A Combined Finite Element Framework for Contact and Fluid-Structure Interaction

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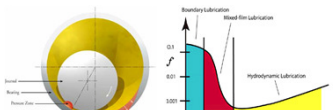
Introduction

- Within this work, we develop an approach for a combined contact and fluid-structure interaction (FSI) framework based on monolithic coupling schemes
- The aim is to achieve a smooth crossing between FSI and frictional dry contact and vice versa
- For contact discretization we use mortar finite element methods with finite deformations [1]
- For fluid-structure interaction we employ a fixed-grid approach based on the extended finite element method (XFEM) [2]

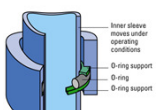
Motivation and applications


compactors


gears

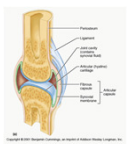


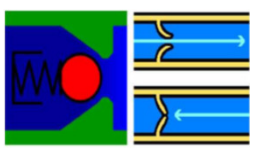
bearings

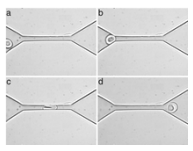


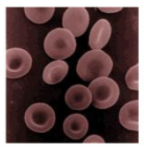
seals

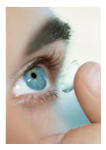

wet tyres, wipers


joints


valve, artificial heart valves

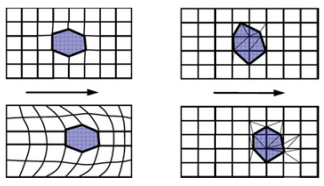

capillary flow of red blood cells

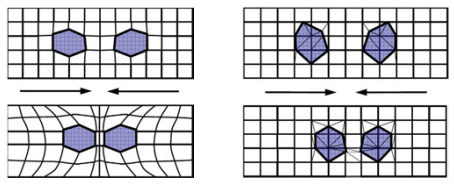

red blood cells


contact lens

High potential of fixed-grid approach

- Topology changes due to contact can be handled properly
- No need to artificially keep contacting surfaces apart
- No need for tedious mesh update procedures


comparison of moving- and fixed-grid FSI


comparison of contact in the context of moving- and fixed-grid FSI

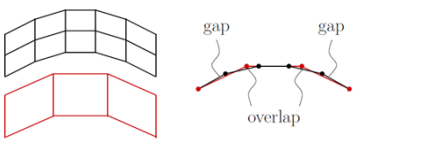
Two major challenges

1. As the weak constraint enforcement of the mortar method allows for small local penetrations, the surfaces of the structural bodies may encounter small local overlaps while being in contact
   → our Cut-library could not handle overlapping cut meshes

   ✓ The Selfcut-library replaces the surfaces of an arbitrary number of structural bodies by one new consistent surface mesh

2. Using linear finite elements in the fluid gap results in a conflict between the weak enforcement of the no-slip boundary condition and the weak enforcement of the conservation of mass

   ✓ Our Cut-library, our fluid stabilization and our interface stabilization are extended to second order interpolation

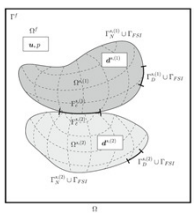


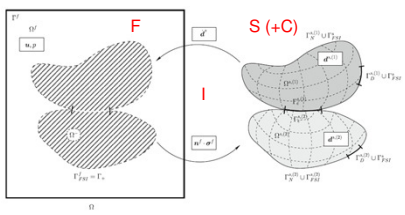
schematic contact scenario with gaps and overlaps at the contact interface

schematic hex8 and hex20 flow profiles for a fluid gap with less than one element gap width

Partitioned FSI with Contact

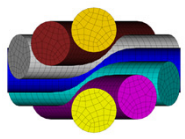
- Iterative Dirichlet-Neumann FSI coupling:
  - solve fluid flow with prescribed Dirichlet velocity at the FSI-interface
  - solve structural bodies with prescribed Neumann forces at the FSI-interface
- if contact between the structural bodies occurs, solve the contact problem within the structure block in a monolithic way


schematic fluid-structure interaction problem with contact [3]



partitioned fluid-structure interaction framework with contact [3]

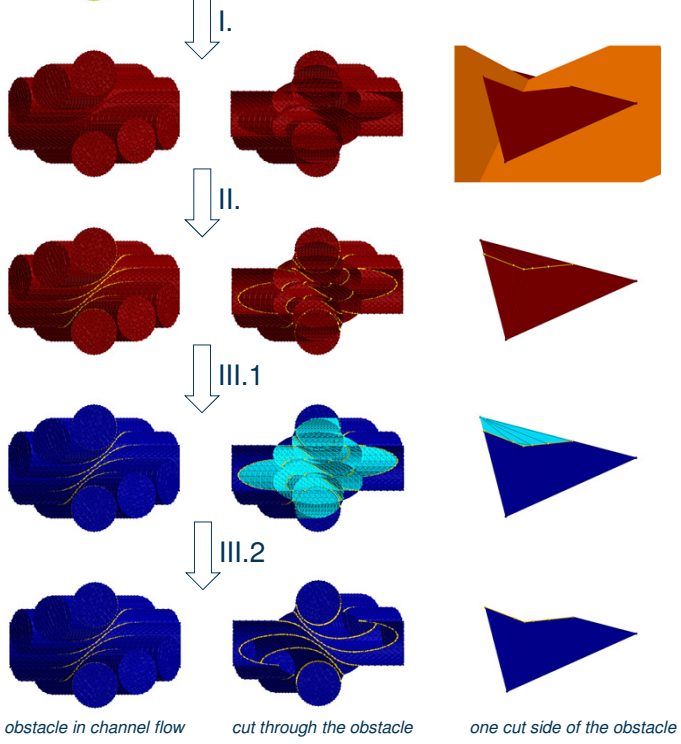
The three components of the Selfcut-library


7 cylinders example

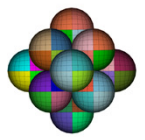
I. Collision Detection
- find possible cutting sides

II. Mesh Intersection
- create new nodes, new edges and new sides
- erase cut sides and cut edges

III. Positional Selection
- determine position of nodes, edges and sides with respect to the other bodies
- erase inner sides, inner edges and inner nodes



obstacle in channel flow | cut through the obstacle | one cut side of the obstacle


15 balls example

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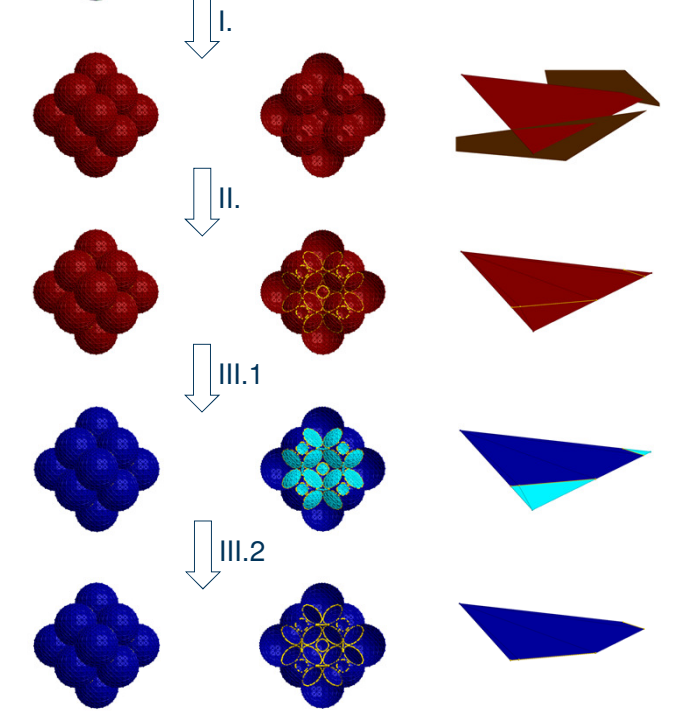
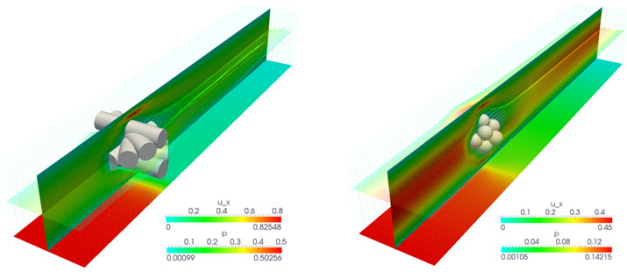


obstacle in channel flow | cut through the obstacle | one cut side of the obstacle

- laminar flow around rigid obstacle
- Newtonian fluid ($\nu = 10^{-3}$ m^2/s, $\rho = 1.0$ kg/m^3)
- parabolic velocity profile at the inflow ($u_{max} = 0.45$ m/s)


numerical results

Future work

- Implementation of a monolithic coupling of our fixed-grid FSI and contact frameworks
- Integration of micro-scale effects into the model
- Simulation of practical applications

References

[1] POPP, A.; GITTERLE, M.; GEE, M.W.; WALL, W.A.: A dual mortar approach for 3D finite deformation contact with consistent linearization. In: *International Journal for Numerical Methods in Engineering* **83** (2010), 1428-1465

[2] SCHOTT, B.; WALL, W.A.: A new face-oriented stabilized XFEM approach for 3D incompressible Navier-Stokes equations. Submitted for publication in: *Computer Methods in Applied Mechanics and Engineering* (2013)

[3] MAYER, U.M.; POPP, A.; GERSTENBERGER, A.; WALL, W.A.: 3D fluid–structure-contact interaction based on a combined XFEM FSI and dual mortar contact approach. In: *Computational Mechanics* **46** (2010), 53-67