Operator structures in quantum information theory 12w5084
February 26 to March 2, 2012

MEALS

*Breakfast (Buffet): 7:00–9:30 am, Sally Borden Building, Monday–Friday
*Lunch (Buffet): 11:30 am–1:30 pm, Sally Borden Building, Monday–Friday
*Dinner (Buffet): 5:30–7:30 pm, Sally Borden Building, Sunday–Thursday
Coffee Breaks: As per daily schedule, in the foyer of the TransCanada Pipeline Pavilion (TCPL)
***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in the new lecture theater in the TransCanada Pipelines Pavilion (TCPL). LCD projector and blackboards are available for presentations.

SCHEDULE

Sunday

16:00	Check-in begins (Front Desk - Professional Development Centre - open 24 hours)
17:30–19:30	Buffet Dinner, Sally Borden Building
20:00	Informal gathering in 2nd floor lounge, Corbett Hall (if desired)
	Beverages and a small assortment of snacks are available on a cash honor system.

Monday

7:00–8:45	Breakfast
8:45–9:00	Introduction and Welcome by BIRS Station Manager, TCPL
chair	Ed Effros (irreplaceable, but Ruskai will fill in)
9:00–10:00	Paulsen, Vern
10:00–10:35	break
10:35–11:20	Jencova, Anna
11:25–12:10	Winter, Andreas
12:15 –13:00	Lunch
13:00–14:00	Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall
chair	Frank Verstraete
14:00–14:45	Collins, Benoit
14:50–15:00	poster introductions
15:00–15:45	break
15:45–16:40	Scholz, Volker
16:45–17:30	Eisert, Jens
17:30–19:30	Dinner

Tuesday

7:00–9:00	Breakfast
chair	Doug Farenick
9:00-10:00	Haagerup/Musat
10:00–10:40	break
10:40–11:25	Smith, Graeme
	vote on time of NPT session
11:30–12:15	Junge, Marius
12:15– 13:45	lunch
13:45	Group Photo; meet TBA

Tuesday	(cont.)
13:45	Group Photo; meet TBA
chair	Staszek Szarek
14:00–14:45	Gross, David (or Tobias Fritz)
14:50-15:30	break
15:30–16:15	Christandl, Matthias
16:20–17:20	NPT with Horodecki, Watrous OR *free time to prepare Wed. outing*
17:30–19:30	Dinner
19:30–20:30	NPT with Horodecki, Watrous (*if not in late afternoon*)

Wednesday	
7:00–8:40	Breakfast
chair	Toby Cubitt
8:40–9:25	Szkola, Arleta
9:30–10:30	Hastings, Matt
10: 30–	free to ski, snowboard, X-C tour, ice climb or relax
17:30–19:30	Dinner

Thursday	
7:00–9:00	Breakfast
chair	Ivan Todorov
9:00-10:00	Perez-Garcia, David
10:00–10:40	break
10:40–11:25	Palazuelos, Carlos
11:30–12:10	Briet, Jop
12:15–14:00	lunch
chair	
14:00–14:50	Fritz, Tobias
14:50-15:30	break
15:30–16:15	open problems discussion
16:20–17:20	short talks and/or discussion in Banff hot springs
17:30–19:30	Dinner

Friday	
7:00–9:00	Breakfast
chair	Milan Mosonyi
9:00-9:45	Harrow, Aram
10:50–10:10	short talk
10:15–11:00	Hayden, Patrick
OR	*alternate Fri. schedule*
9:15–10:00	Harrow, Aram
10:05–10:50	Hayden, Patrick
11:30–13:30	Lunch

Checkout by 12 noon.

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ABSTRACTS
(in alphabetic order by speaker surname)

Speaker: **Jop Briët** (CWI, Amsterdam)
Title: *Unbounded violations of three-player XOR games without operator spaces* Abstract: XOR games are the simplest model in which the nonlocal properties of entanglement manifest themselves. When there are two players, it is well known that the bias — the maximum advantage over random play — of entangled players can be at most a constant times greater than that of classical players. Recently, Pérez-García et al. (2008) showed that no such bound holds when there are three or more players. Their proof relies on non-trivial results from operator-space theory, and gives a non-explicit existence proof, leading to a game with a very large number of questions and only a loose control over the local dimension of the players' shared entanglement. In this talk, I will explain an improved, simple and explicit (though still probabilistic) construction of a family of three-player XOR games which achieve a large violation.

Based on joint work with Thomas Vidick.

Speaker: **Matthias Christandl** (ETH Zurich)
Title: *Faithful Squashed Entanglement*
Abstract: Squashed entanglement is a measure for the entanglement of bipartite quantum states. In this paper we present a lower bound for squashed entanglement in terms of a distance to the set of separable states. This implies that squashed entanglement is faithful, that is, it is strictly positive if and only if the state is entangled. We derive the lower bound on squashed entanglement from a lower bound on the quantum conditional mutual information which is used to define squashed entanglement. The quantum conditional mutual information corresponds to the amount by which strong subadditivity of von Neumann entropy fails to be saturated. Our result therefore sheds light on the structure of states that almost satisfy strong subadditivity with equality. The proof is based on two recent results from quantum information theory: the operational interpretation of the quantum mutual information as the optimal rate for state redistribution and the interpretation of the regularised relative entropy of entanglement as an error exponent in hypothesis testing. The result has two applications in complexity theory. The first application is a quasipolynomial-time algorithm solving the weak membership problem for the set of separable states in LOCC or Euclidean norm. The second application concerns quantum Merlin- Arthur games. Here we show that multiple provers are not more powerful than a single prover when the verifier is restricted to LOCC operations thereby providing a new characterisation of the complexity class QMA.

Based on joint work joint work with Fernando Brandao and Jon Yard

Speaker: **Benoit Collins** (University of Ottawa)
Title: *Random quantum channels*
Abstract: We review recent results related to the study of the behavior of typical quantum channels, and techniques to study them, including free probability and Weingarten calculus. We are interested in quantities related to additivity problems and we shall discuss two different models of randomness: channels defined via Haar isometries and random unitary channels with i.i.d. Haar unitary operators.

Based on joint work joint work with Ion Nechita.

Speaker: **Jens Eisert** (Freie Universitt Berlin)
Title: *Timing dissipative quantum processes*
Abstract: Quantum noise is usually seen as being detrimental for quantum information processing. Recently, yet, it has been realized that noise can also be beneficial: Quantum noise can lead to instances of protected quantum information processing, similarly to dissipative quantum phase transitions being conceivable. Formally, if a local Liouvillian generating a dynamical semi-group has a spectral gap and a unique fixed point, the system will be driven to this fixed point in a protected fashion. This robustness, however, comes along with new obstacles, as now the precise timing of processes, measurement, and conditional dynamics are no longer available.

In this talk, we will have a look at ways to overcome this obstacle. We will start from classical Markov chain mixing tools and discuss the so-called cut-off phenomenon - describing card-shuffling, for example. Based on such ideas of classical Markov chains, we will construct timer gadgets - local dissipative systems the state of which can be tuned to switch arbitrarily suddenly - and preparation gadgets - dissipative systems that have the power to prepare states and then stop preparing. In this way, one arrives at a toolbox for fully timed, protected purely dissipative quantum information processing, including even notions of quantum error correction.

In the outlook, if time allows, I will sketch recent activities on the additivity of quantum channels [2], and we will have a look at in what way there is room for fresh hope to tackle the notorious NPT bound entanglement problem, by investigating undecidable problems [3].

[1] Timing dissipative quantum processes, M. Kastoryano and J. Eisert, in preparation (2012).

[2] Entangled inputs cannot make imperfect quantum channels perfect, F.G.S.L. Brandao, J. Eisert, M. Horodecki, D. Yang, Phys. Rev. Lett. 106, 230502 (2011).

[3] Quantum measurement occurrence is undecidable, J. Eisert, M. P. Mueller, C. Gogolin, arXiv:1111.3965 (2011).

Speaker: **Tobias Fritz** (ICFO Barcelona)
Title: *Quantum Correlations and Group C^*-Algebras*
Abstract: Determining the maximal quantum violation of a Bell inequality is a difficult problem in general. I will explain how to identify such a quantum value with the norm of an element in a group C^*–algebra. In this formulation, the hierarchy of semidefinite programs characterizing quantum correlations as well as the connection between Tsirelson's problem and the QWEP conjecture become very natural and intuitive. It also facilitates the application of some results from group theory.

Speaker: **David Gross** (University of Freiburg)
Title: *A coarse view on dynamics of one-dimensional quantum lattice systems*
Abstract: I will present an analysis of the time evolutions that can be realized in one-dimensional quantum systems with discrete space and discrete time. We assume causality, in the sense that in any time step, information can propagate only a finite distance. In this setting, we find that there is a single, simple invariant - an index - which completely solves the following three problems:

1. Classify all time evolutions up to continuous deformations

2. Classify those dynamics which can be realized by quantum gates

3. Classify the pairs of time evolutions U_1, U_2 which can be "pieced together"in the sense that there exists a single large system U which behaves like U_1 in some parts an like U_2 in other parts.

The index takes values in an abelian group (integers or positive rationals - depending on the lattice system), with the map sending reversible time evolutions to their index being a group homomorphism.

Reference: "Index Theory of One Dimensional Quantum Walks and Cellular Automata" D. Gross, V. Nesme, H. Vogts and R. F. Werner *Commun. Math Phys.* on-line (2012) (arXiv:0910.3675)

Speaker: **Haagerup/Musat** (University of Copenhagen)
Title: *Factorizable quantum channels: extreme points, asymptotic properties and the Connes embedding*
Abstract: The class of factorizable quantum channels (originating in work of C. Anantharaman- Delaroche in operator algebras) has gained particular signicance in quantum information theory in con- nection with the settling (in the negative) of the asymptotic quantum Birkhoff conjecture (AQBP). More precisely, we proved earlier that every non-factorizable unital quantum channel (in dimension $n \geq 3$), provides a counterexample for the conjecture. Recently, we have put into evidence another asymptotic behavior of factorizable maps and established that this property holds for all factorizable unital quantum channels in dimension n , for all $n \geq 3$, if and only if the Connes embedding problem has a positive answer. Moreover, we show that the Werner-Holevo channel is factorizable in all dimensions n, except for $n = 3$.

Furthermore, in recent joint work with Mary Beth Ruskai, we construct (based on extreme point methods) large classes of non-factorizable unital quantum channels in all dimensions. Also, we exhibit examples of factorizable channels in dimension n = 3 which are extreme points in the set of unital quantum channels, but not extreme points in the set of all quantum channels in dimension $n = 3$.

Speaker: **Aram Harrow** ()
Title: *Tensor norms, separable states and semi-definite relaxations*
Abstract: Many optimization problems over polynomials are NP-hard to solve exactly, but can be approximated using methods such as the semi-definite programming (SDP) hierarchies of Lasserre, Parrilo, and others. How effective are these methods? And how hard is it to approximately perform these optimizations? Somewhat surprisingly, tools from quantum information can help answer both of these questions. I'll explain how quantum techniques yield hardness results, as well as ways to prove the effectiveness of SDP hierarchies.

Based on joint work with Ashley Montanaro (1001.0017), and with Boaz Barak, Jon Kelner, David Steurer and Yuan Zhou (in preparation).

Speaker: **Matthew Hastings** (Duke University)
Title: *On the quantum PCP conjecture*
Abstract: The classical PCP theorem in computer science says, roughly speaking, that it is hard (in fact, NP-hard) to find approximate solutions to certain NP-complete problems such as SAT, even given a fairly weak sense of approximation. I'll review this result and discuss the quantum PCP conjecture, which conjectures that approximation of certain quantum problems is even harder (so-called QMA-hard). I'll outline a possible program for attacking the quantum PCP conjecture. This program involves showing results that forbid topological order in systems with certain interaction graphs, and it leads to some interesting conjectures in topology and C*-algebras.

Speaker: **Patrick Hayden** (McGill University)
Title: *Operators in Multiuser Information Theory: A Conjecture*
Abstract: Typical subspaces form the bridge between entropy formulas and the communications protocols of quantum information theory. In multiuser settings, unfortunately, the typical subspaces that appear naturally in any given problem often fail to usefully intersect, leading to many difficulties. In this talk, I'll present a conjecture about the approximation of operators on tensor product spaces that, if true, resolves a number of open questions in quantum information theory. Some special cases of the conjecture and its consequences, which I'll list, are known to be true. A generalization of the conjecture can equally well be phrased in terms of min-entropies, in which form it can be used to analyze the security of extractors against quantum adversaries.

Speaker: **Michal Horodecki** ()
Title: *NPT session*
Abstract: Several speakers will discuss operator algebra formulations of the NPT problem, including the concepts of LOCC (vs separable) operations, and distillation of entanglement. This will include a status report from M. Horodecki and evidence for NPT bound entangled states.

Speaker: **Anna Jencova** (Mathematical Institute, Slovak Academy of Sciences)
Title: *Generalized channels and quantum networks*
Abstract: A generalized channel is a completely positive map between finite dimensional C^*-algebras that preserves trace on a certain convex subset of density operators. Conversely, any completely positive trace preserving map defined on a positively generated subspace can be extended to a generalized channel. An important example of such maps, and in fact the motivation for their study, are the so-called quantum combs, which are used in description of quantum networks. We describe the structure of generalized channels and find their extreme points. A particular case is a generalized POVM, which is a generalized channel into a commutative C^*-algebra. We discuss the relation with measurements on convex subsets of the state space and apply the results to channel measurement.

Speaker: **Marius Junge** (University of Illinois)
Title: *Quantum capacity for quantum channels constructed from quantum groups*
Abstract: The starting point of this research is a formula for the cb-entropy of certain classes of covariant channels. These covariant channels generalize Schur multiplies and certain unitary channels simultaneously. Starting from the cb-entropy estimate and the we derive lower and upper bounds for the quantum capacity.

Based on joint work with Ruan, Neufang, and Palazuelos

Speaker: **Carlos Palazuelos** (Universidad Complutense de Madrid)
Title: *Studying Quantum Games with Operator Spaces*
Abstract: In this talk we will introduce Quantum Games. We will show that Operator Spaces are ideally suited to study these kinds of games. Specifically, we will explain that the entangled value $\omega(G)$ and the entangled value with one way communication $\omega_{qow}(G)$ of a rank-one quantum game G can be exactly described by means of certain operator spaces tensor norms. With this connection at hand, we will use some deep results on operator spaces to study two main problems in the area: computability and approximability of the values ω and ω_{qow} and their behavior with respect to the parallel repetition of the game.

Based on joint work with Tom Cooney, Marius Junge and David Pérez García.

Speaker: **Vern Paulsen** (University of Houston)
Title: *Operator Systems: Quotients, Duals, and Tensors with Applications to Connes' Embedding Problem*
Abstract: While operator spaces are determined by their matrix norm structures, operator systems are determined by their order structures. This leads to some significant differences. For example, the matrices are not self-dual as normed objects, but they are self-dual as an operator system. We will then explain quotients and how to use quotients to describe the duals of the operator systems of graphs considered by Winter, et al. We will then introduce tensor products of operator systems and show their relationship to understanding duals. Finally, we will present recent results that show that Connes embedding problem is equivalent to deciding whether or not two operator system structures on a 16 dimensional space are equal.

Speaker: **David Pérez García** (Universidad Complutense de Madrid)
Title: *Bell inequalities as games: an introduction*
Abstract: In this talk I will introduce multi prover-one round games and show how they are connected to Bell inequalities, communication and computational complexity and cryptography. I will review some key results and some of the techniques and tools used to deal with this type of games.

Speaker: **Volkher Scholz** (ETH Zurich)
Title: *The smooth entropy formalism on von Neumann algebras, extensions to operator systems and applications*
Abstract: I shall start by motivating the smooth entropy formalism in the finite-dimensional setting, and explain its usefulness in quantum information theory. After this rough overview, I discuss how to lift this formalism to the setting of von Neumann algebras and possibly operator systems. This will lead us to similar characterizing properties and information-theoretic operational interpretations as in the finite-dimensional case. If time permits, I will sketch applications to information theoretic protocols using quantum system with an infinite number of degrees of freedom.

Based on joint work with Mario Berta from ETH Zurich and Fabian Furrer from the University of Hannover.

Speaker: **Graeme Smith** (IBM)
Title: *Overview of Capacity*
Abstract: Abstract Text

Speaker: **Arleta Szkola** (Max Planck Institute for Mathematics in the Sciences, Leipzig)
Title: *Maximum likelihood type detectors for multiple quantum states"*
Abstract: We will present the construction of POVMs for detecting the true state among a finite number of hypothetic ones. We assume that the underlying complex Hilbert space is of finite dimension. Our algorithm mimics the maximum likelihood method. In particular, it recovers the classical rule in the special case of commuting states. If applied to n copies of the basic quantum system, in the limit of large n the resulting detectors feature an optimal decay of the averaged probability of rejecting the true state among a finite set of pairwise linearly independent states. The corresponding error exponent is equal to the quantum multiple Chernoff distance of the given set. The linear independence condition should be explained in the talk in detail. We also want to shortly discuss both modifications of the maximum likelihood type detector that provide universally attainable bounds on the error exponent, and the corresponding open problems.

Based on joint work with Michael Nussbaum: "An asymptotic error bound for testing multiple quantum hypotheses", to appear in Ann. Statist., see also arXiv:1112.1529

Speaker: **John Watrous** (IQC, University of Waterloo)
Title: *NPT session*
Abstract: Several speakers will discuss operator algebra formulations of the NPT problem, including the concepts of LOCC (vs separable) operations, and distillation of entanglement. This will include a sketch of the proof that there are states which are n-copy distillable, but not $(n-1)$-copy distillable.

Speaker: **Reinhard Werner** (Hanover)
Title: *Quantum memory channels*
Abstract: I will give an overview on quantum channels with memory. This will include older results (with Kretschmann) about the implementation of causal cp maps on a spin chain, and more recent ones connecting the memory required for the implementation of a causal automorphism with its index (see talk of David Gross). I will also state some open problems.

Speaker: **Andreas Winter** (University of Bristol)
Title: *Zero-error communication via quantum channels, non-commutative graphs and a quantum Lovasz number*
Abstract: We study the quantum channel version of Shannon's zero-error capacity problem. Motivated by recent progress on this question, we propose to consider a certain operator space as the quantum generalisation of the adjacency matrix, in terms of which the plain, quantum and entanglement - assisted capacity can be formulated, and for which we show some new basic properties. Most importantly, we define a quantum version of Lovasz' famous theta function, as the norm-completion (or stabilisation) of a "naive" generalisation of theta. We go on to show that this function upper bounds the number of entanglement-assisted zero-error messages, that it is given by a semidefinite programme, whose dual we write down explicitly, and that it is multiplicative with respect to the natural (strong) graph product. We explore various other properties of the new quantity, which reduces to Lovasz' original theta in the classical case, give several applications, and propose to study the operator spaces associated to channels as "non-commutative graphs", using the language of Hilbert modules.

Based on joint work with Runyao Duan and Simone Severini; arXiv:1002.2514

ABSTRACTS of Poster Presentations

Name: **Douglas Farenick** (University of Regina)
Title: *Quantum Averaging via Positive Operator Valued Measures*
Abstract: By taking the position that a positive operator valued measure (POVM) is indeed a measure, one ought to be able to develop a theory of integration for quantum random variables. Such a theory is described in this poster and includes: (i) the definition of integral (quantum averaging); (ii) Radon-Nikodym theorems for POVMs; and (iii) the structure of the space of all POVMs, defined on the Borel sets of a compact Hausdorff space and with values in a fixed finite type I factor, as a compact C^*-convex set.

Name: **Laura Mancinska and Maris Ozols** (IQC, Waterloo)
Title: *A framework for bounding nonlocality*
Abstract: We consider the class of protocols that can be implemented when the participating parties have access only to local quantum operations and classical communication (LOCC). In particular, we focus on the task of discriminating a known set of orthogonal pure states by LOCC. The first quantitative impossibility result for this task was presented in 1999 by Bennett et al. in their paper "Nonlocality without entanglement".

Building on the result by Bennett et al. (1999), we provide a framework for quantifying and bounding the amount of nonlocality of any set of bipartite quantum states. More precisely, we propose a method for showing that any LOCC protocol for discriminating bipartite states from a given set will err with at least a certain probability. As a byproduct of our proof we obtain a quantity that can be interpreted as a measure of nonlocality.

We apply our framework to an orthonormal product basis, known as domino states, and obtain an alternative and simplified proof that quantifies its nonlocality (cf. Bennett et al., 1999). We generalize this result for similar bases in larger dimensions, as well as the "rotated" domino states, thus resolving an open problem posed in the original paper.

Name: **Stephan Weis** (Max Planck Institute for Mathematics in the Sciences, Leipzig)
Title: *Continuity in Gibbsian inference*
Abstract: Given a C^{**}-subalgebra A of complex $N \times N$-matrices we consider an operator system B in A. We refer to the corresponding real and self-adjoint space $U, (U + iU) = B$, as observable space. The mean value set M is defined as the orthogonal projection of the state space S of A onto the observable space U with respect to the Hilbert-Schmidt scalar product.

Gibbsian inference $J : M \to S$ assigns to each mean value m in M the unique state S, which $m$aximizes the von Neumann entropy among all states whose projection onto U equals m. The restriction of the inference J to the relative interior of M is a real analytic map, its image G is known as Gibbsian family.

But this real analytic mapping does not necessarily have a continuous extension to M. A counterexample for matrices of size three has recently been found. We have two questions and some suggestions:

Q1: How to describe the set $J(M)$?
- a) by topological norm closure of G (SOLVED FALSE: too large)
- b) by topological rI-closure of G (SOLVED TRUE)
- c) by geometrical e-closure of G (SOLVED FALSE: too small)
- d) by geometrical m-closure of G (OPEN PROBLEM)

Q2: How to find discontinuities of the inference J ?
- a) by creation of non-exposed faces at $M = M(U)$ when U varies in Grassmannian manifolds (OPEN)
- b) by an openness condition on the orthogonal projection $S \to M$ (SOLVED TRUE)