Uniwersytet Gdański

INTERNATIONAL CENTRE FOR THEORY OF QUANTUM TECHNOLOGIES

18th International Conference on

QUANTUM PHYSICS AND LOGIC

7-11/06/2021, GDAŃSK, POLAND

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QPL 2021

Book of Abstracts

Dzień dobry and welcome to the record breaking, and somewhat experimental, 18th edition of Quantum Physics and Logic, QPL2021 Gdańsk!

This year we've had a record number of talk submissions, record number of registered participants, and, at least if all goes to plan, its going to have a record number of talks, posters, and active participants too!

For the first time this year we will host an industry showcase to highlight how the research that our community is involved in can have reach beyond academia. And, for the first time we have unscheduled talks, because there were far too many brilliant submissions to be contained in any reasonable schedule. And, for the first time we're hosting the event in a virtual world of the QPL Metropolis in gather.town, which, to be honest, I'm terrified is going to melt down completely due to the number of participants... And, most importantly, for the first time we have an official (and highly experimental) QPL beer[1].

I'd like to thank everyone who has been involved so far for all of the effort that they have put in to get us to this stage, to ICTQT and the University of Gdańsk for hosting the event, and to our sponsors, CQC, Google, and IQC, who have made this event possible. From here on though it's down to the rest of you to make this a great event. I encourage you all to get actively involved with all of the activities of the week, to have fun catching up with one another and meeting new people, and to generally have a great time.

See you in gather.town,

Na zdrowie!

John Selby

1 This definitely has nothing to do with trying to outdo Ross's organisation of a conference dinner in a brewery for QPL2016.

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Monday, June 7, 2021

8:00	*Online Registration – Online Platform Opening*
9:45 – 9:50	Welcome talk by the Director of ICTQT **Marek Żukowski**
9:50 – 10:00	Logistics talk by the Manager/ Local Organizer of QPL conference **John Selby**
	Chairperson: Łukasz Rudnicki
10:00 – 11:00	Tutorial given by **Martha Lewis** Natural Language Processing and Quantum Theory
	Break - For discussion with the speaker go to the Scheduled Talks Area (Daily Live Rooms)
	Scheduled Session I (11:30 – 13:00)
11:30 – 12:00	**Konstantinos Meichanetzidis** QNLP: Compositional Models of Meaning on a Quantum Computer
12:00 – 12:30	**Robin Kaarsgaard** Bennett and Stinespring, Together at Last
12:30 – 13:00	**Martin Plávala** Jordan products of quantum channels and their compatibility
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)
	Chairperson: Bárbara Amaral
	Scheduled Session II (14:30 – 16:10)
14:30 – 15:00	**Arthur Parzygnat** Conditional distributions for quantum systems
15:00 – 15:40	**Alastair Abbott and Victoria Wright** Two SDP hierarchies for bounding and characterising quantum contextuality
15:40 – 16:10	**David Schmid** The Stabilizer Subtheory Has a Unique Noncontextual Model
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)
16:30 – 17:00	**Unscheduled Session** *Visit the QPL Youtube channel / Go to the Unscheduled Talks Area (TV Rooms)*
	Break - For discussion with speakers go to the TV Rooms
17:30 – 18:30	Tutorial given by **Ariel Bendersky** Descriptive complexity as a tool for quantum correlations
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Tuesday, June 8, 2021

Chairperson: Hector Miller-Bakewell

Scheduled Session III (11:30 – 13:00)

11:30 – 12:00	**Titouan Carette** Quantum Algorithms and Oracles with the Scalable ZX-calculus
12:00 – 12:30	**Alexandre Clément** Coherent control and distinguishability of quantum channels via PBS-diagrams
12:30 – 13:00	**John van de Wetering** Constructing quantum circuits with global gates

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Chairperson: Miriam Backens

Scheduled Session IV (14:30 – 16:00)

14:30 – 15:00	**John van de Wetering** The ZH-calculus: completeness and extensions
15:00 – 15:30	**Titouan Carette** Graphical Language with Delayed Trace: Picturing Quantum Computing with Finite Memory
15:30 – 16:00	**Alexis Toumi** Diagrammatic Differentiation for Quantum Machine Learning

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

16:30 – 17:30	**Unscheduled Session** *Visit the QPL Youtube channel / Go to the Unscheduled Talks Area (TV Rooms)*

Break - For discussion with speakers go to the TV Rooms

18:00 – 19:00	**Industry Showcase** Host: Bob Coecke
18:00 – 18:15	**Ilyas Khan** Cambridge Quantum Computing
18:15 – 18:30	**Craig Gidney** Google
18:30 – 18:45	**Brendan Fong** Topos Institute
18:45 – 19:00	**Sarah Kaiser** Unitary Fund
19:00 – 20:30	**Poster Session** *Go to the Poster & Industry Session Area*

Wednesday, June 9, 2021

Chairperson: Ravi Kunjwal

10:00 – 11:00 Invited talk given by **Matty Hoban**
Quantum networks and composition self-test all entangled states

Break - For discussion with the speaker go to the Scheduled Talks Area (Daily Live Rooms)

Chairperson: Michał Horodecki

Scheduled Session V (11:15 – 13:15)

11:15 – 11:45 **Christophe Chareton**
A Deductive Verification Framework for Circuit-building Quantum Programs

11:45 – 12:15 **Robert Booth**
F-flow: determinism in measurement-based quantum computation with qudits

12:15 – 12:45 **Marco Túlio Quintino**
Success-or-draw: A strategy allowing repeat-until-success in quantum computation

12:45 – 13:15 **Will Simmons**
Relating measurement patterns to circuits via Pauli flow and Pauli Dependency DAGs

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Chairperson: Victoria Wright

Scheduled Session VI (14:45 – 16:15)

14:45 – 15:15 **Roberto Dobal Baldijão**
Quantum Darwinism and the spreading of classical information in non-classical theories

15:15 – 15:45 **Paulo Cavalcanti**
Witworld: A generalised probabilistic theory featuring post-quantum steering

15:45 – 16:15 **Leevi Leppäjärvi**
Measurement simulability: overview and applications

Break - For discussion with speakers go to the Scheduled Talks Area

16:30 – 17:00 **Unscheduled Session**
Visit the QPL Youtube channel / Go to the Unscheduled Talks Area (TV Rooms)

Break - For discussion with speakers go to the TV Rooms

17:15 – 17:45 Invited talk given by **Anna Jencova**
Incompatibility in general probabilistic theories, generalized spectrahedra, and tensor norms

Scheduled Session VII (17:45 – 18:45)

17:45 – 18:15 **Guillaume Aubrun**
Entangleability of cones

18:15 – 18:45 **Matthew Graydon**
Composites and Categories of Euclidean Jordan Algebras with Superselection Sectors

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Thursday, June 10, 2021

Chairperson: Lídia del Rio

Scheduled Session VIII (10:00 – 11:00)

10:00 – 10:30 **Yokojima Wataru**
Consequences of preserving reversibility in quantum superchannels

10:30 – 11:00 **Nitica Sakharwade**
Hierarchy of Theories with Indefinite Causal Structures: A Second Look at the Causaloid Framework

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Scheduled Session IX (11:30 – 13:00)

11:30 – 12:00 **Matt Wilson**
Causality in Higher Order Physics

12:00 – 12:30 **Mariami Gachechiladze**
Quantifying causal influences in the presence of a quantum common cause

12:30 – 13:00 **Hippolyte Dourdent**
Semi-Device-Independent Certification of Causal Nonseparability with Trusted Quantum Inputs

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

14:30 – 15:30 **Unscheduled Session**
Visit the QPL Youtube channel / Go to the Unscheduled Talks Area (TV Rooms)

Break - For discussion with speakers go to the TV Rooms

Chairperson: Paweł Horodecki

16:00 – 17:00 Invited talk given by **Flaminia Giacomini**
A no-go theorem on the nature of the gravitational field beyond quantum theory

Break - For discussion with the speaker go to the Scheduled Talks Area (Daily Live Rooms)

Scheduled Session X (17:30 – 18:30)

17:30 – 18:00 **Frank Fu, Kohei Kishida and Peter Selinger**
Linear Dependent Type Theory for Quantum Programming Languages

18:00 – 18:40 **Xiaoning Bian and Sarah Li**
Generators and Relations for $O_n(\mathbb{Z}[1/2])$ and $U_n(\mathbb{Z}[1/2, i])$

Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Friday, June 11, 2021

Chairperson: Tomasz Paterek

10:00 – 11:00	Invited talk given by **Hlér Kristjánsson** A second-quantised Shannon theory
	Break - For discussion with the speaker go to the Scheduled Talks Area (Daily Live Rooms)
	Scheduled Session XI (11:30 – 13:00)
11:30 – 12:00	**Giannicola Scarpa** Agreement between observers: a physical principle?
12:00 – 12:30	**Máté Farkas** Mutually unbiased bases and symmetric informationally complete measurements in Bell experiments
12:30 – 13:00	**Samuel Kuypers** On non-commuting qubits, with an application to the closed time-like curve problem
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

Chairperson: Vilasini Venkatesh

	Scheduled Session XII (14:30 – 15:30)
14:30 – 15:00	**Paweł Mazurek** Thermodynamics of Minimal Coupling Quantum Heat Engines
15:00 – 15:30	**Marcin Wierzbiński** Genuinely quantum SudoQ and its cardinality
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)
15:45 – 16:45	**Unscheduled Session** *Visit the QPL Youtube channel / Go to the Unscheduled Talks Area (TV Rooms)*
	Break - For discussion with speakers go to the TV Rooms
	Scheduled Session XIII (17:00 – 18:30)
17:00 – 17:30	**David Schmid** The interplay of entanglement and nonlocality demystified: developing a new branch of entanglement theory
17:30 – 18:00	**Kuntal Sengupta** Quantum Bell Nonlocality is Entanglement
18:00 – 18:30	**Carlo Maria Scandolo** Dynamical entanglement
18:30 – 18:45	Closing talk by the Manager/ Local Organizer of QPL conference **John Selby**
	Break - For discussion with speakers go to the Scheduled Talks Area (Daily Live Rooms)

List of unscheduled talks

No.	Topic	Speaker
1	The Sheaf-Theoretic Structure of Definite Causality	Nicola Pinzani
2	Revisiting the coherent control of quantum channels	Augustin Vanrietvelde
3	Learning and forgetting in Spekkens' toy theory	Ladina Hausmann
4	Distributive Laws, Spans and the ZX-Calculus	Cole Comfort
5	Routed quantum circuits	Augustin Vanrietvelde
6	Information leak and incompatibility of physical context: A modfied approach	Arindam Mitra
7	Quantum Superpositions of Graphs	Marios Christodoulou
8	CPM Categories for Galois Extensions	James Hefford
9	Hyper-hybrid entanglement state $\wedge$ Unit fidelity quantum teleportation $\Rightarrow$ cloning of any arbitary quantum state	Soumya Das
10	Classical-quantum network coding: a story about tensors	Clément Meignant
11	Thirty six entangled officers of Euler and quantum error correction codes	Grzegorz Rajchel-Mieldzioć
12	Foundations for Near-Term Quantum Natural Language Processing	Bob Coecke
13	Fermionic State Discrimination by Local Operations and Classical Communication	Matteo Lugli
14	Restricted Hidden Cardinality Constraints in Causal Models	Beata Zjawin
15	Closing Bell: Boxing black box simulations in the resource theory of contextuality	Rui Soares Barbosa, Martti Karvonen and Shane Mansfield
16	Quantum Advantage from Randomised Teleportation on a Hypergrid	Sivert Aasnaess
17	A generalized cohomology theory for quantum contextuality	Cihan Okay
18	Hidden Variable Model for Universal Quantum Computation with Magic States on Qubits	Michael Zurel
19	Witnessing Wigner Negativity	Pierre-Emmanuel Emeriau
20	The Usefulness of Negativity: Anomalous Fisher-Information Distillation	Aleksander Lasek
21	Conditions tighter than noncommutation needed for nonclassicality	David Arvidsson-Shukur
22	Negative translations of orthomodular lattices and their logic	Wesley Fussner
23	Maximal violation of steering inequalities and the matrix cube	Andreas Bluhm
24	A structure theorem for all noncontextual ontological models of an operational theory	Matthew Pusey
25	Generators and Relations for Real Stabilizer Operators	Justin Makary
26	Semi-device-independent framework based on restricted distrust in prepare-and-measure experiments	Armin Tavakoli
27	A New Connective in Natural Deduction, and its Application to Quantum Computing	Gilles Dowek
28	Quantum Control in the Unitary Sphere: Lambda-S1 and its Categorical Model	Alejandro Díaz-Caro
29	Operational Theories in Phase Space: Toy Model for the Harmonic Oscillator	Martin Plávala
30	AKLT-states as ZX-diagrams: diagrammatic reasoning for quantum states	Richard East
31	Weakly measured while loops: peeking at quantum states	Pablo Andres-Martinez
32	Arithmetic loophole in Bell's theorem: An overlooked threat for entangled-state quantum cryptography	Marek Czachor

Access to the unscheduled talks on youtube channel:
https://www.youtube.com/channel/UCBD8N6ydze3GB8k1pjbUycw/featured

List of posters

No.	Topic	Presenter
1	Toward Formalizing the Q# Programming Language	Sarah Marshall
2	Formal Verification of Gottesman Semantics	Jake Zweifler
3	Contextuality and Semi-Module Cohomology	Sidiney B. Montanhano
4	Bounding the Set of Quantum Correlations with Information Causality Principle	Nikolai Miklin
5	Locality vs free choice: Two sides of the same coin	Pawel Blasiak
6	Entanglement and Sympathetic cooling between ion and mechanical oscillator in optomechanical system	Devender Garg
7	Genuine multipartite entanglement is not a precondition for secure conference key Agreement	Giacomo Carrara
8	Simulating Some Game Semantics Models on IBM Quantum Computer	Milad Ghadimi
9	A Stability Indicator of Quantum Computing Systems via Quantum Random Number Generation	Kentaro Tamura
10	Using a Resource Theoretic Perspective to Witness and Engineer Quantum Generalized Contextuality for Prepare-and-Measure Scenarios	Rafael Wagner
11	Classifying Complexity with the ZX-Calculus: Jones Polynomials and Potts Partition Functions	Alex Townsend-Teague
12	Inflated Graph States Refuting Communication-Assisted LHV Models	Uta Meyer
13	Relating compatibility and divisibility of quantum channels	Lorenzo Catani
14	Fitch’s Knowability Axioms are Incompatible with Quantum Theory	Nuriya Nurgalieva
15	Wigner's friend and the quasi-ideal clock	Vinicius Pretti Rossi
16	An abstract theory of physical measurements	Pedro Resende
17	Diagrammatic security proof for 8-state encoding	Boris Skoric
18	Exponential modalities and complementarity	Priyaa Varshinee
19	A Model-Theoretic Approach to Physical Resources	Patrick Fraser
20	Limitations in quantum computing from resource constraints	Marco Fellous Asiani
21	Temporal Observable-Dependent Logic for Quantum finite Automata	Tsubasa Takagi
22	Phase Space Logic	Felix Huber
23	Quantum Magic Rectangles: Characterization and Application to Certified Randomness Expansion	Sean Adamson
24	Automated detection of contextuality proofs with intermediate numbers of observables	Henri de Boutray
25	Applying a Variational Eigensolver for Hybrid Quantum-Classical Machine Learning	Daniel Pompa
26	Neither contextuality nor non-locality admit catalysts	Martti Karvonen
27	The many-valued logic of quantum mechanics	Jarosław Pykacz
28	Strict hierarchy between parallel, sequential, and indefinite-causal-order strategies for channel discrimination	Jessica Bavaresco
29	Causal reappraisal of the quantum three box paradox	Ewa Borsuk
30	Operational Resource Theory of Imaginarity	Tulja Varun Kondra

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Invited academic talks

Anna Jencova

Mathematical Institute, Slovak Academy of Sciences

Incompatibility in general probabilistic theories, generalized spectrahedra, and tensor norms

Incompatibility of quantum measurements is one of the fundamental non-classical features of quantum theory. As a crucial ingredient in many quantum information protocols, incompatibility has become an important resource for quantum information theory, similar to entanglement. It is therefore a natural question how much of this resource is available in a given situation, characterized by the dimension of the quantum system, number of measurements and their outcomes.

It is known that incompatibility is not restricted to quantum mechanics but is present in any non-classical theory, in the framework of general probabilistic theories (GPT). This broader setting allows us to study and characterize incompatibility of measurements from different perspectives and using different mathematical tools. In this talk, we first concentrate on two-outcome measurements (or effects) and characterize their incompatibility in terms of tensor norms on Banach spaces. For measurements with more outcomes this does not seem possible, so we use a characterization by a GPT generalization of free spectrahedra and their inclusion constants, and by extensibility and separability properties of certain positive maps. As an application we explore compatibility regions and degrees of several GPT's of interest, in particular, we find a tight lower bound on incompatibility of any number of qubit effects.

The talk is based on a joint work with Andreas Bluhm and Ion Nechita, arxiv:2011.06497.

Matty Hoban

Cambridge Quantum Computing & Goldsmiths, University of London

Quantum networks and composition self-test all entangled states

Self-testing is a method for certifying the production of quantum states with making minimal assumptions about the devices. In recent years a plethora of quantum states have been shown to be amenable to self-testing, but the question of whether an arbitrary quantum state can be self-tested, and up to which transformations, is an open question. I will show a method for self-testing an arbitrary (pure) quantum state, up to local transformations and global complex conjugation. The method is compositional in nature, utilising simple quantum networks with EPR pairs distributed throughout. I will also indicate how the global complex conjugation symmetry can be removed if the sources of EPR pairs are assumed to be independent. This is from joint work with Ivan Šupi

Flaminia Giacomini

Perimeter Institute

A no-go theorem on the nature of the gravitational field beyond quantum theory

Recently, table-top experiments involving massive quantum systems have been proposed to test the interface of quantum theory and gravity. In particular, the crucial point of the debate is whether it is possible to conclude anything on the quantum nature of the gravitational field, provided that two quantum systems become entangled due to solely the gravitational interaction. Typically, this question has been addressed by assuming an underlying physical theory to describe the gravitational interaction, but no systematic approach to characterise the set of possible gravitational theories which are compatible with the observation of entanglement has been proposed. Here, we introduce the framework of Generalised Probabilistic Theories (GPTs) to the study of the nature of the gravitational field. This framework has the advantage that it only relies on the set of operationally accessible states, transformations, and measurements, without presupposing an underlying theory. Hence, it provides a framework to systematically study all theories compatible with the detection of entanglement generated via the gravitational interaction between two non-classical systems. Assuming that such gravitationally mediated entanglement is observed we prove a no-go theorem stating that gravity cannot simultaneously satisfy the following conditions i) it is a theory with no faster-than-light signalling; ii) it mediates the gravitational interaction via a physical degree of freedom; iii) it is classical. We further show what the violation of each condition implies, and in particular, when iii) is violated, we provide examples of non-classical and non-quantum theories which are logically consistent with the other conditions.

Hlér Kristjánsson

University of Oxford

A second-quantised Shannon theory

Traditionally, quantum Shannon theory has focused on scenarios where the internal state of the information carriers is quantum, while their trajectory is classical. However, as illustrated by the iconic double slit experiment, quantum particles can also propagate in a quantum superposition along multiple trajectories. In this talk, I shall discuss the recent extension of quantum Shannon theory to a second level of quantisation, where both the information and its propagation in spacetime is treated quantum mechanically.

First, I shall discuss our theoretical framework for formalising these scenarios, showing that when a single particle propagates through a superposition of multiple paths, the joint action of the independent noisy processes on each path is uniquely determined by their individual action on the vacuum state [G Chiribella & HK, Proc R Soc A 475.2225, 2019]. Secondly, I shall show how the same formalism can be extended further to describe the transmission of a quantum particle at a superposition of alternative moments in time [HK, W Mao, G Chiribella, arXiv:2004.06090, 2020]. When successive uses of a transmission line are correlated, we find that contrary to classical intuition, these correlations can be probed by a single quantum particle propagating at a superposition of times, and exploited to carry a larger amount of information per channel use.

Finally, I shall show that the mathematical structures arising in the physical scenarios of the second-quantised Shannon theory cannot be adequately described within the standard framework of quantum circuits. Consequently, I shall provide a brief introduction to our extended framework of routed quantum circuits [A Vanrietvelde, HK, J Barrett, arXiv:2011.08120, 2020], the details of which are left for another talk.

Invited tutorials

Martha Lewis

University of Bristol

Natural Language Processing and Quantum Theory

Natural language processing (NLP) is a field of artificial intelligence that looks at representing natural language in a way that computers can take in, process, and interpret. One branch of NLP has had astonishing success over the last decade or so by representing words as vectors in vector spaces. A natural question then arises: can the tools and techniques of quantum theory be usefully applied in the area of NLP? In this tutorial I will give an overview of the use of vector semantics in NLP and an outline of applications of quantum techniques within NLP. These will include a principled approach to word and phrase composition in NLP, use of quantum structures such as density matrices for text representation, and an overview of how to move towards implementing these techniques on quantum computers.

Ariel Bendersky

CS departments, FCEyN, Universidad de Buenos Aires, Argentina CONICET (National Scientific and Technical Research Council), Argentina

Descriptive complexity as a tool for quantum correlations

In this tutorial I will review some tools from theoretical computer science and descriptive complexity and show how can they be used to provide new insights into quantum foundations. In particular, I will show how Kolmogorov complexity and algorithmic randomness can be used in the context of quantum non-locality to analyse syntactic properties of sequences of experiments and provide a different notion of non-locality [1], new loopholes [2], new insight into the nature of quantum correlations [3] and open the doors into new informational principles for correlations.

[1] Wolf, S. (2015). Nonlocality without counterfactual reasoning. Physical Review A, 92(5), 052102.

[2] Bendersky, A., De La Torre, G., Senno, G., Figueira, S., & Acín, A. (2016). Algorithmic pseudorandomness in quantum setups. Physical review letters, 116(23), 230402.

[3] Bendersky, A., Senno, G., De La Torre, G., Figueira, S., & Acin, A. (2017). Nonsignaling deterministic models for nonlocal correlations have to be uncomputable. Physical review letters, 118(13), 130401.

Scheduled Talks

#01 QNLP: Compositional Models of Meaning on a Quantum Computer

Speaker: Konstantinos Meichanetzidis
Date: 07.06.2021
Time: 11:30

Extended abstract: PDF

Quantum Natural Language Processing (QNLP) deals with the design and implementation of NLP models intended to be run on quantum hardware. The categorical compositional distributional model of meaning that combines vector space semantics with compositional syntax and grammar, compels a formal analogy of the tensor structure it features with the mathematical structure of quantum theory. This encourages its use for QNLP since grammatical sentences can then naturally be represented as parameterised quantum circuits. Here we present experimental results for simple sentence classification tasks with small to medium scale datasets, from implementations on noisy quantum computers provided by IBMQ.

#02 Bennett and Stinespring, Together at Last

Speaker: Robin Kaarsgaard
Date: 07.06.2021
Time: 12:00

Extended abstract: PDF

We present a universal construction that relates reversible dynamics on open systems to arbitrary dynamics on closed systems: the well-pointed restriction affine completion of a monoidal restriction category. This categorical completion encompasses both quantum channels, via Stinespring dilation, and classical computing, via Bennett's method. Moreover, in these two cases, we show how our construction can be 'undone' by a further universal construction. This shows how both mixed quantum theory and classical computation rest on entirely reversible foundations.

#03 Jordan products of quantum channels and their compatibility

Speaker: Martin Plávala
Date: 07.06.2021
Time: 12:30

Extended abstract: PDF

Given two quantum channels, we examine the task of determining whether they are compatible - meaning that one can perform both channels simultaneously but, in the future, choose exactly one channel whose output is desired, while forfeiting the output of the other channel. We show several results concerning this task. First, we show it is equivalent to the quantum state marginal problem, i.e., every quantum state marginal problem can be recast as the compatibility of two channels, and vice versa. Second, we show that compatible measure-and-prepare channels (i.e., entanglement-breaking channels) do not necessarily have a measure-and-prepare compatibilizing channel. Third, we extend the notion of the Jordan product of POVMs to quantum channels and present sufficient conditions for channel compatibility. Last, we formulate the different notions of compatibility as semidefinite programs to numerically test when families of partially dephasing-depolarizing channels are compatible.

#04 Conditional distributions for quantum systems

Speaker: Arthur Parzygnat
Date: 07.06.2021
Time: 14:30

Extended abstract: PDF

Conditional distributions, as defined by the Markov category framework, are studied in the setting of matrix algebras (quantum systems). Their construction as linear unital maps are obtained via a categorical Bayesian inversion procedure. Simple criteria establishing when such linear maps are positive are obtained. Several examples are provided, including the standard EPR scenario, where the EPR correlations are reproduced in a purely compositional (categorical) manner. A comparison between the Bayes map and the Petz recovery map is provided, illustrating some key differences.

#05 Two SDP hierarchies for bounding and characterising quantum contextuality

Speaker: Alastair Abbott and Victoria Wright
Date: 07.06.2021
Time: 15:00

Extended abstract: PDF

This presentation merges the contributions of two papers, whose respective abstracts are the following:

+ We introduce a hierarchy of semidefinite relaxations of the set of contextual quantum correlations, providing a versatile tool for bounding the possible violation of noncontextual inequalities in quantum mechanics. To illustrate its utility, we use it to determine the maximal quantum violation of several noncontextuality inequalities whose maximum violations were previously unknown. We then go further and use it to prove that certain contextual correlations cannot be explained with pure states, thereby showing that mixed states are an indispensable resource for contextuality. This contribution is based on a paper to appear in PRX Quantum (arXiv:2010.04751 [quant-ph]).

+ The predictions of quantum theory resist generalised noncontextual explanations. In addition to the foundational relevance of this fact, the particular extent to which quantum theory violates noncontextuality limits available quantum advantage in communication and information processing. In the first part of this work, we formally define contextuality scenarios via prepare-and-measure experiments, along with the polytope of general contextual behaviours containing the set of quantum contextual behaviours. This framework allows us to recover several properties of set of quantum behaviours in these scenarios . Most surprisingly, we discover contextuality scenarios and associated noncontextuality inequalities that require for their violation the individual quantum preparation and measurement procedures to be mixed states and unsharp measurements. With the framework in place, we formulate novel semidefinite programming relaxations for bounding these sets of quantum contextual behaviours. Most significantly, to circumvent the inadequacy of pure states and projective measurements in contextuality scenarios, we present a novel unitary operator based semidefinite relaxation technique. We demonstrate the efficacy of these relaxations by obtaining tight upper bounds on the quantum violation of several noncontextuality inequalities and identifying novel maximally contextual quantum strategies. To further illustrate the versatility of these relaxations, we demonstrate monogamy of preparation contextuality in a tripartite setting, and present a secure semi-device independent quantum key distribution scheme powered by quantum advantage in parity oblivious random access codes.

#06 The Stabilizer Subtheory Has a Unique Noncontextual Model

Speaker: David Schmid
Date: 07.06.2021
Time: 15:40

Extended abstract: PDF

We prove that there is a unique nonnegative and diagram-preserving quasiprobability representation of the stabilizer subtheory in all odd dimensions, namely Gross's discrete Wigner function. This representation is equivalent to Spekkens' epistemically restricted toy theory, which is consequently singled out as the unique noncontextual ontological model for the stabilizer subtheory. Strikingly, the principle of noncontextuality is powerful enough (at least in this setting) to single out one particular classical realist interpretation. Our result explains the practical utility of Gross's representation, e.g. why (in the setting of the stabilizer subtheory) negativity in this particular representation implies generalized contextuality, and hence sheds light on why negativity of this particular representation is a resource for quantum computational speedup. It also allows us to prove that generalized contextuality is a necessary resource for universal quantum computation in the state injection model. In all even dimensions, we prove that there does not exist any nonnegative and diagram-preserving quasiprobability representation of the stabilizer subtheory, and, hence, that the stabilizer subtheory is contextual in all even dimensions. Together, these results constitute a complete characterization of the (non)classicality of all stabilizer subtheories. This submission is based on https://arxiv.org/abs/2101.06263.

#07 Quantum Algorithms and Oracles with the Scalable ZX-calculus

Speaker: Titouan Carette
Date: 08.06.2021
Time: 11:30

Extended abstract: PDF

The ZX-calculus was introduced as a graphical language able to represent specific quantum primitives in an intuitive way. The recent completeness results have shown the theoretical possibility of a purely graphical description of quantum processes. However, in practice, such approaches are limited by the intrinsic low level nature of ZX calculus. The scalable notations have been proposed as an attempt to recover a higher level point of view while maintaining the topological rewriting rules of a graphical language. We demonstrate that the scalable ZX-calculus provides a formal, intuitive, and compact framework to describe and prove quantum algorithms. As a proof of concept, we consider the standard oracle-based quantum algorithms: Deutsch-Jozsa, Bernstein-Vazirani, Simon, and Grover algorithms, and we show they can be formulated and proved graphically.

#08 Coherent control and distinguishability of quantum channels via PBS-diagrams

Speaker: Alexandre Clément
Date: 08.06.2021
Time: 12:00

Extended abstract: PDF

Even though coherent control of quantum operations appears to be achievable in practice, it is still not yet well understood. Among theoretical challenges, standard completely positive trace preserving (CPTP) maps are known not to be appropriate to represent coherently controlled quantum channels. We introduce here a graphical language for coherent control of general quantum channels inspired by practical quantum optical setups involving polarising beam splitters (PBS). We consider different situations of coherent control and disambiguate CPTP maps by considering purified channels, an extension of Stinespring's dilation. First, we show that in classical control settings, the observational equivalence classes of purified channels correspond to the standard definition of quantum channels (CPTP maps). Then, we propose a refinement of this equivalence class generalising the "half quantum switch" situation, where one is allowed to coherently control which quantum channel is applied; in this case, quantum channel implementations can be distinguished using a so-called transformation matrix. A further refinement characterising observational equivalence with general extended PBS-diagrams as contexts is also obtained. Finally, we propose a refinement that could be used for more general coherent control settings.

#09 Constructing quantum circuits with global gates

Speaker: John van de Wetering
Date: 08.06.2021
Time: 12:30

Extended abstract: PDF

There are various gate sets that can be used to describe a quantum computation. A particularly popular gate set in the literature on quantum computing consists of arbitrary single-qubit gates and 2-qubit CNOT gates. A CNOT gate is however not always the natural multi-qubit interaction that can be implemented on a given physical quantum computer, necessitating a compilation step that transforms these CNOT gates to the native gate set. An especially interesting case where compilation is necessary is for ion trap quantum computers, where the natural entangling operation can act on more than 2 qubits and can even act globally on all qubits at once. This calls for an entirely different approach to constructing efficient circuits. In this paper we study the problem of converting a given circuit that uses 2-qubit gates to one that uses global gates. Our three main contributions are as follows. First, we find an efficient algorithm for transforming an arbitrary circuit consisting of Clifford gates and arbitrary phase gates into a circuit consisting of single-qubit gates and a number of global interactions proportional to the number of non-Clifford phases present in the original circuit. Second, we find a general strategy to transform a global gate that targets all qubits into one that targets only a subset of the qubits. This approach scales linearly with the number of qubits that are not targeted, in contrast to the exponential scaling reported in (Maslov & Nam, N. J. Phys. 2018). Third, we improve on the number of global gates required to synthesise an arbitrary n-qubit Clifford circuit from the 12n-18 reported in (Maslov & Nam, N. J. Phys. 2018) to 6n-8.

#10 The ZH-calculus: completeness and extensions

Speaker: John van de Wetering
Date: 08.06.2021
Time: 14:30

Extended abstract: PDF

The ZH-calculus is a graphical calculus for describing and manipulating quantum computations, first introduced at QPL'18. Much like its older cousin, the ZX-calculus, it admits straightforward encodings of quantum circuits and several flavours of measurement-based quantum computation. However, unlike ZX, ZH is able to elegantly capture and reason about 'AND-gate like' structures (e.g. Toffoli gates) arising in quantum computation. As a rough analogy with circuits, diagrams of the ZX-calculus can be seen as an extension of the universal families of Clifford+T or Clifford+Rz circuits, whereas ZH-calculus diagrams most readily extend the (also universal) family of Toffoli+Hadamard circuits. This makes them well-suited for producing efficient decompositions of Toffoli gates using graphical Fourier theory, giving a diagrammatic account of the path-sum approach to quantum circuit verification, and working with hypergraph states, a generalisation of graph states which feature in several new MBQC schemes. In this article we give a comprehensive account of the core theory of the ZH-calculus, which includes two major new completeness theorems. It was shown in an earlier paper that there exists a complete presentation for ZH if we allow complex-valued parameters. In the current work, we give new completeness proofs for the parameter-free ZH-calculus and a generalisation of the ZH-calculus which takes its parameters from any commutative ring with characteristic not equal to 2.

#11 Graphical Language with Delayed Trace: Picturing Quantum Computing with Finite Memory

Speaker: Titouan Carette
Date: 08.06.2021
Time: 15:00

Extended abstract: PDF

Graphical languages, like quantum circuits or ZX-calculus, have been successfully designed to represent (memoryless) quantum computations acting on a finite number of qubits. Meanwhile, delayed traces have been used as a graphical way to represent finite-memory computations on streams, in a classical setting (cartesian data types). We merge those two approaches and describe a general construction that extends any graphical language, equipped with a notion of discarding, to a graphical language of finite memory computations. In order to handle cases like the ZX-calculus, which is complete for post-selected quantum mechanics, we extend the delayed trace formalism beyond the causal case, refining the notion of causality for stream transformers. We design a stream semantics based on stateful morphism sequences and, under some assumptions, show universality and completeness results. Finally, we investigate the links of our framework with previous works on cartesian data types, signal flow graphs, and quantum channels with memories.

#12 Diagrammatic Differentiation for Quantum Machine Learning

Speaker: Alexis Toumi
Date: 08.06.2021
Time: 15:30

Extended abstract: PDF

We introduce diagrammatic differentiation for tensor calculus by generalising the dual number construction from rigs to monoidal categories. Applying this to ZX diagrams, we show how to calculate diagrammatically the gradient of a linear map with respect to a phase parameter. For diagrams of parametrised quantum circuits, we get the well-known parameter-shift rule at the basis of many variational quantum algorithms. We then extend our method to the automatic differentiation of hybrid classical-quantum circuits, using diagrams with bubbles to encode arbitrary non-linear operators. Moreover, diagrammatic differentiation comes with an open-source implementation in DisCoPy, the Python library for monoidal categories. Diagrammatic gradients of classical-quantum circuits can then be simplified using the PyZX library and executed on quantum hardware via the tket compiler. This opens the door to many practical applications harnessing both the structure of string diagrams and the computational power of quantum machine learning.

#13 A Deductive Verification Framework for Circuit-building Quantum Programs

Speaker: Christophe Chareton
Date: 09.06.2021
Time: 11:15

Extended abstract: PDF

While recent progress in quantum hardware open the door for significant speedup in certain key areas, quantum algorithms are still hard to implement right, and the validation of such quantum programs is a challenge. Early attempts either suffer from the lack of automation or parametrized reasoning, or target high-level abstract algorithm description languages far from the current de facto consensus of circuit-building quantum programming languages. As a consequence, no significant quantum algorithm implementation has been currently verified in a scale-invariant manner. We propose Qbricks, the first formal verification environment for circuit-building quantum programs, featuring clear separation between code and proof, parametric specifications and proofs, high degree of proof automation and allowing to encode quantum programs in a natural way, i.e. close to textbook style. Qbricks builds on best practice of formal verification for the classical case and tailor them to the quantum case: we bring a new domain-specific circuit-building language for quantum programs, namely Qbricks-DSL, together with a new logical specification language Qbricks-Spec and a dedicated Hoare-style deductive verification rule named Hybrid Quantum Hoare Logic. Especially, we introduce and intensively build upon HOPS, a higher-order extension of the recent path-sum symbolic representation, used for both specification and automation. To illustrate the opportunity of Qbricks, we implement the first verified parametric implementations of several famous and non-trivial quantum algorithms, including the quantum part of Shor integer factoring (Order Finding - Shor-OF), quantum phase estimation (QPE) - a basic building block of many quantum algorithms, and Grover search. These breakthroughs were amply facilitated by the specification and automated deduction principles introduced within Qbricks.

#14 F-flow: determinism in measurement-based quantum computation with qudits

Speaker: Robert Booth
Date: 09.06.2021
Time: 11:45

Extended abstract: PDF

In measurement-based quantum computing (MBQC), computation is carried out by a sequence of measurements and corrections on an entangled state. Flow, and related concepts, are powerful techniques for characterising the dependence of the corrections on previous measurement outcomes. We introduce flow-based methods for MBQC with qudits graph states, which we call F-flow, when the local dimension is a power of an odd prime. These are inspired by, but not equivalent to, the usual notions of causal flow and g-flow for qubit MBQC. Along the way, we find a suitable generalisation of the concept of measurement planes to this setting, and prove that local-Clifford operations preserve the existence of an F-flow.

#15 Success-or-draw: A strategy allowing repeat-until-success in quantum computation

Speaker: Konstantinos Meichanetzidis
Date: 09.06.2021
Time: 12:15

Extended abstract: PDF

Repeat-until-success strategy is a standard method to obtain success with a probability which grows exponentially in the number of iterations. However, since quantum systems are disturbed after a quantum measurement in general, it is not straightforward how to perform repeat-until-success strategies in certain quantum algorithms.
In this submission, we provide a universal construction for a repeat-until-success implementation of any probabilistic higher-order transformation on unitary operations.
To this end, we first prove that, given a higher-order transformation on unitary operations that to be implemented, there always exists an implementation with “success-or-draw” property.
We then present a semidefinite programming approach to obtain optimal success-or-draw protocols and analyze in detail the problem of inverting a general unitary operation.

#16 Relating measurement patterns to circuits via Pauli flow and Pauli Dependency DAGs

Speaker: Will Simmons
Date: 09.06.2021
Time: 12:45

Extended abstract: PDF

The one-way model of Measurement-Based Quantum Computing and the gate-based circuit model give two different presentations of how quantum computation can be performed. There are known methods for converting any gate-based quantum circuit into a one-way computation, whereas the reverse is only efficient given some constraints on the structure of the measurement pattern. Causal flow and generalised flow have already been shown as sufficient, with efficient algorithms for identifying these properties and performing the circuit extraction. Pauli flow is a weaker set of conditions that extends generalised flow to use the knowledge that some vertices are measured in a Pauli basis. In this paper, we show that Pauli flow can similarly be identified efficiently and that any measurement pattern whose underlying graph admits a Pauli flow can be efficiently transformed into a gate-based circuit without using ancilla qubits. We then use this relationship to derive simulation results for the effects of graph-theoretic rewrites in the ZX-calculus using a more circuit-like data structure - the Pauli Dependency DAG.

#17 Quantum Darwinism and the spreading of classical information in non-classical theories

Speaker: Roberto Dobal Baldijão
Date: 09.06.2021
Time: 14:45

Extended abstract: PDF

Quantum Darwinism posits that the emergence of a classical reality relies on the spreading of classical information from a quantum system to many parts of its environment. But what are the essential physical principles of quantum theory that make this mechanism possible? We address this question by formulating the simplest instance of Darwinism -- CNOT-like fan-out interactions -- in a class of probabilistic theories that contain classical and quantum theory as special cases. We determine necessary and sufficient conditions for any theory to admit such interactions. We find that every non-classical theory that admits this spreading of classical information must have both entangled states and entangled measurements. Furthermore, we show that Spekkens' toy theory admits this form of Darwinism, and so do all probabilistic theories that satisfy principles like strong symmetry, or contain a certain type of decoherence processes. Our result suggests the counterintuitive general principle that in the presence of local non-classicality, a classical world can only emerge if this non-classicality can be "amplified" to a form of entanglement.

#18 Witworld: A generalised probabilistic theory featuring post-quantum steering

Speaker: Paulo Cavalcanti
Date: 09.06.2021
Time: 15:15

Extended abstract: PDF

We introduce Witworld: a generalised probabilistic theory with strong post-quantum features, which subsumes the theory colloquially known as Boxworld. Indeed, Witworld is the first theory that is known to feature post- quantum steering, and also the first that outperforms quantum theory at the task of remote state preparation. We link moreover these two results by showing post-quantum steering to be the source of this advantage, and, hence, this result constitutes the first instance in which post-quantum steering is a stronger-than-quantum resource for information processing.

#19 Measurement simulability: overview and applications

Speaker: Leevi Leppäjärvi
Date: 09.06.2021
Time: 15:45

Extended abstract: PDF

The simulation scheme describes a process of obtaining new measurement devices out of some existing ones by the means of operational manipulations of mixing and post-processing. We consider this simulation of measurement devices within the operational framework of general probabilistic theories (GPTs) and see how it relates to several different concepts in GPTs and quantum theory. First, we introduce the simulation irreducible observables that can only be simulated by itself but which can be used to simulate any other observable. We use the simulation irreducible observables to characterize the set of fully compatible observables that can be measured jointly with any other observable. We find that there are theories where the so-called no-free-information principle does not hold meaning that, unlike in quantum theory, the set of fully compatible observables does not coincide with the trivial coin-tossing observables. On the other hand, we argue that if one is to go beyond the no-restriction hypothesis where not all mathematically valid effects or observables are taken to be measurements in the theory, the physically feasible set of measurements should still be closed under simulation. Furthermore, we give examples of restrictions of measurements of different types.

#20 Entangleability of cones

Speaker: Guillaume Aubrun
Date: 09.06.2021
Time: 17:45

Extended abstract: PDF

Quantum entanglement is usually thought of as a genuine signature of quan- tum mechanics, deeply rooted within its formalism and intimately connected with the ex- istence of superpositions. Such a connection between a local phenomenon (superposition) and a global one (entanglement) seems however a mere consequence of the peculiar math- ematical form of quantum theory. In our work we show that this is not the case, and that any pair of non-classical local theories satisfying some general axioms has the potential to give rise to entanglement at the level of bipartite systems. This entails that non-classicality and entangleability are profoundly connected notions.

#21 Composites and Categories of Euclidean Jordan Algebras with Superselection Sectors

Speaker: Matthew Graydon
Date: 09.06.2021
Time: 18:15

Extended abstract: PDF

We survey our recent work [Quantum 4, p.359, 2020] --- see also the monograph \texttt{arXiv: 1606.09331 [quant-ph]}) --- wherein we establish the existence and cast the structure of symmetric monoidal and dagger compact closed categories of special euclidean Jordan algebras of mixed (real, complex, and quaternionic) types. We also prove a new result forbidding the inclusion of higher spin factors into such categories.

In [Quantum 4, p.359, 2020], we derive the structure of all possible nonsignalling composites of probabilistic models based on euclidean Jordan algebras. Some curiosities emerge when such models are reducible. We prove, for instance, that euclidean Jordan algebras admitting exceptional ideals compose only with classical systems. Physical systems modeled via the exceptional Jordan algebra $\mathcal{M}_{3}(\mathbb{O})_{\text{sa}}$ are thus isolated from physical systems modeled via special euclidean Jordan algebras of nontrivial ranks. We prove that a composite of special euclidean Jordan algebras must be an ideal of Hanche-Olsen's universal tensor product, which sharply limits the possibilities and thus motivates our subsequent categorical constructions. Indeed, we introduce the dagger compact closed category $\mathbf{InvQM}$, which unites real, complex, and quaternionic post-quantum theories with superselection sectors. Our monoidal product therein is such that usual complex quantum composites arise with an extra classical bit. Put otherwise, the composite of two complex quantum systems in $\mathbf{InvQM}$ comes equipped with an extra $\{0,1\}$-valued superselection rule. This functions to make the transpose automorphism of $\mathcal{M}_{n}(\mathbb{C})_{\text{sa}}$ --- often regarded as a model of time-reversal --- count as a morphism. This extra classical bit is flipped by the Jordan transpose on either factor of such a composite, but unaffected if both parties effect the Jordan transpose. In general, we demand neither tomographic locality, nor preservation of purity from our composites. $\mathbf{InvQM}$ is a physical theory wherein both of the aforementioned conditions can fail; moreover, supermultiplicative information capacities are exhibited under our compositions.

In addition to surveying our recent work, we address the question of whether or not $\mathbf{InvQM}$, or in fact any reasonable Jordan algebraic post-quantum theory can include state/effect cones with ambient spaces isomorphic to "higher'' euclidean Jordan algebras (those with order automorphism groups whose identity connected component is isomorphic to $\mathsf{SO}(1,n)$ for $n\in\{4\}\cup\mathbb{N}_{\geq 6}$.) We prove that under very mild conditions the answer to the aforementioned question is negative.

#22 Consequences of preserving reversibility in quantum superchannels

Speaker: Yokojima Wataru
Date: 10.06.2021
Time: 10:00

Extended abstract: PDF

Similarly to quantum states, quantum operations can also be transformed by means of quantum superchannels, also known as process matrices. Quantum superchannels with multiple slots are deterministic transformations which take independent quantum operations as inputs. While they are enforced to respect the laws of quantum mechanics, the use of input operations may lack a definite causal order and characterizations of general superchannels in terms of quantum objects with a physical implementation have been missing. In this work we provide a mathematical characterization for pure superchannels with two slots (also known as bipartite pure processes), which are superchannels preserving the reversibility of quantum operations. We show that the reversibility preserving condition restricts all pure superchannels with two slots to be either a quantum circuit only consisting of unitary operations or a coherent superposition of two unitary quantum circuits where the two input operations are differently ordered. The latter may be seen as a generalization of the quantum switch, allowing a physical interpretation for pure two-slot superchannels. This submission is based on a preprint arXiv: 2003.05682 [quant-ph].

#23 Hierarchy of Theories with Indefinite Causal Structures: A Second Look at the Causaloid Framework

Speaker: Nitica Sakharwade
Date: 10.06.2021
Time: 10:30

Extended abstract: PDF

The Causaloid framework introduced by Hardy suggests a research program aimed at finding a theory of Quantum Gravity. On one side General Relativity while deterministic (once the metric is provided) features dynamic causal structures, on the other side Quantum Theory while having fixed causal structures is probabilistic in nature. It is natural to then expect Quantum Gravity to house both of the radical aspects of GR and QT, and therefore incorporate indefinite causal structure. The Causaloid framework is operational, it is based on the assertion that any physical theory, whatever it does, must correlate recorded data. Imagine a person inside a closed space, having access to a stack of cards with recorded data (procedures, outcomes, locations); and the person is tasked with inferring(aspects of) the underlying physical theory that governs the data. The correlation of recorded data due to the physical theory means the stack of cards is riddled with redundancy. The person in the box distills away the redundancy by compressing the data. We call this physical compression. In this framework there are three levels of compression: 1) Tomographic Compression, 2) CompositionalCompression and 3) Meta Compression. In this work, we present a diagrammatic form for physical compression to facilitate exposition of the Causaloid framework. Further, building upon the work from we study Meta compression and find a hierarchy of theories characterised by Meta Compression for which we provide a general form. We will proceed to populate this hierarchy. The theory of circuits forms the simplest case, which we express diagrammatically through Duotensors, following which we construct Triotensors using hyper3wires (hyperedges connecting three operations)for the next rung in the hierarchy. Finally, we discuss the broad implications of this work.

#24 Causality in Higher Order Physics

Speaker: Matt Wilson
Date: 10.06.2021
Time: 11:30

Extended abstract: PDF

Quantum supermaps provide a framework in which physical processes can act on other physical processes, giving rise to new features such as indefinite causal structure. Here we show that many of the key structural features of quantum supermaps can be captured through fairly general categorical axioms. To this purpose, we adopt a categorical framework, called higher order process theory and based on the notion of closed symmetric monoidal category. This framework includes as a special case an earlier categorical construction by Kissinger and Uijlen based on *-autonomous categories, and provides sufficient structure to explore connections between causality, signalling, and structural features of physical theories.

#25 Quantifying causal influences in the presence of a quantum common cause

Speaker: Mariami Gachechiladze
Date: 10.06.2021
Time: 12:00

Extended abstract: PDF

Quantum mechanics challenges our intuition on the cause-effect relations in nature. Some fundamental concepts, including Reichenbach's common cause principle or the notion of local realism, have to be reconsidered. Traditionally, this is witnessed by the violation of a Bell inequality. But are Bell inequalities the only signature of the incompatibility between quantum correlations and causality theory? Motivated by this question in our recent publication [PRL 125 (23), 230401 (2020)], we introduce a general framework able to estimate causal influences between two variables, without the need of interventions and irrespective of the classical, quantum, or even post-quantum nature of a common cause. In particular, by considering the simplest instrumental scenario -for which violation of Bell inequalities is not possible- we show that every pure bipartite entangled state violates the classical bounds on causal influence, thus answering in negative to the posed question and opening a new venue to explore the role of causality within quantum theory.

#26 Semi-Device-Independent Certification of Causal Nonseparability with Trusted Quantum Inputs

Speaker: Hippolyte Dourdent
Date: 10.06.2021
Time: 12:30

Extended abstract: PDF

While the standard formulation of quantum theory assumes a fixed background causal structure, one can relax this assumption within the so-called "process matrix framework". Astonishingly, some processes, termed causally nonseparable, are not compatible with a well-defined causal order between the parties Alice and Bob.

In this contribution, we introduce the notion of a "causally separable distributed measurement", a POVM induced by Alice and Bob's operations on a shared causally separable process matrix, when they are provided with additional quantum inputs. We investigate the question of whether the causal nonseparability of a process matrix can be inferred by examining the induced distributed POVM generated from it by providing suitable quantum inputs. We show firstly that this is indeed possible for any causally nonseparable process matrix that can violate a causal inequality. More interestingly, however, we show that such semi-device-independent certification with quantum inputs is possible for some processes that admit a causal model, notably including for the quantum switch. It remains an open question, however, whether all causally nonseparable process matrices can be certified in this way.

We also consider the case of examining simply a single element of a distributed POVM. With a specific additional structure on the operations performed by the parties, we show that the causal separability of a bipartite process matrix imposes nontrivial constraints on the individual elements of Alice and Bob's induced distributed POVMs. Crucially, we do not trust the actual measurements or channels implemented by the parties, and hence call such scenarios measurement-device-and-channel-independent (MDCI). Introducing the concept of a MDCI causal witness, we then show that such witnesses allow one to detect the causal nonseparability of all causally nonseparable bipartite processes without trusting Alice and Bob's operations. We extend our result to the specific tripartite scenario of the quantum switch, treating Alice and Bob's operations in a MDCI way, and where the operation of a third party, Charlie, is introduced, with a trivial outgoing system, and treated in a fully device-independent way.

Our work paves the way towards fully device-independent certification of causal nonseparability for all causally nonseparable processes, which we are currently investigating.

#27 Linear Dependent Type Theory for Quantum Programming Languages

Speaker: Frank Fu, Kohei Kishida and Peter Selinger
Date: 10.06.2021
Time: 17:30

Extended abstract: PDF

Modern quantum programming languages integrate quantum resources and classical control. They must, on the one hand, be linearly typed to reflect the no-cloning property of quantum resources. On the other hand, high-level and practical languages should also support quantum circuits as first-class citizens, as well as families of circuits that are indexed by some classical parameters. Quantum programming languages thus need linear dependent type theory. This paper defines a general semantic structure for such a type theory via certain fibrations of monoidal categories. The categorical model of the quantum circuit description language Proto-Quipper-M in [Rios-Selinger 2017] constitutes an example of such a fibration, which means that the language can readily be integrated with dependent types. We then devise both a general linear dependent type system and a dependently typed extension of Proto-Quipper-M, and provide them with operational semantics as well as a prototype implementation.

#28 Generators and Relations for O_n(ℤ[1/2]) and U_n(ℤ[1/2,i])

Speaker: Xiaoning Bian and Sarah Li
Date: 10.06.2021
Time: 18:00–18:40

Extended abstract: PDF

This presentation merges the contributions of two papers, whose respective abstracts are the following:

+ Consider the universal gate set for quantum computing consisting of the gates X, CX, CCX, ω†H and S. All of these gates have matrix entries in the ring ℤ[½, i], the smallest subring of the complex numbers containing ½ and i. Amy, Glaudell, and Ross proved the converse, i.e., any unitary matrix with entries in ℤ[½, i] can be realized by a quantum circuit over the above gate set using at most one ancilla. In this paper, we give a finite presentation by generators and relations of Un(ℤ[½, i]), the group of unitary n×n-matrices with entries in ℤ[½, i].

+ We give a finite presentation by generators and relations for the group On(Z[1/2]) of n-dimensional orthogonal matrices with entries in Z[1/2]. We then obtain a similar presentation for the group of n-dimensional orthogonal matrices of the form M/sqrt{2k}, where k is a nonnegative integer and M is an integer matrix. Both groups arise in the study of quantum circuits. In particular, when the dimension is a power of 2, the elements of the latter group are precisely the unitary matrices that can be represented by a quantum circuit over the universal gate set consisting of the Toffoli gate, the Hadamard gate, and the computational ancilla.

#29 Agreement between observers: a physical principle?

Speaker: Giannicola Scarpa
Date: 11.06.2021
Time: 11:30

Extended abstract: PDF

Is the world quantum? An active research line in quantum foundations is devoted to exploring what constraints can rule out the post-quantum theories that are consistent with experimentally observed results. We explore this question in the context of epistemics, and ask whether agreement between observers can serve as a physical principle that must hold for any theory of the world. Aumann's seminal Agreement Theorem states that two (classical) agents cannot agree to disagree. We propose an extension of this theorem to no-signaling settings. In particular, we establish an Agreement Theorem for quantum agents, while we construct examples of (post-quantum) no-signaling boxes where agents can agree to disagree. The PR box is an extremal instance of this phenomenon. These results make it plausible that agreement between observers might be a physical principle, while they also establish links between the fields of epistemics and quantum information that seem worthy of further exploration.

#30 Mutually unbiased bases and symmetric informationally complete measurements in Bell experiments

Speaker: Máté Farkas
Date: 11.06.2021
Time: 12:00

Extended abstract: PDF

Mutually unbiased bases (MUBs) and symmetric informationally complete projectors (SICs) are crucial to many conceptual and practical aspects of quantum theory. Here, we develop their role in quantum nonlocality by (i) introducing families of Bell inequalities that are maximally violated by d-dimensional MUBs and SICs, respectively, (ii) proving device-independent certification of natural operational notions of MUBs and SICs, and (iii) using MUBs and SICs to develop optimal-rate and nearly optimal-rate protocols for device-independent quantum key distribution and device-independent quantum random number generation, respectively. Moreover, we also present the first example of an extremal point of the quantum set of correlations that admits physically inequivalent quantum realizations. Our results elaborately demonstrate the foundational and practical relevance of the two most important discrete Hilbert space structures to the field of quantum nonlocality.

#31 On non-commuting qubits, with an application to the closed time-like curve problem

Speaker: Samuel Kuypers
Date: 11.06.2021
Time: 12:30

Extended abstract: PDF

It is axiomatic in what I shall call orthodox quantum theory that systems at space-like separations have observables that commute. This commutation constraint severely limits quantum theory's explanatory power. For instance, space-like separated systems cannot commute in the presence of closed time-like curves, and similarly, the commutation constraint conflicts with Bekenstein's bound.

In this talk, I investigate an alternative quantum theory, which is different from the orthodox one only in its omission of the commutation constraint. In particular, I study a network of qubits that do not commute at space-like separations. I will demonstrate that such non-commuting qubits can instantiate classical information and use them to model the behaviour of quantum systems on a closed time-like curve.

#32 Thermodynamics of Minimal Coupling Quantum Heat Engines

Speaker: Paweł Mazurek
Date: 11.06.2021
Time: 14:30

Extended abstract: PDF

The minimal-coupling quantum heat engine is a thermal machine consisting of an explicit energy storage system, heat baths, and a working body, which alternatively couples to subsystems through discrete strokes --- energy-conserving two-body quantum operations. Within this paradigm, we present a general framework of quantum thermodynamics, where a work extraction process is fundamentally limited by a flow of non-passive energy (ergotropy), while energy dissipation is expressed through a flow of passive energy.
It turns out that small dimensionality of the working body and a restriction only to two-body operations make the engine fundamentally irreversible.
Our main result is finding the optimal efficiency and work production per cycle within the whole class of irreversible minimal-coupling engines composed of three strokes and with the two-level working body, where we take into account all possible quantum correlations between the working body and the battery.
One of the key new tools is the introduced “control-marginal stat” --- one which acts only on a working body Hilbert space, but encapsulates all features regarding work extraction of the total working body-battery system. In addition, we propose a generalization of the many-stroke engine, and we analyze efficiency vs extracted work trade-offs, as well as work fluctuations after many cycles of the running of the engine.

#33 Genuinely quantum SudoQ and its cardinality

Speaker: Marcin Wierzbiński
Date: 11.06.2021
Time: 15:00

Extended abstract: PDF

We expand the quantum variant of the popular game Sudoku by introducing the notion of cardinality of a quantum Sudoku (SudoQ), equal to the number of distinct vectors appearing in the pattern. Our considerations are focused on the genuinely quantum solutions – the solutions of size N^2 that have cardinality greater than N^2, and therefore cannot be reduced to classical counterparts by a unitary operation. We find the complete parameterization of the genuinely quantum solutions of 4 * 4 SudoQ game and establish that the admissible cardinalities in that case are 4, 6, 8 and 16. In particular, a solution with maximal cardinality equal to 16 is presented. In general, we proved that for any N it is possible to find an N^2 * N^2 SudoQ solution of cardinality N^4. Provided construction resembles the construction of mutually unbiased bases.

#34 The interplay of entanglement and nonlocality demystified: developing a new branch of entanglement theory

Speaker: Konstantinos Meichanetzidis
Date: 11.06.2021
Time: 17:00

Extended abstract: PDF

A standard approach to quantifying resources is to determine which operations on the resources are freely available and to deduce the partial order over resources that is induced by the relation of convertibility under the free operations. If the resource of interest is the nonclassicality of the correlations embodied in a quantum state, i.e., entanglement, then the common assumption is that the appropriate choice of free operations is Local Operations and Classical Communication (LOCC). We here argue that this is not the best choice for quantifying entanglement in one of the most prominent applications of entanglement theory, namely, the study of Bell scenarios. A better choice, we claim, is Local Operations and Shared Randomness (LOSR). We support this thesis by showing that various perverse features of the interplay between the entanglement of states and the nonlocality of the correlations in a Bell experiment (the properties describing Bell inequality violations) are merely an artifact of the use of LOCC-entanglement and that if one uses LOSR-entanglement instead, then this interplay becomes natural and intuitive. Specifically, we show that the LOSR paradigm (i) provides a resolution of the anomaly of nonlocality, wherein partially entangled states exhibit more nonlocality than maximally entangled states, (ii) entails a notion of genuine multipartite entanglement that is distinct from the conventional one and which is free of several of its pathological features, and (iii) makes possible a resource-theoretic account of the self-testing of entangled states which simplifies and generalizes prior results. Along the way, we derive some fundamental results concerning the necessary and sufficient conditions for convertibility between pure entangled states under LOSR and highlight some of their consequences, such as the impossibility of catalysis for bipartite pure states. Our results motivate the study of LOSR-entanglement as a new branch of entanglement theory.

#35 Quantum Bell Nonlocality is Entanglement

Speaker: Kuntal Sengupta
Date: 11.06.2021
Time: 17:30

Extended abstract: PDF

The precise relationship between nonlocality and entanglement has been a notorious open problem. In this paper, we resolve this problem by developing a dynamical framework in which quantum Bell nonlocality emerges as special form of entanglement, and both are unified as resources under local operations and classical communication (LOCC). Our framework is built on the notion of quantum processes, which are abstract quantum channels mapping elements between fixed intervals in space and time. Entanglement is then identified as a quantum process that cannot be generated by LOCC while Bell nonlocality is the subset of these processes that have an instantaneous input-output delay time. LOCC pre-processing is a natural set of free operations in this theory, thereby enabling all entangled states to activate some form of Bell nonlocality.

#36 Dynamical entanglement

Speaker: Carlo Maria Scandolo
Date: 11.06.2021
Time: 18:00

Extended abstract: PDF

Unlike the entanglement of quantum states, very little is known about the entanglement of bipartite channels, called dynamical entanglement. Here we work with the partial transpose of a superchannel, and use it to define computable measures of dynamical entanglement, such as the negativity. We show that a version of it, the max-logarithmic negativity, represents the exact asymptotic dynamical entanglement cost. We discover a family of dynamical entanglement measures that provide necessary and sufficient conditions for bipartite channel simulation under local operations and classical communication and under operations with positive partial transpose.

Unscheduled Talks

#01 The Sheaf-Theoretic Structure of Definite Causality

Speaker: Nicola Pinzani

Extended abstract: PDF

Youtube: youtu.be/M1i9T5cWV68

We extend the sheaf-theoretic framework for non-locality by Abramsky and Brandenburger to deal with operational scenarios in the presence of arbitrary definite causal orders.

#02 Revisiting the coherent control of quantum channels

Speaker: Augustin Vanrietvelde

Extended abstract: PDF

Youtube: youtu.be/H3lBmJII0jQ

No universal circuit architecture can implement the coherently controlled version of a unitary gate from a use of this gate. Yet, universal coherent control has been realised in experimental implementations that make use of slightly different resources. Here, we modellise the task that these experimental implementations realise, and extend it to the case of noisy channels, and of more involved types of control, forming what we call composite control. We find that the necessary resources for the implementation of controlled channels on a d-dimensional system are sector-preserving channels of type (d,1), and that a universal circuit architecture can realise this implementation. We show that analogous results can be found in the case of composite control. We discuss the extension of our results to the control of several channels, and present a formal construction, that of supermaps on routed channels, that allows to describe it in a neater way, getting rid of superfluous information.

#03 Learning and forgetting in Spekkens' toy theory

Speaker: Ladina Hausmann

Extended abstract: PDF

Youtube: youtu.be/kIlLZnCOJNk

If we model agents as physical systems, they have to be equipped with physical memories, where they store the information acquired via their reasoning process. It was shown that some theories (namely, quantum theory and GPTs), where both of of these requirements are satisfied -- where agents reason about each other's knowledge and are themselves modeled as physical memories within the scope of the model -- experience inconsistencies. Here, we investigate Spekkens' toy theory, an example of an epistemically restricted model which partially mimics the behaviour of quantum mechanics. We give a review of the existing approaches, propose a way to model agents and their memories, and derive a condition to quantify the certainty of inferences the agents can make about each other's outcomes. Based on this condition, we prove that the Frauchiger-Renner paradox is not reproduced in the toy theory.

#04 Distributive Laws, Spans and the ZX-Calculus

Speaker: Cole Comfort

Extended abstract: PDF

Youtube: youtu.be/PF2uwuoZrbs

We modularly build increasingly larger fragments of the ZX-calculus by modularly adding new generators and relations, at each point, giving some concrete semantics in terms of some category of spans. This is performed using Lack's technique of composing props via distributive laws, as well as the technique of pushout cubes of Zanasi.

We do this for the fragment of the ZX-calculus with only the black \$\pi\$-phase (and no Hadamard gate) as well as well as the fragment which additionally has the and gate as a generator (which is equivalent to the natural number H-box fragment of the ZH-calculus).

In the former case, we show that this is equivalent to the full subcategory of spans of (possibly empty) free, finite dimensional affine \$\F_2\$-vector spaces, where the objects are the non-empty affine vector spaces. In the latter case, we show that this is equivalent to the full subcategory of spans of finite sets where the objects are powers of the two element set. Because these fragments of the ZX-calculus have semantics in terms of full subcategories of categories of spans, they can not be presented by distributive laws over groupoids. Instead, we first construct their subcategories of partial isomorphisms via distributive laws over all isomorphims with subobjects adjoined. After which, the full subcategory of spans are obtained by freely adjoining units and counits the the semi-Frobenius structures given by the diagonal and codiagonal maps.

#05 Routed quantum circuits

Speaker: Augustin Vanrietvelde

Extended abstract: PDF

Youtube: youtu.be/adlDP92nJBg

We argue that the quantum-theoretical structures studied in several recent lines of research cannot be adequately described within the standard framework of quantum circuits. This is in particular the case whenever the combination of subsystems is described by a nontrivial blend of direct sums and tensor products of Hilbert spaces. We therefore propose an extension to the framework of quantum circuits, given by routed linear maps and routed quantum circuits. We prove that this new framework allows for a consistent and intuitive diagrammatic representation in terms of circuit diagrams, applicable to both pure and mixed quantum theory, and exemplify its use in several situations, including the superposition of quantum channels and the causal decompositions of unitaries. We show that our framework encompasses the 'extended circuit diagrams' of Lorenz and Barrett [arXiv:2001.07774 (2020)], which we derive as a special case, endowing them with a sound semantics.

#06 Information leak and incompatibility of physical context: A modified approach

Speaker: Arindam Mitra

Extended abstract: PDF

Youtube: youtu.be/vPWbHPUOxLw

A beautiful idea about the incompatibility of Physical Context(IPC) was introduced in [Phys. Rev. A 102, 050201(R) (2020)]. Here, a context is defined as a set of a quantum state and two sharp rank-one measurements, and the incompatibility of physical context is defined as the leakage of information while implementing those two measurements successively in that quantum state. In this work, we show the limitations in their approach. The three primary limitations are that, (i) their approach is not generalized for POVM measurements and (ii), they restrict information theoretic agents Alice, Eve and Bob to specific quantum operations and do not consider most general quantum operations i.e., quantum instruments and (iii), their measure of IPC can take negative values in specific cases in a more general scenario which implies the limitation of their information measure. Thereby, we have introduced a generalization and modification to their approach in more general and convenient way, such that this idea is well-defined for generic measurements, without these limitations. We also present a comparison of the measure of the IPC through their and our method. Lastly, we show how the IPC reduces in the presence of memory using our modification, which further validates our approach.

#07 Quantum Superpositions of Graphs

Speaker: Marios Christodoulou

Extended abstract: PDF

Youtube: youtu.be/r5-aWIiWHDk

We provide a robust notion of quantum superpositions of graphs. Crucially, we show that quantum superpositions of graphs require node names to account for their alignment, as we demonstrate through a non-signalling argument. Nevertheless, node names are a fiducial construct, serving a similar purpose to the labelling of points through a choice of coordinates in continuous space. We explain that graph renamings can be seen as a change of coordinates on the graph and thus correspond to a natively discrete analogue of diffeomorphisms. We propose renaming invariance as a symmetry principle of similar weight to diffeomorphism invariance for theories based on graphs, and show how to impose it at the level of quantum superpositions of graphs.

#08 CPM Categories for Galois Extensions

Speaker: James Hefford

Extended abstract: PDF

Youtube: youtu.be/bqVdUQYD2CU

By considering a generalisation of the CPM construction, we develop an infinite hierarchy of probabilistic theories, exhibiting compositional decoherence structures which generalise the traditional quantum-to-classical transition. Analogously to the quantum-to-classical case, these decoherences reduce the degrees of freedom in physical systems, while at the same time restricting the fields over which the systems are defined. These theories possess fully fledged operational semantics, allowing both categorical and GPT-style approaches to their study.

#09 Hyper-hybrid entanglement state ∧ Unit fidelity quantum teleportation ⇒ cloning of any arbitrary quantum state

Speaker: Soumya Das

Extended abstract: PDF

Youtube: youtu.be/J8oaq3V_z0c

Quantum particles possess some counter-intuitive features that classical particles don't for example they can be in a superposition state, they can have correlations across space-like separated regions etc. However, they are also devoid of some features from classical particles like cloning of any arbitrary quantum state, restriction of sharing of quantum correlations etc., which is known as no-go theorems such as no-cloning theorem, monogamy of entanglement, etc. Unlike classical particles, there are two types of quantum particles; distinguishable and indistinguishable. Distinguishable particles can perform unit fidelity quantum teleportation and indistinguishable particles can produce a hyper hybrid entangled state. In this article, we prove that quantum particles (either distinguishable or indistinguishable) can simultaneously produce and perform hyper hybrid entangled state and unit fidelity quantum teleportation respectively then using that cloning of any arbitrary quantum state is possible. As the no-cloning theorem cannot be violated using in quantum theory, the logical conclusion from this statement can be written in the form of two no-go theorems; (i) no-hyper hybrid entangled state for distinguishable particles and (ii) no-unit fidelity quantum teleportation for indistinguishable particles.

This is an extended abstract for the arXiv:2101.10089 preprint, which is published in Physical Review A. Detailed Proofs and technicalities may be found there.

#10 Classical-quantum network coding: a story about tensors

Speaker: Clément Meignant

Extended abstract: PDF

Youtube: youtu.be/lw5X8y6DKyU

We study here the conditions to perform the distribution of a pure state on a quantum network using quantum operations which can succeed with a non-zero probability, the Stochastic Local Operation and Classical Communication (SLOCC) operations. In their pioneering 2010 work, Kobayashi et al. showed how to convert any classical network coding protocol into a quantum network coding protocol. However, they left open whether the existence of a quantum network coding protocol implied the existence of a classical one. Motivated by this question, we characterize the set of distribution tasks achievable with non zero probability for both classical and quantum networks. We develop a formalism which encompasses both types of distribution protocols by reducing the solving of a distribution task to the factorization of a tensor in C or R+. Using this formalism, we examine the equivalences and differences between both types of distribution protocols exhibiting several elementary and fundamental relations between them as well as concrete examples of both convergence and divergence. We answer by the negative to the issue previously left open: some tasks are achievable in the quantum setting, but not in the classical one. We believe this formalism to be a useful tool for studying the extent of quantum network ability to perform multipartite distribution tasks.

#11 Thirty six entangled officers of Euler and quantum error correction codes

Speaker: Grzegorz Rajchel-Mieldzioć

Extended abstract: PDF

Youtube: youtu.be/utfIzPsC_8Y

The negative solution to the famous problem of 36 officers of Euler implies that there are no two orthogonal Latin squares of order six. We show that the problem has a solution, provided the officers can be entangled and construct two quantum orthogonal Latin squares of this size.

In other words, we found an Absolutely Maximally Entangled state AME(4,6) for four subsystems with six levels each, equivalently a 2-unitary matrix U of size 36 which maximizes the entangling power among all bi-partite unitary gates of this dimension, or a perfect tensor with four indices, each running from one to six, or pure non-additive quantum error correction code ((4,1,3))_6.

This is a submission for the preprint arXiv:2104.05122 [quant-ph].

#12 Foundations for Near-Term Quantum Natural Language Processing

Speaker: Bob Coecke

Extended abstract: PDF

Youtube: youtu.be/dXGnsCKLXrE

Short QPL contribution of the paper with the same title, that has been commissioned for a volume of the European Journal of Physics --- Quantum Technology, special issue on Quantum Industry. The full version is arXiv:2012.03755.
We provide conceptual and mathematical foundations for near-term quantum natural language processing (QNLP), and do so in quantum computer scientist friendly terms. We opted for an expository presentation style, and provide references for supporting empirical evidence and formal statements concerning mathematical generality.
We recall how the quantum model for natural language that we employ canonically combines linguistic meanings with rich linguistic structure, most notably grammar. In particular, the fact that it takes a quantum-like model to combine meaning and structure, establishes QNLP as quantum-native, on par with simulation of quantum systems. Moreover, the now leading Noisy Intermediate-Scale Quantum (NISQ) paradigm for encoding classical data on quantum hardware, variational quantum circuits, makes NISQ exceptionally QNLP-friendly: linguistic structure can be encoded as a free lunch, in contrast to the apparently exponentially expensive classical encoding of grammar.
Quantum speed-up for QNLP tasks has already been established in previous work with Will Zeng. Here we provide a broader range of tasks which all enjoy the same advantage.
Diagrammatic reasoning is at the heart of QNLP. Firstly, the quantum model interprets language as quantum processes via the diagrammatic formalism of categorical quantum mechanics. Secondly, these diagrams are via ZX-calculus translated into quantum circuits. Parameterisations of meanings then become the circuit variables to be learned.
Our encoding of linguistic structure within quantum circuits also embodies a novel approach for establishing word-meanings that goes beyond the current standards in mainstream AI, by placing linguistic structure at the heart of Wittgenstein's meaning-is-context.

#13 Fermionic State Discrimination by Local Operations and Classical Communication

Speaker: Matteo Lugli

Extended abstract: PDF

Youtube: youtu.be/0IqPus3J6a0

We consider the problem of local operations and classical communication (LOCC) discrimination between two bipartite pure states of fermionic systems. We show that, contrary to the case of quantum systems, for fermionic systems it is generally not possible to achieve the ideal state discrimination performances through LOCC measurements. On the other hand, we show that an ancillary system made of two fermionic modes in a maximally entangled state is a sufficient additional resource to attain the ideal performances via LOCC measurements.

#14 Restricted Hidden Cardinality Constraints in Causal Models

Speaker: Beata Zjawin

Extended abstract: PDF

Youtube: youtu.be/eHKesp-l_dY

Causal models with unobserved variables impose nontrivial constraints on the distributions over the observed variables. When a common cause of two variables is unobserved, it is impossible to uncover the causal relation between them without making additional assumptions about the model. In this work, we consider causal models with a premise that unobserved variables have known cardinalities. We derive inequality constraints implied by d-separation in such models. Moreover, we explore the possibility of leveraging this result to study causal influence in models that involve quantum systems.

#15 Closing Bell: Boxing black box simulations in the resource theory of contextuality

Speaker: Rui Soares Barbosa, Martti Karvonen and Shane Mansfield

Extended abstract: PDF

Youtube: youtu.be/rShNOuaim_U

This is a short (non-proceedings) submission summarising the contents of an article that will appear in an upcoming book dedicated to Samson Abramsky's contributions to logic. The chapter contains an exposition of the sheaf-theoretic framework for contextuality emphasising resource-theoretic aspects, as well as original results on this topic, which have not been presented elsewhere and which we summarise here. Previous work by Abramsky and us introduced a compositional resource theory of contextuality. Such a resource-theoretic perspective places the emphasis on simulations, or transformations, between contextual behaviours rather than on individual instances of such behaviours, i.e. on morphisms rather than objects, to adopt the language of category theory. A novel upshot of this perspective is a uniform treatment of some important concepts from the literature: here, we show that non-local games, for example, arise as particular instances of simulations. Our main contribution concerns the structure of this resource theory of contextuality. The 'free' transformations (i.e. the classical simulations) between contextual behaviours are characterised by regarding transformations as empirical behaviours in their own right and reducing the question of `free'-ness to that of noncontextuality of the corresponding behaviour. In categorical language, this is achieved by internalising the hom-sets, yielding a closed structure in the category of simulations.

#16 Quantum Advantage with Shallow Circuits from Contextuality

Speaker: Sivert Aasnaess

Extended abstract: PDF

Youtube: youtu.be/XmpZESpdxWE

We consider a family of randomised teleportation protocols acting on an n-qudit state \psi and a graph state with the structure of the hypergrid $[k]^l$. When l is fixed the outcome statistics of the protocol is generated by a shallow quantum circuit Q_k, however, if \psi is contextual then it is not generated by any shallow classical circuit. We show that quantum advantage is witnessed by a simulation procedure relating the teleportation protocol to \psi. This procedure induces a map from Bell inequalities violated by \psi to search problems witnessing quantum advantage. Let \gamma > b denote the value of \psi on a Bell inequality B with classical bound b. There is a search problem B_k, of query depth two, such that the success probability of Q_k satisfies p_S(Q_k, B_k) = \gamma and p_S(C_k, B_k) \leq b + \epsilon k^{-l} for any shallow classical circuit C_k. At the cost of restricting to the generalised qudit Pauli measurements, and increasing the classical bound to b + \epsilon k^{-l+1}, we show that the query depth can be decreased to one.

#17 A generalized cohomology theory for quantum contextuality

Speaker: Cihan Okay

Extended abstract: PDF

Youtube: youtu.be/6k5OMwc2yoM

Linear constraint systems (LCS) provide instances of Kochen–Specker type contextuality proofs. Our goal in this work is to introduce a new generalized cohomology theory that can be used to classify quantum solutions of LCSs. It turns out that our cohomology theory is a computable invariant of LCSs with promising applications to constructing new classes of contextual examples.

#18 Hidden Variable Model for Universal Quantum Computation with Magic States on Qubits

Speaker: Michael Zurel

Extended abstract: PDF

Youtube: youtu.be/ZJwLBAiV_Zc

We show that every quantum computation can be described by a probabilistic update of a probability distribution on a finite phase space. Negativity in a quasiprobability function is not required in states nor operations. Our result is consistent with Gleason's theorem and the Pusey-Barrett-Rudolph theorem. This abstract represents [Phys. Rev. Lett. 125, 260404 (2020)].

#19 Witnessing Wigner Negativity

Speaker: Pierre-Emmanuel Emeriau

Extended abstract: PDF

Youtube: youtu.be/88zIIYsuwv4

Negativity of the Wigner function is arguably one of the most striking non-classical features of quantum states. Beyond its fundamental relevance, it is also a necessary resource for quantum speedup with continuous variables. As quantum technologies emerge, the need to identify and characterize the resources which provide an advantage over existing classical technologies becomes more pressing.

Here we derive witnesses for Wigner negativity of quantum states, based on fidelities with Fock states, which can be reliably measured using standard detection setups. They possess a threshold expected value indicating whether the measured state exhibits the desired property or not. We phrase the problem of finding the threshold values for our witnesses as an infinite-dimensional linear optimisation. By relaxing and restricting the corresponding linear programs, we derive two hierarchies of semidefinite programs, which provide numerical sequences of increasingly tighter upper and lower bounds for the threshold values. We further show that both sequences converge to the threshold value. Moreover, our witnesses form a complete family - each Wigner negative state is detected by at least one witness - thus providing a reliable method for experimentally witnessing Wigner negativity of quantum states from few measurements. From a foundational perspective, our work provides insights on the set of positive Wigner functions which still lacks a proper characterisation.

#20 The Usefulness of Negativity: Anomalous Fisher-Information Distillation

Speaker: Aleksander Lasek

Extended abstract: PDF

Youtube: youtu.be/_i7B4LNiBRw

We show that postselection offers a nonclassical advantage in metrology. In every parameter-estimation experiment, the final measurement or the postprocessing incurs some cost. Postselection can improve the rate of Fisher information (the average information learned about an unknown parameter from an experimental trial) to cost. This improvement, we show, stems from the negativity of a quasiprobability distribution, a quantum extension of a probability distribution. In a classical theory, in which all observables commute, our quasiprobability distribution can be expressed as real and nonnegative. In a quantum-mechanically noncommuting theory, nonclassicality manifests in negative or nonreal quasiprobabilities. The distribution's nonclassically negative values enable postselected experiments to outperform even postselection-free experiments whose input states and final measurements are optimized: Postselected quantum experiments can yield anomalously large information-cost rates. We prove that this advantage is genuinely nonclassical: no classically commuting theory can describe any quantum experiment that delivers an anomalously large Fisher information. Finally, we outline a preparation-and-postselection procedure that can yield an arbitrarily large Fisher information. Our results establish the nonclassicality of a metrological advantage, leveraging our quasiprobability distribution as a mathematical tool.

Reference: https://www.nature.com/articles/s41467-020-17559-w

#21 Conditions tighter than noncommutation needed for nonclassicality

Speaker: David Arvidsson-Shukur

Extended abstract: PDF

Youtube: youtu.be/v92W2pU0yEk

Kirkwood discovered in 1933, and Dirac discovered in 1945, a representation of quantum states that has undergone a renaissance recently. The Kirkwood-Dirac (KD) distribution has been employed to study nonclassicality across quantum physics, from metrology to chaos to the foundations of quantum theory. The KD distribution is a quasiprobability distribution, a quantum generalization of a probability distribution, which can behave nonclassically by having negative or nonreal elements. Negative KD elements signify quantum information scrambling and potential metrological quantum advantages. Nonreal elements encode measurement disturbance and thermodynamic nonclassicality. KD distributions' nonclassicality has been believed to follow necessarily from noncommutation of operators. We show that noncommutation does not suffice. We prove sufficient conditions for the KD distribution to be nonclassical (equivalently, necessary conditions for it to be classical). We also quantify the KD nonclassicality achievable under various conditions. This work resolves long-standing questions about nonclassicality and may be used to engineer quantum advantages.

Reference: https://arxiv.org/abs/2009.04468

#22 Negative translations of orthomodular lattices and their logic

Speaker: Wesley Fussner

Extended abstract: PDF

Youtube: youtu.be/tqb3mHzcn88

We introduce residuated ortholattices as a generalization of – and environment for the investigation of – orthomodular lattices. We establish a number of basic algebraic facts regarding these structures, characterize orthomodular lattices as those residuated ortholattices whose residual operation is term-definable in the involutive lattice signature, and demonstrate that residuated ortholattices are the equivalent algebraic semantics of an algebraizable propositional logic. We also show that orthomodular lattices may be interpreted in residuated ortholattices via a translation in the spirit of the double-negation translation of Boolean algebras into Heyting algebras, and conclude with some remarks about decidability.

#23 Maximal violation of steering inequalities and the matrix cube

Speaker: Andreas Bluhm

Extended abstract: PDF

Youtube: youtu.be/OnygpPBUsmg

In this work, we connect the maximal violation of a steering inequality to an inclusion problem of free spectrahedra. In particular, we show that the maximal violation of a given unbiased dichotomic steering inequality is given by the inclusion constants of the matrix cube, which is a well-studied object in convex optimization theory. This allows us to find new upper bounds on the maximal violation of such inequalities and to show that previously obtained violations are optimal. In order to do this, we prove lower bounds on the inclusion constants of the complex matrix cube, which might be of independent interest.

#24 A structure theorem for all noncontextual ontological models of an operational theory

Speaker: Matthew Pusey

Extended abstract: PDF

Youtube: youtu.be/K0uTNMAwpJo

We prove that there is a unique nonnegative and diagram-preserving quasiprobability representation of the stabilizer subtheory in all odd dimensions, namely Gross's discrete Wigner function. This representation is equivalent to Spekkens' epistemically restricted toy theory, which is consequently singled out as the unique noncontextual ontological model for the stabilizer subtheory. Strikingly, the principle of noncontextuality is powerful enough (at least in this setting) to single out one particular classical realist interpretation. Our result explains the practical utility of Gross's representation, e.g. why (in the setting of the stabilizer subtheory) negativity in this particular representation implies generalized contextuality, and hence sheds light on why negativity of this particular representation is a resource for quantum computational speedup. It also allows us to prove that generalized contextuality is a necessary resource for universal quantum computation in the state injection model. In all even dimensions, we prove that there does not exist any nonnegative and diagram-preserving quasiprobability representation of the stabilizer subtheory, and, hence, that the stabilizer subtheory is contextual in all even dimensions. Together, these results constitute a complete characterization of the (non)classicality of all stabilizer subtheories. This submission is based on https://arxiv.org/abs/2101.06263.

#25 Generators and Relations for Real Stabilizer Operators

Speaker: Justin Makary

Extended abstract: PDF

Youtube: youtu.be/Lohon-j5xdY

Real stabilizer operators, which are also known as real Clifford operators, are generated, through composition and tensor product, by the Hadamard gate, the Pauli Z gate, and the controlled-Z gate. We introduce a normal form for real stabilizer circuits and show that every real stabilizer operator admits a unique normal form. Moreover, we give a finite set of relations that suffice to rewrite any real stabilizer circuit to its normal form.

#26 Semi-device-independent framework based on restricted distrust in prepare-and-measure experiments

Speaker: Armin Tavakoli

Extended abstract: PDF

Youtube: youtu.be/FfiI1Eob4QI

The semi-device-independent (DI) approach to quantum information processing aims to efficiently implement protocols under weak assumptions. Here, a semi-device-independent framework for prepare-and-measure experiments is introduced in which an experimenter can tune the degree of distrust in the performance of the quantum devices. In this framework, a receiver operates an uncharacterised measurement device and a sender operates a preparation device that emits states with a bounded fidelity with respect to a set of target states. In contrast to the main previous framework, no assumption on Hilbert space dimension is required. The set of quantum correlations is investigated and bounded from both the interior and the exterior using semidefinite programming methods. These tools are then applied to exemplify applications of the framework in a number of concrete tasks, namely quantum state discrimination, certification of detection efficiency, certification of sets of quantum measurements and random number generation.

#27 A New Connective in Natural Deduction, and its Application to Quantum Computing

Speaker: Gilles Dowek

Extended abstract: PDF

Youtube: youtu.be/au0TDDp5qSw

We investigate an unsuspected connection between non harmonious logical connectives, such as Prior's tonk, and quantum computing. We defend the idea that non harmonious connectives model the information erasure, the non-reversibility, and the non-determinism that occur, among other places, in quantum measurement. More concretely, we introduce a propositional logic with a non harmonious connective sup, prove cut elimination for this logic, and show that its proof language forms the core of a quantum programming language.

#28 Quantum Control in the Unitary Sphere: Lambda-S1 and its Categorical Model

Speaker: Alejandro Díaz-Caro

Extended abstract: PDF

Youtube: youtu.be/WJetZSCp0cE

In a recent paper, a realizability technique has been used to give a semantics of a quantum lambda calculus. Such a technique gives rise to an infinite number of valid typing rules, without giving preference to any subset of those. In this paper, we introduce a valid subset of typing rules, defining an expressive enough quantum calculus. Then, we propose a categorical semantics for it. Such a semantics consists of an adjunction between the category of distributive-action spaces of value distributions (that is, linear combinations of values in the lambda calculus), and the category of sets of value distributions.

#29 Operational Theories in Phase Space: Toy Model for the Harmonic Oscillator

Speaker: Martin Plávala

Extended abstract: PDF

Youtube: youtu.be/oCmaQtv-xB0

We construct a toy model for the harmonic oscillator that is neither classical nor quantum. The model features a discrete energy spectrum, a ground state with sharp position and momentum, an eigenstate with non-positive Wigner function as well as a state that has tunneling properties. The underlying formalism exploits that the Wigner--Weyl approach to quantum theory and the Hamilton formalism in classical theory can be formulated in the same operational language, which we then use to construct toy model with well-defined phase space. The toy model demonstrates that operational theories are a viable alternative to operator-based approaches for building physical theories.

#30 AKLT-states as ZX-diagrams: diagrammatic reasoning for quantum states

Speaker: Richard East

Extended abstract: PDF

Youtube: youtu.be/vi-ndkgKgQY

From Feynman diagrams to tensor networks, diagrammatic representations of computations in quantum mechanics have catalysed progress in physics. These diagrams represent the underlying mathematical operations and aid physical interpretation, but cannot generally be computed with directly. In this paper we introduce the ZXH-calculus, a graphical language based on the ZX-calculus, that we use to represent and reason about many-body states entirely graphically. As a demonstration, we express the 1D AKLT state, a symmetry protected topological state, in the ZXH-calculus by developing a representation of spins higher than 1/2 within the calculus. By exploiting the simplifying power of the ZXH-calculus rules we show how this representation straightforwardly recovers two important properties, the existence of topologically protected edge states, and the non-vanishing of a string order parameter. We furthermore show how the AKLT matrix-product state representation can be recovered from our diagrams. In addition, we provide an alternative proof that the 2D AKLT state on a hexagonal lattice can be reduced to a graph state, demonstrating that it is a universal quantum computing resource. Our results show that the ZXH-calculus is a powerful language for representing and computing with physical states entirely graphically, paving the way to develop more efficient many-body algorithms.

#31 Weakly measured while loops: peeking at quantum states

Speaker: Pablo Andres-Martinez

Extended abstract: PDF

Youtube: youtu.be/DUWJ2XQMgIA

While loops test a predicate on every iteration. Such measurement collapses quantum superposition, affecting the evolution of the algorithm. We define a while loop primitive using weak measurements, offering a trade-off between the collapse caused and the amount of information gained per iteration. This trade-off is adjusted with a parameter set by the programmer. We give sufficient conditions for the collapse not to affect the evolution in a detrimental way. As an example, we implement Grover's algorithm with a while loop, maintaining the quadratic quantum speed-up.

#32 Arithmetic loophole in Bell's theorem: An overlooked threat for entangled-state quantum cryptography

Speaker: Marek Czachor

Extended abstract: PDF

Youtube: youtu.be/Ze3OYpG0G_U

Bell's theorem is supposed to exclude all local hidden-variable models of quantum correlations. However, an explicit counterexample shows that a new class of local realistic models, based on generalized arithmetic and calculus, can exactly reconstruct rotationally symmetric quantum probabilities typical of two-electron singlet states. Observable probabilities are consistent with the usual arithmetic employed by macroscopic observers, but counterfactual aspects of Bell's theorem are sensitive to the choice of hidden-variable arithmetic and calculus. The model is classical in the sense of Einstein, Podolsky, Rosen, and Bell: elements of reality exist and probabilities are modeled by integrals of hidden-variable probability densities. Probability densities have a Clauser-Horne product form typical of local realistic theories. However, neither the product nor the integral nor the representation of rotations are the usual ones.

The integral has all the standard properties but only with respect to the arithmetic that defines the product. Certain formal transformations of integral expressions one finds in the usual proofs \`a la Bell do not work, so standard Bell-type inequalities cannot be proved. The system we consider is deterministic, local-realistic, rotationally invariant, observers have free will, detectors are perfect, so is free of all the canonical loopholes discussed in the literature.

Poster Presentations

#01 Toward Formalizing the Q# Programming Language

Presenter: Sarah Marshall

Link to poster: PDF

Q# is a high-level programming language from Microsoft for writing and running quantum programs. Like most industrial languages, it was designed without a formal specification, which can naturally lead to ambiguity in its interpretation. We aim to provide a formal specification and semantics for Q#, placing the language on a solid mathematical foundation, enabling further evolution of its design and type system, and leading to research in program correctness and verified compiler implementation. This poster describes our current progress and outlines the next steps.

#02 Formal Verification of Gottesman Semantics

Presenter: Jake Zweifler

Link to poster: PDF

In “Gottesman Types for Quantum Programs”, Rand et al. introduced a type system, based on the Gottesman-Knill theorem for characterizing quantum circuits that use the Clifford gate set. While this system is implemented in the Coq proof assistant (allowing easy typechecking), it is not verified using that tool. Instead, a user must convince herself that the theorems in the paper are true, that the type system reflects those theorems.

This work aims to patch these holes by directly providing a semantics for Gottesman types in Coq, and proving the necessary theorems from by Gottesman and Rand et al. inside the proof assistant. This guarantees the type system actually enforces the desired properties, including specifying the set of input and outputs and guaranteeing separability. This allows us to verify typing rules that go beyond the limited expressivity of our current rules and the limitations of the Clifford gate set.

#03 Contextuality and Semi-Module Cohomology

Presenter: Sidiney B. Montanhano

Link to poster: PDF

Contextuality is the inability to turn local compatibility into global compatibility, which makes it possible to use the presheaf formalism, the Čech cohomology and the relation between contextuality and obstruction. But this kind of cohomology, as usual, imposes the Abelian group structure in each local section, resulting in strong contextual behaviour even with trivial obstruction. In order to overcome this failure, we look for the more natural structure of semi-modules on the semi-ring used to measure the events. There is already a literature of Čech cohomology on semi-modules, but the notion of obstruction is still missing. In our approach, we define the notion of obstruction even without the inverse and cancellation properties (usually missing in a semi-module), imposing that the semi-ring be a semi-field, and defining a new way to codify the data of the difference between marginalizations. With this tool, we can caracterize the contextual behavior as the non-trivial obstruction of the presheaf.

#04 Bounding the Set of Quantum Correlations with Information Causality Principle

Presenter: Nikolai Miklin

Link to poster: PDF

Determining whether certain correlations have a quantum realization in the Bell experiment is an undecidable problem. The best-known method for outer approximation of the set of quantum correlations is based on a hierarchy of semidefinite programs, is numerical and typically computationally demanding in complex scenarios. Information Causality provides an alternative solution that can give easy to check analytical necessary conditions. Besides, Information Causality being a physical principle does not rely on the formalism of quantum theory and instead requires a small set of information-theoretic assumptions. The current submission is based on two recent results, [N. Miklin et.al., arXiv: 2101.12710] and [M. Gachechiladze et.al., arXiv:2103.05029], aiming at bounding the set of quantum correlations using the Information Causality principle. The first result proposes a way to obtain bounds from this principle without concatenation, which is an originally proposed very involved method to enhance the constraining power of Information Causality. In the second result, we derive a family of quadratic inequalities expressed directly in terms of observed probabilities and which encloses the set of correlations satisfying the Information Causality principle. We compare these two results with the first level of the hierarchy of semidefinite programs, which is also known to correspond to the principle of Macroscopic Locality, and identify a subspace in the correlation space where our results provide strictly better bounds.

#05 Measuring locality vs free choice

Presenter: Pawel Blasiak

Link to poster: PDF

Bell inequalities rest on three fundamental assumptions: realism, locality, and free choice, which lead to nontrivial constraints on correlations in very simple experiments. If we retain realism, then violation of the inequalities implies that at least one of the remaining two assumptions must fail, which can have profound consequences for the causal explanation of the experiment. We investigate the extent to which a given assumption needs to be relaxed for the other to hold at all costs, based on the observation that a violation need not occur on every experimental trial, even when describing correlations violating Bell inequalities. How often this needs to be the case determines the degree of, respectively, locality or free choice in the observed experimental behavior. Despite their disparate character, we show that both assumptions are equally costly. Namely, the resources required to explain the experimental statistics (measured by the frequency of causal interventions of either sort) are exactly the same. Furthermore, we compute such defined measures of locality and free choice for any nonsignaling statistics in a Bell experiment with binary settings, showing that it is directly related to the amount of violation of the so-called Clauser-Horne-Shimony-Holt inequalities. This result is theory independent as it refers directly to the experimental statistics. Additionally, we show how the local fraction results for quantum-mechanical frameworks with infinite number of settings translate into analogous statements for the measure of free choice we introduce. Thus, concerning statistics, causal explanations resorting to either locality or free choice violations are fully interchangeable.

#06 Entanglement and Sympathetic cooling between ion and mechanical oscillator in optomechanical system

Presenter: Devender Garg

Link to poster: PDF

The optomechanical interaction involves the radiation pressure force of the cavity field acting upon the mechanical system [1,2]. In our model, we studied the interaction between an ion trapped and mechanical mode in the optomechanical system [3]. Cavity mode mediates the coupling between the ion and mechanical modes. In a large cavity detuning limit, we adiabatically eliminate the electronic state of ion [4]. We found that a state can be transferred between an ion's vibrational mode and the mechanical mode through cavity mode. In addition, we investigate the steady-state entanglement between the mechanical mode and motional mode of ions [5]. We further investigate the effect of temperature on entanglement. We also analyze the effect of sympathetic cooling of the mechanical system using the ion vibrational mode. The system can be utilized for facilitating quantum-information transfer between mechanical systems and ions.

[1] M. Aspelmeyer, T. J. Kippenberg, and F. Marquardt, Rev. Mod.Phys. 86, 1391 (2014).
[2] F. Marquardt, J. P. Chen, A. A. Clerk, and S.M. Girvin, Phys. Rev. Lett. 99, 093902 (2007).
[3] Devender Garg and Asoka Biswas, Phys. Rev. A 100, 053822 (2019).
[4] C. Maschler and H. Ritsch, Opt. Commun. 243, 145 (2004).
[5] R. Simon, Phys. Rev.Lett 84, 2726 (1999).

#07 Genuine multipartite entanglement is not a precondition for secure conference key agreement

Presenter: Giacomo Carrara

Link to poster: PDF

Entanglement plays a crucial role in the security of quantum key distribution. A secret key can only be obtained by two parties if there exists a corresponding entanglement-based description of the protocol in which entanglement is witnessed, as shown by Curty et al (2004). Here we investigate the role of entanglement for the generalization of quantum key distribution to the multipartite scenario, namely conference key agreement. In particular, we ask whether the strongest form of multipartite entanglement, namely genuine multipartite entanglement, is necessary to establish a conference key. We show that, surprisingly, a non-zero conference key can be obtained even if the parties share biseparable states in each round of the protocol. Moreover we relate conference key agreement with entanglement witnesses and show that a non-zero conference key can be interpreted as a non-linear entanglement witness that detects a class of states which cannot be detected by usual linear entanglement witnesses.

#08 Simulating Some Game Semantics Models on IBM Quantum Computer

Presenter: Milad Ghadimi

Link to poster: PDF

Game theoretical techniques have been implemented in many fields of science to model behavior of social agents. Some of fruitful usage of game theory have been in a variety of branches of logic. Recently application of quantum theory in computation, due to its promising results has attracted lots of attention. Here we investigate and simulate some aspects of mixing quantum theory into Game Theoretical Semantics. All the simulations are executed on IBM quantum computer.

#09 A Stability Indicator of Quantum Computing Systems via Quantum Random Number Generation

Presenter: Kentaro Tamura

Link to poster: PDF

A quantum computer can be considered a system whose target is the computational result corresponding to the program. For a system to be controlled to achieve the target, it is required that the system is stable. A quantum computing system is no exception. A stable quantum computing system can be defined as a system that is robust to noise and sustains the same relationship between the program and the computational result. We propose two schemes that detect a quantum computing system that is unstable. The two schemes detect different types of changes in the relationship between the program and the computational result. Both schemes are based on performing quantum random number generation on a quantum computing system. We apply the schemes to an actual seven-qubit cloud quantum computing system. The results of one of the schemes imply an unstable quantum computing system.

#10 Using a Resource Theoretic Perspective to Witness and Engineer Quantum Generalized Contextuality for Prepare-and-Measure Scenarios

Presenter: Rafael Wagner

Link to poster: PDF

We use the resource theory framework of generalized contextuality as a tool for analyzing the structure and applications of prepare-and-measure scenarios. We argue that this framework is capable of witnessing quantum contextuality and of straightening known arguments regarding the robustness of experimental implementations or verifications of contextuality. As a case study, we witness quantum contextuality associated with any nontrivial noncontextuality inequality for a class of scenarios by noticing a connection between the resource theory and measurement simulability. We also expose a rule for composing behaviours that allows one to build complex scenarios from simpler ones, which provides an explanation of the non-contextual polytope structure for complex scenarios and facilitates finding possible quantum violations.

#11 Classifying Complexity with the ZX-Calculus: Jones Polynomials and Potts Partition Functions

Presenter: Alex Townsend-Teague

Link to poster: PDF

The ZX-calculus is a graphical language that allows for reasoning about suitably represented tensor networks - namely ZX-diagrams - in terms of rewrite rules. Here, we focus on problems that amount to exactly computing a scalar encoded as a closed tensor network. In general, such problems are #P-hard. However, there are families of such problems which are known to be in P when the dimension is below a certain value. By expressing problem instances from these families as ZX-diagrams, we see that the easy instances belong to the stabilizer fragment of the ZX-calculus. Building on previous work on efficient simplification of qubit stabilizer diagrams, we present simplifying rewrites for the case of qutrits, which are of independent interest in the field of quantum circuit optimisation. Finally, we look at the specific examples of evaluating the Jones polynomial and of counting graph-colourings. Our exposition further champions the ZX-calculus as a suitable and unifying language for studying the complexity of a broad range of classical and quantum problems.

#12 Inflated Graph States Refuting Communication-Assisted LHV Models

Presenter: Uta Meyer

Link to poster: PDF

We propose a family of graph states that can be constructed from any graph by inflating it, i.e. adding a number of new nodes in between every edge. We provide a set of measurements on the inflated graph state that any local-hidden-variable model fails to reproduce even including a round of communication between adjacent nodes of the graph. Thus, we extend a result by Barrett et. al that found applications in solving computational problems with a quantum advantage.

#13 Relating compatibility and divisibility of quantum channels

Presenter: Lorenzo Catani

Link to poster: PDF

We connect two key concepts in quantum information: compatibility and divisibility of quantum channels. Two channels are compatible if they can be both obtained via marginalization from a third channel. A channel divides another channel if it reproduces its action by sequential composition with a third channel. (In)compatibility is of central importance for studying the difference between classical and quantum dynamics. The relevance of divisibility stands in its close relationship with the onset of Markovianity. We emphasize the simulability character of compatibility and divisibility, and, despite their structural difference, we find a set of channels – self-degradable channels – for which the two notions coincide. We also show that, for degradable channels, compatibility implies divisibility, and that, for anti-degradable channels, divisibility implies compatibility. These results motivate further research on these classes of channels and shed new light on the meaning of these two largely studied notions.

#14 Fitch's Knowability Axioms are Incompatible with Quantum Theory

Presenter: Nuriya Nurgalieva

Link to poster: PDF

The preprint associated with this talk may be found at arXiv:2009.00321 [quant-ph]. In this work we introduce a framework in which we can study epistemic logical paradoxes and foundational issues in quantum theory. First we build a simple epistemic modal logic and show how to model quantum knowledge within it. Then, we express common epistemic assumptions which lead to a surprising logical result known as Fitch's paradox. We then translate the conclusion of the Frauchiger-Renner quantum thought experiment into the language of epistemic logic to show that Fitch's paradox is not compatible with quantum settings.

#15 Wigner's friend and the quasi-ideal clock

Presenter: Vinicius Pretti Rossi

Link to poster: PDF

In 1962, Eugene P. Wigner introduced a thought experiment that highlighted the incompatibility in quantum theory between unitary evolution and wave function reduction in a measurement. This work resulted in a class of thought experiments often called Wigner's Friend Scenarios, which have been providing insights over many frameworks and interpretations of quantum theory. Recently, a no-go theorem obtained by Daniela Frauchiger and Renato Renner brought attention back to the Wigner’s Friend and its potential of putting theories to test. Many answers to this result pointed out how timing in the thought experiment could be yielding a paradox. In this work, we ask what would happen if the isolated friend in a Wigner's Friend Scenario did not share a time reference frame with the outer observer, and time should be tracked by a quantum clock. For this purpose, we recollect concepts provided by the theory of quantum reference frames and the quantum resource theory of asymmetry, to learn how to internalize time in this scenario, and introduce a model for a feasible quantum clock proposed by Mischa P. Woods, Ralph Silva and Jonathan Oppenheim, called the quasi-ideal clock. Our results have shown that no decoherent behaviour comes from this approach, and the disagreement between the superobserver and its friend persists even for an imprecise clock on Wigner's side. However, the gaussian spread of this clock model can control what observables do not raise a paradox, indicating the relevance of deepening this analysis.

#16 An abstract theory of physical measurements

Presenter: Pedro Resende

Link to poster: PDF

The question of what should be meant by a measurement is tackled from a mathematical perspective whose physical interpretation is that a measurement is a fundamental process via which a finite amount of classical information is produced. This translates into an algebraic and topological definition of measurement space that caters for the distinction between quantum and classical measurements and allows a notion of observer to be derived.

#17 Diagrammatic security proof for 8-state encoding

Presenter: Boris Skoric

Link to poster: PDF

Dirac notation is the most common way to describe quantum states and operations on states. It is very convenient and allows for quick visual distinction between vectors, scalars and operators. For quantum processes that involve interactions of multiple systems an even better visualisation has been proposed by Coecke and Kissinger, in the form of a diagrammatic formalism [CK2017]. Their notation expresses formulas in the form of diagrams, somewhat similar to Feynman diagrams, and is more general than the circuit notation for quantum computing.

This document consists of two parts.
(1) We give a brief summary of the diagrammatic notation of quantum processes, tailored to readers who already know quantum physics and are not interested in general process theory. For this audience our summary is less daunting than the encyclopaedic book by Coecke and Kissinger [CK2017], and on the other hand more accessible than the ultra-compact introduction of [KTW2017]. We deviate a somewhat from [CK2017,KTW2017] in that we do not assume basis states to equal their own complex conjugate; this means that we do not use symmetric notation for basis states, and it leads us to explicitly show arrows on wires where they are usually omitted.
(2) We extend the work of Kissinger, Tull and Westerbaan [KTW2017] which gives a diagrammatic security proof for BB84 and 6-state Quantum Key Distribution. Their proof is based on a sequence of diagrammatic manipulations that works when the bases used in the protocol are mutually unbiased. We extend this result to 8-state encoding, which has been proposed as a tool in quantum key recycling protocols [SdV2017,LS2018], and which does not have mutually unbiased bases.

#18 Exponential modalities and complementarity

Presenter: Priyaa Varshinee

Link to poster: PDF

The exponential modality has been used as a defacto structure for modelling infinite dimensional quantum systems. However, this does not explain what the exponential modalities of linear logic have to do with complementarity. Using the formulation of quantum systems in mixed unitary categories -- based on $\dagger$-linear logic -- a formulation of measurement, referred to as ``compaction'', is described. It is then shown how complementary systems arise as a ``compaction'' of free exponential modalities. Recalling that, in linear logic, exponential modalities have two dual components, the article shows how these components may be ``compacted'' into the usual notion of complementarity between two Frobenius algebras on the same object. This exhibits a complementary system as arising via the compaction of two distinct but dual systems.

#19 A Model-Theoretic Approach to Physical Resources

Presenter: Patrick Fraser

Link to poster: PDF

In this paper, I provide a model-theoretic account of general resource theories using quantified modal logic. This enables one to more exhaustively explore the landscape of possible operational theories by appealing to classes of models with certain properties which need nota priori have any mathematical formalism in particular (such as a Hilbert space formalism), and allows one to explore physical theories involving large cardinalities with ease. This allows one to discuss physical theories without assuming any significant structural features of the world from the outset and provides clarity to the foundational value of resource theories an general operational theories more broadly. The long abstract given here introduces the basic ideas of this work and sketches the further developments which will be included in the full manuscript (simple proofs are omitted here for brevity).

#20 Limitations in quantum computing from resource constraints

Presenter: Marco Fellous Asiani

Link to poster: PDF

Fault tolerant quantum computing (FTQC) prescribes how, by adding more physical elements (qubits and gates), computational errors can be removed, performing error correction. An assumption behind such constructions is that the error per physical element does not grow with the number of elements. We relax this assumption, which is rarely verified experimentally and study the general consequences. We showed that this problem is related to optimizing the minimum resource (like energy) required to perform a calculation, allowing to study the energetic cost of quantum computing. Reference of the paper: arXiv:2007.01966

#21 Temporal Observable-Dependent Logic for Quantum finite Automata

Presenter: Tsubasa Takagi

Link to poster: PDF

Quantum finite automata (QFAs) and modal logic are related through finite Kripke models. Thus, if there is a kind of modal logic which is expressive enough to deal with quantum computation, we can determine whether a given QFA accepts a finite word or not automatically by probabilistic model checking. For this reason, we suggest temporal observable-dependent logic (TOD logic) by combining linear temporal logic and observable-dependent logic, and suggest algorithms of constructing finite Kripke model for TOD logic from QFAs. Furthermore, we formulate the proof system for TOD logic that is sound and complete.

#22 Phase Space Logic

Presenter: Felix Huber

Link to poster: PDF

We propose a phase space logic that can capture the behavior of quantum and quantum-like systems. The proposal is similar to the more generic concept of epistemic logic: it encodes knowledge or perhaps more correctly, predictions about outcomes of future observations on some systems. For a quantum system, these predictions are statements about future outcomes of measurements performed on specific degrees of freedom of the system. The proposed logic will include propositions and their relations including connectives, but importantly also transformations between propositions on different degrees of freedom of the systems. A key point is the addition of a transformation that allows to convert propositions about single systems into propositions about correlations between systems. We will see that subtle choices of the properties of the transformations lead to drastically different underlying mathematical models; one choice gives stabilizer quantum mechanics, while another choice gives Spekkens' toy theory. This points to a crucial basic property of quantum and quantum-like systems that can be handled within the present phase space logic by adjusting the mentioned choice. It also enables a discussion on what behaviors are properly quantum or only quantum-like, relating to that choice and how it manifests in the system under scrutiny.

#23 Quantum Magic Rectangles: Characterization and Application to Certified Randomness Expansion

Presenter: Sean Adamson

Link to poster: PDF

We study a generalization of the Mermin–Peres magic square game to arbitrary rectangular dimensions. We characterize these in terms of their optimal win probabilities for quantum strategies. We find that for dimensions at least 3×3, quantum strategies can win with certainty; for dimensions 1×n, they do not outperform classical strategies; for dimensions 2×n, we give lower/upper bounds that both outperform the classical strategies. Finally, we apply our findings to certified randomness expansion. We first find the winning probability of games having a distinguished input with deterministic outcome, and then give robustness and rates following C. A. Miller and Y. Shi (2017).

#24 Automated detection of contextuality proofs with intermediate numbers of observables

Presenter: Henri de Boutray

Link to poster: PDF

Quantum contextuality takes an important place amongst the concepts of quantum computing that bring an advantage over its classical counterpart. For a large class of contextuality proofs, aka. observable-based proofs of the Kochen-Specker Theorem, we first formulate the contextuality property as the absence of solutions to a linear system. Then we explain why subgeometries of binary symplectic polar spaces are candidates for contextuality proofs. We report first results of a software that generates these subgeometries and decides their contextuality. The proofs we consider involve more contexts and observables than the smallest known proofs. The intermediate size property of those proofs is interesting for experimental tests, but could also be interesting in quantum game theory.

#25 Applying a Variational Eigensolver for Hybrid Quantum-Classical Machine Learning

Presenter: Daniel Pompa

Link to poster: PDF

Adaptations to classical machine learning models allowing them to take advantage of quantum computations can enable a hybrid approach for identifying machine learning models. The specification of some classes of machine learning models can be accomplished by finding a minimum eigenvalue of an operator matrix. Thus, the solution of this problem in a quantum environment can be advantageous as compared to using a classical electronic computer. We use a Variational Quantum Eigensolver (VQE) based upon the Ritz variational principle that is specifically formulated to avoid decoherence issues. In particular, the quantum computer prepares a wave function ansatz and estimates the expected value of its Hamiltonian. An optimization technique running on a classical computer is likewise used to update the quantum circuit parameters to converge upon the goal of finding the ground state wave function thus yielding the minimal eigenvalue represented as an energy state. Experimental results are provided using the IBM-Q machines to demonstrate this approach.

#26 Neither contextuality nor non-locality admit catalysts

Presenter: Martti Karvonen

Link to poster: PDF

This is a short (non-proceedings) submission summarising a pre-print (available at https://arxiv.org/abs/2102.07637). In the work we are describing, we show that the resource theory of contextuality does not admit catalysts. As a corollary, we observe that the same holds for non-locality. This adds a further example to the list of ``anomalies of entanglement'', showing that non-locality and entanglement (as measured by (S)LOCC) behave differently as resources.

#27 The Many-Valued Logic of Quantum Mechanics

Presenter: Jarosław Pykacz

Link to poster: PDF

It is shown that any quantum logic in the Birkhoff - von Neumann sense that possesses an ordering set of states can be isomorphically represented as a particular kind of infinite-valued Łukasiewicz logic with partially defined conjunction and disjunction. It is argued that such non-classical features of BvN quantum logic as lack of distributivity or validity of the orthomodular law follows from properties of Łukasiewicz conjunction and disjunction.

#28 Strict hierarchy between parallel, sequential, and indefinite-causal-order strategies for channel discrimination

Presenter: Jessica Bavaresco

Link to poster: PDF

We present an instance of a task of minimum-error discrimination of two qubit-qubit quantum channels for which a sequential strategy outperforms any parallel strategy. We then establish two new classes of strategies for channel discrimination that involve indefinite causal order and show that there exists a strict hierarchy among the performance of all four strategies. Our proof technique employs a general method of computer-assisted proofs, which the interest may go beyond the particular task of discriminating quantum channels. We also provide a systematic method for finding pairs of channels that showcase this phenomenon, demonstrating that the hierarchy between the strategies is not exclusive to our main example.

#29 Causal reappraisal of the quantum three box paradox

Presenter: Ewa Borsuk

Link to poster: PDF

Quantum three box paradox is a prototypical example of some bizarre predictions for intermediate measurements made on pre- and post-selected systems. Although in principle those effects can be explained by measurement disturbance, it is not clear what mechanisms are required to fully account for the observed correlations. In this paper, this paradox is scrutinised from a causal point of view. We consider an array of potential causal structures behind the experiment eliminating those without enough explanatory power. This gives us a way of differentiating between the various mechanisms in which measurement disturbance can propagate in the system. Specifically, we distinguish whether it is just the measurement outcome or the full context specified by the choice of measurement that is required for the causal explanation of the observed statistics. We show that the latter must be the case, but only when the full statistics is taken into account (with any of the three boxes being checked). Surprisingly, if limited to the original formulation of the paradox, where just two choices are considered, then the mere outcome dependence is enough. Furthermore, we also consider a subtle interpretative distinction between pure and realist causal setting, where the latter additionally assumes richness of the paradox.

#30 Operational Resource Theory of Imaginarity

Presenter: Tulja Varun Kondra

Link to poster: PDF

Wave-particle duality is one of the basic features of quantum mechanics, giving rise to the use of complex numbers in describing states of quantum systems, their dynamics, and interaction. Since the inception of quantum theory, it has been debated whether complex numbers are actually essential, or whether an alternative consistent formulation is possible using real numbers only. Here, we attack this long-standing problem both theoretically and experimentally, using the powerful tools of quantum resource theories. We show that – under reasonable assumptions – quantum states are easier to create and manipulate if they only have real elements. This gives an operational meaning to the resource theory of imaginarity. We identify and answer several important questions which include the state-conversion problem for all qubit states and all pure states of any dimension, and the approximate imaginarity distillation for all quantum states. As an application, we show that imaginarity plays a crucial role for state discrimination: there exist real quantum states which can be perfectly distinguished via local operations and classical communication, but which cannot be distinguished with any nonzero probability if one of the parties has no access to imaginarity. We confirm this phenomenon experimentally with linear optics, performing discrimination of different two-photon quantum states by local projective measurements. These results prove that complex numbers are an indispensable part of quantum mechanics.

https://arxiv.org/pdf/2007.14847.pdf