QPL 2026 program (17 – 21 August 2026 in Amsterdam, NL)

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Overview of the program

Welcome to Amsterdam! Registration opens at 8:50 AM on Monday, August 17, at the University of Amsterdam's Roeterseiland campus. The conference runs through Friday, August 21, 2026, with three parallel sessions each afternoon. On Wednesday, there is a boat tour and conference dinner after the parallel sessions. On Thursday, a career fair follows the parallel sessions.

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Monday, August 17th

8:50 – 9:30	Registration
Long plenary talks Room A0.01	
9:30 – 10:15	Alex Maltesson, Ludvig Rodung, Niklas Budinger, Giulia Ferrini, Cameron Calcluth **Equivalence of continuous- and discrete-variable gate-based quantum computers with finite energy**
10:15 – 11:00	Raphaël Mothe, Jessica Bavaresco **Efficient quantum-circuit simulation of classical control of causal order**
Coffee break	
Short plenary talks Room A0.01	
11:30 – 11:55	Vinicius Pretti Rossi, Beata Zjawin, Roberto D. Baldijão, David Schmid, John H. Selby, Ana Belén Sainz **How typical is contextuality?**
11:55 – 12:20	Dichuan Gao, Razin A. Shaikh, Aleks Kissinger **Graphical algebraic geometry: from ideals and varieties to qudit ZH completeness**
Lunch break	

	Parallel A Room A0.01	Parallel B Room A1.02	Parallel C Room A1.03
14:30 – 14:55	Yìlè Yīng, Maria Ciudad Alanon, Daniel Centeno, Jacopo Surace, Marina Maciel Ansanelli, Ruizhi Liu, David Schmid, Robert Spekkens **On whether quantum theory needs complex numbers: the foil theories perspective**	Tomoaki Kawano, Ryo Kashima **Restricted negation in orthomodular logic**	Alexandre Clément **A complete equational theory for real-Clifford+CH quantum circuits**
14:55 – 15:20	Timothée Hoffreumon, Mischa P. Woods **On the experimental falsification of real QT**	Tim Achenbach, Andreas Bluhm, Leevi Leppäjärvi, Ion Nechita, Martin Plávala **Factorization of multimeters: a unified view on nonclassical quantum phenomena**	Xiaoning Bian, Sarah Meng Li, Neil J. Ross, John van de Wetering, Yuming Zhao **A complete and natural rule set for multi-qudit Clifford circuits in all odd prime dimensions**
15:20 – 15:45	Timothée Hoffreumon, Mischa P. Woods **A real matrix theory consistent with QT**	Bert Lindenhovius, Vladimir Zamdzhiev **Operator spaces, linear logic and the Heisenberg–Schrödinger duality of quantum theory**	Colin Blake **Completeness for prime-dimensional phase-affine circuits**
Coffee break			
16:15 – 16:40	Beata Zjawin, Marina Maciel Ansanelli, David Schmid, Yìlè Yīng, John H. Selby, Ciarán M. Gilligan-Lee, Ana Belén Sainz, Robert Spekkens **The resource theory of causal influence and knowledge of causal influence**	Priyaa Varshinee Srinivasan, Jean-Simon Pacaud Lemay, Robin Cockett **Generalized inverses of quantum channels: a categorical perspective**	Fedor Kuyanov, Aleks Kissinger **Efficient classical simulation of low-rank-width quantum circuits using ZX-calculus**

16:40 – 17:05	Luca Apadula, Alessandro Bisio, Giulio Chiribella, Paolo Perinotti, Kyrylo Simonov **Higher-order transformations of bidirectional quantum processes** Remote	Andre Kornell, Bert Lindenhovius **The category of quantum graphs is closed**	Kwok Ho Wan, Zhenghao Zhong, Ainhoa Zapirain **Simulating magic state cultivation with few Clifford terms** Remote
17:05 – 17:30	Carla Ferradini, Giulia Mazzola, V. Vilasini **Emergent causal order and time direction: bridging causal models and tensor networks**	James Hefford **Nuclearity and trace in monoidal bicategories with application to extended CFTs**	Mark Koch **Classical Clifford+T sampling without computing marginals**

Tuesday, August 18th

Long plenary talks **(merged)** Room A0.01	
9:30 – 10:15	Benjamin Rodatz, Boldizsár Poór, Aleks Kissinger / Maximilian Rüsch, Aleks Kissinger, Benjamin Rodatz **Fault tolerance by construction / Completeness for fault equivalence of Clifford ZX diagrams**
10:15 – 11:00	Samson Abramsky, Rui Soares Barbosa, Carmen Constantin, Martti Karvonen **Algebraic paradoxes in adaptive quantum computation**
Coffee break	
Short plenary talks Room A0.01	
11:30 – 11:55	Manuel Mekonnen, Thomas D. Galley, Markus P. Müller **Invariance under quantum permutations rules out parastatistics**
11:55 – 12:20	Marek Arsenault, Hlér Kristjánsson **Linearised quantum signal processing**
Lunch break	

	Parallel A Room A0.01	Parallel B Room A1.02	Parallel C Room A1.03
14:30 – 14:55	Andrey Boris Khesin, Sarah Meng Li, Boldizsár Poór, Benjamin Rodatz, John van de Wetering, Richie Yeung **SpiderCat: optimal fault-tolerant CAT state preparation**	Roberto D. Baldijão, Marco Erba, David Schmid, John Selby, Ana Belén Sainz **Tomographically-nonlocal entanglement**	Matthew Wilson **Agent policies from higher-order causal functions**
14:55 – 15:20	Kwok Ho Wan, Henry Price, Qing Yao **Holographic codes seen through ZX-calculus** Remote	Alexandru Baltag, Sonja Smets **Logic meets Wigner's friend (and their friends)**	V. Vilasini, Lin-Qing Chen, Liuhang Ye, Renato Renner **Events and their localisation are relative to a lab**
15:20 – 15:45	Cole Comfort, Giovanni de Felice **The delayed stabiliser ZX-calculus**	Cihan Okay, Aziz Kharoof **The geometry of fiber products of probability polytopes**	Zixuan Liu, Ognyan Oreshkov **Parity erasure: a foundational principle for indefinite causal order**
Coffee break			
16:15 – 16:40	Vincenzo Fiorentino, Kuntal Sengupta **No extension of the Quantum Tensor Product admits a superposition principle**	Tom Williams, Mina Doosti, Farid Shahandeh **Sheaf-theoretic preparation contextuality via stochastic extension**	Luca Apadula, Alexei Grinbaum, Časlav Brukner **Reference frames for process matrices: from coordinate parametrization to spacetime representation**
16:40 – 17:05	Gaurang Agrawal, Matt Wilson **Deriving the generalised Born rule from first principles**	Theodoros Yianni, Farid Shahandeh, Nyan Raess **Linear algebra of generalized contextuality in prepare-transform-measure scenarios**	Raphaël Le Bihan, Alastair Abbott, Mnacho Echenim **Probing the composition of processes with first-order-ISOMIX logic**

17:05 – 17:30	James Hefford, Matt Wilson **Quantum theory can decohere from a causally-indefinite post-quantum theory**	David Schmid, Roberto D. Baldijão, John Selby, Ana Belen Sainz, Robert W. Spekkens **Noncontextuality inequalities for prepare-transform-measure scenarios**	Yassine Benhaj, Kuntal Sengupta, Cyril Branciard **How many systems can be dephased before the quantum switch becomes causally definite?**
Poster session (with reception) 17:30 – 19:30			

Wednesday, August 19th

Long plenary talks **(merged)** Room A0.01	
9:30 – 10:15	Miriam Backens, Simon Perdrix / Miriam Backens **Completeness for flow-preserving rewrite rules / Generating one-way computations with flow: flow-preserving rewriting that ignores the interpretation**
10:15 – 11:00	Quanlong Wang, Richard D. P. East, Razin A. Shaikh, Lia Yeh, Boldizsár Poór, Bob Coecke **Beyond Penrose tensor diagrams with the ZX calculus: applications to quantum computing, quantum machine learning, condensed matter physics, and quantum gravity**
Coffee break	
Industry session 11:30 – 12:20 Room A0.01	
Lunch break	

	Parallel A Room A0.01	Parallel B Room A1.02	Parallel C Room A1.03
14:30 – 14:55	Leonardo Vaglini, Nasra Daher Ahmed, Ravi Kunjwal **Causal inequalities witness non-stabilizerness without magic**	Nathan Claudet, Simon Perdrix **Insights in graph state entanglement via r-local complementation: structure and a quasi-polynomial algorithm**	Pablo Arrighi, Doğukan Bakircioglu, Nathan Houyet **Quantum theory over dual-complex numbers**
14:55 – 15:20	Matthew Wilson, James Hefford, Timothée Hoffreumon **Supermaps on generalised theories**	Piotr Mitosek, Miriam Backens **Working with measurement-based computations on qudits**	Nicolas Moulonguet, Augustin Vanrietvelde **Subsystems as subsets of quantum channels, and the strange case of blind agents**
15:20 – 15:45	Samson Abramsky, Radha Jagadeesan **Essential unitarity for higher-order quantum computation**	Aleks Kissinger, John van de Wetering **ZX-flow: a flexible criterion for deterministic computation with ZX-diagrams**	John Harding, Alexander Wilce **Classical explanations in (and of) general probabilistic theories**
Coffee break			
16:15 – 16:40	Thomas Bartsch, Yuhan Gai, Sakura Schäfer-Nameki **Beyond Wigner – how non-invertible symmetries preserve probabilities** Remote	Haytham McDowall-Rose, Razin A. Shaikh, Lia Yeh **From fermions to qubits: a ZX-calculus perspective**	Amrapali Sen, Flavio Del Santo **Superluminal transformations and indeterminism**
16:40 – 17:05	Vanessa Brzić, Satoshi Yoshida, Mio Murao, Marco Túlio Quintino **Higher-order quantum computing with known input states**	Lia Yeh, Jiaxin Huang, Aleks Kissinger, Sarah Meng Li, John van de Wetering **A three-way normal form for stabiliser codes across ZX diagrams, circuits, and tableaus**	Maarten Grothus, V. Vilasini **Impossibility of superluminal signalling rules out causal loops in conical spacetimes**
Boat tour 17:30 – 18:30			
Conference dinner starting 19:00			

Thursday, August 20th

Long plenary talks Room A0.01	
9:30 – 10:15	Cole Comfort, Robert I. Booth **Denotational semantics for stabiliser quantum programs**
10:15 – 11:00	Kathleen Barsse, Romain Péchoux, Simon Perdrix **Quantum control and general recursion beyond the unitary case**
Coffee break	
Short plenary talk Room A0.01	
11:30 – 11:55	Aabhas Gulati, Ion Nechita, Clément Pellegrini **Entanglement in the Dicke subspace**
Conference photo 11:55 – 12:20	
Lunch break	

	Parallel A Room A1.02	Parallel B Room A2.09	Parallel C Room A1.03
14:30 – 14:55	Arianne Meijer-van de Griend, Leo Becker **Pauli gadget synthesis for gatesets with arbitrary even-arity Clifford gates**	Haruki Emori **Quantum statistical functions**	Nadish de Silva, Santanil Jana, Ming Yin **Three-qubit nonlocality paradoxes: beyond GHZ**
14:55 – 15:20	Soichiro Yamazaki, Seiseki Akibue **Multi-qubit controlled gate with optimal T-count**	Michael Zurel, Jack Davis **Basis-independent stabilizerness and maximally noisy magic states**	Shashaank Khanna, Matthew Pusey, Roger Colbeck **Spurious quantum correlations**
15:20 – 15:45	Akash Kundu **Tensor and gadget reinforcement learning for improved, hardware-aware quantum architecture search**	Cameron Calcluth, Oliver Hahn, Juani Bermejo Vega, Alessandro Ferraro, Giulia Ferrini **Classical simulation of circuits with realistic odd-dimensional Gottesman–Kitaev–Preskill states**	C. E. Lopetegui-Gonzalez, G. Masse, E. Oudot, U. I. Meyer, F. Centrone, F. Grosshans, P. E. Emeriau, U. Chabaud, M. Walschaers **A unified framework for Bell inequalities from continuous-variable contextuality**
15:45 – 16:10	Mark Deaconu, Nihar Gargava, Amolak Ratan Kalra, Michele Mosca, Jon Yard **Buildings for synthesis with Clifford+R**	Massimo Frigerio, Mattia Walschaers, Andrei Aralov, Carlos Ernesto Lopetegui-Gonzalez, Emilie Gillet **Algebraic techniques for photonic state preparation and characterization**	Martin J. Renner, Edwin Peter Lobo, Arturo Konderak, Remigiusz Augusiak, Antonio Acín **Full nonlocality for non-maximally entangled states**
Coffee break 16:10 – 16:40			
Career fair 16:40 – 19:00			

Friday, August 21st

Long plenary talks Room A0.01	
9:30 – 10:15	Thea Li, Vladimir Zamdzhiev **Quantum coherence spaces revisited: a von Neumann (co)algebraic approach**
10:15 – 11:00	Matilde Baroni, Dominik Leichtle, Ivan Šupić, Damian Markham, Marco Túlio Quintino **Composable simultaneous purification: when all communication scenarios reduce to spatial correlations**
Coffee break	
Business meeting 11:30 – 12:20	
Lunch break	

	Parallel A Room A0.01	Parallel B Room A1.02	Parallel C Room A1.03
14:30 – 14:55	Simon Burton, Hussain Anwar **Meromorphic quantum computing**	Noé Delorme, Simon Perdrix **Diagrammatic reasoning with control as a constructor, applications to quantum circuits**	David Schmid, John H. Selby, Vinicius Pretti Rossi, Roberto D. Baldijão, Ana Belén Sainz **Shadows and subsystems of generalised probabilistic theories: when tomographic incompleteness is not a loophole for contextuality proofs**
14:55 – 15:20	Christine Li, Lia Yeh **Transversal AND in quantum codes**	Chris Heunen, Robin Kaarsgaard, Louis Lemonnier **One rig to control them all**	Jan-Åke Larsson **The contextual Heisenberg microscope**
15:20 – 15:45	Jin Ming Koh, Anqi Gong, Andrei C. Diaconu, Daniel Bochen Tan, Alexandra A. Geim, Michael J. Gullans, Norman Y. Yao, Mikhail D. Lukin, Shayan Majidy **Phantom codes: entangling logical qubits without physical operations** Remote	William Schober, Scott Wesley **A complete equational theory for quantum circuits with generalized control**	Daniel McNulty **Quantifying quantum measurement incompatibility via graph invariants**
Coffee break			
16:15 – 16:40	Vivien Vandaele **Asymptotically optimal quantum circuits for comparators and incrementers**	Sacha Cerf, Harold Ollivier **The perturbative method for quantum correlations**	Raffaele D'Avino, Lorenzo Caramelli, Raja Yehia, Gabriel Senno, Roberto González Pousa, Antonio Acín, Tamás Kriváchy **Device independent quantum key distribution with a single measurement per site**
16:40 – 17:05	Giuseppe De Riso, Giuseppe Catalano, Seth Lloyd, Vittorio Giovannetti, Dario De Santis **A resource-efficient quantum-walker quantum RAM**		Paul Becsi, Matthew Joseph Hoban **Bounding classical and quantum correlations in Bayesian networks with quasiprobabilities**
End of QPL 2026. Goodbye!			

Abstracts

Abstracts are reproduced from the front matter of the submitted papers, in the order the talks are scheduled. Where a submission carries no abstract of its own, the abstract of the paper's arXiv version is given instead and labelled with its arXiv id.

Monday, August 17th

Long plenary talks

9:30 – 10:15

Equivalence of continuous- and discrete-variable gate-based quantum computers with finite energy

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

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. 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 built from a polynomial sequence of elementary gates in a finite set, with total energy polynomial in the number of modes. We prove that, under realistic constraints, a gate-based model of continuous-variable quantum computers can be efficiently simulated using discrete-variable devices, thereby establishing a computational equivalence between these paradigms.

10:15 – 11:00

Efficient quantum-circuit simulation of classical control of causal order

Raphaël Mothe, Jessica Bavaresco

We show that quantum circuits with classical control of causal order admit an efficient simulation by fixed-order quantum circuits: any such transformation acting on N independent channels can be deterministically, exactly, and universally simulated using at most N 2 channel queries. For quantum circuits with quantum control of order, we prove a similar simulation result, but restricted to unitary input channels (hence non-universal). We further generalize these constructions to extended, bipartite quantum channels and demonstrate that they can be implemented catalytically, without consuming the additional N 2 –N queries required for the simulation. These results show the limitations of the computational power of quantum circuits with classical control of causal order in general, and of quantum circuits with quantum control of causal order when only their action on unitary channels is considered.

Short plenary talks

11:30 – 11:55

How typical is contextuality?

Vinicius Pretti Rossi, Beata Zjawin, Roberto D. Baldijão, David Schmid, John H. Selby, Ana Belén Sainz

Identifying when observed statistics cannot be explained by any reasonable classical model is a central problem in quantum foundations. A principled and universally applicable approach to defining and identifying nonclassicality is given by the notion of generalised noncontextuality. Here, we study the typicality of contextuality — namely, the likelihood that randomly chosen quantum preparations and measurements produce nonclassical statistics. Using numerical linear programs to test for the existence of a generalised-noncontextual model, we find that contextuality is fairly common: even in experiments with only a modest number of random preparations and measurements, contextuality arises with probability over 99%. We also show that while the typicality of contextuality decreases as the purity (sharpness) of the preparations (measurements) decreases, this dependence is not especially pronounced, so contextuality is fairly typical even in settings with realistic noise. Finally, we show that although nonzero contextuality is quite typical, quantitatively high degrees of contextuality are not as typical, and so large quantum advantages (like for parity-oblivious multiplexing, which we take as a case study) are not as typical. We provide an open-source toolbox that outputs the typicality of contextuality as a function of tunable parameters (such as lower and upper bounds on purity and other constraints on states and measurements). This toolbox can inform the design of experiments that achieve the desired typicality of contextuality for specified experimental constraints.

11:55 – 12:20

Graphical algebraic geometry: from ideals and varieties to qudit ZH completeness

Dichuan Gao, Razin A. Shaikh, Aleks Kissinger

We introduce Graphical Algebraic Geometry (GAG), a family of diagrammatic languages extending the Graphical Linear Algebra programme. We construct several languages within this family and prove that they are universal and complete for the corresponding (co)span semantics of commutative algebras and affine varieties. This framework provides clear graphical representations of algebraic structures -- such as polynomials, ideals, and varieties -- enabling intuitive yet rigorous diagrammatic reasoning. We showcase two practical viewpoints on GAG. First, we show that instances of counting constraint satisfaction problem (#CSP) are recast as rewrite problems of closed diagrams in GAG. This means that deciding rewritability in GAG is #P-hard, and GAG can be viewed as a complete and compositional rewrite system for networks of polynomial constraints. Second, we characterize the qudit ZH calculus, a diagrammatic language for quantum computation, as an extension of Graphical Algebraic Geometry. This establishes the correspondence that Graphical Algebraic Geometry is to the ZH calculus what Graphical Linear Algebra is to the ZX calculus. Using this construction, we show that computing amplitudes in qudit ZH requires only a constant number of queries to a GAG oracle.

Abstract from the arXiv version, arXiv:2605.13993.

Parallel sessions

14:30 – 14:55 · Parallel A

On whether quantum theory needs complex numbers: the foil theories perspective

Yìlè Yīng, Maria Ciudad Alanon, Daniel Centeno, Jacopo Surace, Marina Maciel Ansanelli, Ruizhi Liu, David Schmid, Robert Spekkens

Recent work by Renou et al. (2021) has led to some controversy concerning the question of whether quantum theory requires complex numbers for its formulation. We promote the view that the main result of that work is best understood not as a claim about the relative merits of different representations of quantum theory, but rather as a claim about the possibility of experimentally adjudicating between standard quantum theory and an alternative theory—a foil theory —known as real-amplitude quantum theory (RQT). In particular, the claim is that this adjudication can be achieved given only an assumption about the causal structure of the experiment. Here, we aim to shed some light on why this is possible, by reconceptualizing the comparison of the two theories as an instance of a broader class of such theory comparisons. By recasting RQT as the subtheory of quantum theory that arises by symmetrizing with respect to the collective action of a time-reversal symmetry, we can compare it to other subtheories that arise by symmetrization, but for different symmetries. If the symmetry has a unitary representation, the resulting foil theory is termed a twirled quantum world, and if it does not (as is the case in RQT), the resulting foil theory is termed a swirled quantum world. We show that, in contrast to RQT, there is no possibility of distinguishing any twirled quantum world from quantum theory given only an assumption about causal structure. We also define analogues of twirling and swirling for an arbitrary generalized probabilistic theory and identify certain necessary conditions on a causal structure for it to be able to support a causal compatibility gap between the theory and its symmetrized version. We draw out the implications of these analyses for the question of how a lack of a shared reference frame state features into the possibility of such a gap.

14:30 – 14:55 · Parallel B

Restricted negation in orthomodular logic

Tomoaki Kawano, Ryo Kashima

Orthomodular logic has long been studied as a fundamental logical framework within quantum logic. In addition to its lattice-theoretic foundations, various formulations have been proposed that incorporate specialized implication connectives and more complex logical operators. In this study, we reconstruct orthomodular logic by introducing an operator referred to as restricted negation, which has received comparatively little attention in the existing literature. We demonstrate that this operator provides a natural and expressive basis for formulating the core principles of orthomodular logic. Furthermore, as a main result, we construct new proof system for orthomodular logic founded on this operator.

14:30 – 14:55 · Parallel C

A complete equational theory for real-Clifford+CH quantum circuits

Alexandre Clément

We introduce a complete equational theory for the fragment of quantum circuits generated by the real Clifford gates plus the twoqubit controlled-Hadamard gate. That is, we give a simple set of equalities between circuits of this fragment, and prove that any other true equation can be derived from these. This is the first such completeness result for a finitely-generated, universal fragment of quantum circuits, with no parameterized gates and no need for ancillas.

14:55 – 15:20 · Parallel A

On the experimental falsification of real QT

Timothée Hoffreumon, Mischa P. Woods

Whether the complex numbers of standard quantum theory are experimentally indispensable has remained open for decades. Real quantum theory (RQT), obtained by replacing complex amplitudes with real ones while retaining the usual Kronecker-product composition rule, reproduces all single-party and bipartite Bell correlations of quantum theory (QT), but its lack of local tomography suggested that the two theories might diverge in more general local experiments. This possibility appeared to be confirmed by Renou et al., who argued that a bilocal network experiment can falsify RQT without falsifying QT. Here we show that this conclusion relies on an experimentally untestable assumption. The key distinction is between product-state independence, which constrains the mathematical form of source states, and operational independence, which is defined entirely by the absence of observable cross-source correlations. We prove that, once source independence is imposed operationally, every finite network correlation achievable in QT is also achievable in RQT with the same locality structure of the measurements. We then extend this equivalence to arbitrary finite sequential multipartite protocols involving channels and measurements with prescribed locality structure. Thus, as long as no violation of QT is observed, RQT cannot be experimentally falsified. Our results restore the empirical indistinguishability of QT and RQT, while showing that they support markedly different pictures of the correlation structure underlying the same observed world.

Abstract from the arXiv version, arXiv:2603.19208.

14:55 – 15:20 · Parallel B

Factorization of multimeters: a unified view on nonclassical quantum phenomena

Tim Achenbach, Andreas Bluhm, Leevi Leppäjärvi, Ion Nechita, Martin Plávala

Quantum theory exhibits various nonclassical features, such as measurement incompatibility, contextuality, steering, and Bell nonlocality, which distinguish it from classical physics. These phenomena are often studied separately, but they possess deep interconnections. This work introduces a unified mathematical framework based on commuting diagrams that unifies them. By representing collections of measurements (multimeters) as maps to the set of column-stochastic matrices, we show that measurement compatibility and simulability correspond to specific factorizations of these maps through intermediate systems. We apply this framework to put forward connections between different nonclassical notions and provide factorization-based characterizations for steering assemblages and Bell correlations, including a new perspective on the CHSH inequality witnessing measurement incompatibility. We also investigate the symmetric n-extensions of multimeters and no-signaling behaviors and connect these extensions to a notion of n-wise compatibility and to the existence of n-wise LHV models, respectively. Furthermore, we investigate robustness to noise of nonlocal features by examining factorization conditions for maps involving noisy state spaces, providing geometric criteria for when noisy multimeters can be simulated by simpler measurement settings.

Abstract from the arXiv version, arXiv:2504.19865.

14:55 – 15:20 · Parallel C

A complete and natural rule set for multi-qudit Clifford circuits in all odd prime dimensions

Xiaoning Bian, Sarah Meng Li, Neil J. Ross, John van de Wetering, Yuming Zhao

We present a complete set of rewrite rules for multi-qudit Clifford circuits, where qudit denotes a d-level quantum system with d an odd prime. Completeness means that any two Clifford circuits representing the same linear map can be transformed into each other using these rules. In total, there are 19 Clifford relations, each involving at most three qudits and admitting an intuitive interpretation. Our approach leverages the isomorphism between the symplectic group $\mathrm{Sp}(2n, \mathbb{Z}_d)$ and the quotient of the Clifford group by the Pauli group. We first derive a complete set of symplectic relations for $\mathrm{Sp}(2n, \mathbb{Z}_d)$, and then lift them to Clifford relations by incorporating Pauli corrections. To do this, we introduce a symplectic normal form that captures the stabiliser tableau of a Clifford operator and is unique up to Pauli correction. This simplification enables a streamlined derivation of a complete set of 66 relations, which we further compress to 18 symplectic relations. Our computations in $\mathrm{Sp}(2n, \mathbb{Z}_d)$ are formalised in the Agda proof assistant, providing a machine-verified proof of correctness.

15:20 – 15:45 · Parallel A

A real matrix theory consistent with QT

Timothée Hoffreumon, Mischa P. Woods

Quantum theory was radically different from the theories of nature which came before it. One key difference was its use of complex numbers. This opened a longstanding debate over whether quantum theory fundamentally requires complex numbers -- or if their use is merely a convenient choice. Until recently, this question was considered open. However, in a 2021 Nature article, a decisive argument was presented asserting that quantum theory needs complex numbers since real-number quantum theory is inconsistent with the postulates of quantum theory. In this work, we show that this conclusion was premature, and in actual fact, a real-number quantum theory is consistent with the postulates of quantum theory. Our theory retains key features such as representation locality (i.e. local physical operations are represented by local changes to the states). A direct consequence of our results is that quantum theory based on real or complex numbers are experimentally indistinguishable.

Abstract from the arXiv version, arXiv:2504.02808.

15:20 – 15:45 · Parallel B

Operator spaces, linear logic and the Heisenberg–Schrödinger duality of quantum theory

Bert Lindenhovius, Vladimir Zamdzhiev

We show that the category OS of operator spaces, with complete contractions as morphisms, is locally countably presentable and a model of Intuitionistic Linear Logic in the sense of Lafont. We then describe a model of Classical Linear Logic, based on OS, whose duality is compatible with the HeisenbergSchrödinger duality of quantum theory. We explore connections between the Haagerup tensor product on OS and BV-logic and we also show that OS provides a good setting for studying pure state and mixed state quantum information, the interaction between the two, and even higher-order quantum maps such as the quantum switch. This work was published in LICS'25 [1]. A preprint with many omitted proofs is available [2] and we also have a detailed companion paper [3] that provides a proof of the local presentability of OS and proofs that establish other important categorical properties of OS.

15:20 – 15:45 · Parallel C

Completeness for prime-dimensional phase-affine circuits

Colin Blake

Equational reasoning about circuits is central in quantum software for validation, optimisation, and verification. For qubits, the CNOT-dihedral fragment supports efficient rewriting via phase polynomials and layered normal forms, yielding a complete and practically effective equational theory. In this work we generalise that CNOT-dihedral picture from qubits to prime-dimensional qudits. We present a compact PROP for reversible affine circuits over a prime field, with a strict symmetric monoidal semantics into the affine group and a Lafont-style affine normal form. We then adjoin finite-angle diagonal phase generators and organise them by polynomial degree, obtaining linear, quadratic (odd prime), and cubic (prime greater than 3) calculi. Using binomial-basis identities we derive uniform transport rules, establish unique phase-affine normal forms, and prove completeness: semantic equality coincides with derivable equality. This yields a prime-dimensional, phase-polynomial-aligned generalisation of the CNOT-dihedral equational theory.

16:15 – 16:40 · Parallel A

The resource theory of causal influence and knowledge of causal influence

Beata Zjawin, Marina Maciel Ansanelli, David Schmid, Yìlè Yīng, John H. Selby, Ciarán M. Gilligan-Lee, Ana Belén Sainz, Robert Spekkens

Understanding and quantifying causal relationships between variables is essential for reasoning about the physical world. In this work, we develop a resource-theoretic framework to do so. Here, we focus on the simplest nontrivial setting— two (classical) variables that are causally ordered, meaning that the first has the potential to influence the second. First, we introduce the resource theory that directly quantifies causal influence of a functional dependence in this setting and show that the problem of deciding convertibility of resources and identifying a complete set of monotones has a straightforward solution. Then, we introduce the resource theory that arises naturally when one has uncertainty about the functional dependence. We describe a linear program for deciding the question of whether one resource (i.e., probability distribution over functions) can be converted to another. Moreover, for the case where the variables are binary, we identify a triple of monotones that are complete. We provide an interpretation of these monotones and show that resourcefulness consists both of knowledge of the functional relations and of the degree of causal connectivity of the function relating the variables. Finally, we discuss how our resource theory connects to standard methods for quantifying cause-effect relations and Shannon theory, as well as its possible quantum generalization.

16:15 – 16:40 · Parallel B

Generalized inverses of quantum channels: a categorical perspective

Priyaa Varshinee Srinivasan, Jean-Simon Pacaud Lemay, Robin Cockett

A quantum channel is defined as being completely positive (CP) and trace preserving (TP). While not every quantum channel is invertible or reversible, every quantum channel admits various kinds of generalized inverses such as the Moore-Penrose inverse and the Drazin inverse. A generalized inverse of a quantum channel may not itself be a quantum channel: it often fails to be CP. However, generalized inverses still play an important role in quantum error mitigation. Here, because it is often desirable for the generalized inverse of a quantum channel to be at least TP, the Drazin inverse, which is TP, is favoured over the Moore-Penrose inverse, which is not in general TP. In this paper, we take a categorical perspective on generalized inverses of quantum channels. This allows us to give a simple proof of the fact that the Drazin inverse of a quantum channel is always TP. It also allows us to show that for unital quantum channels, the Drazin inverse is also unital. We then generalize this result to dagger Drazin inverses, which allows us to show that for unital quantum channels, the Moore-Penrose inverse is both TP and unital as well. This opens the door to new

applications of both the Drazin inverse and Moore-Penrose inverse in quantum information theory and, in particular, in quantum error mitigation.

16:15 – 16:40 · Parallel C

Efficient classical simulation of low-rank-width quantum circuits using ZX-calculus

Fedor Kuyanov, Aleks Kissinger

In this paper, we introduce an algorithm for contracting (i.e. numerically evaluating) ZX-diagrams whose computational complexity is governed by rank-width, a structural graph parameter that behaves nicely under ZX rewrite rules. Our method evaluates a graph-like ZX-diagram in $\tilde{O}(4^R)$ time, given its rank-decomposition of width R. By constructing suitable rank-decompositions, we provide a classical simulation algorithm for quantum circuits whose runtime is bounded by both $\tilde{O}(2^n)$ and $\tilde{O}(2^{t/2})$, where n is the number of qubits and t is the number of non-Clifford phase gates. Thus, our method is no slower than either the naïve state-vector simulation or the elementary stabiliser decomposition baseline, and in practice can be even faster when the reduced ZX-diagram has low rank-width. We benchmark our simulation algorithm against Quimb, a popular tensor contraction library, and observe substantial reductions in floating-point operations, often by several orders of magnitude, for random and structured non-Clifford circuits and for random ZX-diagrams.

16:40 – 17:05 · Parallel A

Higher-order transformations of bidirectional quantum processes

Luca Apadula, Alessandro Bisio, Giulio Chiribella, Paolo Perinotti, Kyrylo Simonov

Bidirectional devices are devices for which the roles of the input and output ports can be exchanged. Mathematically, these devices are described by bistochastic quantum channels, namely completely positive linear maps that are both trace-preserving and identity-preserving. Recently, it has been shown that bidirectional quantum devices can, in principle, be used in ways that are incompatible with a definite input-output direction, giving rise to a new phenomenon called input-output indefiniteness. Here we characterize the most general forms of input-output indefiniteness, associated with a hierarchy of higher-order transformations built from transformations of bistochastic quantum channels. Some levels of the hierarchy correspond to transformations that combine bistochastic channels in a definite causal order, while generally using each channel in an indefinite input-output direction. For other levels of the hierarchy, the indefiniteness can involve both the local input-output direction of each process and the global causal order among the processes. On the foundational side, the hierarchy of higher-order transformations characterized here can be regarded as the largest set of physical processes compatible with a time-symmetric variant of quantum theory, where the possible state transformations are restricted to bistochastic channels.

Abstract from the arXiv version, arXiv:2602.00856.

16:40 – 17:05 · Parallel B

The category of quantum graphs is closed

Andre Kornell, Bert Lindenhovius

We introduce a category qGph of quantum graphs, whose definition is motivated entirely from noncommutative geometry. For all quantum graphs G and H in qGph, we then construct a quantum graph $[G,H]$ of homomorphisms from G to H, making qGph a closed symmetric monoidal category. We prove that for all finite graphs G and H, the quantum graph $[G,H]$ is nonempty iff the (G,H)-homomorphism game has a winning quantum strategy, directly generalizing the classical case. The finite quantum graphs in qGph are tracial, real, and self-adjoint, and the morphisms between them are CP morphisms that are adjoint to a unital $*$-homomorphism. We prove that Weaver's two notions of a CP morphism coincide in this context. We also include a short proof that every finite reflexive quantum graph is the confusability quantum graph of a quantum channel.

Abstract from the arXiv version, arXiv:2601.09685.

16:40 – 17:05 · Parallel C

Simulating magic state cultivation with few Clifford terms

Kwok Ho Wan, Zhenghao Zhong, Ainhoa Zapirain

Building upon [arXiv:2509.01224], we present a few methods on how to simulate the non-Clifford $d=5$ magic state cultivation circuits [arXiv:2409.17595] with a sum of ≈ 8 Clifford ZX-diagrams on average, at 0.1% noise. Compared to a magic cat state stabiliser decomposition of all 53 non-Clifford spiders ($6{,}377{,}292$ terms required), this is more than 7×10^{5} times reduction in the number of terms. Our stabiliser decomposition has the advantage of representing the final non-Clifford state (in light of circuit errors) as a sum of Clifford ZX-diagrams. This will be useful in simulating the escape stage of magic state cultivation, where one needs to port the resultant state of cultivation into a larger Clifford circuit with many more qubits. Still, it's necessary to only track ≈ 8 Clifford terms. Our result sheds light on the simulability of operationally relevant, high T-count quantum circuits with some internal structure. Finally, we provide numerical results for full non-Clifford stabiliser rank simulation based on $

\mathtt{tsim}$ along with optimisations using our cutting decompositions. Nearly 4×10^{6} shots per second can be obtained on a laptop for the smaller $d = 3$ circuits at SD6 circuit level noise $p=0.0005$, making it only $\sim$ 1.1 times slower than its (circuit-unspecific and un-optimised) fully Clifford proxy simulation via $\mathtt{stim}$ using S gates.

Abstract from the arXiv version, arXiv:2509.08658.

17:05 – 17:30 · Parallel A

Emergent causal order and time direction: bridging causal models and tensor networks

Carla Ferradini, Giulia Mazzola, V. Vilasini

Can the direction of time and the causal structure of space-time be inferred from operational principles? Causal models and tensor networks offer complementary perspectives: the former encodes cause-effect relations via directed graphs, with intrinsic ordering; the latter describes multipartite systems on undirected graphs, without presupposing directionality. We construct two-way mappings between these two frameworks, linking direction agnostic correlation functions and operational notions of signalling. This clarifies the operational meaning of causal influence in tensor networks and introduces discrete "spacetime rotations" of causal models which preserve signalling relations. Applying our framework to holographic tensor networks, we use tools from causal inference, like graph-separation, to analyse emergent causal structures. By permitting cyclic and indefinite causal structures, our results enable transfer of techniques across tensor networks and a range of causality frameworks.

17:05 – 17:30 · Parallel B

Nuclearity and trace in monoidal bicategories with application to extended CFTs

James Hefford

We develop the theory of nuclear and trace 2-ideals in monoidal bicategories. We show that such 2ideals are present in a certain bicategory of conformal cobordisms and in the bicategory of measured categories. Viewing the latter as a model of infinite dimensional 2-Hilbert spaces we give a definition of a once extended conformal field theory as a nuclear 2-functor.

17:05 – 17:30 · Parallel C

Classical Clifford+T sampling without computing marginals

Mark Koch

We introduce a new exact classical sampling algorithm for Clifford+T circuits, called T-by-T sampling. For a circuit with T-count t, it reduces sampling to evaluating 2t amplitudes of circuits with successively increasing T-counts 1,2,...,t, without the need to compute costly marginal probabilities. Crucially, the number of amplitude evaluations is completely independent of the surrounding Clifford structure. This makes T-by-T sampling well suited for use together with low-rank stabiliser decompositions, which enable efficient amplitude evaluations as long as the T-count is not too high. In that sense, T-by-T sampling is an improvement over the gate-by-gate sampling technique introduced by Bravyi, Gosset, and Liu [6], where the number of amplitudes instead scales with the number of non-monomial operations such as Hadamard gates, which can remain large even in circuits with low stabiliser rank. Concretely, T-by-T sampling offers significant speedups in regimes where T gates are embedded within large Clifford computations. This makes it well suited for applications such as simulating quantum error correction experiments, which typically have lower T complexity but involve extensive Clifford operations and measurements. In particular, we show how T-by-T sampling allows us to take samples from recent end-to-end magic state cultivation circuits with escape up to distance 19 in a couple of seconds.

Tuesday, August 18th

Long plenary talks (merged)

9:30 – 10:15

Fault tolerance by construction

Benjamin Rodatz, Boldizsár Poór, Aleks Kissinger

A key challenge in fault-tolerant quantum computing is synthesising and optimising circuits in a noisy environment, as traditional techniques often fail to account for the effect of noise on circuits. In this work, we propose a framework for designing fault-tolerant quantum circuits that are correct by construction. The framework starts with idealised specifications of fault-tolerant gadgets and refines them using provably sound basic transformations. To reason about manipulating circuits while preserving their error correction properties, we define fault equivalence; two circuits are considered fault-equivalent if all undetectable faults on one circuit have a corresponding fault on the other. This guarantees that the effect of undetectable faults on both circuits is the same. We argue that fault equivalence is a concept that is already implicitly present in the literature. Many problems, such as state preparation and syndrome extraction,

can be naturally expressed as finding an implementable circuit that is fault-equivalent to an idealised specification. To utilise fault equivalence in a computationally tractable manner, we adapt the ZX calculus, a diagrammatic language for quantum computing. We restrict its rewrite system to not only preserve the underlying linear map but also fault equivalence, i.e. the circuit's behaviour under noise. Enabled by our framework, we verify, optimise and synthesise new and efficient circuits for syndrome extraction and cat state preparation. We anticipate that fault equivalence can capture and unify different approaches in fault-tolerant quantum computing, paving the way for an end-to-end circuit compilation framework.

9:30 – 10:15

Completeness for fault equivalence of Clifford ZX diagrams

Maximilian Rüsch, Aleks Kissinger, Benjamin Rodatz

Two circuits are considered to be equivalent under noise if the effect of faults on one circuit is no worse than the effect of faults on the other circuit. We call this relationship fault equivalence. Fault equivalence offers a way to transform circuits while provably preserving their fault-tolerant properties, enabling a framework for fault-tolerant circuit synthesis and optimisation that is correct by construction. The ZX calculus offers a diagrammatic way to represent and reason about quantum circuits and is a useful tool for manipulating circuits while preserving fault equivalence. For this, the usual set of ZX rewrites has to be restricted to not only preserve the underlying linear map represented by the diagram, but also fault equivalence. In this work, we provide a set of ZX rewrites that are sound and complete for fault equivalence of Clifford ZX diagrams. This means that any equivalence that can be derived using the proposed rules is certain to be correct, and any correct equivalence can be derived using only these rules. For this, we utilise diagrammatic constructions called fault gadgets to reason about arbitrary, possibly correlated Pauli faults in ZX diagrams. Fault gadgets allow us to separate the diagram into a fault-free part, which captures the noise-free behaviour of a diagram, and a noisy part that enumerates the effects of all possible faults. Using this, we provide a unique normal form for ZX diagrams under noise and show that any diagram can be brought into this normal form using our proposed rule set.

10:15 – 11:00

Algebraic paradoxes in adaptive quantum computation

Samson Abramsky, Rui Soares Barbosa, Carmen Constantin, Martti Karvonen

Measurement-based quantum computation (MBQC) is a universal model of quantum computation whose full power requires adaptivity. Contextuality is known to power quantum advantage in MBQC, yet it has resisted algebraic analysis in the adaptive setting. We show that if an adaptive $\mathbb{Z}_2$-linear measurement-based quantum computing protocol deterministically computes a non-affine Boolean function, then the underlying quantum resource satisfies an inconsistent set of linear equations. This witnesses an algebraic form of strong contextuality generalising Mermin's All-versus-Nothing arguments. Such algebraic contextuality can be detected cohomologically, resolving an open question posed by Raussendorf, who had established cohomological witnesses of contextuality for non-adaptive protocols, but left the adaptive case open. We prove this result constructively: we model adaptive measurement protocols as ordinary measurements on a larger scenario of tree-like measurements, and explicitly build the inconsistent equations inductively.

Abstract from the arXiv version, arXiv:2607.26157.

Short plenary talks

11:30 – 11:55

Invariance under quantum permutations rules out parastatistics

Manuel Mekonnen, Thomas D. Galley, Markus P. Müller

Quantum systems invariant under particle exchange are either Bosons or Fermions, even though quantum theory in principle admits more general behavior under permutations. But why do we not observe such paraparticles in nature? The analysis of this question was previously limited primarily to specific quantum field theory models. Here we give two distinct model-independent arguments that rule out parastatistics, i.e. fundamentally indistinguishable quantum systems transforming under higher-dimensional representations of the symmetric group, which draw on quantum information theory and recent research on internal quantum reference frames. First, we introduce a notion of complete invariance: quantum systems should not only preserve their local state under permutations, but also the quantum information they carry about other systems, in analogy to the notion of complete positivity in quantum information theory. Second, we demand that quantum systems are invariant under quantum permutations, i.e. permutations conditioned on values of permutationinvariant observables. For both, we show that the respective principle is fulfilled if and only if the particle is a Boson or Fermion. Our results show how quantum reference frames can shed light on a longstanding problem of quantum physics, they underline the crucial role played by the compositional structure

of quantum information, and demonstrate the explanatory power but also subtle limitations of recently proposed quantum covariance principles.

11:55 – 12:20

Linearised quantum signal processing

Marek Arsenault, Hlér Kristjánsson

Quantum functional programming has been developed through two distinct paradigms in the last few years: Quantum Signal Processing (QSP)-based methods, including the Quantum Singular Value Transformation (QSVT), and methods based on higher-order quantum transformations, such as the Universal Hamiltonian Eigenvalue Transformation (UHET). While UHET performs functional transformations of Hamiltonian dynamics, its relationship to QSP-based techniques has remained unclear despite evident structural similarities. In this work, we resolve this gap by establishing a connection between UHET and QSP-based frameworks; specifically, we show that UHET can be interpreted as a (randomised) linearisation of Generalised QSP (GQSP). Building on this result, we introduce a linearised variant of (Hamiltonian-based) QSVT, which we call Universal Hamiltonian Singular Value Transformation (UHSVT), that enables the efficient transformation of the singular values of any arbitrary matrix A encoded in a block of a Hamiltonian, whose dynamics is accessible as a black box, by any sufficiently differentiable complex-valued function f. Our algorithm requires the sole condition that f vanishes at the origin, in contrast to previous QSVT-based approaches that assumed either a lower bound on the singular values of A or the ability to perform X-rotation gates on the induced two-dimensional 'qubitised' subspace.

Abstract from the arXiv version, arXiv:2608.14387.

Parallel sessions

14:30 – 14:55 · Parallel A

SpiderCat: optimal fault-tolerant CAT state preparation

Andrey Boris Khesin, Sarah Meng Li, Boldizsár Poór, Benjamin Rodatz, John van de Wetering, Richie Yeung

The ability to fault-tolerantly prepare CAT states, also known as multi-qubit GHZ states, is an important primitive for quantum error correction. It is required for Shor-style syndrome extraction, and can also be used as a subroutine for doing fault-tolerant state preparation of CSS codewords. Existing approaches to fault-tolerant CAT state preparations have been found using computationally expensive heuristics involving SAT solving, reinforcement learning, or exhaustive analysis. In this paper, we constructively find optimal circuits for CAT states in a more scalable way. In particular, we derive formal lower bounds on the number of CNOT gates required for circuits implementing n-qubit CAT states that do not spread errors of weight at most t for $1 \leq t \leq 5$. We do this by using fault-equivalent rewrites of ZX-diagrams to reduce it to a problem of characterising certain 3-regular simple graphs. We then provide families of such optimal graphs for infinitely many values of n and $t \leq 5$. By encoding the construction of optimal graphs as a constraint satisfaction problem we find explicit constructions for circuits that match this lower bound on CNOT count for all $n \leq 50$ and $t \leq 5$ and for nearly all pairs (n, t) with $n \leq 100$ and $t \leq 5$ or $n \leq 50$ and $t \leq 7$, significantly extending the regimes that were achievable by previous methods and improving the resource counts for existing constructions. We additionally show how to trade CNOT count against depth, allowing us to construct constant-depth fault-tolerant implementations using $O(n)$ ancilla and $O(n)$ CNOT gates.

Abstract from the arXiv version, arXiv:2603.05391.

14:30 – 14:55 · Parallel B

Tomographically-nonlocal entanglement

Roberto D. Baldijão, Marco Erba, David Schmid, John Selby, Ana Belén Sainz

Entanglement is a central and subtle feature of quantum theory, whose structure and operational behavior can change dramatically when additional physical constraints, such as symmetries or superselection rules, are imposed. Such constraints can give rise to striking and counter-intuitive phenomena, including local broadcasting of entangled states and failures of entanglement monogamy. These effects naturally arise in tomographically nonlocal theories (like real quantum theory, twirled worlds, or fermionic quantum theory), where composite systems possess holistic degrees of freedom that are inaccessible to local measurements. In this work, we study entanglement in such theories within the framework of generalized probabilistic theories. We show that the failure of tomographic locality leads to two qualitatively distinct forms of entanglement, which we term $\textit{tomographically-local}$ entanglement and $\textit{tomographically-nonlocal}$ entanglement. We analyze the operational consequences of this distinction, proving that tomographically-nonlocal entanglement is useless for Bell nonlocality, steering, and teleportation, but sufficient for dense coding and perfectly secure data hiding. This framework clarifies the origin of several previously puzzling features of entanglement that arise when tomographic locality fails, as can happen even in quantum theory when one considers fermions or fundamental superselection rules.

Abstract from the arXiv version, arXiv:2602.16280.

14:30 – 14:55 · Parallel C

Agent policies from higher-order causal functions

Matthew Wilson

We establish a correspondence between equivalence classes of agent-state policies for deterministic POMDPs and one-input process functions (the classical-deterministic limit of higher-order quantum operations). We use this correspondence to build a bridge between the agent-environment interaction in artificial intelligence, causal structure in the foundations of physics, and logic in computer science. We construct a *-autonomous category PF of types which supports an interpretation of one-step evaluation of policies, and multi-agent observation constraints, into cuts and monoidal products. In terms of types, we develop the correspondence further by identifying observation-independent decentralised POMDPs as the natural domain for the multi-input process functions used to model indefinite causality. We then prove a strict separation between general multi-input process function and definite-ordered process function performance on such dec-POMDPs, by finding an instance for which policies utilizing an indefinite causal structure can achieve greater finite-horizon rewards than policies which are restricted to a fixed background causal structure.

Abstract from the arXiv version, arXiv:2512.10937.

14:55 – 15:20 · Parallel A

Holographic codes seen through ZX-calculus

Kwok Ho Wan, Henry Price, Qing Yao

We re-visit the pentagon holographic quantum error correcting code from a ZX-calculus perspective. By expressing the underlying tensors as ZX-diagrams, we study the stabiliser structure of the code via Pauli webs. In addition, we obtain a diagrammatic understanding of its logical operators, encoding isometries, Rényi entropy and toy models of black holes/wormholes. Then, motivated by the pentagon holographic code's ZX-diagram, we introduce a family of codes constructed from ZX-diagrams on its dual hyperbolic tessellations and study their logical error rates using belief propagation decoders.

Abstract from the arXiv version, arXiv:2601.04467.

14:55 – 15:20 · Parallel B

Logic meets Wigner's friend (and their friends)

Alexandru Baltag, Sonja Smets

The abstract for this talk at QPL 2026 is based on [6]: https://arxiv.org/abs/2307.01713 In this presentation we look at the interplay of multi-agent epistemic logic and quantum mechanics. We show under which conditions a logically consistent framework can be provided that satisfies both the standard rules and axioms of multi-agent epistemic reasoning and the axiomatic theory that regulates the flow of quantum information. We take a fresh look at Wigner's Friend thought-experiment [31] and some of its more recent variants and extensions [15, 10] , such as the Frauchiger-Renner (FR) Paradox [18]. The questions we answer include: What is the correct epistemic interpretation of the multiplicity of state assignments in these scenarios? Under which conditions can one include classical observers into the quantum state descriptions, in a way that is still compatible with traditional Quantum Mechanics? Under which conditions can one system be admitted as an additional 'observer' from the perspective of another background observer? By answering these questions we provide a principled solution to Wigner Friend-type paradoxes.

14:55 – 15:20 · Parallel C

Events and their localisation are relative to a lab

V. Vilasini, Lin-Qing Chen, Liuhang Ye, Renato Renner

The notions of events and their localisation fundamentally differ between quantum theory and general relativity, reconciling them becomes even more important and challenging in the context of quantum gravity where a classical spacetime background can no longer be assumed. We therefore propose an operational approach drawing from quantum information, to define events and their localisation relative to a Lab, which in particular includes a choice of physical degree of freedom (the reference) providing a generalised notion of "location". We define a property of the reference, relative measurability, that is sensitive to correlations between the Lab's reference and objects of study. Applying this proposal to analyse the quantum switch (QS), a process widely associated with indefinite causal order, we uncover differences between classical and quantum spacetime realisations of QS, rooted in the relative measurability of the associated references and possibilities for agents' interventions. Our analysis also clarifies a longstanding debate on the interpretation of QS experiments, demonstrating how different conclusions stem from distinct assumptions on the Labs. This provides a foundation for a more unified view of events, localisation, and causality across quantum and relativistic domains.

Abstract from the arXiv version, arXiv:2505.21797.

15:20 – 15:45 · Parallel A

The delayed stabiliser ZX-calculus

Cole Comfort, Giovanni de Felice

We introduce the delayed stabiliser ZX-calculus, a formal graphical language for translation-invariant stabiliser quantum processes: enabling compact, finite reasoning about various families of infinite stabiliser-codes, such as quantum convolutional codes and lattice codes. Our calculus extends the odd-prime-dimensional stabiliser ZX-calculus with only a single additional generator, the delay, which feeds data from one time step to the next. First, we give an interpretation of delayed ZX diagrams as sequences of finite approximations obtained by unrolling the diagram in time. We define a notion of observational equivalence between such sequences and prove that, modulo this equivalence relation, each sequence determines a unique infinite-dimensional stabiliser group. Second, we interpret the delay as multiplication by a formal polynomial indeterminate, encoding infinite sequences of Pauli operators as fractions of polynomials. This allows us to represent the infinite stabiliser group of a delayed stabiliser circuit in terms of a finite generating tableau. We connect both semantics via geometric-series expansion, showing that composition in the infinite stabiliser group semantics approximates composition in the generating tableau semantics. Finally, we give an equational theory for delayed stabiliser ZX-calculus, featuring generalised Euler decomposition and colour change rules. We show that this calculus is sound and universal for the generating tableau semantics. Combining delayed ZX calculus with scalable notation [9], we present a novel generalised local complementation rule for translation-invariant graph state. We conjecture that this rule follows from the axioms of our calculus, from which completeness would follow.

15:20 – 15:45 · Parallel B

The geometry of fiber products of probability polytopes

Cihan Okay, Aziz Kharoof

We develop tools for characterizing vertices of fiber products of polytopes and apply them to simplicial distribution polytopes, a class of probability polytopes arising in quantum foundations and quantum information. In the theory of simplicial distributions, a pair of simplicial sets encoding measurement and outcome spaces determines a convex polytope of compatible probability assignments. Our first results give geometric criteria for detecting vertices of fiber products in terms of support data. These results are obtained in the more general framework of inverse limits of diagrams of polytopes in standard form, and they translate to corresponding criteria for simplicial distributions on arbitrary colimits of measurement spaces. We then focus on one-dimensional measurement spaces, where simplicial distributions recover and generalize local marginal polytopes in graphical models. In this setting, our sharpest results concern dipole graphs, for which we obtain a complete characterization of vertices and refine it to a graph-theoretic criterion. These characterizations are reminiscent of the classical support-graph criteria for transportation polytopes, but they arise in a richer class of polytopes in which vertex structure depends not only on support acyclicity but also on additional geometric compatibility data. Using the collapsing method from simplicial topology, we transfer the dipole characterization to rose graphs and obtain analogous results there. Finally, we apply collapsing to complete bipartite graphs, which encode physically relevant bipartite Bell scenarios, and more generally to arbitrary connected graphs, yielding lower bounds on the number of vertices.

Abstract from the arXiv version, arXiv:2603.19479.

15:20 – 15:45 · Parallel C

Parity erasure: a foundational principle for indefinite causal order

Zixuan Liu, Ognyan Oreshkov

Processes with indefinite causal order can arise when quantum theory is locally valid and they allow accomplishing new informational tasks. Despite recent progress, the correlations allowed in such processes have not been clearly understood. Here, we propose to study the constraints on information exchange through such processes in a paradigm of locally sequential operations. In this paradigm, we identify an information-theoretic principle constraining the correlations, termed parity erasure, which follows from the local validity of causality. We show that this principle completely characterizes the local-tomography representation of higher-order processes with indefinite causal order: among all multipartite channels, the ones describing valid higher-order processes are those and only those whose input-output correlations respect parity erasure. This approach reveals a fundamental property of information exchange in scenarios with indefinite causal structure and opens a new arena for exploring their potential applications.

Abstract from the arXiv version, arXiv:2512.08635.

16:15 – 16:40 · Parallel A

No extension of the Quantum Tensor Product admits a superposition principle

Vincenzo Fiorentino, Kuntal Sengupta

Textbook quantum superposition refers to the feature that certain linear combinations of Hilbert space rays, each representing a valid state, are themselves valid states. Recently, superposition has been at the heart of experimental proposals for demonstrating indefinite causal order within quantum theory as well as non-classicality of gravity. However, unlike Bell nonlocality, an operational description of superposition has not been extensively explored. In addition, whether such an understanding can provide insights into finding information-theoretic principles to reconstruct quantum theory remains unclear. In this work we explore these both and answer the latter in the positive, while making connections between superposition, entanglement and preparational uncertainty.

We present an operational notion of superposition in the framework of Generalised Probabilistic Theories (GPTs) that is based on properties of observed measurement statistics. By remaining theory-independent, our definition extends the notion of superposition to theories where states are not necessarily represented by rays in a Hilbert space. We then use this notion to formulate three superposition principles that capture structural features of the quantum state space related to superposition, and investigate their presence GPTs such as Boxworld, Spekkens' toy model, and regular polygons. We then provide conditions under which presence of superposition in subsystems extends to their compositions. As our main result we show that no extension of the quantum tensor product can simultaneously admit no-restriction hypothesis and all three of our proposed principles. Finally we show how preparational uncertainty and entanglement, that are usually studied separately, can be viewed as special forms of superposition.

16:15 – 16:40 · Parallel B

Sheaf-theoretic preparation contextuality via stochastic extension

Tom Williams, Mina Doosti, Farid Shahandeh

We introduce a preparation-dual notion of contextuality, formulated as an obstruction to stochastic extension. In parallel with the sheaf-theoretic formulation of measurement contextuality, preparation contextuality arises when locally specified preparation statistics cannot be extended to a single global response matrix compatible with all source contexts. Whereas measurement contextuality concerns the incompatibility of restriction maps (marginalisation), the preparation setting requires stochastic extension of partial conditioning data, which is inherently non-unique. We identify minimal structural and preparation compatibility conditions on admissible extension matrices and show that they enforce a rigid product form. This leads to a notion of preparation contextuality in which the absence of any admissible global response representation witnesses contextuality, while preparation compatibility identifies the cases in which this obstruction is nontrivial. The framework is formulated explicitly in matrix form and illustrated by a quantum-mechanical example exhibiting preparation contextuality.

Abstract from the arXiv version, arXiv:2605.00975.

16:15 – 16:40 · Parallel C

Reference frames for process matrices: from coordinate parametrization to spacetime representation

Luca Apadula, Alexei Grinbaum, Časlav Brukner

We study how to implement and transform frame perspectives for quantum processes in the process-matrix formalism. We argue that, for pure processes, the causal reference frames (CRF)and time-delocalized subsystems (TDS) formalisms should be understood as coordinate parametrizations of a single perspective-neutral higher-order object. A genuine perspective arises when one endows the process with additional frame data by choosing an operational foliation into circuit fragments (events). With this distinction, existing no-go results acquire a clear scope: they rule out unitary transformations that preserve time foliation, attempting to switch perspectives while keeping the fragment boundaries -- hence the global past/future partition -- fixed. Focusing on the quantum switch, we construct explicit maps that transform perspectives unitarily at the price of reshuffling the notions of past and future. We then show that unitary transformations between perspectives can also be achieved in a different way, namely by extending the process with subsystems that define quantum reference frames and provide a shared spatiotemporal scaffold. In this extended setting, complementary CRF/TDS perspectives become unitarily related while preserving global past and future. We discuss how this frame-perspectival approach informs the broader question of empirical realizability of abstract process matrices.

Abstract from the arXiv version, arXiv:2604.02873.

16:40 – 17:05 · Parallel A

Deriving the generalised Born rule from first principles

Gaurang Agrawal, Matt Wilson

A basic postulate of modern compositional approaches to generalised physical theories is the generalised Born rule, in which probabilities are postulated to be computable from the composition of states and effects. In this paper we consider whether this postulate, and the strength of the identification between scalars and probabilities, can be argued from basic principles. To this end, we first consider the most naive possible process- theoretic interpretation of textbook

quantum theory, in which physical processes (unitaries) along with states and effects (kets and bras) and a probability function from states and effects satisfying just some basic compatibility axioms are identified. We then show that any process theory equipped with such structure is equivalent to an alternative process theory in which the generalised Born rule holds. We proceed to consider introduction of noise into any such theory, and observe that the result of doing so is a strengthening of the identification between scalars and probabilities; from bare monoid homomorphisms to semiring isomorphisms.

Abstract from the arXiv version, arXiv:2511.21355.

16:40 – 17:05 · Parallel B

Linear algebra of generalized contextuality in prepare-transform-measure scenarios

Theodoros Yianni, Farid Shahandeh, Nyan Raess

Generalized contextuality is a canonical distinguishing property of nonclassical generalized probabilistic theories, in particular quantum mechanics. Methods for certification and characterization of generalized contextuality of a given generalized probabilistic theory are well developed for prepare-measure and single-stage prepare-transform-measure scenarios. In a recent work [arXiv:2512.10000], a bottom-up, statistics-first linear-algebraic framework for contextuality in prepare-measure scenarios was introduced. We extend this approach to operational scenarios with sequential transformations with an arbitrary number of stages. We give a full decision procedure for contextuality of such scenarios within operational theories and analyze its computational complexity. In particular, our decision procedure has a complexity linearly exponential in the minimum generalized probabilistic theory (GPT) dimension, and polynomial in the number of procedures. We demonstrate our framework and approach through multiple examples, including Spekkens' toy theory and the 8-state single-qubit stabilizer theory. In particular, we construct an operational theory in which contextuality manifests itself only in the sequential structure of the transformations. Our findings thus shed new light on the significant role of compositional structures in the phenomenon of generalized contextuality.

Abstract from the arXiv version, arXiv:2607.26139.

16:40 – 17:05 · Parallel C

Probing the composition of processes with first-order-ISOMIX logic

Raphaël Le Bihan, Alastair Abbott, Mnacho Echenim

The Causal Logic of Simmons and Kissinger (arXiv:2403.09297) provides a sound and complete logic to decide causal consistency in the framework of causal categories. Given a formula F in Causal Logic, the validity of F (denoted $\vdash$F) can be determined according to a proof-net criterion, and F is logically valid iff it is causally consistent. In general, however, determining the validity of a balanced formula, i.e. verifying the correctness of a given proof-net, is a coNP-complete problem.

Here, we interest ourselves in a slightly more specific problem: determining the validity of compositions of higher-order processes (e.g., the composition of multiple quantum supermaps). While Causal Logic can be used to address this problem, it is sufficient to study some pertinent fragments of the logic for this purpose. In Causal Logic, formulas can contain two sorts of variables: first-order variables, and regular (or higher-order) variables, in addition to the unit atom I, and connectors $\otimes$, $\parr$ and $<$. ISOMIX is the fragment of Causal Logic containing only formulas with regular variables, I and the connectors $\otimes$ and $\parr$, while First-Order-ISOMIX (FO-ISOMIX) is defined analogously, but with only first-order variables. FO-ISOMIX turns out to be the relevant fragment for the compositional problem described above, but formulas' validity remains coNP-hard to decide. On the other hand, the validity of (balanced) ISOMIX formulas can be efficiently determined.

We study the relation between ISOMIX and FO-ISOMIX, and in particular a mapping from formulas F of the latter to the former, HO(F), obtained by replacing first-order variables by higher-order variables. While it is easy to show that if HO(F) is valid, then so is F, the converse does not hold in general. We show, however, that if F is valid and HO(F) is not valid, then F must contain a "forbidden structure", which can be detected in linear time by parsing the formula F. This provides an efficient pre-check when aiming to determine the validity of F: if F has no forbidden structure, then the non-validity of HO(F) -- which can be checked efficiently -- implies the non-validity of F.

These results provide a criteria for determining when, e.g., the validity of the composition of higher-order processes can efficiently determined. In work in progress, we apply this to the composition of quantum supermaps, enumerating all possible compositions of two bipartite supermaps, and determining the sets of valid compositions. This provides a first step in the study of how small supermaps can be consistently combined into more complex ones.

17:05 – 17:30 · Parallel A

Quantum theory can decohere from a causally-indefinite post-quantum theory

James Hefford, Matt Wilson

We find a process satisfying the axioms of hyper-decoherence which produces standard quantum theory from the theory of quantum boxes (higher-order quantum theory with the non-signalling tensor product). This hyper-decoherence map evades the no-go theorem of Lee and Selby [8] by relaxing constraints on signalling to the past and the uniqueness of purifications. We discuss some natural opposing conclusions: that the existence of this map might be evidence of a genuine hyper-decoherence process producing causal quantum theory from its causally-indefinite higher-order theory; or that it serves as an indication that the axioms of hyper-decoherence might need careful re-consideration, especially regarding the subtle albeit central role that purity plays.

17:05 – 17:30 · Parallel B

Noncontextuality inequalities for prepare-transform-measure scenarios

David Schmid, Roberto D. Baldijão, John Selby, Ana Belen Sainz, Robert W. Spekkens

We provide the first systematic technique for deriving witnesses of contextuality in prepare-transform-measure scenarios. More specifically, we show how linear quantifier elimination can be used to compute a polytope of correlations consistent with generalized noncontextuality in such scenarios. This polytope is specified as a set of noncontextuality inequalities that are necessary and sufficient conditions for observed data in the scenario to admit of a classical explanation relative to any linear operational identities, if one ignores some constraints from diagram preservation. While including these latter constraints generally leads to tighter inequalities, it seems that nonlinear quantifier elimination would be required to systematically include them. We also provide a linear program which can certify the nonclassicality of a set of numerical data arising in a prepare-transform-measure experiment. We apply our results to get a robust noncontextuality inequality for transformations that can be violated within the stabilizer subtheory. Finally, we give a simple algorithm for computing all the linear operational identities holding among a given set of states, of transformations, or of measurements.

Abstract from the arXiv version, arXiv:2407.09624.

17:05 – 17:30 · Parallel C

How many systems can be dephased before the quantum switch becomes causally definite?

Yassine Benhaj, Kuntal Sengupta, Cyril Branciard

Higher order operations within quantum theory feature processes that allow operations to take place without a well-defined causal order [1, 2]. This feature, often referred to as indefinite causal order or causal nonseparability, has recently received much attention, both in quantum foundations, in the understanding of causation, and in its ability to provide leverage in information processing tasks over scenarios where all operations occur in definite order. A natural enquiry is to investigate how much quantumness, or non-classicality is required for a process to feature indefinite causal order.

Wednesday, August 19th

Long plenary talks (merged)

9:30 – 10:15

Completeness for flow-preserving rewrite rules

Miriam Backens, Simon Perdrix

Complete sets of graphical rewrite rules enable fully graphical reasoning about quantum computations and have been an area of active research for more than a decade. Many recent applications of the ZX-calculus have made use of the close correspondence between ZX-diagrams and computations in the one-way model of measurement-based quantum computation. In this model, various kinds of flow properties ensure deterministic implementability; for ZX-diagrams, these same properties allow efficient translation into quantum circuits (a problem that is known to be #P-hard in general). Therefore, flow-preserving ZX-calculus rewrite rules are of strong interest.

Here, we extend the set of flow-preserving rules appearing in the literature with a few new rules and extensions of existing rules. We then show that the resulting rule set is complete for all flow-preserving translations between ZX-diagrams of appropriate form. The proof employs a manifestly flow-preserving equivalent of circuit extraction, where a diagram with gflow is transformed, using only flow-preserving rewrite rules, into a diagram with causal flow.

Abstract from the arXiv version, arXiv:2608.13035.

9:30 – 10:15

Generating one-way computations with flow: flow-preserving rewriting that ignores the interpretation

Miriam Backens

The one-way model is a universal model of quantum computation, driven by successive adaptive single-qubit measurements on an entangled resource state. Measurements are non-deterministic, yet if the computation satisfies one of several related families of conditions known as 'flows', the computation can be made deterministic overall by modifying later measurements depending on the outcomes of earlier ones. Flow properties also enable efficient translation from one-way computations to circuits, motivating research into rewriting one-way computations while preserving the existence of flow. Existing approaches to flow-preserving rewriting are used for compilation or optimisation and preserve both the interpretation and the existence of flow. Here, we broaden our perspective to consider flow-preserving rewriting that does not necessarily preserve the interpretation, with applications to creating test instances for software that works with flow, as well as to generating ansätze for quantum machine learning. We show that a family of just three flow-preserving rewrite rules suffices to generate any diagram with flow from a trivial diagram with the desired number of inputs and outputs. This rule set is nearly the same as the complete set of flow- and interpretation-preserving rewrite rules for one-way computations in which all measurements are Pauli; and just a small subset of the flow- and interpretation-preserving rewrite rules for arbitrary measurements.

Abstract from the arXiv version, arXiv:2607.03250.

10:15 – 11:00

Beyond Penrose tensor diagrams with the ZX calculus: applications to quantum computing, quantum machine learning, condensed matter physics, and quantum gravity

Quanlong Wang, Richard D. P. East, Razin A. Shaikh, Lia Yeh, Boldizsár Poór, Bob Coecke

We introduce the Spin-ZX calculus as an elevation of Penrose's diagrams and associated binor calculus to the level of a formal diagrammatic language. The power of doing so is illustrated by the variety of scientific areas we apply it to: permutational quantum computing, quantum machine learning, condensed matter physics, and quantum gravity. Respectively, we analyse permutational computing transition amplitudes, evaluate barren plateaus for SU(2) symmetric ansätze, study properties of AKLT states, and derive the minimum quantised volume in loop quantum gravity. Our starting point is the mixed-dimensional ZX calculus, a purely diagrammatic language that has been proven to be complete for finite-dimensional Hilbert spaces. That is, any equation that can be derived in the Hilbert space formalism, can also be derived in the mixed-dimensional ZX calculus. We embed the Spin-ZX calculus inside the mixed-dimensional ZX calculus, rendering it a quantum information flavoured diagrammatic language for the quantum theory of angular momentum, i.e. SU(2) representation theory. We diagrammatically derive the fundamental spin coupling objects - such as Clebsch-Gordan coefficients, symmetrising mappings between qubits and spin spaces, and spin Hamiltonians - under this embedding. Our results establish the Spin-ZX calculus as a powerful tool for representing and computing with SU(2) systems graphically, offering new insights into foundational relationships and paving the way for new diagrammatic algorithms for theoretical physics.

Abstract from the arXiv version, arXiv:2511.06012.

Parallel sessions

14:30 – 14:55 · Parallel A

Causal inequalities witness non-stabilizerness without magic

Leonardo Vaglini, Nasra Daher Ahmed, Ravi Kunjwal

The operational and axiomatic approaches to the resource theory of magic, where the defining free operations are, respectively, stabilizer operations and completely stabilizer-preserving operations, are known to differ. An example showing the separation is given by the existence of a stabilizer product basis, the so-called SHIFT basis, whose states cannot be perfectly discriminated using stabilizer operations alone, even though they can be prepared in a classically efficient way, thus exhibiting non-stabilizerness without magic (NSWM). Any stabilizer product basis can be put in one-to-one correspondence with a mathematical object originally developed to describe deterministic classical communication among different parties in a correlational scenario: process functions. Specifically, such a function governs the classical communication among the parties while remaining logically consistent and can yield correlations that cannot be explained by communication taking place with a definite causal order. In this work, we consider a state discrimination task where stabilizer operations alone are allowed; we then study whether perfect discrimination of the states in the stabilizer product basis is possible in relation to the causal structure of the associated process function. Considering the multiqudit scenario with prime dimension d, we first show that the possibility of adding ancillary systems and performing joint operations on system and ancillary qudits does not offer any advantage. We then show that a multiqudit stabilizer product basis with prime d exhibits NSWM if and only if the associated process function is non-causal. As a corollary, a causal inequality violation implies NSWM for the corresponding basis. We also briefly discuss, in the qubit case, how the causal structure of the process function affects the non-Cliffordness of the unitary that maps the computational basis to the given stabilizer product basis.

14:30 – 14:55 · Parallel B

Insights in graph state entanglement via r-local complementation: structure and a quasi-

polynomial algorithm

Nathan Claudet, Simon Perdrix

We describe an algorithm with quasi-polynomial runtime $n^{\log_2(n)+O(1)}$ for deciding local unitary (LU) equivalence of graph states. The algorithm builds on a recent graphical characterisation of LU-equivalence via generalised local complementation. By first transforming the corresponding graphs into a standard form using usual local complementations, LU-equivalence reduces to the existence of a single generalised local complementation that maps one graph to the other. We crucially demonstrate that this reduces to solving a system of quasi-polynomially many linear equations, avoiding an exponential blow-up. As a byproduct, we generalise Bouchet's algorithm for deciding local Clifford (LC) equivalence of graph states by allowing the addition of arbitrary linear constraints. We also improve existing bounds on the size of graph states that are LU- but not LC-equivalent. While the smallest known examples involve 27 qubits, and it is established that no such examples exist for up to 8 qubits, we refine this bound by proving that LU- and LC-equivalence coincide for graph states involving up to 19 qubits.

Abstract from the arXiv version, arXiv:2502.06566.

14:30 – 14:55 · Parallel C

Quantum theory over dual-complex numbers

Pablo Arrighi, Doğukan Bakircioglu, Nathan Houyet

We take quantum theory and replace C by C[ε] where ε2 = 0, i.e. we extend quantum theory to the ring of dual complex numbers. The aim is to develop a common language in which to treat continuous quantum physics and discrete quantum models in a unified manner, including their symmetries. Since quantum theory is linear, introducing ε is enough to model infinitesimals. A first objection to this programme is that C[ε] is not a field, since division by ε is undefined, while quantum mechanics typically relies on division. A second objection concerns whether unitarity still makes sense given ε2 = 0. Hence, the core of this work is dedicated to proving that dual-complex quantum theory remains fully consistent. In particular, norm is preserved at all times, and renormalization never requires dividing by an infinitesimal. An equivalence with conventional quantum theory is demonstrated: the dual-complex extension of a parametrized quantum operation automatically provides a linear treatment of its first-order variations. As a first example application, we provide a unified description of both the Dirac equation in the continuum and the Dirac Quantum Walk in the discrete. We establish the discrete Lorentz covariance of the latter.

14:55 – 15:20 · Parallel A

Supermaps on generalised theories

Matthew Wilson, James Hefford, Timothée Hoffreumon

Categorical supermaps generalise higher-order quantum operations from finite-dimensional quantum theory to arbitrary circuit theories. In this paper, we establish the Yoneda lemma for categorical supermaps, which states that whenever a physical theory has a suitable notion of channel-state duality, then categorical supermaps on that theory can be concretely represented in terms of that duality. This lemma eliminates any guesswork or ambiguity when defining the appropriate notion of supermap for these theories. As a concrete application, we show that the categorical supermaps on Boxworld are in general characterised by a physically well-motivated weaking of the recently proposed NSWSE principle for higher-order processes on boxworld. Furthermore, via the same Yoneda lemma we put forward a stable definition for supermaps in real quantum theory.

Abstract from the arXiv version, arXiv:2602.23865.

14:55 – 15:20 · Parallel B

Working with measurement-based computations on qudits

Piotr Mitosek, Miriam Backens

Measurement-based quantum computing is a universal model of quantum computation in which successive product measurements of an entangled resource state drive the computation. The nondeterministic nature of measurements necessitates adaptivity to ensure an overall deterministic computation. Flow structures characterise cases in which such an adaptive correction procedure is possible. Recently, flow has been defined in a setting where the resource states are prime-dimensional qudit graph states rather than the usual qubit graph states. Yet, this qudit flow definition is more burdensome to work with than analogous definitions for qubits. Here, we give a simpler definition of qudit flow and consider various useful properties of this flow, drawing on results for the qubit case. In particular, we show how to focus qudit flow and argue that focused flow is canonical. We improve the previous algebraic formulation to capture focused flow and use it to obtain an $O(n^3)$ flow-finding algorithm (where n is the number of qudits), matching the best known complexity for qubit flows and improving on the previous $O(n^4)$ result for qudits. Furthermore, we explore multiple flow-preserving transformations, thus opening a pathway to using flow for optimisation. These transformations include pivoting, removal and insertion of certain types of vertices, and reversibility of flow. Lastly, we propose an algorithmic approach to generating large qudit computations with flow, for testing or machine learning.

14:55 – 15:20 · Parallel C

Subsystems as subsets of quantum channels, and the strange case of blind agents

Nicolas Moulonguet, Augustin Vanrietvelde

Defining subsystems is a critical task in any theory of the world, and especially in causal modelling, where these subsystems are the causal relata. We investigate the operational definition of subsystems in quantum theory, within a framework recently proposed by Chiribella, in which those are identified with subsets of transformations. We argue that it is reasonable to restrict to what we call 'bicom-closed' subsystems, admitting a notion of complementation. We make the point that, due to the unphysicalness of global phase, the transformations at hand for a closed quantum system are not unitary operators, but unitary channels; this has major consequences for subsystems, opening the way to new instances beyond the traditionally adopted C*-algebraic ones. We provide a full mathematical classification of the channel-based subsystems that arise as the commutant or bicommutant of one unitary channel. We investigate the admissible measurements that can be performed on such subsystems, and point out that some of them admit no measurement at all, despite being non-trivial. We discuss the two possible attitudes regarding these results — dismissing such subsystems, or taking them seriously — and the challenges that each entails.

15:20 – 15:45 · Parallel A

Essential unitarity for higher-order quantum computation

Samson Abramsky, Radha Jagadeesan

We develop a semantic framework for higher-order quantum computation based on a boundarycentric presentation of compact closed categories, building on the Kelly–Laplaza construction as reformulated by Abramsky. Morphisms are represented as polarized boundary linkings composed by execution, and a unit-free monoidal sum provides reversible control and branching. Within this setting, we identify a notion of essential unitarity that extends ordinary unitary evolution from first-order quantum processes to higher-order interfaces. At first order, essential unitarity coincides with standard unitarity; for higher-order interfaces, it characterizes when information is preserved relative to the boundary. We prove that essential unitarity is the unique predicate compatible with dagger-monoidal structure, coherence reindexing, and currying, and agreeing with ordinary unitarity at first order, for all morphisms that coherently mix uniform signature blocks—a condition satisfied throughout the quantum core. We show that this framework is expressively sufficient for higher-order quantum computation. In particular, one-slot, equal-size, purity-preserving supermaps admit coherent realizations entirely within the framework, including a coherent quantum switch.

15:20 – 15:45 · Parallel B

ZX-flow: a flexible criterion for deterministic computation with ZX-diagrams

Aleks Kissinger, John van de Wetering

Flow criteria are used to efficiently extract computations, either in the form of measurement patterns or quantum circuits, from ZX-diagrams. Existing criteria such as causal flow, generalised flow, and Pauli flow, were all originally formulated for graph states, so they require ZX-diagrams to be in a very particular graph-state-like form. This form is easily broken by applying basic ZX rules and makes establishing some desirable properties very complicated. Here, we introduce a new "ZXnative" flow criterion called ZX-flow, formulated using a new type of decoration of a ZX-diagram we call Pauli semiwebs. These are a generalisation of Pauli webs, which have recently been used extensively in reasoning about fault-tolerant computations in the ZX-calculus. We show that ZX-flow is straightforwardly preserved by all Clifford rewrites and furthermore that a ZX-diagram has ZXflow if and only if it is Clifford-equivalent to a graph-like ZX-diagram with Pauli flow. Finally, we show that any diagram with ZX-flow can be readily interpreted either as a deterministic measurementbased computation or as a Clifford isometry followed by a sequence of Pauli exponentials. The latter can then be efficiently extracted to a quantum circuit.

15:20 – 15:45 · Parallel C

Classical explanations in (and of) general probabilistic theories

John Harding, Alexander Wilce

We introduce a notion of the ``explanation" of one (generalized) probabilistic model by another as particular kind of span in the category $\Prob$ of probabilistic models and morphisms. We show that explanations compose under a standard pullback construction (notwithstanding that $\Prob$ does not support arbitrary pullbacks). We then show that every locally-finite probabilistic model has a canonical, sharp classical explanation. The construction is functorial, so every locally-finite probabilistic theory has a canonical, sharp classical (though of course, usually non-local) representation.

Abstract from the arXiv version, arXiv:2603.05627.

16:15 – 16:40 · Parallel A

Beyond Wigner – how non-invertible symmetries preserve probabilities

Thomas Bartsch, Yuhan Gai, Sakura Schäfer-Nameki

In recent years, the traditional notion of symmetry in quantum theory was expanded to so-called generalised or categorical symmetries, which, unlike ordinary group symmetries, may be non-invertible. This appears to be at odds with Wigner's theorem, which requires quantum symmetries to be implemented by (anti)unitary -- and hence invertible -- operators in order to preserve probabilities. We resolve this puzzle for (higher) fusion category symmetries $\mathcal{C}$ by proposing that, instead of acting by unitary operators on a fixed Hilbert space, symmetry defects in $\mathcal{C}$ act as isometries between distinct Hilbert spaces constructed from twisted sectors. As a result, we find that non-invertible symmetries naturally act as trace-preserving quantum channels. Crucially, our construction relies on the symmetry category $\mathcal{C}$ being unitary. We illustrate our proposal through several examples that include Tambara-Yamagami, Fibonacci, and Yang-Lee as well as higher categorical symmetries.

Abstract from the arXiv version, arXiv:2602.07110.

16:15 – 16:40 · Parallel B

From fermions to qubits: a ZX-calculus perspective

Haytham McDowall-Rose, Razin A. Shaikh, Lia Yeh

Mapping fermionic systems to qubits on a quantum computer is often the first step for algorithms in quantum chemistry and condensed matter physics. However, it is difficult to reconcile the many different approaches that have been proposed, such as those based on binary matrices, ternary trees, and stabilizer codes. This challenge is further exacerbated by the many ways to describe them -- transformation of Majorana operators, action on Fock states, encoder circuits, and stabilizers of local encodings -- making it challenging to know when the mappings are equivalent. In this work, we present a graphical framework for fermion-to-qubit mappings that streamlines and unifies various representations through the ZX-calculus. To start, we present the correspondence between linear encodings of the Fock basis and phase-free ZX-diagrams. The commutation rules of scalable ZX-calculus allows us to convert the fermionic operators to Pauli operators under any linear encoding. Next, we give a translation from ternary tree mappings to scalable ZX-diagrams, which not only directly represents the encoder map as a CNOT circuit, but also retains the same structure as the tree. Consequently, we graphically prove that ternary tree transformations are equivalent to linear encodings, a recent result by Chiew et al. The scalable ZX representation moreover enables us to construct an algorithm to directly compute the binary matrix for any ternary tree mapping. Lastly, we present the graphical representation of local fermion-to-qubit encodings. Its encoder ZX-diagram has the same connectivity as the interaction graph of the fermionic Hamiltonian and also allows us to easily identify stabilizers of the encoding.

Abstract from the arXiv version, arXiv:2505.06212.

16:15 – 16:40 · Parallel C

Superluminal transformations and indeterminism

Amrapali Sen, Flavio Del Santo

Quantum theory is widely regarded as fundamentally indeterministic, yet classical frameworks can also exhibit indeterminism once infinite information is abandoned. At the same time, relativity is usually taken to forbid superluminal signalling, although Lorentz symmetry formally admits superluminal transformations (SpTs). Dragan and Ekert have argued that SpTs entail a form of indeterminism analogous to that encountered in quantum theory. Here, we derive a theory-independent no-go theorem from a set of natural assumptions: any framework admitting non-order-preserving SpTs must either abandon finite information, relinquish time-symmetric informational content, deny that the past stores memory, or abandon the notion that time determines a preferred causal ordering. In particular, one possible implication is that any theory accommodating SpTs suggests an ontology with unbounded informational content, akin to deterministic classical theories formulated over the real numbers. Consequently, any ontic indeterminacy associated with superluminal transformations cannot originate from finite information.

Abstract from the arXiv version, arXiv:2601.15263.

16:40 – 17:05 · Parallel A

Higher-order quantum computing with known input states

Vanessa Brzić, Satoshi Yoshida, Mio Murao, Marco Túlio Quintino

In higher-order quantum computing (HOQC), one typically considers the universal transformation of unknown quantum operations, treated as blackboxes. It is also implicitly assumed that the resulting operation must act on arbitrary, and thus unknown, input states. In this work, we explore a variant of this framework in which the operation remains unknown, but the input state is fixed and known. We argue that this assumption is well-motivated in certain practical contexts, such as unitary programming, and show that classical knowledge of the input state can significantly enhance performance. We demonstrate that in the SAR protocol, this knowledge leads to an exponential advantage through a repeat-until-success strategy, highlighting the operational power of known-state higher-order transformations. Moreover, this assumption allows us to distinguish between protocols designed for pure, bipartite, and mixed states, and to identify the class of mixed states for which deterministic and exact implementation becomes

possible. Finally, in the numerically tested regimes, general strategies offer no advantage over adaptive or sequential ones, suggesting that indefinite causal order does not help in the known-input setting.

16:40 – 17:05 · Parallel B

A three-way normal form for stabiliser codes across ZX diagrams, circuits, and tableaus

Lia Yeh, Jiaxin Huang, Aleks Kissinger, Sarah Meng Li, John van de Wetering

The ZX-calculus and stabiliser formalism are two ubiquitous multi-tools in quantum computation. Here, we unify these reasoning schemes by establishing a three-way translation between a general stabiliser code, its canonical ZX normal form, and its encoder circuit. We achieve this by extending the Affine-with-Phases normal form from stabiliser states to arbitrary Clifford isometries, and by providing efficient algorithms for constructing this normal form, both graphically in the ZX-calculus and algebraically via tableau operations. This extension yields a canonical normal form for stabiliser tableaus, which corresponds to a factorisation of any stabiliser code into an inner CSS code together with a diagonal Clifford unitary. This unified perspective provides a structurally coherent view of quantum error-correcting codes and paves the way for automated design pipelines for fault-tolerant quantum computation.

16:40 – 17:05 · Parallel C

Impossibility of superluminal signalling rules out causal loops in conical spacetimes

Maarten Grothus, V. Vilasini

Contrary to popular belief, in [1] it was shown that it is theoretically possible to have operationally detectable causal loops without violating the principle of no superluminal signalling (NSS) in (1 + 1)-Minkowski spacetime. No such examples are known in (d + 1)-Minkowski spacetimes for d > 1 spatial dimensions. The formalism underlying this finding is known as the affects framework [2], and is based on causal modelling [3, 4] which provides a-priori independent of spacetime, information-theoretic way to define causality. This allows to precisely distinguish causation and signalling (noting that these are not equivalent due to possibility of causal fine-tuning), and as a consequence, embedding these models in spacetime, it was found that NSS does not imply absence of superluminal causation (this is true in all Minkowski spacetimes, not just d = 1). Whether or not such superluminal causal influences compatible with NSS can be used to form operationally detectable causal loops also in d > 1 dimensions, has remained a key question. Our previous work [5] developed new techniques relating to (1) information-theoretic methods to infer causation from signalling, in presence of operational redundancies and fine-tuning, and (2) ordertheoretic properties of spacetime geometry, in particular identifying such a property conicality satisfied in d > 1 dimensional Minkowski spacetimes but violated in d = 1. Building on this, the current submission resolves the open question showing that in any conical spacetime, no superluminal signalling does rule out all operationally detectable causal loops. This highlights that the relationships between information-theoretic causality and relativistic principles can generally depend on spacetime geometry.

Thursday, August 20th

Long plenary talks

9:30 – 10:15

Denotational semantics for stabiliser quantum programs

Cole Comfort, Robert I. Booth

The stabiliser fragment of quantum theory is a foundational building block for quantum error correction, and hence for the fault-tolerant compilation of quantum programs. In this article, we develop a sound, universal, and complete denotational semantics for stabiliser operations, including measurement, classically controlled Pauli operators, and affine classical computation; supporting an explicit treatment of quantum error-correcting codes. We interpret stabiliser operations as affine relations over finite fields, yielding a semantics that reflects the algebraic structure underlying stabiliser quantum error correction. Because stabiliser quantum mechanics has a well-behaved algebraic structure, our relational semantics is conceptually transparent and computationally tractable when compared to standard denotational models for general quantum programs. We demonstrate the resulting semantics by describing a small assembly language for stabiliser programs with fully-abstract denotational semantics.

10:15 – 11:00

Quantum control and general recursion beyond the unitary case

Kathleen Barsse, Romain Péchoux, Simon Perdrix

Coherent control, aka quantum control, is a central concept in quantum computing that is attracting increasing attention from both the quantum foundations and quantum software communities. Defining coherent control in the presence of recursion and measurement has long been known to be a major challenge. In particular, no-go results have been established for standard semantical domains like completely positive maps. We address this problem by introducing the first quantum programming language with recursion that allows for the coherent control of arbitrary

quantum operations. We equip this language with both an operational and a denotational semantics that we prove to be adequate. To design these semantics, we show that combining coherent control, recursion, and measurement crucially requires describing the evolution of subprograms in the absence of input. To address this, the operational semantics takes into account a default evolution branch, while the denotational semantics uses the concept of coherent quantum operation, based on vacuum extensions. We strengthen the validity of our approach by developing an observational equivalence: two programs are equivalent if their probability of termination is the same in any context. The denotational semantics is shown to be fully abstract with respect to this observational equivalence.

Abstract from the arXiv version, arXiv:2507.10466.

Short plenary talk

11:30 – 11:55

Entanglement in the Dicke subspace

Aabhas Gulati, Ion Nechita, Clément Pellegrini

We provide a complete mathematical theory for the entanglement of mixtures of Dicke states. These quantum states form an important subclass of bosonic states arising in the study of indistinguishable particles. We introduce a tensor-based parametrization where the diagonal entries of these states are encoded as a symmetric tensor, enabling a direct translation between entanglement properties and well-studied convex cones of tensors. Our results bridge multipartite entanglement theory with semialgebraic geometry and the theory of completely positive and copositive tensors. This dictionary maps separability to completely positive tensors, the PPT property to moment tensors, entanglement witnesses to copositive tensors, and decomposable witnesses to sum of squares tensors. Using this framework, we construct explicit PPT entangled states in three or more qutrits, disproving a recent conjecture. We establish that PPT entanglement exists for all multipartite systems with local dimension d >= 3 and n >= 3 parties. We also show that, for mixtures of Dicke states, the PPT condition with respect to the most balanced bipartition implies all other PPT conditions. We further connect bosonic extendibility of mixtures of Dicke states to the duals of known hierarchies for non-negative polynomials, such as the ones by Reznick and Polya. We thus provide semidefinite programming relaxations for separability and entanglement testing in the Dicke subspace.

Abstract from the arXiv version, arXiv:2602.15800.

Parallel sessions

14:30 – 14:55 · Parallel A

Pauli gadget synthesis for gatesets with arbitrary even-arity Clifford gates

Arianne Meijer-van de Griend, Leo Becker

We propose an algorithm that can synthesize circuits to gate sets consisting of an 2n-arity Clifford gate and arbitrary single qubit rotations. To do this, we represent the circuit as a sequence of Pauli gadgets and jointly synthesize them by placing the multi-qubit Clifford in the synthesized circuit and pushing its adjoint through the remaining gadgets such that some qubits are disconnected from some gadgets. The pushed gadgets are collected in a Clifford tableau, which is decomposed afterwards. With the help of our algorithm we run experiments where we synthesize circuits to varying sizes of target multi-qubit gates. These experiments indicate that increases in gate size can lead to smaller output circuits, and that different connectivity constraints have meaningful differences in how higher arity gates effect the circuit sized.

14:30 – 14:55 · Parallel B

Quantum statistical functions

Haruki Emori

Statistical functions such as the moment-generating, characteristic, cumulant-generating, and second characteristic functions are standard tools in classical statistics and probability theory. They provide a systematic means to analyze the statistical properties of a system and find applications in diverse fields. While these functions are ubiquitous in classical theory, a quantum counterpart has remained underdeveloped because of the noncommutativity of operators. The absence of such a framework has obscured the connections between statistical quantities and the nonclassical features of quantum mechanics. Here, we construct a framework for quantum statistical functions that addresses these limitations and unifies the languages of quantum statistics. We show that the functions reproduce standard statistical quantities such as expectation values, variance, and covariance upon differentiation. By extending the framework to include pre- and post-selection, we define conditional functions that generate conditional statistical quantities, including the weak value and the weak variance. We further show that multivariable functions, defined with specific operator orderings, correspond to the Kirkwood--Dirac, Margenau--Hill, and Wigner distributions. By generalizing Bochner's theorem within the theory of compactly supported distributions, we obtain a criterion that separates classical statistics from quantum statistics, linking the failure of positive definiteness of the multivariable function

to the emergence of quasiprobability. As an application, we import the classical method of moments and generalized method of moments into quantum estimation, introducing quantum estimators that exploit the proposed functions. Our framework reproduces quantum statistical quantities and incorporates the nonclassical features of quasiprobability, providing a basis for further study of quantum statistics.

Abstract from the arXiv version, arXiv:2602.05821.

14:30 – 14:55 · Parallel C

Three-qubit nonlocality paradoxes: beyond GHZ

Nadish de Silva, Santanil Jana, Ming Yin

Quantum nonlocality paradoxes, such as the GHZ paradox, give inequality-free and logically sharp separations between classical and quantum correlations, and play a central role in information-theoretic tasks admitting unconditional quantum advantage. In this work, we introduce a graph-theoretic and logical framework for analysing nonlocality paradoxes. We give an exhaustive classification of all threequbit nonlocality paradoxes that admit biconditional parity proofs. We show that the resulting structures are substantially richer than previously understood, violating regularity conditions underlying previously known families.

14:55 – 15:20 · Parallel A

Multi-qubit controlled gate with optimal T-count

Soichiro Yamazaki, Seiseki Akibue

Controlled gates are key components in various quantum algorithms. Improving on the prior work of Gosset et al., we show that, for an allowed error ε, $3\log_2(1/\varepsilon) + o(\log(1/\varepsilon))$ T gates are sufficient to approximate most multi-qubit controlled SU(2)s. We also show that this T-count matches the lower bound among approximating circuits that preserve the block-diagonal form. As an application, general controlled gate synthesis and efficient SU(4) gate synthesis are given.

14:55 – 15:20 · Parallel B

Basis-independent stabilizerness and maximally noisy magic states

Michael Zurel, Jack Davis

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.

Abstract from the arXiv version, arXiv:2602.22336.

14:55 – 15:20 · Parallel C

Spurious quantum correlations

Shashaank Khanna, Matthew Pusey, Roger Colbeck

In his seminal paper, Bell [Physics Physique Fizika 1, 195 (1964)] considers the correlations that result from spacelike separated measurements on a pair of entangled particles. He uses relativity theory to motivate the Bell causal structure, then shows the existence of quantum correlations that cannot be explained classically within this causal structure. Classical explanations of such quantum correlations are possible in alternative causal structures, for instance, those that allow superluminal causal influences, but, as shown by Spekkens and Wood [New Journal of Physics 17 033002 (2015)], all such alternative explanations require fine tuning. Here we show the existence of spurious quantum correlations — correlations that look quantum in one causal structure, but have a natural non fine-tuned classical explanation in another. More precisely, there are causal structures that admit quantum correlations unexplainable classically, but for which the same correlations have a faithful (i.e., not fine-tuned) classical explanation in another causal structure. In fact, not only can the realisation in the other causal structure be done faithfully, it can also be done without breaking any natural constraints on the causal structure that follow from relativity theory. However, like the Bell inequality violating correlations in the Bell causal structure, there exist a few other causal structures which support non-classical quantum correlations that resist any classical causal explanation in another alternate causal structure unless one resorts to fine-tuning.

15:20 – 15:45 · Parallel A

Tensor and gadget reinforcement learning for improved, hardware-aware quantum architecture search

Akash Kundu

Variational quantum algorithms hold the promise to address meaningful quantum problems already on noisy intermediate-scale quantum hardware. In spite of the promise, they face the challenge of designing quantum circuits that both solve the target problem and comply with device limitations. Quantum architecture search (QAS) automates the design process of quantum circuits, with reinforcement learning (RL) emerging as a promising approach. Yet, RL-based QAS methods encounter significant scalability issues, as computational and training costs grow rapidly with the number of qubits, circuit depth, and hardware noise. To address these challenges, we introduce $\textit{TensorRL-QAS}$, an improved framework that combines tensor network methods with RL for QAS. By warm-starting the QAS with a matrix product state approximation of the target solution, TensorRL-QAS effectively narrows the search space to physically meaningful circuits and accelerates the convergence to the desired solution. Tested on several quantum chemistry problems of up to 12-qubit, TensorRL-QAS achieves up to a 10-fold reduction in CNOT count and circuit depth compared to baseline methods, while maintaining or surpassing chemical accuracy. It reduces classical optimizer function evaluation by up to 100-fold, accelerates training episodes by up to 98$\%$, and can achieve 50$\%$ success probability for 10-qubit systems, far exceeding the $<$1$\%$ rates of baseline. Robustness and versatility are demonstrated both in the noiseless and noisy scenarios, where we report a simulation of an 8-qubit system. Furthermore, TensorRL-QAS demonstrates effectiveness on systems on 20-qubit quantum systems, positioning it as a state-of-the-art quantum circuit discovery framework for near-term hardware and beyond.

Abstract from the arXiv version, arXiv:2505.09371.

15:20 – 15:45 · Parallel B

Classical simulation of circuits with realistic odd-dimensional Gottesman–Kitaev–Preskill states

Cameron Calcluth, Oliver Hahn, Juani Bermejo Vega, Alessandro Ferraro, Giulia Ferrini

Classically simulating circuits with bosonic codes is challenging due to the prohibitive cost of simulating quantum systems with many, possibly infinite, energy levels. We propose an algorithm to simulate circuits with encoded Gottesman-Kitaev-Preskill (GKP) states, specifically for odd-dimensional encoded qudits. Our approach is tailored to be especially effective in the most challenging but practically relevant regime, where the codeword states exhibit high (but finite) squeezing. Our algorithm leverages the Zak-Gross Wigner function introduced by Davis, Fabre, and Chabaud, which represents infinitely squeezed encoded stabilizer states positively. The run-time of the algorithm scales with the negativity of the Wigner function, allowing for efficient simulation of certain large-scale circuits—namely, input stabilizer GKP states undergoing generalized GKP-encoded Clifford operations followed by modular measurement—with a high degree of squeezing. For stabilizer GKP states exhibiting 12 dB of squeezing, our algorithm can simulate circuits with up to 1000 modes with less than double the number of samples required for a single input mode, which is in stark contrast to existing simulators. Therefore, this approach holds significant potential for benchmarking early implementations of quantum computing architectures utilizing bosonic codes.

15:20 – 15:45 · Parallel C

A unified framework for Bell inequalities from continuous-variable contextuality

C. E. Lopetegui-Gonzalez, G. Masse, E. Oudot, U. I. Meyer, F. Centrone, F. Grosshans, P. E. Emeriau, U. Chabaud, M. Walschaers

Although the original EPR paradox was formulated in terms of position and momentum, most studies of these phenomena have focused on measurement scenarios with only a discrete number of possible measurement outcomes. Here, we present a framework for studying non-locality that is agnostic to the dimension of the physical systems involved, allowing us to probe purely continuous-variable, discrete-variable, or hybrid non-locality. Our approach allows us to find the optimal Bell inequality for any given measurement scenario and quantifies the amount of non-locality that is present in measurement statistics. This formalism unifies the existing literature on continuous-variable non-locality and allows us to identify new states in which Bell non-locality can be probed through homodyne detection. Notably, we find the first example of continuous-variable non-locality that cannot be mapped to a CHSH Bell inequality. Moreover, we provide several examples of simple hybrid DV-CV entangled states that could lead to near-term violation of Bell inequalities.

Abstract from the arXiv version, arXiv:2601.07686.

15:45 – 16:10 · Parallel A

Buildings for synthesis with Clifford+R

Mark Deaconu, Nihar Gargava, Amolak Ratan Kalra, Michele Mosca, Jon Yard

We study the problem of exact synthesis for the Clifford+R gate set and give the explicit structure of the underlying Bruhat-Tits building for this group. In this process, we also give an alternative proof of the arithmetic nature of this gate set.

15:45 – 16:10 · Parallel B

Algebraic techniques for photonic state preparation and characterization

Massimo Frigerio, Mattia Walschaers, Andrei Aralov, Carlos Ernesto Lopetegui-Gonzalez, Emilie Gillet

Multimode multiphoton states are central resources for photonic quantum computing, sensing, and the description of finite-stellar-rank non-Gaussian states. Yet their preparation and entanglement structure remain poorly understood, with most states inaccessible from multimode Fock states using interferometers alone. We exploit the stellar-polynomial representation to connect algebraic properties of multivariate polynomials with physical state preparation and non-Gaussian correlations. The atomic decomposition of the stellar polynomial, together with an associated structural graph, provides a complete characterization of mode-intrinsic entanglement. Its connected components identify all mode partitions compatible with passive separability under linear-optical transformations. Essential variables further determine the minimum number of effective modes required to represent the state, in correspondence with its symplectic rank. This framework yields complete separability criteria for two-mode states and for arbitrary multimode states of stellar rank two. We additionally introduce an exact and finite preparation procedure based on interferometers, photon additions, displacements, and photon-number-resolving detection. By relating stellar polynomials to symmetric tensor decompositions, we identify a photon-catalysis mechanism in which ancillary photons generate otherwise inaccessible entanglement. A generalized decomposition minimizes the number of catalysing photons while retaining perfect preparation fidelity. The method also prepares superpositions of different total photon numbers through an inexpensive dehomogenization step. Realistic implementations reduce to instances of boson sampling or Gaussian boson sampling, providing experimentally relevant routes to universal multimode photonic-state engineering.

15:45 – 16:10 · Parallel C

Full nonlocality for non-maximally entangled states

Martin J. Renner, Edwin Peter Lobo, Arturo Konderak, Remigiusz Augusiak, Antonio Acín

It is a well-established fact that some quantum correlations are nonlocal, meaning they cannot be described by a local hidden variable model. Certain quantum correlations are so strong that they cannot be reproduced even if one allows only a small fraction of the rounds to admit a local hidden variable description. These correlations are called fully nonlocal and they lead to Bell inequalities in which the quantum bound saturates the non-signaling bound. A famous and well-known example is the Peres-Mermin square in which the underlying state is a four dimensional maximally entangled state. Surprisingly, examples of full nonlocality are so-far only known for maximally entangled states. In this work, we show that in every local Hilbert space dimension d ≥3 there are non-maximally entangled states that are fully nonlocal. In fact, we derive simple criteria to ensure full nonlocality that are only based on the smallest and largest Schmidt coefficient. Furthermore, we show that all pure entangled states can be activated to show full nonlocality in the many-copy scenario.

Friday, August 21st

Long plenary talks

9:30 – 10:15

Quantum coherence spaces revisited: a von Neumann (co)algebraic approach

Thea Li, Vladimir Zamdzhiev

We describe a categorical model of MALL (Multiplicative Additive Linear Logic) inspired by the HeisenbergSchr¨odinger duality of finite-dimensional quantum theory. Proofs of formulas with positive logical polarity correspond to CPTP (completely positive trace-preserving) maps in our model, i.e. the quantum operations in the Schr¨odinger picture, whereas proofs of formulas with negative logical polarity correspond to CPU (completely positive unital) maps, i.e. the quantum operations in the Heisenberg picture. The mathematical development is based on noncommutative geometry and finite-dimensional von Neumann (co)algebras, which can be defined as special kinds of (co)monoid objects internal to the category of finite-dimensional operator spaces. The full version is accepted to FoSSaCS 2026, see [LZ26] for the extended version with appendices.

10:15 – 11:00

Composable simultaneous purification: when all communication scenarios reduce to spatial correlations

Matilde Baroni, Dominik Leichtle, Ivan Šupić, Damian Markham, Marco Túlio Quintino

Bell non-locality is a powerful framework to distinguish classical, quantum and post-quantum resources, which relies on non-communicating players. Under which restriction can we have the same separations, if we allow for communi-

cation? Non-signalling state assemblages, and the fact that they can always be simultaneously purified, turned out to be the key element to restrict the simplest bipartite communication scenario, the prepare-and-measure, to the standard bipartite Bell scenario. Yet, many distinctive features of quantum theory are genuinely multipartite and cannot be reduced to two-party behaviour. In this work we are interested in extending this simultaneous purification inspired result to all multipartite communication schemes. As a first step, we unify and extend the simultaneous purification result from states to instruments and super-instruments, which are composable structures, and open up the possibility to explore more complex communication scenarios. Our main contribution is to establish that arbitrary compositions of non-signalling assemblages cannot escape the standard spatial quantum Bell correlations set. As a consequence, any interactive quantum realization of correlations outside of this set must involve at least one signalling assemblage of quantum operations, even when the resulting correlations are non-signalling.

Abstract from the arXiv version, arXiv:2601.05158.

Parallel sessions

14:30 – 14:55 · Parallel A

Meromorphic quantum computing

Simon Burton, Hussain Anwar

We consider the kinematic axioms of quantum mechanics projectively. Instead of normalized (pure) states up to global phase, states become one-dimensional subspaces of vector spaces. This process of projectivization is functorial and lax monoidal. For qubits it identifies the Bloch sphere with the Riemann sphere. We interpret a fragment of the ZXW-calculus projectively and thereby provide an alternate derivation of the arithmetic GHZ/W-calculus of Coecke et al. We find meromorphic functions that characterize the coherent behaviour of circuits for logical state preparation of quantum codes and magic state distillation.

14:30 – 14:55 · Parallel B

Diagrammatic reasoning with control as a constructor, applications to quantum circuits

Noé Delorme, Simon Perdrix

Control is a fundamental concept in quantum and reversible computational models. It enables the conditional application of a transformation to a system, depending on the state of another system. We introduce a general framework for diagrammatic reasoning featuring control as a constructor. To this end, we provide an elementary axiomatisation of control functors, extending the standard formalism of props to controlled props. As an application, we show that controlled props facilitate diagrammatic reasoning for quantum circuits by introducing a simple and complete set of relations involving at most three qubits, whereas in the standard prop setting any complete axiomatisation necessarily requires relations acting on arbitrarily many qubits.

Abstract from the arXiv version, arXiv:2508.21756.

14:30 – 14:55 · Parallel C

Shadows and subsystems of generalised probabilistic theories: when tomographic incompleteness is not a loophole for contextuality proofs

David Schmid, John H. Selby, Vinicius Pretti Rossi, Roberto D. Baldijão, Ana Belén Sainz

It is commonly believed that failures of tomographic completeness undermine assessments of nonclassicality in noncontextuality experiments. In this work, we study how such failures can indeed lead to mistaken assessments of nonclassicality. We then show that proofs of the failure of noncontextuality are robust to a very broad class of failures of tomographic completeness, including the kinds of failures that are likely to occur in real experiments. We do so by showing that such proofs actually rely on a much weaker assumption that we term relative tomographic completeness: namely, that one's experimental procedures are tomographic for each other. Thus, the failure of noncontextuality can be established even with coarse-grained, effective, emergent, or virtual degrees of freedom. This also implies that the existence of a deeper theory of nature (beyond that being probed in one's experiment) does not in and of itself pose any challenge to proofs of nonclassicality. To prove these results, we first introduce a number of useful new concepts within the framework of generalised probabilistic theories (GPTs). Most notably, we introduce the notion of a GPT subsystem, generalising a range of preexisting notions of subsystems (including those arising from tensor products, direct sums, decoherence processes, virtual encodings, and more). We also introduce the notion of a shadow of a GPT fragment, which captures the information lost when one's states and effects are unknowingly not tomographic for one another.

14:55 – 15:20 · Parallel A

Transversal AND in quantum codes

Christine Li, Lia Yeh

The AND gate is not reversible$\unicode{x2014}$on qubits. However, it is reversible on qutrits, making it a building block for efficient simulation of qubit computation using qutrits. We first observe that there are multiple two-qutrit Clifford+T unitaries that realize the AND gate with T-count 3, and its generalizations to n qubits with T-count $3n-3$. Our main result is the construction of a novel qutrit $\mathopen{[\![} 6,2,2 \mathclose{]\!]}$ quantum error-correcting code with a transversal implementation of the AND gate. The key insight in our approach is that a symmetric T-depth one circuit decomposition$\unicode{x2014}$composed of a CX circuit, T and T dagger gates, followed by the CX circuit in reverse$\unicode{x2014}$of a given unitary can be interpreted as a CSS code. We can increase the code distance by augmenting the code circuit with additional stabilizers while preserving the logical gate. This results in a code with a "built-in" transversal implementation of the original unitary, which can be further concatenated to attain a $\mathopen{[\![} 48,2,4 \mathclose{]\!]}$ code with the same transversal logical gate. Furthermore, we present several protocols for mixed qubit-qutrit codes which we call Qubit Subspace Codes, and for magic state distillation and injection.

Abstract from the arXiv version, arXiv:2603.04548.

14:55 – 15:20 · Parallel B

One rig to control them all

Chris Heunen, Robin Kaarsgaard, Louis Lemonnier

Controlled commands—computations whose execution depends on a separate input—play a central role in reversible Boolean circuits and quantum circuits. However, existing formalisms typically treat control only implicitly, entangled with other aspects of computation. From a semantic perspective, control is most naturally expressed in semisimple rig categories, which—unlike standard circuit models such as props—support both parallel and conditional composition. We present a construction that freely adjoins an explicit syntactic notion of control to a circuit theory specified as a suitable prop, subject to eight universally quantified equations. Our main result is that these equations are sound and complete for the intended semantics of control: the resulting theory satisfies a universal property, identifying it exactly as the circuit subtheory of the free semisimple rig completion. The proof combines coherence for rig categories with a new method based on induction over Gray codes. We illustrate the usefulness of the framework by showing that it simplifies several existing sound and complete axiomatisations of quantum circuits, isolating a small and conceptually clean set of generators and equations. In addition, the same equations yield a sound and complete axiomatisation of the multiply controlled Toffoli gate set, that is universal for reversible Boolean circuits.

14:55 – 15:20 · Parallel C

The contextual Heisenberg microscope

Jan-Åke Larsson

The Heisenberg microscope provides a powerful mental image of the measurement process of quantum mechanics (QM), attempting to explain the uncertainty relation through an uncontrollable back-action from the measurement device. However, Heisenberg's proposed back-action uses features that are not present in the QM description of the world, and according to Bohr not present in the world. Therefore, Bohr argues, the mental image proposed by Heisenberg should be avoided. Later developments by Bell and Kochen-Specker shows that a model that contains the features used for the Heisenberg microscope is in principle possible but must necessarily be nonlocal and contextual. In this paper we will re-examine the measurement process within a restriction of QM known as Stabilizer QM (SQM), that still exhibits for example Greenberger-Horne-Zeilinger nonlocality and Peres-Mermin contextuality. The re-examination will use a recent extension of SQM, the Contextual Ontological Model (COM), where the system state gives a complete description of future measurement outcomes reproducing the quantum predictions, including the mentioned phenomena. We will see that this gives a contextual Heisenberg microscope [1] whose back-action can be completely described within COM, and that the associated randomness originates in the initial state of the pointer system, exactly as in the original description of the Heisenberg microscope. The presence of contextuality, usually seen as prohibiting ontological models, suggests that the contextual Heisenberg microscope picture could perhaps be enabled in general QM.

15:20 – 15:45 · Parallel A

Phantom codes: entangling logical qubits without physical operations

Jin Ming Koh, Anqi Gong, Andrei C. Diaconu, Daniel Bochen Tan, Alexandra A. Geim, Michael J. Gullans, Norman Y. Yao, Mikhail D. Lukin, Shayan Majidy

Fault-tolerant logical entangling gates are essential for scalable quantum computing, but are limited by the error rates and overheads of physical two-qubit gates and measurements. To address this limitation, we introduce phantom codes-quantum error-correcting codes that realize entangling gates between all logical qubits in a code block purely through relabelling of physical qubits during compilation, yielding perfect fidelity with no spatial or temporal overhead. We present a systematic study of such codes. First, we identify phantom codes using complementary numerical and analytical approaches. We exhaustively enumerate all 2.71×10^{10} inequivalent CSS codes up to $n=14$ and identify additional instances up to $n=21$ via SAT-based methods. We then construct higher-distance phantom-

code families using quantum Reed-Muller codes and the binarization of qudit codes. Across all identified codes, we characterize other supported fault-tolerant logical Clifford and non-Clifford operations. Second, through end-to-end noisy simulations with state preparation, full QEC cycles, and realistic physical error rates, we demonstrate scalable advantages of phantom codes over the surface code across multiple tasks. We observe a one-to-two order-of-magnitude reduction in logical infidelity at comparable qubit overhead for GHZ-state preparation and Trotterized many-body simulation tasks, given a modest preselection acceptance rate. Our work establishes phantom codes as a viable architectural route to fault-tolerant quantum computation with scalable benefits for workloads with dense local entangling structure, and introduces general tools for systematically exploring the broader landscape of quantum error-correcting codes.

Abstract from the arXiv version, arXiv:2601.20927.

15:20 – 15:45 · Parallel B

A complete equational theory for quantum circuits with generalized control

William Schober, Scott Wesley

Controlled subcircuits are commonplace in quantum algorithms as they represent the quantum analogue of branching statements (if then). We introduce a generalization of controlled subcircuits in the form of a binary operation which sends pairs of unitary quantum circuits to a generalized controlled operation, whose semantics are based on matrix exponentials and logarithms. The family of quantum circuits with generalized controlled operations and circuit exponentiation is denoted HQC for Hierarchical Quantum Circuits. We formalize HQC as a modified prop category using a novel category-theoretic construction, and provide a sound and complete equational theory for diagrammatic reasoning in HQC.

15:20 – 15:45 · Parallel C

Quantifying quantum measurement incompatibility via graph invariants

Daniel McNulty

Measurement incompatibility--the impossibility of jointly measuring certain quantum observables--is a fundamental resource for quantum information processing. We develop a graph-theoretic framework for quantifying this resource for large families of binary measurements, including Pauli observables on multi-qubit systems and k-body Majorana observables on n-mode fermionic systems. To each set of observables we associate an anti-commutativity graph, whose vertices represent observables and whose edges indicate pairs that anti-commute. In this representation, the incompatibility robustness--the minimal amount of classical noise required to render the set jointly measurable--becomes a graph invariant. We derive general bounds on this invariant in terms of the Lovász number, clique number, and fractional chromatic number, and show that the Lovász number yields the correct asymptotic scaling for k-body Majorana observables. For line graphs $L(G)$, which naturally arise in the characterisation of exactly solvable spin models, we obtain spectral bounds on the robustness expressed through the energy and skew-energy of the underlying graph G. These bounds become tight for highly symmetric graphs, leading to closed formulas for several graph families. Finally, we identify structural conditions under which the robustness is determined by a simple function of the graph's maximum degree and the number of vertices and edges, and show that such extremal cases occur only when combinatorial structures such as Hadamard, conference or weighing matrices exist.

Abstract from the arXiv version, arXiv:2511.15954.

16:15 – 16:40 · Parallel A

Asymptotically optimal quantum circuits for comparators and incrementers

Vivien Vandaele

We present quantum circuits for comparison and increment operations that achieve an asymptotically optimal gate count of Θ(n) and depth of Θ(log n) over the Clifford+Toffoli gate set, while using a provably minimal number of qubits. We extend these results to classical–quantum comparators, yielding an improved classical– quantum adder with an optimal qubit count. Given the ubiquity of these operations as algorithmic building blocks, our constructions translate directly into reduced circuit complexity for many quantum algorithms. As a notable example, they can be used to improve a space-efficient circuit for Shor's factoring algorithm, reducing circuit depth from O(n3) to O(n2 log2 n) without increasing either the qubit count or the asymptotic gate complexity. Underpinning these results is a general theorem demonstrating how to trade ancilla qubits for control qubits with low overhead in both depth and gate count, providing a broadly applicable tool for quantum circuit design.

16:15 – 16:40 · Parallel B

The perturbative method for quantum correlations

Sacha Cerf, Harold Ollivier

The characterization of the set of quantum correlations Q—the collection of probability distributions achievable by space-like separated parties sharing a quantum state—remains a foundational challenge in quantum information

theory. Since Tsirelson's seminal work [1], the study of nonlocality — in several scenarios beyond the Bell case — has largely relied on convex geometric and algebraic methods [2–4], and hierarchies of semidefinite programs stemming from operator algebras [5–8]. However, despite having been thoroughly studied in the bipartite case [9], the geometric structure of Q in the multipartite setting remains unexplored.

16:15 – 16:40 · Parallel C

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

It is commonly accepted that conducting device-independent quantum key distribution (DIQKD) requires users to change their measurement settings, i.e. use "inputs". Building on Bell nonlocality in causally constrained networks, we provide an example for a DIQKD protocol which uses only a single measurement setting per party, a first of its kind. We do so by relying on the topological robustness of the nonlocality of networks, allowing the quantum key distribution protocol to be secure even in large networks, where one may not be able to assume the exact causal structure, only locally in the lab. Our results "close the loop" on Bell nonlocality in loops, allowing to contrast the loop network nonlocality with standard Bell nonlocality even operationally, and motivate the study of further protocols based on network nonlocality. In particular, we identify a scenario where fixed-measurement DIQKD could be useful: the correlations among all parties in a loop network can be built up and stored classically, and only later must the network decide which pair of parties will establish a secret key, which can be established using only classical postprocessing of classically saved data.

16:40 – 17:05 · Parallel A

A resource-efficient quantum-walker quantum RAM

Giuseppe De Riso, Giuseppe Catalano, Seth Lloyd, Vittorio Giovannetti, Dario De Santis

Efficient and coherent data retrieval and storage are essential for harnessing quantum algorithms' speedup. Such a fundamental task is addressed by a quantum Random Access Memory (qRAM). Despite their promising scaling properties, current qRAM proposals demand excessive resources and rely on operations beyond the capabilities of current hardware requirements, rendering their practical realization inefficient. We introduce a novel architecture that significantly reduces resource requirements while preserving optimal complexity scaling for quantum queries. Moreover, unlike previous proposals, our algorithm design leverages a simple, repeated operational block based exclusively on local unitary operations and short-range interactions between a limited number of quantum walkers traveling over a single binary tree. This novel approach not only simplifies experimental requirements by reducing the complexity of necessary operations but also enhances the architecture's scalability by ensuring a resource-efficient, modular design that maintains optimal quantum query performance.

Abstract from the arXiv version, arXiv:2508.02855.

16:40 – 17:05 · Parallel C

Bounding classical and quantum correlations in Bayesian networks with quasiprobabilities

Paul Becsi, Matthew Joseph Hoban

Bell's theorem reveals that quantum theory is in tension with classical causal reasoning and, in particular, the notion of local causality. This is now understood as a particular example of non-classicality in the study of correlations in (Bayesian) networks with both unobserved and observed nodes: the correlations are probability distributions over the observed nodes. There is a great deal of work aiming to understand the bounds on quantum and classical correlations in such networks and one approach is to consider outer approximations to the former. Along these lines, we consider quasiprobabilistic models for Bayesian networks, which can be seen as classical models but the probability distributions involving unobserved nodes are "replaced" with quasiprobabilities that respect normalisation but not positivity. We denote the set of correlations resulting from these models as the quasi set. Such models have a history in the study of Bell-type non-classicality where it has been shown that they can produce all non-signalling correlations. We show a generalisation of this result for a broad class of networks, which motivates a conjecture that the quasi set recovers the so called nested Markov model. Our work utilises a connection to tensor network decompositions, which may be of independent interest.

Abstract from the arXiv version, arXiv:2606.23372.

Poster abstracts

All posters are presented at the poster session on Tuesday, August 18th, 17:30 – 19:30, in the central hall on the first floor of the A-building. Each poster hangs on the numbered board given with its abstract below, and the abstracts run in board order.

Board 1

No quantum solutions to linear constraint systems from monomial measurement-based quantum computation in odd prime dimension

Markus Frembs, Cihan Okay, Ho Yiu Chung

We combine the study of resources in measurement-based quantum computation (MBQC) with that of quantum solutions to linear constraint systems (LCS). Contextuality of the input state in MBQC has been identified as a key resource for quantum advantage, and in a stronger form, underlies algebraic relations between (measurement) operators which obey classically unsatisfiable (linear) constraints. Here, we compare these two perspectives on contextuality, and study to what extent they are related. More precisely, we associate a LCS to certain MBQC which exhibit strong forms of state-dependent contextuality, and ask if the measurement operators in such MBQC give rise to state-independent contextuality in the form of quantum solutions of its associated LCS. Our main result rules out such quantum solutions for a large class of MBQC. This both sharpens the distinction between state-dependent and state-independent forms of contextuality, and further generalises results on the non-existence of quantum solutions to LCS in finite odd (prime) dimension.

Board 2

Practical implementation of Toffoli-based qubit rotation

Christoffer Hindlycke, Jakov Krnic, Jan-Åke Larsson

The Toffoli gate is an important universal quantum gate, and will alongside the Clifford gates be available in future fault-tolerant quantum computing hardware. Many quantum algorithms rely on performing arbitrarily small single-qubit rotations for their function, and these rotations may also be used to construct any unitary from a limited (but universal) gate set. How to carry out such rotations is then of significant interest. In this work, we evaluate the performance of a recently proposed single-qubit rotation algorithm using the Clifford plus Toffoli gate set by implementation of a one-shot version on both a real and a simulated quantum computer. We test the algorithm under various simulated noise levels using a per-qubit depolarizing error noise model and examine how the probabilities and process fidelities are affected. We then conduct live runs and find that the results reasonably match the simulated results. We also attempt to model the hardware noise by combining a number of noise models, matching the results to results of the live runs to approximate the hardware noise. Our results suggest that the algorithm will perform well for up to 1% noise under the noise models we chose. We further posit the use of our algorithm as a benchmark for quantum processing units, given that it has a low complexity that is easy to fine-tune in small steps. We provide details for how to do this.

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Board 3

Paradox-free classical non-causality and unambiguous non-locality without entanglement are equivalent

Hippolyte Dourdent, Kyrylo Simonov, Andreas Leitherer, Emanuel-Cristian Boghiu, Ravi Kunjwal, Saronath Halder, Remigiusz Augusiak, Antonio Acin

Closed timelike curves (CTCs) challenge our conception of causality by allowing information to loop back into its own past. Any consistent description of such scenarios must avoid time-travel paradoxes while respecting the no-new-physics principle, which requires that the set of operations available within any local spacetime region remain unchanged, irrespective of whether CTCs exist elsewhere. Within an information-theoretic framework, this leads to process functions: deterministic classical communication structures that remain logically consistent under arbitrary local operations, yet can exhibit correlations incompatible with any definite causal order—a phenomenon known as non-causality. In this work, we provide the first complete recursive characterization of process functions and of (non-)causal process functions. We use it to establish a correspondence between process functions and unambiguous complete product bases, i.e., product bases in which every local state belongs to a unique local basis. This equivalence implies that non-causality of process functions is exactly mirrored by quantum nonlocality without entanglement (QNLWE)—the impossibility of perfectly distinguishing separable states using local operations and causal classical communication—for such bases. Our results generalize previous special cases to arbitrary local dimensions and any number of parties, enable systematic constructions of non-causal process functions and unambiguous QNLWE bases, and reveal an unexpected connection between certain non-signaling inequalities and causal inequalities.

Board 4

Emergence of classicality derived from consistent value assignments

Giuseppe Antonio Nistico

The present study proposes an alternative approach to the problem of the emergence of classicality in quantum physics. Let us synthetically describe the approach. The very origin of non classicality of quantum phenomenology can be identified in the empirically ascertained failure of the classical principle according to which every specimen of the physical system is assigned a value for each magnitude, as an objective property. The present approach shows how for specific macroscopic quantum systems the emergence of classicality can be explained by the possibility of overcoming these limitations to consistent value assignments, according to quantum theory.

Board 5

Circuit optimization under constrained preparations and measurements

Rajarsi Pal, Harold Ollivier

Circuit optimization is usually formulated as the task of simplifying a circuit with the aim of reducing the cost of executing it while preserving the implemented unitary. In this work, we tackle circuit optimization with additional constraints: the admissible input states are promised to be stabilized by a stabilizer group, the only observables measured on the output state are promised to be a commuting family of Pauli strings, and the circuit is described as an ordered sequence of Pauli evolutions. Given this instance, we formulate the notion of measurement irrelevance, which asks whether a Pauli evolution in the circuit can actually affect the outcomes of the promised measurements, and use it as an effective criterion for identifying redundant components in the circuit, which is the objective of our optimization. We observe that Pauli evolutions acting on stabilized input states admit representational freedom: their generators can sometimes be rewritten without changing their action on the promised inputs, while changing how they interact with the promised measurement. Our main contribution is an optimization routine that exploits these two properties together. We do this by representing the entire description as a directed acyclic graph built from the data of the input promise, the circuit, and the measurement promise, which allows efficient tracking of both the representational freedom of Pauli evolutions and their measurement relevance. Circuit optimization is then framed as systematically using this representational freedom to rewrite Pauli evolutions so that as many of them as possible become measurement irrelevant. We show that the feasibility of such rewrites can be formulated as the solvability of binary linear-algebraic constraints and can therefore be checked efficiently. The main optimization procedure iteratively applies such certified rewrites and terminates when no further such rewrite is available. We prove that, upon termination, the algorithm returns a fixed point that is maximal within the adopted rewrite discipline studied here. Further we discuss how the objectives pursued and techniques developed have strong implications for a wide variety of topics such as variational algorithms, measurement based quantum computing, etc.

Board 6

Understanding the lattice of signalling in higher-order quantum processes

Timothée Hoffreumon, Anna Jenčova

This work investigates signalling relations in higher-order quantum processes (HOQPs). Building on the established type-theoretic framework for HOQPs, where the types of processes form a model of BV-logic, we study the lattice structure induced by multipartite signalling constraints. We formalise it as the "signalling lattice", the finite distributive lattice generated by totally ordered signalling relations among n parties.

For the tripartite case (n=3), we provide a full characterisation of intersections of signalling types, identify the join-irreducible elements, and prove that the lattice has rank 12. Interpreting these intersections of signalling types as communication scenarios, we show that only one has not yet been interpreted in terms of its signalling structure. We introduce a notion of a "strict signalling" type connector to clarify its interpretation: it corresponds to the class of processes that require two parties to cooperate in order to receive signalling from a third.

Board 7

Optimizing Entanglement Manipulation via Algebraic-Geometric Decompositions and Semidefinite Programming Hierarchies

Seiseki Akibue, Jisho Miyazaki, Hiroyuki Osaka

In the study of distributed quantum information processing, it is a fundamental problem to optimize local operations in the implementation of non-local quantum operations assisted by limited entanglement. We develop an algebraic-geometric framework that systematically simplifies optimization over separable (SEP) channels—widely used as approximations of local operations—and strengthens the Doherty–Parrilo–Spedalieri (DPS) hierarchy for solving such problems. We apply this framework to computing maximum success probability for exactly implementing a broad range of different non-local operations under SEP channels. First, we present a unified generalization of previous analytical results on the entanglement cost. Via the generalization, we resolve an open problem posed by Yu et al.

regarding the entanglement cost of local state discrimination. Second, we determine the trade-off between the strength of entanglement and the success probability of implementing various operations—such as entanglement distillation, non-local unitary channels, measurements, state verification, and multipartite entanglement distribution.

Board 8

Formalising dynamical causal order beyond QC-QCs

Maarten Grothus, Pierre Pocreau, Raphaël Mothe

We study notions of dynamicality and influenceability in quantum supermaps, which for the subclass of QC-QCs have been formally characterised in arXiv:2507.07992.

To advance the understanding of these notions – both for QC-QCs and beyond – we analyse those and related properties using a selection of different frameworks. In particular, we give a routed quantum circuit decomposition for any non-dynamical QC-QC, and discuss generalised signatures of dynamicality encoded into the "branch graph" associated with a routed circuit decomposition. Based on this, we clarify that every unitary QC-QC with indefinite causal order also features dynamical causal order.

Furthermore, we consider the framework of affects relations, which give an abstract model for signalling in presence of agents' interventions. Extending this framework to capture quantum settings as well as correlations between signalling relations in a precise manner, we are able to give statements capturing notions of dynamicality and influenceability in a precise manner. We then consider their connection with sets of causal correlations previously established to capture notions of non-dynamicality and non-influenceability. Finally, we discuss generalisations of such correlations to non-causal correlations and processes, and their relation to properties of process functions.

Board 9

Semi-device-independent self-testing of unitary operations

Rajdeep Paul, Prabuddha Roy, A. K. Pan

We present a semi-device-independent (SDI) self-testing protocol designed to certify unitary operations within a variant of prepare-measure framework. We consider a communication game which we refer to as a variant of 3-bit prepare-measure random access code (PMRAC) involving two parties, Alice and Bob, who share a prior two-qubit quantum state. Alice encodes her message by applying unitary operations on her subsystem and sends it to Bob. To decode the message, Bob performs a measurement on the whole system. We demonstrate that the optimal quantum advantage of the variant of 3-bit PMRAC over the classical bound enables the self-testing of Alice's unitary operations and Bob's measurements. The derivation of the optimal quantum success probability is fully analytical.

Board 10

Automated quantum circuit optimization with randomized replacements

Marcin Szyniszewski, Aleks Kissinger, Noah Linden, Paul Skrzypczyk

Quantum circuit optimization - the process of transforming a quantum circuit into an equivalent one with reduced time and space requirements - is crucial for maximizing the utility of current and near-future quantum devices. While most automated optimization techniques focus on transforming circuits into equivalent ones that implement the same unitary, we show that substantial new opportunities for resource reduction can be achieved by (1) allowing approximate local transformations and (2) employing mixed quantum channels to approximate pure circuits. Our novel automated protocol for approximate circuit rewriting is a refined evolution of automated optimization techniques based on the ZX-calculus, where we add a greedy strategy that selectively replaces ZX-diagrams with small phase angles with stochastic mixtures of the identity and carefully chosen over-rotations, which are designed to reduce the overall gate count in expectation while staying within a strict error budget. This approach yields modest two-qubit gate count reduction in random quantum circuits, and achieves a substantial reduction in structured circuits such as the quantum Fourier transform. Fundamentally, our protocol converts experimental noise due to gate applications into deliberately engineered random noise, outperforming many other approximation methods on average. These results highlight the potential of mixed-channel approximations to enhance future quantum circuit performance, suggesting new directions for resource-aware automated quantum compilation beyond pure unitary channels.

Board 11

Clifford Circuit Synthesis for Distributed Quantum Architectures with Arbitrary Network Topology

Tuomas Laakkonen

To achieve large-scale fault-tolerant quantum computation, it may be easier to combine many small sets of qubits than to construct a single large set. For example via quantum error correction with block codes, or distributed quantum processors utilizing shared entanglement. In these regimes, the time or error budget of the overall quantum computation may be dominated by non-local operations. Hence, it is worthwhile to minimize the number of these

operations. We consider the case where both non-local and local connectivity may be arbitrarily restricted, and give an asymptotically efficient synthesis method for distributed CNOT and Clifford circuits, based on block-matrix Gaussian elimination. We extend this to all Clifford+RZ circuits by generalizing the Pauli exponential circuit representation; this naturally integrates with existing methods for optimizing T-count. Finally, we discuss the application of this method to recently introduced architectures such as phantom codes and IBM's bicycle architecture.

Board 12

Quantum Channels on Graphs: a Resonant Tunneling Perspective

Giuseppe Catalano, Farzan Kianvash, Vittorio Giovannetti

We develop a compositional quantum-information-theoretic framework for coherent transport on quantum graphs, in which a network of scattering sites is treated as a quantum channel between designated input and output ports. The global channel is assembled from local scattering matrices via the Redheffer star product, a nonlinear composition rule that naturally encodes internal back-reflections. This resonant concatenation of channels, where a quantum particle may traverse the same scattering centers in multiple orders depending on its energy, shares structural features with indefinite causal order: the effective causal ordering between scattering events is not fixed, but emerges from the interference of multiple traversal paths through the graph. We show that resonant concatenation can dramatically suppress noise and enable superactivation of the quantum capacity, yielding strictly positive capacity in regimes where every constituent channel individually has zero capacity. These effects are demonstrated explicitly in resonant-tunneling models and extend naturally to arbitrary graph topologies. Our framework provides a general, compositional methodology for analyzing coherent information flow in structured quantum networks, with implications for quantum communication and the resource-theoretic understanding of causal structure.

Board 13

Linear Program Witness for Network Nonlocality in Arbitrary Networks

Salome Hayes-Shuptar, Daniel Bhatti, Ana Belen Sainz, David Elkouss

Network nonlocality extends Bell nonlocality to settings with multiple independent sources and parties. The set of network-local correlations is non-convex, which makes certifying network nonlocality a highly non-trivial task. Existing approaches involve leveraging network-specific properties, or inflation-based methods whose constraints grow combinatorially in the number of local variables. We introduce a linear programming witness for network nonlocality built from five network-agnostic classes of linear constraints. We apply our method to a family of ring networks, and certify network nonlocality for a concrete example. Our work advances the search for efficient witnesses to certify network nonlocality across diverse quantum network architectures.

Board 14

Resource-Aware Quantum Programming with General Recursion and Quantum Control

Kostia Chardonnet, Emmanuel Hainry, Romain Péchoux, Thomas Vinet

This paper introduces the hybrid quantum language with general recursion Hyrql, which is driven towards resource-analysis. By design, Hyrql does not require the specification of an initial set of quantum gates. Hence, it is well amenable towards a generic cost analysis, unlike languages that use different sets of quantum gates, which yield quantum circuits of distinct complexity. It also satisfies standard properties of programming languages, such as progress, subject reduction and confluence.

Regarding resource-analysis, we show how to relate the runtime of an expressive fragment of Hyrql programs with the size of the corresponding quantum circuits. We also manage to capture the class of functions computable in quantum polynomial time, which, by Yao's Theorem, corresponds to families of circuits of polynomial size. Consequently, this result paves the way for the use of termination and runtime-analysis techniques designed for classical programs to guarantee bounds on the size of quantum circuits.

Full version: https://arxiv.org/abs/2510.20452

Board 15

Closing the problem of which causal structures of up to six total nodes have a classical-quantum gap

Shashaank Khanna, Matthew Pusey, Roger Colbeck

The discovery of Bell that there exist quantum correlations that cannot be reproduced classically is one of the most important in the foundations of quantum mechanics, as well as having practical implications. Bell's result was originally proven in a simple bipartite causal structure, but analogous results have also been shown in further causal structures. Here we study the only causal structure with six or fewer nodes in which the question of whether or not there exist quantum correlations that cannot be achieved classically was open. In this causal structure we show that such quantum correlations exist using a method that involves imposing additional restrictions on the correlations. This

hence completes the picture of which causal structures of up to six nodes support non-classical quantum correlations. We also provide further illustrations of our method using other causal structures.

Board 16

Quantum Hoare Logic With Infinitary Addition And Recursion

Xin Sun, Piotr Kulicki, Elzbieta Drozdowska

In earlier work on establishing the relative completeness of satisfaction-based quantum Hoare logic, infinitary addition was used in the assertion language. A problem with this treatment is that terms containing infinitary addition may not converge. In this paper, we provide two solutions to the problem. The first solution is obtained by removing subtraction from the assertion language and limiting rational numbers to non-negative rational numbers. The second solution is obtained by adding truncated subtraction to the first solution. We use the second assertion language to develop a new weakest precondition calculus and proof system, thereby significantly simplifying the proof of relative completeness. We further use the second assertion language to develop a weakest precondition calculus and proof system for quantum Hoare logic with recursion.

Board 17

Routing for Steerability

Cisco Gooding

In a continuous variable setting, we consider a generalization of entanglement routing, using Einstein-Podolsky-Rosen (EPR) steerability as a resource rather than entanglement. We focus on the simple case of three-mode bipartite Gaussian states, and explore connections between global (i.e. three-mode) and reduced (i.e. two-mode) steerabilities within the system. Finally, we comment on conditions under which steerability can be routed.

Board 18

All star-incompatible measurements can certify steering-based randomness

Shintaro Minagawa, Ravi Kunjwal

We address the question of which incompatible sets of measurements can certify randomness in the one-sided device-independent (1SDI) scenario, i.e., steering-based randomness. We show that all sets of star-incompatible measurements (i.e., whose compatibility structure lacks a star graph) can generate assemblages with certified randomness for some bipartite entangled state. While star-incompatibility was known to be a necessary resource for certification of steering-based randomness, we show that it is also sufficient. We also obtain an inequality to lower bound the amount of star-incompatibility required for generating an assemblage with a given amount of certified randomness.

Board 19

Higher-order quantum objects are strong profunctors

Matthew Wilson, James Hefford

We explore the sense in which the existing constructions for higher-order maps on quantum theory based on causality constraints and compositionality constraints respectively, coincide. More precisely, we construct a functor $F : \mathrm{Caus}(C) \longrightarrow \mathrm{StProf}(C1)$ from higher-order causal categories to the category of strong profunctors over first-order causal processes that is lax-lax duoidal, full, faithful, and strongly closed whenever C is additive. When $C = CP$ this embedding is furthermore strong on the sequencer for duoidal categories, expressing the possibility to interpret one-way signalling (but not general non-signalling) constraints in terms of the coend calculus for profunctors. We conclude that in so far as compositional constraints can be used to express causality constraints, the profunctorial approach generalises higher-order quantum theory to a construction over general symmetric monoidal categories.

Board 20

Bridging Treewidth and T-Count: A Hybrid Method for Strong Quantum Circuit Simulation

Matthew Sutcliffe

Amongst the most notable and effective methods for strong classical simulation of quantum circuits are tensor contraction and stabiliser decomposition. The computational complexity of the former scales exponentially with the treewidth of the circuit's tensor network graph, and with little regard for the number of non-Clifford gates involved, making it most effective for sparsely connected circuits. Conversely, the stabiliser decomposition approach scales exponentially in complexity with the number (or 'T-count') of non-Clifford gates in the circuit, largely irrespective of the density of edge connections. This paper introduces a novel hybrid method for strong simulation, efficiently and optimally exploiting the strengths of both approaches. This hybrid method is based on optimally k-partitioning (ZX-diagram representations of) quantum circuits and computing a scalar tensor for each (densely connected, low T-count) subgraph via stabiliser decomposition, before aggregating these results into a single scalar - giving the amplitude of the whole circuit - via tensor contraction of the sparse connections between these subgraphs. The paper ultimately analyses how this hybrid approach fares against its constituent methods for circuits of various size, shape, and degree

of interconnectedness, demonstrating that in the worst case it becomes essentially equivalent to either method and in many cases is able to outperform both in speed by many orders of magnitude.

Board 21

Towards causal decompositions in infinite dimensions: the one-way influence case

Seonghun Jung, Augustin Vanrietvelde

The conjecture of causal decompositions seeks to establish an equivalence between the causal and compositional structure of unitary channels. The causal structure consists of specifying which inputs of the unitary are allowed to influence which output, and as such has a direct operational meaning. The corresponding compositional structure, on the other hand, concerns the existence of suitable decompositions of that unitary. To date, the conjecture has been solved in some finite-dimensional cases. A successful proof technique consisted of shifting from Hilbert spaces to finite-dimensional C*-algebras, thereby recasting the relevant decompositions in an intrinsically algebraic framework. The present project aims to extend this programme to the infinite-dimensional regime. In that regime, the central framework is that of infinite-dimensional operator algebras, in which physical systems are described not primarily by rays in a Hilbert space, but by algebras of observables. This transition introduces genuinely new technical obstacles: infinite-dimensional operator algebras involve topology and functional analysis, and many of the convenient simplifications of finite-dimensional linear algebra cease to apply. In infinite-dimensional quantum theory, both the formulation of the conjecture and its proof naturally require the decompositional perspective already utilised for finite-dimensional cases, articulated this time in the language of von Neumann algebras. In this perspective, rather than building a global algebra through the tensor products of smaller ones, one works with ambient algebras, their subalgebras, and unitary *-isomorphisms between them. Foremost among the ensuing difficulties is the classification of von Neumann algebras into distinct types. Indeed, the bicommutant theorem—a pivotal ingredient for both the statement and the proof of causal decompositions—is no longer guaranteed when the ambient algebra is not of type I. A further obstacle is the reconciliation of the decompositional perspective with the compositional one expressed through tensor products: in the operator-algebraic framework, tensor products of von Neumann algebras are not canonical a priori, in stark contrast with the essentially unique tensor product structure in the Hilbert space framework. The present ongoing work elucidates the status of the conjecture of causal decompositions for the one-way influence case within the operator-algebraic framework. The setting consists of two ambient algebras $\mathcal{W}_{\text{in}}$ and $\mathcal{W}_{\text{out}}$, each admitting bipartitions into two mutually commuting von Neumann subalgebras, namely $\mathcal{A}, \mathcal{B} \subseteq \mathcal{W}_{\text{in}}$ and $\mathcal{C}, \mathcal{D} \subseteq \mathcal{W}_{\text{out}}$, respectively. These are interpreted as the input and output algebras of a unitary *-isomorphism $\mathcal{U} : \mathcal{W}_{\text{in}} \to \mathcal{W}_{\text{out}}$, subject to the one-way influence causal structure: the image of the input subalgebra $\mathcal{A} \subseteq \mathcal{W}_{\text{in}}$ commutes with the output subalgebra $\mathcal{D} \subseteq \mathcal{W}_{\text{out}}$. At the level of algebraic partitions, we show that the desired causal decomposition exists if and only if the image of the input subalgebra $\mathcal{U}(\mathcal{A})$ is normal within $\mathcal{C} = \mathcal{D}'$; equivalently, $\mathcal{U}(\mathcal{A})$ coincides with its bicommutant taken inside $\mathcal{C}$. We also connect this result, when it exists, with the compositional perspective by employing the weak* tensor product of von Neumann algebras. In addition, this recovers the Hilbert space framework when the algebras at hand are type I factors. What remains is to show that these algebraic decompositions of the ambient algebras indeed induce corresponding decompositions of the unitary *-isomorphism.

Author's footnote: refer to https://doi.org/10.48550/arXiv.quant-ph/0104027

Board 22

A Fine-Grained Perspective on Higher Order Operations: Modelling Agents in Spacetime

Emilien de Bank, Cyril Branciard, Vilasini V.

Causality is a fundamental concept that takes on markedly different forms in quantum and relativistic theories. Yet in quantum information protocols implemented in spacetime, both notions must coexist consistently. This raises compelling questions: How can we describe a measurement on a quantum system that is in a superposition of spacetime locations? Can an agent locally extract an outcome from such a system without collapsing its spatiotemporal coherence? We explore how such measurements can be modelled within quantum information theory in a manner consistent with relativistic causality.

This connects closely to questions about the physicality of indefinite causal order (ICO) processes, where the ordering of agents' operations is not fixed or acyclic. Broadly, two categories of approaches exist in this context:

(1) A coarse-grained perspective which exhibits indefinite causal order. For example, the framework of quantum circuits with quantum control of causal order (QC-QCs) captures scenarios in which a quantum system coherently controls the order of operations. The canonical example for such class is the quantum switch (QS).

(2) A fine-grained perspective in which such processes are embedded in spacetime in a way that respects relativistic causality, where the process can be unravelled into one with a definite and acyclic causal order between operations. The process box framework is representative of this approach.

Here we propose a modelling of quantum measurements in spacetime that informs how agents' interventions can be described within the fine-grained, definite-order picture, while still capturing the operational correlations found in the coarse-grained ICO framework, ensuring that each agent acts once and only once on a quantum system that may be non-localised in spacetime.

While QC-QCs and process boxes have been linked before, we build on this connection for deriving the structure of QC-QC's causal correlations from relativistic principles by explicitly modelling measurements of systems lacking localisation in spacetime. This sheds light on the limits of correlations attainable with quantum protocols in spacetime. Finally, considering recent experimental claims for certifying non-classical correlations in ICO processes, we analyse how they align with a fine-grained, spacetime-consistent interpretation which can involve superpositions of arrival times. This can enable a better understanding of the physical resources responsible for these non-classical features in the fine-grained picture, which accounts for both quantum information and relativistic aspects.

Board 23

Against probability: A quantum state is more than a list of probability distributions

Ladina Hausmann, Renato Renner

The state of a quantum system can be represented by listing the outcome probabilities for a tomographically complete set of measurements. Such representations appear throughout physics, for example, in quantum field theory via correlation functions and in quantum foundations within generalized probabilistic frameworks. In this work, we show a no-go result: To enable operationally meaningful statements, the probability representation map must be topologically robust—preserving the notion of closeness between states. Yet, a topologically robust probability representation cannot simultaneously retain other essential structure, such as the subsystem structure.

Board 24

Higher-order quantum processes respecting closed labs in a spacetime have quantum controlled causal order

Matthias Salzger, V. Vilasini

In quantum causality and quantum information, there is a vast landscape of abstract quantum protocols that permit cyclic or non-acyclic causal structures between quantum operations. This includes widely studied frameworks for indefinite causal order and higher-order quantum processes, such as process matrices. However, a longstanding open question has been which is the largest class of such abstract processes that admit physical realisations without post-selection. In this work, we provide a rigorous answer by adopting a top-down approach grounded in relativistic causality principles, motivated by the fact that physical experiments are implemented consistently with such principles in spacetimes with acyclic lightcone structures. Building on the framework of causal boxes, which characterise the most general quantum information-processing protocols compatible with fixed background spacetimes, we formalise additional physically motivated constraints (Acting Once + Local Order) capturing the closed-laboratory assumptions of the process matrix framework at a fine-grained spacetime level. We prove that any protocol realisable in a classical acyclic spacetime and satisfying these spatiotemporal closed-lab conditions is behaviourally equivalent to a quantum circuit with quantum control of causal orders (QC-QC), providing a top-down derivation of QC-QCs from physical principles. Our results therefore show that QC-QCs constitute precisely the class of higher-order quantum processes, including those with indefinite orders, that can be physically realised within classical spacetime, clearly ruling out the possibility of any experiment in this regime that could realise more general non-causal processes under such a closed-labs assumption. This clarifies the relationship between abstract higher-order process matrix frameworks and experimentally accessible quantum protocols, as well as the interplay between coarse-grained cyclic and fine-grained acyclic operational causal structures. We also develop characterisation techniques and results for process box protocols that lead to new causality-based open questions concerning spacetime quantum protocols and relativistic quantum experiments.

Board 25

Compatibility and agreement in Wigner's friend paradox

Julio Cesar Fernandes da Silva, Cristhiano Duarte, Bruno Ferreira Rizzuti

There has been an upsurge of interest in the consequences for quantum physics of the so-called Wigner's Friend Paradox. In its original formulation, the paradox has been turned inside out, and virtually every aspect of it has been looked into. Although it is becoming widely accepted that it is only in light of its many extensions that we can find puzzling consequences of Wigner's thought experiment, this contribution returns to the sources. It focuses on unexplored corners of Wigner's original formulation. Understanding the question as an inference problem, we advance a Bayesian interpretation showing no contradiction between Wigner's and Wigner's Friend's descriptions—neither classically nor quantumly, and consequently with no paradoxical conclusion. In doing so, we flesh out and expose previously untouched aspects of the so-called paradox, in particular, the fact that compatibility and agreement are preponderant to our understanding of it.

Board 26

Preserving MWPM-Decodability in Fault-Equivalent Rewrites

Maximilian Schweikart, Linnea Grans-Samuelsson, Aleks Kissinger, Benjamin Rodatz

Decoding a quantum error correction code is generally NP-hard, but corrections must be applied at a high frequency to suppress noise successfully. Matchable codes, like the surface code, exhibit a special structure that makes it possible to efficiently, approximately solve the decoding problem through minimum-weight perfect matching (MWPM). However, this efficiency-enabling property can be lost when constructing implementations for fault-tolerant gadgets such as syndrome-extraction circuits or logical operations. In this work, we take a circuit-centric perspective to formalise how the decoding problem changes when applying ZX rewrites to a ZX diagram with a given detector basis. We demonstrate a set of rewrites that preserve MWPM-decodability of circuits and show that these matchability-preserving rewrites can be used to fault-tolerantly extract quantum circuits from phase-free ZX diagrams. In particular, this allows us to build efficiently decodable, fault-tolerant syndrome-extraction circuits for matchable codes.

Board 27

Reconstruction of finite Quasi-Probability and Probability from Principles: The Role of Syntactic Locality

Jacopo Surace

Quasi-probabilities appear across diverse areas of physics, but their conceptual foundations remain unclear: they are often treated merely as computational tools, and operations like conditioning and Bayes' theorem become ambiguous. We address both issues by developing a principled framework that derives quasi-probabilities and their conditional calculus from structural consistency requirements on how statements are valued across different universes of discourse, understood as finite Boolean algebras of statements.We begin with a universal valuation that assigns definite (possibly complex) values to all statements. The central concept is Syntactic Locality: every universe can be embedded within a larger ambient one, and the universal valuation must behave coherently under such embeddings and restrictions. From a set of structural principles, we prove a representation theorem showing that every admissible valuation can be re-expressed as a finitely additive measure on mutually exclusive statements, mirroring the usual probability sum rule. We call such additive representatives pre-probabilities. This representation is unique up to an additive regraduation freedom. When this freedom can be fixed canonically, pre-probabilities reduce to finite quasi-probabilities, thereby elevating quasi-probability theory from a computational device to a uniquely determined additive representation of universal valuations. Classical finite probabilities arise as the subclass of quasi-probabilities stable under relativisation, i.e., closed under restriction to sub-universes. Finally, the same framework enables us to define a coherent theory of conditionals, yielding a well-defined generalized Bayes' theorem applicable to both pre-probabilities and quasi-probabilities. We conclude by discussing additional regularity conditions, including the role of rational versus irrational probabilities in this setting.

Board 28

Generalized Dynamics in Phase Space: Some Quantum States Require Quantum Time Evolution

Joel Huber, Matthias Kleinmann

Within the Hilbert space formulation of quantum mechanics, reversible dynamics is described by unitary time evolution and hence by the Schrödinger equation. We investigate how quantum dynamics can be altered while still yielding a consistent theory. For this, we use a phase-space formulation of quantum mechanics, which readily allows for modifications of quantum theory. Specifically, in the Wigner–Weyl formalism, quantum states are described as quasi-probability densities over phase space, and quantum time evolution is governed by the Moyal bracket. To study deviations from this dynamics, we consider generalizations of the Moyal bracket and how they affect time evolution under anharmonic potentials. The effects on the momentum and position distributions are, at least in principle, experimentally accessible. We analyze which modifications correspond to consistent dynamics, meaning that the position and momentum distributions are valid probability densities for all times—in particular, they are required to be non-negative. Previously, it has been shown that an algebraic condition, specifically the Jacobi identity, uniquely singles out the Moyal bracket. Here, we show that the operational positivity condition alone suffices to rule out modifications; in fact, we find that it is sufficient to only consider the ground state and the first excited state of the quantum mechanical harmonic oscillator. For Gaussian states, any time evolution in between classical and quantum dynamics is consistent, whereas the first excited state is only compatible with quantum evolution. In the case of ideal preparation of these states, phase space dynamics is strongly constrained, and quantum dynamics is found to be the only consistent reversible time evolution, at least to the order that can be probed in a cubic potential.

Board 29

Semantic Entropy of Compressed Proofs: Sheaf Geometry and Quantum Verification of DLDS Certificates

Lorenzo Saraiva, Edward Hermann Haeusler, Guilherme Lima

We introduce semantic entropy, a structural invariant of compressed Dag–Like Derivability Structures (DLDS), and show that it governs both the robustness and the quantum detectability of invalid proof certificates. Assuming natural structural properties of compressed derivations, semantic entropy equals the logarithmic multiplicity of global sections of a sheaf of admissible local proof choices and simultaneously the minimal Hilbert-space dimension hidden from closure-verification observables.

Polynomial semantic entropy implies inverse-polynomial density of invalid certificates and efficient detection via quantum amplitude amplification. Conceptually, this establishes a bridge between proof compression, sheaf-theoretic geometry of information, and quantum verification complexity.

Board 30

Unifying Graph Measures and Stabilizer Decompositions for the Classical Simulation of Quantum Circuits

Julien Codsi, Tuomas Laakkonen

Various algorithms have been developed to simulate quantum circuits on classical hardware. Among the most prominent are approaches based on stabilizer decompositions and tensor network contraction. In this work, we present a unified framework that bridges these two approaches, placing them under a common formalism. Using this, we present two new algorithms to simulate an n-qubit circuit C: one that runs in O(T^tw(C)) time and the other in O(T^(alpha rw(C))) time, where tw(C) and rw(C) refer to the the tree-width and rank-width, respectively, of a tensor network associated to C, T is the number of non-Clifford gates in C, and alpha ~ 3.42. The proposed algorithms are simple, only require a linear amount of memory, are trivially parallelizable, and interact nicely with ZX-diagram simplification routines. Furthermore, we introduce the refined complexity measures focused tree-width and focused rank-width, which are always at least as efficient as their standard equivalent; these can be directly applied within our simulation algorithms, allowing for a more precise upper bound on the run time.

Board 31

Spectral Semialgebraic Semantics for Approximate Quantum Computation

Dongho Lee

Approximate quantum algorithms rely on polynomial approximation, yet existing semantic models largely describe exact quantum computation. We present an ongoing project toward a compositional semantic framework for approximate quantum computation based on semialgebraic geometry and spectral quantum processes.

Board 32

Witnessing quantum circuits architecture

Raphaël Mothe, Otfried Gühne

A quantum circuit transforms input systems into output systems by applying a sequence of quantum gates according to a given circuit architecture, i.e. an ordered list of the systems onto which the quantum gates are successively applied. In this work, we introduce a framework to construct fidelity-based witnesses, defined in terms of fidelities between Choi states, which certify the incompatibility of a quantum circuit with a prescribed architecture. Focusing on quantum circuits made of unitary gates we employ a semidefinite programming approach to build explicit witnesses for various architectures made of 2 or 3 two-qubit gates. For circuits composed of Clifford unitaries, we show that the problem simplifies substantially by exploiting the stabiliser formalism, reducing the witness construction to linear programming and enabling analytical solutions. This allows us to deal numerically with general Clifford circuits made of up to 7 two-qubit gates, and analytically with some particular Clifford circuits made of an arbitrarily large number of gates.

Board 33

Quantum Models for Multi-Stage Compositional Concept Generalization

Mina Abbaszadeh, Matilda Karabina Moore, Mehrnoosh Sadrzadeh, Martha Lewis

Compositional generalization requires the systematic reuse of learned primitives under novel combinations. We study this capability within the Distributional Compositional Categorical (DisCoCat) framework and its functorial translation to variational quantum circuits. Exploiting the shared compact closed structure of DisCoCat and categorical quantum mechanics, we propose a multi-stage training scheme that disentangles object grounding from relational learning. Noun representations are first learned from single-object image–caption pairs and subsequently transferred as frozen morphisms during relational training, restricting optimization to relational components. This procedure enforces compositional reuse directly at the circuit level. We further examine quantum encodings of CLIP-derived image embeddings, contrasting amplitude encoding, which preserves linear structure under unitary evolution, with angle encoding, which introduces nonlinear feature lifting prior to circuit transformation. Empirically, staged learning combined with structured encodings improves relational generalization while requiring orders of magnitude fewer parameters than classical baselines. Our results provide evidence that categorical structure and encoding design play a central role in compositional generalization for quantum multimodal models.

Boards 34 – 36

Quantum-native structures for discrete computational physics

Ossi Niemimäki, Oskari Kerppo, Valtteri Lahtinen, Timo Tarhasaari

This is a work in progress in building a bridge between conventional computational physics and emerging quantum-computational models. Existing quantum-computing routines focus on linear systems of equations that have worked well in classical computation, but we claim that these equation-driven solvers are missing the deeper structural context. How then to interpret discretized problems in computational physics as quantum processes in a natural way? As a first step, we begin to formalize different interpretations of finite relations and functions as part of quantum systems, and how to map between what could be a classical representation vs a quantum representation. Eventually, we would like to find structural connections between the two to a level of precision that allows us to define what exactly a 'quantum-native' solver would need to fulfll.

Board 37

Quantum Weakest Precondition Semantics from Categorical Axiomatics

Lucas Stinchcombe, Kenta Cho, Ichiro Hasuo

We study weakest preconditions (wps)—a central construct in program verification—for quantum programs. The distinction between total and partial wps is well-known for classical programs, and has been known for quantum programs as well. In our first contribution, building upon the works by Aguirre, Katsumata, and Kura, we develop a categorical framework that encompasses well-behaved quantum wps. Under suitable well-behavedness requirements —namely compositionality and conservative extension—we show that each well-behaved wp is obtained as a lifting of the total wp via the partiality comonad. This allows for the enumeration of all such wps. We do so for various notions of quantum predicates analogous to classical probabilities and (positive/bounded) expectations. In our second contribution, we introduce convergence-conditional wp semantics, to capture preconditions conditioned on successful execution. We address the non-commutativity of quantum predicates using the sequential product to uniquely define the conditional precondition, and present simple applications to quantum programs with postselection.

Board 38

Multiple-shot labeling of quantum observables

Seyed Arash Ghoreishi, Nidhin Sudarsanan Ragini, Mario Ziman, Sk Sazim

Quantum labeling tasks ask one to recover the missing associations between classical outcome labels and the effects of a known POVM implemented by an unlabeled measurement device, and can be formulated as a channel-discrimination problem. Building on the single-shot setting introduced in [Physical Review A 109, 052415 (2024)], we study labeling in the multiple-shot regime, allowing a finite number of uses of the device and the most general tester-based strategies, including adaptivity. For binary observables, we show that if perfect labeling is impossible in a single shot, then it remains impossible with any finite number of shots. We then characterise the minimum-error performance and highlight a counter-intuitive even–odd behaviour in the swap-label setting. For non-binary observables, we derive the optimal single-shot minimum-error success probability in closed form, and show that entanglement assistance does not improve this optimum. We also provide finite-shot schemes for (perfect or partial) labeling and give illustrative examples, including the qubit trine POVM where the optimal two-shot success probability can be computed explicitly.

Board 39

ZW-calculus in q-arithmetic

Renaud Vilmart, Vincent Nguyen

We introduce a ZW-calculus, featuring fermionic swaps, and whose semantic uses q-arithmetic, a central tool in the theory of quantum groups, hence paving the way towards a full-fledged graphical language for such theories. We present a rather short equational theory, that we show to be complete w.r.t. the q-interpretation of the diagrams, and in the process, axiomatise, and characterise by graphical means, the fermionic swap in the context of compact-close props.

Board 40

Revisiting genuine-multipartiteness in causally indefinite correlations and processes

Matthieu Bruant, Alastair Abbott

There has been extensive interest in recent years in understanding and characterising notions of causal indefiniteness. On the one hand, causal correlations are those compatible with being produced in a well-defined causal structure; on the other hand, causal separability captures the idea that a quantum supermap, or process matrix, is compatible with such a well-defined causal structure. The violation of these notions - noncausal correlations and causally nonseparable processes - are interesting resources for quantum information processing. In multipartite settings, it is relevant to understand when these resources are genuinely multipartite, as apposed to exhibiting causal indefiniteness arising from just some parties.

In this contribution we revisit the notion of genuinely multipartite causal indefiniteness for both correlations and process matrices. While a notion of genuinely multipartite noncausal correlations has previously been proposed, no such notion has been formalised for process matrices. We fill that hole, but, more importantly, we revisit the motivation behind the definition, identifying that a stronger notion of genuinely multipartite causal indefiniteness can be identified. We formalise this stronger notion, both for correlations and process matrices, and study it in detail.

For correlations, we characterise the polytope of "partially bicausal correlations" in the simplest tripartite scenario, identifying several interesting inequalities and finding process matrices violating them. For process matrices, we characterise the set of "partially bicausally separable" processes with SDP constraints, and study the multipartiteness of several well-known causally indefinite process matrices. Our results set the ground for a better understanding of multipartite causal indefiniteness and its role as a resource in different tasks.

Board 41

Quantum Hamlets: Distributed Compilation of Large Algorithmic Graph States

Anthony Micciche, Naphan Benchasattabuse, Andrew McGregor, Stefan Krastanov, Michal Hajdusek, Rodney Van Meter

We investigate the problem of compiling the generation of graph states to arbitrarily many distributed homogeneous quantum processing units (QPUs), providing a scalable partitioning algorithm and graph state generation protocol to minimize the number of Bell pairs required. To this goal, we consider the problem of balanced k graph partitioning with the objective of minimizing the sizes of the maximum matchings between partitions, a more natural measure of entanglement compared to the naive but common metric of cut edges. We show that our heuristic algorithm, BURY, partitions graph states to require fewer Bell pairs for generation than state-of-the-art k partition algorithms. Furthermore, we show that BURY reduces the cut-rank of the partitions, demonstrating that the partitioning found by our algorithm is likely to minimize the Bell pair utilization of any future improved distributed graph state generation protocol. Additionally, we discuss how one could straightforwardly apply our methods to the dynamic case where the graph state generation and measurement are performed concurrently. Our study of the balanced minimum maximum matching k partition problem and the heuristic algorithm we design provides a scalable foundation for reducing quantum network overhead for distributed measurement-based quantum computation (MBQC), as well as any scheme where distributed graph state generation is desired.

Board 42

Scalable non-markovian tomography with higher-order maps

Daniel Bilsborrow, Hler Kristjansson

Characterizing and predicting quantum dynamics is essential for the development of robust quantum technologies. However, real-world quantum devices often exhibit temporally correlated noise—non-Markovian effects where errors propagate through time and degrade quantum information processing. In this work, we present a scalable tomographic framework for multi-time quantum processes using the higher-order transformation (process tensor) formulation. Our approach accounts for scenarios where past gate errors non-trivially influence future outcomes. By integrating shadow tomography, and tensor network learning techniques, we achieve efficient noise characterization for large-scale quantum systems. This scalable, higher-order map framework provides new avenues for accurately simulating and mitigating complex noise in next-generation quantum hardware.

Board 43

Resourcefulness of non-classical continuous-variable quantum gates

Antoine Debray, Massimo Frigerio, Nicolas Treps, Mattia Walschaers

In continuous-variable quantum computation, identifying key elements that enable a quantum computational advantage is a long-standing issue. Starting from the standard results on the necessity of Wigner negativity, we develop a comprehensive and versatile approach in which the techniques of (s)-ordered quasiprobabilities are exploited to provide rigorous statements on the simulability of photonic quantum circuits consisting of previously characterized gates and thereby identifying the contribution of each quantum gate to the potential achievement of quantum computational advantage. This is achieved by means of an analysis of the so-called transfer function, allowing us to highlight the resourcefulness of a gate set. As such this technique can be straightforwardly applied to current continuous-variables quantum circuits, while also constraining the tolerable amount of losses above which any potential quantum advantage can be ruled out. We use (s)-ordered quasiprobability distributions on phase-space to capture the non-classical features in the protocol, and focus our technique entirely on the ordering parameter s. This allows us to highlight the resourcefulness and robustness to loss of a universal set of unitary gates comprising three distinct Gaussian gates and any non-Gaussian unitary gate, providing important insight on the role of non-Gaussianity.

See arXiv:2410.09226 (not the most recent version; recently submitted to Quantum).

Board 44

Optimal pure state cloning and transposition are complementary channels

Vanessa Brzić, Dmitry Grinko, Michał Studziński, Marco Túlio Quintino

State cloning and state transposition are fundamental transformations which, despite being desirable, cannot be perfectly implemented in quantum theory. In this work, we determine the optimal approximation for transforming N qudits into K copies of their transposition and prove the optimal fidelity for pure input states. We further show that the optimal qudit $N \to K$ transposition map is the complementary channel of the optimal universal symmetric $N \to N + K$ quantum cloning machine on pure states, implying that both tasks can be simultaneously realised by the same quantum operation and attain the same optimal fidelity. We then present an explicit quantum circuit that simultaneously implements optimal $N \to K$ transposition and $N \to N + K$ cloning and discuss its gate efficiency. Lastly, we investigate mixed-state $N \to 1$ qudit transposition and find the optimal performance in terms white noise visibility, yielding the optimal structural physical approximation of state transposition in the multicopy regime.

Board 45

Order Unit Spaces and Probabilistic Models

John Harding, Alexander Wilce

Historically, there have been two principle ways in which people have sought to construct a generalized probability theory allowing for incompatible measurements. One is based on the idea of a test space, that is, a catalogue of experimental outcome-sets. The other, often referred to as the convex-operational approach, begins with an order-unit space and represents a (possibly "unsharp") finite experiment by a sequences a_1,...,a_n of effects summing to the unit effect. However, owing to the possibility of repeated terms in such a sequence, it is not immediately clear how to represent it in terms of the outcome-set of an experiment. This difficulty can be overcome by passing to the graph of the sequence, that is, the set of ordered pairs (i,a_i). Bulding on this, we construct a functor from the category OUS of order-unit spaces and positive, unit-preserving mappings into the category PROB of probabilistic models (test spaces with designated state spaces) and morphisms thereof. Restricted to any subcategory of OUS that is monoidal with respect to a bilinear composition rule, our functor is also monoidal. This much shows that the convex-operational approach to physical theories can be subsumed by the test-space approach (without resort to "generalized test spaces" involving multisets). A second, less functorial, construction, equipping a probabilistic model with tests representing "weighted coins," also sheds light on the nature of unsharp observables.

Board 46

Towards a new quantum logic

Julien Lamiroy

Notions of safety are central to the study of higher order quantum processes. Whether a given process actually conserves states, or transformations of states, and is extensible, can be difficult to ascertain depending on the framework used to describe it. In this work in progress, we introduce Intuitionistic Unitary Linear Logic, a logic designed to produce processes, especially higher order processes, that by construction conserve relevant properties.

Board 47

Shor-Style Fault-Tolerant Clifford synthesis in the ZX calculus

Serban Cercelescu, Benjamin Rodatz

Fault-tolerant (FT) logical operations are essential for scalable quantum computing. Building upon the recently introduced "fault tolerance by construction" framework (arXiv:2506.17181), we present a code-agnostic methodology for synthesising fault-tolerant Clifford gates natively within the ZX-calculus. Our approach systematically converts arbitrary implementations of logical Clifford unitaries into fault-tolerant circuits through the repeated measurement of diagram gauge operators. Notably, our generalised synthesis technique readily encompasses and recovers established protocols, including Knill-style fault-tolerant Clifford implementations.

Board 48

Contextuality in Sequential State Discrimination

Nyan Raess, Farid Shahandeh

Generalized contextuality is known to be required in optimal strategies for quantum state discrimination protocols. More recently, sequential discrimination tasks have been studied; n players attempt to determine in which state a qubit was prepared, in such a way that they all have a finite probability of success. We consider the extent to which contextuality plays a role in sequential versions of both unambiguous and minimum error discrimination. In the standard nonsequential case where $n = 1$, we use the COPE formalism to demonstrate that the presence of contextuality is guaranteed not only for the optimal measurement, but for a specific set of nonoptimal measurements as well. In the sequential case $n > 1$, we show that the presence of contextuality depends on which states can be prepared, and on the protocol (unambiguous or minimum error) selected.

Board 49

Quantum Nonlocality and Device-Independent Randomness are robust to Noisy Signalling Channels

Kuntal Sengupta, Lewis Wooltorton

Given a pair of isolated devices that accept random binary inputs and return binary outputs, a user can deduce from the observed data alone if the underlying mechanism can be explained classically. Bell's theorem further states that a classical explanation can be ruled out if the devices perform certain measurements on an entangled quantum state, underpinning the security of cryptographic protocols that are device-independent (DI). For certain protocols, such as those performed in a tight space, it may be difficult to perfectly enforce the non-signalling assumption required in Bell's theorem. This prompts the question: is quantum nonlocality robust to such imperfections? We show that if a binary channel sends a noisy copy of one party's input to the other before any measurements take place, the answer is yes. We completely characterize the vertices and facets of the local polytope in this scenario, and identify Bell inequalities that certify non-signalling quantum correlations. This is possible even when a near perfect copy of the input is sent. We go on to show that the identified inequalities are more robust to depolarizing noise than the Clauser-Horne-Shimony-Holt inequality when certifying DI randomness in this scenario. In addition, we characterize the vertices and facets of the local polytope when both parties receive a noisy copy of each other's input, leaving many new potential Bell inequalities to be explored.

Board 50

Minimality of the Stabilizer ZX Calculus

Harry Stoltz

The stabilizer fragment of the ZX calculus is amongst the most important fragments of the theory. Crucially, the stabilizer calculus can be described by a small collection of rewrites, most of which have been shown to be necessary by Backens-Perdrix-Wang. However, two rules, describing the red/green compact-structure coincidence and the important bialgebra law, had not been shown to be necessary. We present a countermodel-style argument showing that both of these rules are individually necessary relative to the connectivity meta-rule, and hence establish that the rule set has no redundant rewrite rule.

Board 51

How unitaries encode the trade-off between causal order and locality

Nasra Daher Ahmed, Ravi Kunjwal

An ensemble of product quantum states that cannot be perfectly discriminated using only local operations and classical communication (LOCC) is said to exhibit the phenomenon of "quantum nonlocality without entanglement" (QNLWE). Besides the obvious protocol of giving up on LOCC and simply measuring all the systems together in the same lab, it has been recently shown [R. Kunjwal and ¨A. Baumeler, Phys. Rev. Lett. 131 (2023)] that another logical possibility exists: giving up on causal order in the classical communication (modelling it via process functions) while keeping all operations local. Exploring this possibility has revealed deep connections between the two concepts of indefinite causal order and QNLWE. Taking our cue from this, we investigate a third concept that ties together the other two: the structure of unitaries that rotate the computational basis to the orthonormal bases defined by QNLWE ensembles. Specifically, we focus on unitaries that encode the trade-off between causal order and locality represented by process functions, terming them process function unitaries (PFUs). We obtain a sufficient condition—the mutual exclusivity of control conditions (MECC)—for an arbitrary unitary to be a process function unitary and show that this condition is inequivalent to a recently proposed characterization of QNLWE ensembles that encode process functions, namely, unambiguity. We also show how we can gain combinatorial insight into the depth of some PFU circuits via matching problems on Hamming graphs. Finally, we how how a process function unitary can be used to construct a unitary purification of the associated process function in the process-matrix framework

Board 52

Four Party Absolutely Maximal Contextual Correlations

Nripendra Majumdar

The Kochen-Specker theorem revealed contextuality as a fundamental non-classical feature of nature. Non-locality arises as a special case of contextuality, where entangled states shared by space-like separated parties exhibit nonlocal correlations. The notion of maximality in correlations, analogous to maximal entanglement, is less explored in multi-partite systems. In our work, we have defined maximal correlations in terms of contextual models, which are analogous to absolutely maximally entangled (AME) states. Employing the sheaf-theoretic framework, we introduce maximal contextual correlations associated with the corresponding maximal contextual model. The formalism introduces the contextual fraction CF as a measure of contextuality, taking values from 0 (non-contextual) to 1 (fully contextual). This enables the formulation of a new class of correlations termed absolutely maximal contextual correlations (AMCC), which are both maximally contextual and maximal marginals. In the bipartite setting, the canonical example is the

Popescu–Rohrlich (PR) box, while in the tripartite case, it includes Greenberger–Horne–Zeilinger (GHZ) correlations and three-way nonlocal correlations. In this work, we introduce and formalize the notion of AMCCs for four-party correlations. Notably, no AME state exists for four qubits, which introduces a subtle difference between AMCC and AME. The construction follows the constraint satisfaction problem (CSP) and parity-check methods. In particular, the explicit realization of a non-AMCC correlation that is maximally contextual yet not maximal marginal is obtained within the CSP framework.