Simulation of non-localized to localized transition in discrete time quantum walks

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Recently, discrete time quantum walks (DTQW) [1, 2] are emerging as a platform for quantum simulators both theoretically and experimentally. Among the targets for simulations are transport phenomena in disordered systems [3, 4]. The discrete time evolution based on iterative applications of a unitary operator of the familiar form $U = SC$ makes the DTQW attractive from the experimental point of view. Both the shift operator S and the coin operator C can be decomposed into independent, essentially local operations, allowing efficient implementation in linear optical networks[5, 6, 7]. The simple definition, however, does not imply simple dynamics. Among other things, quantum walks have been shown both theoretically and experimentally to exhibit non-trivial features such as Anderson-localization [8, 9, 10, 11], and topological phases [12, 13].

A split step 2D quantum walk, using a 2 dimensional coin, has been theoretically studied in [14] displaying a combination of 1D and 2D effects. In this presentation we address the consequence of phase noise on a quantum walk with a 4 dimensional coin on a 2D square lattice, similar to that realized in [15]. Our findings are supported by a theorem due to Joye [16] guaranteeing the emergence of a localized regime in the parameter space of the coin operators. Our numerical calculations were aimed at the quantitative study of the transition from the localized to the delocalized regimes in the phase space of the coin operator and the degree of disorder. We performed a finite size scaling analysis of the walker's variance, complemented by a similar analysis of the spectral statistics of the evolution operator. These calculations allowed us to locate the transition line, and determine various critical exponents opening ways to characterize the critical behaviour, and make comparisons with standard results on Anderson localization.

Our results indicate that quantum walks may be an excellent tool for simulating systems close to their phase transition points, a regime where the approximations usually employed in classical simulation algorithms tend to break down due to diverging correlation lengths. While the present results are pointing out new perspectives for applications of quantum walks, a generalization beyond the presently treated non-interacting lattice models would be desirable.

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