Counterdiabatic Corrections to the Quantum Approximate Optimization Algorithm

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Abstract

The Quantum Approximate Optimization Algorithm (QAOA) is a promising hybrid quantum-classical algorithm that can solve combinatorial optimization problems [1]. The quantum part of the algorithm involves using parametric unitary operations on a quantum computer to prepare a trial solution state. The parametric QAOA angles are variationally optimized minimizing a cost function using classical methods. Generalizing the results on ref. [2], we study a generalized QAOA ansatz that includes corrections to the Trotter expansion at the first and second order based on the Baker-Campbell-Hausdorff (BCH) expansion [3]. By utilizing terms in the BCH expansion as additional control unitaries, each with its own angle, we can improve convergence compared to standard QAOA (Figure 1). The additional angles are treated as independent free parameters, rather than keeping them fixed to the prescription of the BCH expansion, resulting in a cost function simpler to deal with (Figure 2).

References

[1] E. Farhi, J. Goldstone, and S. Gutmann, arXiv:1411.4028 (2014)
[2] J. Wurtz and P. J. Love, Quantum, vol. 6, (Jan. 2022), p. 635.
[3] X.-P. Li and J. Q. Broughton, The Journal of Chemical Physics, (May 1987), vol. 86, pp. 5094–5100

Figures

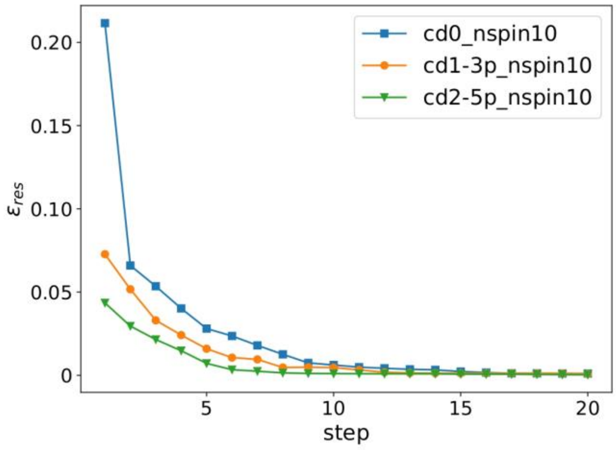

Figure 1: Residual energy (ε_{res}) for a 10-spin chain with random couplings and open boundary conditions vs number of QAOA steps. We see that, each step, the generalized QAOA ansatzes (cd1-3p and cd2-5p) yield smaller residual energies than the standard ansatz (cd0).

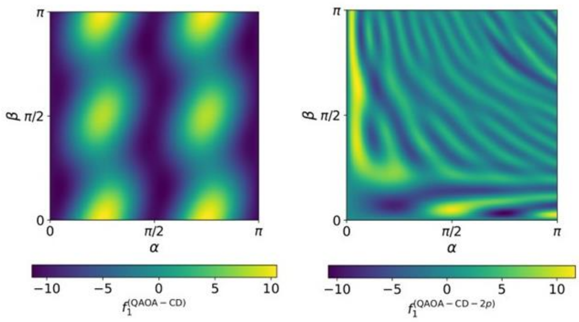

Figure 2: Cost function of the generalized QAOA ansatz including first-order BCH correction at step $p = 1$. Left panel: free BCH angle. Right panel: constrained BCH angle. The cost function landscape is evidently rougher in the right panel.