Satellite at NetSci 2014, Berkeley.

Quantum Frontiers in Network Science (QNET)

Book of Abstracts

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Organizers: Mauro Faccin,
Filippo Radicchi and
Zoltan Zimboras

A grand challenge in contemporary complex network science is to reconcile the staple statistical mechanics based approach, with a theory based on quantum physics. When considering networks where quantum coherence effects play a non-trivial role, the predictive power of complex network science has been shown to break down. A new theory is now being developed which is based on quantum theory, from first principles. Network theory is a diverse subject which developed independently in several disciplines to rely on graphs with additional structure to model complex systems. Network science has of course played a significant role in quantum theory, ranging from methods of "tensor network states", "chiral quantum walks on complex networks", "categorical tensor networks" and "categorical models of quantum circuits", to name only a few. However, the ideas of complex network science are only now starting to be united with modern quantum theory. From this respect, one aim of the workshop is to put in contact two big and, generally not very well connected, scientific communities: statistical and quantum physicists.

The topic of network science underwent a revolution when it was realized that systems such as social or transport networks could be interrelated through common network properties, but what are the relevant properties to consider when facing quantum systems? This question is particularly timely as there has been a recent push towards studying increasingly larger quantum mechanical systems, where the analysis is only beginning to undergo a shift towards embracing the concepts of complex networks.

For example, theoretical and experimental attention has turned to explaining transport in photosynthetic complexes comprising tens to hundreds of molecules and thousands of atoms using quantum mechanics. Likewise, in condensed matter physics using the language of chiral quantum walks, the topological structure of the interconnections comprising complex materials strongly affects their transport properties.

An ultimate goal is a mathematical theory and formal description which pinpoints the similarities and differences between the use of networks throughout the quantum sciences. This would give rise to a theory of networks augmenting the current statistical mechanics approach to complex network structure, evolution, and process with a new theory based on quantum mechanics.

Topics covered in the satellite

- Quantum transport and chiral quantum walks on complex networks
- Detecting community structure in quantum systems
- Tensor algebra and multiplex networks
- Quantum information measures (such as entropy) applied to complex networks
- Quantum critical phenomena in complex networks
- Quantum models of network growth
- Quantum techniques for reaction networks

- Quantum algorithms for problems in complex network science
- Foundations of quantum theory in relation to complex networks and processes thereon
- Quantum inspired mathematics as a foundation for network science

Satellite program

08:30	welcome
08:45	**Ginestra Bianconi**
09:30	**Tomi Johnson**
10:00	**Silvano Garnerone**
10:30	Coffee break
11:00	**Leonardo Banchi**
11:30	**Blake Pollard**
12:00	**Tomi Johnson**

Keynote Talk

Statistical Mechanics of Quantum Complex Networks

Ginestra Bianconi

Queen Mary (London)

In this talk I will describe the interplay between complex networks structures and quantum statistical mechanics, considering two approaches.

First of all I will show how symmetries in growing networks models can be used to construct on one side scale-free networks with "energy" of the nodes described by the Bose-Einstein distribution and on the other side Cayley trees with "energy" of the nodes described by the Fermi distribution.

These results demonstrate that complex networks topologies of non-equilibrium growing networks can be characterized by quantum statistics. Moreover the mapping between the complex networks and the corresponding quantum gas is able to predict that growing complex networks might undergo a structural phase transition called the Bose-Einstein condensation of complex networks in which one node grabs a finite fraction of all the links.

Secondly I will show that complex scale-free network topologies can change the phase diagram of quantum critical phenomena such as the Transverse Ising model, the Bose-Hubbard model or the Jaynes-Cumming model, offering the possibility to explore the interplay between quantum critical phenomena and the topology of complex networks.

Invited talks

Community detection in quantum networks

Tomi Johnson

ISI Foundation (Turin)

Determining the community structure is a central topic in the study of classical networks. In this talk we give a first attempt at extending the concept of community detection to quantum systems. We demonstrate that certain quantum mechanical effects cannot be captured using current classical complex network tools, and thus we develop new tools. To illustrate the effectiveness our approach to detect community structure in quantum systems we provide many examples, including a naturally occurring light harvesting complex, LHCII. The prediction of our simplest algorithm, semi-classical in nature, mostly agrees with a supposed partitioning for the LHCII found in quantum chemistry literature, whereas our fully quantum algorithms uncover a new, consistent and appropriately quantum community structure.

Adiabatic quantum algorithm for search engine ranking

Silvano Garnerone

Institute for Quantum Computing (Waterloo)

We propose an adiabatic quantum algorithm for generating a quantum pure state encoding of the PageRank vector, the most widely used tool in ranking the relative importance of internet pages. We present extensive numerical simulations which provide evidence that this algorithm can prepare the quantum PageRank state in a time which, on average, scales polylogarithmically in the number of webpages. We argue that the main topological feature of the underlying web graph allowing for such a scaling is the out-degree distribution. The top ranked log(n) entries of the quantum PageRank state can then be estimated with a polynomial quantum speedup. Moreover, the quantum PageRank state can be used in "q-sampling" protocols for testing properties of distributions, which require exponentially fewer measurements than all classical schemes designed for the same task. This can be used to decide whether to run a classical update of the PageRank.

Engineered Quantum Networks for Entanglement Sharing and Generation

Leonardo Banchi

UCL (London)

We optimize a quantum walk of multiple fermions following a quench to generate near ideal resources for quantum networking. We first prove an useful theorem mapping the correlations evolved from specific quenches to the apparently unrelated problem of quantum state transfer between distinct sites. This mapping is then exploited to optimize the dynamics and produce large amounts of entanglement distributed in very special ways. Two applications are considered: the simultaneous generation of many Bell states between pairs of distant spins (maximal block entropy), or high entanglement between the ends of an arbitrarily long linear chain (distance independent entanglement). Thanks to the generality of the result, we study its implementation in different experimental setups using present technology: NMR, ion traps and ultracold atoms in optical lattices.

Quantropy

Blake Pollard

University of California, Riverside

There is a well-known analogy between statistical and quantum mechanics. In statistical mechanics, Boltzmann realized that the probability for a system in thermal equilibrium to occupy a given state is proportional to $\exp(E/kT)$ where E is the energy of that state. In quantum mechanics, Feynman realized that the amplitude for a system to undergo a given history is proportional to $\exp(S/i\hbar)$ where S is the action of that history. In statistical mechanics we can recover Boltzmanns formula by maximizing entropy subject to a constraint on the expected energy. This raises the question: what is the quantum mechanical analogue of entropy? We give a formula for this quantity, and for lack of a better name we call it quantropy. We recover Feynmans formula from assuming that histories have complex amplitudes, that these amplitudes sum to one, and that the amplitudes give a stationary point of quantropy subject to a constraint on the expected action. Alternatively, we can assume the amplitudes sum to one and that they give a stationary point of a quantity we call free action, which is analogous to free energy in statistical mechanics. We compute the quantropy, expected action and free action for a free particle, and draw some conclusions from the results.

Quantum-style tensor network factorisation in stochastic networks

Tomi Johnson

Oxford (UK)

Estimating the expected value of a dynamical observable appearing in a stochastic process usually involves sampling. If its variance is high, many samples are required. In this talk we show how to perform the same task without sampling, using tensor network compression tools proposed for quantum systems. We provide examples for which matching the accuracy and efficiency of our method would require a sample size scaling exponentially with system size. Specifically, our example observables are exponentials of the work done on an out-of-equilibrium Ising model, related by Jarzynski's equality to free energy estimation.