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Quantum Optimisation Algorithms on Calculating Ramsey Numbers

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The computation of Ramsey Numbers in graph theory looks for the appearance of order of a certain substructure in a graph of given size. Mathematically, the calculation of a Ramsey Number R(k, l) = n is a two colouring problem that finds the smallest graph of size n, that contains either a colouring of size k or a different colouring of size l, [1]. This is a formidable computational challenge. Classical algorithms face a search space that grows super-exponentially with the number of vertices, rendering the problem intractable. This abstract presents an approach to utilizing Quantum Optimisation Algorithms to address this complexity, with an experimental implementation targeting IBMQ quantum hardware.
The following paper, [2], reformulates the problem of determining if R(k, l) > n (i.e., if an n-vertex graph exists with no k-clique or l-independent set) into a Quadratic Unconstrained Binary Optimisation (QUBO) problem. The associated Problem Hamiltonian, HP , is constructed such that its ground state corresponds to a solution that satisfies our decision problem.

We employ the Variational Algorithm, a leading hybrid quantum-classical method. The circuit is implemented using the Qiskit framework and executed on accessible IBMQ systems. A key aspect of our work is the introduction of quantum approaches in this field and execution on Utility scale IBMQ architecture.
To our knowledge, the following paper, [3], solves R(5, 5) = 45 with Majorana based Algebra on a Photonic Quantum Computer, using only 5 qubits.
We have verified classical results for the computation of small, yet non-trivial, Ramsey numbers, such as R(3, 3), by benchmarking the performance classical optimization. We would like to investigate the scale-up performance and quality of results on Utility scale quantum computers. Our findings will contribute to the knowledge of solving problems beyond the reach of conventional High Performance Computing (HPC) resources.

[1] - Bondy, J.A., and P. Erd¨os. “Ramsey numbers for cycles in graphs.” Journal of Combinatorial Theory, Series B, vol. 14, no. 1, 1973, pp. 46–54. Crossref, https://doi.org/10.1016/S0095-8956(73)80005-X
[2] - Wang, Hefeng. “Determining Ramsey Numbers on a Quantum Computer.” Physical Review A, vol. 93, no. 3, Mar. 2016. Crossref, https://doi.org/10.1103/physreva.93.032301
[3] - Tamburini, Fabrizio. “Random-projector quantum diagnostics of Ramsey numbers and a prime-factor heuristic for R(5,5)=45.” arXiv, 2025. arXiv:2508.16699.

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