The Cavendish QI Seminars

Hosted by the Cavendish QI Group and the Hitachi Cambridge Laboratory

Spring 2021: 5 February – 26 March

*(abstracts listed below)
**(all times are UK times)

5 February (11.00am)
Electron cascade for distant spin readout
Sjaak van Diepen (Delft University of Technology)

12 February (11.00am)
Contextuality of quantum linear response
Matteo Lostaglio (Delft University of Technology)

19 February (11.00am)
Controlling Thermoelectric Properties of Large-Scale Molecular Junction via Quantum Interference Effect
Xintai Wang (University of Cambridge)

26 February (11.20am)
Quantum Earth Mover's Distance: A New Approach to Learning Quantum Data
Bobak Kiani (MIT)

5 March (11.00am)
Optical (non)classicality, quadrature coherence and environmental decoherence of bosonic quantum field states
Stephan De Bièvre (Université de Lille - CNRS)

12 March (11.00am)
From quantum foundation to quantum cryptography
Xiongfeng Ma (Tsinghua University)

19 March (11.00am)
Advances in Variational Quantum Algorithms
Balint Koczor (University of Oxford)

26 March (11.00am)
Enhancing Precision with Incompatible Measurements
Noah Lupu-Gladstein (University of Toronto)

Where: Virtually on Zoom
https://us02web.zoom.us/j/82842287029?pwd=S3JOOU80elRaa04xSHJEMkt2bmRmUT09
Passcode: 135241

Electron cascade for distant spin readout

(Spin-based Quantum Computing)

5 February 11.00am
Sjaak van Diepen
Delft University of Technology

Spin-qubits based on gate-defined semiconductor quantum dots are a promising platform for quantum computation and simulation. An important advantage of quantum dots is their small footprint. The dot pitch is about 100 nm, hence 100 million dots fit on 1 mm^2. A problem is that qubit readout with charge sensing based on capacitive coupling only enables to sense nearby quantum dots and placing charge sensors within the quantum dot array hosting the qubits is detrimental for connectivity of the qubits. In this work we demonstrate cascade-based readout of a spin distant from the charge sensor. The cascade consists of an initial charge transition, far away from the sensor, and subsequent charge transitions induced by Coulomb repulsion, with the final transition nearby the sensor. Combined with spin-to-charge conversion a cascade enables the readout of charge and spin occupation of quantum dots remote from the charge sensor. We experimentally demonstrate cascade-based readout with Pauli spin blockade in a quadruple dot with a sensing dot.

1) C.J. van Diepen, T.-K. Hsiao, U. Mukhopadhyay, C. Reichl, W. Wegscheider, L.M.K. Vandersypen, Electron cascade for distant spin readout. Nat Comm 12, 77 (2021). https://www.nature.com/articles/s41467-020-20388-6

Contextuality of quantum linear response

(Foundations of Quantum Mechanics)

12 February 11.00am
Matteo Lostaglio
Delft University of Technology

I present a recent work that highlights a fundamental difference between classical and quantum dynamics in the linear response regime by showing that the latter is, in general, contextual. This allows one to provide an example of a quantum engine whose favorable power output scaling *unavoidably* requires nonclassical effects in the form of contextuality. Furthermore, I describe contextual advantages for local metrology. Given the ubiquity of linear response theory, I anticipate that these tools will allow one to certify the nonclassicality of a wide array of quantum phenomena.

1) M. Lostaglio, *Certifying quantum signatures in thermodynamics and metrology via contextuality of quantum linear response*, Phys. Rev. Lett. 125, 230603 (2020) https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.230603

2) R. Spekkens, *Negativity and Contextuality are Equivalent Notions of Nonclassicality,* Phys. Rev. Lett. 101, 020401 (2008) https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.101.020401

3) David RM Arvidsson-Shukur, *Quantum advantage in postselected metrology,* Nat. Comm 11, 3775 (2020) https://www.nature.com/articles/s41467-020-17559-w

Controlling Thermoelectric Properties of Large-Scale Molecular Junction via Quantum Interference Effect

(Molecular Electronics)

19 February (11.00am)
Xintai Wang
University of Cambridge

Molecular electronics is an active topic for years, with ultimate goal of using molecules as active component for electronic device such as logic gates, sensors, memories and thermoelectric energy harvesters. The molecular electronic measurement is either conducted in single molecular scale or large scale molecular thin film in parallel arrays prepared by Self-Assembled Monolayers (SAMs). The central challenge for single molecular electronic is the uncertainty of the binding geometry while molecule is lying in two electrodes, but it is not a problem of SAMs because molecules are fixed in specific conformation due to the intermolecular force between it and its neighbours. The transport properties of SAMs are determined both by its molecular backbone structure and SAMs-electrode interface. One way for controlling the molecular transport is the quantum interference (QI) behaviour, which was intensively studied in single molecular electronics in recent years. In the present work, I would like to show the effort from our group on scaling up QI effect to SAMs scale, and controlling such effect via altering the SAMs-electrode interface, both by changing the SAMs-electrode coupling and the SAMs-electrode binding geometry.

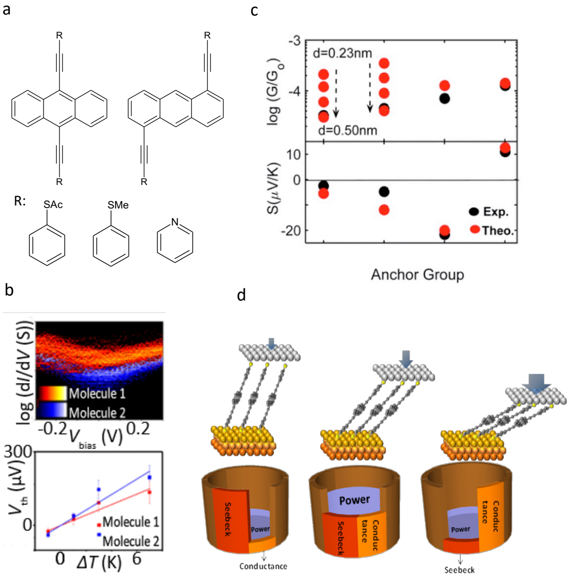

Figure 1. (a) molecular structure of presented work. (b-d) thermoelectric property of molecular junctions based on different backbone structure (b), SAMs-electrode coupling (c) and SAMs electrode binding geometry.

1) Wang, X. T.; Bennett, T. L. R.; Ismael, A.; Wilkinson, L. A.; Hamill, J.; White, A. J. P.; Grace, I. M.; Kolosov, O. V.; Albrecht, T.; Robinson, B. J.; Long, N. J.; Cohen, L. F.; Lambert, C. J., Scale-Up of Room-Temperature Constructive Quantum Interference from Single Molecules to Self-Assembled Molecular-Electronic Films. *J Am Chem Soc* **2020,** *142* (19), 8555-8560. https://pubs.acs.org/doi/abs/10.1021/jacs.9b13578

2) Ismael, A.; Wang, X. T.; Bennett, T. L. R.; Wilkinson, L. A.; Robinson, B. J.; Long, N. J.; Cohen, L. F.; Lambert, C. J., Tuning the thermoelectrical properties of anthracene-based self-assembled monolayers. *Chem Sci* **2020,** *11* (26), 6836-6841. https://pubs.rsc.org/en/content/articlelanding/2020/sc/d0sc02193h#!divAbstract

Quantum Earth Mover's Distance: A New Approach to Learning Quantum Data

(Quantum Machine Learning)

26 February 11.**20**am
Bobak Kiani
MIT

Quantifying how far the output of a learning algorithm is from its target is an essential task in machine learning. However, in quantum settings, the loss landscapes of commonly used distance metrics often produce undesirable outcomes such as poor local minima and exponentially decaying gradients. As a new approach, we consider here the quantum earth mover's (EM) or Wasserstein-1 distance, recently proposed in [De Palma et al., arXiv:2009.04469] as a quantum analog to the classical EM distance. We show that the quantum EM distance possesses unique properties, not found in other commonly used quantum distance metrics, that make quantum learning more stable and efficient. We propose a quantum Wasserstein generative adversarial network (qWGAN) which takes advantage of the quantum EM distance and provides an efficient means of performing learning on quantum data. Our qWGAN requires resources polynomial in the number of qubits, and our numerical experiments demonstrate that it is capable of learning a diverse set of quantum data.

1) Bobak Toussi Kiani, Giacomo De Palma, Milad Marvian, Zi-Wen Liu, Seth Lloyd, *Quantum Earth Mover's Distance: A New Approach to Learning Quantum Data,* https://arxiv.org/abs/2101.03037

Optical (non)classicality, quadrature coherence and environmental decoherence of bosonic quantum field states

(Fundamental Quantum Mechanics)

5 March 11.00am
Stephan De Bièvre
Université de Lille – CNRS

In quantum optics, the electromagnetic field is often restricted to a finite number of field modes. A quantum state of the field is then said to be optically classical, if it is a mixture of coherent states. Given a state, the question arises how to establish if it is nonclassical and if so, how strongly. A number of witnesses, measures and monotones of optical nonclassicality have been developed for that purpose over the years. I will review some of this literature and present a new such optical nonclassicality measure recently introduced [2]: the quadrature coherence scale (QCS) of a state. The QCS links optical nonclassicality to the presence of ``coherences" in the density matrix of the state far away from its diagonal. It allows to understand why strongly optically nonclassical states are extremely sensitive to environmental disturbance and therefore hard to create and maintain. And it provides an upper bound on entanglement.

1) Measuring the nonclassicality of bosonic field quantum states via operator ordering sensitivity, with D. B. Horoshko, G. Patera et M. I. Kolobov, Phys. Rev. Lett. 122, 080402, 2019. arXiv.org 1809.02047. https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.122.080402

2) Quadrature coherence scale driven fast decoherence of bosonic quantum field states, with A. Hertz, Phys. Rev. Lett. 2020. arXiv.org 1909.05025. https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.124.090402

3) Relating the entanglement and optical nonclassicality of multimode states of a bosonic quantum field, Anaelle Hertz, Nicolas J. Cerf, and Stephan De Bièvre. Phys. Rev. A 102, 032413, 2020. arXiv:2004.11782. https://journals.aps.org/pra/abstract/10.1103/PhysRevA.102.032413

From quantum foundation to quantum cryptography

(Quantum Cryptography)

12 March 11.00am
Xiongfeng Ma
Tsinghua University

The peculiar features of quantum mechanics, such as unpredictable randomness and nonlocal correlation, cause lots of trouble on its interpretation at the early stage of development. The unpredictable randomness is quantified by quantum coherence, while the nonlocal correlation is quantified by quantum entanglement. Today, these features are employed in information processing and become useful resources to enable tasks otherwise impossible with classical means. In modern cryptography, true randomness generation and key distribution are two challenges. These can be handled with the introduction of quantum cryptography. In this talk, I shall introduce the concepts of coherence and entanglement, which, respectively, enable true randomness generation and key distribution. Meanwhile, I shall also cover some of the recent exciting developments in this field.

1) 'Quantum Coherence and Intrinsic Randomness', X. Yuan *et al.*, *Advanced Quantum Technologies*, (2019), https://onlinelibrary.wiley.com/doi/abs/10.1002/qute.201900053

2) 'Quantum Random Number Generation', X. Ma *et al.*, *NPJ Quantum Information*, (2016), https://www.nature.com/articles/npjqi201621

Advances in Variational Quantum Algorithms

(Quantum Algorithms)

19 March 11.00am
Balint Koczor
University of Oxford

Quantum devices have recently been announced whose behaviour cannot be simulated using classical computers with practical levels of resource. In this era, quantum computers may have the potential to perform useful tasks of value despite their high levels of noise. One very promising class of approaches are generically called quantum variational algorithms in which one seeks to make use of a quantum circuit of relatively low depth by adjusting its function through varying a set of classical parameters. The emerging quantum states can be very complex, while inevitably being restricted to a small proportion of the exponentially large Hilbert space. These variational approaches promise to solve key problems, such as finding ground states of quantum systems in quantum chemistry and in materials science, but require non-trivial classical optimisation. I will give an overview of some of our recent works in the context of variational quantum algorithms. I will discuss two novel optimisation approaches: Quantum Natural Gradient and imaginary time evolution [1,2] which extract information about the geometry of quantum states and Quantum Analytic Descent [3] which offloads more work from the quantum device via an efficient analytical approximation. I will then briefly discuss applications to quantum metrology [4].

1) B. Koczor, S. C. Benjamin: Quantum natural gradient generalised to non-unitary circuits. arXiv preprint arXiv:1912.08660 (2019). https://arxiv.org/abs/1912.08660

2) S. McArdle, T. Jones, S. Endo, Y. Li, S. C. Benjamin, X. Yuan: Variational ansatz-based quantum simulation of imaginary time evolution. npj Quantum Information 5, no. 1 (2019): 1-6. https://www.nature.com/articles/s41534-019-0187-2

3) B. Koczor, S. C. Benjamin: Quantum Analytic Descent. arXiv preprint arXiv:2008.13774 (2020). https://arxiv.org/abs/2008.13774

4) B. Koczor, S. Endo, T. Jones, Y. Matsuzaki, S. C. Benjamin: Variational-state quantum metrology. New Journal of Physics 22, no. 8 (2020): 083038. https://iopscience.iop.org/article/10.1088/1367-2630/ab965e

Enhancing Precision with Incompatible Measurements

(Quantum Metrology)

26 March 11.00am
Noah Lupu-Gladstein
University of Toronto

We report on an experiment to quantify the metrological superiority of experiments with incompatible measurements over those with only compatible measurements. The precision of an experiment is limited by how much data it can process, and thus practical considerations like detector saturation and finite storage volume. A well-designed filter placed at the end of an experiment, also called a postselection, can improve precision by increasing the information per datum processed. A postselective filter is compatible with an experiment if moving it to the beginning of the experiment would not change the results. Such filters suffer a fundamental limit to their enhancement of information per datum. We terminate an optical birefringent phase estimation experiment with an incompatible polarization filter and observe the precision of our phase estimates surpass that fundamental limit. We link our enhanced precision to non-classical values in a quasi-probability distribution that describes the statistics of our incompatible measurements. We prove that the quantum Fisher information of our postselected state is directly proportional to the negativity of this distribution as quantified by the difference between the distribution's largest and smallest square absolute values. In comparison to another postselected measurement strategy, weak value amplification, our method is simpler theoretically and arguably useful to a broader class of measurement tasks.