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Expanding the class of Free Fermions

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We present a novel graph-theoretic approach to simplifying generic many-body Hamiltonians. Our primary result introduces a recursive twin-collapse algorithm, leveraging the identification and elimination of symmetric vertex pairs (twins) within the frustration graph of the Hamiltonian. This method systematically block-diagonalizes Hamiltonians, reducing complexity while preserving the energetic spectrum. Importantly, our approach expands the class of models that can be mapped to non-interacting fermionic Hamiltonians (free-fermion solutions), thereby broadening the applicability of classical solvability methods. Through numerical experiments on spin Hamiltonians arranged in periodic lattice configurations and Majorana Hamiltonians, we demonstrate that the twin-collapse substantially increases the identification of simplicial and claw-free graph structures, which characterize free-fermion solvability. Finally, we extend our framework by presenting a generalized discrete Stone-von Neumann theorem. This comprehensive framework provides new insights into Hamiltonian simplification techniques, free-fermion solutions, and group-theoretical characterizations relevant for quantum chemistry, condensed matter physics, and quantum computation.

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