

SCALABLE BAYESIAN OPTIMIZATION FOR AERODYNAMIC DESIGN OPTIMIZATION VIA MULTI-MODEL STRATEGIES

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Abstract

Aerodynamic design optimization relies heavily on high-fidelity Computational Fluid Dynamics, which presents a significant computational burden. Bayesian Optimization (BO) has emerged as a premier method for these problems due to its ability to find global optima with a minimal number of expensive evaluations. However, standard BO implementations utilizing Gaussian Process (GP) surrogates face a scaling wall. As the number of design samples increases, the computational cost of model training scales cubically, and the correlation matrix frequently becomes ill-conditioned. These numerical instabilities lead to failed model updates and stalled optimization processes, particularly when samples cluster near high-performing design regions.

We propose a multi-model strategy to circumvent these limitations, ensuring both numerical robustness and computational efficiency. By transitioning from a single global surrogate to an architecture of distributed or partitioned sub-models, the size of individual correlation matrices is strictly capped. This approach not only prevents the inversion of large, near-singular matrices but also allows for parallelized model training, significantly reducing the overhead associated with the optimization loop.

We evaluate the performance of the proposed multi-model framework on a series of benchmark problems, including standard analytical test functions and representative test cases such as transonic airfoil drag minimization. The results demonstrate that the multi-model strategy maintains high predictive accuracy while avoiding the stagnation typically seen in standard BO as the sample budget grows. Furthermore, we analyze the trade-offs between domain-partitioning techniques and aggregated ensemble methods in the context of high-dimensional aerodynamic design spaces.