# Quantum Modeling, Estimation and Control


## June 25, 2013
(Aula Magna "Lepschy", Dept. of Information Engineering)

9:00 - 10:00 **Welcome & Coffee**

10:30 - 11:30 **R. Alicki** (Uniwersytet Gdanski)
**Periodically Controlled Quantum Open Systems**

Markovian Master equation for a quantum system controlled by a periodic in time Hamiltonian and weakly coupled to stationary environment is derived. The obtained completely positive dynamics satisfies the laws of thermodynamics with properly defined heat currents and power. This formalism has been already applied to microscopic models of heat engines and refrigerators and will be applied soon to models of solar machines including those of biological relevance. Another future applications include dynamical decoupling models and dynamical quantum memory based on periodic error correction procedures.

11:30 - 12:30 **D. Reeb** (Technische Universität München)
**Cutoff Phenomenon, and Spectral Convergence Bounds**

In the first part of the talk I describe the cutoff phenomenon in Markov chains and in the time evolution of open systems generally. As a specific quantum information task, I discuss the dissipative preparation of graph states on multi-qubit systems, which exhibits cutoff behavior. In the second part I give new spectral bounds on the convergence time of open systems evolutions that exploit the power-boundedness of Markovian generators and use methods from harmonic analysis.

12:30 - 14:00 Lunch Break

Università degli Studi di Padova

# Workshop Program & Abstracts

14:00 - 15:00 **V. Giovannetti** (Scuola Normale Superiore di Pisa)
**Non-Abelian Phases from a Quantum Zeno Dynamics**

A connection is established between the non-Abelian phases obtained via adiabatic driving and that acquired via a quantum Zeno dynamics induced by repeated projective measurements. In comparison to the adiabatic case, the Zeno dynamics is shown to be more flexible in tuning the system evolution, which paves the way to the implementation of unitary quantum gates and applications in quantum control.

15:00 - 16:00 **A. Rivas** (Universidad Complutense de Madrid)
**Quantum non-Markovianty and Steady Entangled States**

Historically, Markovian quantum time evolutions were associated to the Kossakowki-Lindblad form of master equations and, as a consequence, all of the quantum dynamics which do not form a quantum dynamical semigroup were ofter considered as non-Markovian. However, the existence of time-dependent Kossakowski-Lindblad forms has lately attracted the attention of several groups asking for a broad definition of Markovianity and quantifying deviations from it. In this talk, we propose a unique solution for the problem of how to define Markovianity. This takes the advantage of previous ideas and approaches leading to a well-defined mathematical property (the so-called "divisibility property") which, in addition, enjoys an operational meaning. We complete the explanation by introducing some computable measures which assess the degree of non-Markovianity of a quantum dynamics. Finally, we present an example of non-Markovianity-assisted steady state entanglement. In this is a phenomenon non-Markovianity turns out to be an essential, quantifiable resource that may support the formation of steady state entanglement whereas under the same circumstances purely Markovian dynamics governed by dynamical semigroups lead to separable steady states.

**16:00 - 16:30 Coffee Break**

16:30 - 17:30 **L. Viola**
**Quantum state stabilization with engineered quasi-local Markovian dissipation**

Harnessing dissipation is a goal of increasing significance for quantum control. In this context, characterizing Markovian evolutions which admit a desired pure state as their unique asymptotically stable state is both relevant for a system-theoretic understanding of open-system stability properties and potentially useful for dissipative quantum state preparation. In this talk, I will focus on addressing under which conditions a multipartite qubit system can be driven to a desired pure entangled state by a Lindblad dynamics that obeys suitably defined "quasi-locality" constraints. I will first present a necessary and sufficient linear-algebraic criterion for the simplest scenario where the target system is driftless and quasi-local stabilization is possible for arbitrary initial states solely based on dissipative control resources. If the required conditions are not met, I will further address whether the control objective may be achieved conditional upon initialization in a proper subspace and/or by additionally exploiting Hamiltonian control. Applications to engineering entangled states of physical interest and explicit schemes for synthesizing the required controls will be discussed.

## 17:30 - 18:30 **M. Müller** (Universidad Complutense de Madrid)
## **Open-System Quantum Simulation with Atoms and Ion**

A universal quantum simulator is a controllable device, which allows one to reproduce efficiently the dynamics of any other quantum system with short-range interactions. Such time evolution can refer to coherent Hamiltonian dynamics of closed quantum systems, as well as dissipative open-system dynamics. In our talk we introduce schemes for digital quantum simulation with trapped ions and Rydberg atoms in optical lattices. We show how to use combinations of coherent quantum gates with optical pumping of ancillary qubits for the engineering of coherent and dissipative multi-particle Kraus maps. These can be harnessed for the simulation of complex Hamiltonians involving n-body interactions such as Kitaev's toric code, as well as for the dissipative preparation and stabilization of entangled states and quantum phases. In addition, we show how the competition of coherent and dissipative dynamical maps can lead to novel new-equilibrium manybody dynamics with associated dynamical phase transitions with no immediate counterpart in equilibrium condensed matter systems. We report on a series of recent experiments with trapped ions, where the concepts of digital and open-system quantum simulation have been demonstrated and the hallmark signatures of open-system non-equilibrium many-body physics have been observed, using up to six qubits. Finally, we discuss an error detection and reduction toolbox based on open- and closed-loop feedback schemes, which has been recently developed and implemented as a first step in the direction of faithful quantum simulation of larger systems.

## June 26, 2013

### (Aula Magna "Lepschy", Dept. of Information Engineering)

9:00 - 10:00 **D. Gross** (ETH Zurich)
**The Complexity of Learning Quantum States**

The complete characterization of a quantum system by physical measurements seems to be a conceptually simple task and is routinely carried out experimentally. It is thus all the more surprising that many fundamental questions pertaining to this procedure remain unanswered. (And, what is more, lead to highly non-trivial mathematical problems). A prime example is determining the sample complexity of quantum state estimation: under realistic conditions, how many experimental runs does one need in order to obtain an estimate for an unknown quantum state with acceptable error bars? Simple answers based on asymptotic statistics turn out to be highly inaccurate (in fact, way too pessimistic). I will report recent progress on this and related problems. It is both based on, and has contributed to, new developments in classical statistics and machine learning theory. I will mention proposals for tasks as varied as face recognition and prediction of online behavior which have been influenced by methods from quantum state tomography.

10:00 - 10:30 **Coffee Break**

10:30 - 11:30 **M. Paris** (Università di Milano)
**Quantum estimation of states and operations from incomplete data**

We review minimum Kullback entropy principle for estimation of quantum states and operations and discuss its application to qubit and harmonic oscillator systems. We also investigate in some details in which conditions an approximate solutions of the minimization problem may be effectively used.

11:30 - 12:30 **R. Blume-Kohut** (Sandia National Laboratories)
**Debugging a Running Qubit**

I present two techniques to diagnose and correct systematic errors in quantum information processing hardware (e.g., qubits and logic gates). The first is gate-set tomography, which provides an arbitrarily accurate and self-consistent estimate of a set of quantum gates (i.e., the completely positive maps implemented by a set of repeatable control sequences), using data obtained by applying a variety of sequences of those gates. Gate-set tomography combines robustness to systematic errors and SPAM noise (exceeding even that of randomized benchmarking) with the ability to deliver all the information needed to debug or fine-tune the gates -- potentially even in real time. The second, drift control, demonstrates the possibility of characterizing and correcting systematic errors (albeit a simpler model) in real time. Drift control uses the syndrome measurement results from an N-qubit error correcting code to estimate and compensate for drift (time variation) in each physical qubit's Hamiltonian, on the fly, without damaging the encoded information or interfering with error correction. I will demonstrate both techniques in simulations, and discuss where we may hope to go from here.

12:30 - 14:00 Lunch Break

14:00 - 15:00 **M. Guta** (University of Nottingham)
**System identification for quantum open systems**

**Abstract -TBA**

15:00 - 16:00 **S. Schirmer** (Swansea University)

**Title and Abstract - TBA**

16:00 - 16:30 **Coffee Break**

16:30 - 17:30 **P. Rouchon** (Mines ParisTech)
**Two kinds of feedback for open quantum systems and the developments of mathematical quantum systems theory**

For quantum systems exist two kinds of stabilizing feedback: measurement-based feedback and coherent feedback. These feedbacks will be presented for the photon-box developed by Serge Haroche and his collaborators. For the measurement-based feedback, the stabilizing scheme is classical and admits an observer/controller structure. For the coherent feedback scheme, the "controller" is quantum. It relies on measurement back-action and reservoir engineering to stabilize a goal quantum state. These two kinds of feedback illustrate key differences with mathematical (classical) systems theory. They also motivate the development of systematic methods for the simulation, the control and the estimation of open quantum systems. A preliminary list of research items underlying mathematical quantum systems theory will be given as conclusion

17:30 - 18:30 **C. Pellegrini** (Université Paul Sabatier, Tolouse)
**Indirect Quantum Non-Demoliton Measurement: Discrete and Continuous Time Models**

We study the evolution of a quantum system undergoing indirect quantum measurement. We present discrete time and continuous time models of evolution. Discrete time models refer to the principle of Quantum Repeated Measurements. Continuous Time models are described trough jump-diffusion stochastic master equations. In the context of Quantum Non-demolition Measurement, we investigate the large time behavior of the state of the system. Link between discrete time models and continuous time models are also presented.

19:30 - **Social Dinner**

## June 27, 2013
### (Aula Magna "Lepschy", Dept. of Information Engineering)

9:00 - 10:00 **J. Gough** (Aberystwyth University)
**Quantum Control through Interconnection**

We review the "S,L,H" approach to quantum open systems, and the quantum feedback network formalism for connecting quantum open systems. We will describe the potential applications of these networks to quantum coherent control, as well as recent modeling developments.

10:00 - 10:30 **Coffee Break**

10:30 - 11:30 **A. Sarlette** (Ghent University)
**A Consensus Algorithm Framework for Quantum Networks**

In this talk we propose an extension of the so-called "consensus" framework to networks of quantum systems. The goal of classical consensus is that states associated to different subsystems in a network, converge to an average "agreement" (or consensus) value by iterating local interaction rules. In the quantum context, due to the tensor product structure of the joint state space, the notion of "agreement" among subsystems must be re-defined and we distinguish different types of consensus. Since the classical consensus algorithms are based on communication of state values, which is unfeasible with quantum subsystems, we propose an adapted algorithm on the basis of physically realizable subsystem permutations. We prove the convergence of this algorithm. Finally, we discuss how this leads to a more general viewpoint on consensus as a symmetrization task -- that is a task which fits the quantum physics ingredients outstandingly well.

11:30 - 12:30 **K. Jacobs** (University of Massachusetts Boston)
**When Coherent Feedback Beats Measurement-Based Feedback**

In the first part of the talk I will give a dynamical explanation for why it is that coherent feedback can outperform measurement-based feedback under constraints on the speed of control. I will also examine briefly the relative merits of the two forms of feedback in terms of practical implementation. In the second part of the talk I will discuss the problems that I think are presently the most interesting questions in coherent feedback control and its relationship to measurement-based feedback.

12:30 - 14:00 Lunch Break

## (Meeting Room DEI/G, Dept. of Information Engineering)

14:00 - 15:00 **D. D'Alessandro** (Iowa State University)

### Exact Algebraic Conditions for Indirect Controllability in Quantum Coherent Feedback Schemes

In coherent quantum feedback control schemes, a target quantum system S is put in contact with an auxiliary system A and the coherent control can directly affect only A. The system S is controlled indirectly through the interaction with A. The system S is said to be indirectly controllable if every unitary transformation can be performed on the state of S with this scheme. The indirect controllability of S will depend on the dynamical Lie algebra L characterizing the dynamics of the total system S+A and on the initial state of the auxiliary system A. In this talk we describe this characterization exactly.

15:00 - 16:00 **D. Sugny** (University of Bourgogne)

### Geometric Optimal Control of Open Quantum Systems with Applications in Nuclear Magnetic Resonance

We apply recent developments in geometric optimal control to analyze the control of open quantum systems whose dynamics is governed by the Lindblad equation. Geometric optimal control is a vast domain based on the application of the Pontryagin Maximum Principle (PMP) which leads to a global analysis of the control problem. This study completes and guides the purely numerical computations. We will consider different basic problems of quantum mechanics such as the control in minimum time of a two-level dissipative quantum system. Some applications in Nu- clear Magnetic Resonance and Magnetic Resonance Imaging will illustrate this theoretical work.

16:00 - 17:00 **U. Boscain** (CNRS-Ecole Polytechnique)

### Spectral conditions for the controllability of the Schroedinger equation

In this talk I will review some controllability conditions for closed quantum systems. In the first part I will discuss sufficient conditions for the approximate controllability of the Schroedinger equation as a PDE. In the second part I will discuss a constructive method for systems with two controls which makes use of the presence of conical eigenvalue intersections in the space of controls. This method permits to get exact controllability for finite dimensional quantum systems and approximate controllability of the Schroedinger equation as a PDE.