QI 1: Quantum Foundations

Time: Monday 9:30–13:00 Location: HFT-FT 101

Invited Talk QI 1.1 Mon 9:30 HFT-FT 101

Quantum causal structure and quantum memory — •Fabio Costa — Nordita, Stockholm University and KTH Royal Institute of Technology, Stockholm, Sweden

In recent years, a new formalism has been proposed to describe quantum processes where causal relations between events can be unknown or indefinite. The same formalism has been shown to be useful to describe multi-time memory in causally ordered, non-Markovian open quantum systems. Here I will review the approach and some of the most recent developments, with a focus on the definition and characterisation of non-classical memory and its relation to entanglement characterisation.

QI 1.2 Mon 10:00 HFT-FT 101

Causal modeling quantum non-Markovianity — •Leonardo Silva Vieira Santos and Otfried Gühne — University of Siegen

The interaction of every quantum system with its surrounding environment introduces deviations in its temporal evolution from the reversible trajectory predicted by the Schrödinger equation. When one can access the system on a timescale comparable to the characteristic decay time of correlations and excitations in the environment, memory effects (i.e., non-Markovianity) become significant. The question arises: Is there anything inherently non-classical about the evolution of non-Markovian open quantum systems? This question is somewhat non-trivial, as defining what is truly "non-classical" involves subtle considerations. In the realm of quantum correlations, Bell's theorem stands out as arguably the strongest notion of non-classicality ever discovered and experimentally tested. In this work, we take steps toward establishing Bell-type theorems for the multi-time statistics of non-Markovian open quantum systems. We derive a scalable family of Bell-type inequalities designed to detect the non-classicality of quantum stochastic processes. Our findings demonstrate that the violation of these inequalities serves as a device-independent test for quantum memory – the environment's memory that cannot be classically simulated.

QI 1.3 Mon 10:15 HFT-FT 101

Towards exact factorization of quantum dynamics via Lie algebras — •David Edward Bruschi[1], André Xuereb[2], and Robert Zeier[3] — [1]Institue for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Jülich, Germany — [2]Department of Physics, University of Malta, Malta — [3]Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany

Determining exactly the dynamics of a physical system is the paramount goal of any branch of physics. Quantum dynamics are characterized by the non-commutativity of operators, which implies that the dynamics usually cannot be tackled analytically and require ad-hoc solutions or numerical approaches. A priori knowledge on the ability to obtain exact results would be of great advantage for many tasks of modern interest, such as quantum computing, quantum simulation and quantum annealing.

In this work we lay the foundations for an approach to determine the dimensionality of a Hamiltonian Lie algebra by appropriately characterizing its generating terms. This requires us to develop a new tool to construct sequences of operators that determine the final dimension of the algebra itself. Our work is exact and fully general, therefore providing statements on the ultimate ability to exactly control the dynamics or simulate specific classes of physical systems. This work has important implications not only for theoretical physics, but it also aids our understanding of the structure of the Hilbert space, as well as Lie algebras.

QI 1.4 Mon 10:30 HFT-FT 101

State reachability in isolated systems with 2-body Hamiltonians — •Konrad Szymanski — Universität Siegen, Siegen, Germany

In the most basic physical systems, the dynamics is governed by time-independent 2-body interactions. A natural question arises: is the entire set of states explored if an arbitrary classical initial state and interaction pattern can be chosen? Different definitions are possible: for qubits, the pure product states are evolved with Hamiltonians composed by combinations of length-2 and 1 Pauli strings.

Only trivial conserved quantities exist in the general case, which limits the available approaches to investigate this reachability problem. Nevertheless, we show that unreachable states exist for a sufficiently complex model system. However, the problem for the most general models remains unsolved, and we present related open questions.

QI 1.5 Mon 10:45 HFT-FT 101

New Partial Trace Inequalities and Distillability of Werner States — •Pablo Costa Rico — TUM, Müchen, Deutschland

We present a new characterization for the n-distillability of Werner states and classify some of them according to their 2-distillability. This result brings out new inequalities with respect to partial traces with bound on the dimension of the system and also the rank of the matrix. For an n-partite system we prove that there are $2^n - 1$ partial trace inequalities using the dimension of the systems, and for the bounds with respect to the rank, for the case $n = 2$ we prove

$$\|tr_1 C\|_2^2 + \|tr_2 C\|_2^2 \leq r\|C\|_2^2 + \frac{1}{r}|trC|^2$$

for matrices, which can be written as a rank 1 plus a normal matrix, and

$$\big|\|tr_1 C\|_2^2 - \|tr_2 C\|_2^2\big| \leq r\|C\|_2^2 - \frac{1}{r}|trC|^2$$

for any matrix. Here we also present the proofs for many other inequalities in bipartite systems, and for tripartite systems we also obtain some results for positive matrices. Finally, we show numerical results indicating that this results could also be generalized to more families of inequalities depending on more parameters, such as the norm or exponents.

15 min. break

QI 1.6 Mon 11:15 HFT-FT 101

Contextuality, Coherences, and Quantum Cheshire Cats — •Jonte Hance[1,2], Ming Ji[1], and Holger Hofmann[1] — [1]Department of Quantum Matter, Graduate School of Advanced Science and Engineering, Hiroshima University, Kagamiyama 1-3-1, Higashi Hiroshima 739-8530, Japan — [2]Quantum Engineering Technology Laboratories, Department of Electrical and Electronic Engineering, University of Bristol, Woodland Road, Bristol, BS8 1US, UK

We analyse the quantum Cheshire cat using contextuality theory, to see if this can tell us anything about how best to interpret this paradox. We show that this scenario can be analysed using the relation between three different measurements, which seem to result in a logical contradiction. We discuss how this contextual behaviour links to weak values, and coherences between prohibited states. Rather than showing a property of the particle is disembodied, the quantum Cheshire cat instead demonstrates the effects of these coherences, which are typically found in pre- and postselected systems. See https://iopscience.iop.org/article/10.1088/1367-2630/ad0bd4 for more details.

QI 1.7 Mon 11:30 HFT-FT 101

Quantum incompatibility of multipartite measurements — •Lucas Tendick — Inria Paris-Saclay, Bâtiment Alan Turing, FRA 91120 Palaiseau

The incompatibility of quantum measurements, i.e., the effect that certain observable quantities cannot be measured simultaneously has traditionally and extensively been studied for measurements on a single system. Here, we introduce the notion of incompatibility for distributed measurements acting on multiple systems. We define and study the basic notions of incompatibility in this setting and show how to characterize and witness different locality constraints. Furthermore, we draw connections between the incompatibility of distributed measurements and multipartite quantum correlations. Finally, we discuss more generally the resources for potential applications that are provided by these type of incompatible measurements.

QI 1.8 Mon 11:45 HFT-FT 101

On the Product of Weak Values — •Vinay Tumuluru[1,2,3], Jan Dziewior[1,2,3], Carlotta Versmold[1,2,3], Florian Huber[1,2,3], Lev Vaidman[4], and Harald Weinfurter[1,2,3,5] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80797 München — [2]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Munich Center for Quantum Science and Technology (MCQST),

80797 München — [4]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Israel — [5]Univ. Gdansk, Inst. of Physics, Sobieskiego 18, PL-80-216 Gdansk-Wrzeszcz, Poland

The weak value of an operator, as put forth by Aharonov, Albert, and Vaidman, is a property of a pre- and post-selected quantum system and, in general, a complex entity. It is observed by weakly coupling a system of interest to a pointer system and manifests as a change in the state of the pointer. Contrary to the eigenvalue of an operator, the weak value can exceed its eigenspectrum resulting in 'weak value amplification' [1,2]. By pre- and post-selecting on the path *and* polarisation degrees of freedom of an optical Mach-Zehnder interferometer, the weak values of the path-projection and polarisation operators as well as that of their product are observed, with the transverse mode of the beam being the pointer. This effect is state sensitive, as introducing correlations between path and polarisation in the pre- or post-selected states prevents the observation of the product of the weak values [3,4].

[1] Y. Aharonov et al, PRL. **60**, 1351 (1988) [2] L. Vaidman et al, Phys. Rev. A **96**, 032114 (2017) [3] X. Xu et al, Opt. Lett **45**, 1715 (2020) [4] X. Xu et al, PRL. **122**, 100405 (2019)

QI 1.9 Mon 12:00 HFT-FT 101

Attempting to Simplify the Search for SIC-POVMs — •Ghislaine Coulter-de Wit[1,2], David Llamas[1], Matt Weiss[1], and Christopher Fuchs[1] — [1]University of Massachusettes Boston, Boston, USA — [2]Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Deutschland

Symmetric informationally complete quantum measurements or SIC-POVMs are interesting from a number of perspectives. For example in QBism, SIC-POVMs give a way of representing the Born Rule such that the form minimizes the distinction between it and the classical law of total probability [DeBrota, Fuchs, and Stacey, Phys. Rev. Res. 2, 013074 (2020)]. However, it is unclear whether they exist in all dimensions. In the search for SIC-POVMs, we are most interested in the group covariant case, where the problem boils down to finding a single fiducial vector for generating the whole structure. For finite dimensions d, this amounts to finding a solution to d^2 simultaneous fourth-order polynomial equations generated by the discrete Weyl-Heisenberg group. However, it has been conjectured that it is already enough to satisfy only $3d/2$ of the defining equations to find a solution [Appleby, Dang, and Fuchs, Entropy 16, 1484 (2014)]. Using techniques of gradient descent we find strong correlations in the solutions between the conjecture and full d^2 equations. These numerical results imply that the conjecture is true, dropping the complexity of numerically searching for SICs from a quadratic to a linear number of equations in d.

QI 1.10 Mon 12:15 HFT-FT 101

Classical phase-space model for gravity-mediated entanglement — Marta Marchese, •Martin Plávala, Matthias Kleinmann, and Stefan Nimmrichter — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Strasse 3, 57068 Siegen, Germany

Whether gravity is fundamentally quantum or not is still a debated question. On one side, there are several well-established quantum-gravity theories, on the other, there are semi-classical descriptions that treat the gravity field as a classical measurement-feedback channel. The lack of experimental evidence leaves the problem still unresolved, but experiments with massive interference particles have been proposed: witnessing entanglement generated by the gravitational interaction between two masses in a matter-wave interferometer is claimed to probe the quantum nature of the gravitational field. Here, we argue that such a scheme is not sufficient to rule out all possible classical descriptions of gravity. Indeed, one can achieve the same entanglement built up through a classical evolution of the Wigner function of the two gravitationally interacting masses, making use of a second-order approximation of the Newtonian potential. This suggests that alternative experimental schemes be developed to test the quantum nature of gravity.

QI 1.11 Mon 12:30 HFT-FT 101

Measurement in the complex SYK thermofield double and its holographic dual — Stefan Forste[1], Saurabh Natu[1], Yannic Kruse[1], and •Raphael Brinster[1,2] — [1]Bethe Center for Theoretical Physics and Physikalisches Institut der Universität Bonn,Germany — [2]Faculty of Mathematics and Natural Sciences, Heinrich Heine University Düsseldorf, Germany

In this talk, I will briefly introduce the concepts of holography and the AdS/CFT correspondence. Then, I will explain how to calculate the entropy of the thermofield double State (TFD) in the complex SYK model (two non-interacting copies of systems describing N Dirac fermions with an all-to-all coupling) after a $U(1)$-charge measurement was applied and relate it to the von-Neumann entropy of some spacetime region in a black hole background. By introducing a specific decoding operator, a quantum teleportation protocol can be realised, sending information from one side of the TFD to the other. By the correspondence, this is related to a traversable wormhole. In contrast to similar work that has been done in the Majorana SYK model, the results are measurement-dependent, i.e. they depend on the total charge of the system.

QI 1.12 Mon 12:45 HFT-FT 101

Critical models and discrete holography — •Dimitris Saraidaris and Alexander Jahn — Freie Universität Berlin, Germany

Tensor networks on hyperbolic lattices have been recently studied as prominent models of discrete holography. In particular, by filling the bulk of a hyperbolic lattice with matchgate tensors, following the inflation rules imposed by its geometry, the disordered states appearing on the boundary are related to critical models. We use the Multi-scale Quasicrystal Ansatz to translate these boundary states into coupling constants for the disordered XY and XXZ Heisenberg model with periodic boundary conditions. Firstly, we observe that there is a range of disorder strengths, that show entanglement entropy scaling similar to the uniform critical model. Generalizing to the non-Gaussian model, we observe that the criticality of the disordered boundary states does not depend on the choice of the tensors in the bulk, but on the geometry of the tiling. Finally, we study the same models with open boundary conditions. Here, we can find disordered models whose entanglement entropy exceeds the excepted value for the uniform critical model, with a correction term that grows linearly with subsystem size.