QI 2: Quantum Foundations

Time: Monday 11:00–13:00 Location: B302

QI 2.1 Mon 11:00 B302

Uncertainty relations from graph theory — •Kiara Hansenne, Carlos de Gois, and Otfried Gühne — Universität Siegen, Siegen, Germany

Quantum measurements are inherently probabilistic and quantum theory often forbids to precisely predict the outcomes of simultaneous measurements. This phenomenon is captured and quantified through uncertainty relations. Although studied since the inception of quantum theory, the problem of determining the possible expectation values of a collection of quantum measurements remains, in general, unsolved. By constructing a close connection between observables and graph theory, we derive uncertainty relations valid for any set of dichotomic observables. These relations are, in many cases, tight, and related to the size of the maximum clique of the associated graph. As applications, our results can be straightforwardly used to formulate entropic uncertainty relations, separability criteria and entanglement witnesses.

QI 2.2 Mon 11:15 B302

Many-particle coherence and higher-order interference — •Marc-Oliver Pleinert[1], Eric Lutz[2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Institute for Theoretical Physics I, University of Stuttgart, 70550 Stuttgart, Germany

Quantum mechanics is based on a set of only a few postulates, which can be separated into two parts: one part governing the 'inner' structure, i.e., the definition and dynamics of the state space, the wave function and the observables; and one part making the connection to experiments. The latter is known as Born's rule, which – simply put – relates detection probabilities to the modulus square of the wave function. The resulting structure of quantum theory permits interference of indistinguishable paths; but, at the same time, limits such interference to certain interference orders. In general, quantum mechanics allows for interference up to order $2M$ in M-particle correlations. Depending on the mutual coherence of the particles, however, the related interference hierarchy can terminate earlier. Here, we show that mutually coherent particles can exhibit interference of the highest orders allowed. We further demonstrate that interference of mutually incoherent particles truncates already at order $M+1$ although interference of the latter is principally more multifaceted. Finally, we demonstrate the disparate vanishing of such higher-order interference terms as a function of coherence in experiments with mutually coherent and incoherent sources.

QI 2.3 Mon 11:30 B302

What aspects of the phenomenology of interference witness nonclassicality? — •Lorenzo Catani[1], Matthew Leifer[2], Giovanni Scala[3], David Schmid[3], and Robert Spekkens[4] — [1]Technische Universitaet Berlin — [2]Chapman University — [3]University of Gdansk — [4]Perimeter Institute for Theoretical Physics

Interference phenomena are often claimed to resist classical explanation. However, such claims are undermined by the fact that the specific aspects of the phenomenology upon which they are based can in fact be reproduced in a noncontextual ontological model [Catani et al. arXiv:2111.13727]. This raises the question of what other aspects of the phenomenology of interference do in fact resist classical explanation. We answer this question by demonstrating that the most basic quantum wave-particle duality relation, which expresses the precise trade-off between path distinguishability and fringe visibility, cannot be reproduced in any noncontextual model. We do this by showing that it is a specific type of uncertainty relation, and then leveraging a recent result establishing that noncontextuality restricts the functional form of this uncertainty relation [Catani et al. arXiv:2207.11779]. Finally, we discuss what sorts of interferometric experiment can demonstrate contextuality via the wave-particle duality relation.

QI 2.4 Mon 11:45 B302

Contextuality as a precondition for entanglement — •Martin Plávala and Otfried Gühne — Universität Siegen, Siegen, Deutschland

Quantum theory features several phenomena which can be considered as resources for information processing tasks. Some of these effects, such as entanglement, arise in a non-local scenario, where a quantum state is distributed between different parties. Other phenomena, such as contextuality can be observed, if quantum states are prepared and then subjected to sequences of measurements. Here we provide an intimate connection between different resources by proving that entanglement in a non-local scenario can only arise if there is preparation & measurement contextuality in a sequential scenario derived from the non-local one by remote state preparation. Moreover, the robust absence of entanglement implies the absence of contextuality. As a direct consequence, our result allows to translate any inequality for testing preparation & measurement contextuality into an entanglement test; in addition, entanglement witnesses can be used to obtain novel contextuality inequalities.

QI 2.5 Mon 12:00 B302

Distribution of quantum incompatibility across subsets of multiple measurements — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, D-40225 Düsseldorf, Germany

The incompatibility of quantum measurements, i.e., the impossibility of measuring two or more observable quantities simultaneously, is one of the most fundamental properties of quantum physics. Not only are incompatible measurements necessary to reveal nonlocal effects, such as quantum steering and the violation of Bell inequalities, but they are also valuable resources that provide advantages in various information processing tasks. It is generally known that increasing the number of distinct measurements can also increase the incompatibility. However, it is yet unknown how much incompatibility can be gained from adding more measurements to an existing measurement scheme and on what this gain depends. Here, we show how the maximal incompatibility that can be gained by increasing the number of measurements can be upper bounded by functions of the incompatibility of respective subsets of the available measurements. More generally, we show how to bound the incompatibility of a set of measurements using the properties of its subsets, which reveals a new notion of measurement incompatibility. We prove the relevance of our bounds by providing tight examples using noisy measurements based on mutually unbiased bases. Finally, we discuss the direct consequences of our results for the nonlocality that could be gained by increasing the number of measurements in a Bell experiment.

QI 2.6 Mon 12:15 B302

Simulability of Sets of Continuous and Infinite-Dimensional POVMs — •Sophie Egelhaaf[1], Juha-Pekka Pellonpää[2], and Roope Uola[1] — [1]Département de Physique Appliquée, Université de Genève, CH-1205 Genève, Switzerland — [2]Department of Physics and Astronomy, University of Turku, FI-20014 Turun yliopisto, Finland

When considering quantum information tasks such as steering and Bell non-locality, the statistics not only depend on the state(s) shared by the parties but also the set of POVMs available to them. A key feature for witnessing true quantum behaviour is the incompatibility of POVMs. If a set of POVMs is jointly measurable, i.e. not incompatible, it can be fully compressed. Hence Ioannou et al [1] use the compression dimension of a set of POVMs, named the simulability, to quantify the incompatibility of the set. However, so far many findings only apply to finite-dimensional and discrete POVMs. We are working on adapting these findings such that they also hold for infinite-dimensional and continuous POVMs. In this context we are interested in finding the most incompatible and least compressible pair of continuous and infinite-dimensional POVMs, examples potentially being position and momentum as well as number and phase.

[1] M. Ioannou et al. Simulability of high-dimensional quantum measurements. arXiv preprint arXiv:2202.12980 (2022)

QI 2.7 Mon 12:30 B302

Causality and signalling in a quantum information space-time — •Leonardo Silva Vieira Santos — Universitat Siegen, Siegen, Germany

In recent years, there has been a growing interest and effort in understanding causality in the quantum domain. Much of this is due to the tension between the two most successful scientific theories of modern physics: quantum mechanics and Einstein's general relativity. On the one hand, quantum mechanics is a probabilistic theory whose application typically takes place in contexts with a fixed and well-defined causal structure. General relativity, on the other hand, is deterministic but has a dynamical causal structure. We propose a framework to study space-time causal structures from the point of view of quantum information theory. In our approach, the causal constrains of a space-time determines the possible deterministic transformations between states of quantum systems called quantum causal probes. As a result, we demonstrate how well-known processes with indefinite causal order and indefinite time direction emerge from the formalism.

QI 2.8 Mon 12:45 B302

Bohmian Trajectories of Quantum Walks — •Florian Huber[1,2,3], Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Lukas Knips[1,2,3], Eric Meyer[4], Harald Weinfurter[1,2,3], Alexander Szameit[4], and Jasmin Meinecke[1,2,3] — [1]Department für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Institute of Physics, University of Rostock, Germany

Quantum walks are the quantum mechanical analogue of classical random walks. While in classical mechanics each particle follows a definite trajectory, in standard quantum mechanics (QM) no such description of the coherent propagation of the quantum walker is possible. However, certain interpretations of QM, as for example Bohmian mechanics, a non-local hidden variable theory, attribute definite positions and momenta to particles and therefore allow to visualize particle trajectories.

For photons these Bohmian trajectories correspond to energy flow lines given by the Poynting vector in classical electrodynamics and can be reconstructed from weak measurements. We report on the simulation and first measurement results of such energy flow lines of a quantum walk, realized in an integrated waveguide array written into fused silica substrate. By analyzing different time steps of the quantum walk evolution we are able to reconstruct the trajectories giving information about the energy flow in quantum walk structures.