Southwest Quantum Information and Technology

Twelfth Annual Workshop

El Dorado Hotel

Santa Fe, New Mexico

February 18, 2010 – February 21, 2010

CQuIC

Center for Quantum Information and Control

Twelfth Annual SQuInT Workshop Sponsors

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University of New Mexico; University of Arizona

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Los Alamos National Laboratory: Quantum Initiative

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ORAL PRESENTATIONS

SESSION 1: CQUIC KICKOFF KEYNOTES

Quantum-circuit guide to optical and atomic interferometry

Carlton Caves, University of New Mexico

(Session 1 : Thursday 4:00pm to 4:30pm)

Abstract. Atomic (qubit) and optical or microwave (modal) phase-estimation protocols are placed on the same footing in terms of quantum-circuit diagrams. Circuit equivalences are used to demonstrate the equivalence of protocols that achieve the Heisenberg limit by employing entangled superpositions of Fock states, such as N00N states. The key equivalences are those that disentangle a circuit so that phase information is written exclusively on a mode or modes or on a qubit. The Fock-state-superposition phase-estimation circuits are converted to use entangled coherent-state superpositions; the resulting protocols are more amenable to realization in the lab, particularly in a qubit/cavity setting at microwave frequencies.

Quantum control and computation in circuit quantum electrodynamics.

Gerard Milburn, The University of Queensland

(Session 1 : Thursday 4:30pm - 5:15pm)

Abstract. The new field of circuit quantum electrodynamics (circuit QED for short) has developed in less than a decade driven by technological improvements in the ability to fabricate small circuits from superconducting metals. Much of this development has been motivated by the possibility of implementing quantum computing in such systems, but they are of much wider interest. In this talk I will discuss the feasibility of a number of schemes for quantum feedback control enabled by the new technology. Lehnert has recently demonstrated quantum limited interferometry with high readout efficiency, equivalent to that of a photo-detector reading out an ideal interferometor with efficiency=0.27. This opens up the possibility of doing some important quantum feedback control experiments that are very difficult to do in an atomic or quantum optical setting but very much more feasible in circuit QED. In a quantum optical setting, quantum limited feedback requires that we use all the light leaving the cavity in the measurement process. This is difficult to do in an optical setting but in principle easier in a circuit QED setting. Unlike in an optical setting, all the measured fields are voltages and currents at GHz frequencies on a superconducting wire and thus there is no need to convert from an optical frequency down to a fast electronic signal. Finally the time scales are slower in a circuit to what they are in an all-optical setting and thus fast feedback is more feasible, even with some in-line signal processing. On the other hand, circuit QED presents a difficulty that is not found in optics: we need to make quantum limited homodyne measurements on the cavity output. Lehnert's scheme uses a Josephson parametric amplifier (JPA) which is a phase sensitive amplifier. JPAs have long been used in superconducting electronics, but a key difference in the new devices is the presence of a significant Kerr nonlinearity. I will discuss the quantum noise performance of such devices in circuit QED.

Simulated Electric and Magnetic Fields for Quantum Degenerate Neutral Atoms

William Phillips, Joint Quantum Institute

(Session 1 : Thursday 6:45pm – 7:30pm)

Collaborators: William D. Phillips, Robert L. Compton, Karina Jiménez-García, Yu-Ju Lin, James V. Porto, and Ian B. Spielman Joint Quantum Institute, National Institute of Standards and Technology, and University of Maryland, Gaithersburg, Maryland, 20899, USA

Abstract. We create an effective vector potential for ultra-cold neutral 87Rb atoms by applying laser beams that Raman-couple different magnetic sublevels having different linear momenta. The resulting distorted energy-momentum dispersion relationship is analogous to the Hamiltonian for a charged particle in a magnetic vector potential. A time-varying effective vector potential creates a synthetic electric field, and a spatially varying vector potential creates a synthetic magnetic field. Measuring the momentum imparted to the atoms allows a direct measurement of the impulse imparted by the synthetic electric field, and observation of vortices in the atom cloud reveals the action of the synthetic magnetic field. Such synthetic fields should address some of the difficulties in other approaches to using neutral atoms as quantum simulators of the integer and fractional quantum Hall effects. This work was supported by DARPA/ARO, the NSF, and the ONR.

How to build a fault-tolerant logical qubit with quantum dots

Andrew Landahl, Sandia National Laboratories

(Session 1 : Thursday 7:30pm – 8:15pm)

Abstract. After a brief overview of Sandia's quantum information science effort, I will focus on our current "Grand Challenge" QIST program, a large part of which is aimed at designing a fault-tolerant logical qubit with quantum dots. Because this technology may not be familiar to everyone, I will spend some time reviewing it with especial focus on why silicon might be a good material for quantum-dot qubits. Many theoretical analyses of fault-tolerant quantum error correction omit engineering-level constraints such as the space needed to route control wires to the qubits. We have found that these kinds of considerations have a HUGE impact on the accuracy threshold, and in fact can even cause the accuracy threshold to disappear altogether. I will discuss how theoretical ideas such as quantum local check codes and dynamical decoupling can ameliorate some of these constraints in the quantum dot setting. We have developed several logical qubit architectures based on these ideas, and using high-performance computing we have generated optimal schedules for processing them. Our Monte-Carlo simulations point to the accuracy threshold disappearing entirely if dynamical decoupling is not used in conjunction with fault-tolerant quantum error correction, and when it is, the threshold lies between roughly 10^{-5} to 10^{-3} depending on which local check code is used. Based on arXiv:0904.0003. This work was supported through the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Quantum Key Distribution: longer ranges and stronger security with superconducting detectors and decoy states

Richard Hughes, Los Alamos National Laboratory

(Session 1 : Thursday 8:15pm – 9:00pm)

Abstract. The past few years have seen dramatic advances in the range, rate and security of quantum key distribution (QKD) over optical fiber. These advances have arisen from the development of decoy-state protocols and new superconducting single-photon detector technologies. The former permit rigorous security without adversely impacting the signal-to-noise, and the later offer lower error rates with higher clock rates than conventional detectors. I will describe the results of QKD experiments using superconducting single photon detectors, and the prospects for incorporating decoy-state QKD into transparent optical fiber networks.

SESSION 2: TRAPPED ION QI

Quantum Information Science with Trapped Ca+ Ions

Rainer Blatt, University of Innsbruck

(Session 2 : Friday 8:30am – 9:15am)

Abstract. Trapped strings of cold ions provide an ideal system for quantum information processing. The quantum information can be stored in individual ions and these qubits can be individually prepared; the corresponding quantum states can be manipulated and measured with nearly 100% detection efficiency. With a small ion-trap quantum computer based on up to eight trapped Ca+ ions as qubits we have generated genuine quantum states in a pre-programmed way. In particular, we have generated GHZ and W states in a fast and scalable way and we have demonstrated for the first time a Toffoli gate with trapped ions which is analyzed via state and process tomography. High fidelity CNOT-gate operations are investigated towards fault-tolerant quantum computing and using logical qubits encoded in decoherence-free subspaces, a universal set of gate operations was implemented and analyzed. As applications of quantum information processing, an experimental state-independent test of quantum contextuality was performed, a simulation of the Dirac equation was implemented and a quantum walk with a trapped ion was realized.

Putting the pieces together: Recent progress with trapped ions at NIST

David Hanneke, National Institute of Standards and Technology

(Session 2 : Friday 9:15am – 9:45am)

Abstract. Storing quantum bits in the internal states of trapped atomic ions has proven a successful approach to quantum information processing because of long coherence times and precise interaction with light fields for coherent control and entanglement generation. Here, we present an experiment that combines a complete set of scalable techniques to realize a programmable two-qubit quantum processor. We also highlight other work at NIST that aims at facilitating the realization of large-scale quantum processors using trapped ions. This work includes the development of scalable trap technologies, studies of dynamical-decoupling techniques for memory preservation, and progress towards large scale entanglement generation and quantum simulation. *Work supported by DARPA, NSA, ONR, IARPA, Sandia, and the NIST Quantum Information Program.

Entanglement of Atomic Qubits using an Optical Frequency Comb

David Hayes, Joint Quantum Institute/University of Maryland

(Session 2 : Friday 10:15am – 10:45am)

Abstract. Our group has demonstrated the use of an optical frequency comb to coherently control and entangle atomic qubits. A train of off-resonant ultrafast laser pulses is used to efficiently and coherently transfer population between electronic and vibrational states of trapped atomic ions and implement entangling quantum logic gates with high fidelity. This technique can be extended to the strong field limit with single ultrafast pulses, and this general approach can be applied to the quantum control of more complex systems, such as large collections of interacting atoms or molecules.

Towards wiring up trapped ions

Nikolaos Daniilidis, University of California, Berkeley

(Session 2 : Friday 10:45am – 11:15am)

Abstract . We are pursuing experiments aiming at a transmission-line interface to transfer quantum information between distant ions: An oscillating trapped ion induces oscillating image charges in the trap electrodes. If this current is sent to the electrodes of a second trap, it influences the motion of an ion in the second trap. The expected time for a complete exchange of the motional states can be 1 ms for coupling via a floating conductor located above a surface trap. Alternatively resonant-circuit based geometries with increased coupling rates are also considered. We discuss coupling rates and expected heating rates for different approaches. In addition we discuss trap operation in the presence of a floating conductor. The latter will serve as the coupling electrode in experiments aiming at exchange of the motional states of ions in neighboring trapping regions. This "wire-mediated" coupling may be used for scalable quantum information processing, but may also interconnect atomic systems to solid-state systems.

Novel Ion Trap for Efficient Fluorescence Collection from Trapped Ion Qubits

Gang Shu, University of Washington

Session 2 : Friday 11:15am – 11:45am)

Abstract . Efficient ion fluorescence collection is critical for fast reliable qubit state detection and higher photon collection rates from single trapped ions or atoms would lead to more efficient single-photon sources and ion-photon entanglement. By integrating a high N.A. spherical mirror into a linear Paul trap, we achieved 10% photon collection efficiency from a single Barium ion qubit. Based on the current successful trap, we designed and built a novel trap in which the reflective optical surface serves as the RF electrode. The new trap geometry is very open and almost 30% of the photons emitted by the ion will be intercepted. Additionally, the axial symmetry of the trap provides means for self-alignment of the ion trapping position and the optical axis of the spherical mirror. Its smaller size will proportionally reduce the spherical aberration so that we can achieve diffraction-limited ion image, and attempt to couple ion fluorescence into a single mode optical fiber for remote ion entanglement. The design can be easily miniaturized and fabricated with standard MEMS technology. Compared to refractive optics systems, our solution has the advantage of simplicity, low cost, flexibility and scale-up potential.

SESSION 3: QUANTUM INFORMATION THEORY

New Evidence that Quantum Mechanics is Hard to Simulate on Classical Computers

Scott Aaronson, Massachusetts Institute of Technology

(Session 3 : Friday 1:15pm – 2:00pm)

Abstract . I'll discuss new types of evidence that quantum mechanics is hard to simulate classically -- evidence that is more complexity-theoretic in character than (say) Shor's factoring algorithm, and that also corresponds to experiments that seem easier than building a universal quantum computer. Specifically: (1) I'll show that linear-optics (that is, systems of non-interacting bosons) produce probability distributions that cannot be efficiently sampled by a classical computer, unless P^#P = BPP^NP and hence the polynomial hierarchy collapses. I'll also discuss an extension of this result to samplers that only approximate the boson distribution. (Based on recent joint work with Alex Arkhipov) (2) Time permitting, I'll also discuss new oracle evidence that BQP has capabilities outside the entire polynomial hierarchy. (arXiv:0910.4698)

An information-theoretic interpretation of topological entanglement entropy

Jon Yard, Los Alamos National Laboratory

(Session 3 : Friday 2:00pm – 2:30pm)

Abstract. Topological entanglement entropy, as defined by Preskill & Kitaev (PRL) and Levin & Wen (PRL), is an entropic quantity that tells when a 2D quantum system displays topological order. But what exactly does it measure? Topological entanglement entropy can be expressed via the quantum conditional mutual information I(A;B|C) associated to certain kinds of partitions of the system into parts A,B,C and D. In this talk, I will show how an operational interpretation of I(A;B|C) that I co-discovered with Devetak (PRL, IEEE Trans. Info. Th.) may lead to an understanding of topological entanglement entropy as the qubit communication cost associated with a particular topology change of the underlying regions. This opens the door for a more precise understanding of the sort of nonlocalized entanglement that is quantified by topological entanglement entropy.

What is special about quantum entropy?

Howard Barnum, Perimeter Institute for Theoretical Physics

(Session 3 : Friday 2:30pm – 3:00pm)

Abstract. What is special about quantum entropy? Howard Barnum, Perimeter Institute for Theoretical Physics Pawlowski et. al. recently showed that stronger-than-quantum correlations (ones that violate the Tsirel'son bound on the strength of CHSH/Bell correlations) violate a principle they call Information Causality. The principle states that, using some shared correlations plus classical communication as a resource, the total mutual information Alice can make available to Bob about a set S of classical bits cannot exceed the number of bits of classical communication she uses, even though this total mutual information is the sum of alternative, possibly mutually exclusive strategies Bob can use to get each of the bits of S ("random-access coding", in computer science jargon). They also showed that quantum theory satisfies this principle. We examine the question of what properties of a theory may lead to its correlations satisfying information causality. We define measurement and preparation entropies for states of a general class of theories: the minimum, over finegrained measurements on the state, of the Shannon entropy of the probabilities of the outcomes of the measurement, and the minimum, over pure-state ensembles for the state, of the Shannon entropies of the ensemble probabilities. We find sufficient conditions for information causality in terms of these entropies: If the measurement entropy satisfies a data-processing inequality, and if the conditional measurement entropy is positive when the conditioning is on a classical system, then information causality holds. Besides the principle of strong subadditivity (which is closely related to data processing) this focuses attention on another property of quantum entropy, the positivity of entropy conditional on a classical system. We show that this property follows from another very natural one exhibited by quantum theory, but that does not hold in general: the equality of measurement and preparation entropy. We briefly consider the implications of this principle for the structure and information-processing possibilities of theories. Joint work with Jonathan Barrett, Lisa Orloff Clark, Matthew Leifer, Robert Spekkens, Nicholas Stepanik, Alex Wilce, and Robin Wilke.

SESSION 4: NANOMECHANICAL RESONATORS

Preparation and Detection of an RF Mechanical Resonator Near the Ground State of Motion

Keith Schwab, Caltech

(Session 4 : Friday 3:30pm – 4:15pm)

Abstract. The tools and techniques to prepare mechanical structures in fundamental quantum states are being rapidly developed, using both optical and electrical techniques. To prepare the quantum ground state, we are preforming experiments with a mechanical resonator parametrically coupled to a electrical resonator. The mechanical resonator is a very low dissipation (Q>1M), 6 MHz, nanomechanical structure; the electrical resonator is a lithographic, low dissipation (Q=20,000), superconducting niobium, 7.5 GHz resonator. We pump this structure with carefully prepared microwave photons and demonstrate cooling of the mechanical structure of quantum occupation <N>=3.8. The deep quantum limit, <N> <<1, appears within reach with a modified device.

Nanomechanical motion measured with an imprecision below the standard quantum limit

Tobias Donner, JILA, National Institute of Standards and Technology and the University of Colorado, Boulder

(Session 4 : Friday 4:15pm – 4:45pm)

Abstract. Observing quantum behavior of mechanical motion is challenging because it is difficult both to prepare pure quantum states of motion and to detect those states with high enough precision. We present displacement measurements of a nanomechanical oscillator with an imprecision below that at the standard quantum limit [1]. To achieve this, we couple the motion of the oscillator to the microwave field in a high-Q superconducting resonant circuit. The oscillator's displacement imprints a phase modulation on the microwave signal. We attain the low imprecision by reading out the modulation with a Josephson Parametric Amplifier, realizing a microwave interferometer that operates near the shot-noise limit. The apparent motion of the mechanical oscillator due the interferometer's noise is now substantially less than its zero-point motion, making future detection of quantum states feasible. In addition, the phase sensitivity of the demonstrated interferometer is 30 times higher than previous microwave interferometers, providing a critical piece of technology for many experiments investigating quantum information encoded in microwave fields. [1] J. D. Teufel, T. Donner, M. A. Castellanos-Beltran, J. W. Harlow, K. W. Lehnert, Nature Nanotechnology, doi:10.1038/nnano.2009.343, (2009).

<u>SESSION 6: NEUTRAL ATOM QI</u>

"Quantum Interference Experiments with One and More Neutral Atoms"

Dieter Meschede, Universitaet Bonn

(Session 6 : Saturday 8:30am – 9:15am)

Abstract. The wave properties of material particles are one of the most widely known features of quantum physics. Wave properties become apparent in diffraction and perhaps most strikingly in interference phenomena. In this talk I will present experiments where we trap and control up to a dozen neutral atoms by means of optical dipole forces. I will show how to selectively address individual atoms, how to transport and sort them, and how to store and retrieve information from the atomic qubits. Recently, we have taken the atoms to the full quantum regime, i.e. to the observation of matter wave interferences at the single trapped atom level. We have demonstrated the quantum analogue of Brownian motion, the quantum walk, a concept of relevance in quantum information science. We have furthermore obtained excellent control of atomic motion using microwaves, including cooling to the vibrational ground levels and the creation of single particle entangled states. In a separate line of experiments we have been able to read out the spin quantum states in dispersive manner. I will discuss the options to create correlated many atom quantum states based on the available protocols.

Single-Atom Single-Photon Quantum Interface

David Moehring, Sandia National Laboratories

(Session 6 : Saturday 9:15am – 9:45am)

Abstract. We report on the implementation of a deterministic protocol where a single rubidium atom trapped within a high-finesse optical cavity is entangled with a single emitted photon. After a chosen time, the atomic state is mapped onto a second photon, thus generating an entangled photon pair. Compared to previous experiments, the long trapping times of exactly one atom in the mode of the cavity allow for 10^5 times more entangled photons per atom. The entanglement is verified by a Bell inequality measurement and via quantum state tomography, both showing a clear violation of classical physics. The combination of two independent atom-cavity systems may further allow for the efficient generation of remote-atom entanglement in the near future. *The presented work was completed at the Max Planck Institute of Quantum Optics in the group of Gerhard Rempe.

Quantum Control of Neutral Atoms Qudits and Transport

Brian Mischuck, University of New Mexico

(Session 6 : Saturday 10:15am – 10:45am)

Abstract. Quantum control offers a variety of techniques to manipulate quantum systems in order to perform a desired evolution. We describe the application of these ideas to two different problems in the control of neutral atoms. In the first problem, we consider control of the hyperfine spin manifold a cloud of cold atoms driven by microwave and radio-frequency fields. The large number of spin states available in individual atoms makes them candidates for a qudit based quantum computer. Because the Hamiltonians that drive the system may vary spatially and/or temporally, collections of atoms form ensembles of distinguishable qudits. Borrowing from ideas originally developed for NMR, we show how to drive the ensembles through a given desired evolution. This allows for robust control and spatial selectivity of ensembles of atoms. In the second problem we show how atoms' transport in an optical lattice can be controlled through polarization control of the optical lattice and global microwave pulses. This control is a necessary first step in many of the neutral atom based schemes for quantum computation and simulation, as well as a realization of a quantum walk. We show that with the available global control, any unitary or state synthesis consistent with translational invariance may be performed.

Quantum State Mapping in the Cs 133 Full Hyperfine Ground Manifold

Aaron Smith, University of Arizona

(Session 6 : Saturday 10:45am – 11:15am)

Collaborators: Aaron Smith, Brian E. Anderson, Poul Jessen: Center for Quantum Information and Control, College of Optical Sciences, University of Arizona

Abstract. Quantum systems with Hilbert space dimension greater than two (qudits) are often thought of as carriers of quantum information, usually by isolating a convenient pair of states (qubit) and working entirely within this two dimensional embedded subspace. Quantum control of the entire qudit system could prove to be very useful for information processing tasks allowing for the implementation of novel protocols for robust qubit manipulation and error correction. Quantum control of systems with large Hilbert space dimension, especially collective spins, also has near-term applications in quantum metrology. We will describe a method in which to achieve universal quantum control of the entire 16 dimensional hyperfine ground manifold of Cesium using a nearly decoherence free protocol involving the application of static, RF, and microwave magnetic fields. A simple numerical optimization routine can be used to design time dependent control fields that map any initial state onto any target state. We have implemented this control protocol in our experiment and have successfully mapped our initial state, |F=4, m=4>, onto all 16 magnetic eigenstates. We measure the fidelity of the state mapping using Stern-Gerlach analysis and we have achieved fidelities in the range ~ 94% - 98% which is limited almost entirely by errors in the control fields. Our next step is to implement a weak measurement in combination with dynamical control, and to perform quantum state reconstruction based on the resulting measurement record.

A neutral atom quantum memory created by diffraction of laser light at an array of pinholes

Katharina Gillen, California Polytechnic State University, San Luis Obispo

(Session 6 : Saturday 11:15am – 11:45am)

Abstract. We present an idea for a new quantum memory for neutral atom quantum computing: Atom traps formed behind an array of pinholes. The diffraction pattern directly behind a circular

aperture exhibits localized intensity maxima and minima that can serve as red-detuned or blue-detuned dipole traps for cold atoms, respectively. Previous calculations [1] suggest that the trap frequencies (kHz to 10s of kHz) achieved for even moderate laser powers (~100 mW) are theoretically sufficient for trapping atoms with low decoherence rates from motional heating and trap light scattering. This approach can be extended to an array of pinholes, thereby creating a 2D array of trapping sites that can be used as a quantum memory. The 2D geometry allows addressing of individual trapping sites with a focused laser beam for performance of single qubit operations. In addition to trapping atoms in the sites of this pattern, the polarization-dependence of atoms in certain atomic substates [2] can be exploited to bring pairs of atoms together and apart to facilitate two-qubit quantum gates. We will discuss our latest computational results on these trap arrays and the ability of bringing pairs of traps together and apart for quantum operations. [1] G. D. Gillen, et al., Phys. Rev. A 73, 013409 (2006), [2] I. H. Deutsch, et al., Phys. Rev. A, 57 (3), 1972-1986 (1998).

Session 7: Quantum Algorithms

QIP = PSPACE

John Watrous, University of Waterloo
(Session 7 : Saturday 1:15pm – 2:00pm)

Abstract. The interactive proof system model of computation is a cornerstone of complexity theory, and its quantum computational variant has been a topic of study in quantum complexity theory for the past decade. In this talk I will present an exact characterization of the expressive power of quantum interactive proof systems that I recently proved in collaboration with Rahul Jain, Zhengfeng Ji, and Sarvagya Upadhyay. The characterization states that QIP = PSPACE, or in other words that the collection of computational problems having quantum interactive proof systems consists precisely of those problems solvable in polynomial space with an ordinary classical Turing machine. This characterization implies the striking fact that quantum computing does not provide an increase in computational power over classical computing in the context of interactive proof systems.

Multi-query quantum algorithms for summation

David Meyer, University of California/San Diego
(Session 7 : Saturday 2:00pm – 2:30pm)

Abstract. PARITY is the problem of determining the parity of a string f of n bits given access to an oracle that responds to a query x ∈ {0, ..., n-1} with the xth bit of the string, f(x). Classically n queries are required to succeed with probability greater than 1/2, but only the least integer greater than n/2 number of quantum queries suffice to determine the parity with probability 1. We consider a generalization to strings f of n elements of Z_{k} and the problem of determining ∑f(x). By constructing an explicit algorithm, we show that with n - r quantum queries the optimal success probability is at least the greatest integer less than n/r, divided by k. This quantum algorithm utilizes the n - r queries sequentially and adaptively, like Grover's algorithm, but in a different way that is not amplitude amplification.

Fast Quantum Algorithms for Traversing Paths of Eigenstates

Rolando Somma, Los Alamos National Laboratory

(Session 7 : Saturday 2:30pm – 3:00pm)

Abstract. We present optimal quantum algorithms to traverse the path of eigenstates of a discrete or continuous family of Hamiltonians. The implementation cost of the algorithms is the total evolution time with the Hamiltonians. Under some assumptions, the cost of the method is proportional to the ratio of the length of the eigenstate path to the minimum eigenvalue gap of the Hamiltonians. When no assumptions are made, the worst-case cost scales with the inverse of the gap squared. Our algorithms advance by preparing eigenstates from previous ones through a version of fixed point search that is approximated using the phase estimation algorithm. The cost of our methods is optimal and significantly improves upon the cost of known general methods for quantum adiabatic state preparation. In some cases, our methods yield a quantum speed-up over well-known classical annealing methods. (Unitary versions of the method can also be considered.)

SESSION 8: BREAKOUT I: QUANTUM COMPUTING

Permutational Quantum Computing

Stephen Jordan, California Institute of Technology

(Session 8 : Saturday 3:30pm – 4:00pm)

Abstract. In topological quantum computation the geometric details of a particle trajectory are irrelevant; only the topology matters. Taking this one step further, we consider a model of computation that disregards even the topology of the particle trajectory, and computes by permuting particles. Whereas topological quantum computation requires anyons, permutational quantum computation can be performed with ordinary spin-1/2 particles, using a variant of the spin-network scheme of Marzuoli and Rasetti. We do not know whether permutational computation is universal. It may represent a new complexity class within BQP. Nevertheless, permutational quantum computers can in polynomial time approximate matrix elements of certain irreducible representations of the symmetric group and simulate certain processes in the Ponzano-Regge spin foam model of quantum gravity. No polynomial time classical algorithms for these problems are known.

Some new constructions for Local Hamiltonian and universal adiabatic quantum computing

Peter Love, Haverford College

(Session 8 : Saturday 4:00pm – 4:30pm)

Abstract. The difficulty of finding the ground state energy of a Hamiltonian is formalized in quantum complexity theory through the problem Local Hamiltonian. Various restrictions of the form of the Hamiltonians in this problem have been studied, including, inter alia, restricted locality and geometry of couplings, coupling strengths, interaction types and stoquasticity of the Hamiltonians. Concomitantly, such results typically tell us which physical Hamiltonians are capable of realizing universal quantum computation adiabatically. In this talk I will describe some new results on the problem Local Hamiltonian that allow universal adiabatic quantum computation in stoquastic Hamiltonians, restrict the form of the Hamiltonian required, and reduce (but do not eliminate) the need for perturbative gadgets. I will discuss the implications of these results for the design of universal adiabatic quantum computers.

Geometrization of quantum adiabatic computation

Ali Rezakhani , University of Southern California

(Session 8 : Saturday 4:30pm – 5:00pm)

Abstract. A time-optimal approach to adiabatic quantum computation (AQC) will be formulated. The corresponding natural Riemannian metric is also derived, through which AQC can be understood as the problem of finding a geodesic on the manifold of control parameters. This geometrization of AQC and its relation with quantum phase transitions are demonstrated through some examples, where we show that the geometric formulation leads to improved performance of AQC, and sheds light on the roles of entanglement and curvature of the control manifold in algorithmic performance.

Distinguishing the Borel subgroups of PSL(2; q)

Aaron Denney, University of New Mexico

(Session 8 : Saturday 5:00pm – 5:30pm)

Abstract. The Hidden Subgroup Problem (HSP) has been a fruitful framework for expressing many quantum algorithms, and the Abelian case is completely understood. Most efforts to attack non-Abelian groups have been based on splitting these groups into simpler factors. The non-Abelian simple group PSL(2; q) has no non-trivial factors, so cannot be attacked in this way. Further, it has no known efficient quantum Fourier transform. As such, the standard method for distinguishing subgroups fails almost from the beginning. However, we can use the 3-transitivity of PSL(2; q) to distinguish among a large set of stabilizer subgroups by working with their intersections, and reducing to a smaller group with an efficient transform. These stabilizer subgroups are conjugates of the Borel subgroup of upper triangular matrices. Although restricted to this one class of subgroups, this is the first efficient algorithm for a case of the HSP in a family of non-Abelian simple groups.

SESSION 9: BREAKOUT II – METROLOGY AND MEASUREMENT

Practical quantum metrology with Bose-Einstein condensates

Alexandre Tacla, University of New Mexico

(Session 9 : Saturday 3:30pm - 4:00pm)

Abstract. We analyze in detail the recently proposed experiment [Boixo et al., Phys. Rev. Lett. 101 , 040403 (2008)] for achieving better than 1/N scaling in a quantum metrology protocol using a two mode Bose-Einstein condensate of N atoms. There were several simplifying assumptions in the original proposal that made it easy to see how a scaling approaching 1/N^(3/2) may be obtained. We look at these assumptions in detail to see when they may be justified. We present numerical results that confirm our theoretical predictions for the effect of the spreading of the BEC wave function with increasing N on the scaling. Numerical integration of the coupled Gross-Pitaevskii equations for the two mode BEC also shows that the assumption that the two modes share the same spatial wave function is justified for a length of time that is sufficient to run the metrology scheme.

Quantum Eraser and Phase-Matching for Exponential Spin-Squeezing via Coherent Optical Feedback

Colin Trail, University of New Mexico

(Session 9 : Saturday 4:00pm - 4:30pm)

Abstract. A scheme for squeezing collective atomic spin states via coherent optical feedback was proposed by M. Takeuchi et. al., Phys. Rev. Lett. 94, 023003, 2005. In the first pass, the Faraday effect acts to entangle the light with the atoms. In a coherent second pass, this information is imprinted back onto the atoms, creating an effective nonlinear interaction and entanglement between atoms. However, the light is still entangled to the atoms when it escapes, leading to substantial decoherence, and moreover, the interaction slowly rotates the system out of sync with the squeezing axis, both of which result in suboptimal squeezing. We show how the addition of a quantum eraser and phase matching can lead to radically improved exponential scaling. We analyze this system in the presence of realistic imperfections such as photon scattering, optical pumping, losses in transmission and reflection, finite detector efficiency, and nonprojective measurements, and show that spin squeezing near 10 dB should be possible.

Time-Symmetric Quantum Smoothing: A General Theory of Optimal Quantum Sensing

Mankei Tsang, University of New Mexico

(Session 9 : Saturday 4:30pm – 5:00pm)

Abstract. In real-world sensing applications, the signal to be estimated, such as the position of an aircraft, a gravitational wave, or a magnetic field, is seldom a parameter constant in time but a fluctuating random process. Drawing insights from Bayesian estimation theory, I shall demonstrate how the optimal estimation of a random process coupled to a quantum sensor can be done using the recently proposed quantum smoothing theory. The theory calls for the use of not one but two density operators, one to be solved forward in time and one backward in time, and can out-perform conventional quantum filtering methods if delay is permitted in the estimation. Potential applications include gravitational wave sensing and atomic magnetometry. The accuracy improvement of quantum optical phase estimation due to smoothing has recently been experimentally demonstrated by an Australian-Japanese collaboration [Wheatley et al., arXiv:0912.1162].

Tomographic reconstruction of the Wigner function of an itinerant microwave field.

Francois Mallet, Joint Institute for Laboratory Astrophysics

(Session 9 : Saturday 5:00pm – 5:30pm)

Collaborators: Francois Mallet,, Manuel Castellanos-Beltran, Hsiang-Sheng Ku, Kent Irwin, Leila Vale, Gene Hilton, Konrad Lehnert.

Abstract. In an increasing number of experiments, the desired information (for example the state of nanomechanical resonators or of superconducting qubits) is successfully encoded into the state of a coherent microwave field. However these experiments suffer from the lack of high efficiency detectors at microwave frequencies: the best commercially available amplifiers add twenty times more noise than the intrinsic quantum fluctuations of the field. Our group has made a crucial step to overcome this important limitation by developing quantum limited Josephson Parametric Amplifiers (JPAs) [1]. In this talk I will show how we dramatically increase the performance of the Quantum State Tomography of a squeezed state of the microwave field by using our JPAs. The achieved degree of squeezing and the quantum efficiency of the state tomography will be presented from the point of view of using these squeezed states as building blocks of a more global strategy to perform Quantum Information experiments. Indeed it has been shown in the field of Continuous Variables Quantum Information that theses squeezed states, can be combined to create EPR-like entangled states. Conveniently, the non-classical squeezed states are themselves created by the JPAs. [1] Amplification and squeezing of quantum noise with a tunable Josephson metamaterial, M. Castellanos-Beltran et al., Nat. Phys. 4, 929-931 (2008).

SESSION 10: BREAKOUT III – QUANTUM COMMUNICATION

Mathematical model for real-world entanglement swapping and applications to practical long-distance quantum key distribution

Artur Scherer, Institute for Quantum Information Science at the University of Calgary

(Session 10 : Saturday 3:30pm – 4:00pm)

Abstract. Entanglement swapping between photon pairs is a key building block in entanglement-based quantum communication schemes using quantum relays or quantum repeaters to overcome the range limits of long-distance quantum key distribution (QKD). We present a nonperturbative mathematical model for practical entanglement swapping, which accounts for real-world imperfections due to detector inefficiencies, detector dark counts and the unavoidable multipair events of current realistic sources of entangled photon pairs. Our closed-form solution for the actual quantum states prepared by realistic entanglement swapping is useful for planning long-distance QKD experiments. In particular, our analysis provides the optimal photon-pair production rate (brightness) of the sources that maximizes the secret key rate for a given distance between a sender (Alice) and a receiver (Bob).

A photonic cluster state machine gun

Netanel Lindner, Caltech - Institute of Quantum Information

(Session 10 : Saturday 4:00pm – 4:30pm)

Abstract. We present a method to convert certain single photon sources into devices capable of emitting large strings of photonic cluster state in a controlled and pulsed ‘‘on-demand’’ manner. Standard spin errors, such as dephasing, are shown to affect only 1 or 2 of the emitted photons at a time. This allows for the use of standard fault tolerance techniques, and shows that the photonic machine gun can be fired for arbitrarily long times. Using realistic parameters for current quantum dot sources, we conclude high entangled photon emission rates are achievable, with Pauli-error rates per photon of less than 0.2%. For quantum dot sources, the method has the added advantage of alleviating the problematic issues of obtaining identical photons from independent, nonidentical quantum dots, and of exciton dephasing.

Frequency Translation of Single-Photon States by Four-Wave Mixing in a Photonic Crystal Fiber

Hayden McGuinness, University of Oregon

(Session 10 : Saturday 4:30pm – 5:00pm)

Abstract. We study the effect of frequency translation of single-photon states in optical fiber through use of the Bragg scattering four-wave mixing process. Preliminary evidence shows that we have successfully translated single-photon wave-packets from wavelength 696 nm to 680 nm, while maintaining photon statistics in the nonclassical regime.

Quantum secret sharing with qudit graph states

Ben Fortescue, Institute for Quantum Information Science, University of Calgary

(Session 10 : Saturday 5:00pm – 5:30pm)

Abstract. We present a formalism for quantum secret sharing using graph states of systems with prime dimension. As we show, such states allow for a unified structure for the sharing of classical and quantum secrets over both classical and quantum channels. We give explicit protocols for three varieties of threshold secret sharing within this formalism. Joint work with Adrian Keet and Barry C. Sanders.

Session 11: Quantum Information and Condensed Matter

Proving Hall Conductance Quantization

Matthew Hastings, Microsoft Station Q

(Session 11 : Sunday 8:30am – 9:15am)

Abstract. Ever since Laughlin's original gauge argument for Hall conductance quantization, mathematicians and physicists have tried to find a general proof. Unfortunately, current approaches either require extra assumptions or are limited to noninteracting electrons. Using quasi-adiabatic continuation, we are able to remove these limitations. I will try to explain how quasi-adiabatic continuation can be used as a general "toolkit": once the machinery is developed, many results follow directly, including this, the higher dimensional Lieb-Schultz-Mattis theorem, Goldstone's theorem, and more. This is joint work with S. Michalakis.

Trapping ultracold dysprosium

Benjamin Lev, University of Illinois at Urbana-Champaign

(Session 11 : Sunday 9:15am – 9:45am)

Abstract. Ultracold dysprosium gases, with a magnetic moment ten times that of alkali atoms and equal only to terbium as the most magnetic atom, are expected to exhibit a multitude of

fascinating collisional dynamics and quantum dipolar phases, including quantum liquid crystal physics. We report the first laser cooling and trapping of half a billion Dy atoms using a repumper-free magneto-optical trap (MOT) and continuously loaded magnetic confinement, and we characterize the trap recycling dynamics for bosonic and fermionic isotopes. The first inelastic collision measurements in the few partial wave, 100 uK to 1 mK, regime are made in a system possessing a submerged open electronic f-shell. In addition, we observe unusual stripes of intra-MOT <10 uK sub-Doppler cooled atoms.

SESSION 12: QUANTUM SIMULATION

Quantum mechanical aspects of photosynthesis

Mohan Sarovar, University of California, Berkeley

(Session 12 : Sunday 10:15am – 10:45am)

Abstract. Identification of non-trivial quantum mechanical effects in the functioning of biological systems has been a long-standing and elusive goal in the fields of physics, chemistry and biology. Recent progress in control and measurement technologies, especially in the optical spectroscopy domain, have made possible the identification of such effects. In particular, electronic coherence was recently shown to survive for relatively long times in photosynthetic light harvesting complexes despite the effects of noisy bio-molecular environments. Combining techniques from quantum information, quantum dynamical theory and chemical physics, we performed several detailed studies to characterize the extent and nature of quantum dynamics in light harvesting structures. I will present results that demonstrate (i) the presence of long-lived quantum entanglement in these biologically relevant structures, (ii) the lack of sustained quantum speedup in light harvesting complex dynamics, and (iii) the effect of environmental fluctuations on coherence and transport properties in these systems. Our results scrutinize the fine details of light harvesting complex dynamics and reveal the complex interplay between coherent and decoherent dynamics present in these systems.

An efficient algorithm to find mean field and Matrix Product State solutions for one-dimensional systems

Norbert Schuch, California Institute of Technology

(Session 12 : Sunday 10:45am – 11:15am)

Abstract. We prove that the best approximation to ground states of one-dimensional quantum systems within the two most common variational ansatzes, namely the mean field ansatz and Matrix Product States, can be found efficiently. This shows that the corresponding variational methods, in particular the Density Matrix Renormalization Group method, can be realized in a provably efficient way, placing their success on a rigorous footing. Moreover, our findings imply that ground states of commuting Hamiltonians in one dimension can be found efficiently.

Spin Squeezing, Large-Scale Entanglement, and Quantum Simulation in Ion Crystals

Michael Biercuk, National Institute of Standards and Technology

(Session 12: Sunday 11:15am – 11:45am)

Collaborators: M.J. Biercuk, H. Uys, D. Meiser, A. P. VanDevender, C. Ospelkaus, N. Shiga, W. M. Itano, and J. J. Bollinger

Abstract. We describe experimental and theoretical efforts aimed at the realization of nonlinear multipartite interactions using planar ion crystals in a Penning trap. This system benefits from the ability to confine large ion arrays with regular and stable crystalline order, and direct measures of particle number through resonant fluorescence detection. A global entangling interaction is engineered using state-dependent optical dipole forces, resulting in a simple distance-independent Ising interaction similar to single-axis-twisting spin squeezing. We present direct

observations of optical-dipole-force excitation of the center-of-mass (COM) mode for a planar crystal using phase-coherent Doppler velocimetry. By combining state-dependent excitation of the COM mode with microwave-mediated global spin control in arrays of up to ~150 ions, we demonstrate a frequency-dependent loss of phase coherence in the spin ensemble due to coherent interaction of spin and motion. Prospects for realizing true deterministic spin squeezing using trapped ions, including the influence of dissipation via elastic Rayleigh scattering are presented, and future experimental directions described.

POSTER PRESENTATIONS

1. Scalable Ion Traps for Quantum Information Processing

Jason Amini, National Institute of Standards and Technology

Abstract. The basic components for a quantum information processor using trapped ions have been demonstrated in a number of experiments. To perform complex algorithms that are not tractable with classical computers, these components need to be integrated and scaled to larger numbers of qubits. We report the design, fabrication, and preliminary testing of a 150 zone array built in a `surface-electrode' geometry microfabricated on a single substrate. We demonstrate transport of atomic ions between legs of a `Y'-type junction and measure the in-situ heating rates for the ions. The trap design demonstrates use of a basic component design library that can be quickly assembled to form structures optimized for a particular experiment. *Work supported by IARPA, DARPA, NSA, ONR, Sandia, and the NIST Quantum Information Program.

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2. Synchronization of Barium Ion Qubit Controls

Aaron Avril, University of Washington

Abstract. We report on the progress of construction and integration into experiment of a pulse programmer for synchronizing equipment used in Ba+ ion hyperfine qubit control. The hardware includes 3 direct digital synthesizer (DDS) boards for synthesizing wave packets of arbitrary frequency, amplitude, and phase with frequencies up to 800MHz, 28 TTL outputs with rise times below 5ns, and 8 TTL inputs. Together, these features may be used to control acousto-optical modulators, shape laser pulses, trigger lab equipment, read the data, and react to external events. This hardware is synchronized to a single internal clock, and controlled by a sequencer board that distributes commands from user-specified functions. At the time of writing, we are in the process of characterizing the behavior of the DDS boards to ensure reliability. We are developing firmware to count inputs from a photomultiplier tube that will be used to record detection of the qubit state.

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3. Ultra Smooth Microfabricated Mirrors for Atom Chip Based Cavity QED

Grant Biedermann, Sandia National Laboratories

*Collaborators***:** T. Loyd, F. Benito, G. Biedermann, K. Fortier, D. Stick, P. Schwindt, M. Blain Sandia National Laboratories, Albuquerque, NM 87185

Abstract. Microfabricated optical cavities are an attractive system for atomic physics research. When paired with an atom the small mode volume can lead to strong atom-cavity coupling with only a modest finesse. Such systems are of significant interest for applications in quantum information [1]. While experiments using a single cavity or a small number of cavities tend to be tractable, scaling the number of cavities required for a useful quantum network remains speculative [2]. In response, we are blending microfabricated Si mirrors [3] with atom chip technology and its inherent precision [4]. We have demonstrated that our micro-mirror fabrication technique produces ultra smooth mirror surfaces of 2.16 Angstroms rms. Optical cavities formed with these mirrors exhibit a high finesse of 64,000. This performance leads to a calculated single atom cooperativity of over 200 making these cavities attractive candidates for integrated cavity QED experiments and quantum information processing on a chip. [1]. P K. Vahala, ed., Optical Microcavities, (World Scientific, Singapore, 2004). [2]. H. J. Kimble, Nature, 453, 1023 (2008). [3]. M. Trupke, E. A. Hinds, S. Eriksson, E. A. Curtis, Z. Moktadir, E. Kukharenka, and M. Kraft, Appl. Phys. Lett., 87, 211106 (2005). [4]. Y. Colombe, T. Steinmetz, G. Dubois, F. Linke, D. Hunger, J. Reichel, Nature, 450, 272 (2007).

5. Quantum Information and Simulation with ⁸⁷Sr

Michael Bishof, JILA/University of Colorado at Boulder

Abstract. Quantum Information and Simulation with ⁸⁷Sr Michael Bishof, Matthew Swallows, Michael J. Martin, Yige Lin, Sebastian Blatt, Travis L. Nicholson, Benjamin Bloom, and Jun Ye Fermionic alkaline earth(like) atoms have recently attracted considerable attention in the context of quantum information science. When trapped in optical lattices, their unique properties offer novel solutions to current challenges in neutral atom quantum information processing. Recent proposals have outlined schemes for quantum computation that employ these atoms as single qubits or few qubit registers. In a broader context, new ideas have emerged on how to use lattice-trapped alkaline earth atoms as quantum simulators of unique many-body phenomena. We present possible implementations of these proposals for the specific case of ⁸⁷Sr, a fermionic isotope with a 9/2 nuclear spin.

6. Arbitrary and Dynamic Painted Potentials for Bose-Einstein Condensates

Malcolm Boshier, Los Alamos National Labs.

Collaborators: Changhyun Ryu, Kevin C. Henderson, and Malcolm G. Boshier

Abstract. We report on a robust and straightforward method to create potentials for trapping Bose-Einstein condensates which are simultaneously dynamic, fully arbitrary, and sufficiently stable to not heat the ultracold gas. Our technique uses a rapidly-moving laser beam that “paints” a time-averaged optical dipole potential in which we create BECs in a variety of geometries, including toroids, ring lattices, and square lattices. Matter wave interference patterns confirm that the trapped gas is a condensate. As a simple illustration of dynamics, we show that the technique can transform a toroidal condensate into a ring lattice and back into a toroid.

7. Atom-chip based tunable optomechanical system

Thierry Botter, UCB

Abstract. Ultracold atoms placed inside high-finesse cavities have provided a new perspective on optomechanics. Much like their solid-state counterparts, involving micromechanical membranes and small-scale cavities, these atom-based systems involve strong coupling between the mechanical motion of the atomic ensemble and the circulating light field. However, they have the added benefits of having a low thermal occupation number and little coupling to the surroundings. In our atom-chip based optomechanical system, atoms can be freely positioned relative to the standing wave, leading to both linear and quadratic optomechanical coupling, with contrast as large as 80%. Both the mechanical resonator frequency and the coupling strength can be tuned by varying the intracavity field intensity.We report on recent results from this system, including optical bistability, optomechanical frequency shift and heating in both coupling regimes.

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8. 4.2 K surface electrode trap for Be+ ions

Kenton Brown, National Institute of Standards and Technology

Abstract. Ion traps with cryogenic electrodes present several advantages over their room temperature counterparts, including longer ion lifetimes, lower motional heating rates, and the possibility of coupling ions to other systems that function only at cryogenic temperatures. We have recently built a surface electrode ion trap for Be+ ions (ion height 40 microns) that incorporates electrodes cooled to 4.2 K, a bakeable copper vacuum enclosure surrounding the electrodes, and an achromatic, completely reflective, in-vacuum imaging objective. Preliminary results indicate an ion lifetime limited only by the stability of our cooling laser, effective shielding from magnetic field fluctuations, and high trapping frequencies (> 30 MHz). We will present these results as well as initial data on ion heating. We will also discuss our plans for experiments taking advantage of the low heating rates that should be realizable in this apparatus. This work is supported by DARPA, NSA, ONR, IARPA, Sandia and The NIST Quantum Information Program.

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9. Optical ultra-precise parameter estimation

Hugo Cable, Centre for Quantum Technologies

Abstract. I will present the results of collaborative work with Gabriel Durkin on optical ultra-precise parameter estimation [1]. We are investigating the application of multi-photon entangled light generated by parametric down-conversion, and more specifically of singlet states defined in two pairs of polarization modes. The symmetry of these states is maintained under the action of a loss channel, and this suggests the usefulness of the source for quantum sensor applications. We have considered one and two-parameter detection, and also the possibilities for differential measurements between two spatially-separate regions. In a lossless setting, optimal parameter-independent scaling of sensitivity at the Heisenberg limit is possible using number-resolved photodetectors. We find that supra-classical precision is possible for moderate photon losses also. [1] Cable and Durkin arXiv:0910.1957 (2009)

10. Scalar and vector differential light shift measurements in optical lattice-trapped ⁸⁷Rb

Radu Chicireanu, NIST/Joint Quantum Institute

Abstract. The existence of ‘magic wavelengths’ for hyperfine transitions in alkali atoms is of interest for their applications in quantum information and frequency metrology. Magic wavelength predictions for Rb and Cs have met with some controversy, and it is likely that they do not exist in ‘traditional’ optical lattices. In a state-dependent lattice though, the scalar and vector differential light shifts can have opposite signs, leading to a prospected significant reduction in the sensitivity of the transition frequency to fluctuations in the trapping light field. We investigate this effect, and present preliminary results of a precision measurement of light shifts in lattice-trapped ⁸⁷Rb, focusing on the differential light shift between the ground-state hyperfine levels F=1,2.

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11. A fully connected qubit network model for quantum information processing applications

Mark Coffey, Colorado School of Mines

Abstract. We describe a fully connected spin network model for quantum information processing applications. This scalable network in the case of spin 1/2 has recently been realized in the laboratory, using Josephson phase qubits, and other solid-state implementations are likely. We have recently jointly developed a rigorous protocol for producing the important maximally entangled generalized GHZ states for this implementation [1]. An exact solution for the eigenstructure of a certain subspace of partial uniform superpositions enables the protocol to be detailed for an arbitrary number of qubits. An investigation of other quantum information processing applications of the spin network is underway. Joint work with Andrei Galiautdinov and Ron Deiotte. [1] A. Galiautdinov, M. W. Coffey, and R. Deiotte, arXiv:0907.2225v2 (2009); to appear in Phys. Rev. A. Work of MWC and RD partly supported by Northrop Grumman.

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12. Two-party information splitting

Patrick Coles, Carnegie Mellon University

Abstract. Consider, for example, a scattering process between particles A and B; it can be viewed abstractly as a partial flow of information from A to B, or alternatively, as an isometric encoding of A’s initial state into the full space AB followed by a splitting of this information (about A’s initial state) between the two emerging particles A and B. We treat the more general case of isometric encoding a d-dimensional system into a Hilbert space of dimension dA*dB, which is then split into systems A and B of dimension dA and dB, respectively. We imagine sending different types of information, each type being an orthonormal basis (a particular set of density operators), through the channel. To quantify the local information of each type that the channel outputs have about the input, we construct several information measures that quantify the distinguishability of local density operators. Using these measures, we find trade-off inequalities for an information type in A and a mutually-unbiased type in B. Equations relating complete sets of mutually-unbiased bases are also derived. The most intriguing finding is that, for certain information measures, the information splitting between A and B, I(W,A)-I(W,B), is invariant to the information type W. The fundamental phenomena of measurement and decoherence can be viewed as information splitting processes between the system and the apparatus (or environment), so our results are applicable to these phenomena.

13. Control in the Flow

Gregory Crosswhite, University of Washington, Department of Physics

Abstract. A classical transistor can be conceptualized as a device through which information flows in such a way that a computation is performed on the information as it moves through it. In this poster we present an analagous quantum system in which information is dragged from one side to the other by means of an adiabatic change to the Hamiltonian, such that when it reaches the other side we see that it is as if we had instantaneously applied a quantum gate to the original information. We furthermore present numerical studies of this system that show the relationship of the energy gap --- a key quantity that tells us how quickly we can do our “dragging” --- to the size of the system.

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14. Fermionic Resources for Quantum Teleportation

Adam DSouza, Institute for Quantum Information Science, University of Calgary

Abstract. The measurement-based quantum computing (MBQC) model requires the creation of a massively entangled "resource state", on which computation proceeds via single-qubit measurements. Although 2D resource states are believed necessary for universal MBQC, 1D states can serve as resources for certain tasks as well, such as quantum teleportation. One possible route to a resource state is to cool a gapped, two-body system whose ground state encodes the resource. This poster describes recent work in which we investigate candidate fermionic systems using the Density Matrix Renormalization Group method and the Matrix Product States description of highly entangled 1D states.

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15. Simulating Concordant Computations Composed of Two-qubit Gates

Bryan Eastin, National Institute of Standards and Technology

Abstract. A quantum state is called concordant if it has zero quantum discord with respect to any part. By extension, a concordant computation is one such that the state of the computer, at each time step, is concordant. In this presentation, I describe a classical algorithm that, given a product state as input, permits the efficient simulation of any concordant computation composed of gates acting on two or fewer qubits. This shows that a quantum computation composed of two-qubit gates must generate quantum discord if it is to efficiently solve a problem that requires super-polynomial time classically. While I employ the restriction to two-qubit gates sparingly, a crucial component of the simulation algorithm appears not to be extensible to gates acting on higher dimensional systems. Collaborators: Emanuel Knill, Carlton Caves, Vaibov Madhok, Anil Shaji, Adam Meier

16. Polarized atoms in a far-off-resonance YAG laser optical dipole trap

Fang Fang, Los Alamos National Lab

Abstract. Optical trapping of radioactive atoms has a great potential in precision measurements for testing fundamental physics such as electric dipole moment (EDM), atomic parity non-conservation (PNC) and parity violating beta-decay correlation coefficients. One challenge that remains is to polarize the atoms to a high degree and to measure the polarization of the sample and its evolution over time. We report on the polarization study of Rb atoms in a yttrium-aluminum-garnett (YAG) laser optical dipole trap using resolved Zeeman spectroscopy techniques. We have prepared a cold cloud of polarized atoms to 97% by optical pumping in the YAG dipole trap. The spin polarization is further purified to 99% and maintained when the two-body collision loss rate between atoms in mixed spin states is greater than the one-body trap loss. These advancements are an important step towards a new generation of precision measurement with polarized trapped atoms. LA-UR: 09-07784

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17. Most entangled states cannot be locally cloned

Vlad Gheorghiu, Carnegie Mellon University

Abstract. We derive a set of necessary conditions for the local cloning by separable operations of a set S of full Schmidt rank partially entangled states using a blank state of the same Schmidt rank, not necessarily maximally entangled. We first prove that no information about which state was cloned can be present at the output of the cloning machine, and conclude that in general local cloning cannot be accomplished by local discrimination with preservation of entanglement (see PhysRevA.75.052313). We further show that the states in S must have equal G-concurrence, and explain why our result is not a consequence of PhysRevA.73.012343, the latter being based on an incorrect proof. In addition, we prove that the states in S which are inter-convertible under separable operations must share the same set of Schmidt coefficients.

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18. Multipartite Nonlocality in N-qubit Generalized GHZ states

Shohini Ghose, Wilfrid Laurier University

Abstract. We analyze genuine multipartite nonlocality in the class of pure N-qubit generalized GHZ states that are of interest for various quantum information processing applications. For the case of 2 qubits, bipartite entanglement leads to violations of Bell inequalities, showing that no local hidden variable theory can account for the correlations between certain measurement outcomes. We show here that the connection between multipartite entanglement and tests of genuine multipartite nonlocality is quite diﬀerent from the 2-qubit case. We use the Svetlichny inequality to test for N-partite nonlocality in the N-qubit generalized GHZ states and ﬁnd an analytical formula for the maximum value of the Svetlichny parameter for these states. Our results conﬁrm and generalize previous numerical studies of these states and show that not all N-qubit generalized GHZ states can violate the Svetlichny inequality. Our work is a step towards understanding the complex nature of entanglement and nonlocality in multiqubit states.

19. Micro-fabricated surface ion traps for quantum computation

Clark Highstrete, Sandia National Laboratories

Abstract. This poster will present results of the design, operation, and performance of surface ion micro-traps fabricated at Sandia. Microfabrication of linear and junction traps will be described, including recent improvements in the controlled etching of oxide insulators and incorporation of on-chip filters. Recent results in testing of the micro-traps will also be highlighted, including successful motional control of ions and the validation of simulations with experiments. We will also highlight the progress we have made in integrating micro-optical components, and addressing other obstacles to the development of ion traps suitable for performing quantum computations.

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20. Universal quantum processing using a complete scalable methods set*

Jonathan Home, National Institute of Standards and Technology

Collaborators: J. P. Home, D. Hanneke, J. D. Jost, R. Bowler, J. Amini, D. Leibfried, and D. J. Wineland

Abstract. A major challenge in quantum information technology is to scale up from systems performing fixed tasks on small numbers of qubits to a large scale device which could perform general computations on large numbers of qubits. Here we describe experiments which demonstrate the combination of all of the fundamental building blocks required for large-scale quantum information processing using trapped atomic ions [1]. We store qubit information robustly using a magnetic-field insensitive transition in 9Be+ and transport information by moving the ions themselves using time-varying potentials applied to the electrodes of a multi-zone Paul trap. Both ambient heating and imperfect control of the ions during transport lead to motional excitation of the ions, impeding our ability to perform subsequent two-qubit gates. We counter this effect by trapping 24Mg+ "refrigerant" ions along with the 9Be+, allowing us to sympathetically cool the 9Be+ ions to the ground state without disturbing the stored quantum information. We characterize the repeatability of a multi-qubit operation involving a combination of single- and two-qubit gates and transport of trapped-ion qubits over macroscopic distances, and demonstrate no loss of gate performance due to transport. The ability to concatenate operations allows us to realize a universal two-qubit quantum information processor capable of performing any unitary transformation in SU(4)[2]. We have programmed this device with 160 operations chosen at random and characterized its performance using state and process tomography. * supported by DARPA, NSA, ONR, IARPA and the NIST Quantum Information Program [1] J. P. Home et al. Science 325, 1227 (2009) [2] D. Hanneke et al. Nature Physics, doi:10.1038/nphys1453 (2009)

21. Optical Feshbach Resonances in Ytterbium 171

Krittika Kanjilal, University of New Mexico

Abstract. Feshbach resonances are a very powerful tool in atomic physics to control the interaction between ultracold atoms. Whereas magnetic Feshbach resonances (MFRs) are widely used for alkaline atoms, they rely on ground-state hyperfine structure, not available in the alkaline-earth-like atoms. Here we explore optical Feshbach resonances (OFRs), obtained through laser coupling to excited molecular bound states. OFRs provide a possible alternative to MFRs, particularly in the case of alkaline-earth-like atoms, due to their very narrow 3S0 -> 3P1 intercombination line. In addition OFRs provide unique features in that one can turn interactions on and off much more rapidly than MFRs and spatially modulate the interaction strength through local variations in laser intensity. Moreover, one can independently tune even and odd partial wave resonances through absorption selection rules, opening possibilities to study, e.g., p-wave superfluidity. We study OFRs in the context of Yb-171, a fermionic species with spin-1/2 nucleus, making it an interesting candidate for quantum information processing.

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22. Quantum Frustration of Ising Spins with Trapped Ions

Kihwan Kim, Joint Quantum Insitute and University of Maryland

Abstract. Spin systems exhibit frustration when the spins cannot satisfy all of their mutual interactions in a simple ordered configuration, which gives rise to a large ground state degeneracy, with analogues in liquids and ice [1,2]. In quantum spins, the frustrated ground states are expected to be highly entangled. Here we report experimental simulations of three quantum Ising spins in a textbook example of triangular geometrical frustration. We study the ground state properties through adiabatic evolutions from simple polarized states, and also measure correlations and entanglement witnesses of these ground states. We directly observe that such ground states are accompanied by an added degree of degeneracy and entanglement when the underlying Hamiltonian features frustration. [1] H. T. Diep, Frustrated Spin Systems (World Scientific Publishing Company, 2005). [2] R. Moessner and A. P. Ramirez, Phys. Today 59, 24 (Feb 2006).

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23. Quantum computing with trapped barium ions

Nathan Kurz, University of Washington

Abstract. Barium is a very favorable candidate for trapped ion quantum computation, with a simple cooling scheme accessible at diode wavelengths, high natural abundance of two useful isotopes and easily accessible, long-lived D-states for readout via electron shelving. Recently in our lab we have demonstrated qubit rotations between the hyperfine levels of the ground state in the odd isotope, as well as improved state-selective shelving on the narrow S-D dipole-forbidden transition with a microcontroller cavity-locked fiber laser at 1762 nm. We have demonstrated the ability to generate single photons with spontaneous decay and gained an order of magnitude increase in ion fluorescence collection for ion-photon entanglement generation through integration of in-vacuum reflective elements. Work in progress includes entangling remote ions with fluorescence from the pair mode-matched on a beam splitter, development of a second repump at 614 nm to generate single photons from both excited P states, further improving shelving efficiency with an OPA-based system, implementing new trap designs to further increase fluorescence and perhaps improve scalability, and implementation of an pulse programmer for greater RF pulse switching control.

. 24. Progress in Controlling the Quantum Mechanical Motion of Cs Atoms in an Optical Lattice using Microwaves

Jae Hoon Lee, University of Arizona

Abstract. Quantum coherent transport is an important requirement for many methods of quantum information processing in optical lattices. We are studying new schemes for which we can do such transport in a more robust and controllable fashion using microwave transitions. First, in order to understand the physics of this system we calculated the band structure and Bloch states, and then integrated the Schrodinger equation in the Bloch basis. With this model we can simulate Rabi oscillations between spin up and spin down states for various lattice configurations. Finally, we were able to accurately model experimental data from arbitrary lattice configurations by including in our model the inhomogeneous broadening from variations in the lattice depth and magnetic field across the atomic ensemble.

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25. Types and Location of Information

Shiang Yong Looi, Carnegie Mellon University

Abstract. Imagine having some input quantum information encoded in n carrier qubits. We are interested in the question of how much information is present in a subset of the carrier qubits. In the case where the encoding is done using a stabilizer code, we have a precise and complete answer. The two extreme cases of having too small a subset whereby no information is present versus having a large subset of almost all n qubits from which all the information can be extracted are already well understood. In this talk we focus on the intermediate situation where partial information is present. For this purpose we define different ``types" of information, where the presence of a type of information on a subset of carrier qubits implies the ability to distinguish a particular set of encoded states associated to that type. With this we can determine how much and what types of information are present in any given subset of carrier qubits. With the help of some simple examples, we will show how sometimes only ``classical" information is present and sometimes both quantum and classical information are simultaneously present. We also found that the presence/absence of types of information on a subset strongly restricts what types of information can be present in the complement of the subset. Our results can also be generalized to higher dimensional qudit stabilizer codes.

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26. Quantum-enhanced measurement using trapped ions

Warren Lybarger, Los Alamos National Laboratory

Collaborators: Warren Lybarger (LANL), Malcolm Boshier (LANL), and John Chiaverini

Abstract. The application of algorithms and techniques from the realm of quantum information processing to the problem of metrology can enable better precision than is possible with traditional measurement protocols using similar resources. We describe plans for the use of trapped ion quantum processors to surpass the shot-noise limit to precision for measurements of various quantities of interest. In particular, the motional states of ions trapped in a 3D harmonic well may be put into superposition states (Schroedinger-cat-type states) that are more sensitive to displacements than classical-like coherent states. These states may be created using

operations similar to those employed for trapped-ion quantum computing gates. Also, superpositions of internal atomic states may be used to more quickly achieve a prescribed precision in the measurement of external fields through use of a bit-by-bit phase estimation algorithm via conditional coherent operations applied to an individual ion. There is also the possibility to use nonlinear interactions among many-body probe systems to surpass the standard quantum limit for measurement; trapped-ion arrays may be exploited to achieve this kind of enhanced sensitivity to external fields of interest.

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27. Using and Extending Randomized Benchmarks

Adam Meier, National Institute of Standards at Boulder and University of Colorado at Boulder

Abstract. Randomized benchmarking is a procedure that extracts a "typical" error probability for an experimental quantum computer. This number describes the failure rate of a typical gate in the middle of a long computation and is a worthwhile figure of merit for quantum control demonstrations. I will present a practical, systematic approach to randomized benchmarking using examples from planned experiments in ion traps. I will discuss ways to extend the data analysis to reveal information about individual gates. Finally, I will look at the simplifying assumptions made regarding the error models and randomness of the experimental gates and how they could be generalized. This work has been done in collaboration with E. Knill, K. Brown, D. Hanneke, and J. Home.

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28. Benchmarking the Krotov Algorithm

Seth Merkel, Institute for Quantum Computing (University of Waterloo)

Abstract. A remarkable feature of quantum open-loop control is the ability to find high fidelity control functions using very simple search techniques. While complicated protocols such as simulated annealing and genetic algorithm techniques have been explored, the current standard for optimizing quantum controls, such as the GRAPE algorithm, are based on gradient searches. Gradient searches are generally easy to implementation and for the case of quantum control converge very quickly to an optimal answer. Even simpler than gradient searches, however, are greedy searches, which one can view as the basis for the Krotov algorithm. In this poster we describe an implementation of the Krotov algorithm and look at benchmarking its performance versus that of a GRAPE implementation.

29. Implementation of a Quantum Computer Compiler

Tzvetan Metodi, The Aerospace Corporation

Abstract. A full-scale quantum computer will be a complex interaction of both classical computer and quantum subsystems. Their realization will require significant advances in both the underlying quantum technologies that implement the qubits and gates and in the overall system level design and analysis. The implementation of a full-scale quantum application (complete with error correction) will require the orchestration of many millions of qubit interactions at each cycle of execution. In order to better understand both the system design and physical implementation we have developed a Quantum Compiler. The quantum compiler allows us to analyze the transformation and performance of a high-level quantum program that is mapped into a specific physical architecture of qubits and gates. The compiler can be applied to trade studies for optimizing reliability and latency of the program execution and to determine the error correction resources required to implement the quantum program. We describe the quantum compiler design and software implementation. The quantum compiler consist of three stages: (1) A pre-compiler that translates a human readable high-level specification of a quantum circuit into a machine readable quantum intermediate representation (QIR); (2) An assembler that maps the QIR representation of the circuit into an equivalent low-level quantum assembly representation composed of a universal set of logic gates; (3) Assembly legalization which maps each quantum assembly-level instruction to corresponding machine instructions. The machine instructions are based on the specific technology-dependent physical architecture of the quantum computer.

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30. Tools for planar ion trap development

Soenke Moeller, University of California, Berkeley

Abstract. We are pursuing experiments to address scalability of ion-trap based quantum information processing. In a first direction, we concentrate on planar ion trap development to facilitate scalable ion trap quantum computing. We present a set of tools which allow convenient control of planar trap potentials, as well as tools to characterize planar traps in terms of stray electrostatic fields and electromagnetic noise. We show an implementation of these tools in characterizing microfabricated gold-on-sapphire traps. A second direction focuses on using a transmission-line interface to transfer quantum information between distant ions. We present a cryogenic ion trap setup based on a closed cycle cryostat which will be used in this effort.

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31. A Numerical Quantum and Classical Adversary

Mike Mullan, National Institute of Standards and Technology

Abstract. The Quantum Adversary Method has proven to be a successful technique for deriving lower bounds on a wide variety of problems. However, its application can be difficult as one must understand the detailed combinatorial properties of the problem under consideration. In addition, it assumes perfect quantum computation, which in most modern devices, is unrealistic. Here, we develop a generalization of this technique which allows it to be applied to arbitrary small problems automatically. To do this, we reformulate the spectral adversary such that the objective value of the semidefinite program corresponds to the probability that a quantum computer will output the correct value after a specified number of queries. This technique is naturally extended to include decoherence. 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 semidefinite programming formulation of a classical adversary, and so are able to automatically compute optimal classical success probabilities for small problem sizes. This work is in collaboration with E. Knill.

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32. Quantum Control of Collective Spin Ensembles

Leigh Norris, University of New Mexico

Abstract. Trapped atomic ensembles have emerged as important tools in quantum information processing, with a range of applications including the production of spin squeezed states and the development of light-atom interfaces. We investigate the effects of collective entangling interactions and local unitary control on a large ensemble of atomic spins. In particular, we explore the nature of multi-body entanglement in this ensemble, the relationship between spin squeezing and entanglement, and the possible enhancement of existing squeezing protocols through entangling interactions.

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33. Micro Ion Frequency Standard

Heather Partner, Sandia National Laboratories and University of New Mexico

Abstract. We are developing a highly miniaturized trapped ion clock to probe the 12.6 GHz hyperfine transition in the 171Yb+ ion. Our goals are to develop a clock that is less than 5 cm^3 in size, consumes <50 mW of power, and has a long-term frequency stability of 10^-14 at one month. Realizing a clock of this size requires advanced technologies to create a miniaturized vacuum package with an integral linear ion trap, Yb source, and pump. Integrated light sources for photoionization, state preparation and detection and a low-phase-noise micro resonator for use as a local oscillator must also be developed. We report on our design for this frequency standard and our progress toward its realization. P. D. D. Schwindt, R. Olsson, K. Wojciechowski, D. Serkland, T. Statom, H. Partner, G. Biedermann, L. Fang, A. Casias, R. Manginell, Y.Y. Jau.
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34. Quantum emulation with trapped ions

Thaned Pruttivarasin, University of California Berkeley, Haeffner Group

Abstract. Crystal interfaces play an important role in condensed matter physics. In particular, if the lattice constants of the crystals are incommensurate, interesting phenomena such as crystal dislocations and dry friction arise. The so-called Frenkel-Kontorova model captures the essential physics of these phenomena and is therefore investigated in great detail by theorists. Here we propose to study the Frenkel-Kontorova model experimentally by placing an ion crystal in a periodic optical lattice potential formed inside a resonator. The goal of the experiment is to observe the so-called analyticity breaking transition from the pinned phase to the sliding (unpinned)phase of the ion chain which is prominent in both the classical and quantum regimes. By look at the crystal deformation and the phonon spectrum, our preliminary numerical calculations of the of the ion chain show that such a transition is observable with our experimental parameters. Moreover, the effective dimensionless Planck constant for our system can be varied from 0.1 to 2 by changing the axial trapping frequency, hence allowing us to investigate the physics of this particular model in the quantum regime.

35. A new class of optimal entanglement witnesses

Justyna Pytel, Nicolaus Copernicus University

Abstract. We provide a new class of indecomposable entanglement witnesses. In 4 x 4 case it reproduces the well know Breuer-Hall witness. We prove that these new witnesses are optimal and atomic, i.e. they are able to detect the "weakest" quantum entanglement encoded into states with positive partial transposition (PPT). Equivalently, we provide a new construction of indecomposable atomic maps in the algebra of 2k x 2k complex matrices. It is shown that their structural physical approximations give rise to entanglement breaking channels. This result supports recent conjecture by Korbicz et. al. [Phys. Rev. A 78 , 062105 (2008)].

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36. Echo quench and its application in adiabatic quantum computation

Haitao Quan, Los Alamos National Laboratory

Abstract. The quantum adiabatic theorem has aroused a lot of debate in recent years. How to ensure the adiabaticity of a quantum dynamic process remains an open problem. We propose a simple method to test the adiabaticity of a quantum quench process when we know only the eigenstates of the initial Hamiltonian. This method promises important applications in implementing adiabatic quantum computation algorithm.

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37. Quantum state reconstruction of the 16 dimensional hyperfine manifold in cesium via continuous measurement and control

Carlos Riofrio, University of New Mexico

Abstract. Quantum state reconstruction techniques based on weak continuous measurement have the advantage of being fast, accurate, and almost non-perturbative. Moreover, they have been successfully implemented in experiments on large spin systems (PRL 97, 180403 (2006)). In this poster, an application of the reconstruction algorithm developed by Silberfarb et al. (PRL 95, 030402 (2005)) is presented for the reconstruction of quantum states stored in the 16 dimensional ground-electronic hyperfine manifolds (F=3, F=4) of an ensemble of 133Cs atoms controlled by microwaves and radio- frequency magnetic fields. Simulations showed that randomly generated control fields produce informationally complete measurement records and thus give high fidelity reconstructed states. Furthermore, exploration of appropriate operation regimes is shown for possible experimental implementation.

38. Atom Chip Matter Wave Interferometer

Rob Sewell, The Institute of Photonic Sciences (ICFO)

Abstract. We have fabricated and tested an atom chip that operates as a matter wave interferometer. We coherently split a single Bose Einstein condensate (BEC) in two using a radio-frequency field to deform a magnetic trap smoothly from a single to a double well. We read out the relative phase between the two modes from the interference pattern that is produced when they are released from the trap and allowed to overlap in free fall. The interferometer has good phase stability and a coherence time limited by phase spreading due to atom-atom interactions. We have tested it as a measurement device by introducing a known small energy difference between the two minima of the trapping potential and reading out the resulting phase difference from the interference pattern. We discuss our results and future plans to increase the sensitivity of the interferometer by exploiting atom-atom interactions during the splitting process to induce number squeezing and increase the phase coherence time.

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39. Compressed Quantum Process Tomography

Alireza Shabani, Princeton University

Abstract. The characterization of a decoherence process is among the central challenges in quantum physics. A major difficulty with current quantum process tomography methods is the enormous number of experiments needed to accomplish a tomography task. Here we present a highly efficient method for tomography of a quantum process that has a small number of significant elements. Our method is based on the compressed sensing techniques being used in information theory. In this new method, for a system with Hilbert space dimension n and a process matrix of dimension n^2 x n^2 with sparsity s, the required number of experimental configurations is O(s log n^4). This heralds a logarithmic advantage in contrast to other methods of quantum process tomography. More specifically, for q-qubits with n=2^q, the scaling of resources is O(sq) linear in the product of sparsity and number of qubits.

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40. Classical communication using quantum states in the absence of a shared reference frame

Michael Skotiniotis, Institute for Quantum Information Science, University of Calgary

Abstract. We address the problem of quantum communication between two parties who lack a requisite shared reference to decode classical information encoded in quantum systems. Specifically, we develop a theory for quantum encoding and decoding protocols utilizing relative parameters, whereby information is encoded in relational properties of quantum systems such as the angle between two spins. If the reference frames are related by finite group transformations, we develop an encoding strategy and optimize the choice of measurements for decoding. Our method obviates the need to perform tasks requiring significant use of resources, such as reference frame alignment. Consider the case where Alice and Bob lack a shared reference frame for ascertaining which way is up in the other party's locale. Such a reference frame is associated with the SO(3) symmetry group. When a reference frame is lacking, parties

wishing to communicate can either expend precious resources to establish a shared reference frame or use physical properties of systems that are independent of a reference frame. The latter approach has been studied for the case where the associated symmetry group is SU(2). Following a similar recipe, and using techniques from quantum estimation theory, we determine the optimal encoding states and decoding measurements for the cases where the requisite reference frame is associated with a general, finite group of transformations.

41. Silicon surface-electrode ions traps for quantum information processing*

Dick Slusher, Georgia Tech Research Institute

Abstract. The Georgia Tech Research Institute (GTRI) is designing, fabricating, and testing scalable surface-electrode ion traps for quantum information applications with a wide range of trap architectures fabricated in scalable silicon VLSI technology. We will present designs and initial test results for several of our traps, including a linear trap that holds long chains of equally spaced ions, a 90-degree X-junction, and an integrated micromirror with collection efficiency up to 20%. We will also present results on fabrication features that can be integrated with the surface electrode designs such as multilayer interconnects, optics for enhanced light collection, flexible optical access through beveled slots extending through the substrate, and recessed wire bonds for clear laser access across the trap surface. Traps are designed at GTRI using in-house codes that calculate the fields, compute the full motion of ions confined in the trap including the micromotion, and optimize the electrode shapes and transport waveforms using genetic algorithms. *Support for this work provided by IARPA through the Army Research Office award W911NF081-0315 and by DARPA through award W911NF-07-1-0576.

42. Controlled interactions between ultracold Lithium and Cesium atoms in optical lattices for quantum information processing

Kathy-Anne Soderberg, The University of Chicago

Abstract. We present progress on a quantum information processing experiment using degenerate gases of bosonic 133Cs and fermionic 6Li, each confined in an independently controlled, overlapping optical lattice. An insulating state of 6Li will prepare an initial state with exactly one atom per lattice site. These atoms serve as quantum bits (qubits). 133Cs atoms are sparsely loaded into a second lattice, and act as messenger bits to carry entanglement between distant qubits. Qubit operations are mediated through magnetic dipole transitions to a 6Li-133Cs molecular state that is formed only when qubit and messenger are overlapped. The 133Cs messenger atom can interact with (multiple and distant) 6Li qubits through translation of the Cs lattice using an electro-optic modulator array, making this implementation scalable. We present progress on the first spectroscopy experiments of the 6Li 133Cs molecular states. These findings will guide the best strategies for implementing qubit operations using messenger atoms.

43. Macroscopic two-state system with cold atoms: towards BEC flux qubit

Dmitry Solenov, Los Alamos National Laboratory

Abstract. We investigate macroscopic properties of Bose-Einstein condensate of interacting neutral (spin-0) atoms confined in a ring with weak Josephson tunneling link. We show that, similar to superconducting Josephson ring, cold atom BEC system of such geometry can be tuned to create macroscopic two-state system. We analyze its many-body wave function and derive an effective low energy Schrodinger equation to the leading order as an expansion in the number of particles. We determine the range of parameters in which quantization of the macroscopic variable adequately describes low-energy physics and predicts measurement. Finally, we outline signatures of the time-of-flight experiment expected for neutral atom Josephson ring systems in two-state regime.

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44. Optimized Entanglement Assisted Quantum Error Correction

Soraya Taghavi, University of Southern California

Abstract. Using convex optimization, we propose entanglement assisted quantum error correction procedures which are optimized for given noise channels. We demonstrate through numerical examples that such an optimized error correction method achieves a higher channel fidelity than existing methods. This outperformance, which leads to perfect error correction for a larger class of error channels, is interpreted by quantum teleportation.

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45. Mixed state quantum reference frame resources

Borzumehr Toloui, Institute for Quantum Information Science at the University of Calgary

Abstract. Situations where the operations of a noisy channel used for the transmission and retrieval of quantum states belong to a specific group of transformations give rise to resources beside entanglement that allow us to overcome the ensuing constraints, such as when shared reference frames (RF) associated with symmetry groups are lacking between the nodes of a quantum channel. So far, most work on this new kind of resource, dubbed "frameness", has been focused on pure state transformations even though almost all states and operations in the lab involve some degree of mixedness. Here we address the problem of quantifying the frameness of mixed states. We introduce a new family of pure state frameness measures associated with Abelian Lie groups in a Hilbert space of arbitrary but finite dimensions, whose convex roof

extensions remain monotonic. In particular, we show that this family of frameness monotones are closely related to generalized concurrence functions of the reduced density operators of entangled states. This highlights interesting and deep links between frameness and entanglement resource theories, and provides a new way of classifying all frameness monotones as functions of the "twirled" state that results from tracing out the RF, where the state plus the RF are treated as a joint entangled system. Finally, we use a member of this family of frameness monotones to determine the explicit analytical form of a qubit's frameness of formation. The frameness of formation denotes the minimum average cost of preparing the ensemble of pure states that realize a given mixed state, and can be used to quantify the frameness of that state under certain conditions. Our results thus extends Wootter's formula for the entanglement of formation of bipartite qubit states to a whole new and different class of resources.

46. Quantum Interferometric Metrology in the Presence of Photon Loss

Dmitry Uskov, Tulane University and Hearne Institute for Theoretical Physics

Abstract. I will report on our recent progress [1] in solving the problem of optimization of the interferometric phase measurement with two-mode entangled photon states in the presence of loss, and optimization of quantum operations on such states [2]. Our main result is that in the presence of photon loss one can single out two distinct regimes: 1) a low-loss regime, favoring purely quantum states, akin the |N00N> states and 2) a high-loss regime, when the generalized coherent SU(2) states become the optimal ones. [1] T. Lee et al, Phys. Rev. A 80, 063803 (2009). [2] D. Uskov et al, arXiv:0908.2482.

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47. Generic two-qubit photonic gates implemented by number-resolving photodetection

Dmitry Uskov, Tulane University

Abstract. We use numerical techniques [Uskov et al., Phys. Rev.A79, 042326 (2009)] to obtain optimal implementations of generic linear-optical Knill-Laflamme-Milburne-type two-qubit entangling gates inside the whole volume of the Weyl chamber. We find that while any two-qubit controlled-U gate can be implemented using only two ancilla resources a generic SU(4) operation requires three ancilla photons. We show that single-shot implementation of a generic SU(4) gate offers more than an order of magnitude increase in the success probability and a two-fold reduction in overhead ancilla resources compared to standard triple-CNOT and double-B gate decompositions. Some applications for photonic quantum information processing and metrology with lossy modes are also discussed.

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48. Quantum Search by Quantum Cellular Automata

Kevin Van De Bogart, University of Calgary

Abstract. Quantum Cellular Automata provide a description of quantum systems whose evolution is periodic in space and time. The drawing feature of QCA is that evolution is described by global operations that can be decomposed into periodic components, instead of operations on individual data registers. While it has been demonstrated that QCA can be constructed that are equivalent to the circuit model, these constructions do not lend themselves easily to a physical system. However it is possible to create QCA that, while they do not correspond to a fully programmable quantum computer, can nevertheless implement quantum algorithms. By drawing on the connection between quantum walks and QCA, I demonstrate that it is possible to implement Grover's algorithm on a system that may be readily translated to a physical implementation.

49. Fiber Optics in Surface Ion Traps

Aaron VanDevender, National Institute of Technology

Abstract. Fiber optics provide a more scalable and resource efficient means of delivering light to and collecting fluorescence from a trapped ion than bulk optics. We demonstrate trapping of a 24Mg+ ion in a gold-on-quartz surface-electrode trap with an integrated high numerical-aperture photonic-crystal multi-mode fiber 100 microns from the ion, and observe fluorescence photons through the fiber. The trap features multiple RF electrodes whose potentials can be adjusted to vary the height of the pseudopotential zero from 30 to 50 microns above the electrode surface (80 to 100 microns from the fiber). This demonstrates the ability to trap ions very near dielectrics, an important step toward trapping ions in small volume fiber optic cavities useful for the strong coupling of ions and photons. * supported by DARPA, NSA, ONR, IARPA, Sandia and The NIST Quantum Information Program

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50. Generalized X-states for N-qubits

Sai Vinjanampathy, Louisiana State University

Abstract. X-states of a pair of qubits are density matrices whose non-zero elements lie along its diagonal and anti-diagonal. Such states have been useful in the study of the sudden death of entanglement and in understanding quantum correlations in spin chains. We present the generalization of X-states to N-qubits and characterize the algebra of the operators involved. We will present connections between N-qubit X-states and N-simplexes and discuss some applications.

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51. Continuous quantum non-demolition measurement of Fock states of a nanoresonator using feedback-controlled circuit QED

Matthew Woolley, University of Queensland

Abstract. An important benchmark for quantum control is the ability to prepare and detect a harmonic oscillator in a Fock state, an energy eigenstate. Meanwhile, a major goal of the study of nanomechanical systems near the quantum limit is to prepare quantum states of the nanomechanical resonator. We propose a scheme for the quantum non-demolition (QND) measurement of Fock states of a nanomechanical resonator via feedback control of a coupled circuit QED system. A Cooper pair box (CPB) is coupled to both the nanoresonator and microwave cavity. The CPB is read-out via homodyne detection on the cavity and feedback control is used to effect a non-dissipative measurement of the CPB. This realizes an indirect QND measurement of the nanoresonator via a second-order coupling of the CPB to the nanoresonator number operator. The phonon number of the Fock state may be determined by integrating the stochastic master equation derived, or by processing of the measurement signal.

52. Multipartite entanglement verification

Jun Yin, University of Oregon

Abstract. We propose a general data analysis scheme for multipartite entanglement verification under limited number of measurements, making use of several information criteria. We show that in most situations, models can be simplified according to the measurement performed, without the entanglement verification process being compromised. We also show that some entanglement related properties are sensitive to these criteria while others are not.

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53. Stroboscopic Generation of Topological Protection

Kevin Young, University of California - Berkeley

Abstract. Trapped neutral atoms oﬀer a powerful route to robust simulation of complex quantum systems. We present here a stroboscopic scheme for realization of a Hamiltonian with n-body interactions on a set of neutral atoms trapped in an addressable optical lattice, using only 1- and 2-body physical operations together with a dissipative mechanism that allows thermalization to ﬁnite temperature or cooling to the ground state. We demonstrate this scheme with application to the toric code Hamiltonian, ground states of which can be used to robustly store quantum information when coupled to a low temperature reservoir.

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54. Efficient local implementation of bipartite quantum gates

Li Yu, Carnegie Mellon University

Abstract. Any bipartite nonlocal unitary operation can be carried out by teleporting a quantum state from one party to the other, performing the unitary locally, and teleporting a state back again. This paper investigates unitaries which can be carried out using less prior entanglement than needed for teleportation. In particular large families of such unitaries are constructed using (projective) representations of finite groups. Among the tools employed are: a diagrammatic approach to the analysis of quantum circuits, a theorem on the necessary absence of information at certain locations, and a representation of bipartite unitaries based on a generalized Fourier transform.

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55. Computable and asymptotically optimal lower bounds on confidence for rejecting local realism given experimental data

Yanbao Zhang, University of Colorado at Boulder

Abstract. Because of the fundamental importance of Bell's theorem, loophole-free demonstrations of violations of local realism (VLR) are highly desirable. Besides the locality and detection loopholes in current experimental tests of VLR, there is another loophole--the memory loophole, which concerns the time dependence of the local hidden variables on the previous measurement settings and outcomes. This loophole affects the confidence at which local realism is (hopefully) rejected by a finite number of experimental data. We suggest the use of a prediction-based

likelihood ratio to lower-bound the rejection confidence. The method gives a strict lower bound with no assumptions on memory, experimental stability or independence of each data point from previous ones. If the prepared state does not vary in time, the bound is asymptotically optimal. We demonstrate our method with simulated data for the configuration used in conventional Bell tests with balanced or unbalanced Bell states. Collaborators: Emanuel Knill and Scott Glancy

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56. Quantum Darwinism in hazy environments

Michael Zwolak, Los Alamos National Laboratory

Abstract. Quantum Darwinism provides an information-theoretic framework for the emergence of the classical world from the quantum substrate. It recognizes that we - the observers - acquire our information about the "systems of interest" indirectly from their imprints on the environment. Objectivity, a key property of the classical world, arises via the proliferation of redundant information into the environment where many observers can then intercept it and independently determine the state of the system. After a general introduction to this framework, we demonstrate how non-ideal initial states of the environment (e.g., mixed states) affect its ability to act as a communication channel for information about the system. The environment's capacity for transmitting information is directly related to its ability to increase its entropy. Therefore, environments that remain nearly invariant under the Hamiltonian dynamics, such as very mixed states, have a diminished ability to transmit information. However, despite this, the environment almost always redundantly transmits information about the system.

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57. Recent Experiments with Phase Qubits at UCSB

Radek Bialczak, Max Hofheinz, Mike Lenander, Erik Lucero, Matteo Mariantoni, Matthew Neeley, Aaron A. O'Connell, Daniel Sank, Haohua Wang, Martin Weides, James Wenner, Yi Yin, Andrew Cleland, John Martinis – University of California, Santa Barbara

Abstract.. We present new experimental results in quantum information processing using Josephson phase qubits and superconducting microwave resonators. We have used a coupled qubit-resonator system to demonstrate deterministic arbitrary state preparation in the resonator with terms up to the tenth Fock state. We confirmed these state preparations by measuring the Wigner function of the resonator. In another experiment, we showed that higher energy states in the phase qubit can be used to simulate geometric phase effects typically discussed in the context of spin particles. By driving the various qubit level transitions at the appropriate relative strengths, the dynamics of spin operators were experimentally simulated for spins 1/2, 1, and 3/2, and various geometric phases were measured. In a third experiment we used entanglement of two qubits to demonstrate a violation of Bell's inequality. Underlying these results are qubits with high enough energy (T1) and phase (T2) coherence times to allow for complex algorithms to be executed. More interesting and complex information processing will demand qubits with longer lifetimes. To achieve this, we need a more complete understanding of the physical processes that cause decoherence. We report on recent advances in our understanding of decoherence from magnetic flux fluctuations, radiative loss in resonators, and quasiparticle tunneling effects in the Josephson junctions.

Work supported by: IARPA, ARO, NSA, NSF, CNSI

58. Verification of Entanglement for HOM-like States

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Abstract. We propose a simple method of verifying the entanglement of two mode states similar to Hong-Ou-Mandel states $1/\sqrt{2}\,(|02\rangle - |20\rangle)$. While full state tomography can be used to verify the entanglement of such states, it is measurement intensive. Our method relies on a bounding scheme that requires far fewer measurements than required for full state tomography.