UNIVERSITÀ DI PAVIA

COMPMECH
Computational Mechanics & Advanced Materials

A short course on Immersed Boundary Methods with Engineering Applications

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Abstract

‘Cutting’ a structure out of a larger body is a standard CAD-operation (typically associated with the term ‘trimming’) in geometric modelling. The reverse operation, i.e., immersing a computational in a ‘fictitious’ domain was suggested already in the 1960ies for numerical approximation of boundary value problems. Yet only during the last decade, a unification of these two views of 'immersing' and 'trimming' in Immersed Boundary Methods (IBM) has been realized as an attractive possibility for integrating geometric modelling and computation. This short course, focusing on a Computational Engineering view of IBM, gives an introduction in the principles and then concentrates on a specific variant, the Finite Cell Method (FCM), a combination of IBM with Higher Order FEM and Isogeometric Analysis.

The major asset of IBM compared to classical boundary conforming Finite Element Methods is obvious: The physical domain of computation needs not be meshed into finite elements, which is, in cases of complex three-dimensional geometries still a major issue for many applications. Instead, the simply shaped fictitious domain is divided into a Cartesian grid of uniform cells. On this grid, points inside and outside the original physical body are characterized by a point-membership test, i.e., a basic operation, which is available for virtually any geometric model. The grid defined in this way is then used as a 'mesh' of cells, treating each of them similarly to a finite element. The central advantage of saving the effort to generate a mesh yet opens several critical questions. Integration of cells cut by the boundary of the physical domain needs special treatment, imposition of boundary conditions along segments, which are not matching with edges or faces of grid cells is an issue, and cells, which have only a small cut part interior to the physical domain require special consideration.

After discussing these basic principles, we then address the connection of geometric models to numerical analysis. The considered models include classical Boundary Representation and Constructive Solid Geometry as used e.g., in today’s feature-based CAD-systems as well as representations obtained from Computer Tomography or from 3D point clouds resulting from digital imaging. Real-life examples ranging from mechanical and civil engineering over biomechanical simulation to specific questions in additive manufacturing will demonstrate the wide field of applications of immersed boundary methods.

Program

The short course is structured in a lecture and an optional seminar part. The lectures are a self-contained introduction to the principles and applications of IBM. In the seminar, recent research papers with an emphasis on applications in engineering and biomechanics will be provided to participants. The topics of these papers will be worked on by participants together with the course instructor and presented in short talks on the last afternoon.

Content of Lecture part:

Immersed Boundary Methods (IBM): Basic Ideas • From FEM to IBM • Integration of cut cells: Quadtree/Octree • Moment fitting • Boundary conditions: Penalty Method • Boundary conditions: Nitsche’s method • Small cut cells: Conditioning issues • Preconditioning • Ghost penalty method • Fictitious stiffness method • Hierarchical local refinement • Immersed Isogeometric Analysis • IBM for shells • k-extension for immersed IGA • IGA and Finite Cells for thin solids • IGA and Finite Cells for massive solids • IBM and parametric Constructive Solid Geometry • IBM and Boundary Representation • ‘Dirty Geometry’ • IBM and voxel-based models

The seminar part can, following the interest of participants include papers on:

Topology Optimization and IBM • Structural dynamics • Simulation of Bone Fracture by FCM • Non Destructive Testing • 3D printed High Damping Composites • Point-cloud based structural simulation • FCM and cohesive fracture • FCM and phase field models for fracture • FCM for 3D printing • ‘As designed’ versus ‘as built’ comparison by FCM

Location: Department of Civil Engineering and Architecture of the University of Pavia (MS1 room)
Lectures will be held Mon 27/3 through Fri 31/3 from 9:30 am to 12 pm.
Seminars will be held Mon 27/3, Tue 28/3, Thu 30/3 and Fri 31/3 from 2 to 4 pm.

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