ICFO

PhD Thesis Defense PIOTR MIGDAL 'Symmetries and Self-Similarity of Many-Body Wavefunctions'

PIOTR MIGDAL

December 11, 2014

Thursday December 11, 11:00. ICFO Auditorium

PIOTR MIGDAL

Quantum Optics Theory

ICFO-The Institute of Photonic Sciences, SPAIN

The study of the structure of quantum states can provide insight into the possibilities of quantum mechanics applied to quantum communication, cryptography and computations, as well as the study of condensed matter systems. For example, it shows the physical restrictions on the ways how a quantum state can be used and allows us to tell which quantum states are equivalent up to local operations.

Therefore, it is crucial for any analysis of the properties and applications of quantum states.

This PhD thesis is dedicated to the study of the interplay between symmetries of quantum states and their self-similar properties. It consists of three connected threads of research: polynomial invariants for multiphoton states, visualization schemes for quantum many-body systems and a complex networks approach to quantum walks on a graph.

First, we study the problem of which many-photon states are equivalent up to the action of passive linear optics. We prove that it can be converted into the problem of equivalence of two permutation-symmetric states, not necessarily restricted to the same operation on all parties. We show that the problem can be formulated in terms of symmetries of complex polynomials of many variables, and provide two families of invariants, which are straightforward to compute and provide analytical results. Furthermore, we prove that some highly symmetric states (singlet states implemented with photons) offer two degrees of robustness - both against collective decoherence and against a photon loss. Additionally, we provide two proposals for experiments, feasible with an optical setup and current technology: one related to the direct measurement of a family of invariants using photon-counting, and the other concerning the protection of transmitted quantum information employing the symmetries of the state.

Second, we study a family of recursive visualization schemes for many-particle systems, for which we have coined the name ?qubism?. While all many-qudit states can be plotted with qubism, it is especially useful for spin chains and one-dimensional translationally invariant states. This symmetry results in self-similarity of the plot, making it more comprehensible and allowing to discover certain structures. This visualization scheme allows to compare states of different particle numbers (which may be useful in numerical simulations when particle number is an open parameter) and puts emphasis on correlations between neighboring particles. The visualization scheme can be used to plot probability distribution of sequences, e.g. related to series of nucleotides in RNA and DNA or - aminoacids in proteins. However, unlike classical probabilistic ensembles of sequences, visualizing quantum states offers more - showing entanglement and allowing to observe quantum phase transitions.

Third, we study quantum walks of a single particle on graphs, which are classical analogues of random walks. Our focus in on the long-time limit of the probability distribution. We define ?quantumness? to be the difference between the probability distributions of the quantum and related classical random walks. Moreover, we study how (especially in the long-time limit) off-diagonal elements of the density matrix behave. That is, we measure coherence between different nodes, and we use them to perform quantum community detection --- splitting of a graph into subgraphs in such a way that the coherence between them is small. We perform a bottom-up hierarchical aggregation, with a scheme similar to modularity maximization, which is a standard tool for the, so called, community detection for (classical) complex networks. However, our method captures properties that classical methods cannot --- the impact of constructive and destructive interference, as well as the dependence of the results on the tunneling phase.

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