HYBRID QUANTUM-CLASSICAL WALKS WITH APPLICATIONS TO MACHINE LEARNING

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Most systems in nature can be represented as complex networks, where their elements are nodes, and edges represent the interactions between them. Traditional classical random walks (CRWs) are often employed in machine learning tasks for the study of graphs. In this work, we introduce a Hybrid Quantum-Classical Walk (HQCW) model that is based on a modified version of the Lindblad master equation, and is able to combine both coherent quantum evolution and incoherent classical jumps with a tuning parameter $\alpha \in [0, 1]$. The Quantum-Jump approach allows for the unraveling of these dynamics into stochastic quantum-jump trajectories that produce individual node-visit sequences and whose ensemble statistics recover the Lindblad density matrix evolution. We show that using these HQCW trajectories as a sampling strategy for Graph Representation Learning yields embeddings that break classical ranking degeneracies on a small directed graph, correctly recover the split of Zachary's Karate Club into two communities, and separate four defined communities in a synthetic clustered network, even at low embedding dimension d. We find that a near-classical regime ($\alpha \approx 0.8$) optimally captures the global structure of networks and yields high-quality node embeddings. Our results demonstrate that HQCWs are a powerful, scalable alternative for network analysis, paving the way for quantum-inspired methods in machine learning and the study of complex networks.

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