1st IMSc School on Quantum Information
19-31 January 2014

http://www.imsc.res.in/∼qischool14/

Lecturers

- **Fernando Brandão (UCL, London)**
- **Eric Chitambar (SIU, Carbondale)**
- **Pranab Sen (TIFR, Mumbai)**
- **Graeme Smith (IBM, Yorktown Heights)**
- **Andreas Winter (UAB, Barcelona) — coordinator**

General description

The first installment of what will be an annual school, or workshop, on recent topics in quantum information theory, will offer five lecturers talking about some of their most recent contributions. The workshops are aimed at an audience already having sufficient background knowledge of quantum information science broadly, but keen to delve deep into some more specialized, more recent, or simply more technical topics.

This year the focus is on quantum Shannon theory, its impact on quantum many-body physics and locality constraints on quantum operations.

The format is to have lectures in the morning (normally two, each of 90 minutes duration) and tutorials in the afternoon, which offer the participants the opportunity to go through the lecture material once more, to solve exercises and problems, or even to discuss open research questions suggested by the lectures.

Topics, by lecturer (incl. number of lectures and week)

Graeme Smith (5, week 1) – Bosonic Quantum Communication.
The lectures will cover the theory of bosonic quantum communication and information from basic concepts to current research [1–3]. *Basics:* quantum harmonic oscillator, P and Q quadratures and Wigner Functions. Homodyne and heterodyne measurements. Gaussian states and channels and their entropic characteristics. *Advanced topics:* PPT and distillability of NPT gaussian states; Entropy Power Inequalities and applications; Minimum output entropy and classical capacity; Continuous variable quantum key distribution; Open questions and more.

Fernando Brandão (4, week 1) – Information Theory and Area Laws.
The lectures will introduce the idea of area laws for entanglement and show its usefulness for describing quantum many-body states appearing in physical systems of interest. Then, the problem of proving area laws will be connected to concepts in quantum information theory such as data hiding, max-entropies, and chain rules for mutual information. The main goal of the lectures is to present in detail a recent proof of an area law for 1D states with exponential decay of correlations

using tools from single-shot quantum information theory, obtained by the speaker and Michał Horodecki [4].

Eric Chitambar (4, week 2) – Quantum Operations under Locality Constraints.
Lecture 1: LOCC and its Cousins. In the first lecture we motivate the subject by quickly reviewing the fundamental task of teleportation. We then introduce the class of LOCC instruments and the more general classes of separable and PPT instruments following the formalism of Ref. [5].
Lectures 2 & 3: State Discrimination. We consider the problem of LOCC quantum state discrimination. A full solution to 2-qubit ensembles will be presented along the lines of Ref. [6]. We then turn to the phenomenon of "nonlocality without entanglement" and consider the so-called "domino states" originally constructed in Ref. [7]. We give a new proof on the impossibility of distinguishing these states by asymptotic LOCC, as recently presented in Ref. [8].
Lecture 4: Entanglement Monotones and Entanglement Transformations. The theory of entanglement monotones and its application to LOCC entanglement transformations will be introduced. We focus attention on the structure of bipartite monotones and discuss the fundamental tasks of entanglement dilution and distillation [9].

Andreas Winter (4, weeks 1 and 2) – Strong Converses to Quantum Coding Theorems.
The plan is to explore a recently active topic in quantum Shannon theory, so-called *strong converses*. Indeed, while *coding theorems* contain the description of good codes to achieve a certain rate, the converse is to show that no coding scheme whatsoever can go above that rate. A strong converse states that any attempt of communicating at rates above the capacity necessarily has asymptotically maximum error. Such a statement cannot hold for too wide a class of channels, hence we will focus on the discrete memoryless model here. We will go through different known approaches to prove such strong converses, all of which require techniques beyond the usual entropy and typicality framework: channel simulation (Quantum Reverse Shannon Theorem [10], entanglement cost of channels [11]); one-shot analysis via min-entropies [12, 13]; hypothesis testing approach via quantum Rényi divergences [14]. Each approach only works for some particular capacity, or even only for some subclass of channels; many questions regarding strong converses remain open, including whether they even hold universally for quantum capacities.

Pranab Sen (3, week 2) – Quantum Channel Coding and Decoding.
Once the entropy basics are set up, the plan is to start off with an inner bound for the single-user classical-quantum channel, proved using geometric arguments (non commutative union bound, approximate intersection of subspaces) developed in [15]. Next, assuming a recent result in quantum hypothesis testing also proved using geometric arguments, we will show how one can lift many inner bound proofs in network Shannon theory from the classical to the quantum setting, using Marton's inner bound for broadcast channel as a working example.

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[2] G. Smith, J.A. Smolin, "An exactly solvable model for quantum communications", *Nature* **504**(7479):263-267, 2013.

[3] V. Giovannetti, R. García-Patrón, N.J. Cerf, A.S. Holevo, "Ultimate communication capacity of quantum optical channels by solving the Gaussian minimum-entropy conjecture", `arXiv[quant-ph]:1312.6225`.

[4] F.G.L.S. Brandão, M. Horodecki, "Exponential Decay of Correlations Implies Area Law", `arXiv[quant-ph]:1206.2947`.

[5] E. Chitambar, D. Leung, L. Mančinska, M. Ozols, A. Winter, "Everything You Always Wanted to Know About LOCC (But Were Afraid to Ask)", arXiv[quant-ph]:1210.4583.

[6] E. Chitambar, R. Duan, M.-H. Hsieh, "When do Local Operations and Classical Communication Suffice for Two-Qubit State Discrimination?", arXiv[quant-ph]:1308.1737.

[7] C. Bennett, D. DiVincenzo, C. Fuchs, T. Mor, E. Rains, P. Shor, J. Smolin, W. Wootters, "Quantum Nonlocality without Entanglement", *Phys. Rev. A* **59** 1070–1091, 1999.

[8] E. Chitambar, M.H. Hsieh, "Asymptotic State Discrimination and a Strict Hierarchy in Distinguishability Norms", arXiv[quant-ph]:1311.1536.

[9] C. Bennett, H. Bernstein, S. Popescu, B. Schumacher, "Concentrating Partial Entanglement by Local Operations", *Phys. Rev. A* **53** 2046–2052, 1996.

[10] C.H. Bennett, I. Devetak, A.W. Harrow, P.W. Shor, A. Winter, "Quantum Reverse Shannon Theorem", `arXiv[quant-ph]:0912.5537`.

[11] M. Berta, F. Brandão, M. Christandl, S. Wehner, "Entanglement Cost of Quantum Cannels", `arXiv[quant-ph]:1108.5357`.

[12] M. Tomamichel, *A Framework for Non-Asymptotic Quantum Information Theory*, PhD thesis, ETH Zürich, 2012. `arXiv[quant-ph]:1203.2142`.

[13] C. Morgan, A. Winter, "'Pretty strong' converse for the quantum capacity of degradable channels", `arXiv[quant-ph]:1301.4927`.

[14] M.M. Wilde, A. Winter, D. Yang, "Strong converse for the classical capacity of entanglement-breaking and Hadamard channels", `arXiv[quant-ph]:1306.1586`.

[15] P. Sen, "Achieving the Han-Kobayashi inner bound for the quantum interference channel by sequential decoding", `arXiv[quant-ph]:1109.0802`.