INTRIQ Student Conference 2012 Program

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Quantum Dots I

Introduction To Spin Qubits In Lateral Quantum Dots

Chloé Bureau-Oxton, supervisor: Michel Pioro-Ladrière (Sherbrooke)

An electron in a quantum box constitutes a perfect two-level system and is thus a good candidate for a qubit. In my talk, I will give an introduction to lateral quantum dots, their fabrication process and how they can be used as qubits.

Fabrication Of Silicon Quantum Dots For Quantum Information

Patrick Harvey-Collard, Dominique Drouin, supervisor: Michel Pioro-Ladrière (Sherbrooke)

I am interested in the fabrication and manipulation of electron spin qubits. These qubits are promising for their potentially long (millisecond) decoherence times. Nevertheless, decoherence affects greatly the otherwise successful GaAs quantum dots due to the high concentration of nuclear spins, calling for new architectures. Silicon is a good candidate, since it has more than 95 % of its atoms that are nuclear spin-free isotopes and is highly processable. Moreover, it is predicted to have a longer coherence time. In this talk, I will introduce a new fabrication process that could enable quantum information processing in a silicon quantum dot.

Theory Of Anomalous Magnetotransport In Triple Quantum Dots

Benjamin D'Anjou, supervisor: William Coish (McGill)

Magneto-transport measurements on a triple quantum dot ring have recently shown anomalous quantum oscillations with dominant frequencies separated by a factor of three in magnetic flux [1]. Such oscillations, suggestive of a one-third periodicity in the flux quantum, are usually not observed in larger mesoscopic rings in which only larger periods are observed. We develop a microscopic transport model for the triple dot and show that the anomalous oscillations can dominate the transport behavior under certain conditions. Furthermore, we discuss the range of validity of our model by studying dephasing due to broadening and electric dipole interactions.

Theory Of Heavy-Hole Spin-Echo Decay

Xiaoya (Judy) Wang, supervisor: William Coish (McGill)

Heavy-hole spin states have emerged as a robust new qubit candidate. Nevertheless, the coupling of the hole spin to nuclei in the surrounding medium likely limits hole-spin coherence and has, until very recently, been overlooked. We describe the real-time spin decoherence of a heavy-hole in a semiconductor quantum dot, subject to spin echo pulses. Including the (previously neglected) nuclear Zeeman term in the Hamiltonian, we find a nontrivial dependence of the decay on the applied magnetic field. We also observe motional narrowing and envelope modulation, which could significantly extend the hole-spin memory time in near-future experiments.

Topological Quantum Computing

Search for non-Abelian Anyons in the 5/2 fractional quantum hall state

Benjamin Schmidt, supervisor: Guillaume Gervais (McGill)

An ideal candidate system for practical quantum computation should be easy to manipulate, yet, paradoxically, robust against decoherence, which is in a sense manipulation by the environment. Two dimensional particles known as non-Abelian anyons are of particular interest, since their set of degenerate ground states are topologically protected from local perturbations. I will discuss our proposal for an experiment to probe the 5/2 fractional quantum state for non-Abelian behaviour by directly detecting the topologically degenerate ground state via an unusual adiabatic cooling effect. I will also discuss our progress toward implementing the scheme experimentally.

Majorana Fermions In Semiconductor Heterostructures

Michel Savard, Chenxu Shao, Binxin Wu, supervisor: Guillaume Gervais (McGill)

It was found a long time ago that the Dirac equation can be modified to allow one real solution that would describe a special particle with the elegant property of being its own anti-particle. Taking the name of its discoverer, the Majorana fermions have received a lot of attention lately in the condensed matter community because they are believed to be a suitable qubit for fault tolerant quantum computing. In this talk I will present a progress report on our group`s efforts to tackle the challenge of creating these long sought particles in a solid state system. This project is a collaborative work between three groups from McGill University and emphasis will be put on the specific experimental techniques and device architecture we plan to use to obtain the elusive Majorana fermions.

Topological Decoding Through Artificial Confinement

Guillaume Duclos-Cianci, supervisor: David Poulin (Sherbrooke)

2D topological stabilizer codes have attracted a lot of attention in recent years for two main reasons. First, they provide exactly solvable models which exhibit topological order and anyonic excitations. Second, they naturally lead to quantum stabilizer error-correcting codes having macroscopic minimum distance. Although these codes are robust at zero temperature, quasi-particles appear and freely diffuse in the system at any finite temperature. If this diffusion is unchecked, errors will occur. Consequently, active error-correction is needed. We want to propose a cellular automaton that would perform this correction. It would \"manually\" confine the quasi-particles by simulating artificial attraction between them and moving them accordingly. We obtained encouraging preliminary results for error-correction and hope to generalize them to fault-tolerance.

Quantum Information

Characterizing Entanglement

Benno Salwey, supervisors: Gilles Brassard and Alain Tapp (Université de Montréal)

I will give a brief introduction into entanglement and local operations(LOCC). Then, a mathematical characterization of entanglement is introduced and known results are presented such as the distinctness of W and GHZ entanglement. Finally, the concept of permutation operations on multiple copies of a (multipartite) state will be introduced and shown to serve as a powerful tool for the characterization of entanglement.

Coding For Classical-Quantum Channels

Ivan Savov, supervisor: Patrick Hayden (McGill)

Sending classical data over a quantum channel is one of the fundamental problems of quantum information theory. The Holevo-Schumacher-Westmoreland Theorem gives a precise characterization of the classical capacity of classical-quantum channels. The proof combines classical probability theory (for the random encoding used by the sender) and quantum theory (for the choice of decoding measurement performed by the receiver). This presentation will give an intuitive explanation of the HSW Theorem. Time permitting, we will discuss generalizations to classical-quantum channels with many senders/receivers (network information theory).

Quantum Query Complexity

Artem Kaznatcheev, supervisor: Prakash Panangaden (McGill)

A ‘hard’ computation is measured by use of resources such as energy, space or time. Unfortunately, the most popular notion of hardness — time complexity — is notoriously difficult to characterize in a quantum (or classical) computing model. If we want to show what a model of computation can and can't do or seperate two (or separate two models), we must use a related, but simpler measure of complexity. For quantum computing this measure is quantum query complexity. This talk will introduce quantum query complexity and the powerful lower bound technique of the (negative) adversary method. If time permits we will also sketch how the negative adversary method perfectly characterizes quantum query complexity through its connection to span programs.

Guildenstern And Rosencrantz In Quantumland

Paul Raymond-Robichaud, Vincent Duhamel, supervisor: Gilles Brassard (Université de Montréal)

Welcome to a theater play by Tom Stoppard! With the power of His pen, He can create strange worlds! Each of these worlds are deterministic, yet create the terrible illusion of randomness! These worlds will be inhabited by copies of Guildenstern and Rosencrantz, seeking first and foremost to understand the Law of its Creator. Does it truly matter whether they are living a simple life in a single lonely universe, or whether they are living in a travesty of a life where they die each night only to have multiple copies of them appear each morning in various universes for all eternity?

Quantum Dots II

Large Magnetic Field Generation For Ultra-Fast Single Spin Rotations

Julien Camirand Lemyre, C. Bureau-Oxton, S. Rochette, M. Lacerte, W.A Coish, supervisor: M. Pioro-Ladrière (Sherbrooke)

Spin qubit have proved to be good candidate for the implementation of a quantum computer. However, single-spin rotations in GaAs/AlGaAs quantum dots are limited by the hyperfine interaction with the neighboring nuclear spins. This interaction causes decoherence on a timescale of 10-100ns. In order to achieve high fidelity single-spin rotations, we need to be able to manipulate the electron spin faster than the decoherence. I will first show how this is possible using large magnetic fields gradients in quantum dots. Then, I will explain different strategies to produce these magnetic fields with micro-fabricated magnets.

Integration of micro-magnets to silicon double quantum dots for spin control

Sophie Rochette, supervisor: Michel Pioro-Ladrière (Sherbrooke)

Spins are a promising avenue for the implementation of a quantum computer. Information is encoded in the electron spin, which is confined electrostatically by a quantum dot in a semi-conductor substrate, and manipulated by micro-magnets. Fabrication and control methods for this type of devices are very well known and used, but progress is limited by the fast decoherence arising from the host material's nuclear spins. By using a material with a smaller nuclear magnetic field, such as silicon, instead of widely-used materials such as gallium arsenite, we could greatly reduce the decoherence in our quantum dots. Many models have been proposed for silicon-based quantum dots. In this presentation, I will briefly describe the design of enhancement mode silicon MOS double quantum dot developped by the group of Malcolm S. Carroll, from Sandia National Laboratories. I will then present some simulation's results of micro-magnets integration on those quantum dots for spin control. Finally, If time allows it, I'll talk a little bit about the experimental difficulties of this project.

Quantum Cellular Automata: From Concept To Fabrication

Gabriel Droulers, supervisor: Michel Pioro-Ladrière (Sherbrooke)

As classical (CMOS) information technologies approach their performance limits, alternative concepts are developed to enable continuous performance increase of devices and chips. A Quantum Cellular Automata (QCA) is a device used for classical computing at very low energies. This device is based on the position of a few electrons in the circuit instead of the movement of many in the actual CMOS technology. Also, computation is done with the ground state and is edge-driven which gives this approach very high energy efficiency. Spin effects in QCA are unexplored and may lead to quantum information as well.

Superconducting Qubits

Quantum Computing with Superconducting Circuits : an Introduction

Maxime Boissonneault, supervisor: Alexandre Blais (Sherbrooke)

If you were to build a classical computer, you would probably think of semi-conductors, integrated circuits and transistors. If you want to build a quantum computer however, all bets are off on the technology that you could use. There are many proposals out there, and each has its pros and cons. Electrical circuits, may them be semi- or super-conducting, have the advantage of relying on well developped and controlled fabrication techniques. In this talk, I will introduce the why and the how, as well as the good, the bad and the interesting about superconducting circuits as an architecture for quantum computing.

Quantum Gates By Qubit Frequency Modulation In Circuit QED

Félix Beaudoin, supervisor: Alexandre Blais (Sherbrooke)

Several types of two-qubit gates have been realized experimentally in circuit QED. These are based, for example, on tuning the pair of qubits in resonance with each other [Majer, Nature 449, 443-447 (2007)] or on a microwave pulse on one qubit at the transition frequency of a second qubit [Chow, Phys. Rev. Lett. 107, 080502 (2011)]. Another realization is based on a sequence of blue-sideband transitions generated by microwave pulses [Leek, Phys. Rev. B 79, 180511(R) (2009)]. Here, we propose a different approach relying on oscillations of the qubit frequency using a flux-bias line. We explain how frequency modulation leads to tunable qubit-resonator and qubit-qubit interactions. We also show how this form of quantum control leads to faster (first-order) sideband transitions and consider applications to two-qubit gates.

Quantum Optics in a Transmission Line

Kevin Lalumière, Barry Sanders, supervisor: Alexandre Blais (Sherbrooke)

Quantum optics is a field that is interested in the interaction between light and atoms. There's been a lot of spectacular experiments in quantum optics, especially in cavity quantum electrodynamics, where an atom interact strongly with the electromagnetic field when it passes through a cavity. In this talk, I will explain how to do such experiments in electric circuit with artificial atoms. The main advantage of doing this is that we have a really precise control over the hamiltonian parameters when working with an electrical circuit.

[talk cancelled] Hong-Ou-Mandel Interference In Circuit QED Experiments

Matthew Woolley, supervisors: Alexandre Blais and Aashish Clerk (Sherbrooke and McGill)

The Hong-Ou-Mandel (HOM) effect is a quantum interference effect whereby two indistinguishable photons incident at either side of a balanced beam splitter will be detected together at one output port or the other, but never with one photon at each output port. Here we determine the signature of microwave HOM interference in a system consisting of two independent circuit QED systems out-coupled into an on-chip microwave beam splitter. Preliminary experimental results from the group of Wallraff at ETH Zurich will be discussed.

Other Physical Systems

Gpu Acceleration And An Application To Quantum Transport

Mohammed Harb, supervisor: Hong Guo (McGill)

Modern high performance computers are heterogeneous systems consisting of multi-core processors and specialized GPU. Graphics Processing Units (GPU) contain hundreds of cores, consume less power and are ideal for performing certain computationally intensive operations that have crippled performance in the past. We discuss our GPU implementation, the pros and cons of this kind of approach and present benchmarks and comparisons to several other platforms. Although GPU acceleration can be applied to any branch science or engineering, I will present a concrete quantum transport application: computing the transmission function of a ~140,000 atom Si system using four Nvida Tesla C2050 cards.

Practical Characterization Of Quantum Devices Without Tomography

Olivier Landon-Cardinal, supervisor: David Poulin (Sherbrooke)

Quantum tomography is the main method used to assess the quality of quantum information processing devices. However, the amount of resources needed for quantum tomography is exponential in the device size. Part of the problem is that tomography generates much more information than is usually sought. Taking a more targeted approach, we develop schemes that enable (i) estimating the fidelity of an experiment to a theoretical ideal description, (ii) learning which description within a reduced subset best matches the experimental data. Both these approaches yield a significant reduction in resources. In particular, we demonstrate that fidelity can be estimated from a number of simple experiments.

High Sensitivity Magnetometry With Diamond

David Roy-Guay, supervisors: Michel Pioro-Ladrière and Denis Morris (Sherbrooke)

A good solid state qubit for quantum information must preserve its quantum state over a long coherence time. Nitrogen-vacancy centers in diamond fulfill this requirement even at room-temperature, driving their use as single qubit gates and quantum memories in hybrid architectures. Alternatively, the long coherence time can enhance the sensitivity of electric and magnetic field detectors, down to the detection of a single nuclear spin. In this talk, I discuss how the magnetic sensitivity of nitrogen-vacancies can be enhanced to make a very accurate magnetometer. This is relevant to map local magnetic fields produced by micromagnets in spin qubits architectures.

How Fast Can We Modulate Noise?

Kevin Spahr, supervisor: Bertrand Reulet (Sherbrooke)

The current noise density of a conductor in equilibrium, the Johnson noise, is determined by its temperature T. We can define the sample's noise temperature which generalizes T for a system out of equilibrium. We can then define a complex frequency-dependent variable that measures how variate the sample\'s noise temperature respectively to a variation of an oscillating power at a given frequency : "The Noise Thermal Impedance" (NTI). By this quantity, one can access the main energy relaxation time that occurs in the conductor such as the electron-phonon or electron-electron interaction time.