CRUNCH Seminars at Brown, Division of Applied Mathematics

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Phase field modeling of fracture with isogeometric analysis and machine learning methods

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We will discuss the advances and applications of phase field modeling in brittle fracture analysis. In phase field approach, the crack paths are automatically determined as part of the solution and no interface tracking is required, contrary to the discrete fracture modeling methods. However, the flexibility comes with associated difficulties: (1) a very fine spatial discretization is required to represent sharp local gradients correctly; (2) fine discretization results in high computational cost; (3) computation of higher-order derivatives for improved convergence rates and (4) curse of dimensionality in conventional numerical integration techniques. Consequently, the practical applicability of phase field models is severely limited.

In the first part of the talk, we will discuss about a novel adaptive refinement scheme that could be coupled with the fourth-order phase field model to improve the computational efficiency. The developed algorithm relies on polynomial splines over hierarchical T-meshes (PHT-splines) in the framework of isogeometric analysis (IGA). The fourth-order model uses the second-order derivatives of phase field. Unfortunately, when modeling complex geometries using PHT-splines, multiple parameter spaces (patches) are joined together to describe the physical domain and there is typically a loss of continuity (C0 parametrization) at the patch boundaries. Hence, the application of the fourth-order model is severely restricted. On the other hand, the second-order model requires a very fine spatial discretization to resolve the crack path accurately. To overcome the high computational cost of the second-order model, we propose a dual-mesh approach.

In the second part of the talk we discuss about a novel formulation for phase field-based fracture modeling employing physics informed deep neural networks (PINN). The network is trained based on the minimization of the variational energy of the system described by general non-linear partial differential equations while respecting any given law of physics. The developed approach needs only a set of points to define the geometry, contrary to the conventional mesh-based discretization techniques. To accelerate the solution procedure, the concept of `transfer learning' is integrated with the developed PINN approach. The PINN approach allows a numerically stable crack growth even with larger displacement steps, which is contrary to the mesh-based approaches. An adaptive refinement scheme based on the generation of more quadrature points in the damage zone is developed within this framework.