Workshop quantum measurements concentration and functional inequalities 2023, Toulouse

Titles and abstracts

Juan P. Garrahan *Statistics of trajectories and bounds on fluctuations, from classical to quantum*

I will present basic ideas about the ensemble approach for the study of trajectories of stochastic many-body systems. I will review the method of dynamical large deviations, and discuss lower bounds (known as thermodynamic uncertainty relations) and upper bounds (inverse TURs) on the size of fluctuations of dynamical observables. I will also explain how to generalise these ideas to quantum Markovian systems.

Federico Girotti *Concentration Inequalities for Output Statistics of Quantum Markov Processes*

Quantum Markov chains describe the evolution of a quantum system, which interacts successively with a sequence of identically prepared ancillary systems (input). Such dynamics can be seen as discrete-time versions of continuous-time open system evolutions as encountered in quantum optics and formalize the input–output theory of quantum filtering and control. After the interaction, the probes (output) are in a finitely correlated state, which carries information about the dynamics; such information can be extracted by performing successive measurements on the outgoing probes and the simplest statistics that one can consider are time-averages of measurement outcomes.

In our talk we will show how some ideas exploited for proving concentration bounds for empirical averages of Markov chains can be used to derive Bernstein and Hoeffding type inequalities for time-averages of measurement outcomes. We will also discuss how, specialized to classical Markov chains, they provide new concentration bounds for empirical fluxes and how the techniques also work for quantum counting processes. The talk is based on joint work with J. P. Garrahan and M. Guta.

Linda Greggio *Asymptotic statistics of repeated quantum measurements*

Given a quantum system subject to repeated indirect measurements, we are interested in the asymptotic properties of the counting process of a certain outcome. In this talk we will tackle the most general case of a quantum channel having multiple invariant states, without requiring any ergodicity assumption on it. We will show how it is possible to reconduce this case to the unique invariant state case, exploiting a decomposition of the outcomes law into a convex combination of conditional laws. This trick will permit us to generalize the Central Limit Theorem for the counting process presented in [1], where some ergodicity and identifiability hypotheses were made. The CLT is derived by exploiting martingale techniques, thanks to a martingale approximation of the counting process' fluctuations around the LLN's asymptotic value. This martingale is constructed exploiting a solution to the Poisson equation. Furthermore we will show how it is possible to circumvent the non identifiability problem considering equivalence classes, thus finally obtaining a general result that does not require any specific assumptions on the quantum channel or on the outcomes law.

In doing so we present a new way to extend the work presented in [1], previously improved in [3] by making use of deformation techniques and spectral theory.

We will finally give an idea of how the same trick could be used to derive statistical asymptotic laws for the counting process of a finite length sequence of outcomes, exploiting a different solution to the Poisson equation derived in [2]. The talk is based on a joint work with T. Benoist and C. Pellegrini.

References:

[1] Stéphane Attal, Nadine Guillotin-Plantard, and Christophe Sabot. Central limit theorems for open quantum random walks and quantum measurement records, 2013.

[2] Federico Girotti, Juan P. Garrahan, and Mădălin Guţă. Concentration inequalities for output statistics of quantum markov processes, 2022.

[3] Raffaella Carbone, Federico Girotti, and Anderson Melchor Hernandez. On a generalized central limit theorem and large deviations for homogeneous open quantum walks. Journal of Statistical Physics, 188(1):1–33, 2022.

Mădălin Guţă *Displaced-null measurements for optimal estimation of pure states and quantum Markov chains*

In the first part of the talk I will discuss the problem of estimating a pure state and investigate the performance of a specific scheme which consists of measuring in a basis that contains the state to be estimated. While this is sometimes claimed to achieve the quantum Cramer-Rao bound, I will show that such null-measurement is suboptimal due to the non-identifiability of the associated classical statistical model. I will then show how a modified version called displaced-null measurement does achieve the quantum Cramer-Rao bound asymptotically, and explain how this relates to the estimation of the mean of a coherent state using counting measurements.

In the second part, I will discuss the problem of estimating dynamical parameters of a quantum Markov chain. The key tool will be the use of a coherent quantum absorber which transforms the problem into a simpler one pertaining to a system with a pure stationary state. I will then define certain translationally invariant modes of the output and show that the output state reduces to a coherent state of these modes. This provides a concrete representation of the local asymptotic normality phenomenon for Markov dynamics. The technique of null-measurement measurements can then be used to optimally estimate dynamical parameters by performing counting measurements in the output.

Cambyse Rouzé *Efficient learning of thermal phases of matter*

In this talk, we will consider two related tasks: (a) estimating a parameterisation of a given Gibbs state and expectation values of extensive, linear and non-linear observables; and (b) learning the expectation values of local observables within a thermal phase of matter. In both cases, we wish to minimise the number of samples we use to learn these properties to a given precision. For the first task, we develop new techniques to learn parameterisations of classes of systems, including quantum Gibbs states of non-commuting Hamiltonians with exponential decay of correlations and the approximate Markov property. We show it is possible to infer the expectation values of all extensive properties of the state from a number of copies that not only scales polylogarithmically with the system size, but polynomially in the observable's locality – an exponential improvement over previous methods. For the second task, we develop efficient algorithms for learning observables in a thermal phase of matter of a quantum system. By exploiting the locality of the Hamiltonian, we show that sums of local observables can be learned with high probability using a number of samples that scales logarithmically with the size of the system, and quasi-polynomially with the required precision. In addition, our sample complexity applies to the worse case setting in contrast with standard machine learning techniques. This is based on joint work (arXiv:2301.12946) with Emilio Onorati (TUM), Daniel Stilck Franca (ENS Lyon) and James Watson (Maryland).

Daniel Stilk-Franca *Concentration properties of shallow and noisy quantum circuits*

The impressive progress in quantum hardware of the last years has raised the interest of the quantum computing community in harvesting the computational power of such devices. However, in the absence of error correction, these devices can only reliably implement very shallow circuits or comparatively deeper circuits at the expense of a nontrivial density of errors. In this work, we obtain extremely tight limitation bounds for standard NISQ proposals in both the noisy and noiseless regimes, with or without error-mitigation tools. The bounds limit the performance of both circuit model algorithms, such as QAOA, and also continuous-time algorithms, such as quantum annealing. In the noisy regime with local depolarizing noise p, we prove that at depths $L = \mathcal{O}(p^{-1})$ it is exponentially unlikely that the outcome of a noisy quantum circuit outperforms efficient classical algorithms for combinatorial optimization problems like Max-Cut. Although previous results already showed that classical algorithms outperform noisy quantum circuits at constant depth, these results only held for the expectation value of the output. Our results are based on newly developed quantum entropic and concentration inequalities, which constitute a homogeneous toolkit of theoretical methods from the quantum theory of optimal mass transport whose potential usefulness goes beyond the study of variational quantum algorithms.

Furthermore, we will extend our concentration inequalities to quantum many-body states such as MPS through elementary proofs.

Melchior Wirth *Logarithmic Sobolev inequalities - beyond matrix algebras and tracial symmetry*

Some recent progress on (modified) logarithmic Sobolev inequalities for quantum Markov semigroups that act on infinite-dimensional von Neumann algebras and are not necessarily symmetric with respect to a trace will be presented. I will discuss a de Bruijn identity in this setting, which implies the equivalence of the modified logarithmic Sobolev inequality and exponential entropy decay. For GNS-symmetric semigroups I will give an intertwining criterion for the modified logarithmic Sobolev inequality and show that the logarithmic Sobolev inequality and hypercontractivity are equivalent.