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Neural Network Implementation of High-order Discontinuous Galerkin Methods

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Finite element methods have conventionally focused running on central processing units (CPUs). However, hardware is advancing rapidly, partly driven by machine learning applications. Representing numerical solvers with neural networks and implementing them with machine learning packages can bring advantages such as hardware agnosticism, automatic differentiation, and easy integration with data-driven models. This work implements unstructured finite element solvers using graph neural networks for the first time and shows its architecture agnosticism with tests on graphics processing units (GPUs). Specifically, high-order discontinuous Galerkin methods with an interior penalty scheme are adopted. The approach is first demonstrated on diffusion problems to illustrate the graph representation of an unstructured mesh, matrix-free residual evaluation inside neural networks, and a multigrid method consisting of p-multigrid levels and algebraic multigrid levels, which is shown to be scalable and robust. The approach is then extended to hyper-elasticity, incompressible flow, and finally, FSI problems. Overall, the approach has shown promising speed in diffusion and hyper-elasticity compared to some highly optimised implementations in the literature while maintaining high accuracy, i.e. $(p+1)$-order convergence for p-th order elements, in the three types of problems.

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