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Multigrid Multilevel Monte Carlo for Efficient Trace Estimation in Lattice QCD Simulations

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Trace estimation poses a significant challenge in lattice QCD simulations. The Hutchinson method's accuracy scales with the square root of the sample size, resulting in high costs for achieving precise estimates. To alleviate this issue, variance reduction techniques are employed, such as deflating the lowest eigen or singular vectors of the matrix.

This study explores Multigrid Multilevel Monte Carlo (MGMLMC) to reduce the computational cost of constructing the deflation subspace while maintaining an efficient application of the deflation projectors and improving variance reduction. In MGMLMC, spectral deflation is accomplished using a projector derived from the multigrid prolongator P employed in solving linear systems involving the Wilson-Dirac operator D. By utilizing the low-mode spectral information inherent in P, this approach significantly lowers memory requirements while achieving up to a three-fold variance reduction compared to inexact deflation which relies on a few iterations of the inverse block power method to derive the deflation subspace.

We investigate the efficacy of MGMLMC for computing $\mathrm{tr}(B(t)D^{-1}(t,t))$, where $B(t)$ is an operator which acts on spin, color and space indices, for example a combination of gamma matrices and gauge covariant spatial derivatives.

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