X-DMS 2015
eXtended Discretization MethodS
September 9-11, 2015, Ferrara, Italy

Stabilized XFEM based discretization approaches for complex coupled flow problems using cut elements

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Key words: Cut elements, unfitted meshes, incompressible Navier-Stokes equations, fluid-structure interaction, two-phase flow, ghost penalty, stabilization.

ABSTRACT

XFEM based fixed-grid methods represent very promising approaches when dealing with moving boundaries or interfaces for flow problems. In particular for applications like fluid-structure interaction or multiphase flows, where the interfaces can undergo large displacements or even topological changes, classical pure ALE-based discretization schemes are limited. Cutting elements of a background fluid mesh at the interface position and formulating the fluid equations in an Eulerian framework open up a broad field of new discretization methods for highly challenging interface-coupled problems.

In this talk, we propose a stabilized fluid formulation for 3D incompressible Navier-Stokes equations using cut elements [1]. The method is proven to be stable and optimally convergent for low and high Reynolds number flows independent of the interface location with respect to the underlying mesh [2].

The approach is built from the following essential ingredients: since the mesh is not fitted to the fluid domain, boundary and coupling conditions are imposed weakly using a stabilized Nitsche-type approach including additional boundary/interface stabilization terms to control the enforcement of boundary conditions and the mass conservation for convection dominated flows. As elements are cut along the interface, control of non-physical degrees of freedom outside the physical domain is crucial and is retained by a recently developed ghost-penalty stabilization technique. Adaptions of face-oriented fluid stabilizations in the interface zone to control the inf-sup instability, as well as instabilities arising from the convective derivative and from the incompressibility constraint for convection dominated flows on cut elements will be presented.

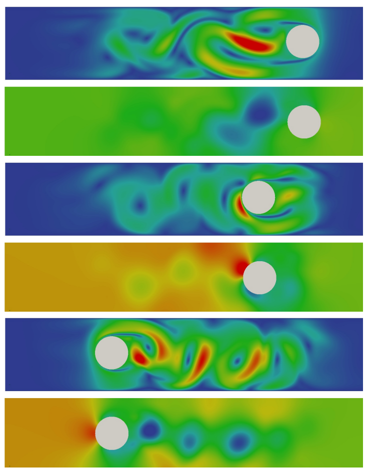

Figure 1: Weak enforcement of boundary conditions for a moving rigid cylinder at $RE = 300$.

We focus on the stabilization techniques in the interface zone with emphasis on transient convection dominated flows. Besides the presentation of major results from our numerical analysis, we give an overview about recently developed discretization approaches applied to highly challenging applications, ranging from the weak enforcement

of essential boundary conditions, see also Fig. 1, to highly complex two-phase flows [3] and more advanced algorithms for fluid-structure interaction problems. Regarding fluid-structure interaction, results of two different XFEM-based monolithic approaches will be presented, a hybrid ALE-fixed-grid embedding mesh method [4], see also Fig. 2 and Fig. 3, and an unfitted fixed-grid fluid-structure interaction approach.

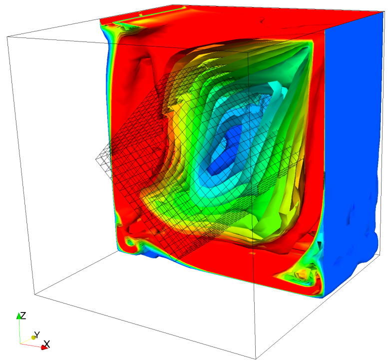

Figure 2: XFEM-based hybrid embedding mesh technique for a lid driven cavity at $RE = 10000$.

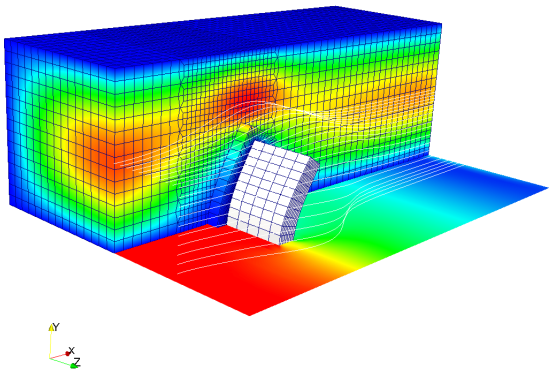

Figure 3: Bending of a flexible wall solved with a hybrid ALE-fixed-grid embedding mesh approach for fluid-structure interaction.

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