UBC Department of Physics & Astronomy

Workshop on Quantum Algorithms, Computational Models, and Foundation of Quantum Mechanics

July 23-25, 2010

University of British Columbia
Vancouver, Canada

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II. About The Research Workshop

The Workshop on Quantum Algorithms, Computational Models, and Foundations of Quantum Mechanics, will be held from July 23 to July 25, 2010 at the University of British Columbia, Vancouver, Canada. This three-day workshop will focus on the mathematical aspects of quantum information: algorithms, computational models and foundations of quantum mechanics. It will serve as a focal point for experts in quantum information science to present their cutting edge research. The interdisciplinary nature and the industrial relevance of the topic will provide novel opportunities for researchers from different disciplines to exchange ideas and develop collaborations with a lasting impact, which may result in industrial applications.

Recently, surprising connections between quantum information and graph theory, and between quantum information and foundations of quantum mechanics have been established. A major purpose of this workshop is to discuss these connections from various points of view, and to coordinate the efforts of future research.

A further objective of the workshop is to facilitate industry-academics partnership. We wish to note that this workshop is partially sponsored by D-Wave Systems Inc., a Burnaby-based company dedicated to building large-scale adiabatic quantum computers.

This workshop is a satellite event to the 10th Canadian Summer School on Quantum Information, giving students a rare learning opportunity to see real-world applications of quantum information science research. Summer school students (post-docs and graduate students) are invited to attend the workshop free of charge.

This research workshop is an informal successor to two previous workshops, namely (1) Workshop “Graph Theory and Quantum Information: Emerging Connections” held at Perimeter Institute Waterloo, April 28 - May 2, 2008, and (2) QICS Workshop on “Foundational Structures for Quantum Information and Computation” September 14-20, 2008, Obergurgl, Tyrol, Austria.

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*Maarten **van den Nest**, Max-Planck-Institut für Quantenoptik, Garching, Germany

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* Invited Speaker

+ Workshop Organizer

V. PROGRAMME

Friday, July 23rd @ Henn 201

Morning - Session 1: Models of quantum computation - Adiabatic

9:00 AM - 9:45 AM	Boris Altshuler (Columbia U)	Adiabatic quantum optimization and Anderson localization
9:45 AM - 10:15 AM	Vicky Choi (Virginia Tech)	Adiabatic Quantum Algorithms for the NP-Complete Maximum-Weight Independent Set, Exact Cover and 3SAT Problems
10:15 AM - 10:45 AM	COFFEE BREAK	
10:45 AM - 11:30 AM	Daniel Lidar (University of Southern California)	Combining dynamical decoupling with fault-tolerant quantum computation
11:30- 11:40 AM	QUICK BREAK	
11:40 AM – 12:25 PM	Steve Flammia (Perimeter)	Adiabatic Quantum Transistors

Afternoon - Session 2: Foundations of quantum mechanics

2:00 PM – 2:45 PM	Rob Spekkens (Perimeter)	Why the quantum? Insights from classical theories with a statistical restriction
2:45 PM – 3:30 PM	Gemma De las Cuevas (Innsbruck)	Unifying Classical Spin Models Using A Quantum Formalism
3:30 PM – 4PM	COFFEE BREAK	
4:00 PM – 4:30 PM	Chris Ferrie (University of Waterloo)	On the relevance of quasi-probability representations to quantum foundations and quantum information theory
4:30 PM – 4:40 PM	QUICK BREAK	
4:40 PM – 5:10 PM	Osama Moussa (University of Waterloo)	Testing Contextuality on Quantum Ensembles with One Clean Qubit

Workshop Dinner

7:30pm	Workshop Dinner @ Seasons in the Park Restaurant Meeting at 6:00pm in front of Henn 201

Saturday July 24 @ Henn 201 **Morning – Session 3: Quantum Algorithms (+ hardness of their classical simulation)**		
9:00 AM - 9:45 AM	David Poulin (Université de Sherbrooke)	Quantum Metropolis Sampling: An algorithm to simulate thermal systems with a quantum computer
9:45 AM – 10:30 AM	Maarten van den Nest (Max-Planck-Institut für Quantenoptik)	Simulating quantum computers with probabilistic methods
10:30 – 11:00 AM	COFFEE BREAK	
11:00 AM – 11:30 AM	Gorjan Alagic (University of Waterloo)	Quantum Algorithms from Topological Quantum Field Theories
11:30 AM – 11:40 AM	QUICK BREAK	
11:40 AM – 12:10 PM	Vincenzo Tamma (University of Maryland, Università degli Studi di Bari)	Factoring numbers with periodic interferograms
Afternoon – Session 4: Models of quantum computation – Measurement-based		
2:00 PM – 2:45 PM	Dan Browne (University College London)	Correlations in Measurement-Based Quantum Computing and Bell Inequalities
2:45 PM – 3:15 PM	Ernesto Galvao (Univ. Federal Fluminense, Brazil)	Closed time-like curves in measurement-based quantum computation
3:15 PM – 4PM	COFFEE BREAK	
4:00 PM – 4:30 PM	Akimasa Miyake (Perimeter Institute)	Quantum computation on the edge of a symmetry-protected topological order
Early Evening – Session 5: Poster Session at the Abdul Ladha Science Student Centre		
4:30pm – 5:00pm	BREAK, Poster Set Up	
5:00pm – 6:30pm	Poster Session	

Sunday July 25 @ IBLC 281 Morning – Session 6, Quantum error correction & Topological quantum computation		
9:00 AM - 9:30 AM	Eduardo Mucciolo (University of Central Florida)	For How Long Is It Possible To Quantum Compute?
9:30 AM – 10:00 AM	Guillaume Duclos-Cianci (Université de Sherbrooke)	Fast Decoders for Topological Quantum Codes
10:00 AM – 10:30 AM	Héctor Bombín (Perimeter Institute)	Twists in topological codes
10:30- 11:00 AM	COFFEE BREAK	
Morning – Session 7, Algorithms II		
11:00 AM – 11:45 AM	Pawel Wocjan (University of Central Florida)	Quantum Algorithm for Preparing Thermal Gibbs States
11:45 AM – 12:15 PM	Viv Kendon (University of Leeds)	Fractional scaling of quantum walks on percolation lattices
12:15 PM – 12:25 PM	QUICK BREAK	
12:25 PM – 12:55 PM	Michael Mullan (University of Colorado at Boulder)	A Numerical Quantum and Classical Adversary
Afternoon - Session 8, Lab tour at D-wave (workshop participants)		
Afternoon	Bus pick up at 2pm outside of the UBC Bookstore. Tour will start at 3pm (3-5pm).	

VI. Workshop Venue

All workshop talks and events will be held in the following three buildings:

Hennings Building (HENN)

6224 Agricultural Road, Vancouver, BC

The Hennings Building is the home of the UBC Department of Physics & Astronomy. Workshop sessions will locate in Henn 201 on Friday, July 23rd and Saturday, July 24th. The easiest way to find Henn 201 is to enter the building from the north side entrance.

Irving K. Barber Learning Centre (IBLC)

1961 East Mall, Vancouver, BC

Opened in 2008, this renovated learning space contains a library, reading rooms, teaching and learning facilities, meetings rooms, cafe, and much more. Workshop sessions on Sunday, July 25th, will be held in room 182 (Victoria Learning Centre) of the Ike Barber Learning Centre.

Abdul Ladha Science Student Centre

2055 East Mall, Vancouver, BC

The Abdul Ladha Centre is the Home of the UBC Science Undergraduate Society. It is a social space to encourage both informal and organized academic, club, and social activities and interactions for those students enrolled in the Faculty of Science at the University of British Columbia Vancouver. It is the venue for our workshop poster session.

MAP

FIGURE 1 VENUE & IMPORTANT LOCATIONS

QAMF Workshop - July 23rd & 24th

Hennings Room 201

QAMF workshop - July 25th

IBLC Room 182

QAMF Poster Session

Abdul Ladha Science Undergraduate Student Centre

Hennings Building (Henn)

6224 Agricultural Road

Ike Barber Learning Centre (IBLC)

1961 East Mall

Abdul Ladha Science Student Centre

2055 East Mall

North Parkade

The parkade closest to the meeting location (Hennings building)

North Bus Loop (Main Bus Loop)

The main bus loop - for diesel buses
#99, #33, #44, #84, #41, #43, #49, #258, #480

2nd Bus Loop

2nd bus loop for cable buses
#4, #17, #9

Info Centre

Brock Hall 1874 East Mall

Info Centre (run by students)

6138 Student Union Blvd (Student Union Building)
Not the official information centre, but the students there should be able to answer any general questions

UBC Bookstore

Meet up for D-Wave tours
6200 University Boulevard

Carey Centre - Invited Speaker Accommodation

5920 Iona Drive

Place Vanier - QI10 Financial Support Winners Accommodation

1935 Lower Mall

VII. Abstracts

A. Invited Presentations

Altshuler: Adiabatic quantum optimization and Anderson localization

Understanding NP-complete problems is a central topic in computer science. This is why adiabatic quantum optimization has attracted so much attention, as it provided a new approach to tackle NP-complete problems using a quantum computer. The efficiency of this approach is limited by small spectral gaps between the ground and excited states of the quantum computer's Hamiltonian. We will discuss the statistics of the gaps using the borrowed from the theory of quantum disordered systems. It turns out that due to a phenomenon similar to Anderson localization exponentially small gaps appear close to the end of the adiabatic algorithm for large random instances of NP-complete problems. We will present the quantitative analysis of the small spectral gaps and discuss possible consequence of this phenomenon on the adiabatic optimization paradigm.

Browne: Correlations in Measurement-Based Quantum Computing and Bell Inequalities

Measurement-based quantum computation (or the one-way quantum computation) is a model in which a series of adaptive single qubit measurements upon an entangled resource state can produce classical output data equivalent to an arbitrary quantum logic circuit. Loosely speaking, the correlations in these measurements can be considered the resource which allows the computation to be performed.

Bell inequalities demonstrate that quantum mechanics permits the outcomes of sets of measurements to be correlated in ways incompatible with the predictions of any local hidden variable theory, including classical physics. In the Bell inequality, and multi-party generalisations, a set of single-qubit measurements are performed, on spatially separated systems. Correlations in these measurements can act as a signature that no local hidden variable description of the experiment is possible.

At first sight, we see superficial similarities between these settings. In both cases, non-classical correlations play a central role. However, there are also some key differences. Most importantly, measurement-based quantum computing requires adaptive measurements, at odds with the spatial-separated nature of Bell inequality experiments. Nevertheless some striking connections have been reported [1], [2] particularly between GHZ-type paradoxes and deterministic MBQC computations, and between CHSH-type Bell inequalities and non-deterministic MBQC correlations [1], [3]. In my talk I will survey these works and some recent results [3], [4] from my group at UCL, in which a number of connections between multi-party Bell inequalities and MBQC are explored.

[1] J. Anders and D.E. Browne, "The Computational Power of Correlations", Physical Review Letters 102, 050502 (2009)
[2] R. Raussendorf, "Quantum computation, discreteness, and contextuality", arxiv:0907.5449
[3] M. J. Hoban, E.T. Campbell, K. Loukopolous, D.E. Browne, "Non-adaptive measurement-based quantum computation and multi-party Bell inequalties", in preparation.
[4] M. J. Hoban and D.E. Browne, in preparation.

De las Cuevas: Unifying classical spin models using a quantum formalism

We have recently shown that the partition function of any classical spin model, including all discrete standard statistical models and all Abelian discrete lattice gauge theories, can be expressed as the specific instance of the partition function of a four dimensional Ising lattice gauge theory. This unifies models with apparently very different features (global vs. local symmetries, many body interactions, different dimensions, etc) in a single complete model. The proof of the result uses techniques from quantum information. In this talk we review these mappings and discuss recent developments, including quantum algorithms to approximate the partition function.

Flammia: Adiabatic Quantum Transistors

Authors: Dave Bacon, Gregory M. Crosswhite, and *Steven T. Flammia*

The invention of the transistor was a watershed moment in the history of computing: it provided a logic element that was naturally robust to noise and error. Quantum computers offer the potential to exponentially speed up some computational problems, but have not been built in large part because quantum information is notoriously fragile and quickly becomes classical information in the presence of noise. In theory, the quantum threshold theorem asserts that these difficulties can be circumvented, but in practice the requirements of this theorem are daunting. Here we propose a novel method for building a fault-tolerant quantum computer which much more closely mimics the classical transistor. We show how a suitably engineered material can be made to quantum compute by the simple application of an external field to the sample. This construction opens a new path toward the engineering of a large-scale quantum computer with design and control advantages over prior state of the art. Just as a transistor works by causing a phase transition between an insulating and conducting phase conditional on an external electric field, the applied field here causes a phase transition at the end of which a quantum gate has been enacted and quantum information propagated across the device.

LIDAR: ACCURATE AND DECOHERENCE-PROTECTED ADIABATIC QUANTUM COMPUTATION

In the closed system setting I will show how to obtain extremely accurate adiabatic QC by proper choice of the interpolation between the initial and final Hamiltonians. Namely, given an analytic interpolation whose first N initial and final time derivatives vanish, the error can be made to be smaller than 1/N^N, with an evolution time which scales as N and the square of the norm of the time-derivative of the Hamiltonian, divided by the cube of the gap (joint work with Ali Rezakhani and Alioscia Hamma). In the open system setting I will describe a method for protecting adiabatic QC by use of a hybrid encoding-dynamical decoupling scheme. This strategy can be used to protect spin-based universal adiabatic QC against arbitrary 1-local noise using only global magnetic fields. By combining error bounds for the closed and open system settings, I will show that in principle the method is scalable to arbitrarily large computations.

References:

Closed system case: J. Math. Phys. 50, 102106 (2009)
Open system case: Phys. Rev. Lett. 100, 160506 (2008)

POULIN: QUANTUM METROPOLIS SAMPLING: AN ALGORITHM TO SIMULATE THERMAL SYSTEMS WITH A QUANTUM COMPUTER

Authors: K. Temme, T.J. Osborne, K. Vollbrecht, David Poulin, and *F. Verstraete*

The original motivation to build a quantum computer came from Feynman who envisaged a machine capable of simulating generic quantum mechanical systems, a task that is intractable for classical computers. Such a machine would have tremendous applications in all physical sciences, including condensed matter physics, chemistry, and high energy physics. Part of Feynman's challenge was met by Lloyd who showed how to approximately decompose the time-evolution operator of interacting quantum particles into a short sequence of elementary gates, suitable for operation on a quantum computer. However, this left open the more fundamental problem of how to simulate the equilibrium and static properties of quantum systems. This requires the preparation of ground and Gibb's states on a quantum computer. For classical systems, this problem is solved by the ubiquitous Metropolis algorithm, a method that basically acquired a monopoly for the simulation of interacting particles. In this talk, I will demonstrate that the corresponding quantum problem can be solved by a quantum Metropolis algorithm. This validates the quantum computer as a universal simulator, and proves that the so-called sign problem occurring in quantum Monte Carlo methods can be resolved with a quantum computer.

SPEKKENS: WHY THE QUANTUM? INSIGHTS FROM CLASSICAL THEORIES WITH A STATISTICAL RESTRICTION

A significant part of quantum theory can be obtained by postulating a single conceptual innovation relative to classical theories, namely, that agents face a fundamental restriction on what they can know about the physical state of any system. This talk will consider a particular sort of statistical restriction wherein only classical variables with vanishing Poisson bracket can be known simultaneously. When this principle is applied to a classical statistical theory of three-level systems (trits), the resulting theory is found to be operationally equivalent to the stabilizer formalism for qutrits. Applied to a classical theory of harmonic oscillators, it yields quantum mechanics restricted to quadrature eigenstates and observables. Finally, applied to a classical statistical theory of bits, it yields a theory that is almost equivalent to (but interestingly different from) the stabilizer formalism for qubits. I will discuss the significance of these results for the project of deriving the formalism of quantum theory from physical principles.

VAN DEN NEST: SIMULATING QUANTUM COMPUTERS WITH PROBABILISTIC METHODS

The study of quantum computations that can be simulated efficiently classically is of interest for numerous reasons. From a fundamental point of view, such an investigation sheds light on the intrinsic computational power harnessed in quantum mechanics as compared to classical physics. More practically, understanding which quantum computations do not offer any speed-up over classical computation provides insights in where (not) to look for novel quantum algorithmic primitives. In this talk we discuss novel classical simulation methods that are centered on probabilistic methods ('weak simulation'). We show how these techniques outperform existing methods that rely on the exact computation of measurement probabilities ('strong simulation'). Using weak simulation methods, several new classes of simulatable quantum circuits are generated. For example, we show that various concatenations of matchgate, Toffoli, Clifford, bounded-depth, Fourier transform and other circuits are classically simulatable. Finally, we focus on famous quantum algorithms and investigate the origin of their computational power, or their lack thereof.

WOCJAN: QUANTUM ALGORITHM FOR PREPARING THERMAL GIBBS STATES

We present a quantum algorithm for preparing thermal Gibbs states of interacting quantum systems. This algorithm is based on Grover's technique for quantum state engineering, and its running time is dominated by the factor sqrt{D/Z}, where D and Z_beta denote the dimension of the quantum system and its partition function at inverse temperature beta, respectively. We discuss the differences between this algorithm and quantum Metropolis sampling (see the presentation by David Poulin) and outline the analysis of the errors that arise due to imperfect simulation of Hamiltonian time evolutions and limited performance of phase estimation (finite accuracy and nonzero probability of failure).

B. Contributed Talks

Alagic: Quantum Algorithms from Topological Quantum Field Theories

Topological Quantum Field Theories (or TQFTs) are abstract constructions from category theory and mathematical physics. Their conception was originally motivated by the search for a physical theory that unifies general relativity and quantum mechanics. At its core, a TQFT is a map from manifolds (e.g., spacetimes) to linear maps (e.g., quantum operations) that satisfies some physically sensible properties. For instance, the disjoint union of two manifolds must be mapped to the tensor product of the two corresponding linear maps. To manifolds without boundary, a TQFT assigns a topologically invariant number called a quantum invariant. This discovery added a beautiful new direction in the study of manifold invariants in pure mathematics. For this reason and many others, this area has seen a tremendous amount of work in the past two decades, from physicists and mathematicians alike.

In this talk, we will discuss how this theory can be applied to design quantum algorithms for approximating certain quantum invariants. The aim of the talk is to give an accessible introduction to some of the ideas in this area, and to motivate quantum computation enthusiasts to study it further. We will begin with the simplest two-dimensional state-sum models. These examples are quite attractive, since they can be described in a combinatorial manner by means of triangulations. We will then define a three-dimensional state-sum TQFT, called the Turaev-Viro theory. Finally, we will discuss a recent result (joint with Stephen Jordan, Robert Koenig, and Ben Reichardt) showing that approximating the Turaev-Viro quantum invariant is a universal problem for quantum computation.

Bombín: Twists in topological codes

There exists a close relationship between topological quantum error-correcting codes and topological order in condensed matter systems. Indeed, a topological stabilizer code can be regarded as the ground state of a suitable Hamiltonian model, so that "wrong" syndromes correspond to excitations. These excitations are anyons, quasiparticles that carry a topological charge and exhibit exotic statistics.

Anyon models can be symmetric under some permutations of their topological charges. One can then conceive topological defects that, under monodromy, transform anyons according to a symmetry. We call these defects twists. Twists give rise to new topological degrees of freedom in the ground state, useful as a quantum memory. Moreover, twists can be braided to perform topologically protected gates on these topological qubits.

Thus, twists provide a new way to encode and compute with topological codes through code deformations. Because the properties of twists depend on the anyon model, codes with different anyon content give rise to different computational capabilities. E.g., in the well-known toric code a process where suitable twists are braided and fused has the same outcome as if they were Ising anyons. These are non-abelian anyons: braiding produces non-trivial gates on encoded qubits.

CHOI: ADIABATIC QUANTUM ALGORITHMS FOR THE NP-COMPLETE MAXIMUM-WEIGHT INDEPENDENT SET, EXACT COVER AND 3SAT PROBLEMS

The problem Hamiltonian of the adiabatic quantum algorithm for the maximum-weight independent set problem (MIS) that is based on the reduction to the Ising problem (as described in [Choi08]) has flexible parameters. We show that by choosing the parameters appropriately in the problem Hamiltonian (without changing the problem to be solved) for MIS on CK graphs, we can prevent the first order quantum phase transition and significantly change the minimum spectral gap. We raise the basic question about what the appropriate formulation of adiabatic running time should be. We also describe adiabatic quantum algorithms for Exact Cover and 3SAT in which the problem Hamiltonians are based on the reduction to MIS. We point out that the argument in Altshuler et al.(arXiv:0908.2782 [quant-ph]) that their adiabatic quantum algorithm failed with high probability for randomly generated instances of Exact Cover does not carry over to this new algorithm.

DUCLOS-CIANCI: FAST DECODERS FOR TOPOLOGICAL QUANTUM CODES

Authors: *Guillaume Duclos-Cianci*, David Poulin

Topological quantum computation and topological error correcting codes attracted a lot of interest recently because they require realistic nearest neighbors couplings and, by encoding the information in non-local topological degrees of freedom, they offer a very high resilience to local noise. I will present a family of algorithms, combining real-space renormalization methods and belief propagation, to estimate the free energy of a topologically ordered system in the presence of defects (Phys. Rev. Lett. 104, 050504 (2010)). Such an algorithm is needed to preserve the quantum information stored in the ground space of a topologically ordered system and to decode topological error-correcting codes. For a system of linear size L, our algorithm runs in time log L compared to L^6 needed for the minimum-weight perfect matching algorithm previously used in this context and achieves a higher depolarizing error threshold (16.5% vs 15.5%). I will introduce the intuitions behind the method and present new developments.

FERRIE: ON THE RELEVANCE OF QUASI-PROBABILITY REPRESENTATIONS TO QUANTUM FOUNDATIONS AND QUANTUM INFORMATION THEORY

Authors: *Chris Ferrie*, Joseph Emerson

Several quasi-probability representations of quantum states have been proposed to study various problems in quantum information theory and quantum foundations. These representations are often defined only on restricted dimensions and their physical significance in contexts such as drawing quantum-classical comparisons is limited by the non-uniqueness of the particular representation. Here we show how the mathematical theory of frames provides a unified formalism which accommodates all known quasi-probability representations of quantum systems. Moreover, we show that any quasi-probability representation is equivalent to a frame representation and then prove that any such representation of quantum mechanics must exhibit either negativity or a deformed probability calculus.

GALVÃO: CLOSED TIME-LIKE CURVES IN MEASUREMENT-BASED QUANTUM COMPUTATION

Authors: Raphael Dias da Silva, *Ernesto F. Galvão,* Elham Kashefi

Many results have been recently obtained regarding the power of hypothetical closed time-like curves (CTC's) in quantum computation. Most of them have been derived using Deutsch's influential model for quantum CTCs [D. Deutsch, Phys. Rev. D 44, 3197 (1991)]. Deutsch's model demands self-consistency for the time-travelling system, but in the absence of (hypothetical) physical CTCs, it cannot be tested experimentally.

In this paper we show how the one-way model of measurement-based quantum computation (MBQC) can be used to test Deutsch's model for CTCs. Using the stabilizer formalism, we identify predictions that MBQC makes about a specific class of CTCs involving travel in time of quantum systems. Using a simple example we show that Deutsch's formalism leads to predictions conflicting with those of the one-way model.

There exists an alternative, little-discussed model for quantum time-travel due to Bennett and Schumacher (in unpublished work, see http://bit.ly/cjWUT2), which was rediscovered recently by Svetlichny [arXiv:0902.4898v1]. This model uses quantum teleportation to simulate (probabilistically) what would happen if one sends quantum states back in time. We show how the Bennett/ Schumacher/ Svetlichny (BSS) model for CTCs fits in naturally within the formalism of MBQC. We identify a class of CTC's in this model that can be simulated deterministically using techniques associated with the stabilizer formalism. We also identify the fundamental limitation of Deutsch's model that accounts for its conflict with the predictions of MBQC and the BSS model.

Kendon: Fractional Scaling of Quantum Walks on Percolation Lattices

Quantum walks have been used as simple models of quantum transport phenomena, applicable to systems as diverse as spin chains and bio-molecules. Here we investigate the properties of quantum walks on percolation lattices, disordered structures appropriate for modelling biological and experimentally realistic systems. Both bond (edge) and site percolation have similar definitions: with independent randomly chosen probability p the bond or site is present in the lattice. In two and higher dimensions, percolation lattices exhibit a phase transition from a set of small disconnected regions to a more highly connected structure ("one giant cluster"). On 2D Cartesian lattices, the critical probability pc = 0.5 (bond) and pc = 0.5927... (site).

Below pc, the quantum walk will not be able to spread. Approaching pc from above, the spreading slows down completely, as the number of long-distance connected paths reduces to zero. For p = 1, the lattice is fully connected, and the standard quantum walk spreading applies (linear in T). In between, we find the quantum walks show fractional scaling of the spreading, i.e., proportional to T to the power alpha (0.5 < alpha < 1).

Our (numerical) results are skewed by finite size effects: the increase in alpha from zero begins before p = pc. It then flattens toward the classical random walk spreading rate of alpha = 0.5 around p = 0.85, followed by a steep rise to the quantum value of alpha = 1 at p = 1. At this stage, we do not have enough data to predict the large T behaviour, but think the steep rise will becomes a "step" function at p = 1 as T -> infinity. The randomness in the percolation lattice would thus act as decoherence in the large T limit. However, such a limit could only be approached for quite large values of T, and from the point of view of models for disordered systems on smaller scales (tens of sites), the faster-than-classical fractional scaling is very much the dominant feature.

Miyake: Quantum Computation on the Edge of a Symmetry-protected Topological Order

We elaborate the idea of quantum computation through measuring the correlation of a gapped ground state, while the bulk Hamiltonian is utilized to stabilize the resource. A simple computational primitive, by pulling out a single spin adiabatically from the bulk followed by its measurement, is shown to make any ground state of the one-dimensional isotropic Haldane phase useful ubiquitously as a quantum logical wire. The primitive is compatible with certain discrete symmetries that are crucial to protect this topological order, and the antiferromagnetic Heisenberg spin-1 chain of a finite length is practically a sufficient resource. Our approach manifests a holographic principle in that the logical information of a universal quantum computer can be written and processed perfectly on the edge state (i.e. boundary) of the system, supported by the persistent entanglement from the bulk even when the ground state and its evolution cannot be exactly analyzed. Reference: arXiv:1003.4! 662

MOUSSA: TESTING CONTEXTUALITY ON QUANTUM ENSEMBLES WITH ONE CLEAN QUBIT

Authors: *Osama Moussa*, Colm A. Ryan, David G. Cory, and Raymond Laflamme

The main question at hand is whether nature is fundamentally contextual. A number of recent experimental results have tackled this question in different settings, and this work examines an important, hitherto unexplored, piece of the puzzle; proposing and demonstrating a protocol to experimentally test contextuality without recourse to the isolation of individual quantum systems nor strong measurement.

MUCCIOLO: FOR HOW LONG IS IT POSSIBLE TO QUANTUM COMPUTE?

Authors: *Eduardo R. Mucciolo*, E. Novais, Harold U. Baranger

One of the key problems in quantum information processing is to understand the physical limits to quantum computation. Several strategies have been proposed to attenuate errors caused by the interaction of the computer with its surrounding environment and quantum error correction (QEC) is likely the most versatile. A large effort has been devoted to proving that resilience can be achieved by concatenating QEC codes in logical structures. In our work we look into this question at a different angle: we provide an upper bound on the time available to computation given a certain computer, a QEC code, and a decohering environment. We consider a broad class of environments, including those where correlation effects can be induced by gapless modes.

Our approach is based on a Hamiltonian formulation where we use coarse graining in time to derive an explicit quantum evolution operator for the logical qubits, taking into account the QEC code. We show that this evolution operator has the same form as that for the original physical qubits, except for a reduced coupling to the environment which can be evaluated systematically for a given geometry and QEC code structure.

To quantify the effectiveness of QEC, we compute the trace distance between the real and ideal states of a logical qubit after an arbitrary number of QEC cycles. We derive expressions for the long-time trace distance for several for super-ohmic-, ohmic-, and sub-ohmic-like baths. Given a confidence threshold for the trace distance, we establish the maximum time available for computation in those three cases. This maximum time is controlled by an exponent related to the spatial dimensions and other characteristics of the computer and the environment. For the super-ohmic regime, we find that computation can continue indefinitely, while in the other regimes the maximum time depends strongly on the QEC code, on the number of logical qubits, and on the original environment-computer strength interaction.

MULLAN: A NUMERICAL QUANTUM AND CLASSICAL ADVERSARY

Authors: *Michael Mullan*, Emanuel Knill

The Quantum Adversary Method has proven to be a successful technique for deriving lower bounds on a wide variety of problems. However, it assumes perfect quantum computation, which in most modern devices, is unrealistic. Here, we develop a generalization of this technique without this assumption, which can be applied to arbitrary small problems automatically. To do this, we start by reformulating the objective value of the semidefinite program of the spectral adversary method. By relating the final measurement stage of a quantum computation to remote state preparation, we prove that the optimal value of the new objective corresponds to the probability that the quantum computer will output the correct value after a specified number of queries. Once in this framework, the addition of decoherence is natural. In particular, the optimum probability of success can be determined for any probability of phase error. In the limit of complete phase decoherence, we recover the optimal p! robability of success for a classical computation. Our semidefinite programming formulation is suitably general, and so has application outside that of algorithms. In particular, we apply it to the optimization of quantum clocks.

TAMMA: FACTORING NUMBERS WITH PERIODIC INTERFEROGRAMS

Authors: *Vincenzo Tamma*, Heyi Zhang, Xuehua He, Augusto Garuccio, Wolfgang P. Schleich, and Yanhua Shih

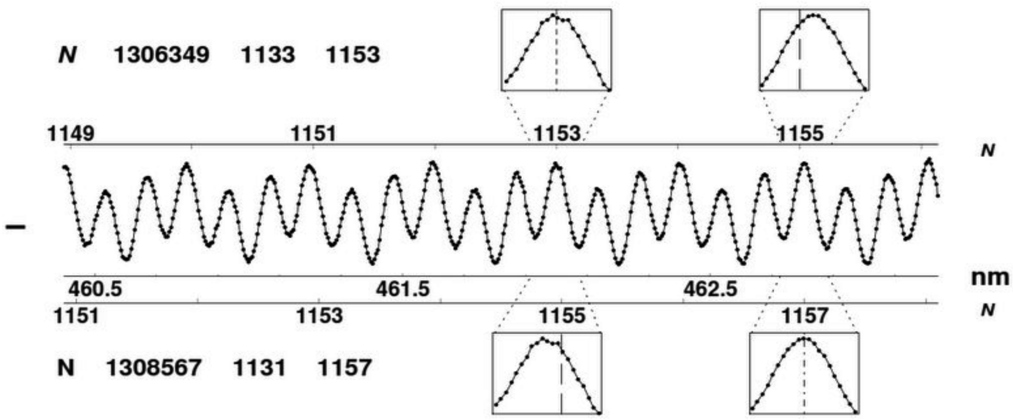
The security of codes, for example in credit card and government information, relies on the fact that the factorization of a large integer number N is a rather costly process on a classical digital computer. Such a security is endangered by the Shor's algorithm which employs entangled quantum systems to find, with a polynomial number of resources, the period of a function which is connected with the factors of N. We can surely expect a possible future realization of such a method for large numbers, but so far the period of Shor's function has been only computed for the number 15.

Inspired by Shor's idea, our work aims to methods of factorization based on the periodicity measurement of a given continuous periodic “factoring function" which is physically implementable using an analog computer.

In particular, we have focused on both the theoretical and the experimental analysis of Gauss sums with continuous arguments leading to a new factorization algorithm. The procedure allows, for the first time, to factor several numbers by measuring the periodicity of Gauss sums performing first-order “factoring" interference processes.

We experimentally implemented this idea by exploiting polychromatic optical interference in the visible range with a multi-path interferometer, and achieved the factorization of seven digit numbers (see figure). For each number N to factorize, the corresponding trial factors associated with the brightest wavelengths (maxima in the interferogram) are the factors.

The physical principle behind this “factoring" interference procedure can be potentially exploited also on entangled systems, as multi-photon entangled states, in order to achieve a polynomial scaling in the number of resources.



C. Poster Presentations

Arimitsu: Non-equilibrium Thermo Field Dynamics and its Application to Quantum Information

We present our original framework of the canonical operator formalism for dissipative and/or stochastic quantum systems named Non-Equilibrium Thermo Field Dynamics (NETFD). NETFD is a canonical operator formalism providing us with a full set of methods to tackle problems in dissipative quantum systems in a similar way as quantum mechanics and quantum field theory. Within NETFD, the dynamics of dissipative quantum systems is described by the stochastic and/or dissipative "Schroedinger equation" for an unstable vacuum that has the same amount of information contained in the statistical operator (the density operator). A consistent and unified system of stochastic differential equations in the operator formalism, together with a theory of quantum Brownian motion, allows one to analyze time-evolution of noisy quantum systems in a practical manner.

As an attractive application of NETFD, we will treat the system of qubits under the influence of spatially correlated noises. By the introduction of tilde degrees of freedom, completely positive maps (CP maps) describing the error or the error-correction procedure are represented within NETFD by operators acting on both bra- and ket-thermal vacuums for qubits, which makes analyses of error-correction procedures transparent; this makes a contrast to the case within the density operator formalism where CP maps are super-operator acting on density operator. It is shown that errors due to the correlated noises can be corrected by the quantum error-correction code and error-correction procedure that is prepared for spatially independent noises. This result is valid generally for the stabilizer code, which is quite a large class of quantum error-correction codes.

If time permits, we will present, as another application of NETFD, the study on the influence of imperfect generation of squeezed states and of imperfect measurements to quantum teleportation of continuous variables by investigating the fidelity of the quantum channel.

Benjamin: Detecting Majorana bound states

Authors: *Colin Benjamin*, Jiannis K. Pachos

We propose a set of interferometric methods on how to detect Majorana bound states induced by a topological insulator. The existence of these states can be easily determined by the conductance oscillations as function of magnetic flux and/or electric voltage. We study the system in the presence and absence of Majorana bound states and observe strikingly different behaviors. Importantly, we show that the presence of coupled Majorana bound states can induce a persistent current in absence of any external magnetic field.

CHOI: MINOR-EMBEDDING IN ADIABATIC QUANTUM OPTIMIZATION

We introduce the notion of minor-embedding in adiabatic quantum optimization. A minor-embedding of a graph G in a quantum hardware graph U is a subgraph of U such that G can be obtained from it by contracting edges. We show that the NP-hard quadratic unconstrained binary optimization (QUBO) problem on a graph G can be solved using an adiabatic quantum computer that implements an Ising spin-1/2 Hamiltonian, by reduction through minor-embedding of G in the quantum hardware graph U. There are two components to this reduction: embedding and parameter setting. The embedding problem is to find a minor-embedding of a graph G in U. The parameter setting problem is to determine the corresponding parameters, qubit biases and coupler strengths, of the embedded Ising Hamiltonian. We will also describe the intertwined adiabatic quantum architecture design problem, which is to construct a hardware graph U that satisfies all known physical constraints and, at the same time, permits an efficient minor-embedding algorithm. We illustrate an optimal complete-graph-minor hardware graph. We will also discuss several related algorithmic problems that need to be investigated in order to facilitate the design of adiabatic algorithms and AQC architectures.

DICKSON: ALGORITHMIC APPROACH TO ADIABATIC QUANTUM OPTIMIZATION

Authors: *Neil G. Dickson*, M. H. S. Amin

Recent papers have suggested that brute force Adiabatic Quantum Optimization (AQO) fails on random hard problem instances because of the presence of 1st-order Quantum Phase Transitions (QPTs). However, by removing several assumptions, we present a simple, heuristic algorithm for eliminating 1st-order QPTs, based on 2nd-order perturbation. Hard random and structured instances with ~10^3 to ~10^18 highly-degenerate local minima and a unique global minimum were generated, and the algorithm was simulated using Quantum Monte Carlo (QMC) and special analysis techniques. A new visualization provides a very detailed look into QPTs and the operation of this algorithm. The algorithm was found to eliminate or reduce the severity of many of the QPTs. This suggests a possible path forward for development of non-brute-force, practical AQO algorithms.

KAWAKUBO: HOMODYNE DETECTION IN VIEW OF JOINT PROBABILITY AND QUANTUM STATE OF LASER

A long-standing problem concerning the quantum state of a laser field is resolved. Considering the photon-number superselection rule, it turns out that the phase of only one laser in the system can be arbitrary fixed. Although the relative phase between independent laser fields are initially random, localization of the relative phase almost always occurs in an interference experiment. Using the concept of conditional independence, it is shown to be valid to assign a coherent state to a laser field, although its phase may be a priori unknown.

LANDON-CARDINAL: EFFICIENT DIRECT TOMOGRAPHY FOR MATRIX PRODUCT STATES

Authors: *Olivier Landon-Cardinal*, Yi-Kai Liu, David Poulin

Matrix product states (MPS) are a variational class of states that can be specified by a small number of parameters. Their importance in quantum many-body physics and quantum information science stems from the fact that they seem to capture the low energy physics of a wide range of one-dimensional systems. We adress the following question: given a state, is it possible to efficiently perform quantum state tomography in order to extract its MPS tensor representation ?

We describe a method for reconstructing these states from a small number of efficiently-implementable measurements. Our method is exponentially faster than standard tomography, and can be used to certify that the unknown state is an MPS. The basic idea is to use local unitary operations to disentangle parts of the system, giving direct access to the tensor representation. This compares favorably with recently and independently proposed methods that recover the MPS tensors by performing a variational minimization, which requires significantly more elaborate computations. Our method also has the advantage of recovering any MPS, while other approaches exclude important examples such as GHZ. There is ongoing work to extend this method to other tensor network states.

MORADI: MIXED STATE ENTANGLEMENT IN RELATIVISTIC FRAMES

In recent years, much interest has been focused in quantum entanglement in relativistic regime. For inertial observers entanglement has no invariant meaning. The reason is that under a Lorentz boost the spin undergoes a Wigner rotation whose direction and magnitude depend on the momentum of the particle. Even if the initial state is a direct product of a function of momentum and a function of spin, the transformed state is not a direct product. Spin and momentum appear to be entangled. A state which is maximally entangled in an inertial frame becomes less entangled if the observers are relatively accelerated. This phenomenon shows that entanglement is an observer-dependent quantity in non inertial frames. The entanglement is degraded by the Unruh effect and asymptotically reaches a nonvanishing minimum value in the infinite acceleration limit. This means that the state always remains entangled to a degree and can be used in quantum information tasks, such as teleportation, between parties in relative uniform acceleration. As a further step along these lines, we investigate the entanglement of mixture of a maximally entangled state and a separable state orthogonal to it in the inertial and non inertial frames. In an inertial frame we study entanglement under Wigner rotations induced by Lorentz transformations. In non inertial frame we investigate the entanglement of scalar and Dirac fields as seen by two accelerated observers. In both cases we show that there are states that will change from entangled into separable for a certain value of velocity or acceleration.

YANG: INEQUALITIES FOR THE QUANTUM SET

Authors: *Tzyh Haur YANG*, Miguel NAVASCUES, Lana SHERIDAN, Valerio SCARANI

The set of probabilities distributions that can arise from measurements on composite quantum systems is not trivial. It contains the set of “local” probabilities, i.e. those that can be generated by shared randomness; and is contained in the set of “no-signaling” probabilities; but is strictly different from both. A characterization in terms of an operational hierarchy of conditions has been given recently [1,2]. For the simplest case of 2 parties, 2 inputs and 2 outputs (“CHSH scenario”), analytical conditions that approximate quite well the quantum set are known [3,4,5] and have been improved in [1,2]. But this is the only case in which such a “quantum inequality” is known. In this work, we exploit the techniques of “macroscopic locality” [6] and obtain a recipe to construct quantum inequalities from Bell’s inequalities. The recipe applies to scenarios with 2 parties and 2 outputs but any number of inputs. Since a large number of Bell inequalities are known for these scenarios, this is an important step in the analytical characterization of the quantum set. We study the tightness of the conditions that are obtained through our method.

[1] M. Navascues, S. Pironio, A. Acin, Phys. Rev. Lett. 98, 010401 (2007)
[2] M. Navascues, S. Pironio, A. Acin, New J. Phys. 10, 073013 (2008)
[3] B. Tsirelson, Had. J. Suppl. 8, 329 (1993)
[4] L.J. Landau, Found. Phys. 18, 449 (1988)
[5] L. Masanes, arXiv:quant-ph/0512100v1
[6] M. Navascues, H. Wunderlich, Proc.Roy.Soc.Lond.A 466, 881 (2009)

VIII. ADDITIONAL ACTIVITIES

BANQUET DINNER – JULY 23RD

Enjoy a three course dinner with workshop attendees at the **Seasons in the Park Restaurant.** Pre-registration is required.

"Poised in Queen Elizabeth Park at the highest point in the city, and overlooking the exquisite quarry gardens, Seasons in the Park Restaurant is a local landmark in a class of its own, having set the standard for distinctive regional cuisine and exceptional service in Vancouver for almost 20 years."

Date and Time: July 23rd, 2010 at 7:30pm

We will meet at 6:00pm in front of Hennings 201 and together take public transportation to the restaurant. Please ensure that you have coins for bus fare. Please note that it will take a 5 minute uphill walk in the Queen Elizabeth Park in order to reach the restaurant.

If you would like to go directly to the restaurant, the Seasons in the Park restaurant is within the Queen Elizabeth Park.

Queen Elizabeth Park
West 33rd Avenue and Main St.,
Vancouver, B.C. Canada
T: 604-874-8008; http://www.vancouverdine.com/seasons0experience.aspx.

There are several transit busses going to the banquet dinner. The easiest way is to take #33 bus and ask the bus driver to let you off at Ontario and West 33rd Avenue. Then take the park entrance road to the top of 'Little Mountain,' which is the Queen Elizabeth Park.

Figure 3 Map of the Seasons in the Park Restaurant

POSTER SESSION – JULY 24TH

The poster session will take place in the Abdul Ladha Science Student Centre (2055 East Mall).

Date & Time: Saturday, July 24th, from 5:00pm to 6:30pm

Set up time: 4:30-5:00 pm

D-WAVE TOUR – JULY 25TH

Bus pick up at 2pm outside of the UBC Bookstore. Tour will start at 3pm (3-5pm).

Includes a two-hour tour to the D-wave lab and a simple demo of a working system, designed mostly for physicists. Bus transportation has been arranged. After the tour participants will be brought back to UBC and dropped off at the Bookstore.

A signup sheet will be available for participants to sign up during the research workshop. If you are unable to locate the signup sheet, please email Theresa Liao (info@qi10.ca) to sign up.

WORKSHOP EVALUATION

We would like to know what you think of the workshop. Your feedback is very important for us in developing future events. An online evaluation form will be available on our website: http://qi10.ca later on.

An email reminder will be sent out after the workshop. We thank you in advance for your help.

NOTES