KEYNOTE Tuesday 15 September · 09:30–10:20

The design of novel quantum algorithms

Seth Lloyd

MIT

ABSTRACT

How do we discover new quantum algorithms? As quantum computers edge closer to reality, they require practical applications. Quantum computation provides generic square root speedups, and multiple exponential speedups for problems involving linear algebra. This talk explores avenues for developing novel quantum algorithms by expanding the scope of fields in which quantum computers can operate, including finance, data analysis, artificial intelligence, and pure mathematics.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

CONTRIBUTED Tuesday 15 September · 10:20–10:40

Trajectory-protected quantum computing

Barbara Soda, P.A. Graham, T.R. Perche, G. Singh

University of Zagreb

ABSTRACT

We introduce a novel method that simultaneously isolates a quantum computer from decoherence and enables the controlled implementation of computational gates. This quantum computing model utilizes a qubit's motion to protect it from decoherence. We model a qubit interacting with a quantum field via the standard light-matter interaction model: an Unruh-DeWitt detector, i.e. the qubit, follows a prescribed classical trajectory while interacting with a scalar quantum field. The rotating-wave terms, i.e. the resonant transitions, are switched off by using the technique of acceleration-induced transparency which eliminates the dominant decoherence channels by controlling the qubit's trajectory. We are able to perform one qubit gates by stimulating the counter-rotating wave terms (i.e. the non-resonant transitions) and two qubit gates by extracting the entanglement from the quantum field prepared in a squeezed state. Finally, we discuss the fundamental limits on quantum error protection: on the trade-off between isolating a quantum computer from decoherence, and the speed with which entangling gates may be applied, comparable to the Eastin-Knill theorem for quantum error correction.

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CONTRIBUTED Tuesday 15 September · 10:40–11:10

Rational Quantum Mechanics

Tim Palmer

Department of Physics, University of Oxford

ABSTRACT

Motivated in part by John Wheeler's assertion that the continuum nature of Hilbert Space conceals the "it-from-bit" information-theoretic character of the quantum wavefunction, a theory of quantum physics (Rational Quantum Mechanics–RaQM) is proposed based on a specific discretization of complex Hilbert Space. The Schrödinger equation is not modified in RaQM, even during measurement. However, the bases in which the quantum state is defined must satisfy certain rational-number constraints. These constraints lead to the notion of finite qubit information capacity. While QM and RaQM are experimentally indistinguishable for small numbers of qubits, RaQM predicts that the exponential advantage of quantum algorithms which, like Shor's, require bases with maximal N-qubit superposition/entanglement, will have saturated at 1,000 error-corrected qubits. This predicted breakdown of QM could be testable in less than 5 y. RaQM is a simpler theory than QM: Born's rule is emergent in RaQM and the violation of Bell's inequality arises from holistic but not nonlocal laws of physics. Examples of the former include Mach's Principle, Penrose Spin Networks and the geometry of chaotic attractors in state space.

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INVITED Tuesday 15 September · 11:40–12:10

Time-reverse metrology

Nicole Yunger Halpern

National Institute of Standards and Technology, University of Maryland

ABSTRACT

The arrow of time is one of the most ubiquitous, yet also most complex, features of physics. Physicists do not know how to turn back the clock, but several techniques can effectively reverse time. Quantum metrologists have applied these techniques to enhance measurements, in the field of quantum metrology. I will introduce these applications, which collaborators and I have grouped into four categories, unified under the heading of time-reverse metrology. I will illustrate with metrology reliant on the quantum simulation of closed timelike curves, worldlines that loop back on themselves in time. Time-reverse metrology offers opportunities in quantum metrology; quantum foundations; quantum information science; atomic, molecular, and optical physics; and solid-state physics.

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CONTRIBUTED Tuesday 15 September · 12:10–12:40

Foils of Quantum Theory Defined by Alternative State-Update Rules

Stefan Weigert, Vincenzo Fiorentino

University of York, UK

ABSTRACT

Are there consistent and physically reasonable alternatives to the projection postulate? Does it have unique properties compared to acceptable alternatives? We answer these questions by systematically investigating other, hypothetical state-update rules for quantum systems that nature could have chosen over the Lüders rule. Any prospective rule is required to have some basic, physically motivated properties: it must define unique post-measurement states and not allow for superluminal signalling, for example. Particular attention must be paid to defining post-measurement states when performing local measurements in composite systems. Explicit examples of valid, unconventional update rules are presented, each of them resulting in a distinct, well-defined foil of quantum theory. This framework of state-update rules allows us to identify operational properties that distinguish the projective update rule from all others, and to put earlier derivations of the projection postulate into perspective.

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FLASH TALK Tuesday 15 September · 12:40–12:50

Characterizing the Kirkwood-Dirac distribution via quantum conditional expectations

Matéo Spriet, Raymond Brummelhuis, Christopher Langrenez, Stephan De Bièvre

Université de Lille

ABSTRACT

In this talk, I will present how to adapt the classical probabilistic notion of conditional expectation to the quantum context. We will see that the equivalent definitions of the classical conditional expectation give rise to several distinct possible definitions in the quantum framework. The most natural one is to define the quantum conditional expectation of the observable $\hat{X}$ knowing the observable $\hat{Y}$ as that operator $f(\hat{Y})$ which is the best estimator of $\hat{X}$. The so-obtained object relates directly to weak-value physics. Alternatively, one can construct a quantum conditional expectation using an underlying choice of a quasiprobability representation $(Q, \tilde{Q})$ that is compatible with the Born rule. The main result I will present is that these two definitions agree if and only if the chosen quasiprobability representation is the Kirkwood-Dirac distribution.

We will then see how this result can be used in quantum metrology to single out phase insensitive states using the real sector of the Kirkwood-Dirac distribution.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

INVITED Tuesday 15 September · 14:30–15:00

Quantum algorithms for classical dynamics

Matteo Lostaglio

PsiQuantum

With PsiQuantum's application team.

ABSTRACT

The case for quantum computation rests on a simple idea: because Nature is fundamentally quantum mechanical, some physical systems should be more efficiently simulated by quantum computers than by classical ones. This expectation appears especially well founded in quantum chemistry, which is widely regarded as one of the most promising applications of future fault-tolerant quantum computers. However, some of the most consequential simulation problems arise not in quantum systems, but in classical dynamical systems such as fluids and plasmas. To what extent can quantum computers accelerate the simulation of such systems? The answer bears directly on the true scope of quantum advantage and, ultimately, on the breadth of quantum computing applications. In this talk, I will review the current evidence, discuss key open questions, and present ongoing work at PsiQuantum aimed at clarifying where quantum algorithms may offer meaningful improvements for the simulation of classical dynamics.

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CONTRIBUTED Tuesday 15 September · 15:00–15:20

Superradiance and static Bell tests in pilot-wave hydrodynamics

Konstantinos Papatryfonos, Louis Vervoort, Mélanie Ruelle, Corentin Bourdiol, André Nachbin, Valeri Frumkin, Matthieu Labousse, John W. M. Bush

CNRS – IEMN

ABSTRACT

Hydrodynamic pilot-wave systems, in which bouncing or emitted droplets are guided by their self-generated surface waves, provide a classical platform for examining wave–particle duality and quantum-like correlations. Here we summarize recent results on two related manifestations of wave-mediated collectivity. First, numerical and experimental cavity-emission systems exhibit superradiance- and subradiance-like behavior: the presence of a second droplet or emitter can enhance or suppress transition probabilities and emission rates, with a sinusoidal dependence on separation. Second, the same cooperative-tunneling geometry can be used to define static Bell-type tests, where barrier depths act as analyzer settings and droplet positions provide binary outcomes. Because the pilot wave spans the full apparatus, the effective hidden variables associated with the droplet-wave (walker) state depend on the complete geometry of the experiment. Static Bell–CHSH violations therefore arise without invoking superluminal signaling: for a narrow region of parameter space, the coupled system reaches a maximum reported value of $S = 2.49 \pm 0.04$. These results suggest that pilot-wave hydrodynamics can serve as a testbed for identifying which aspects of superradiance and Bell-type correlations are intrinsically quantum, and which may arise more generally from classical wave-mediated dynamics.

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FLASH TALK Tuesday 15 September · 15:20–15:30

The Power of Power-of-SWAP: Postselected Quantum Computation with the Exchange Interaction

Jedrzej Burkat, Sergii Strelchuk, Michal Studzinski

Cavendish Laboratory, University of Cambridge

ABSTRACT

We introduce Exchange Quantum Polynomial Time (XQP) circuits, which comprise quantum computation using only computational basis SPAM and the isotropic Heisenberg exchange interaction. Structurally, this sub-universal model captures decoherence-free subspace computation without access to singlet states. We show that XQP occupies an intermediate position between BPP and BQP, as its efficient multiplicative-error simulation would collapse the polynomial hierarchy to its third level. We further provide evidence that additive-error simulation of XQP would enable efficient additive-error simulation of arbitrary BQP computations. Remarkably, the restricted family of XQP circuits consisting solely of √SWAP gates remains hard to simulate to multiplicative error. We additionally prove that circuits generated by √SWAP gates are semi-universal, generate t-designs for the uniform distribution over SU(2)-invariant unitaries, and maximise the entangling power within XQP. Finally, we derive structural results linking computational basis states in XQP to the Gelfand-Tsetlin basis of the symmetric group, and expressing XQP output probabilities as partition functions of the six-vertex and Potts models. Our findings indicate that XQP circuits are naturally suited to near-term hardware and provide a promising platform for experimental demonstrations of quantum computational advantage. Our paper is available at https://arxiv.org/abs/2603.28527.

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CONTRIBUTED Tuesday 15 September · 15:30–16:00

Beyond Boundary Conditions: Generalised Theories of Quantum Cosmology

Adrian Kent

DAMTP, University of Cambridge

ABSTRACT

Time-symmetric cosmological theories, in which the initial and final states are arranged to have similar features or are independently fixed, have been quite extensively discussed in the literature. However, a more general and perhaps more useful possibility has been surprisingly neglected. Quantum cosmology, like any inherently probabilistic dynamical theory, can be modified by conditioning on the occurrence of a sequence of cosmological events fixed a priori and independently of the hamiltonian and initial state. These more general theories provide a natural class of alternatives which should eventually be useful in quantifying how well the hypothesis that initial conditions suffice is supported by the data. Such theories allow laws that causes the evolution of the universe to tend to follow particular types of path. I give simple illustrations in toy models and discuss how Kolmogorov complexity characterises the extent to which hodological laws explain, rather than merely describe, data. I also discuss motivations for some models of this type.

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KEYNOTE Wednesday 16 September · 09:30–10:20

A hidden variable model for universal quantum computation with magic states on qubits

Robert Raussendorf

Leibniz Universität Hannover

ABSTRACT

We show [1] that every quantum computation can be described by Bayesian update of a probability distribution on a finite state space. When applied to the model of quantum computation with magic states, the size of this state space only depends on the number of magic states used in the quantum computation, and not on the length of the gate and measurement sequence.

Priori, this looks quite puzzling. But there is no contradiction with the no-go theorems of the area — Kochen-Specker, Gleason, PBR. The important point is that measurements are restricted to Pauli observables, which however does not affect computational universality.

The probabilistic state update under measurement proceeds in the so-called Lambda-polytope, the extremal vertices of which are of special interest. In this talk I discuss what has recently been figured out about them [2], [3].

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CONTRIBUTED Wednesday 16 September · 10:20–10:40

Fermionic Insights into Measurement-Based Quantum Computation

Andrew Zhao, Brent Harrison, Vishnu Iyer, Ojas Parekh, Kevin Thompson

Sandia National Laboratories

ABSTRACT

Measurement-based quantum computation (MBQC) is a strong contender for realizing quantum computers. A critical question for MBQC is the identification of resource graph states that can enable universal quantum computation. Any such universal family must have unbounded entanglement width, which is equivalent to the ability to produce any circle graph state from the states in the family using only local Clifford operations, local Pauli measurements, and classical communication. Yet, it was not previously known whether or not circle graph states themselves are a universal resource. We show that, in spite of their expressivity, circle graph states are not efficiently universal for MBQC (i.e., assuming $\mathsf{BQP} \neq \mathsf{BPP}$). We prove this by articulating a precise graph-theoretic correspondence between circle graph states and a certain subset of fermionic Gaussian states. This is accomplished by synthesizing a variety of techniques that allow us to handle both stabilizer states and fermionic Gaussian states at the same time. As such, we anticipate that our developments may have broader applications beyond the domain of MBQC as well.

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CONTRIBUTED Wednesday 16 September · 10:40–11:10

Tight Entropic Uncertainty Relations

Lorenzo Maccone, Alberto Riccardi

Università di Pavia

ABSTRACT

Entropic uncertainty relations H(A)+H(B)>g give a nonzero lower bound g to the sum of the Shannon entropies H of the outcome probabilities of incompatible observables A and B. They are better than the variance-based uncertainty relations because they only depend on the Born statistics of the outcomes and not on the outcomes themselves, and because bounds g typically are state independent. Here we provide a state-independent lower bound g_s that is better than the textbook Maassen-Uffink bound and, in the limit of the parameter s->2, becomes asymptotically tight for all A,B. The bound can be extended to Renyi entropies.

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INVITED Wednesday 16 September · 11:40–12:10

Quantum advantage and classical simulation of continuous-variable quantum computers

Giulia Ferrini

Chalmers University of Technology

ABSTRACT

Continuous-variable (CV) systems—described by observables with continuous spectra, such as the position and momentum quadratures of bosonic fields—are attracting increasing interest as a platform for scalable and fault-tolerant quantum computing. In this talk, I will discuss tools to investigate the boundary between classes of CV quantum circuits that admit efficient classical simulation and those capable of providing a quantum computational advantage. I will then present recent results on the classical estimation of output probability distributions for both discrete- and continuous-variable quantum circuits, highlighting the conceptual connections between these approaches.

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CONTRIBUTED Wednesday 16 September · 12:10–12:30

Basis-independent stabilizerness and maximally noisy magic states

Jack Davis, Michael Zurel

INRIA

ABSTRACT

Absolutely stabilizer states are those that remain convex mixtures of stabilizer states after conjugation by any unitary. Here we give a characterization of such states for multiple qudits of all prime dimensions by introducing a polytope of their allowed spectra. We illustrate this through the examples of one qubit, two qubits, and one qutrit. In particular, the set of absolutely stabilizer states for a single qubit is a ball inscribed in the stabilizer octahedron, but for higher dimensions the geometry is more complicated. For odd-prime-dimensional qudits, we also give a complete characterization of absolutely Wigner-positive states, i.e., states whose Wigner function remains nonnegative after conjugation by any unitary. In so doing, we show there are absolutely Wigner-positive states that are not absolutely stabilizer, which can be seen as a unitarily invariant version of bound magic. We then study the radii of the largest balls contained in the sets of absolutely stabilizer states and absolutely Wigner-positive states. These radii respectively tell us the lowest possible purity of nonstabilizer and Wigner-negative states. Conversely, we also find the radius of the smallest ball containing the set of absolutely Wigner-positive states, giving a tight purity-based necessary condition thereof.

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FLASH TALK Wednesday 16 September · 12:30–12:40

Equivalence of continuous- and discrete-variable gate-based quantum computation

Cameron Calcluth, Alex Maltesson, Ludvig Rodung, Niklas Budinger, Giulia Ferrini

University of Oxford

ABSTRACT

Continuous systems are studied in many branches of modern physics, such as high-energy physics, cosmology, condensed matter physics, quantum chemistry, and field theories. Such systems are expected to benefit from the substantial advantages in computational power of quantum computers. The continuous-variable paradigm of quantum computation provides the most natural computational formalism for these tasks. However, most existing quantum hardware is based on discrete-variable systems. In this work, we address this fundamental discrepancy by providing a rigorous framework for translating native continuous-variable algorithms onto qubit-based quantum processors. This mapping is constructed from a gate-based model of continuous-variable quantum computers, consisting of states and operations whose total energy is polynomial in the number of modes. Gate-based continuous-variable operations refer to the operations that are constructed from a polynomial sequence of elementary gates in a finite set, i.e., those selected from the set of Gaussian operations and cubic phase gates. We employ the stabilizer subsystem decomposition [1] to find the error of approximating continuous-variable quantum computers with discrete-variable ones. This framework allows us to conclude that, under realistic constraints, a gate-based model of continuous-variable quantum computers can be efficiently simulated using discrete-variable devices, which simultaneously establishes a computational equivalence between these paradigms.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

FLASH TALK Wednesday 16 September · 12:40–12:50

Playing Bayesian games better with separable quantum states than with classical resources

Yaqing Wang, Andreas Winter, Giannicola Scarpa

University of Cologne

ABSTRACT

Bayesian games, also known as games with incomplete information, are a fruitful arena for testing out the impact of correlations on a set of independent agents (players) via the game equilibria to which they give rise. It was realised some time ago that quantum states shared between the players can lead to new and beneficial equilibria, compared to classical correlation. While until now examples of this effect required an entangled state, here we show that even separable states can create new, genuinely quantum equilibria in games, that are advantageous with respect to all classically correlated equilibria. This shows that non-classical correlations beyond entanglement are indeed a resource, even in otherwise entirely classical situations. Our result brings quantum advantage in games significantly closer to possible realisation. It also illuminates and differentiates the existing hierarchy of “legitimate notions of equilibrium” in Bayesian games.

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INVITED Wednesday 16 September · 14:30–15:00

Purifying Quantum States: New Protocols and Fundamental Limits

Iman Marvian
Duke University

ABSTRACT

Purifying quantum states is a basic task at the intersection of quantum information, thermodynamics, and quantum foundations: given many noisy copies of an unknown quantum state, how well can one transform them into fewer states of higher purity, and what fundamental principles determine the optimal limits? In this talk, I will give an overview of a series of recent works addressing this question for unknown quantum states under different symmetry assumptions. Remarkably, these works reveal that the performance of optimal purification protocols is governed by a lesser-known quantum Fisher information metric: the right-logarithmic-derivative Fisher information metric. I will then introduce new protocols for purifying unknown qubit states, including an optimal protocol based on random SWAP tests. Finally, I will discuss an analogous purification problem for coherent states of light, and more generally bosonic systems, where we study the distillation of coherent thermal states under phase-insensitive operations and identify asymptotically optimal protocols.

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CONTRIBUTED Wednesday 16 September · 15:00–15:30

Quantum metrology and quantum computing - a non-obvious, but fruitful relationship

Rafal Demkowicz-Dobrzanski

University of Warsaw

ABSTRACT

Fundamental bounds of Quantum metrology allow to impose restirctions on efficiency of some quantum algorithms, e.g. Grover algorithm with noisy oracles, as well as on efficiency of quantum error-correcting codes. On the other hand, quantum-error correction based metroloigcal protocols allow to reach optimal sensing precision allow by fundamental metrological bounds in presence of noise.

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FLASH TALK Wednesday 16 September · 15:30–15:40

Logical Bell Inequalities for Wigner Negativity and Non-Stabilizer Resources

Sanchit Srivastava, Cihan Okay, Selman Ipek, Amolak Ratan Kalra, Shohini Ghose

Institute for Quantum Computing, University of Waterloo

ABSTRACT

Wigner-function negativity is a central signature of non-classicality in the stabilizer formalism and a resource for quantum computation. We present a family of logical Bell inequalities for multi-qudit systems with odd-prime local dimension d. For any k-qudit marginal ($1 \leq k < n$), violation of the corresponding inequality is equivalent to Wigner negativity of that marginal at a specified phase-space point. The witness operator underlying each inequality is, up to normalisation, a Gross discrete Wigner phase-point operator, and the degree of violation gives a quantitative lower bound on the contextual fraction of the marginal state. This provides a concrete way to compare two complementary views of the same resource: contextuality, captured operationally by Bell-type violations, and quantum magic, captured by negativity based monotones such as mana. We will present the construction and discuss ongoing work using these lower bounds to relate contextual fraction to resource measures that appear in magic-state protocols. The broader aim is to turn contextuality witnesses into quantitative tools for studying when non-classical states can be useful for quantum information processing, including tasks such as magic-state distillation.

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CONTRIBUTED Wednesday 16 September · 15:40–16:00

The Quantum Plumber's Problem

Jonte R. Hance, Nicolas Underwood, Holger F. Hofmann

Newcastle University

ABSTRACT

Recent work quantified the notion of quantum counterfactual gain—the advantage quantum interaction-free measurement gives over classical (un-interfering particle-type) strategies for identifying the presence or absence of an absorber in a given path. Using a recent analysis of the relation between states in the five measurement contexts for a three-level system, we here extend this work to identifying quantum advantage in a new scenario, which we term the "quantum plumber's problem". In this scenario, we imagine a "quantum plumber", who knows that one path of an interferometer is blocked, but wants to find the optimal strategy for identifying *which* path this is. We quantify the advantage that the use of quantum resources (beyond either interference-free particles or weak coherent states) gives the plumber, and present strategies for determining the optimal input state for the interferometer for performing such a task.

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KEYNOTE Thursday 17 September · 09:30–10:20

Photonic Quantum Machine Learning

Gerard Milburn, Joshua Burns

National Quantum Computing Centre

ABSTRACT

We describe a quantum recurrent neural network based on single-photon pulses generated and stored in a quantum memory using; (i) optomechanics, (ii) trapped atoms. We do not make the semiclassical approximation thereby enabling a treatment for Fock state signal input. When combined with Fock state time-bin encoding, this is a primitive for quantum machine learning hardware node in a recurrent neural network (RNN) state space model. The semiclassical model using coherent pulses is contrasted with the higher dimensional models enabled using Fock sate pulses. In the quantum case,the number of hidden state space variables increases quadratically with Fock number. We illustrate how the RNN model can be trained as a sensor or time series predictor

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

CONTRIBUTED Thursday 17 September · 10:20–10:40

The Circuit Gauge Operator Formalism and Applications

Ben Criger, Shival Dasu

Quantinuum

ABSTRACT

Quantum circuits are used broadly to represent programs in quantum computing. They are also increasingly being used as toy models of physical phenomena, with phase transitions in monitored circuits being a recent example.

Each operation (state prep, destructive/non-destructive measurement, or unitary gate) within a circuit possesses a gauge group; a set of operators that, if applied around the operation, result in an effectively identical circuit. These gauge operators have previously been used by Bacon, et al to reduce fault-tolerant quantum circuits to quantum subsystem codes, facilitating formal analysis. Recently, we have developed a formal, iterative process for promoting non-fault-tolerant circuits to fault-tolerant ones, in both the Gottesman-Knill and dihedral efficient sub-theories of quantum mechanics.

In this (somewhat pedagogical) presentation, I will derive circuit gauge operators 'from scratch', discuss how they can be used to incrementally construct fault-tolerant quantum circuits, and outline their connection with the ZX calculus. It is my hope that this powerful formalism can find diverse applications outside of fault-tolerant quantum computing.

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INVITED Thursday 17 September · 10:40–11:10

Thermodynamic implications of measured quantum systems

Andrew Jordan

Chapman University

ABSTRACT

Measurements of operators that do not commute with the Hamiltonian leads to energy exchange between the system and measuring device. I will show how this disordered form of energy can be extracted to create engines or refrigerators. Examples of tunneling particles caught in the act and realized vacuum fluctuations will be given.

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INVITED Thursday 17 September · 11:40–12:10

Quantum archeology: Asking quantum systems how they got to be where they are

Aephraim Steinberg

University of Toronto

ABSTRACT

While quantum particles famously don't follow definite trajectories, there are questions one can ask – experimentally as well as theoretically – about where they have spent their time before being observed. This raises thorny issues about how to talk about the past of a quantum system. The interaction of a resonant laser with a cloud of two-level atoms is so well studied that one would hardly expect it to hold any more mystery, and yet it turns out to still have surprises in store when one considers the effect of post-selection.

I will describe two experiments. In one, we probed how much time atoms are caused to spend in the excited state by a single resonant photon. Specifically, we investigated whether the answer depends on whether the photon in question is transmitted or reflected. Not only is the answer yes, but the result for transmitted photons turned out to be quite unexpected. I will present theory and experiment supporting a provocative connection between the delay time experienced by a pulse and the time atoms spend in the excited state. I will also present some curious results which raise questions about how to think about a photon which is prepared in a narrow frequency mode, but later observed at a particular time.

In the second, I will talk about our measurements of the long-controversial "tunneling time," in which we probed how long ultracold Rubidium atoms spend under a barrier formed by a focused laser beam. More recent theory has led us to the discovery of a new timescale, which we interpret as being related to how long a particle takes to "leak out" from a given position within the barrier.

We acknowledge funding from NSERC, the Fetzer Franklin Fund, the QuEnSi quantum alliance, and the John Templeton Foundation.

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CONTRIBUTED Thursday 17 September · 12:10–12:30

Building adjoint representations for tomography and compilation

Subhayan Roy Moulik, Eric Babson

University of Cambridge

ABSTRACT

We consider a general probabilistic system in which gates act linearly on some infinite-dimensional vector space and factor (densely) through a (compact, simple, connected, Lie) group of dimension m. Then every state and effect give a [0,1]-valued (probability) function on this group. We give a method to reconstruct the adjoint representation of the group, using only m^2 evaluations of the gate sequences. Our method works by choosing well-spread probe elements so that the derivatives of the observable at these points span the Lie algebra, then approximating tangent directions near the identity via iterated commutators of gate words. Conjugation queries then reveal how each gate rotates the tangent space, recovering the adjoint action through this embedding. The learned representation enables us to take any (long) gate sequence and replace it with a compiled short sequence (using Solovay-Kitaev process) which will faithfully approximate output probability for any state and effect. Examples of such settings in quantum systems include the restriction of a Hamiltonian to a subspace as in phase estimation, or a 1D-Kitaev spin chain with infinite (rather than two) dimensional state spaces at each of n nodes where the group is SO(n).

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FLASH TALK Thursday 17 September · 12:30–12:40

First-Quantized Electron Scattering Simulations

Chiara Leadbeater, Nathan Fitzpatrick, David Muñoz Ramo, Alex J. W. Thom

Quantinuum, Cambridge, UK · University of Cambridge, UK

ABSTRACT

In conventional quantum chemistry, it is standard to work in the second-quantised representation; fermionic antisymmetry is encoded directly in the algebra of creation and annihilation operators, avoiding explicit construction of Slater determinants and restricting the problem to the antisymmetric subspace of dimension $\binom{N}{\eta}$, rather than the full N^η space.

Accordingly, many early quantum algorithms for chemistry adopt this framework, mapping fermionic operators to Pauli operators while preserving the structure of Fock space. In such encodings, the qubit cost scales linearly with the number of orbitals, typically requiring one qubit per orbital.

Recently, there has been growing interest in first-quantised approaches, motivated by improved qubit efficiency. In this setting, the Hilbert space is constructed by explicitly tracking each particle, forming a tensor product of single-particle spaces of total dimension N^η. Representing this space requires $\eta \log_2 N$ qubits.

In this work, we develop quantum circuits to simulate a simple fermionic scattering experiment using a first-quantised framework. Our method employs a Trotterised split-operator quantum Fourier transform (SO-QFT) scheme [1,2,3], alternating between real- and reciprocal-space representations where potential and kinetic operators are diagonal. We demonstrate the practical viability of this method by executing the resulting circuits on the Quantinuum Helios quantum hardware.

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FLASH TALK Thursday 17 September · 12:40–12:50

Precision bounds for multiple currents in open quantum systems

Saulo Moreira, Marco Radaelli, Alessandro Candeloro, Felix Binder, Mark T. Mitchison

Trinity College Dublin

ABSTRACT

Thermodynamic (TUR) and kinetic (KUR) uncertainty relations are fundamental bounds constraining the fluctuations of current observables in classical, nonequilibrium systems. Several works have verified, however, violations of these classical bounds in open quantum systems, motivating the derivation of new quantum TURs and KURs that account for the role of quantum coherence. Here, we go one step further by deriving multidimensional KUR and TUR for multiple observables in open quantum systems undergoing Markovian dynamics. Our derivation exploits a multiparameter metrology approach, in which the Fisher information matrix plays a central role. Crucially, our bounds are tighter than previously derived quantum TURs and KURs for single observables, precisely because they incorporate correlations between multiple observables. We also find an intriguing quantum signature of correlations that is captured by the off-diagonal element of the Fisher information matrix, which vanishes for classical stochastic dynamics. By considering two examples, namely a coherently driven qubit system and the three-level maser, we demonstrate that the multidimensional quantum KUR bound can even be saturated when the observables are perfectly correlated.

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INVITED Thursday 17 September · 14:30–15:00

Robust control at the quantum speed limit from geometric space curves

Edwin Barnes

Virginia Tech

ABSTRACT

Future technologies such as quantum computing, sensing and communication demand the ability to control microscopic quantum systems with unprecedented speed and accuracy. Control errors and environmental noise are among the primary obstacles to realizing these applications. I will present a theoretical framework for deriving control waveforms that dynamically combat errors and decoherence. This theory exploits a rich geometrical structure hidden within the time-dependent Schrödinger equation in which quantum evolution is mapped to geometric space curves. I will discuss the application of this technique to the design of gates for superconducting, semiconducting, and atomic qubits. I will also discuss what space curves tell us about the speed limit of quantum logic gates.

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[2] https://arxiv.org/abs/2504.09767

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CONTRIBUTED Thursday 17 September · 15:00–15:20

Device-Independent Quantum Key Distribution with a Single Measurement per Site

Raffaele D'Avino, Lorenzo Caramelli, Raja Yehia, Gabriel Senno, Roberto González Pousa, Antonio Acín, **Tamás Kriváchy**

ETH Zürich

ABSTRACT

It has long been thought that in order to observe Bell nonlocality between two parties, they must change their measurement settings, i.e. use "inputs" to their measurement devices. In recent years, it has been realized that in causally constrained networks, nonlocality manifests even if each party uses the same measurement setting (has no inputs). Creating applications based on this effect is met with skepticism due to the stringent requirements on the causal network structure. We provide an example for a device-independent quantum key distribution (DIQKD) protocol which uses only a single measurement setting per site, a first of its kind. We do this by relying on the topological robustness of network nonlocality, allowing the protocol to be secure even in large networks, where one may not be able to assume the exact causal structure. Our results allow to view device-independent quantum key distribution on networks in a different light, relying on foundationally intriguing effects from nonlocality and entangling measurements on networks. Finally, we identify a scenario where our protocol could be useful, as the correlations among all parties can be built up and stored classically, and only later must the network decide which parties establish a secret key.

REFERENCES

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FLASH TALK Thursday 17 September · 15:20–15:30

Competing orders in excitonic insulators

Lara Suárez García, Nigel Cooper

TCM Group, Cavendish Laboratory, University of Cambridge

ABSTRACT

Excitonic insulators are characterized by the spontaneous formation of bound electron-hole pairs, which drive a transition to an insulating phase. They are conventionally described using a BCS-like mean-field theory, which is often incomplete, as it neglects the possibility of competing quantum orders outside the primary electron-hole pairing channel. In this work, we investigate the impact of multiple competing orders on the mean-field description of the excitonic insulating phase. To achieve this, we develop a fully particle-hole symmetric analytic framework based on the weighted Hartree-Fock-Bogoliubov method, systematically accounting for three distinct competing channels: charge density (Hartree), excitonic pairing (Fock), and electron-electron pairing (Bogoliubov). By deriving the multi-channel mean-field equations and calculating the ground state energy, we demonstrate that minimizing the system's energy strictly requires the coexistence of more than one non-zero order parameter. These findings show that the conventional single-channel pairing theory is insufficient, and a multi-order approach is required for accurately capturing the elusive physical properties of excitonic insulators.

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FLASH TALK Thursday 17 September · 15:30–15:40

Near-optimal coherent state discrimination via continuously labelled non-Gaussian measurements

James Moran, Spiros Kechrimparis, Hyukjoon Kwon

Korea Institute for Advanced Study

ABSTRACT

Quantum state discrimination plays a central role in quantum information and communication. For the discrimination of optical quantum states, the two most widely adopted measurement techniques are photon detection, which produces discrete outcomes, and homodyne detection, which produces continuous outcomes. While various protocols using photon detection have been proposed for optimal and near-optimal discrimination between two coherent states, homodyne detection is known to have higher error rates, with its minimum achievable error rate often referred to as the Gaussian limit. In this work, we demonstrate that, despite the fundamental differences between discretely labelled and continuously labelled measurements, continuously labelled non-Gaussian measurements can also achieve near-optimal coherent state discrimination. We design two discrimination protocols that surpass the Gaussian limit: one using non-Gaussian unitary operations with homodyne detection, and another based on orthogonal polynomials. Our results show that photon detection is not required for near-optimal coherent state discrimination and that we can achieve error rates close to the Helstrom bound at low energies with continuously labelled measurements. We also find that our schemes maintain an advantage over the photon detection-based Kennedy receiver for a moderate range of coherent state amplitudes.

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CONTRIBUTED Thursday 17 September · 15:40–16:00

Noisy quantum dynamics and the edge of classical simulations

Cristina Cirstoiu

Quantinuum

This talk is based on work with co-authors as listed in refs. [1] and [3].

ABSTRACT

When does quantum dynamics remain computationally intractable in the presence of noise? At fixed error rates and for broad classes of noisy circuits, observable estimation admits a polynomial-time classical simulation algorithm based on Pauli propagation [1,2] that I will introduce. While it gives a rigorous basis to the intuition that unsuppressed errors make quantum computations easier to simulate classically, the asymptotic results do not settle the finite-size regimes where low error rates, fast operator spreading can still make these classical methods impractical. With recent implementation progress, truncated Pauli propagation emerged as a key classical benchmark for quantum advantage experiments. Improved, high fidelity two qubit gates on Quantinuum's trapped-ion quantum computers have enabled noisy digital quantum simulations that challenge current classical methods, including Pauli propagation, tensor networks and neural networks approaches [3]. After briefly introducing the QCCD architecture, I will present a Trotterised dynamical simulation of the transverse-field 2D Ising model on Quantinuum H2 device, combining error suppression and mitigation. We observe Floquet pre-thermalisation at timescales where state-of-the-art classical simulations become extremely difficult, if not infeasible, for the quenches considered. Finally, based on recent component benchmarking, I will discuss the prospects for quantum simulations using quantum error correction.

REFERENCES

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KEYNOTE Friday 18 September · 09:30–10:20

Photonic resource state factories: controlling matter qubits to produce useful states of light

Sophia Economou

Virginia Tech

ABSTRACT

Entangled photonic 'graph' states are resources for linear-optical quantum computing, quantum networks, and quantum sensing. Generating such states is challenging due to the lack of interactions among photons. Existing approaches rely on probabilistic methods that require heralded measurements and postselection, leading to low generation rates. To overcome this, matter qubits can be leveraged as quantum emitters and mediators of photon-photon interactions. I will discuss my group's contributions and the broader progress toward efficient photonic resource state generation.

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CONTRIBUTED Friday 18 September · 10:20–10:40

Learning from quantum jump trajectories

Felix Binder, Marco Radaelli, Joey Smiga, Gabriel Landi

Trinity College Dublin · Riverlane · University of Rochester

ABSTRACT

If we want to learn the properties of a quantum system we must observe it. Under continuous monitoring such observation gives rise to quantum trajectories which encapsulate complex temporal correlations beyond the i.i.d. assumption.

Here, we introduce a unified framework for parameter estimation in quantum jump trajectories. We show how temporal correlations inherent to single-trajectory data fundamentally alter precision bounds compared to the standard i.i.d. paradigm.

For multi-channel renewal processes, we derive closed-form expressions for the Fisher information by mapping trajectories to an underlying Markov structure. Beyond this regime, we introduce a numerical approach combining monitoring-operator techniques with Gillespie sampling, enabling the evaluation of a trajectory-resolved (stochastic) Fisher information in general non-renewal dynamics. This formulation clarifies how information accumulates along individual quantum trajectories and provides operational meaning in single-shot experiments.

We further quantify the impact of coarse-graining, post-selection, and data compression, identifying regimes where correlations enhance or degrade metrological performance. Our results establish quantum trajectories as a resource for precision measurements in open systems and demonstrate how learning can be achieved in a single-shot and beyond the i.i.d. regime.

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CONTRIBUTED Friday 18 September · 10:40–11:00

Cloning Quantum Channels

Yelena Guryanova

University of Basel / QuantumBasel

ABSTRACT

For states, the no-cloning theorem is one of the first encounters in quantum information: an arbitrary unknown pure state cannot be perfectly copied onto a waiting register. It's clear, then, that cloning N states onto M registers won't work either, but by relaxing the problem to allow for approximate copying, one can investigate the rate and quality of N-to-M cloning. But what if we go further? Can we imagine cloning the cloner? In other words, cloning devices themselves? Questions around states have constituted decades of investigation and were also extended to cloning unitary gates. In this work we pose the question comprehensively and study general quantum channel cloning via ther framework of higher-order quantum operations. We establish necessary conditions for a channel family to exhibit super-replication—those that can be cloned with a quadratic rate at high quality (bounded error). Noisy phase-gates can be super-replicated but the full set of noisy unitaries; classical noise; and amplitude damping channels cannot. We present algorithms that search for cloners and study specific strategies. In many cases, estimating and re-preparing is enough: for the unitaries for which super-replication protocols were known, we construct simpler alternatives, establishing a direct connection between cloning and Bayesian estimation.

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INVITED Friday 18 September · 11:30–12:00

Error mitigation for mid-circuit measurements and feedforward

Jayne Thompson, Jin Ming Koh, Dax Koh

Nanyang Technological University

ABSTRACT

Recent advances in quantum computing have enabled mid-circuit measurements and feedforward, allowing real-time adjustments to quantum circuits based on earlier measurement outcomes. This capability is essential for a wide range of applications, such as measurement-based quantum computing, quantum control, teleportation, circuit stitching and knitting, resource injection, quantum metropolis sampling, amongst many others. As powerful as this technology is, it has an Achillies heel: in practice quantum devices often suffer from significant levels of readout noise, wherein measurement outcomes are inaccurately identified and reported. These mid-circuit readout errors not only corrupt measurement data, but also lead to the execution of incorrect operations later in the computation. This significantly corrupts outcomes.

Here we discuss a general purpose error mitigation method capable of handling these errors and recovering correct outcomes. Our protocol accommodates multiple layers of measurement and feedforward operations, is moderately efficient and necessitates minimal changes to the circuit, and reduces noise by up to 60% in small hardware experiments.

REFERENCES

[1] PRX Quantum 7, 010317

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CONTRIBUTED Friday 18 September · 12:00–12:20

Optimal Hamiltonian control for variational quantum algorithms: on spin-qubit quantum processors

Christopher K. Long, Nicholas J. Mayhall, Sophia E. Economou, Edwin Barnes, Crispin H. W. Barnes, Frederico Martins, David R. M. Arvidsson-Shukur, Normann Mertig

Virginia Tech

ABSTRACT

Variational quantum algorithms (VQAs) were once believed to be the fastest route to demonstrating practical quantum advantage. VQAs use a parameterized quantum circuit to perform a machine-learning task. For example, VQAs can employ the Rayleigh–Ritz method to estimate a molecule's eigenenergies. While VQAs are already used to bootstrap quantum processors, their utility for quantum chemistry tasks has been questioned. The three main concerns are runtime, noise on near-term devices, and optimizability. In this talk, I will present a new approach to VQAs that overcomes all three concerns. To achieve this, coauthors and I replaced the gate-based quantum-circuit approach with a Hamiltonian-control approach tailored to spin-qubit quantum processors. I will present numerical emulations demonstrating a 100-fold acceleration, along with 10^5- and 1000-fold improvements in the required T_1 and T_2^* coherence times, respectively. These improvements bring the device requirements in line with present-day quantum processors. Finally, we retain the optimizability of state-of-the-art adaptive VQE algorithms through adaptive quantum optimal control and careful encoding of molecular Hamiltonians. Specifically, we ensure that the native two-qubit interactions generate the same Lie algebra as time-reversible fermionic excitations within the molecule of interest.

REFERENCES

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FLASH TALK Friday 18 September · 12:20–12:30

A Unified Execution Substrate for Trapped-Ion Moving Qubit ISAs

Scott Jones, Prakash Murali

Department of Computer Science, University of Cambridge

ABSTRACT

Scalable trapped-ion quantum charge-coupled-device (QCCD) architectures are fundamentally constrained by control delivery: each ion transport operation requires coordinated waveform updates across many zones, creating a system-level bottleneck in bandwidth, latency, and power. Existing designs occupy two extremes. Direct-wired QCCD pushes this cost into off-chip communication, leading to prohibitive bandwidth and energy requirements at scale. In contrast, WISE-style shared-DAC architectures eliminate the pin-bandwidth wall but constrain execution to a fixed set of global primitives, reducing achievable logical clock rates.

Underlying both approaches is a common limitation: executing any movement primitive requires expanding a compact description into per-zone control, incurring $\Theta(N)$ work per step and tightly coupling the hardware interface to a specific movement abstraction. At the same time, the field lacks a unified moving-qubit instruction set (ISA), with existing proposals differing widely in granularity and synchronisation while being evaluated under incompatible controller models. We present a QCCD control stack that explores the remaining design point by relocating this $\Theta(N)$ expansion from off-chip communication to cheaper on-chip computation.

On this substrate, we introduce a unified execution model for moving-qubit ISAs and show that a broad class of existing ISAs can be expressed within this model. We build a compiler and cycle-level simulator that lower diverse ISA proposals into this representation, enabling direct, hardware-consistent comparison while decoupling the control interface from any single movement abstraction.

REFERENCES

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[3] https://arxiv.org/abs/2604.19481 (relevant work)

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

INVITED Friday 18 September · 14:30–15:00

Modular 3D-Integrated Superconducting Quantum Devices

Kieran Dalton, Yongxin Song, Graham Norris, Zih-Yang Chen, Ilya Besedin, Johannes Knörzer, Jean-Claude Besse, Andreas Wallraff

ETH Zurich

ABSTRACT

Large-scale quantum computers are expected to benefit from modular architectures, with high-fidelity links between individual modules. We demonstrate single package-scale modularity in superconducting devices using flip-chip bonding, whereby multiple top chips are bonded onto the same carrier chip. This can alleviate finite yield, routing challenges, and correlated errors. We present a six-qubit flip-chip modular device consisting of two three-qubit modules. As a first application, we utilize this device to implement a scalable cross-platform verification protocol, required to efficiently verify the operation of different modules. We show that introducing a high-fidelity inter-module two-qubit gate enables sub-exponential scaling in cross-platform verification, compared to methods using only local operations and classical communication between the modules.

Finally, we use the 3D-integrated platform to develop an XYZ line for multiplexed qubit control, reducing the wiring limitation for large devices.

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CONTRIBUTED Friday 18 September · 15:00–15:20

Singular value transformation for unknown quantum channels

Philip Taranto, Ryotaro Niwa, Zane Rossi, Mio Murao

University of Manchester

ABSTRACT

Given the ability to apply an unknown quantum channel acting on a d-dimensional system, we develop a quantum algorithm for transforming its singular values. The spectrum of a quantum channel as a superoperator is naturally tied to its Liouville representation, which is in general non-Hermitian. Our key contribution is an approximate block-encoding scheme for this representation in a Hermitized form, given only *black-box access* to the channel; this immediately allows us to apply polynomial transformations to the channel's singular values by quantum singular value transformation (QSVT). We then demonstrate an $O(d^3/\delta)$ upper bound and an $\Omega(d/\delta)$ lower bound for the query complexity of constructing a quantum channel that is δ-close in diamond norm to a block-encoding of the unnormalized Hermitized Liouville representation. We show our method applies practically to the problem of learning the q-th singular value moments of unknown quantum channels for arbitrary $q > 2, q \in \mathbb{R}$, which has implications for testing if a quantum channel is entanglement breaking. Our results establish a general framework for manipulating black-box quantum channels with QSVT and related methods, enabling direct evaluation of the channel's spectral properties without tomography or significant classical post-processing.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

FLASH TALK Friday 18 September · 15:20–15:30

Energy landscapes of quantum algorithms in electronic structure and quantum machine learning

Choy Boy, Edoardo Altamura, Dilhan Manawadu, Ivano Tavernelli, Stefano Mensa, Maria-Andreea Filip, David J. Wales

University of Cambridge (Girton College)

ABSTRACT

Variational quantum algorithms (VQAs) are an important class of algorithms that are implementable on near-term quantum computers. They typically require the use of a hybrid quantum-classical interface to optimise a parameterised quantum circuit with unitary $\hat{U}_\theta$ via a given cost function $C(\theta)$ determined by measurement of the Pauli strings comprising the qubit Hamiltonian $\hat{H}_q$. Several challenges continue to persist that attenuate the success of VQAs in harnessing their true potential in obtaining good solutions to the problems they seek to solve. The most commonly cited problem is the emergence of barren plateaus as the size of the quantum circuit increases, and is particularly exacerbated by poor ansatz design and stochastic noise associated with imperfect qubits. Thus, this study aims to broaden the repertoire of VQAs previously explored with energy landscape theory, namely hardware-efficient ansätze and the quantum approximate optimisation algorithm QAOA). Two key areas of expansion include the use of chemically-inspired ansätze in the electronic structure problem, and the use of QML techniques in predicting chemical phenomena.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

FLASH TALK Friday 18 September · 15:30–15:40

Exact Finite-Time Thermalization via Quenching in Coupled Oscillators

Harinarayanan M, Karthik Rajeev

Indian Institute of Technology Madras

ABSTRACT

We present a protocol for the exact thermalization of a quantum harmonic oscillator (QHO) in finite time without invoking a macroscopic reservoir. By employing a single identical auxiliary QHO as a minimal environment and implementing a sudden quench in frequency and mutual coupling, we drive the target system from its ground state to a desired Gibbs state ρ_β. Utilizing the Gaussian nature of the dynamics, we reduce the thermalization condition to a set of three characterization equations for the reduced density matrix. We identify a Special Discrete Set (SDS) of target temperatures—corresponding to commensurate normal mode frequencies, where the system admits exact analytical solutions for the quench parameters ($\tilde{\omega}', \tilde{k}, \tilde{\tau}$). We demonstrate that the SDS is a countably dense subset of the positive real line, ensuring that any target temperature can be reached with arbitrary precision. This approach bypasses the long relaxation times of traditional open-system dynamics, providing a rigorous and experimentally accessible framework for rapid state engineering in platforms such as trapped ions and nanomechanical resonators.

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POSTER Thursday 17 September · 16:00–17:30

Cavity-Mediated All-to-All Connectivity for Neutral Atom Quantum Platforms

Michael Ben Shem, Matthew J. H. Kendall, Jonathan D. Breeze

University College London

ABSTRACT

Scaling neutral atom quantum processors beyond local Rydberg blockade interactions requires a mechanism for fast long-range qubit connectivity. We are developing a hybrid architecture where all-to-all interactions between Rydberg atom qubits are mediated via coherent coupling to a shared microwave mode of a superconducting 3D cavity, implementing a global quantum bus [1]. The effective Hamiltonian generates tuneable all-to-all $iSWAP$ and ZZ entangling interactions without physical shuttling, with gate speeds set by the vacuum Rabi coupling g.

Realising this simultaneously requires high internal quality factor Q, strong g, and electric field homogeneity. We propose a three-dimensional superconducting Niobium cavity architecture achieving $Q > 10^7$ at 4 K with surface treatment, a homogeneous electric mode, and g orders of magnitude larger than recent results with coplanar waveguides [2]. Initial experiments with a helium beam will probe the resonant strong-coupling regime between a 3D cavity and Rydberg atoms for the first time, with direct sensitivity to cavity thermal photon statistics. Further experiments with optically trapped ytterbium atoms in the cavity will demonstrate long-range cavity-mediated entangling gates, exploiting the divalent electronic structure of Yb to maintain trapping throughout the gate [3].

We will discuss the cavity design and fabrication strategy, the path to strong coupling, and prospects for cavity-mediated multi-qubit gates and quantum simulation protocols inaccessible to current atomic architectures.

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POSTER Thursday 17 September · 16:00–17:30

How to unitarily map between any two pure states with a single closed-form exponential

Peter T. J. Bradshaw, Marcus Gouveia, Jonte R. Hance

Newcastle University

ABSTRACT

It is well-known that any two pure quantum states (in the same Hilbert space) can be mapped to any other using unitary transformations. However, previous approaches to this problem required two explicit bases for the Hilbert space, one each for the initial and target states, and thus their complexity necessarily scales with the dimension of the Hilbert space. In this talk, I show how to utilize novel algebraic methods to construct a closed-form exponential unitary transformation which achieves this in general, using only a single unitary generator. This construction is independent of any bases and agnostic to the dimension of the Hilbert space. I highlight the usefulness of this tool for studying relationships between systems of pure states in quantum information theory, as well in elementary analyses of quantum circuits and unitary operators.

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POSTER Thursday 17 September · 16:00–17:30

Sawtooth Wave Adiabatic Passage for a Fully Blue-Detuned MOT

Jiajun Chen

Affiliation to be confirmed

ABSTRACT

We report the realization of a broadband magneto-optical trap (MOT) for ^{88}Sr operating in a fully blue-detuned frequency regime. By spectrally broadening the cooling laser on the narrow-line $^1\mathrm{S}_0$–$^3\mathrm{P}_1$ transition via rapid frequency modulation (Sawtooth Wave Adiabatic Passage) in a completely reversed optical polarization configuration compared to standard MOT, we observe robust laser cooling even when the entire modulation spectrum lies strictly above resonance. We map the trap dynamics as a function of the modulation centre frequency and observe that as the lower bound of the spectrum approaches resonance from the blue, the number of trapped atoms is strongly suppressed. Further downward shifting restores the trap, yielding a distinct double-peak structure in the atom number.

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POSTER Thursday 17 September · 16:00–17:30

Autonomous Quantum Error Correction of Spin-Oscillator Hybrid Qubits

Sungjoo Cho, Ju-yeon Gyhm, Hyukjoon Kwon, Hyunseok Jeong

Seoul National University

ABSTRACT

We construct an autonomous quantum error-correction protocol for a hybrid qubit that encodes quantum information in spin states and oscillator coherent states. The dynamics generated from the engineered dissipation ($\mathcal{L}_{\mathrm{R}} := \kappa_{\mathrm{R}}\mathcal{D}[\hat{\sigma}_z(\alpha - \hat{\sigma}_x\hat{a})]$) continuously stabilizes the code space as a steady-state subspace, thereby exponentially suppressing the logical phase-error rate as the coherent-state amplitude increases. Remarkably, our protocol employs a single correlated jump operator to suppress the phase noise of both the spin and oscillator systems, reducing the resources required for dissipation engineering. We discuss conserved quantities, or elements of the adjoint Liouvillian of the proposed dynamics, to analytically prove the exponential suppression of logical error rates against the amplitude in the rapid stabilization limit. We also show that the proposed dynamics are capable of preserving the metrological capacity of spin-oscillator entangled states, assessed in terms of quantum Fisher information. Furthermore, concatenating the repetition code over dynamically stabilized qubits is capable of achieving fault tolerance against arbitrary local noise. The construction leverages primitives already demonstrated on experimental platforms, such as a controlled beam-splitter operation in trapped-ion systems, suggesting a practical route to hardware-efficient, noise-biased logical qubits without repeated syndrome measurements and feedforward.

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POSTER Thursday 17 September · 16:00–17:30

No-cost Bell nonlocality certification from quantum tomography and its applications in quantum-magic-resource witnessing

Pawel Cieslinski, Lukas Knips, Harald Weinfurter, Wieslaw Laskowski

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ABSTRACT

Tomographic measurements are the standard tool for characterizing quantum states, yet they are usually regarded only as means for state reconstruction or fidelity measurement. Here, we show that the same Pauli-basis measurements (X, Y, Z) can be directly employed for the certification of nonlocality at no additional experimental cost. Our framework allows any tomographic data - including archival datasets – to be reinterpreted in terms of fundamental nonlocality tests. We introduce a generic, constructive method to generate tailored Bell inequalities and showcase their applicability to certify the non-locality of states in realistic experimental scenarios. Recognizing the stabilizer nature of the considered operators, we analyze our inequalities in the context of witnessing quantum magic - a crucial resource for quantum computing. Our approach requires Pauli measurements only and tests the quantum magic solely through the resources present in the state. Violation of the derived Bell inequality stabiliser bound with experimental data confirms the magic nature of the D_4^2 state. Our results establish a universal standard that unifies state tomography with nonlocality certification and its application to quantum magic witnessing, thereby streamlining both fundamental studies and practical applications.

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POSTER Thursday 17 September · 16:00–17:30

Energetic Limits of Quantum Error Correction

Jakub Czartowski, Felix Binder

Trinity College Dublin

ABSTRACT

Quantum error correction (QEC) is central to fault-tolerant quantum computing, yet its fundamental energetic cost remains poorly understood. Existing analyses focus on specific implementations and do not provide general, architecture-independent bounds on energy consumption, see e.g. [1].

We develop a framework for quantifying minimal energy requirements of QEC by separating gate-based costs - such as encoding, decoding, and repeated syndrome-imprinting routines subject to accuracy-energy trade-offs [2] - from thermodynamic costs arising from the inevitability of irreversible syndrome measurement. Focusing on the latter, we derive lower bounds on dissipation for subspace codes by combining the Knill-Laflamme conditions with refined Landauer erasure bounds that remain nontrivial at low temperatures [3]. These bounds relate the minimal energy cost to the entropy of syndrome information - determined by the code, correctable error set, and noise model - that must be irreversibly erased.

For stabiliser codes, we show that code degeneracy reduces this irreducible erasure cost, yielding a fundamental energetic advantage and establishing a direct connection between code structure and thermodynamic efficiency.

Our results provide general limits on the energy consumption of subspace QEC, going beyond protocol-specific analyses [1], and contribute to a thermodynamic understanding of fault-tolerant quantum information processing. These results will be reported in a forthcoming arXiv preprint.

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POSTER Thursday 17 September · 16:00–17:30

Semiclassical gravity: measurements and thermodynamics

Samuel Fedida, Adrian Kent

University of Cambridge

ABSTRACT

We consider a model where classical gravity is coupled to quantum matter via the semiclassical Einstein field equations. We examine the different types of measurements that can be carried out in such a theory and review how classical gravitational field measurements provide a physical realisation of readout devices, which extend quantum theory and imply cloning devices. We show that these need not break fundamental principles, such as no-superluminal signalling nor the second law of thermodynamics, and we introduce a new notion of entropy which extends von Neumann entropy in an operational way whilst avoiding several arguments against nonlinear quantum mechanics found in the literature.

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POSTER Thursday 17 September · 16:00–17:30

Implementation and optimization of a four cities fully meshed quantum network over deployed telecom fiber links

Gilberto Borges, Saeid Salari, Ekta Panwar, Samgeeth Puliyil, Peter Rapčan, Mario Ziman, Djeylan Aktas

Research Center for Quantum Information – Slovak Academy of Sciences (RCQI)

ABSTRACT

The emergence of Quantum Networks (QN) relies on linked quantum systems capable of manipulating, storing, and characterizing quantum-level information. These networks provide a fundamental architecture for transitioning quantum-based solutions into practical large-scale deployments. Significant advances in these infrastructures have recently occurred, with Quantum Key Distribution (QKD) emerging as a primary use case that promises unconditional security based on the laws of quantum physics, referred to as Information Theoretically Secure (ITS). However, scaling symmetric key exchange protocols in modern network infrastructures remains technically challenging and costly.

In this work, we report the development of a quantum network provider (QNP) based on a wavelength multiplexing/demultiplexing strategy. This QNP enables a Quantum Network connecting four cities in western Slovakia in a fully meshed topology without relying on the trusted-node assumption. The network is part of the Slovak quantum network backbone and the EuroQCI initiative. Along with experimental data from laboratory and deployed-network implementations, we present a mathematical formalization for the algorithmic design of entanglement-based fully meshed networks. Our results demonstrate secure key bit rates of up to 800 bits/s for users separated by 64 km over deployed telecommunication fiber and pave the way for tasks beyond QKD.

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POSTER Thursday 17 September · 16:00–17:30

Symmetric $N \to M$ telecloning and remote quantum state inference

Adam G. Hawkins, Hannah McAleese, Mauro Paternostro, Hyukjoon Kwon

Korea Institute for Advanced Study

ABSTRACT

Teleporting unknown quantum states between distant nodes of a network is a significant feature of quantum communication. Fewer studies, however, have been conducted on $N \to M$ telecloning, in which N copies of an unknown quantum state are optimally teleported to $M \geq N$ receivers. Previous works require many-element, non-trivial global POVMs on all copies; here, we show that symmetric $N \to M$ telecloning can be probabilistically performed using only sequential Bell state measurements (BSMs) with auxiliary qubits, allowing the copies to be spatially separated. When successful, the fidelity of each receiver state saturates the bound imposed by the no-cloning theorem, with the probability of success being independent of M. We further show that the teleportation fidelity is likely to still be high in the case of an 'unsuccessful' BSM, with a particular outcome providing information about which axis of the Bloch sphere the unknown state was probably closest to. In this sense, each receiver can remotely infer the unknown quantum state with a level of confidence that scales with the number of copies, even if the fidelity of their own reduced state is sub-optimal. We additionally analyse the required resources to ensure the classical-communication fidelity bound is surpassed.

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POSTER Thursday 17 September · 16:00–17:30

Microwave Cavity–Mediated Long-Range Gates for Neutral-Atom Quantum Computing

Matthew J. H. Kendall, Michael Ben Shem, Jonathan Breeze

University College London

ABSTRACT

Neutral atoms in optical tweezer arrays are a leading platform for universal quantum computing, however non local connectivity provided by atom shuttling has limits on the speed and hence the range of interaction. In this work, we propose an architecture for a neutral atom quantum computer using Ytterbium atoms dispersively coupled to a microwave cavity allowing for fast, cavity mediated long range gates. Operating in the dispersive Tavis-Cummings regime, we show that a cavity-mediated iSWAP gate can be synthesised with experimentally realisable parameters. We derive the dominant error contributions from Rydberg state decay and cavity photon loss, finding that gate fidelity scales as $F \approx 1 - \pi(\kappa\Gamma_r)/g$, and simulate gate performance using the Lindblad master equation. We identify the requirement for Rydberg decay rates below ~20 kHz and show that small coupling inhomogeneities (0-2%) have negligible effect on fidelity. We then assess two quantum computing architectures: a hybrid circuit model combining nearest-neighbour and long-range cavity-mediated gates, and a measurement-based cluster state model. We finally evaluate the impact of cavity mediated gates on low-density parity-check (LDPC) error correcting codes, which require non-local stabilizer measurements.

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POSTER Thursday 17 September · 16:00–17:30

Adiabatic Error Cancellation in Berry Phase Estimation

Chusei Kiumi

The University of Osaka

ABSTRACT

The Berry phase is a geometric quantity acquired under cyclic adiabatic transport, central to modern condensed matter physics: it underpins the classification of topological phases of matter, the modern theory of electric polarization, the anomalous Hall effect, and the quantum geometry of Bloch bands. Its non-abelian generalization—the Wilczek–Zee holonomy—provides the foundation of holonomic quantum computation, where gates inherit intrinsic robustness from their geometric origin. In this work, we show that Berry phase estimation admits a natural and universal adiabatic error-cancellation mechanism, whose robustness makes it a promising candidate for practical quantum computing before full fault tolerance. Concatenating evolutions under $\pm H$ along the loop over adiabatic runtime T cancels the leading $O(T^{-1})$ phase error exactly, and Richardson extrapolation reduces the residual to an oscillatory term with endpoint-controlled coefficient $O(\|\dot{H}(0)\|^2\Delta(0)^{-4}T^{-2})$. Beyond this deterministic cancellation, we establish that, for suitable smooth runtime distributions, runtime randomization suppresses the remaining oscillatory contribution to $O(T^{-M})$ for any fixed M, yielding a randomized Hadamard-test algorithm for Berry phase estimation over the full range $[0, 2\pi)$ with improved runtime scaling under standard sample complexity.

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POSTER Thursday 17 September · 16:00–17:30

Equivalence of axiomatic, microscopic, and operational descriptions of Markovian quantum thermodynamics

Yutong Luo, Jakub Czartowski, Simon Milz, Felix C. Binder

Trinity College Dublin

ABSTRACT

Markovian quantum thermodynamics is commonly formulated in three distinct ways: through axiomatic constraints on Lindbladian dynamics, microscopic models of system–environment interactions, and operational thermodynamic resource theories [1]. Whether these perspectives ultimately describe the same physical processes has remained unclear. Here we establish a structural equivalence between them. Starting from three thermodynamic axioms—Markovianity, time-translation symmetry, and quantum detailed balance—we derive the general form of thermodynamically consistent Lindbladian generators. We then show that these generators arise precisely as the continuous-time limit of energy-conserving thermal collision models [2], providing an explicit microscopic realisation based on repeated system–ancilla interactions. Finally, we show that the dynamical maps generated by these Lindbladians coincide precisely with Markovian thermal operations [3] in the resource-theoretic framework. Together, our results reveal a unifying picture in which axiomatic principles, microscopic dynamics, and operational constraints ultimately select the same dynamical laws for Markovian quantum thermodynamics. Beyond establishing a unified theoretical foundation, our framework enables explicit simulations of open quantum systems and transformations of continuous-time thermal machines into finite-stroke thermal machines, while providing new tools for thermodynamic process design in emerging quantum technologies, including potential applications to thermal-state preparation and quantum Gibbs sampling.

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POSTER Thursday 17 September · 16:00–17:30

Causal Structure from Thermal Constraints in Quantum Processes

Simon Milz, Kyrylo Simonov, Tamal Guha, Saptarshi Roy, Zoltán Zimborás, Giulio Chiribella

Heriot-Watt University, Edinburgh

ABSTRACT

Thermodynamics is among the most successful physical theories, applying universally from microscopic quantum systems to macroscopic phenomena. At the same time, its relation to causality and the emergence of temporal order has long been debated. Here, we extend thermodynamic considerations beyond quantum states and channels to multi-time higher-order quantum processes, where questions of causal structure can be addressed explicitly. In particular, we study "equilibrium" processes that do not contain thermodynamic resources, thereby generalising the notions of Gibbs states and Gibbs-preserving operations to higher-order quantum structures. We find that different notions of thermal compatibility lead to several non-equivalent sets of equilibrium processes – none of which are necessarily causally ordered. Remarkably, the situation changes dramatically when the natural requirement of "complete" thermal compatibility is added. Under this condition, the different classes collapse into a single set of equilibrium superchannels that are both causally ordered and cannot be used to generate athermality. Our results provide first steps towards a consistent thermodynamic description of higher-order quantum processes and identify complete thermodynamic compatibility as a principle enforcing causal structure, revealing a fundamental connection between thermodynamics and causality at the level of quantum processes.

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POSTER
Thursday 17 September · 16:00–17:30

Fast and Reliable Quantum State Tomography

Fabian Müller, Sebastian Murk, Ian Tan, Dominik Šafránek

Department of Condensed Matter Physics, Charles University

ABSTRACT

Precise knowledge of quantum states is essential for quantum computing, communication, and sensing technologies. However, quantum states cannot be measured directly; they must be inferred from measurement outcomes. Quantum state tomography (QST) reconstructs quantum states from such indirect measurements, in a way broadly analogous to how CT imaging combines multiple two-dimensional projections into a three-dimensional model. The goal of QST is to find the quantum state whose predicted measurement statistics best match the experimentally observed data. This typically leads to a nonlinear optimization problem constrained by the physical requirements that quantum states be positive semidefinite and have unit trace. These are known as the density-matrix constraints. We present a Julia implementation that efficiently and robustly minimizes this statistical distance while enforcing these constraints. Our work provides a practical, extensible toolkit for QST and a comparative guide to choosing optimizer based on accuracy, speed, and robustness.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

POSTER Thursday 17 September · 16:00–17:30

Approaching the Limit of Quantum Clock Precision

Chad Nelmes

University of York

ABSTRACT

Precise and autonomous clocks are of fundamental interest to both foundational physics and quantum technologies. A key limitation in timekeeping arises from the trade off between precision and resolution in memoryless ticking processes with irreversible dynamics. Recent work has established a fundamental precision–resolution trade off (PRT), which bounds the maximal achievable precision of independent and identically distributed (i.i.d.) ticks with intrinsic rate Γ [1]. Furthermore, while optimized ring-clock protocols have shown that precision is not strictly limited by the second law of thermodynamics [2], the scaling remains well within the PRT bound.

In this work [3], a blueprint is presented for an autonomous quantum clock governed by time independent interactions. By introducing a modified perfect state transfer (PST) spin chain configuration, engineered coherent transport is exploited in dissipative spin systems. This architecture is shown to achieve the optimal scaling predicted by the PRT upper bound. Additional evidence is provided that this configuration is robust to imprecise dynamical detachment protocols, with particular relevance to superconducting platforms. These results provide a practical route toward saturating fundamental quantum limits of timekeeping without the need for external driving, while remaining compatible with realistic experimental implementations.

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FOUNDATIONS OF QUANTUM TECHNOLOGIES Girton College, Cambridge | 15–18 September 2026

POSTER Thursday 17 September · 16:00–17:30

Exploiting Decoherence for Efficient Simulation of Quantum Brownian Motion

Matthew Ord

University of Cambridge

ABSTRACT

An adsorbate on a surface is fundamentally an open quantum system, where its dynamics and ultimate transition to classical behaviour are driven by interactions with the surrounding environment. As the quantum analogue of the Langevin equation, the Caldeira Leggett Model provides a formally exact description of a quantum system connected to an ohmic environment [1]. The model is however expensive to simulate directly, which limits the application of the theory to the study of experimentally relevant systems. Previous work [2] has therefore been limited to the study of simple 1d analogue systems.

The computational bottleneck arises because current algorithms scale poorly with system size. In quantum surface diffusion the simulation size is large, as it must span the entire region of the surface accessible to the adsorbate. To overcome the scaling issues, we introduce a new “local basis” approach to simulating quantum diffusion which eliminates scaling with system size. By exploiting the inherent decoherence in these systems, our method reduces simulation costs by several orders of magnitude without sacrificing accuracy.

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POSTER Thursday 17 September · 16:00–17:30

Sample- and Hardware-Efficient Fidelity Estimation by Stripping Phase-Dominated Magic

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ABSTRACT

Direct fidelity estimation (DFE) is a famous tool for estimating the fidelity with a target pure state. However, such a method generally requires exponentially many sampling copies due to the large magic of the target state. This work proposes a sample- and gate-efficient fidelity estimation algorithm that is affordable within feasible quantum devices. We show that the fidelity estimation with pure states close to the structure of phase states, for which sample-efficient DFE is limited by their strong entanglement and magic, can be done by using $\mathcal{O}(\mathrm{poly}(n))$ sampling copies, with a *single* n-qubit fan-out gate. As the target state becomes a phase state, the sampling complexity reaches $\mathcal{O}(1)$. Such a drastic improvement stems from a crucial step in our scheme, the so-called phase stripping, which can significantly reduce the target-state magic induced by varying phases on the computational basis. Furthermore, we convert a complex diagonal gate resource, which is needed to design a phase-stripping-adapted algorithm, into nonlinear classical post-processing of Pauli measurements so that we only require a single fan-out gate. Our method offers a significant reduction in sampling overhead for fidelity estimation under limited gate resources, thereby enabling noise-resilient quantum algorithms and communications.

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Measurement driven thermalisation and anti-thermalisation dynamics

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ABSTRACT

On macroscopic scales, an object in thermal contact with a bath via a lead thermalises to the bath temperature, yet this simple process is surprisingly non-trivial to study in quantum systems. Crucially, performing a projective measurement in itself is capable of pumping energy into or removing energy out of a quantum system.

We investigate the behaviour of a quantum system coupled to a thermal bath through an intermediate lead. Under a specific interaction between the system and the lead we realise thermalisation-like dynamics where the system temperature tends towards the bath's spin temperature. Furthermore, we demonstrate how changing the interaction form allows us to exploit non-energy conserving measurements to drive anti-thermalisation dynamics, where the system equilibrates to the population inverse of the bath's spin temperature.

We experimentally realise both dynamics at room temperature using a nitrogen vacancy (NV) electronic spin as the lead qubit and a single ^{13}C nuclear spin as the system qubit. The interaction Hamiltonians are realised through pulse based Hamiltonian engineering.

Analysing our protocol's thermodynamic contributions allows us to account for the energy change in the system under both dynamics. Finally, we comment on potential applications and fundamental insights we can probe using our experiment.

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Characterizing quantum channels from local-unitary invariants

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ABSTRACT

Full reconstruction of quantum channels is resource-intensive, motivating the need for scalable alternatives for their characterization. One approach is to characterize via selected properties. A prominent example is the entangling power [1] which classifies quantum gates according to their entangling capability [2]. However, it is not injective, is restricted to unitary channels, and requires optimization over input states.

In this work, we develop a state-independent framework based on local-unitary (LU) invariants [3,4] that generalizes the entangling power to non-unitary channels and extends it by providing additional information about the channel. By deriving a set of polynomial LU invariants in terms of channel parameters, we establish explicit criteria distinguishing two-qubit channels according to their ability to create, preserve, or break the entanglement. We further show that combining invariants of different orders and channel models provides improved characterization of two-qubit channels, distinguishing channels beyond what the entangling power and related methods can resolve. The framework provides a more general and scalable approach to characterizing entanglement properties in experimentally relevant noisy quantum channels, with a natural extendibility to multi-qubit systems.

Manuscript in preparation.

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Space-Time Optimisations for Early Fault-Tolerant Quantum Computation

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ABSTRACT

Fault-tolerance is the future of quantum computing, ensuring error-corrected quantum computation that can be used for practical applications. Resource requirements for fault-tolerant quantum computing (FTQC) are daunting, and hence, compilation techniques must be designed to ensure resource efficiency. There is a growing need for compilation strategies tailored to the early FTQC regime, which refers to the first generation of fault-tolerant machines operating under stringent resource constraints of fewer physical qubits and limited distillation capacity. Present-day compilation techniques are largely focused on overprovisioning of routing paths and make liberal assumptions regarding the availability of distillation factories. Our work develops compilation techniques that are tailored to the needs of early FTQC systems, including distillation-adaptive qubit layouts and routing techniques. In particular, we show that simple greedy heuristics are extremely effective for this problem, offering up to 60% reduction in the number of qubits compared to prior works. Our techniques offer results with an average overhead of 1.2X in execution time for a 53% reduction in qubits against the theoretical lower bounds. As the industry develops early FTQC systems with tens to hundreds of logical qubits over the coming years, our work has the potential to be widely useful for optimising program executions.

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From Fermionic Mode Entanglement to Effective Flying Qubits

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ABSTRACT

Recent breakthroughs in electron quantum optics have enabled unprecedented control over the generation of quantum electrical currents based on single- to few-electron excitations [1,2]. These advances open the door to high-precision applications, ranging from time-resolved sensing of electromagnetic fields [2,3] to the manipulation of electronic flying qubits [4]. However, exploiting fermionic channels for quantum information processing requires realistic modeling of interaction processes and entanglement between electronic wave packets propagating in distinct channels. A key ingredient is fermionic mode entanglement, constrained by superselection rules, from which an effective qubit description can be extracted.

In this talk, we introduce a method to derive a flying-qubit model from interacting electronic modes [5]. Our approach provides a direct and quantitative bridge between electronic transport models of concrete experimental setups and an effective qubit description, while consistently incorporating decoherence and relaxation effects [6].

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POSTER Thursday 17 September · 16:00–17:30

Classification of five-qubit absolutely maximally entangled states

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ABSTRACT

We classify the local unitary equivalence classes of absolutely maximally entangled (AME) states of five qubits. We show that every 5-qubit AME state is equivalent to a state within the unique $((5, 2, 3))$ quantum error-correcting code $\mathcal{C}$, and that two such states are equivalent if and only if they are related by the action of a transversal gate of $\mathcal{C}$. Furthermore, we exhibit a set of three invariant polynomials that separates these equivalence classes. The classification reveals deep interconnections between r-uniform states, quantum error correcting codes, and Vinberg's theory of graded Lie algebras.

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Entropy conservation as a symmetry and physical justification of unitary evolution

Nicolas Underwood

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ABSTRACT

Unitary evolution is justified through a number of related symmetry theorems, the best known of which are Wigner's theorem and Kadison's theorem. However all such theorems assume reversibility of transformations. We introduce a new symmetry theorem demonstrating that entropy conservation (plus a few basic probability rules) is sufficient to determine unitary evolution. Through understanding entropy as a scalar measure of "information", our theorem provides a physical justification for reversibility in quantum mechanics. This means no-go theorems traditionally proven through the need to break unitarity may instead by motivated by the need to create or destroy information. It may also help inform information theoretic reconstructions of QM (GPTs), and guide efforts to understand exotic relativistic and gravitational scenarios in which unitarity (and therefore entropy) may need to be modified.

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Dipolar Ising coupling between electron and hole spin qubits in ambipolar SiMOS quantum dots

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ABSTRACT

Spin qubits in silicon combine long coherence times with CMOS compatibility, but electrons and holes offer complementary strengths—weak charge-noise coupling and high-fidelity shuttling for electrons, and fast all-electrical control for holes [1, 2, 3]. Ambipolar devices that confine both types of carriers could enable a “best of both worlds” approach, however, engineering an electron-hole spin coupling mechanism is challenging. Coupling an electron qubit to a hole qubit lies outside the reach of exchange coupling, since the electrostatic profile of the confinement potentials leads to exponentially suppressed wavefunction overlap. We propose a longer-ranged electric dipole-dipole interaction coupling electron and hole qubits in neighboring double quantum dots biased near their symmetric points (DQDs), where spin-conditioned charge displacements yield a static Ising (ZZ) interaction. We develop a theory for this spin-electric dipole coupling, extract the geometry-specific electrostatic screening factor from Schrödinger-Poisson simulations of an ambipolar SiMOS device, and derive closed-form scaling laws for the tunnel couplings that optimize the control-Z (CZ) gate under quasistatic $1/f^{\alpha}$ charge noise. We show that sub-100-ns CZ gates with greater than 0.99 unitary fidelity are achievable, robust across the experimentally measured noise-color range. A hole-conditioned splitting of the electron spin resonance (ESR), $\Delta f = 4f_{zz}$, provides an experimental signature.

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