Scan-based immersed finite element simulations

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Immersed finite element methods (such as the finite cell method [1]) can be used in combination with isogeometric analysis [2] (a CAD-based finite element framework) to enable the higher-order discretization of problems on complex volumetric domains. A particularly interesting application of this immersed simulation technique is scan-based analysis [3], where the geometry is smoothly approximated by segmentation of a B-spline level set approximation of voxel data. This presentation aims at introducing the basic concepts in scan-based immersed finite element analysis. Moreover, various state-of-the-art developments for immersed finite element analyses are discussed.

The versatility of isogeometric finite cell simulations for scan-based analysis hinges on the robust numerical treatment of various computational aspects. This presentation highlights the following aspects:

- The *numerical evaluation of integrals* over arbitrarily cut cells is challenging, in particular in the case of image-based analysis, where highly irregular elements are encountered. In our work we employ an octree integration strategy. On the deepest level of integration we close the recursive bi-sectioning of the cut cells by means of a tessellation procedure that we developed to be robust in the setting of scan-based analysis. An adaptive integration procedure is proposed to optimize the efficiency of the constructed quadrature rules.

- A drawback of immersed isogeometric finite element methods is the *conditioning of the resulting linear system.* Small cut elements yield severely ill-conditioned systems that, without dedicated treatment, prohibit iterative solutions. For this reason, many researchers resort to direct solvers. These, however, restrict the size of the systems that can be considered. In our work we have acquired a profound understanding of the effects of small cut elements and we have developed a preconditioner that resolves the conditioning problems and enables iterative solution procedures for large scale problems.

We present various application of the immersed analysis framework for image-based analysis. In the field of solid mechanics, we consider the mechanical analysis of miro-CT based trabecular bone models [3]. Moreover, we discuss applications in the domain of computational fluid dynamics, specifically the analysis of porous medium flows [4].

References

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