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Higher-order meshing of implicit geometries—part I: Integration and interpolation in cut elements

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Abstract

An accurate implicit description of geometries is enabled by the level-set method. Level-set data is given at the nodes of a higher-order background mesh and the interpolated zero-level sets imply boundaries of the domain or interfaces within. The higher-order accurate integration of elements cut by the zero-level sets is described. The proposed strategy relies on an automatic meshing of the cut elements. Firstly, the zero-level sets are identified and meshed by higher-order surface elements. Secondly, the cut elements are decomposed into conforming sub-elements on the two sides of the zero-level sets. Any quadrature rule may then be employed within the sub-elements. The approach is described in two and three dimensions without any requirements on the background meshes. Special attention is given to the consideration of corners and edges of the implicit geometries.

Keywords: Numerical integration, level-set method, fictitious domain method, XFEM, GFEM, interface capturing

1. Introduction

The approximation of boundary value problems (BVPs) based on the finite element method (FEM) has achieved an enormous importance in engineering, physics, and related fields. The goal to achieve higher-order accurate approximations of BVPs can be traced back to the early days of the FEM, see e.g. [1] or the text books [2, 3, 4, 5]. This is typically labeled p-FEM and there are numerous references found. In fact, the isoparametric concept leads to a conceptually simple approach to achieve optimal results. Therefore, an accurate geometry representation based on higher-order elements which consider boundaries and interfaces is necessary, see Fig. 1(a) for an example. The generation of such meshes is, however, not a simple task. Moreover, elements may have to be refined during the analysis, for instance in the context of adaptivity and convergence studies. The interplay of the FEM software, the meshing tool, and the CAD program is far from

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