Book of abstracts of the “Quantum TUT” workshop on quantum statistics and information theory

Organized by the Quantum Information group of the Department of Computer Science and Engineering, Toyohashi University of Technology (TUT), Aichi-ken, Japan.

To be held on Thursday, February 22, 2024, from 10:00 to 17:30, in the TUT satellite office on the 5-th floor of the em-Campus building, near Toyohashi station.

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1. Classification and coarse graining of Quantum Cellular Automata

Alessandro Bisio, Pavia University, Italy

A quantum cellular automata (QCA) is a lattice of quantum systems, such as qudits, fermionic or bosonic modes, along with an update rule that determines the state of each cell at time T+1 depending on the state of a finite neighbourhood of cells at time T. In this talk we will present some recent results on the classification of QCAs, in particular the classification of qubit QCAs with von Neumann neighbouring scheme and an index theory for two dimensional translation invariant QCAs. Finally, we will introduce a coarse graining procedure for QCAs and we will present a characterisation of the one dimensional qubit QCAs that can be coarse grained to another QCA.

2. Barycentric Rényi divergences

Milan Mosonyi, Budapest University of Technology, Hungary

Rényi divergences are a one-parameter family of statistically motivated pseudo-distances of probability measures that play a central role in information theory. Various quantum extensions of these quantities have been studied extensively in the past ten years, and an interest in multi-variate extensions have emerged very recently. In this talk we outline various possible approaches to defining such extensions and their connection to multi-variate weighted matrix geometric means. Talk based on arXiv:2207.14282, joint work with Gergely Bunth and Péter Vrana.

3. Bayesian Nagaoka-Hayashi Bound for Multiparameter Quantum-State Estimation Problem

Jun Suzuki, University of Electro-Communications, Japan

In this work we propose a Bayesian version of the Nagaoka-Hayashi bound when estimating a parametric family of quantum states. This lower bound is a generalization of a recently proposed bound for point estimation to Bayesian estimation. We then show that the proposed lower bound can be efficiently computed as a semidefinite programming problem. As a lower bound, we also derive a Bayesian version of the Holevo-type bound from the Bayesian Nagaoka-Hayashi bound. Lastly, we prove that the new lower bound is tighter than the Bayesian quantum logarithmic derivative bounds.

4. Verifiable measurement-based quantum computation on hypergraph states

Yuki Takeuchi, NTT, Japan

Measurement-based quantum computation (MBQC) is a universal quantum computing model that proceeds computation by adaptively measuring qubits in a resource entangled state (e.g., graph state) one by one. Recently, hypergraph states, which are generalizations of graph states, attract much attention as they require only Pauli single-qubit measurements to achieve the universality. In this talk, I would like to introduce our recent contribution to MBQC on hypergraph states:

- We have shown that Pauli-Y basis measurements are not necessary to achieve the computational universality.
- Although only computationally universal hypergraph states were known, we have constructed strictly universal ones.
- Hypergraph states are not stabilizer states, but we can show that the fidelity can be efficiently estimated with only non-adaptive Pauli-X and Z basis measurements.

5. Optimal convex approximation of quantum superposition

Seiseki Akibue, NTT, Japan

A quantum superposition of distinct pure states cannot be described by their probabilistic mixture. However, the probabilistic mixture is still useful for approximating the superposed state. This leads to the idea of probabilistic synthesis of a quantum state by using a quantum circuit consisting of a finite gate set. This idea has also been leveraged to probabilistically synthesize a unitary transformation, resulting in better approximation or shorter synthesized circuits. In this talk, we present theoretical bounds for the optimal probabilistic approximation of quantum states or unitary transformations. We also introduce an efficient probabilistic synthesis algorithm to achieve the theoretical bounds, supported by some numerical demonstrations. Furthermore, we demonstrate that our technique is general enough to analyze resource measures.

6. Coarse-grained entropies in physics and information theory

Joseph Schindler, Universitat Autònoma de Barcelona, Spain

The law of entropy increase in statistical thermodynamics is intimately tied with the concept of coarse-graining. In this talk I'll give a brief tutorial about the role of coarse-grained entropies in physics, and how they illuminate the subtle connections between thermodynamic, statistical, and informational entropies. We will introduce "observational" entropy as a framework where any measurement can define a coarse-graining, and briefly survey physical applications and information theoretic properties.

7. Incompatible incompatibilities, and how to make them compatible again

Francesco Buscemi, Nagoya University, Japan

While there is a generally accepted definition of incompatibility for POVMs, two possible extensions for instruments are found in the literature, sometimes called "classical incompatibility" and "parallel incompatibility", which are logically inequivalent and have been the source of debate and confusion. Here we resolve this tension by introducing a new, operationally motivated notion, "q-incompatibility", which again reduces to the correct definition for POVMs, but is able to accommodate both classical and parallel incompatibilities in a unified resource-theoretic framework. Finally, we consider another notion of instrument incompatibility, which we call "exclusivity", where the order of the measurements is the crucial ingredient. This is joint work with Kodai Kobayashi, Shintaro Minagawa, Paolo Perinotti, and Alessandro Tosini.

8. Derivation of Standard Quantum Theory via State Discrimination

Hayato Arai, RIKEN, Japan

It is a key issue to characterize the model of standard quantum theory out of general models by an operational condition. The framework of General Probabilistic Theories (GPTs) is a new information theoretical approach to single out standard quantum theory. It is known that traditional properties, for example Bell-CHSH inequality, are not sufficient to single out standard quantum theory among possible models in GPTs. As a more precise property, we focus on the bound of the performance for an information task called state discrimination in general models. We give an equivalent condition for outperforming the minimum discrimination error probability under the standard quantum theory given by the trace norm. Besides, by applying the equivalent condition, we characterize standard quantum theory out of general models in GPTs by the bound of the performance for state discrimination. This talk will start with a brief introduction to the framework of GPTs.

9. Decoding quantum information and complementarity principle

Yoshifumi Nakata, Kyoto University, Japan

Decoding quantum information is an important task in quantum error correction (QEC), quantum communication, and even in fundamental physics. A standard approach in QEC is to classically correct the Pauli-Z and -X errors and combine them, as is the case in default decoders of CSS codes. In this talk, we show that this approach works for any QEC codes. That is, given two POVMs that are able to decode classical information in the Z- and X-basis, respectively, one can always explicitly construct a decoding quantum channel. We further extend this construction to an arbitrary pair of bases and show that decoding performance of the constructed decoding channel depends on how mutually unbiased the two bases are. This reveals a connection between QEC and complementarity.

10. Categorical Quantum Supermaps

Matthew Wilson, University of Oxford, UK

Building on the representation of processes in quantum theory in terms of boxes and wires (quantum circuits), the supermap framework [1] (also known as the process-matrix framework) studies the space of possible environments which could surround quantum processes in terms of boxes and wires *with holes*. The definition of such supermaps in finite dimensional quantum theory has led to a variety of new developments in quantum information theory and quantum foundations, by modelling protocols which treat channels as resources, and by incorporating indefinite causal structures. Whilst the concept of a circuit-theory is well-understood in terms of the abstract mathematics of process theories and category theory, the same cannot be said for the concept of a supermap, and there are domains in which a stable definition for supermaps remains elusive. The idea of developing a categorical approach to quantum supermaps, is to try to develop fully abstract categorical models for boxes with holes, and to apply those models to new domains. In this talk I'll focus mainly on [2] in which a simple diagrammatic definition for boxes with holes was put forward and [3] in which this work was used to construct working tensor products for the study of indefinite causal orders, axiomatic combs, and concrete networks over arbitrary circuit theories.

[1] Quantum computations without definite causal structure, G. Chiribella, G. M. D'Ariano, P. Perinotti, B. Valiron

[2] Quantum Supermaps are Characterized by Locality, M. Wilson, G. Chiribella, A. Kissinger

[3] A Profunctorial Semantics for Quantum Supermaps, J. Hefford, M. Wilson

11. Computations of reduced processes are always operational

Timothy Forrer, Tokyo University, Japan

A key feature of physical theories is a procedure for calculating from a global process on a system, a reduced process on a specified subsystem. Such a technique allows one to describe effective dynamics of local systems without reference to the global dynamics of the entire universe It is known that in both quantum and classical information theory, the reduced process can be computed by the insertion of a state before and an effect after the global process, on the systems one is ignorant of. This computation, therefore, is operational in nature. But is this just a quirk of these theories - or would this be true of any physical theory that has reduced processes? In this talk, I'll argue that any "reasonable" computation for a reduced process must be operational in nature, by using an abstract representation of such a calculation which we call a computational environment structure. I'll then discuss how causality fits into these structures, and how it places this work in the wider body of literature on causality in physical theories.

12. Quantum measurements constrained by the third law of thermodynamics

M. Hamed Mohammady, Université Libre de Bruxelles, Belgium

While quantum theory dictates that the act of measurement must perturb at least some property of the measured system, it does allow for measurements that are minimally invasive. Indeed, the existence of such measurements plays a crucial role in several foundational questions pertaining to quantum reality. For example, the Einstein-Podolsky-Rosen criterion of physical reality implicitly assumes the existence of "ideal" measurements which do not perturb the state of the measured system whenever the measurement outcome can be predicted with certainty. On the other hand, "repeatable" measurements, for which the same outcome is guaranteed to obtain under repeated measurements, are necessary if a property can be said to exist in the system after measurement, even if it does not exist prior to it.

Given that the measurement process must ultimately result from a physical interaction between the measured system and a given measuring apparatus, however, the existence of such minimally invasive measurements may be in conflict with fundamental laws of nature. For example, the Wigner-Araki-Yanase theorem states that when the measurement interaction obeys a conservation law, then only observables that commute with the conserved quantity admit a repeatable measurement. In this work, we address the compatibility of several classes of minimally invasive measurements with another fundamental law of nature: the third law of thermodynamics, which states that no system can be cooled to absolute zero temperature. It is shown that while the third law prohibits ideal and repeatable measurements for all observables, the weaker notions of "approximately" ideal and "first-kind" measurements may be achieved, but only if the measured observable does not admit definite values. Our findings warrant a re-evaluation for the assignment of reality to quantum systems, and in particular lend support to the "Unsharp Reality" project of Busch and Jaeger.