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Quantum spatial search with long-range hopping

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Spatial searches by continuous-time quantum walks have been rigorously studied on lattices with nearest-neighbor hopping, in which search capabilities worsen with decreasing lattice dimension when $d \leq 4$. With the addition of long-range hopping, where the hopping rate τ decays as a power-law with the inter-site distance $\tau \sim \ell^{-\alpha}$, we can avert this deterioration in performance. More precisely, we recover $\mathcal{O}(\sqrt{N})$ runtimes for quantum spatial search conducted on low-dimensional cubic lattices of N sites. This is established via an asymptotic analysis of the spectral gap of the lattice's associated discrete Laplacian. The asymptotics also shed light on the interplay between the lattice's Euclidean dimension d and the long-range hopping exponent α, requiring $\alpha < 3d/2$, $d \in [1, 4]$, for high-fidelity searches in $\mathcal{O}(\sqrt{N})$ runtime. Extending the study to also include Euclidean dimensions $d > 4$, we establish that the *spectral dimension* d_s must satisfy the constraint $d_s > 4$ to achieve optimal search. Moreover, the spectral dimension d_s relies on the Laplacian's spectral density and does not uniquely define the underlying lattice structure, thereby providing a promising metric to understand the complexity class of quantum search algorithms on different graph architectures.

Title

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