A primer on cut finite element methods

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Abstract

Within the last 15 years, cut finite element methods, also known as fictitious domain, embedded domain, finite cell, unfitted or immersed finite element methods, have evolved into a mature and powerful simulation tool that is widely applied across the fields of computational solid and fluid dynamics [1, 2]. Cut finite element methods eliminate the need for boundary conforming meshes that often require time-consuming and error-prone mesh generation procedures, and thus help enable a seamless integration of complex geometric models into finite element analysis. In addition, cut finite element methods naturally accommodate changes of the geometric domain during the solution process, as required for instance in topology optimization or fluid-structure interaction.

The key to their success has been the resolution of three major technical challenges related to using cut finite elements:

1. Numerical quadrature: how can cut elements be integrated accurately and efficiently?
2. Boundary conditions: how can constraints be imposed accurately and robustly at surfaces that cut through elements?
3. Robustness: how can accuracy and efficiency be guaranteed in general simulation scenarios?

In this class, I start with a motivation for the development of cut finite element schemes, including a brief historic overview, and introduce the nature of the underlying challenges in comparison to standard boundary-fitted schemes. I then explain the main ideas and methods to effectively resolve the challenges of quadrature, boundary constraint imposition and robustness. I close with demonstrating the advantages of cut finite elements in practical simulation scenarios, including patient-specific analysis in biomedicine, isogeometric shell analysis of trimmed free-form CAD surfaces, and examples from computational fluid dynamics and fluid-structure interaction.

Bio

Prof Schillinger's research interests are in computational mechanics, focusing on the modelling and finite element analysis of multiphysics and multiscale mechanical systems. In particular, he strives to develop novel geometry-throughanalysis tools that enable the seamless transfer of complex geometric models from computer-aided design and biomedical imaging into simulation results. Specific applications that drive his work include the computational design of aerodynamic structures (for example, turbine blades) and the integration of computer simulations in clinical practice, with the goal of enabling new patient-specific treatments (for example, for bone osteoporosis).

Dominik's work has been distinguished with a number of high-level research awards, in particular the IACM John Argyris Award, the GAMM Richard-von-Mises Prize, the ICE Zienkiewicz Medal, the NSF CAREER Award, and the EMI Leonardo da Vinci Award.

References

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