clément Pellegrini	Large-Time Behavior and Feedback Stabilization of Quantum Trajectories beyond QND Measurements
14	Keyu Xiong, Tao Shang, Chenyi Zhang and Yuchen Liu	T-count Reduction Method Based on Proximal Policy Optimization
15	Wenlong Li, Xue Dong, Guofeng Zhang and Re-Bing Wu	Flying-Qubit Control of Path Integrals
16	Thomas Elliott, Mile Gu, Andrew Garner and Jayne Thompson	Quantum Adaptive Agents with Efficient Long-Term Memories
17	Guangpu Wu, Shibei Xue, Guofeng Zhang and Ian R. Petersen	Model Reduction for Linear Quantum Systems
18	Zexian Li, Xiao-Ming Zhang and Chunlin Yang	Binary Tree Block-encoding of Classical Matrix
19	Daoyi Dong, Liying Bao and Bo Qi	Non-Hermitian Quantum Sensing: Fundamental Bound, Optimisation and Robust Stability

20	Andreas Deutschmann-Olek	Dark Optical Levitation towards Delocalized Quantum States of Motion
21	Jin Zheng, Qing Gao and Maciej Ogorzałek	Approximate Quantum Amplitude Encoding with Parameterized Quantum Circuits
22	Yuting Zhu, Shibei Xue, Fangfang Ju and Haidong Yuan	Fundamental Limits of Quantum Gyroscopes based on Optomechanics-like Structure
23	Eram Taslima, Shyam Kamal and R. K. Saket	Rapid Parameter Estimation in Quantum Systems Using Observer-Based Technique
24	Eason Xie	Quantum Surrogate-Driven Image Classifier: A Gradient-Free Approach to Avoid Barren Plateaus
25	Shiromal Kumara, Jo Plested and Matt Woolley	Training Stochastic Physical Neural Networks Using Forward-Forward Algorithms
26	Tong Dou, Ethan Sigler, Gerard Milburn, David Petty, Jo Plested and Matt Woolley	Continuous-Time Learning with Stochastic Physical Neural Networks
27	João Marcos Cavalcanti de Albuquerque Neto and Guiherme Penello Temporão	Fraud Detection Using Quantum-Assisted Machine Learning Methods
28	Adrian F. Hernández-Borda and Hanz Y. Ramírez-Gómez	Influence of the Dephasing in the Input Bell States on the Realiability of the Quantum Key Distribution Protocol E91
29	Chenfeng Cao, Filippo Maria Gambetta, Ashley Montanaro and Raul A. Santos	Unveiling Quantum Phase Transitions from Traps in Variational Quantum Algorithms
30	Liang Yu, Shan Jin, Yinjie Wu and Xiaoting Wang	Efficient Circuit Design for Quantum Image State Preparation
31	Xue Dong and Rebing Wu	Flying-Qubit Gate Control with a Tunable Waveguide Coupler
32	Xinglei Yu, Xinzhi Zhao, Liangsheng Li, Xiao-Min Hu, Xiangmei Duan, Haidong Yuan and Chengjie Zhang	Toward Heisenberg Scaling in Non-Hermitian Metrology at the Quantum Regime
33	Jinghao Li and Rui Gao	The Quantum Kalman Decomposition: A Gramian Matrix Approach
34	Zhiyuan Dong	Linear Quantum Systems: Poles, Zeros, Invertibility and Sensitivity
35	Xianli Yin, Wenbin Luo and Jieqiao Liao	Non-Markovian Disentanglement Dynamics in Double-Giant-Atom Waveguide-QED Systems
36	Xiaozhen Ge and Shuming Cheng	Unifying Triangle Relations and Geometric Measures for Tripartite Entanglement

Pierre Rouchon
Centre Automatique et Systemes at Mines-Paris, Université PSL

Title: Quantum Feedback Engineering, Bosonic Codes and Quantum Error Correction

Abstract: Quantum error correction relies on a feedback loop. This feedback generally corresponds to a classical controller. Quantum error correction can also exploit the dissipation associated with the phenomenon of decoherence. Called autonomous correction by physicists, it then uses feedback where the controller is a dissipative quantum auxiliary system. This talk focuses on the development of such quantum controllers to stabilize logical qubits encoded in harmonic oscillators (bosonic code). Two types of encoding will be considered: cat-qubit encoded in two coherent states of opposite phases for which bit-flip errors induced by usual noises can be experimentally almost suppressed; GKP-qubit encoded in finite energy grid-states approximating position/impulsion Dirac combs where, in principle, both bit-flips and phase-flips could be almost suppressed.

Bio: Pierre Rouchon is professor with the Centre Automatique et Systemes at Mines-Paris, Université PSL and member of the French Academy of Sciences. He graduated from Ecole Polytechnique in 1983, has obtained a PhD in 1990 and an "habilitation à diriger des recherches" in 2000. From 1993 to 2005, he was associated professor at Ecole Polytechnique in Applied Mathematics. From 1998 to 2002, he was the head of the Centre Automatique et Systèmes. From 2007 to 2018, he was the chair of the department "Mathématiques et Systèmes" at Mines-Paris. Since 2015, he is a member of the Quantic Research team between Inria, Ecole Normale Supérieure de Paris and Mines-Paris. His fields of interest include nonlinear control and system theory with applications to physical systems. His contributions include differential flatness and its extension to infinite dimensional systems, non-linear observers and symmetries, quantum filtering and feedback control. In 2017, he received the "Grand Prix IMT-Académie des sciences de Paris." He is the principal investigator of the ERC Advanced Grant "Quantum Feedback Engineering" (2021-2026).

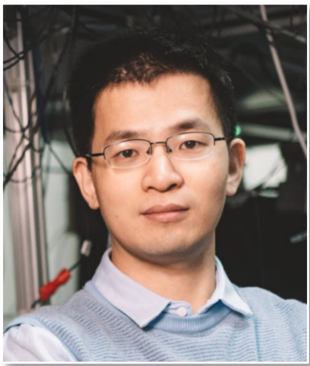
Howard Wiseman
Griffith University

Title: Quantum State Smoothing: Theory and Experiments

Abstract: For a classical system subject to random forces, and monitored imperfectly (i.e. yielding a noisy measurement record) the optimal way to estimate its true state at a certain time t is by smoothing. This means making use of the measurement record obtained both before t and after t. Generalizing this idea to the quantum domain is not straightforward because of the non-commutation of system operators at time t with future (after t) measurement records. However, we can define a smoothed quantum state [1] by considering a quantum system coupled to two environments, observed respectively by Alice and Bob. The "true" state of the system given Alice's and Bob's records is, under some assumptions, pure. But say Alice does not have access to Bob's noisy record – then she cannot know the true state. But she can better estimate the true state of the system at time t if she uses her record in the future of t as well as the past. I will overview the theory and discuss insights obtained over the last 10 years (including the impact of different types of measurements by Bob, linear Gaussian systems, and cases where one would expect classical smoothing to work) as well as unpublished experiments in quantum optics and optomechanics.

[1] Guevara and Wiseman, Phys. Rev. Lett. 115, 180407 (2015).

Bio: Professor Howard Wiseman is an Australian theoretical quantum physicist, best known for his work in quantum information, quantum foundations, and quantum measurement and control. After completing his PhD at the University of Queensland in 1994, he did a postdoc at the University of Auckland before returning to Queensland in 1996. He has been at Griffith University since 1999, and was Director of the Centre for Quantum Dynamics there for 18 years. Wiseman has won several Australian medals and prizes for his physics research, and led the team that won the 2023 Ehrenfest Award for Quantum Foundations from the Österreichische Akademie der Wissenschaften. He has been elected a Fellow of the Australian Academy of Science, the American Physical Society, and the Optical Society of America.



Chaoyang Lu
University of Science and Technology of China (USTC)

Title: From Science-for-QC to QC-for-Science

Abstract: I will go through our recent efforts in my group using photons and atoms to build increasingly large-scale quantum computers and, in turn, how these early quantum computers can already be used for studies of fundamental problems in mathematics, quantum physics, and condensed matter physics. We use the protocol of Gaussian boson sampling to demonstrate quantum computational advantage, with up to 3050 detected photons [Zhong et al. Science 2020, PRL 2021, Deng et al. PRL 2023]. We develop an AI-enabled constant-time-overhead rearrangement protocol to prepare a 2024 defect-free atomic array [Lin et al. 2024]. Using a single atom trapped in an optical tweezer and cooled to the motional ground state in three dimensions, we faithfully realize the Einstein-Bohr recoiling-slit gedankenexperiment tunable at the quantum limit [Zhang et al. 2024]. Based on a bottom-up quantum engineering approach, we experimentally created the fractional quantum Hall state using strongly interacting photons [Wang et al. Science 2024]. We further use the quantum computing platform to rule out a real-value description of standard formalism of quantum theory [Chen et al. PRL 2022].

Bio: Chao-Yang Lu is a Chair Professor in Physics at the University of Science and Technology of China (USTC). He completed his BS and PhD degrees at the USTC and the University of Cambridge in 2011. He has been appointed as the Deputy Director of the Shanghai Center for Quantum Sciences and as the Executive Director of the Quantum Computing Division at the Hefei National Laboratory since 2022. His current research interest includes quantum computation, solid-state quantum photonics, quantum teleportation, superconducting circuits, and atomic arrays. He is the author of over 160 papers in major research journals which have attracted >32000 citations. His work has been selected as by *Physics World* as "Breakthrough of the Year" in 2015, by APS *Physics* as one of the top ten "Highlights of the Year" in 2021 and 2022, and by UNESCO as "World's top 10 digital innovation technologies" in 2021. He is an OSA/Optica/APS Fellow, and a recipient of the EPS Fresnel Prize, AAAS Newcomb Cleveland Prize, Nishina Asian Award, IUPAP-ICO Young Scientist Prize in Optics, OSA Adolph Lomb Medal, APS Rolf Landauer and Charles H. Bennett Award in Quantum Computing, CLEO James P. Gordon Memorial Speakership, and OCPA Achievement in Asia Award. He serves as the Divisional Associate Editor for Physical Review Letters, and recent appointed as the Chairman of World Association of Young Scientists.

Guoyong Xiang
University of Science and Technology of China

Title: Control-enhanced Quantum Precision Measurement

Abstract: One of the primary driving forces in science and technology is the pursuit of the highest achievable measurement precision, which is fundamentally limited by Heisenberg's uncertainty principle. Previous theoretical and experimental studies have shown that this fundamental limit can be reached for single-parameter estimation. However, in most practical applications, multiple parameters typically require estimation, and noise cannot be ignored. In this talk, we will show that quantum control enables us to achieve the highest possible precision simultaneously for two or three parameters, mitigate the negative effects of noise, and enhance measurement accuracy.

Bio: Dr. Guoyong Xiang is a full professor at University of Science & Technology of China. Dr. Xiang received his Ph.D. degree in optics from USTC, in 2005. After that, he worked as a post-doctor in USTC. From 2007-2010, Dr. Xiang worked as a research fellow at center for quantum dynamics in Griffith University. Since 2010, he joined USTC as a faculty. His research focuses on quantum enhanced precision measurement and quantum sensing. He has published over 90 research papers in prestigious journals such as Nat. Phys, Nat. Photonics, Nat. commun., Sci. Adv., and PRL.

Christiane Koch
Free University of Berlin

Title: Training Schrödinger's Cat: A Physicist's Perspective on Quantum Control

Abstract: Quantum control has matured significantly over the past two decades, thanks to the challenges put forth by the emergence of quantum technologies. The quantum control toolbox can now be used routinely to derive protocols for quantum gates or state preparation but also to identify fundamental performance bounds. After showcasing this with a few examples, I will therefore focus on a new and perhaps unexpected way to utilize quantum control theory: I will show how to leverage controllability analysis for quantum device design, minimizing resource consumption for both unitary quantum circuits and measurement-induced dynamics.

Bio: Christiane Koch studied physics at the Humboldt University Berlin and, thanks to a one-year Fulbright scholarship, at the University of Texas at Austin, in the 1990s. Originally inspired to pursue physics by chaos theory, she eventually made her way into quantum physics, via a PhD at the Fritz-Haber-Institute Berlin where she applied open quantum systems' theory to a problem in surface science. This project required "willingness to travel", and Christiane happily commuted between Berlin and Jerusalem where Ronnie Kosloff at the Hebrew University became her second PhD mentor. The focus of her postdoctoral work, carried out with Francoise Masnou at Laboratoire Aimé Cotton in Orsay near Paris and Ronnie Kosloff in Jerusalem, was the coherent control of cold collisions and photo association. Realizing that molecular physics methods should also be useful for quantum information science, Christiane combined the two fields after her return to Germany with a DFG-funded Emmy Noether research group. When Christiane became a professor of theoretical physics at the University of Kassel in 2010, she was proud to have achieved this without going through the traditional German habilitation process. Her current research interests can still be roughly separated into molecular physics and quantum information science, with focuses on chiral molecules and cold and controlled reactions on one hand and optimal control for the quantum technologies on the other hand. Christiane has been a professor for theoretical physics at the Free University of Berlin since 2019.

Mile Gu
Nanyang Technological University

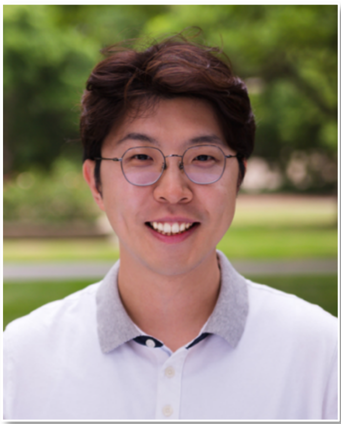
Title: Introducing Quantization^2: Quantum-enhanced Quantization in Predictive Modelling and Its Operational Benefits in Near Future Devices

Abstract: The last decade has seen the unprecedented growth of AI models, deployed in situations of ever-growing complexity. The complexity of such models grows in tandem, with memory and energy costs growing exponentially at unsustainable rates. The need to curtail such growth – especially during inference – has motivated multiple means for model reduction. Model quantization – the use of lower precision floats – represents one prominent approach.

Of course, despite its name, model quantization is purely a classical method. Could quantum technologies further enhance classical quantization?

In this talk, I survey work at the Nanyang Quantum Hub that illustrates how quantum mechanics may help us better isolate the causes of natural things. I show how this allows us access to quantum-enhanced means model reduction, resulting in a framework for quantum-enhanced quantization (quantization^2). I show how this enables us to drastically reduce the resources needed for simulation, prediction, and risk analysis – enabling performance levels impossible with classical machines with similar resource requirements. I then discuss how such technologies can merge with current quantum amplitude estimation methods, enabling significantly reduced technological barriers for quantum-enhanced risk analysis and Monte Carlo methods to be performed in near-future quantum devices.

Bio: Mile Gu is presently associate professor and deputy director of the Nanyang Quantum Hub at Nanyang Technological University. Prior to his current position, Gu grew up on Waiheke Island New Zealand, obtained his Ph.D. from the University of Queensland in 2009 and spent 3 years as faculty the Institute of Interdisciplinary information sciences at Tsinghua university. He currently leads the quantum and complexity science initiative under a 3 million project on quantum-enhanced agents. He is also fellow of the Centre for Quantum technologies, invited member of the Foundational Questions Institute and principal investigator of the French-Singapore joint institute Majulab. Gu's previous accolades include the National Research Foundation Fellow, the Young China 1000 talent, and was also winner of the 2020 IBM Quantum Pitch Contest and the National Research Foundation Investigator.



Joonhee Choi
Stanford University

Title: Benchmarking and Noise Learning in Large-scale Quantum Devices

Abstract: Rapid advances in quantum technologies are bringing large-scale quantum devices closer to practical reality, paving the way for real-world applications beyond proof-of-concept demonstrations. A major challenge, however, is verifying how accurately these systems prepare target quantum states, especially since traditional benchmarking techniques often require fine-tuned control and substantial experimental overhead. In this talk, I will introduce a simple and efficient benchmarking protocol that estimates fidelity using only native Hamiltonian evolution and fixed-basis projective measurements. This approach leverages a universal property of strongly interacting quantum systems: the emergence of many-body chaos, which randomizes information in a way that can be harnessed for fidelity estimation. We demonstrate the protocol experimentally on a Rydberg quantum simulator and validate it numerically across multiple platforms, including superconducting qubits, trapped ions, and optical lattices. Crucially, we find that benchmarking a high-fidelity Rydberg quantum simulator with up to 60 atoms already brings us into a regime beyond the reach of classical simulation. To quantitatively characterize the classical hardness of quantum simulation—and to clarify how far we are from practical quantum advantage—we develop and present a mixed-state entanglement proxy that enables cross-platform comparisons. Finally, I will introduce a new method for learning noise sources directly from measurement data in situ. Together, these benchmarking and noise learning tools provide a robust and scalable framework for evaluating and improving the performance of next-generation quantum devices.

Bio: Joonhee Choi is an Assistant Professor of Electrical Engineering at Stanford University. Joonhee received his Ph.D. and master's from Harvard University, as well as master's and bachelor's degrees from Korea Advanced Institute of Science & Technology. Prior to joining Stanford, he worked as an IQIM postdoctoral fellow at the Institute for Quantum Information and Matter (IQIM) at Caltech. Joonhee's research focus has been on engineering the dynamics of quantum many-body systems to explore fundamental science and demonstrate practical quantum applications. Throughout his career, he has worked in a wide variety of fields, including nonlinear nano-optics, ultrafast phenomena, solid-state and atomic physics, as well as quantum many-body physics. His expertise extends to practical applications in quantum metrology, communication, and information processing. Joonhee is the recipient of the Outstanding Young Researcher Award from the Association of Korean Physicists in America, the winner of the 2024 KSEA Young Investigator Grant in Science, and has been appointed as a Terman Faculty Fellow in the School of Engineering at Stanford.

Yuerui (Larry) Lu
The Australian National University

Title: 2D Quantum Materials for Next-Generation Quantum Photonic Devices

Abstract: Two-dimensional (2D) van der Waals quantum materials have become important building blocks for future electronic, photonic, phononic and quantum devices. The highly enhanced Coulomb interactions in the atomically thin quantum 2D materials, arising from the reduced dimensionality and weak dielectric screening, allows the formation of tightly bound excitons, biexcitons and interlayer biexcitons. These tightly bound quasi-particles have been of keen interest for both fundamental studies and novel device applications, such as entangled photon sources, quantum logic gates, etc. The recently discovered single photon emitters at room temperature from the defects in 2D hexagonal boron nitride could find promising applications for quantum sensing and quantum communications. Because of their ultra-light weight, defect-less surface and low intrinsic losses, atomically thin 2D materials are also perfect candidate materials for ultra-sensitive transducers for sensing and communication applications. In this talk, I would like to talk about how to tailor the van der Waals interactions and engineer the light-matter interactions in ultrathin quantum materials, for next-generation nano-photonic and quantum devices[1-3]. I will highlight our recent work on the discovery of new quantum phases from freestanding hetero bilayers[4,5], as well as the generation of entangled quantum light sources using ultra-thin nonlinear quantum materials[6,7]. Finally, I will talk about my vision and discuss some possible future directions regarding the photonic and quantum applications of novel 2D materials and their heterostructures.

Biography: Prof. Yuerui (Larry) Lu is a professor in School of Engineering at the Australian National University (ANU). He received his Ph.D. degree from Cornell University in 2012, and B.S. degree from University of Science and Technology of China. Professor Lu is currently the chief investigator and program manager at the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology. His research interests include 2D quantum materials and optoelectronic devices, MEMS sensors and actuators, quantum sensors, biomedical novel devices, etc. He has published 2 books (as editor), 7 book chapters, and more than 130 papers in high-impact journals, including Nature, Science, Nature Physics, etc. He was the recipient of several competitive awards, including the prestigious *Prime Minister's Prizes for*

Science - the *Malcolm McIntosh Prize for Physical Scientist of the Year* in 2023, *Pawsey Medal* from Australian Academy of Science in 2023, etc. He is an Optica Fellow (Former OSA) and an associate editor of *Optica*.

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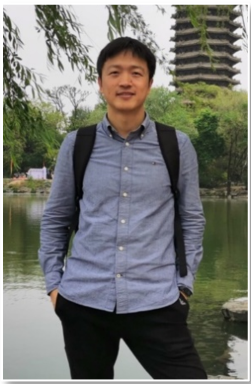
Hidehiro Yonezawa
RIKEN Center for Quantum Computing

Title: Development of Optical Quantum Computer at RIKEN

Abstract: In this talk, I will present an optical quantum computer developed at RIKEN. Our system is a measurement-based quantum computer that utilises continuous variables of electromagnetic field quadratures, i.e., an analog optical quantum computer. Compared to other quantum computing platforms, our approach has several advantages, including fast processing speed, high scalability, room-temperature operation, and compatibility with telecom technologies. The quantum computer employs four THz-bandwidth optical parametric amplifiers developed by NTT to generate squeezed vacuum states. These states are combined using a beam splitter network with optical delay lines to produce large-scale quantum entanglement in the time domain. Quantum computation is performed through sequential measurements on this entangled state with appropriate measurement angles. Our system enables liner transformations on 101 input modes at a clock frequency of 100 MHz. We also developed a cloud-based system with a software development kit, allowing external users to access the quantum computer with enhanced usability.

This work has been undertaken as a part of the Moonshot projects (Project manager: Prof Akira Furusawa) in collaboration with University of Tokyo, NTT, and Fixstars Amplify.

Bio: Hidehiro Yonezawa received his B.E. degree, M.E. degree and Ph.D. in Engineering at the Department of Applied Physics, the University of Tokyo, Japan, in 2002, 2004 and 2007, respectively. Upon completing his Ph.D., he was appointed as a Research Associate (2007-2009) and was later promoted to Project Assistant Professor (2009-2013) at the University of Tokyo. From September 2013 to June 2023, he served as a Senior Lecturer at the University of New South Wales Canberra. He also joined the Centre for Quantum Computation and Communication technology (CQC2T) as a Program Manager, where he worked from 2015 to 2023. In July 2023, he began his current position as a Team Leader at RIKEN Center for Quantum Computing. Through his career he has focused on experimental quantum optics, quantum information and quantum control.



Xiongfeng Ma
Tsinghua University

Title: Hybrid Quantum-classical Optimization of LOCC-assisted Circuits for Scalable Entanglement Generation

Abstract: Long-range entanglement is a cornerstone of quantum technologies, enabling applications from fault-tolerant quantum computing to topological order. However, its experimental realization is hindered by the need for deep quantum circuits, which amplify noise and resource demands. This talk introduces a hybrid quantum-classical framework that leverages Local Operations and Classical Communication (LOCC) to drastically reduce circuit depth while preserving entanglement structure. We present a variational algorithm that optimizes LOCC-assisted protocols through parameterized mid-circuit measurements and gradient-based training. Theoretically, we derive conditions under which our approach avoids barren plateaus, guaranteeing trainability even at scale. Numerically, we demonstrate high-fidelity preparation of long-range entangled states, including perturbed Greenberger–Horne–Zeilinger (GHZ) states and surface code ground states, achieving superior accuracy in energy estimation compared to conventional unitary circuits. Our method not only reduces experimental overhead but also establishes a theoretical pathway for scalable entanglement generation. By integrating quantum control with machine learning, this work bridges critical gaps in quantum resource optimization, offering practical tools for quantum error correction and programmable quantum devices. The results underscore the transformative potential of hybrid protocols in advancing quantum computing, control, and learning—core themes of this conference.

Bio: **Xiongfeng Ma** earned his B.Sc. degree from Peking University in 2003 and a Ph.D. from the University of Toronto in 2008. Currently, he is a Changjiang Distinguished Professor and vice dean of the Institute for Interdisciplinary Information Sciences at Tsinghua University. Xiongfeng is an APS Fellow and an Optica Fellow. Xiongfeng's primary research interest lies in quantum information science, particularly in quantum cryptography, quantum computing, and quantum foundation. According to the Scientometric Assessment of Global Publications from 1992 to 2019, Xiongfeng was one of the most productive researchers worldwide in quantum cryptography by ResearchGate.

Giulio Chiribella
University of Hong Kong

Title: Learning Quantum Systems with Deep Neural Networks

Abstract: Characterizing large quantum systems is notoriously a hard task, due to the exponentially increasing dimension of the underlying Hilbert space. Deep neural networks can provide valuable assistance in this task, by constructing compressed representations of the quantum states of interest. In this talk, I will review an approach developed my group, in which the key idea is to enable a neural network to build a miniature version of quantum theory, by forming its own representation of the quantum state space and its own version of the Born rule. In this approach, the network can be trained offline using classically simulated data from a fiducial set of states and measurements. After training, the network can be employed to characterize previously unseen quantum states from experimental data. In a number of cases, we show that the state representations generated by the network provide accurate predictions about several important properties of multipartite quantum states. In addition, these representations can be used to compare different states and to cluster them according to their representation-space similarity. Remarkably, we find that in certain cases the network even manages to transfer information learnt from lower dimensional quantum systems to higher dimensional ones.

Bio: Giulio Chiribella is a full professor and the director of QICI Quantum Information and Computation Initiative at the School of Computing and Data Science of The University of Hong Kong. His research interests cover quantum information theory and quantum foundations. In particular, he has done pioneering research on quantum causality, on the information-theoretic foundations of quantum theory, and on the ultimate precision limits of quantum measurements, for which he was awarded the Hermann Weyl Prize 2010. In 2020 and 2018 he received Senior Research Fellowships from the Hong Kong Research Grant Council (RGC) and from the Croucher Foundation, respectively. He currently serves as an elected member of the Hong Kong Young Academy of Sciences, a Young Member of the Hong Kong Academy of Engineering Sciences, a visiting professor at the University of Oxford, a visiting fellow of Perimeter Institute for Theoretical Physics, and as an Editorial Board Member of the journal Communications in Mathematical Physics. Before joining the University of Hong Kong, he held faculty positions at Oxford University and Tsinghua University, Beijing.

Z. Y. Ou
City University of Hong Kong

Title: Noise Reduction in Quantum Amplifiers by Feedback

Abstract: Quantum noise in the internal modes of an amplifier is responsible for the excess noise introduced to the amplifier's output, leading to degradation of the signal-to-noise in the output as compared to the input. Reduction of this noise requires manipulation of the internal modes from outside by preparing them in some special quantum states, among which quantum correlated states were recently used. On the other hand, amplifier's internal modes are also correlated to the output. So, by tapping part of the output and feeding back to the amplifier, we can achieve the same feat. We present a detailed study of this novel approach on different amplification platforms. The feedback is found to be phase-sensitive, thus forming an SU(1,1)-type of nonlinear interferometer. The feedback can also lead to onset of oscillation, making the interferometer active and self-sustained. Such a device should find applications in quantum sensing.

Bio: Professor Ou obtained his BS in 1984 from Peking University and Ph.D. in 1990 from University of Rochester. He is now a Chair Professor at the City University of Hong Kong. Professor Ou is an expert in quantum optics, especially in quantum interference, for which he is the co-inventor of the well-known Hong-Ou-Mandel two-photon interferometer and more recently the SU(1,1)-type of nonlinear quantum entangled interferometer. He pioneered the field of multi-photon interference, which he summarized in the monograph "Quantum Multi-Photon Interference" published by Springer in 2007. Professor Ou's current research focuses on quantum metrology, quantum sensing, quantum amplifier, quantum state engineering, quantum information and communication, and more fundamental quantum measurement and quantum coherence problems. Professor Ou is a fellow of American Physical Society and of Optica (formerly Optical Society of America). He is the Associate Editor of **Optica Quantum**.

Yuan Haidong
The Chinese University of Hong Kong

Title: Precision Limits and Tradeoffs for Multi-parameter Quantum Metrology

Abstract: Quantum metrology aims to achieve the highest precision in parameter estimation. While the ultimate precision limits for single-parameter estimation are well understood, practical applications in quantum sensing and quantum imaging often demand the simultaneous estimation of multiple parameters, for which the precision limits are much less clear. This is largely due to the inherent incompatibility of optimal estimation strategies for different parameters, which leads to tradeoffs for the precision of estimating different parameters. We will talk about these incompatibilities and their effects on the precision limits in multi-parameter quantum metrology.

Bio: Haidong Yuan received his B.E. in Electronic Engineering from Tsinghua University, Beijing, China, M.A. in Engineering science and Ph.D. in Applied Mathematics, both from Harvard University. He is currently an associate professor at the department of Mechanical and Automation Engineering, the Chinese University of Hong Kong. His research interests include quantum control, quantum metrology and quantum information science.

Session 1A (13:30-15:30, June 26, Venue: Z205)

Effects of white noise on superconducting qubit control pulses

Yuanzheng Paul Tan, Yung Szen Yap, Patrick Bore, Rangga Perdana Budoyo, Long Nguyen, Kun Hee Park and Rainer Dumke

Meaningful quantum computing is currently bottlenecked by the error rates of current generation Noisy Intermediate Scale Quantum (NISQ) devices. To improve the fidelity of the quantum logic gates, it is essential to recognize the contributions of various sources of errors, including background noise. In this work, we investigate the impact of the noise floor on superconducting qubit control pulses to observe the dependency of the gate fidelity with the signal-to-noise ratio (SNR). We propose a model on how the noise of the control electronics interacts with the qubit system and demonstrate a method for characterizing the noise environment of the qubit control.

An approach to control design for 2-level quantum ensemble systems

Ruikang Liang and Gong Cheng

Ensemble control -- the manipulation of a continuum of identical systems with parameter variations -- is pervasive in the realm of quantum control, with applications in NMR spectroscopy and robust quantum control. While numerous works have primarily focused on the ensemble controllability of bilinear ensemble systems, explicit control design for such systems remains largely unexplored. In this paper, we consider a continuum of driftless 2-level systems on SU(2) steered by two inputs: $iX'(t) = [\omega u(t)\sigma_x + \omega v(t)\sigma_y]X(t)$, $X(0) = \mathrm{Id}$, where σ_x and σ_y are Pauli matrices, and ω is a parameter in a small interval $[a, b] \subset \mathbb{R}_+$. If we recast the system in the interaction frame $\tilde{X}(t) = \exp(it\omega\sigma_x)$ and fix $u \equiv 1$, we obtain an ensemble system of $\tilde{X}(t)$ as $iX'(t) = \omega v(t)\left[\cos(2\omega t)\sigma_y + \sin(2\omega t)\sigma_z\right]\tilde{X}(t)$. Given the presence of the rotational terms with frequency 2ω in the interaction frame, we apply Fourier transform to construct an explicit control signal $v(\cdot)$ that uniformly approximates a final distribution of the form $\exp(-if(\omega)\sigma_y)$. A similar construction can be applied to uniformly approximate $\exp(-if(\omega)\sigma_x)$. We then show a control design strategy with rigorous mathematical proof for the aforementioned driftless 2-level ensemble system. Take a smooth function $\Theta(\cdot)$ from $[a, b]$ to SU(2), then for all $\epsilon > 0$, $n \in \mathbb{N}^*$ and $N \in \mathbb{N}^*$, we can construct bounded control signals $u(\cdot)$ and $v(\cdot)$ over $[0, N/\epsilon]$ steering the ensemble from the common initial state $X(0) = \mathrm{Id}$ to the final distribution $\Theta(\omega)$ with an uniform error of order $O(\epsilon^{n-1} + N^{-1}\epsilon^{-1})$. We also provide numerical experiments demonstrating our control design strategy.

Graybox quantum system identification and control

Ritik Sareen, Yule Mayevsky-Mattiaccio, Akram Youssry Mohamed and Alberto Peruzzo

Quantum technology promises huge prospects for a wide range of applications such as faster computation, secured communication, and precise sensing. Understanding and controlling engineered quantum systems is vital for future development of these technologies. This process is often challenging due to technological limitations, fabrication imperfections and uncertainties such as environmental noise. Many analytical and numerical methods have been proposed over the years to tackle these issues. However, these methods work usually under some assumptions on the noise and/or the control. Here, we propose a generic hybrid "Graybox" approach which uses machine learning "Blackbox"

structures to model the physical quantities prone to uncertainties along with "Whitebox" structures that encode quantum mechanical laws. The model is trained using a dataset constructed as random set of control pulses and the corresponding informationally-complete measurement outcomes. The trained model can then be utilized within an optimization loop to find the optimal control pulses that can achieve high-fidelity quantum gates.

We apply the proposed method experimentally to photonic integrated circuits [1, 2], usually modelled as closed quantum systems. We also demonstrate the approach to open quantum systems subject to non-Markovian classical [3] and quantum noise [4], including the challenging strong-coupling regime, where the perturbative expansions that are foundational to many methods would be intractable to compute. In all these settings, this approach has yielded high fidelity and enabled obtaining physical insights into the system beyond standard blackbox architectures.

Robust control landscape for parameterized quantum gate against time-varying noise

Zigui Zhang and Zibo Miao

The progress of quantum computing is currently hindered by the extreme sensitivity of quantum gates to environmental noise. Although numerous robust control algorithms have been developed to mitigate these noise effects, they often face inherent limitations. In this context, the robust control landscape methodology emerges as a valuable complement. The goal of robust control landscape is to identify more suitable solutions through a set of initial configurations while maintaining both the control objective and robustness.

However, current implementations of robust control landscape only consider quasi-static noise models in dynamical systems, which are insufficient to address time-varying noise. Inspired by filter function theory that quantitatively measures the impact of time-varying noise on quantum gate performance, we overcome this limitation by integrating filter function into robust control landscape optimization.

Through numerical simulations involving parameterized Rx rotation gates, we demonstrate that our method effectively maintains robustness against time-varying noise while preserving fidelity. This work extends the applicability of robust control landscape to time-varying noise scenarios, thereby providing new insights for practical implementations in quantum control systems under time-varying noise conditions.

Receding horizon control for quantum metrology with continuous measurements

Henrik Glavind Clausen and Rafal Wisniewski

In quantum metrology, the aim is to estimate parameters with a precision that outperforms classical strategies, typically quantified in terms of the (quantum) Fisher information. In this work, we consider the problem of designing a feedback control law to enhance the Fisher information along individual stochastic trajectories of a continuously monitored quantum system. As a prototypical example, we consider parameter estimation in a single bosonic mode controlled via a squeezing Hamiltonian while subject to continuous homodyne detection. Since such a system admits a linear Gaussian representation, it allows for tractable numerical algorithms. To solve the problem, we propose a receding horizon approach, where a small optimization problem is solved at each control step based on the latest estimate of the state and parameter. As a benchmark, we formulate the stochastic optimal control problem for maximizing the Fisher information and subsequently solve it via a numerical solution to the corresponding Hamilton-Jacobi-Bellman (HJB) equation.

Numerical simulations show that the receding horizon control significantly improves the Fisher information along individual trajectories compared to open-loop strategies, although the performance is still worse than the benchmark HJB solution.

Optimal splitting of Bose-Einstein Condensates

Andreas Deutschmann-Olek

Ultra-cold atoms provide a powerful platform for experimentally exploring quantum many-body systems. In particular, the magnetic trapping potentials of AtomChips allows for reliable manipulation of the atom cloud such as the transversal splitting of a single elongated quasi-1D systems into two. On an AtomChip, this splitting is accomplished by radio-frequency (RF) controlled double-well potentials and can be controlled by the amplitude of the RF field. Such coherent splitting operations and their inherent quantum noise are key to many experiments in quantum science and quantum metrology such as matter wave interferometry.

Splitting an atomic Bose-Einstein condensate dynamically usually introduces unwanted excitations. To ensure the system remains close to the ground state of the final double-well potential, one can either transition very slowly—an impractical approach for systems with limited coherence time—or leverage the system's inherent nonlinearities to achieve a so-called shortcut to adiabaticity. The latter is typically implemented by solving an optimal control problem, which requires an accurate model of the system's dynamics. However, capturing experimental potential landscapes like the double-well potential from limited measurement data presents a significant challenge.

In this talk, we present a structured approach to achieve splitting of a Bose-Einstein condensate with minimal excitations of its mean-field dynamics in experiments. First, we introduce a simplified physics-based description of the potential landscape, which can be calibrated using measurement data. Next, we discuss strategies for determining sets of identification data to calibrate the model with minimal amounts of data. Based on the identified system dynamics, we derive optimal state transitions close to the fundamental speed limit that minimize unwanted excitations. Finally, we present experimental results that validate the proposed approach.

Session 1B (13:30-15:30, June 26, Venue: Z207)

Adaptive quantum autoencoders with mixed reference states

Hailan Ma, Ian R Petersen and Daoyi Dong

Quantum autoencoders (QAEs) lie at the heart of quantum information processing. Generally, a QAE consists of an encoder that compresses high-dimensional input states into latent states and trash states, which can be discarded, and a decoder that reconstructs the original state using the combination of latent states and reference states. The goal of a QAE is to maximize the fidelity between the trash state and the reference state (i.e., the encoding fidelity) or the fidelity between the recovered state and the original state (i.e., the decoding fidelity).

When choosing the reference state to be pure, there exists an upper bound for the encoding fidelity, which is determined solely by the eigenvalues of the density matrix representation of the input states, regardless of the specific reference state. For states whose rank is not greater than the latent dimension, the upper bound of the encoding fidelity can reach 1. However, when compressing high-rank states, e.g., states with high entropy, this upper bound limits the optimal value of the encoding fidelity and thereby restricts the decoding fidelity.

To overcome this challenge, we allow the reference state to be a mixed state that can be adaptively updated to compensate for the entropy inconsistency between the input states and the recovered states. Specifically, we consider the reference states to be a mixture of maximally mixed states and pure states and propose three strategies for setting the mixedness ratio to achieve a high compression rate. Numerical and experimental results on different states illustrate the effectiveness of our approach.

A retrodictive approach to quantum state smoothing

Mingxuan Liu, Valerio Scarani, Alexia Auffèves and Kiarn Laverick

Smoothing is a technique for estimating the state of an imperfectly monitored open system by combining both prior and posterior measurement information. In the quantum regime, current approaches to smoothing either give unphysical outcomes, due to the non-commutativity of the measurements at different times, or require assumptions about how the environment is measuring the system, which with current technology is unverifiable. We propose a novel definition of the smoothed quantum state based on quantum Bayesian retrodiction, which mirrors the classical retrodictive approach to smoothing. This approach always yields physical results and does not require any assumption on the environment. We show that this smoothed state has, on average, greater purity than the state reconstructed using just the prior information. Finally, we make a connection with the smoothing theory of Guevara and Wiseman in a well-studied regime, and describe from a purely quantum perspective how it conditions on the posterior information.

Decomposition of the Hilbert space of a continuous quantum dynamical semigroup

Nicolas Mousset and Nina Amini

The mean evolution of an open quantum system in continuous time is described by a time continuous semigroup of quantum channels (completely positive and trace-preserving linear maps). Baumgartner and Narnhofer presented a general decomposition of the underlying Hilbert space into a sum of invariant subspaces, also called enclosures. We propose a new reading of this result, inspired by the work of Carbone and Pautrat. In addition, we apply this decomposition to a class of open quantum random walks and to quantum trajectories, where we study its uniqueness.

Estimation of quantum states and dynamical parameters given past and future information

Qi Yu, Kiarn Laverick, Daoyi Dong and Howard Wiseman

This project develops a hybrid quantum-classical smoothing framework for the simultaneous estimation of quantum states and time-varying classical parameters in dynamical quantum systems. Traditional approaches often neglect parameter uncertainties or fail to leverage future measurements, limiting their practical effectiveness. By extending quantum smoothing theory through Bayesian inference, we derive generalized filtering and smoothing equations that accommodate both static and dynamic parameters while addressing non-commutativity challenges. The key contributions of this work are: 1) Development of a hybrid smoothing framework that jointly estimates quantum states and unknown dynamical parameters. 2) Derivation of generalized filtering and smoothing equations for both quantum states and dynamical parameters, with a detailed analysis of

Gaussian systems. 3) Numerical validation using an Optical Parametric Oscillator (OPO) system, demonstrating the effectiveness of the proposed methods. We evaluate performance using relative purity recovery (RPR) for quantum state estimation and relative variance recovery (RVR) for dynamical parameter estimation. The results show that smoothing improves quantum state purity by up to 18% compared to filtering, while reducing the variance of the estimated parameter by up to 35%.

Real matrices larger than a complex matrix: applications to Gaussian quantum information processing

Shan Ma, Yuchen Xiong, Lihan Zhou and Shibei Xue

In this paper, we investigate the set of real symmetric matrices that are larger than a given Hermitian matrix in the semidefinite order, with particular attention to its minimal element. We explore the applications of this result in Gaussian quantum information processing. Furthermore, we propose potential research directions, especially the extension of this result to the set of real symmetric matrices that are larger than multiple given Hermitian matrices. These topics are of interest in both matrix theory and quantum information processing.

Imperfection analyses for random-telegraph-noise mitigation using spectator qubits

Yanan Liu, Areeya Chantasri, Hongting Song and Howard Wiseman

Qubit decoherence from environmental noises is one of the major obstacles to building useful larger-scale quantum computers. Spectator qubits (SQs) for random-telegraph noise mitigation have been proposed by Song et al. [1,2], where an SQ operates as a noise probe to estimate optimal noise-correction control on the hard-to-access data qubits. By assuming that the SQ is affected by the RTP in the same way as the DQ, but with much greater noise sensitivity, $\ks\gg \kd$ (where $\ks$ and $\kd$ are noise sensitivities of the SQ and the DQ, respectively), the Map-based Optimized Adaptive Algorithm for the Asymptotic Regime (MOAAAR) was proposed. This algorithm specifies how frequently one should measure the SQ, what basis to measure in at those times, and what correction to implement on the DQ to globally optimize its decoherence rate.

However, the protocol's practicality in real-world scenarios remained in question due to various sources of imperfection that could affect the performance. In this work, we analyze the proposed adaptive protocol under non-ideal conditions, including parameter uncertainties in the system, efficiency and time delay in readout and reset processes of the SQs, and additional decoherence on the SQs [3]. We also explore analytical methods of Bayesian estimation in the time domain and generalize the map-based formalism to non-ideal scenarios. This allows us to derive imperfection bounds at which the decoherence suppression remains approximately the same as under ideal conditions.

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Session 2A (16:30-18:30, June 26, Venue: Z205)

Designing the C_k phase gate family for the Rydberg atom architecture through the Magnus expansion

Raul Santos and Servaas Kokkelmans

Quantum gate design has tremendously improved over the past few years from the discovery of new numerical methods, which has led to faster and more robust gates, effectively decreasing the depth of near-term quantum circuits. These advances are especially important for the Rydberg atom quantum computing architecture, since the efficacy of their operation is entirely dependent on the number of entangling gates, which can be reduced using specialized multi-qubit gates. In this work, we propose a novel approach to design multi-qubit gates and demonstrate its application on the C_kPhase gate family for the Rydberg atom quantum computing architecture. The method relies on the Magnus expansion to obtain the Lie-algebraic structure of the tunable physical Hamiltonian, yielding an analytical way to tune the effective Hamiltonian generated from a time-varying pulse. With the right lattice geometry and blockade range, we show that the Lie algebra of the problem is equivalent to su(2), reducing the many qubits quantum gate design problem to single qubit gate design. Finally, we obtain conditions for time optimality of the C_kPhase gate designed this way, and compare it with the state-of-the-art.

Generation and control of non-classical microwave photon/phonon fields

Zhihui Peng

Non-classical microwave and acoustic fields have important applications in quantum computing, quantum network, and quantum sensing. Superconducting quantum circuits based on Josephson junctions, due to their excellent quantum nonlinearity, are particularly suitable for the generation, manipulation, and measurement of non-classical microwave and acoustic fields. We will introduce some progress in these fields, as well as our research in this direction, aiming to meet the development of superconducting quantum computing and quantum information technology.

Routine qubit calibration in a compute cluster environment using Qibocal

Yuanzheng Paul Tan, Christoph Hufnagel, Stefano Carrazza and Rainer Dumke

As deployment of superconducting qubit based quantum computers become increasingly widespread, integration with traditional high-performance computing (HPC) clusters are starting to appear. Multiple users will take turns to submit jobs to be run on said Quantum Processing Units (QPUs). However, a period of compute time is needed to be reserved to calibrate the QPU to guarantee that the control parameters are optimized for high fidelity quantum logic gate operations. Said calibration time competes with user time, and a balance needs to be struck to ensure good availability and high gate fidelity. In this work, we investigate the outcomes of using different qubit monitoring and calibration routines on QPUs hosted by the National Quantum Computing Hub (NQCH) using Qibocal, an open-source qubit calibration library.

Efficient isotope-selective ablation loading of a one-dimensional ion crystal into a four-rod electrode trap

Ying Zheng, Jianwei Zhang, Yiting Chen, Shengnan Miao, Wenxin Shi, Shuotian Chen, Haijun Chen and Lijun Wang

Ytterbium is one of the best choice for performing quantum manipulation based on a trapped-ion system. We report an efficient isotope-selective loading method using an Q-switched pulsed laser operating at a wavelength of 532 nm to ablate neutral atoms combined with a photo-ionization process, which can realize one-dimensional Yb+ ion chain collection in seconds. Compared to the thermal oven method, this approach improved the ion-load efficiency by twenty times, reduces the thermal heating effect and pollution to the vacuum chamber, which is more conducive to performing operations on the ions.

Spectral characterization of a superconducting transmon qubit with Fourier transform noise spectroscopy

Snehal Mandal, Biplab Biswas, Ayan Kumar Ghosh and Bhupendra N Dev

Local environment surrounding a quantum processor and random processes in the qubit control and measurement equipment are sources of noise that lead to qubit decoherence and reduce the operational fidelity of the qubits. Qubit noise spectroscopy is a valuable tool for both the characterization of a qubit's environment and as a precursor to more effective qubit control to improve qubit fidelities. While dynamical decoupling offers one of the most successful approaches to characterize noise spectra, it necessitates applying large sequences of π pulses that increase the complexity and cost of the method. Recently, a noise spectroscopy method has been introduced that utilizes only the Fourier transform of free induction decay or spin echo measurements [1], thus removing the need for the application of many π pulses.

In this talk we will first describe the measurement set up that we recently established at our Centre for measurements on superconducting quantum circuits and various characterizations of superconducting qubits, such as longitudinal (T1) and transverse (T2) relaxation times, Ramsey interferometry, Hahn echo, qubit-cavity interaction strength etc. Our effort is to develop a superconducting quantum computer. This requires error-resilient quantum control techniques as well as development of superior materials for enhancing qubit decoherence time [2]. We present our early results on the characterization of the noise spectrum for our transmon qubit from Ramsey and Hahn echo measurements, employing the Fourier transform noise spectroscopy method as described in [1].

[1] Arian Vezvaee, Nanako Shitara, Shuo Sun and Andrés Montoya-Castillo, njp Quantum Information (2024) 10:52

[2] Snehal Mandal, Biplab Biswas, Suvankar Purakait, Anupam Roy, Biswarup Satpati, Indranil Das and B. N. Dev, arXiv:2412.19493v1 (27 Dec 2024)

Experimental Quantum Reservoir Computing with Spin Systems

Zhaokai Li

Quantum reservoir computing (QRC) has emerged as a promising neuromorphic computing paradigm, leveraging high-dimensional quantum dynamics for temporal information processing. However, current experimental implementations have yet to fully exploit its potential due to circuit infidelity and limited readout. We proposed a spin-based QRC framework that harnesses natural spin coupling evolution to achieve dissipative quantum dynamics, reducing complexity and errors from external control. To enhance quantum state space utilization, we implement time-multiplexing for readout, improving the performance and scalability of the reservoir. By utilizing a 9-spin quantum system, our results achieve the state-of-the-art performance of quantum reservoir computing in the experiment, which has a 1–2 orders of magnitude reduction in error on the benchmarking task compared to prior implementations. In long-term weather forecasting, our QRC model significantly outperforms classical reservoirs with thousands of computational nodes, showcasing a potential quantum advantage achievable with current technology.

Session 2B (16:30-18:30, June 26, Venue: Z207)

Heisenberg-limited quantum metrology without ancilla

Qiushi Liu and Yuxiang Yang

Extensive research has been dedicated to the asymptotic theory of quantum metrology, where the goal is to determine the ultimate precision limit of quantum channel estimation when many accesses to the channel are allowed. The ultimate limit has been well established, but in general noiseless and controllable ancilla is required for attaining it. Little is known about the metrological performance without noiseless ancilla, which is more relevant in practical circumstances. In this work, we present a novel theoretical framework to address this problem, bridging quantum metrology and the asymptotic theory of quantum channels. Leveraging this framework, we prove sufficient conditions for achieving the Heisenberg limit with repeated applications of the channel to estimate, both with and without applying interleaved unitary control operations. For the latter case, we design an algorithm to identify explicitly the control operation.

Quantum state tomography via Kirkwood-Dirac quasiprobability

Xiang Li, Yong Wang, Lijun Liu, Yiguang Hong and Shuming Cheng

Quantum state tomography (QST) is essential in quantum science and technology, but remains challenging due to the increasing measurement resources and computational complexity scaling exponentially to the size of quantum systems. Here, we establish the tomography framework based on Kirkwood-Dirac (KD) quasiprobability. In particular, the KD quasiprobability distribution is fed as input data to the state estimator and hence to yield the final estimate state, consuming much less measurement settings (reduced from approximately 3^d for d-dimensional systems with the Pauli basis to only 2 settings). It is experimental friendly that the experimental procedures are significantly simplified by avoiding exponential configuration changes.

Furthermore, several efficient state estimators are tailored to deal with the KD quasiprobability. One is the maximum likelihood estimator (MLE), together with gradient-based algorithms that the gradient computation requires only subtraction, thus improving numerical stability and convergence speed. Numerical tests confirm that it converges within approximately 10 iterations, compared to 1e3-1e4 iterations required by traditional methods. The second is the linear-inversion estimator (LIE) that replaces computationally intensive pseudoinverse operations with efficient matrix additions, surpassing the Pauli basis method. The third is the least-squares estimator (LSE), which is naturally compatible with quasiprobability data. This estimator is well-suited for incorporating prior knowledge about the target state and demonstrates robustness against Gaussian noise.

Extensive numerical simulations are implemented to validate the proposed framework. Notably, we achieve a full reconstruction of random 14-qubit mixed states within 3 minutes using MLE with high fidelity, and random 15-qubit mixed states in just 2 minutes with LIE, and approximately 1 hour using LSE—representing, to our knowledge, the largest-scale experimental demonstrations for all three estimators. Overall, our KD-based quantum tomography framework provides a novel, efficient approach for QST, paving the way for scalable characterization of large quantum systems.

Simultaneous measurement of multiple incompatible observables and tradeoff in multiparameter quantum estimation

Hongzhen Chen, Lingna Wang and Haidong Yuan

How well can multiple incompatible observables be implemented by a single measurement? This is a fundamental problem in quantum mechanics with wide implications for the performance optimization of numerous tasks in quantum information science. While existing studies have been mostly focusing on the approximation of two observables with a single measurement, in practice multiple observables are often encountered, for which the errors of the approximations are little understood. Here we provide a framework to study the implementation of an arbitrary finite number of observables with a single measurement. Our methodology yields novel analytical bounds on the errors of these implementations, significantly advancing our understanding of this fundamental problem.

Additionally, we introduce a more stringent bound utilizing semi-definite programming that, in the context of two observables, generates an analytical bound tighter than previously known bounds. The derived bounds have direct applications in assessing the trade-off between the precision of estimating multiple parameters in quantum metrology, an area with crucial theoretical and practical implications.

To validate the validity of our findings, we conducted experimental verification using a superconducting quantum processor. This experimental validation not only confirms the theoretical results but also effectively bridges the gap between the derived bounds and empirical data obtained from real-world experiments. Our work paves the way for optimizing various tasks in quantum information science that involve multiple noncommutative observables.

Limitations of quantum advantage in unsupervised machine learning

Apoorva Patel

Machine learning models are used for pattern recognition analysis of big data, without direct human intervention. The task of unsupervised learning is to find the probability distribution that would best describe the available data, and then use it to make predictions for observables of interest. Classical models generally fit the data to Boltzmann distribution of Hamiltonians with a large number of tunable parameters. Quantum extensions of these models replace classical probability distributions with quantum density matrices. An advantage can be obtained only when features of density matrices that are absent in classical probability distributions are exploited. Such situations depend on the input data as well as the targeted observables. Explicit examples are discussed that bring out the constraints limiting possible quantum advantage. The problem-dependent extent of quantum advantage has implications for both data analysis and sensing applications.

Strategic codes: The universal spatio-temporal framework for quantum error-correction

Andrew Tanggara, Mile Gu and Kishor Bharti

The susceptibility of quantum systems to noise hinders a scalable quantum computational speed-up, highlighting the need for quantum error-correcting codes (QECC). The emerging paradigm of dynamical QECC has revealed a plethora of possibilities on temporal noise-resilient encoding of quantum information through a sequence of operations, as opposed to a fixed spatial many-body encoding in conventional static QECCs. Although it has lead to progress in our understanding of error-correction and discoveries of more resource-efficient QECCs, an understanding of the physical extent of error-correction is still limited due to the lack of a unified framework. We overcome this by proposing the ``strategic code'' framework, the most general QECC framework encompassing all existing and physically plausible QECCs yet to be discovered, as well as the most general noise with spatial and temporal correlations. The framework uses an ``interrogator'' device, which models the most general quantum processes which adaptively interacts with the noise over multiple time-steps. Using the framework, we establish necessary and sufficient error-correction conditions, which include the analogous static QECC conditions as a special case, as well as propose an optimization-theoretic approach to construct a strategic code that recovers logical information up to a desired fidelity under a general noise model.

Quantum error mitigation via autoencoder neural networks

Xiao-Dao Lin, Hsi-Ming Chang, Jhih-Shih You and Hsiu-Chuan Hsu

Quantum computing has gained significant attention in recent years, with numerous algorithms and applications under active development. Limited by the current quantum technology, quantum noise and readout error have become critical issues. Various methods have been proposed to address readout error through error mitigation techniques, typically involving post-processing of measurement data. However, most of these methods increase the quantum hardware overhead, leading to higher computational costs. In this work, we present a machine-learning-based approach that minimizes hardware overhead while improving accuracy of the measurement probability distributions. We employed a convolutional neural network (CNN) autoencoder, commonly used for image denoising, as our baseline model. The datasets were derived from 4-qubit random circuits with depths ranging from 1 to 18, generated using Qiskit backends for target and noisy measurement data. The model was trained using mean squared error (MSE) as the loss function and Adam optimizer over 500 epochs, achieving an average noise reduction by 95\% across the test set, with no signs of overfitting. To validate the model’s effectiveness across diverse quantum states, we conducted extensive tests on both typical quantum circuits and algorithms, including Grover’s search algorithm, Quantum Fourier Transform, Haar random circuits and Trivial Paramagnet. The results demonstrated consistent and robust denoising in noisy measurement data, indicating that the autoencoder model is well-suited for efficient quantum error mitigation for current noisy quantum computers. This work contributes to the advancement of quantum error mitigation techniques using machine learning.

Session 3A (13:30-15:30, June 27, Venue: Z205)

Benchmark of the full and reduced effective resistance kernel for molecular classification

Adam Wesolowski and Karim Essafi

We present a comprehensive study of the commute time kernel method via the effective resistance framework analyzing the quantum complexity of the originally classical approach. Our study reveals that while there is a trade-off between accuracy and computational complexity, significant improvements can be achieved in terms of runtime efficiency without substantially compromising on precision. Our investigation highlights a notable quantum speedup in calculating the kernel, which offers a quadratic improvement in time complexity over classical approaches in certain instances. In addition, we introduce methodical improvements over the original work on the commute time kernel and provide empirical evidence suggesting the potential reduction of kernel queries without significant impact on result accuracy. Benchmarking our method on several chemistry-based datasets: AIDS, NCL1, PTC-MR, MUTAG, PROTEINS- data points previously unexplored in existing literature, shows that while not always the most accurate, it excels in time efficiency. This makes it a compelling alternative for applications where computational speed is crucial. Our results highlight the balance between accuracy, computational complexity, and speedup offered by quantum computing, promoting further research into efficient algorithms for kernel methods and their applications in chemistry-based datasets.

Quantum coupled-giant-cavity gyroscopes under strict braided topologics

Yuting Zhu, Guangpu Wu and Shibei Xue

Recent progress shows that the surface-acousticwave (SAW) cavity can exhibit great quantum coherence in single-photon-level power, bringing new physics and potential advantages in designing sensors. Especially, when multiple SAW cavities couple to a same waveguide at distant points, forming the so-called quantum giant system, the inherent nonlocality led by the separations introduces an underlying directional coupling. Regrattably, this directional coupling attracts few attention in exsiting works, especially on how it affects sensing. To this end, we propose a quantum gyroscope based on coupled-giantcaivity system, and fully discuss its unique time-delayed dynamics and the directional coupling behind. Our results show that this directional coupling is essentially a nonreciprocal transfer, and it can be a powerful resource in enhancing sensing under proper structures.

Optomechanical cooling in the unresolved sideband regime using coherent feedback control

Aoi Fujimoto, Hiroyuki Ichihara and Rina Kanamoto

Coherent feedback control, which does not destroy the coherence of quantum signals by measurement, outperforms measurement-based feedback control in quantum systems. Nevertheless, systematic methods for designing coherent feedback controllers are absent so far. Thus, expectations for controller design methods are growing from control engineering perspectives. This paper proposes a method for designing a coherent feedback controller based on frequency analysis. Previous studies have rarely considered frequency analysis-based approaches. The paper theoretically reveals that ground-state cooling in the unresolved sideband regime is possible using a simple feedback structure with only a single double-sided cavity as the controller. While the proposed design method is a natural extension of the method based on classical control theory, it has rarely been used in coherent feedback control, thus offering new possibilities for coherent controller design methods.

Feedback stabilization of perturbed quantum systems via reduced filters

Weichao Liang

In practical scenarios, quantum systems often encounter significant uncertainties-such as unknown initial states, imprecise physical parameters, and unmodeled noise-that challenge robust quantum control. We propose a feedback approach leveraging a reduced quantum filter capable of handling both Hamiltonian perturbations and additional unmodeled dissipative dynamics, without requiring prior knowledge of initial states or precise system parameters. Notably, the reduced filter tracks only O(N) real parameters instead of $O(N^2)$, where N is the Hilbert space dimension. By substantially lowering the dimensionality of the filter, this method significantly simplifies real-time implementation and offers a scalable path to robust quantum control in uncertain environments.

Robust feedback-based quantum optimization: analysis of coherent control errors

Mirko Legnini and Julian Berberich

The Feedback-based Algorithm for Quantum Optimization (FALQON) is a Lyapunov inspired quantum algorithm proposed to tackle combinatorial optimization problems. In this paper, we examine the robustness of FALQON against coherent control errors, a class of multiplicative errors that affect the control input. We show that the algorithm is asymptotically robust with respect to systematic errors, and we derive robustness bounds for independent errors. Finally, we propose a robust version of FALQON which minimizes a regularized Lyapunov function. Our theoretical results are supported through simulations.

Collective quantum state tomography: closed-form and numerical solutions, and validation

Shuixin Xiao, Yuanlong Wang, Zhibo Hou, Guo-Yong Xiang, Ian Petersen and Daoyi Dong

Quantum state tomography (QST) is a technique for characterizing, benchmarking, and verifying quantum systems and devices. In this paper, we focus on collective QST using data from collective measurements performed on multiple copies of the state. We propose a closed-form solution and provide an analytical characterization of its computational complexity and mean squared error (MSE) scaling. Additionally, we reformulate the problem as a sum of squares (SOS) optimization problem with semialgebraic constraints, enabling the application of SOS tools for its solution.

The effectiveness of the proposed methods is demonstrated through numerical simulations. Furthermore, we validate the algorithms using two-copy collective experimental data, where the entangled measurement provides information about the state purity. Compared to previous methods, our algorithms achieve lower MSEs and approach the collective MSE bound by leveraging this purity information more efficiently.

Session 3B (13:30-15:30, June 27, Venue: Z207)

Smallest quantum codes for amplitude damping noise

Sourav Dutta, Aditya Jain and Prabha Mandayam

We describe the smallest quantum error correcting (QEC) code to correct for amplitude-damping (AD) noise, namely, a 3-qubit code that corrects up to first order in the damping strength. We generalize this construction to create a family of codes that correct AD noise up to any fixed order. We underpin the fundamental connection between the structure of our codes and the noise structure via a relaxed form of the Knill-Laflamme conditions, that are different from existing formulations of approximate QEC conditions. Although the recovery procedure for this code is non-deterministic, our codes are optimal with respect to overheads and outperform existing codes to tackle AD noise in terms of entanglement fidelity. This alternate formulation of approximate QEC in fact leads us to a new class of quantum codes tailored to AD noise and also gives rise to a noise-adapted quantum Hamming bound for AD noise.

Photonic quantum computing for RNA structure and gene regulation

Kin Tung Michael Ho, Yuk Lung Lawrence Ho, Shang Yu, Kin Lai Michelle Ho, Ronghan Zhang, Zexuan Wang, Giin Yu Amy Tan and Po-Heng Lee

Ribonucleic acids (RNA) play a crucial role in the post-transcriptional regulation of gene expression in cellular metabolic processes. However, analysing their structures and interactions, which are often represented as graph-based problems, poses complex, computationally intensive challenges. Gaussian Boson Sampling (GBS), a photonic quantum computational technique, offers a promising solution beyond the capabilities of classical algorithms. This work investigates the applications of GBS in RNA folding prediction and multi-omics analysis, specifically across transcriptomic and proteomic levels, to address structural and functional relationships in gene regulation. Additionally, we discuss current hardware limitations and future directions for advancing the technology. By bridging quantum computing and molecular biology, this interdisciplinary approach provides transformative opportunities for both fields.

Existence and characterisation of bivariate bicycle codes

Jasper Postema and Servaas Kokkelmans

Encoding quantum information in a quantum error correction (QEC) code offers protection against decoherence and enhances the fidelity of qubits and gate operations. One of the holy grails of QEC is to construct codes with asymptotically good parameters, i.e. a non-vanishing rate and relative minimum distance. Such codes provide compact quantum memory with low overhead and enhanced error correcting capabilities, compared to state-of-the-art topological error correction codes such as the surface or color codes. Finding good codes that can be implemented on near-term quantum hardware is among the key goals in the field of quantum computing. Recently, bivariate bicycle (BB) codes have emerged as a promising candidate for such compact memory, though the exact tradeoff of the code parameters, the rate and relative minimum distance, remain unknown. Here, we explore these parameters by focusing on the subclass of coprime BB codes. In many cases, we can efficiently predict code parameters by leveraging the ring structure of these codes. Finally, we demonstrate asymptotic badness for coprime BB codes. Though this excludes this subclass of codes from the search towards practical good low-density parity check (LDPC) codes, it does not affect the utility of the moderately long codes that are known, which can already be used to experimentally demonstrate better QEC beyond the surface code.

Extending causal control: A parallel serial switch and its device-independent certification

Yiying Chen, Peidong Wang and Zizhu Wang

Causality is a fundamental concept in physics, and the process matrix framework offers a novel perspective on its characterization in quantum theory. Within this framework, causally non-separable processes offer advantages in quantum information processing, such as enabling coherent control in quantum circuits to enhance quantum computation and metrology. However, their exploration in multi-partite scenarios is challenging due to the rapid growth of the process space. In this work, we present a new type of switch derived from classical processes and its quantum certification. By incorporating multiple control states, this extension enables both parallel and sequential applications of operations, offering insights into the broader scope of quantum-controlled processes. To support the experimental implementation of such processes, we derive a device-independent certification for our model in the form of an inequality. These findings deepen our understanding of causality in both the classical and quantum worlds while offering new avenues for experimental and theoretical exploration.

Dimension reduction in quantum sampling of stochastic processes

Chengran Yang, Marta Florida Llinas, Mile Gu and Thomas Elliott

Quantum technologies offer a promising route to the efficient sampling and analysis of stochastic processes, with potential applications across the sciences. Such quantum advantages rely on the preparation of a quantum sample state of the stochastic process, which requires a memory system to propagate correlations between the past and future of the process. Here, we introduce a method of lossy quantum dimension reduction that allows this memory to be compressed, not just beyond classical limits, but also beyond current state-of-the-art quantum stochastic sampling approaches. We investigate the trade-off between the saving in memory resources from this compression, and the distortion it introduces. We show that our approach can be highly effective in low distortion compression of both Markovian and strongly non-Markovian processes alike. We further discuss the application of our results to quantum stochastic modelling more broadly.

Strong quantum entanglement in non-Gaussian quantum states

Hongbin Song, Guofeng Zhang and Hidehiro Yonezawa

Quantum entanglement is a defining feature of a quantum system and plays a critical role in determining the performance of quantum information systems. Two-mode squeezed vacuum states (TMSVs), characterized by Gaussian Wigner functions, are well-known quantum-entangled states that can be generated by combining two squeezed vacuum states. However, the quantum entanglement is highly vulnerable to environmental disturbances, such as losses in quantum channels, which can significantly degrade the performance of quantum systems.

To overcome this challenge, we proposed non-Gaussian quantum-entangled states based on two-mode photon-subtracted squeezed vacuum states (TMPSSVs). The quantum entanglement of these states is analyzed and compared with those of photon-subtracted TMSVs, quantum scissors, and quantum catalysis. Simulation results reveal that TMPSSVs outperform other schemes, demonstrating stronger entanglement and enhanced robustness against quantum channel losses. These properties make TMPSSVs a promising quantum resource for applications in quantum communication and quantum metrology.

Session 4A (16:00-18:00, June 27, Venue: Z205)

Learning quantum systems with deep neural networks

Giulio Chiribella

Noise reduction in quantum amplifiers by feedback

Jeff Ou

Precision limits and tradeoffs for multi-parameter quantum metrology

Haidong Yuan

Please find the abstracts on Pages 25-27.

Session 4B (16:00-18:00, June 27, Venue: Z207)

Quantum medicine in drug discovery and pharmacology

Wilfred Wan Kei Lin

Quantum medicine is an emerging interdisciplinary field that integrates principles of quantum mechanics with biomedical research, particularly in drug discovery. This abstract aims to encapsulate the potential of quantum medicine in revolutionizing the traditional paradigms of drug development, highlighting its implications for enhancing the efficacy and safety of pharmacological interventions.

The foundations of quantum medicine lie in the understanding that biological systems operate at quantum levels, where the behaviors of atoms and molecules can significantly influence physiological processes. Quantum mechanics provides a framework for understanding the interactions at the molecular level, allowing for a more profound exploration of drug-target interactions, molecular dynamics, and the mechanisms of action of therapeutic agents. In the realm of quantum mechanics, the behavior of particles at the atomic and subatomic levels is governed by principles that differ significantly from classical physics. One of the key concepts is wave-particle duality, which posits that particles such as electrons exhibit both wave-like and particle-like properties. This duality is essential for understanding phenomena such as electron cloud distributions around nuclei, which in turn influence how molecules interact with one another.

In drug discovery, quantum medicine offers innovative methodologies that can streamline the identification and optimization of drug candidates. Quantum computing, for instance, has the potential to process vast datasets and simulate molecular interactions at unprecedented speeds, thereby accelerating the drug discovery pipeline. By leveraging quantum algorithms, researchers can predict the binding affinities of compounds to specific biological targets, identify novel drug candidates, and optimize lead compounds more efficiently than traditional computational methods. Quantum chemistry, a subset of quantum mechanics, focuses specifically on applying these principles to chemical systems. By utilizing quantum mechanical methods, chemists can predict the outcomes of chemical reactions with remarkable accuracy. Techniques such as Density Functional Theory (DFT) and Hartree-Fock methods allow researchers to calculate the electronic structure of molecules, providing insights into their reactivity and interaction with other species. These computational approaches have become indispensable tools in drug discovery, enabling scientists to screen vast libraries of compounds and identify promising candidates for further development.

In pharmacology, the ability to model drug-target interactions at the quantum level is particularly transformative. Understanding how a drug molecule interacts with its biological target—often a protein or enzyme—can reveal critical information about its efficacy and safety profile. Quantum mechanical models can simulate the binding process, elucidating the specific interactions between the drug and the target site. This level of detail allows researchers to optimize drug candidates by modifying their chemical structures to enhance binding affinity and selectivity.

Moreover, quantum medicine facilitates a more personalized approach to treatment. By understanding the quantum states of biological systems, researchers can develop drugs tailored to the unique molecular profiles of individual patients, enhancing therapeutic outcomes and minimizing adverse effects. This paradigm shift towards personalized medicine is supported by advancements in quantum sensing and imaging techniques, which allow for real-time monitoring of biological processes at the quantum level.

The integration of quantum principles into drug discovery also raises important ethical and regulatory considerations. As the field progresses, it is crucial to establish guidelines that ensure the responsible application of quantum technologies in medicine. Collaborative efforts among researchers, regulatory bodies, and industry stakeholders will be essential to navigate the complexities of this rapidly evolving landscape.

In conclusion, quantum medicine represents a transformative approach to drug discovery, offering novel insights and methodologies that have the potential to reshape the future of pharmacotherapy. As research in this field continues to advance, it is anticipated that quantum medicine will lead to the development of safer, more effective drugs, ultimately improving patient care and outcomes.

Training robust and generalizable quantum models

Julian Berberich, Daniel Fink, Daniel Pranjic, Christian Tutschku and Christian Holm

Adversarial robustness and generalization are both crucial properties of reliable machine learning models. In this contribution, we study these properties in the context of quantum machine learning based on Lipschitz bounds. We derive parameter-dependent Lipschitz bounds for quantum models with trainable encoding, showing that the norm of the data encoding has a crucial impact on the robustness against data perturbations. Further, we derive a bound on the generalization error which explicitly involves the parameters of the data encoding. Based on these theoretical results, we propose a regularization-based strategy for training quantum models with improved robustness and generalization properties. Moreover, we show that, for fixed and nontrainable encodings, as those frequently employed in quantum machine learning, the Lipschitz bound cannot be influenced by tuning the parameters. Thus trainable encodings are crucial for systematically adapting robustness and generalization during training. The practical implications of our theoretical findings are illustrated with numerical results.

Reinforcement learning for quantum chemistry state preparation

Oliver Chapman and David P. Tew

The simulation of quantum chemistry is one of particular interest in the search for quantum advantage. In order for advantage to be achieved in this space we require the development of efficient state preparation algorithms which are capable of encoding chemical systems onto a quantum computer. At present several encodings exist e.g. ADAPT-VQE, DISCO-VQE, tUPS, however they all have one limitation in common: once the process of optimisation is completed for a given configuration of a given molecule any and all information discovered in the process is lost. No matter how similar (even if identical) the next optimisation will start from scratch. The work demonstrates that this information can be harnessed with the training of a Reinforcement Learning model based on DISCO-VQE fermionic operators. We show how predictions beyond chemical accuracy can be achieved in simulations of small test molecules (e.g. H4) in generalised configuration space using chemical descriptors, leading the way for larger simulations in the future.

Enhancing quantum error mitigation via graph-based learning structures

Xuan Ye and Xiaoting Wang

Various quantum error mitigation methods have been proposed to address the challenge of quantum noise on NISQ (Noisy Intermediate Scale Quantum) devices. Learning-based error mitigation methods have achieved significant results as learning methods continue to advance. However, the explorable search space is constrained by the associated training costs. In this paper, we propose a graph-based learning approach for quantum error mitigation, inspired by constructing the canonical form of a quantum circuit, to enhance the expressive power of the model while maintaining the same quantum circuit training cost. The approach attempts to transform a quantum circuit into a directed acyclic graph (DAG) and apply a graph neural network (GNN) to perform error mitigation tasks in quantum systems. We use our approach to both pseudorandom circuits and variational quantum algorithms. Our numerical simulation results demonstrate that the approach exhibits significant potential for enhancing quantum algorithms in real physical models.

Optimizing maximally entangled state generation via Pontryagin’s principle

Nahid Binandeh Dehaghani, A. Pedro Aguiar and Rafal Wisniewski

We propose an optimal control strategy to generate maximally entangled states in bipartite quantum systems. Leveraging the Pontryagin's Principle, we derive time-dependent control fields that maximize the entanglement measure, specifically concurrence, within minimal time while adhering to input constraints. Our formulation addresses the Liouville-von Neumann dynamics of the reduced density matrix under unitary evolution. The strategy is numerically validated through simulations, demonstrating its ability to drive the system from an initial perturbed separable state to a maximally entangled target state. The results showcase the effectiveness of switching control fields in optimizing entanglement, with potential applications in quantum technologies, including communication, computation, and sensing.

Energetic advantages for quantum agents in online execution of complex strategies

Jayne Thompson, Paul Riechers, Andrew Garner, Thomas Elliott and Mile Gu

Agents often execute complex strategies - continually adapting their reactions to input stimuli to synergize with past actions. As society pushes to automate ever more complex tasks, the computational resource requirements of such agents are growing in tandem – contributing to chip shortages, and a growing energy footprint of such technologies.

In particular the underlying task being executed by an agent of sequence to sequence transduction, requires the agent to take in a sequence of input symbols and generate a corresponding sequence of output symbols in responses. This task has enjoyed significant attention recently, mainly due to its association with natural language processing and large language models. Rapid advances in this field have driven an ever growing footprint for this technology with a doubling in resource requirements every 3-4 months and energetic costs growing in tandem.

Here we derive the fundamental minimal energetic cost on the task of sequence to sequence modelling. In particular we examine the case where the agent receives an L-input symbols at a time, and needs to generate L-output symbols in response. We determine the most memory and energetically efficient constructions for executing this task classically. We then link this fundamental energetic costs to the requirement of generating the sequences in an online format, where at each time-step after L-inputs symbols have been given the agent needs to generate L-output symbols before it can see the upcoming inputs. We show this lack of being able to see upcoming inputs, fundamentally imposes a minimum energetic cost for this the task.

We then demonstrate quantum sequence to sequence models, which use less energy and memory than their classical counterparts. We developed the fundamental necessary and sufficient conditions for quantum advantage both in terms of memory and energy expenditure require to execute this task. We show that, in general, it is more efficient, both in terms of memory and energy requirements, to implement sequence-to-sequence transduction tasks quantum mechanically. We link this phenomenon back to a lower energetic cost for online response in quantum agents.

Session 5A (13:30-15:30, June 28, Venue: Z205)

Unconditional quantum magic advantage in shallow circuit computation

Xingjian Zhang, Zhaokai Pan and Guoding Liu

Quantum theory promises computational speed-ups over classical approaches. The celebrated Gottesman-Knill Theorem implies that the full power of quantum computation resides in the specific resource of ``magic" states --- the secret sauce to establish universal quantum computation. However, it is still questionable whether magic indeed brings the believed quantum advantage, ridding unproven complexity assumptions or black-box oracles. In this work, we demonstrate the first unconditional magic advantage: a separation between the power of generic constant-depth or shallow quantum circuits and magic-free counterparts. For this purpose, we link the shallow circuit computation with the strongest form of quantum nonlocality --- quantum pseudo-telepathy, where distant non-communicating observers generate perfectly synchronous statistics. We prove quantum magic is indispensable for such correlated statistics in a specific nonlocal game inspired by the linear binary constraint system. Then, we translate generating quantum pseudo-telepathy into computational tasks, where magic is necessary for a shallow circuit to meet the target. As a by-product, we provide an efficient algorithm to solve a general linear binary constraint system over the Pauli group, in contrast to the broad undecidability in constraint systems. We anticipate our results will enlighten the final establishment of the unconditional advantage of universal quantum computation.

Fast-forwarding quantum algorithms for linear dissipative differential equations

Dong An, Akwum Onwunta and Gengzhi Yang

Differential equations are fundamental for describing the dynamics of a system and have been widely used in physics, chemistry, engineering, economics, and so on. There has been emerging interest in exploring quantum algorithms for differential equations with substantially improved efficiency. In this work, we study quantum algorithms for linear dissipative ordinary differential equations (ODEs), and establish improved complexity estimates that the time dependence of quantum algorithms for linear dissipative ODEs can be fast-forwarded to be sub-linear. Specifically, we show that quantum algorithm can prepare history states of dissipative ODEs with logarithmic time cost, which is an exponential speedup over the best existing result, and quantum algorithm can prepare final solutions of dissipative ODEs with square-root time cost, which is a polynomial speedup over the best existing result. As applications, we show that quantum algorithms can simulate dissipative non-Hermitian quantum dynamics and heat process with fast-forwarded complexity sub-linear in time.

A dequantized algorithm for the guided local Hamiltonian problem

Yukun Zhang, Yusen Wu and Xiao Yuan

The local Hamiltonian (LH) problem, the quantum analog of the classical constraint satisfaction problem, is a cornerstone of quantum computation and complexity theory. It is known to be QMA-complete, indicating that it is challenging even for quantum computers. Interestingly, the guided local Hamiltonian (GLH) problem -- an LH problem with a guiding state that has a non-trivial overlap with the ground state -- can be efficiently solved on a quantum computer and is proved to be BQP-complete. This makes the GLH problem a valuable framework for exploring the fundamental separation between classical and quantum computation. Remarkably, the quantum algorithm for solving the GLH problem can be `dequantized' (i.e., made classically simulatable) under certain conditions, such as when only constant accuracy is required and when the Hamiltonian satisfies an unrealistic constant operator norm constraint. In this work, we relieve these restrictions by introducing a dequantized classical algorithm for a randomized quantum imaginary-time evolution quantum algorithm. We demonstrate that it achieves either limited or arbitrary constant accuracy, depending on whether the guiding state's overlap is general or exceeds a certain threshold. Crucially, our approach eliminates the constant operator norm constraint on the Hamiltonian, opening its applicability to realistic problems. Our results advance the classical solution of the GLH problem in practical settings and provide new insights into the boundary between classical and quantum computational power.

Design nearly optimal quantum algorithm for linear differential equations via Lindbladians

Zhong-Xia Shang, Naixu Guo, Dong An and Qi Zhao

Solving linear ordinary differential equations (ODE) is one of the most promising applications for quantum computers to demonstrate exponential advantages. The challenge of designing a quantum ODE algorithm is how to embed non-unitary dynamics into intrinsically unitary quantum circuits. In this work, we propose a new quantum algorithm for solving ODEs by harnessing open quantum systems. Specifically, we propose a novel technique called non-diagonal density matrix encoding, which leverages the inherent non-unitary dynamics of Lindbladians to encode general linear ODEs into the non-diagonal blocks of density matrices. This framework enables us to design quantum algorithms with both theoretical simplicity and high performance. Combined with the state-of-the-art quantum Lindbladian simulation algorithms, our algorithm can outperform all existing quantum ODE algorithms and achieve near-optimal dependence on all parameters under a plausible input model. We also give applications of our algorithm including the Gibbs state preparations and the partition function estimations.

Efficient explicit gate construction of block-encoding for Hamiltonians needed for simulating partial differential equations

Nikita Guseynov, Xiajie Huang and Nana Liu

One of the most promising applications of quantum computers is solving partial differential equations (PDEs). By using the Schrödingerisation technique — which converts non-conservative PDEs into Schrödinger equations– the problem can be reduced to Hamiltonian simulations. The particular class of Hamiltonians we consider is shown to be sufficient for simulating almost any linear PDE. In particular, these Hamiltonians consist of discretizations of polynomial products and sums of position and momentum operators. This paper addresses an important gap by efficiently loading these Hamiltonians into the quantum computer through block-encoding. The construction is explicit and efficient in terms of one- and two-qubit operations, forming a fundamental building block for constructing the unitary evolution operator for that class of Hamiltonians. The proposed algorithm demonstrates a squared logarithmic scaling with respect to the spatial partitioning size, offering a polynomial speedup over classical finite-difference methods in the context of spatial partitioning for PDE solving. Furthermore, the algorithm is extended to the multi-dimensional case, achieving an exponential acceleration with respect to the number of dimensions, alleviating the curse of dimensionality problem. This work provides an essential foundation for developing explicit and efficient quantum circuits for PDEs, Hamiltonian simulations, and ground state and thermal state preparation.

Efficient learning of continuous-variable quantum states

Ya-Dong Wu, Yan Zhu, Giulio Chiribella and Nana Liu

The characterization of continuous-variable quantum states is crucial for applications in quantum communication, sensing, simulation, and computing. However, a full characterization of multimode quantum states requires a number of experiments that grows exponentially with the number of modes. Here we propose an alternative approach where the goal is not to reconstruct the full quantum state, but rather to estimate its characteristic function at a given set of points. For multimode states with reflection symmetry, we show that the characteristic function at M points can be estimated using only O(log M) copies of the state, independently of the number of modes. When the characteristic function is known to be positive, as in the case of squeezed vacuum states, the estimation is achieved by an experimentally friendly setup using only beamsplitters and homodyne measurements.

Session 5B (13:30-15:30, June 28, Venue: Z207)

Multiparty quantum secret sharing under noisy scenario

Nirupam Basak and Goutam Paul

Quantum secret sharing (QSS) ensures secure information distribution among multiple parties but is vulnerable to noise. We analyze the effects of bit-flip, phase-flip, and amplitude damping noise on the multiparty QSS for classical message protocol proposed by Zhang et al. (Phys. Rev. A, 71:044301, 2005) and propose an efficient quantum error correction (QEC) implementation using a simplified Shor's code. By exploiting the particular structure of the QSS, we reduce the resource requirements from the default 9 qubits of Shor's code to as small as 3 qubits and still achieve a lower average error rate. Simulation results confirm that QEC enhances the protocol's robustness, making it more practical for real-world applications.

Quantum circuit learning for sparse identification of quantum Hamiltonian dynamics

Yuusei Tateyama and Yuzuru Kato

Quantum circuit learning (QCL) is a hybrid quantum-classical machine learning technique designed for noisy intermediate-scale quantum (NISQ) devices. In QCL, classical data are encoded into quantum states and processed through parameterized quantum gates, and the resulting quantum measurement outcomes are used to optimize circuit parameters via classical optimization algorithms for machine learning.Sparse identification of nonlinear dynamics (SINDy) is a method for estimating classical nonlinear dynamical systems from time series data. In SINDy, system dynamics is approximately represented as a linear combination of a predefined set of basis functions, with their coefficients sparsely estimated from the time-series data. In this study, we propose sparse identification of quantum Hamiltonian dynamics (SIQHDy), a SINDy-inspired quantum circuit learning algorithm for estimating quantum Hamiltonian dynamics from time-series data. In SIQHDy, quantum Hamiltonian dynamics is approximately represented as a product of basis quantum circuits, with their parameters sparsely estimated from time-series data of quantum measurement outcomes. We numerically demonstrate that SIQHDy can successfully estimate the dynamics of single-, two-, and five-qubit systems and that the advantage of sparsity becomes evident when using time-series data with measurement noise.

Local filtering and quantumness

Pankaj Agrawal, Abhisek Panda and Chandan Datta

Sometimes, when a quantum system is in a mixed state, the system is not useful as a quantum resource. This is true even if the state is entangled. For example, if a protocol requires a test of Bell-type inequality violation, the state may not violate the inequality. In the case of multipartite states, one may need to test a monogamy relation. However, there exist local quantum filtering operations that can help us. Local operation cannot introduce or increase entanglement in a quantum state. Using suitable local operations, one can convert such a state to a form which can violate a suitable Bell-type inequality, or violate monogamy relations. We consider many bipartite and multipartite mixed states to demonstrate the usefulness of local filtering operations for violations of Bell-type inequalities and monogamy relations.

Quantum memory circuit for ion channel dynamics in the nervous system

Yu-Juan Sun and Wei-Min Zhang

The mechanism of neural signal transmission depends on the ion channel dynamics. Although the Hodgkin-Huxley model can describe the behavior of ion channel populations, a universal theoretical model for a single ion channel remains to be established. This study modeled a single ion channel as a nanoscale two-terminal molecular tunneling junction, considered the atomic scale and ion selectivity of the ion channel, and explored the role of a time-dependent environment in ion transport. We applied a time-varying bias voltage to simulate the action potential and combined the quantum Langevin equation with the nonequilibrium Green's function method to theoretically calculate the transient current. This study found that the time-varying voltage induces an effective magnetic flux, produces a quantum phase coherence effect, causes the ion current to exhibit a side-band phenomenon, and forms multiple cross-hysteresis structures in the I-V curve. We define this nonlinear behavior as active memory, a memory mechanism induced by changes in environmental stimuli. The number of non-zero crossings of the I-V curve hysteresis and the degree of differential conductance oscillation is positively correlated with the degree of active memory, allowing us to quantitatively describe the amount of active memory generated. We further explore the temperature dependence of the active quantum memory in our system. The discovery of these active quantum memory features provides a new perspective for understanding the underlying mechanisms of ion channel dynamics.

Communication with embezzling catalysts

Junjing Xing, Yunlong Xiao and Yuqi Li

This work builds on the findings from our recent study [arXiv:2406.14395 and Commun Phys 7, 357 (2024)]. Communication is essential for advancing science and technology. Quantum communication processing can benefit from the use of catalysts, which are ancillary entangled states that can enhance performance without being consumed. However, maintaining and manipulating perfect catalysts remains elusive. By allowing minor and controlled deviations of the catalytic system, we employ embezzling catalysts to enhance the performance of both point to point communication and teleportation. We also explore methods to reduce the dimension of catalysts without increasing catalyst consumption, an essential step towards realizing quantum catalysis in practice.

On the expressivity of quantum machine learning models at the physical level

Hanxiao Tao, Jiaqi Hu and Rebing Wu

The expressivity of quantum machine learning (QML) models is of fundamental importance in understanding their potential advantages over classical models. Existing studies are almost all based on gate-based parameterized quantum circuits, whose abstraction makes it hard to see how the expressivity is limited by realistic physical restrictions on the qubits. In this work, we show that QML models can be constructed at the physical level by taking the continuous limit of circuit models. This results in a Schrodinger equation steered by trainable control functions, in which physical restrictions are naturally incorporated in the structure of the Hamiltonian. The model also provides a new way for understanding the expressivity through the system's ensemble controllability, from which we present a universal criterion for assessing the expressivity of generic QML models. Numerical tests are carried out on single-qubit and two-qubit models, which demonstrates the validity of the criterion and their expressive power on approximating different functions.

Session 6 (16:00-18:20, June 28, Venue: Z205)

Quantum control robustness landscapes

Huiqi Xue and Xiu-Hao Deng

Robust quantum control is critical for developing quantum technologies, especially within the noisy intermediate-scale quantum (NISQ) era. We introduce the Quantum Control Robustness Landscape (QCRL), a novel framework that maps control parameters to their robustness against noise. This framework offers an efficient mechanism for identifying resilient control solutions. In contrast to the traditional Quantum Control Landscape, which concentrates on optimizing fidelity for specific quantum gates, the QCRL provides a comprehensive perspective on gate engineering by facilitating the navigation of level sets. This capability enables the identification of equally robust control solutions for a universal family of quantum gates, thereby streamlining the process of achieving resilient quantum operations. By exploring these level sets, QCRL serves as a potent tool for both comprehending control schemes and optimizing robust quantum gates with continuous parameters.

A compact upconversion single-photon imager for full-range and accurate 3-D imaging

Yiwei Chen, Chen Jiang, Yong Liu, Hongye Su, Xiaomin Hu and Yu Pan

The rapid development of single-photon detection technology offers the possibility for an imaging system to go beyond traditional limits. Recently, single-photon imagers based on the upconversion technique have achieved unprecedentedly high resolution and noise tolerance in 3-D imaging. Nevertheless, the limited imaging range, complicated optical path, and long data acquisition time impose remaining challenges to practical applications. In this work, we build an upconversion single-photon imager for full-range and accurate 3-D imaging. A compact all-fiber design allows our system to work robustly in an open environment. Compared to the previous imagers, the imaging speed is increased by three orders of magnitude due to the high upconversion efficiency and photon-efficient algorithm. With the application of a high-repetition laser and a nanosecond optical delay line, we achieve full-range imaging under the upconversion scheme against high solar background noise. For close-up scenes, our imager achieves ultrahigh axial resolution up to 20 μm, which is not affected by the time jitter or pileup effect of the single-photon detector. Our proposal can stimulate practical applications in sophisticated scenarios. For more details, please refer to our journal paper https://doi.org/10.1109/TIM.2023.3280500.

Quantum coherent systems for ground-state problems

Yunyan Lee, Rebbecca Thien, Ian Petersen and Daoyi Dong

This paper offers a perspective on solving ground-state problems in quantum chemistry using a quantum coherent system. Typically, such issues are addressed with Variational Quantum Algorithms (VQAs), which rely on classical optimization to update the parameters iteratively. Using the Quantum Stochastic Differential Equations (QSDEs) framework, we design a quantum system that evolves toward a steady-state solution corresponding to the ground state of the Hamiltonian. Unlike VQAs, this approach eliminates the reliance on classical optimization. Moreover, our method naturally expresses Hamiltonians in terms of annihilation and creation operators, solving the problem directly without requiring a transformation into the Ising model. This approach is further validated in our numerical simulations, which demonstrate the feasibility of the QSDE-based approach, providing a promising solution for ground-state preparation.

Second-order adjoint method for quantum optimal control

Harish S. Bhat

We derive and implement a second-order adjoint method to compute exact gradients and Hessians for a prototypical quantum optimal control problem, that of solving for the minimal energy applied electric field that drives a molecule from a given initial state to a desired target state. For small to moderately sized systems, we demonstrate a vectorized GPU implementation of a second-order adjoint method that computes both Hessians and gradients with wall times only marginally more than those required to compute gradients via commonly used first-order adjoint methods. Pairing our second-order adjoint method with a trust region optimizer (a type of Newton method), we show that it outperforms a first-order method, requiring significantly fewer iterations and wall time to find optimal controls for four molecular systems.

Unravelling mean-field Lindblad equation

Sofiane Chalal and Nina Amini

In this letter, we propose a mean-field particle Monte Carlo method for simulating the N-body Lindblad equation. We provide a convergence result showing that, system of interacting particles converges to the corresponding nonlinear Lindblad equation.

Frequency-locked Si3N4 microring for Doppler frequency shift detection

Chen Jiang, Yixin Xuan, Shuai Wan, Biheng Liu, Xiaomin Hu, Chunhua Dong, Qinmin Yang and Yu Pan

In this paper, we propose to use a homemade all-fiber Si3N4 microring as the frequency discriminator for Doppler frequency shift detection. The full width at half maximum of the microring is 361.83 MHz, which covers the dynamic range of ± 70 m/s for wind measurement applications. By introducing a time-division multiplexing method, we have achieved the frequency locking of the microring to the central frequency of the laser source which effectively stabilizes the measurement accuracy against perturbations such as temperature fluctuations. By alternatively upshifting and downshifting the pulses, a dual-frequency lasing scheme has been designed to realize the double-edge technique for frequency shift detection. A commercial single-photon detector with 25% quantum efficiency and approximately 1300 Hz dark count rate is used to detect the backscattered signals, which circumvents the need for bulky and expensive superconducting single-photon detectors. The proposed system is validated through an outdoor wind speed detection experiment using a reference anemometer. The experiment results demonstrate the feasibility of using microring as the frequency discriminator and that the precise frequency locking control is able to improve the measurement accuracy to the state-of-the-art level under the influence of perturbations, which highlights the potential for highly integrated direct detection Doppler wind lidar design. For more details, please refer to our journal paper https://doi.org/10.1364/OE.539300.