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Hierarchically refined and coarsened splines for moving interface problems, with particular application to phase-field models of prostate tumor growth

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Abstract

Moving interface problems are ubiquitous in science and engineering. To develop an accurate and efficient methodology for this class of problems, we present algorithms for local h-adaptivity of hierarchical B-splines to be utilized in isogeometric analysis. We extend Bézier projection, an efficient quadrature-free local projection technique, to the hierarchical setting. In this case, extraction operators may not be invertible. To address this issue we develop a multi-level reconstruction operator which maintains the locality properties of the projection. We also introduce a balance parameter to control the overlap of hierarchical functions leading to improved numerical conditioning. We apply our algorithms to the simulation of localized prostate cancer growth. We model this disease using the phase-field method and a set of diffusion-reaction equations to account for the dynamics of nutrients and a key biomarker termed Prostate Specific Antigen. Our results include examples on simple 2D and 3D domains and a more compelling tissue-scale, patient-specific simulation, which is run over a prostate anatomy extracted from medical images. Our methods for local h-adaptivity efficiently capture the evolving interface between the tumor and the neighboring healthy tissue with remarkable accuracy in all cases.

Keywords: isogeometric analysis, Bézier projection, local refinement and coarsening, hierarchical spline spaces, phase field, tumor growth

1. Introduction

Isogeometric analysis (IGA) is a computational technology that tightly connects computer aided design (CAD) and finite element analysis (FEA) [1, 2]. The central idea of IGA is to adopt the smooth basis functions which define the CAD geometry as the basis for analysis. Thus, for properly constituted CAD

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