ME Seminar

Recent Advances in Polyhedral Virtual Element Methods and Physics-Informed Deep Neural Networks to Solve PDEs

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ABSTRACT

In this presentation, I will first discuss how recent advances in virtual element methods (VEM, in which basis functions are not required to be explicitly known) on polygonal and polyhedral meshes can enable improved and reliable simulations on finite element meshes. In particular, I will focus on a new integration scheme over polytopal elements, an introduction to the virtual element method, and how agglomeration of finite elements that contain poorly-shaped tetrahedral (sliver) elements into a polyhedral virtual element can improve the critical time step estimates for explicit dynamics. As a second topic, I will present a method to exactly impose boundary conditions in a meshfree solver that is based on physics-informed neural networks (PINNs). We introduce an approach that uses R-functions to construct approximate distance fields in conjunction with transfinite interpolation to satisfy boundary conditions. Instead of multiple (boundary and PDE) loss terms, only the PDE loss term is required, which improves the training of deep neural networks to solve partial differential equations. This method has been incorporated in the April 2022 release of NVIDIA Modulus (NVIDIA, Inc.). I will present verification tests on benchmark problems and numerical tests conducted using NVIDIA Modulus. The work on VEM is joint with Eric Chin (LLNL), Alvin Chen (UC Davis) and Michael Tupek (PTC, Inc.); work on PINNs is with Ankit Srivastava (IIT Chicago), Sanjay Choudhry and Mohammad Nabian (NVIDIA, Inc.), and Hadi Meidani and Rini Gladstone (UIUC); and related work on Petrov-Galerkin PINNs is with Stefano Berrone, Claudio Canuto and Moreno Pintore (University of Torino, Italy).

ABOUT THE SPEAKER

Sukumar holds a B.Tech. in Metallurgical Engineering from IIT Bombay in 1989, a M.S. in Materials Science and Engineering from Oregon Graduate Institute in 1992, and a Ph.D. in Theoretical and Applied Mechanics from Northwestern University in 1998. He was a post-doc at Northwestern University and a research associate at Princeton University, before joining UC Davis in 2001, where he is currently a Professor in Civil and Environmental Engineering. Sukumar is a Regional Editor of International Journal of Fracture and a member of the Editorial Board of Computer Methods in Applied Mechanics and Engineering and Finite Elements in Analysis and Design. He has spent sabbatical visits at Cornell University (2007), SLAC National Accelerator Laboratory (2011) and Los Alamos National Laboratory (2018). Sukumar's research focuses on meshfree (max-entropy and PINN-based) methods, novel discretization methods on polytopal meshes, cubature schemes over polytopes and curved geometries, fracture and composites modeling with spectral extended finite elements, and new methods development (orbital-enriched partition-of-unity methods) for quantum-mechanical materials calculations.

July 13, 2022, 4:00 pm, MMCR, ME@IISc