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A graph neural network-based framework for super-resolution of turbulent reacting flows on complex meshes

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Recent advances in deep learning have been widely applied to reconstruct finer details from low-resolution data in turbulent flows. However, most efforts have focused on structured uniform meshes, thereby limiting their applicability to data relevant to complex geometries, which are typically simulated on structured non-uniform and unstructured meshes. Graph neural networks (GNNs), which are capable of handling unstructured data, represent a viable alternative. This study harnesses the flexibility of GNNs with message-passing layers to propose a framework for reconstructing unresolved small-scale structures from low-resolution data on complex meshes without interpolating them to a uniform mesh. The accuracy of the proposed approach is demonstrated using two test cases: a reacting channel flow on a non-uniform yet structured mesh and a reacting hydrogen engine employing an unstructured mesh. Visual assessments, statistical analyses, and cumulative error reduction are utilized to validate the model's ability to accurately recover fine-scale features. We also compare the accuracy of the GNN based approach to an alternative approach in which the data is first interpolated to a uniform mesh, super-resolved, and then interpolated back to the original complex mesh. Finally, we provide insights into the scalability of the training and inference. Our work presents a pathway for enhancing the fidelity of coarse-grained simulations by improving subgrid-scale modeling, potentially contributing to future developments in the field.