Quantum Approaches to Combinatorial Optimisation Problems in the Automotive Industry

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The binary paint shop problem (BPSP) is a combinatorial optimisation challenge in the automotive industry with the goal to minimise the number of colour swaps required to paint sequences of cars under certain constraints. Optimising the number of colour swaps directly reduces the operational costs of production but also reduces environmental pollutant by-products produced in the cleansing of the painting apparatus during colour changes. The BPSP has previously been mapped to the quantum approximate optimisation algorithm (QAOA) [1]. The problem graph is symmetric, and it approaches 4-regular and unit-couplings as the problem size increases, enabling optimal parameters to be well approximated by efficient precomputation techniques, effectively bypassing the classical optimisation loop [2]. We extend these results by applying a recent variation of QAOA called recursive-QAOA (RQAOA) that was introduced to alleviate inherent computational limits present in QAOA with symmetric local Hamiltonians [3]. We benchmark the BPSP solution qualities obtained by optimising QAOA and RQAOA against classical heuristics and exact solvers. We compare these results with solutions obtained by using precomputed parameters for QAOA and for each recursive step of RQAOA. Two approaches are used to precompute the parameters. The first is by using the parameters obtained in [4]. The second is by using parameter transfer on the median optimal parameters calculated over many smaller instances to approximate optimised parameters for larger unseen instances using QAOAKit [5]. From our experiments, it appears that the performance of RQAOA is resilient to non-optimal approximate parameters and the precomputed parameter approximations result in high quality solutions for the randomly chosen samples of BPSP instances used in this study. This forms the basis for further analysis including the effects of noise and error mitigation, instance space analysis [6] and scaling to investigate quantum advantage.

[1] Edward Farhi, Jeffrey Goldstone, and Sam Gutmann, *arXiv preprint,* arXiv:1411.4028 **(2014)**

[2] Michael Streif, et. al., *Physical Review A,* 104(1):012403 **(2021)**

[3] Sergey Bravyi, et. al., *Physical Review Letters*, 125(26):260505 **(2020)**

[4] Michael Streif and Martin Leib, *Quantum Science and Technology*, 5(3):034008 **(2020)**

[5] Ruslin Shaydulin, et. al., *IEEE/ACM Second International Workshop on QCS*, pages 64-71 **(2021)**

[6] Asier Ozaeta, et. al., *arXiv preprint,* arXiv:2012.03421 **(2021)**