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Accelerating PDE Simulations by Integrating Machine Learning and Finite Difference Technologies

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Abstract

The purpose of this investigation is to explore the benefits of integrating machine learning technologies into a finite difference code for the numerical solutions of partial differential equations. Specifically, the nonlinear viscous Burgers equation, which is representative of the conservation laws in computational fluid dynamics, is taken as the model equation for this study. Both data-driven convolutional and physics-informed neural networks are considered. The partial differential equation solver is based on the Cartesian cut-stencil formulation, which supports the use of a Cartesian grid in arbitrarily complex domains.

Initially, exact solutions of the one-dimensional steady and unsteady Burgers equation are used to compare machine learning strategies and assess the accuracy and efficiency of the machine learning and finite difference approaches. As is well-known, under certain conditions on the mesh size and convection velocity, an upwind discretization of the convective term is necessary to ensure the numerical stability of the finite difference solution. On the other hand, neither the convolutional nor physics-informed neural network experiences such numerical instability.

It is shown that, in terms of computational time, the machine learning approaches have a significant advantage over the finite difference simulation, especially as the grid is refined. However, compared to the finite difference solution, the neural network solutions may be less accurate. This is especially true for the convolutional neural network. Examination of the results leads to a strategy for combining machine learning and finite difference technologies to accelerate the simulation time while maintaining a high degree of accuracy. Extension of these ideas to two-dimensional problems will also be discussed.

Keywords: Machine learning, finite difference, Burgers equation, data-driven neural networks, PINNs