Abstract

Acceleration of Multi−Resolution Topology Optimization via Combination of Pre−trained Models

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Topology optimization aims to maximize structural performance by optimally distributing material within a design domain under given loads, boundary conditions, and manufacturing constraints. However, as the design resolution increases, the number of design variables and degrees of freedom grows rapidly and repeated finite element analyses (FEM) lead to prohibitive computational cost. EMsFEM alleviates this issue by condensing fine−scale heterogeneity into coarse elements through numerical basis functions but still requires solving local cell problems for each coarse element at every design update.

In this study, a machine learning based framework is proposed to replace these local EMsFEM problems with a pre−trained prediction model. The input to the model is constructed from the lower triangular part of the local stiffness matrices of fine scale elements within each sub−grid, and the output is the corresponding numerical basis functions. The model is trained only at a few baseline local resolutions (2×2, 3×3, 5×5 in 2D and $2 \times 2 \times 2$, $3 \times 3 \times 3$ in 3D), and then recursively and combinationally reused to perform static condensation at higher local resolutions. This enables multi−resolution EMsFEM−based topology optimization without generating new training data or retraining the model for each resolution.

The proposed method is validated on a 2D short cantilever beam, a 3D half MBB beam, and a 3D short cantilever beam. In 2D, the compliance error stays around 0.2% across various local resolutions. In 3D, however, in some locally high−resolution cases, overly reducing the global DoFs can weaken member connectivity near the load application region and increase the compliance error up to about 15%. When the local resolution is kept the same but the global resolution is increased, this discontinuity is alleviated and connected topologies are recovered. Therefore, the global DoF setting should be chosen carefully, but the method still achieves a clear speed−up, reducing the overall analysis time by tens of times. Since recursive static condensation is repeated across levels, the condensation cost can accumulate as the reuse level increases; future work will focus on improving the numerical efficiency of the condensation stage and enhancing prediction stability and accuracy in 3D, especially near the load region.