Banff International Research Station
for Mathematical Innovation and Discovery

Operator Structures in Quantum Information Theory (07w5119)

February 11 – February 16, 2007

Organizers:

David Kribs (University of Guelph, Canada) dkribs@uoguelph.ca

Mary Beth Ruskai (Tufts University, USA) marybeth.ruskai@tufts.edu

MEETING ROOMS

All lectures will be held in Max Bell 159 (Max Bell Building accessible by bridge on 2nd floor of Corbett Hall). Hours: 6 am–12 midnight. LCD projector, overhead projectors and blackboards are available for presentations. *Please note that the meeting space designated for BIRS is the lower level of Max Bell, Rooms 155-159. Please respect that all other space has been contracted to other Banff Centre guests, including any Food and Beverage in those areas.*

MEALS

*****Breakfast (Buffet): 7:00 – 9:00 am, Donald Cameron Hall, Monday – Friday
*****Lunch (Buffet): 11:30 am – 1:30 pm, Donald Cameron Hall, Monday – Friday
*****Dinner (Buffet): 5:30 – 7:30 pm, Donald Cameron Hall, Sunday – Thursday
Coffee Breaks: As per daily schedule, 2nd floor lounge, Corbett Hall
***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

Note: A long break is scheduled for Wednesday to permit those who wish to get in a good 4-hour block at prime time in mid-day. For example, one can catch the 11am bus to Sunshine and return on the 3:30 bus. Information on bus schedules and ski rental will be available on Monday. Box lunches will be available on Wednesday, for those who wish, but you will need to sign up early on Monday.

*******SCHEDULE*******

Sunday, February 11

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

Monday, February 12

7:00-8:30 Breakfast

8:30-8:45 Introduction and Welcome to BIRS by BIRS Station Manager, Max Bell 159
8:45-9:35 Ed Effros (UCLA, USA)
Operator spaces I
9:45-10:15 Coffee Break, 2nd floor lounge, Corbett Hall
10:15-11:05 David Kribs (University of Guelph, Canada)
Introduction to quantum error correction
11:15-12:05 Patrick Hayden (McGill University, Canada)
Introduction to Quantum Shannon Theory

12:15-13:30 Lunch

13:00-14:00 Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall

14:00-14:15 Group Photo; meet on the front steps of Corbett Hall
14:15-14:35 Ruedi Seiler (Technische Universitat Berlin, Germany)
Quantum Sanovs theorem
14:40-15:00 Jens Eisert (Imperial College London, UK)
Novel models for measurement-based quantum computation
15:05-15:25 Graeme Smith (California Institute of Technology, USA)
The quantum capacity with a symmetric side channel
15:30-16:00 Coffee Break, 2nd floor lounge, Corbett Hall
16:00-16:20 Michael Wolf (Max-Planck-Institut fuer Quantenoptik, Germany)
Dividing Quantum Channels
16:25-16:45 Matthew Leifer (Perimeter Institute, Canada)
Conditional Density Operators in Quantum Information
16:50-17:10 Cedric Beny (University of Waterloo, Canada)
Operator algebra quantum error correction

17:30-19:30 Dinner
Informal gathering and discussions

Tuesday, February 13

7:00-8:30 Breakfast

8:30-9:20 Vern Paulsen (University of Houston, USA)
Operator spaces II
9:30-10:00 Coffee Break, 2nd floor lounge, Corbett Hall
10:00-10:50 Andreas Klappenecker (Texas A&M University, USA)
Subsystem Codes: Constructions and Bounds
11:00-11:50 Andreas Winter (University of Bristol, U.K.)
Quantum Birkhoff theorem and environment-assisted capacities
12:00-13:30 Lunch

13:30-14:20 Frank Verstraete (California Institute of Technology, USA)
Entanglement theory and strongly correlated quantum many-body systems
14:30-15:20 Bruno Nachtergaele (UC Davis, USA)
Lieb-Robinson bounds and applications to quantum information theory
15:30-16:00 Coffee Break, 2nd floor lounge, Corbett Hall

16:00-18:00 Discussions in Banff hot springs (optional)
17:30-19:30 Dinner

19:45-20:05 Mary Beth Ruskai (Tufts University, USA)
Remarks on commutant lifting and degradable channels
20:10-20:30 Milan Mosonyi (Tohoku University, Japan)
Asymptotics of entropy in quasi-free sates of the spin chain
20:35-20:55 Karol Zyczkowski (Jagiellonian University, Cracow, and Centre for Theoretical Physics, Warsaw, Poland)
Quantum Error Correction and Compression Problems

Wednesday, February 14

7:00-8:30 Breakfast

8:30-9:20 Marius Junge (University of Illinois, USA)
Noncommutative L_p spaces
9:30-10:20 Andrew Cross (MIT, USA)
Fault tolerant quantum computing

10:30-11:00 Coffee Break, 2nd floor lounge, Corbett Hall

11:00-16:00 Free Time

16:00-16:30 Coffee, 2nd floor lounge, Corbett Hall
16:30-17:20 Robert Alicki (IFTiA, University of Gda´nsk, Poland)
Is Quantum Computer a Perpetuum Mobile?

17:30-19:30 Dinner
19:30-20:30 Open problems discussion

Thursday, February 15

7:00-9:00 Breakfast

9:00-9:40 Dennis Kretschman (TU Braunschweig, Germany)
A Continuity Theorem for Stinespring's Representation
9:45-10:05 Arleta Szkola (Max Planck Institute for Mathematics in the Sciences – Leipzig, Germany)
Optimal asymptotical error exponents in symmetric quantum hypothesis testing
10:10-10:40 Coffee Break, 2nd floor lounge, Corbett Hall
10:40-11:00 Bernhard Bodmann (University of Waterloo, Canada)
Decoherence-Insensitive Quantum Communication by Optimal C*-Encoding
11:05-11:45 Anna Jencova (Mathematical Institute of the Slovak Academy of Sciences, Slovakia)
Weak convergence of quantum experiments and quantum local asymptotic normality

12:00-13:30 Lunch

13:30-13:50 John Holbrook (University of Guelph, Canada)
Geometry of higher-rank numerical ranges
13:55-14:15 Man-Duen Choi (University of Toronto, Canada)
My Adventures in Wonderland
14:20-14:40 Matthias Neufang (Carleton University, Canada)
From abstract harmonic analysis to locally compact quantum groups and quantum information theory
14:45-15:30 Open problems session
15:30-16:00 Coffee Break, 2nd floor lounge, Corbett Hall
16:00-17:30 TBA
17:30-19:30 Dinner
Informal gathering and discussions

Friday, February 16

7:00-9:00 Breakfast

9:00-9:40 Koenraad Audenaert (Imperial College London, UK)
Quantum Hypothesis Testing: non-commutative generalisations of the Chernoff and Hoeffding bounds
9:45-10:25 Reinhard Werner (TU Braunschweig, Germany)
Locality and local mechanisms in discrete time quantum lattice systems
10:30-11:00 Coffee Break, 2nd floor lounge, Corbett Hall
11:00-11:40 Possible open problems discussion

12:00-13:30 Lunch

Checkout by 12 noon.

** Participants are welcome to use the BIRS facilities (2nd Floor Lounge, Max Bell Meeting Rooms, Reading Room) until 3 pm on Friday, but are still required to checkout of the guest rooms by 12 noon. **

Banff International Research Station
for Mathematical Innovation and Discovery

Operator Structures in Quantum Information Theory (07w5119)

February 11 – February 16, 2007

Organizers:
David Kribs — University of Guelph, Canada
Mary Beth Ruskai — Tufts University, USA

ABSTRACTS

(alphabetic order by speaker surname)

Speaker: Robert Alicki (IFTiA, University of Gda´nsk, Poland)
Title: Is Quantum Computer a Perpetuum Mobile?
Abstract: Any useful quantum computer would need a mechanism of quantum states protection against the environmental noise. To protect classical information metastable states corresponding to local free energy minima of many-particle systems are used. For example, spin systems with ferromagnetic interaction can yield such metastable states below the critical temperature. This mechanism cannot work for quantum information, because KMS states form a simplex which is an entirely classical figure of states. This property follows from the Second Law of Thermodynamics. The only solution (according to some experts) seems to be a completely new phenomenon of "purely dynamical phase transitions" in systems which do not display the ordinary ones. The interacting spin models proposed by Kitaev are considered as promissing candidates in this context. Therefore, it is desirable to study equilibrium and dynamical properties of such models in terms of rigorous algebraic formalism. Preliminary results concerning uniqueness of the ground and KMS states in the thermodynamic limit and ergodic properties of the finite system coupled to a heat bath are presented for the case of 2-D Kitaev model.

References: A. Kitaev, quant-ph/9707021; E. Dennis et.al.,quant-ph/0110143; R.Alicki and M. Horodecki, quant-ph/0603260.

Speaker: Koenraad Audenaert (Imperial College London, UK)
Title: Quantum Hypothesis Testing: non-commutative generalisations of the Chernoff and Hoeffding bounds
Abstract: In statistics, the Chernoff information, a.k.a. the Chernoff bound, is a quantity describing how well one can distinguish between two given distributions. In a classic 1952 paper, H. Chernoff gave a closed-form formula for the asymptotic efficiency of the corresponding optimal hypothesis test, that is, for the rate at which the total error probability goes to zero when the number of draws in the test goes to infinity. In the quantum setting, one can similarly ask for the asymptotic efficiency of the optimal Hellstrom-Holevo POVM for distinguishing between to given quantum states. Finding the correct quantum generalisation of the Chernoff bound has been a long-standing problem in quantum information theory. In this talk I will discuss the two breakthrough results, the first by Nussbaum and Szkola, and the second by a group of researchers including the speaker, that taken together completely solve this important problem. The latter result is based on a remarkable new trace inequality for positive operators. Time permitting, I will also briefly discuss the solution of another open problem, which is the quantum generalisation of the Hoeffding bound, as obtained by Nagaoka and Hayashi, exploiting the techniques used for solving the Chernoff bound problem.

Speaker: Cedric Beny (University of Waterloo, Canada)
Title: Operator algebra quantum error correction
Abstract: We characterize the observables whose statistic of outcomes is conserved by a given quantum channel. They span the commutant of the channel's Kraus operators and can be actively corrected. We recover standard quantum error correction and operator QEC for the particular case of simple algebras. This more general theory of error correction allows for fewer restrictions on states and characterizes the correction of hybrid quantum memories.

Speaker: Bernhard Bodmann (University of Waterloo, Canada)

Title: Decoherence-Insensitive Quantum Communication by Optimal C*-Encoding

Abstract: The central issue of this talk is to transmit a quantum state in such a way that after some decoherence occurs, most of the information can be restored by a suitable decoding operation. For this purpose, we incorporate redundancy by mapping a given initial quantum state to a messenger state on a larger-dimensional Hilbert space via a C*-algebra embedding. Our noise model for the transmission is a phase damping channel which admits a noiseless or decoherence-free subspace or subsystem. More precisely, the transmission channel is obtained from convex combinations of a set of lowest rank yes/no measurements that leave a component of the messenger state unchanged. The objective of our encoding is to distribute quantum information optimally across the noise-susceptible component of the transmission when the noiseless component is not large enough to contain all the quantum information to be transmitted. We derive simple geometric conditions for optimal encoding and construct examples. (Joint work with David Kribs and Vern Paulsen)

Speaker: Man-Duen Choi (University of Toronto, Canada)

Title: My Adventures in Wonderland

Abstract: In the early 70's, I started off my mathematical journey in the wonderland of completely positive linear maps. Now, in an unexpected era of non-commutative computers, the time moves backwards in an alternate world. As I have to come back to the same scene, I shall report what I found there, through the Looking-Glass.

Speaker: Andrew Cross (MIT, USA)
Title: Fault tolerant quantum computing

Speaker: Ed Effros (UCLA, USA)

Title: Operator Spaces I

Speaker: Jens Eisert (Imperial College London, UK)

Title: Novel models for measurement-based quantum computation

Speaker: Patrick Hayden (McGill University, Canada)

Title: Introduction to Quantum Shannon Theory

Speaker: John Holbrook (University of Guelph)
Title: Geometry of higher-rank numerical ranges
Abstract: The rank-k numerical range of an NxN matrix T is the set of complex z such that PTP=zP for some rank-k orthogonal projection P. While much is known about these planar sets in the case of unitary or normal T, the complete story seems to hinge on general questions of convexity. We describe evidence for such convexity, generalizing the classical Toeplitz-Hausdorff theorem. There is clearly a connection with the Knill-Laflamme criterion for correctable codes, where the additional question of finding a common projection P for several matrices T arises naturally. This is inherent in the convexity question too. The talk includes joint work with Choi, Giesinger, Kribs, and Zyczkowski.

Speaker: Anna Jencova (Mathematical Institute of the Slovak Academy of Sciences, Slovakia)

Title: Weak convergence of quantum experiments and quantum local asymptotic normality
Abstract: An important result of the classical theory of statistical experiments is the local asymptotic normality. It states that the sequence of independent identically distributed random variables, when localized in the neighborhood of some fixed point of the parameter space, converges to a family of Gaussian distributions, in the sense of weak convergence of experiments. We present a quantum version of this result.

To do this, we develop the theory of quantum statistical experiments, parallel to the classical theory, due to Le Cam. By a quantum statistical experiment, we mean a parametrized family of states on a C^*-algebra, representing a quantum system. We introduce the basic notions of randomization, statistical equivalence and convergence of experiments. This is done by extending the concept of quantum sufficiency, introduced by Petz. The talk is based on a joint work with Madalin Guta.

Speaker: Marius Junge (University of Illinois, USA)
Title: Noncommutative L_p spaces

Speaker: Andreas Klappenecker (Texas A&M University, USA)

Title: Subsystem Codes: Constructions and Bounds
Abstract: Protecting quantum information against noise is one of the most challenging tasks in quantum information processing. Recently, subsystem codes (also known as operator quantum error-correcting codes) have been introduced as a generalization and unification of decoherence free subspaces, noiseless subsystems, and quantum error-correcting codes. We briefly sketch how group representation theory can help in constructing subsystem codes. Furthermore, we obtain an extremely useful connection to classical error-correcting codes. We discuss several subsystem code constructions, and the interesting relationship between stabilizer codes and subsystem codes. Finally, we show that linear subsystem codes obey the Singleton bound and give examples of subsystem codes beating the Hamming bound.

Speaker: Dennis Kretschmann (TU Braunschweig, Germany)
Title: A Continuity Theorem for Stinespring's Representation
Abstract: Stinespring's representation theorem is the basic structure theorem for quantum channels: it implies that every quantum channel (i.e., completely positive unital map) arises from an isometric embedding into a larger system. The theorem not only provides a neat characterization of the set of permissible quantum operations, but is also a most useful tool in quantum information science.

In this contribution I will present a continuity theorem for Stinespring's theorem: if two quantum channels (on general von Neumann algebras) are close in cb-norm, then we can always find isometric implementations which are close in operator norm. I will also discuss applications of this result to the information-disturbance tradeoff, the no-broadcasting theorem, and quantum bit commitment.

Joint work with Dirk Schlingemann and Reinhard F. Werner.

Speaker: David Kribs (University of Guelph, Canada)

Title: Introduction to quantum error correction

Speaker: Matthew Leifer (Perimeter Institute, Canada)
Title: Conditional Density Operators in Quantum Information
Abstract: Since quantum information is concerned with probabilistic aspects of quantum theory, it is useful to adopt a framework that makes precise the sense in which quantum theory is a generalization of classical probability theory, such as the operator algebraic formulation. Conditional probability is an important concept in the classical case, and several generalizations to the noncommutative case have been proposed. Whilst quantum conditional information has attracted a great deal of interest in quantum information theory, the associated generalizations of conditional probability have only been used to a limited extent.

In this talk, I will focus on the finite-dimensional case of one particular generalization that I have recently discussed in quant-ph/0606022 and quant-ph/0611233, and that is useful for understanding a variety of concepts in quantum information. Specifically, I will discuss a selection of the following topics:

1) A different operational meaning for the Choi-Jamiolkowski isomorphism when it is interpreted as an isomorphism between conditional density operators and trace-preserving, completely-positive maps.
2) New relations between no-broadcasting theorem and the monogamy of entanglement.
3) Formulations of conditional independence in terms of the conditional density operator and their relation to the equality conditions for the strong-subadditivity of the von Neumann entropy.
4) The formulation of quantum sufficiency in terms of conditional density operators.
5) Results on quantum state pooling based on 3) and 4).

Speaker: Milan Mosonyi (Tohoku University, Japan)

Title: Asymptotics of entropy in quasi-free sates of the spin chain

Speaker: Bruno Nachtergaele (UC Davis, USA)

Title: Lieb-Robinson bounds and applications to quantum information theory

Speaker: Matthias Neufang (Carleton University, Canada)

Title: From abstract harmonic analysis to locally compact quantum groups and quantum information theory
Abstract: Let $\mathbb{G} = (M, G, \varphi , \psi)$ be a locally compact quantum group. In recent work with M. Junge and Z.-J. Ruan, we have constructed and studied a completely isometric representation of the algebra of completely bounded (right) multipliers of $L_1(\mathbb{G})$ on $\mathcal{B} (L_2(\mathbb{G}))$. This extends and unifies earlier work by F. Ghahramani, E. Stormer and myself in the case $M = L_\infty(G)$, and by Z.-J. Ruan, N. Spronk and myself for
$M = \mathit{VN}(G)$, where G is a locally compact group. We show that the multiplier algebra can in fact be identified with the algebra of completely bounded, normal $\widehat{M}$-bimodule maps on $\mathcal{B} (L_2(\mathbb{G}))$ that leave M invariant. The part of the latter algebra consisting of completely positive maps provides a natural class of quantum channels which, from the viewpoint of quantum information theory, are of particular interest in the case of finite-dimensional quantum groups. As we shall see, these channels have highly desirable properties with regard to quantum error correction, and their completely bounded minimal entropy can be calculated explicitly.

Speaker: Vern Paulsen (University of Houston, USA)

Title: Operator Spaces II

Speaker: Mary Beth Ruskai (Tufts University, USA)
Title: Remarks on commutant lifting and degradable channels

Speaker: Ruedi Seiler (Technische Universitat Berlin, Germany)
Title: Quantum Sanovs theorem

Speaker: Graeme Smith (California Institute of Technology, USA)
Title: The quantum capacity with a symmetric side channel
Abstract:I will present an upper bound for the quantum channel capacity that is both additive and convex. This bound can be interpreted as the capacity of a channel for high-fidelity quantum communication when assisted by the family of all channels mapping symmetrically to their output and environment. It seems to be quite tight, and for degradable channels coincides with the unassisted capacity. For the depolarizing channel it can be used to establish new upper bounds for the unassisted quantum capacity. I will review these results, and mention a few unresolved technical issues, most importantly the difficulty we've had finding a bound on the dimension of the symmetric side channel needed to achieve the assisted capacity.

Joint with: John Smolin and Andreas Winter, based on quant-ph/0607039

Speaker: Arleta Szkola (Max Planck Institute for Mathematics in the Sciences – Leipzig, Germany)

Title: Optimal asymptotical error exponents in symmetric quantum hypothesis testing.
Abstract: We consider symmetric hypothesis testing, where two equiprobable hypotheses are represented by density operators associated to the state of a given finite quantum system. The problem is to discriminate between the hypotheses by means of quantum measurements on n copies of the system in question. The optimal quantum tests minimizing Bayesian error probabilities for finite sample size n are well known to be given by the Holevo-Helstrom projections. They are quantum generalizations of classical likelihood ratio tests. We present a quantum extension of the Chernoff lower bound on the minimal asymptotical error exponent. The achievability of the bound was shown recently by Audenaert et al.

References:

1. quant-ph/0607216: M. Nussbaum, A. Szkola, ``A lower bound of Chernoff type for symmetric quantum hypothesis testing"

2. quant-ph/0610027: K.M.R. Audenaert, J. Calsamiglia, Ll. Masanes, R. Munoz-Tapia, A. Acin, E. Bagan, F. Verstraete, ``The Quantum Chernoff Bound"

3. C.W. Helstrom, ``Quantum Detection and Estimation Theory", Academic Press, New York (1976)

4. A.S. Holevo, ``Investigation of a general theory of statistical decision", Proceedings of Stelkov Institute of Mathematics, vol.3 (1978)

Speaker: Frank Verstraete (California Institute of Technology, USA)
Title: Entanglement theory and strongly correlated quantum many-body systems
Abstract:Strongly correlated many-body quantum systems exhibit many fascinating phenomena such as quantum phase transitions and high Tc superconductivity, yet a satisfying theoretical description of those phenomena is lacking. A promising theoretical description of such systems is only starting to emerge based on the formalism of entanglement theory as developed in the field of quantum information theory. I will talk about some variational classes of wavefunctions that seem to capture the physics needed to describe the low-energy sector of strongly correlated quantum systems, and that allow to do numerical simulations of quantum spin and fermionic systems in a regime that is inaccessible by any other numerical method. An exploration of the particular features of these classes of wavefunctions leads to unexpected connections between the fields of many-body quantum systems, area laws and computationial complexity.

Speaker: Reinhard Werner (TU Braunschweig, Germany)
Title: Locality and local mechanisms in discrete time quantum lattice systems

Speaker: Andreas Winter (University of Bristol, UK)

Title: Quantum Birkhoff theorem and environment-assisted capacities

Speaker: Michael Wolf (Max-Planck-Institut fuer Quantenoptik, Germany)
Title: Dividing Quantum Channels
Abstract: We investigate the possibility of dividing quantum channels into concatenations of other channels, thereby studying the semigroup structure of the set of completely-positive trace-preserving maps. We show the existence of 'indivisible' channels which can not be written as non-trivial products of other channels and study the set of 'infinitesimal divisible' channels which are elements of continuous completely positive evolutions. For qubit channels we obtain a complete characterization of the sets of indivisible and infinitesimal divisible channels. Moreover, we identify those channels which are solutions of time-dependent master equations for both positive and completely positive evolutions. For arbitrary finite dimension we prove a representation theorem for elements of continuous completely positive evolutions based on new results on determinants of quantum channels and Markovian approximations. Joint work with J. Ignacio Cirac

Speaker: Karol Zyczkowski (Jagiellonian University, Cracow, and Centre for Theoretical Physics, Warsaw, Poland)
Title: Quantum Error Correction and Compression Problems
Abstract: Conditions for designing classical and quantum error correction codes are compared. A general solution of the quantum error correction problem is presented for the case of bi-unitary channels acting on two-qubit Hilbert space.

We construct qubit codes for such channels on arbitrary dimensional Hilbert space, and identify correctable codes for Pauli-error models not detected by the stabiliser formalism. This is accomplished through solving of certain algebraic compression problems and finding the “higher-rank numerical range” of the error matrix. For bi-unitary channels acting on a k-qubit system we design error correction codes that support (k-1) qubits.