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<tr><th>authors</th><td>Lionel Cheng
Ekhi Ajuria Illarramendi
Guillaume Bogopolsky
Michael Bauerheim
Benedicte Cuenot</td></tr>
<tr><th>title</th><td>Using neural networks to solve the 2D Poisson equation for electric field computation in plasma fluid simulations</td></tr>
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<tr><th>volume</th><td></td></tr>
<tr><th>doi</th><td></td></tr>
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<tr><th>abstract</th><td>The Poisson equation is critical to get a self-consistent solution in plasma fluid simulations used for Hall effect thrusters and streamer discharges, since the Poisson solution appears as a source term of the unsteady nonlinear flow equations. As a first step, solving the 2D Poisson equation with zero Dirichlet boundary conditions using a deep neural network is investigated using multiple-scale architectures, defined in terms of number of branches, depth and receptive field. One key objective is to better understand how neural networks learn the Poisson solutions and provide guidelines to achieve optimal network configurations, especially when coupled to the time-varying Euler equations with plasma source terms. Here, the Receptive Field is found critical to correctly capture large topological structures of the field. The investigation of multiple architectures, losses, and hyperparameters provides an optimal network to solve accurately the steady Poisson problem. The performance of the optimal neural network solver, called PlasmaNet, is then monitored on meshes with increasing number of nodes, and compared with classical parallel linear solvers. Next, PlasmaNet is coupled with an unsteady Euler plasma fluid equations solver in the context of the electron plasma oscillation test case. In this time-evolving problem, a physical loss is necessary to produce a stable simulation. PlasmaNet is finally tested on a more complex case of discharge propagation involving chemistry and advection. The guidelines established in previous sections are applied to build the CNN to solve the same Poisson equation in cylindrical coordinates with different boundary conditions. Results reveal good CNN predictions and pave the way to new computational strategies using modern GPU-based hardware to predict unsteady problems involving a Poisson equation.</td></tr>
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<tr><th>abstract</th><td>The Poisson equation is critical to get a self-consistent solution in plasma fluid simulations used for Hall effect thrusters and streamers discharges. Solving the 2D Poisson equation with zero Dirichlet boundary conditions using a deep neural network is investigated using multiple-scale architectures, defined in terms of number of branches, depth and receptive field 1. The latter is found critical to correctly capture large topological structures of the field. The investigation of multiple architectures, losses, and hyperparameters provides an optimum network to solve accurately the steady Poisson problem. Generalization to new resolutions and domain sizes is then proposed using a proper scaling of the network. Finally, found neural network solver, called PlasmaNet, is coupled with an unsteady Euler plasma fluid equations solver. The test case corresponds to electron plasma oscillations which is used to assess the accuracy of the neural network solution in the context of a time-dependent simulation. In this time-evolving problem, a physical loss is necessary to produce a stable simulation. PlasmaNet is then benchmarked on meshes with increasing number of nodes, and compared with an existing solver based on a standard linear system algorithm for the Poisson equation. Results reveal that PlasmaNet outperforms the classical plasma solver, up to speedups 700 times faster on large meshes containing millions of nodes. PlasmaNet is finally tested on a more complex case of discharge propagation involving chemistry and advection. The guidelines established in previous sections are applied to build the CNN to solve the same Poisson equation but in cylindrical coordinates. Results reveal good CNN predictions with significant speedup. These results pave the way to new computational strategies to predict unsteady problems involving a Poisson equation, including configurations with coupled multiphysics interactions such as in plasma flows.</td></tr>
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