Meshfree analysis on complex geometries using physics-informed deep neural networks

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Abstract

In this presentation, I will introduce a new approach based on distance fields to exactly impose boundary conditions in physics-informed deep neural networks. The challenges in satisfying Dirichlet boundary conditions in meshfree and particle methods are well-known. This issue is also pertinent in the development of physics informed neural networks (PINN) for the meshfree solution of partial differential equations. We introduce geometry-aware trial functions in artifical neural networks to improve the training in deep learning to solve partial differential equations. To this end, we use concepts from constructive solid geometry (R-functions) and generalized barycentric coordinates (mean value potential fields) to construct an approximate distance function to the boundary of a domain. To exactly impose homogeneous Dirichlet boundary conditions, the trial function is taken as the approximate distance function multiplied by the PINN approximation, and its generalization via transfinite interpolation is used to a priori satisfy inhomogeneous Dirichlet (essential), Neumann (natural), and Robin boundary conditions on complex geometries. In doing so, we eliminate modeling error associated with the satisfaction of boundary conditions in a deep collocation method and ensure that kinematic admissibility is met pointwise in a deep Ritz method. I will present numerical solutions to boundary-value problems in 1D and in 2D over curved geometries, and also demonstrate that the approach extends to higher dimensions by solving a Poisson problem with homogeneous Dirichlet boundary conditions over the 4D hypercube. This approach provides a pathway for meshfree analysis to be conducted on the exact geometry without domain discretization. This is joint-work (arXiv:2104.08426) with Ankit Srivastava at Illinois Institute of Technology in Chicago.