# HiFlow$^3$-based Numerical Simulations for Cognition-Guided Surgery

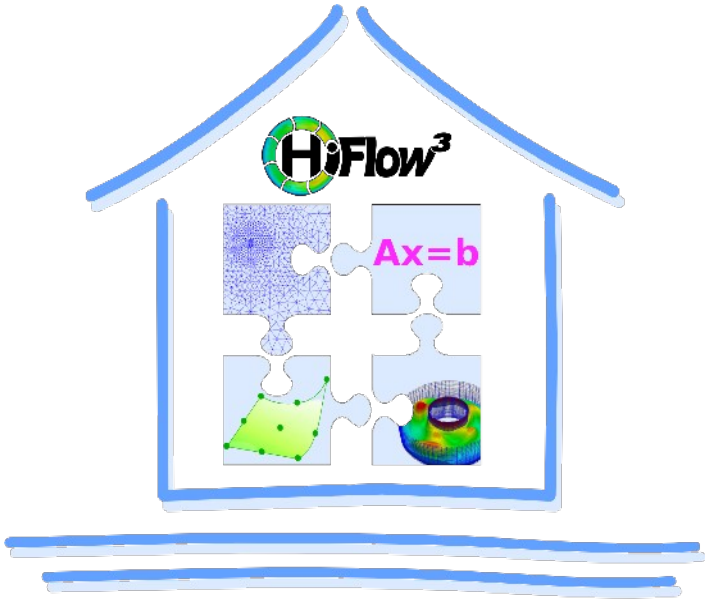
Jonas Kratzke and Nicolai Schoch

# HiFlow3
## Finite Element Software Toolkit for High-Performance Computing (HPC)

Universität Heidelberg
Zukunft. Seit 1386.
IWR Interdisciplinary Center for Scientific Computing

**A modular approach**

### Mesh
- 2D: triangles, quads
- 3D: tetrahedrons, hexahedrons
- unstructured meshes
- h-refinement




### Linear Algebra toolbox
- matrix and vector structures
- linear and nonlinear solvers
- preconditioners

### Finite Element Spaces
- Lagrange Finite Elements
- arbitrary polynomial degree
- p-refinement

### User defined application
- PDE
- assembly of matrices and vectors
- postprocessing
- visualization

# Soft Tissue Simulation
## – Modelling Elasticity (Show Cases)

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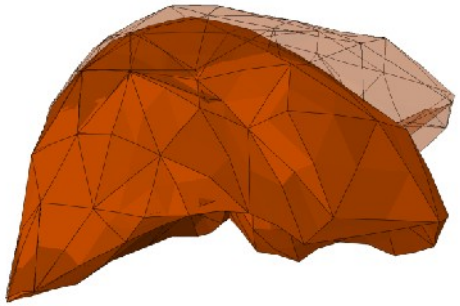
Modeling the Biomechanical Behaviour of Soft Tissue
under the Effect of External (Surgical) Manipulation.

Liver Surgery (Simulation)

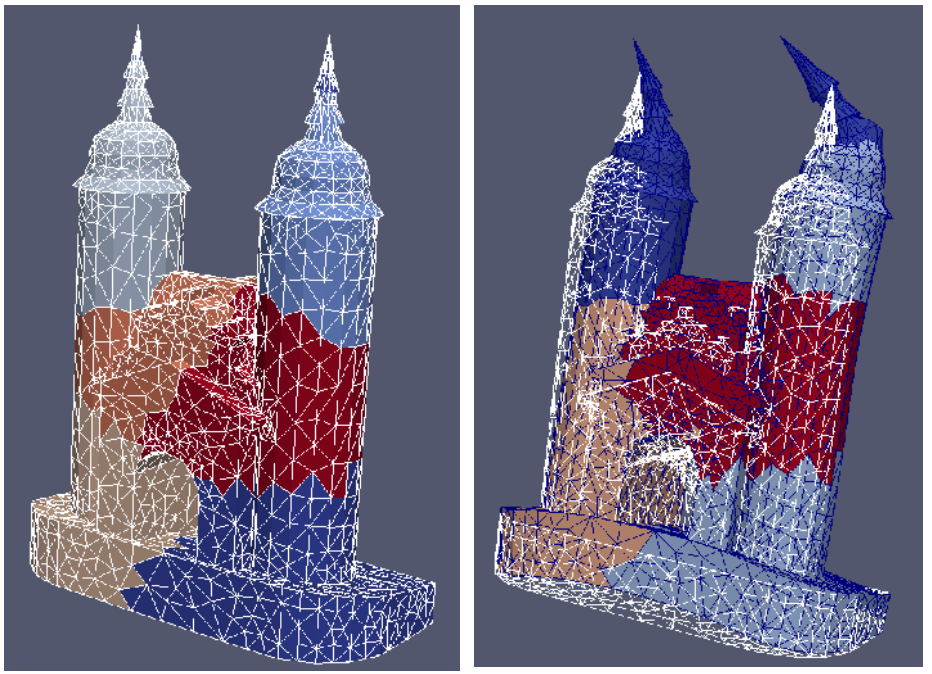


Hiflow³ system matrix assembly
for linear elasticity equations.

HiFlow³ CG/GMRES
with Jacobi/ILU/etc preconditioning.

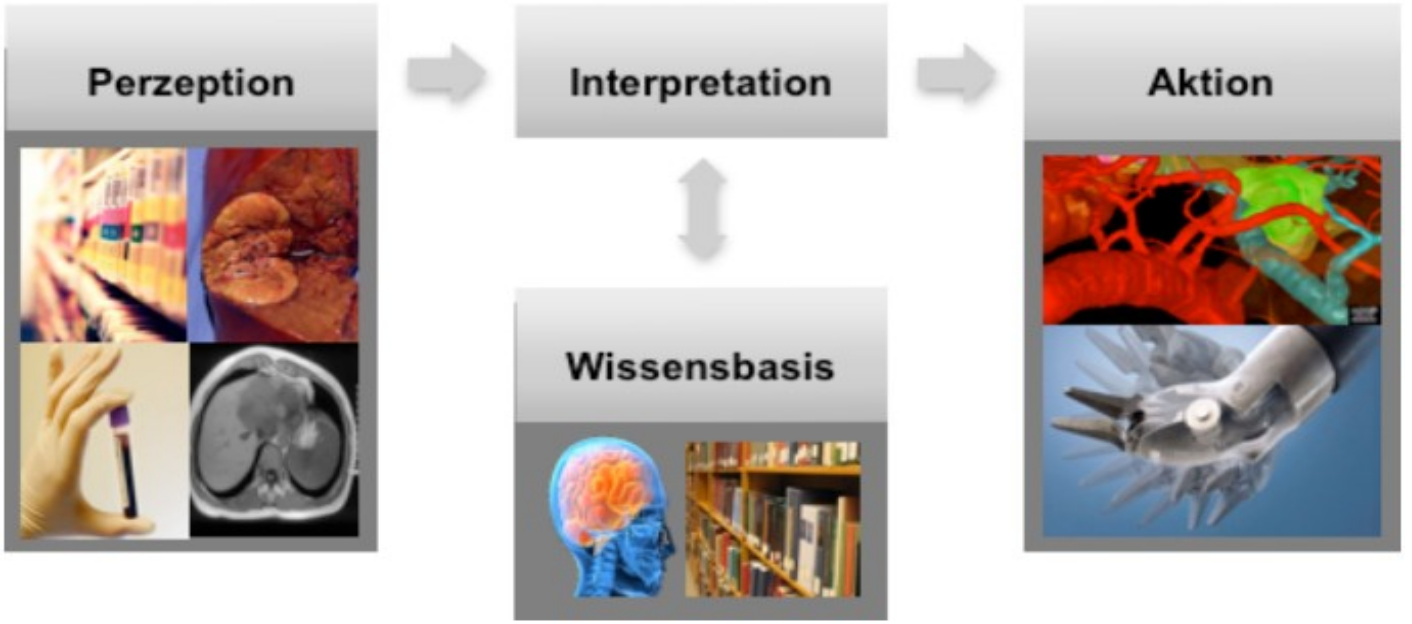
Simulation on HPC systems,
including CUDA-implementation of CG solver.

Heidelberg Bridge meets Pudding (Simulation)



# **Soft Tissue Simulation**
– for Surgery Assistance

## Overview and Project Vision




Vision of '*Surgery in the Future*':

- Surgery lead by machine cognition
- Intelligent surgery support system recognizes clinical situations

EMCL part of collaborative research center
(SFB TRR 125) '*Cognition-Guided Surgery*'
(Start: June 2012, Project Duration: 4 years).

# Soft Tissue Simulation
## – for Surgery Assistance (Show Case)

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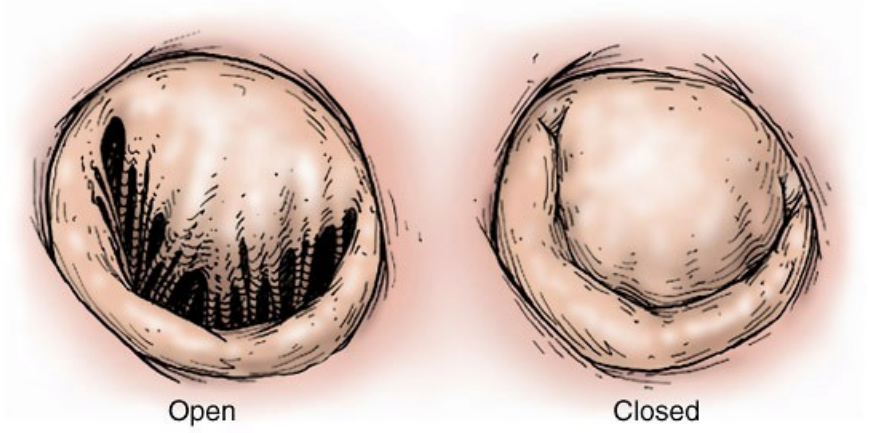
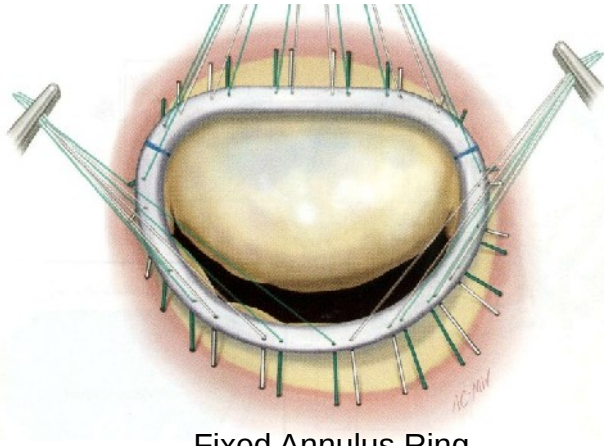
Integration of Biomechanical Simulation into Surgery Assistance System for Mitral Valve Reconstruction

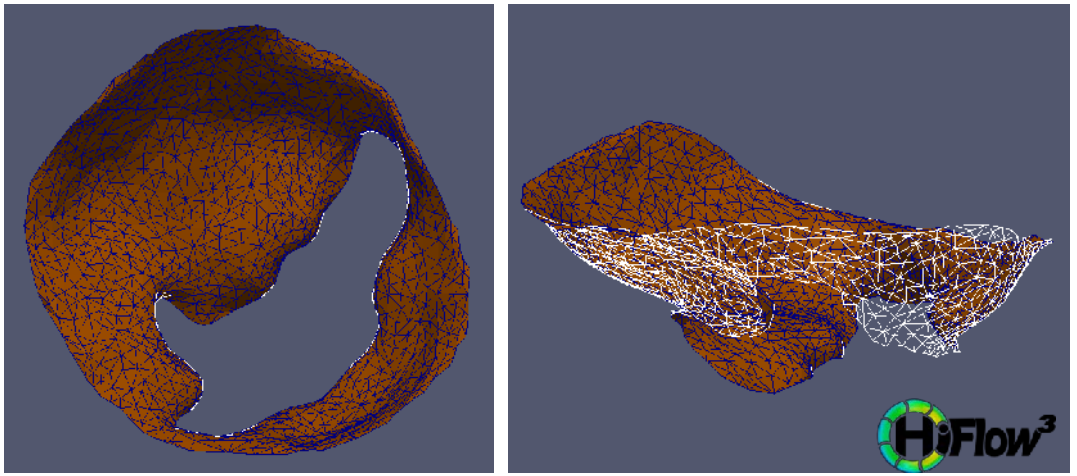


Fixed Annulus Ring

Solve dynamic equation of Mitral Valve leaflets, subject to:

- Chordae tension (displacement & tension),
- surface pressure (fluid flow),
- fixed displacement boundary conditions (Annulus Ring).



# **Simulation of a blood pump**
## Benchmarking with FDA's scenario

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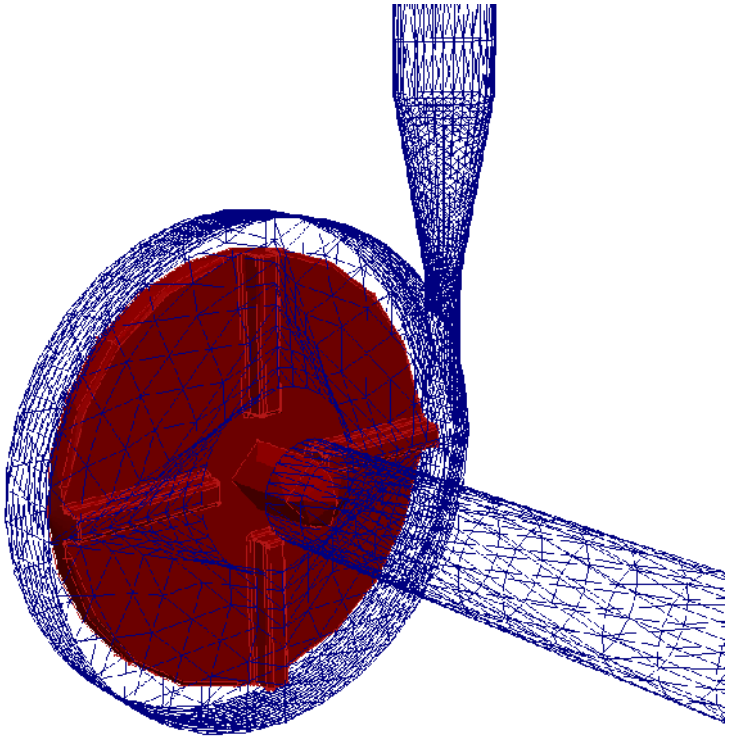
- Idealized ventricular assist device (VAD)
- Volume flow rate 2.5 – 7.0 L/min
- Rotor speed 2500 – 3500 RPM
- Evaluation of physical parameters
- Comparison to physical experiments in a round-robin study



# Simulation of a blood pump
## Benchmarking with FDA's scenario

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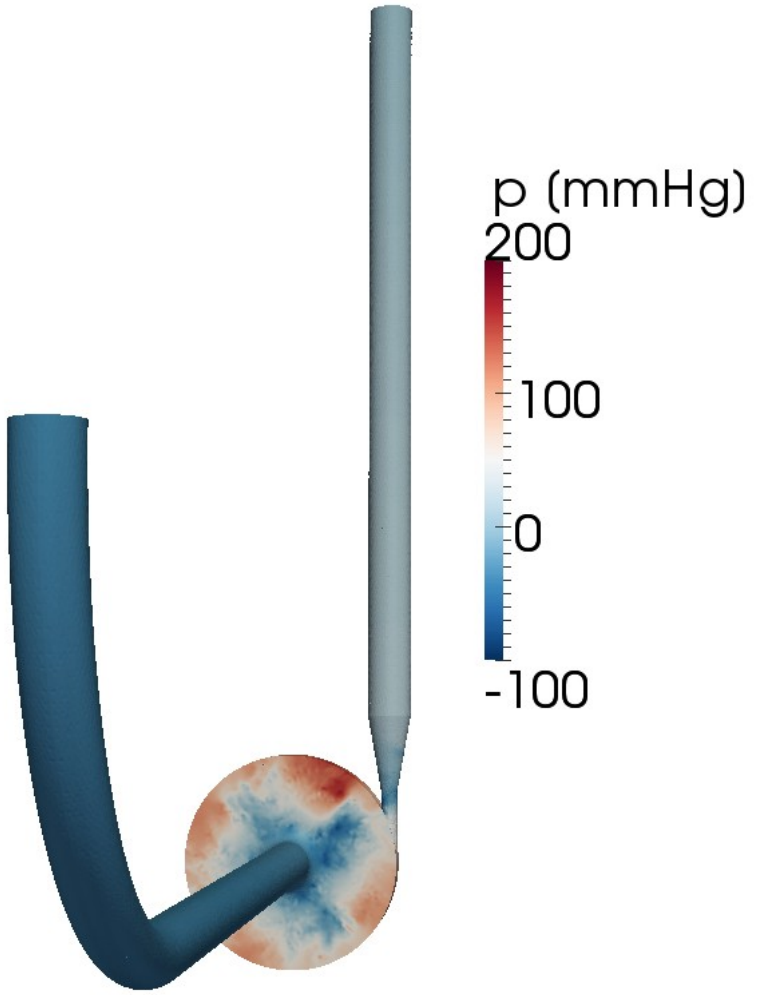
- Hiflow³ system matrix assembly for the incompressible Navier-Stokes equations with streamline diffusion
- Reynolds number: ~250,000
- Interiour mesh adaption to the rotor
- P2/P1 LBB-stable finite elements
- HiFlow³ GMRES with ILU preconditioning
- Simulation on HPC systems



# **Simulation-based Surgery Assistance**
in the Clinic Workflow

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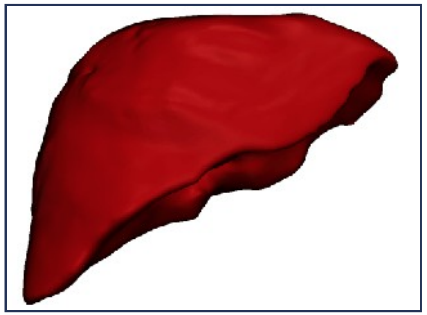


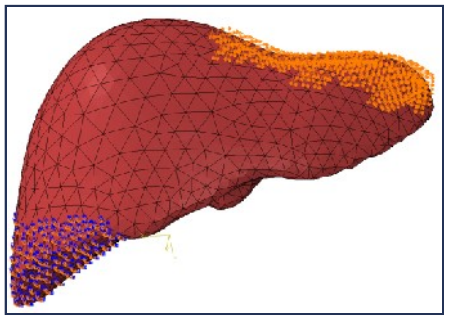
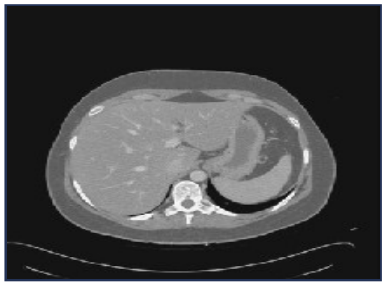


Image → Surface → Volume → Biomech. Model & Simulation → Physics engine → Post-processing



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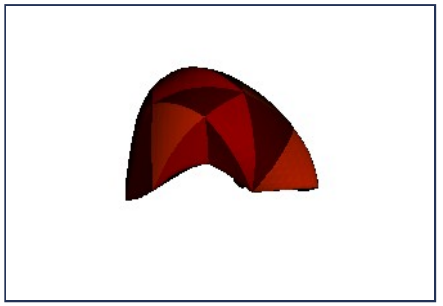
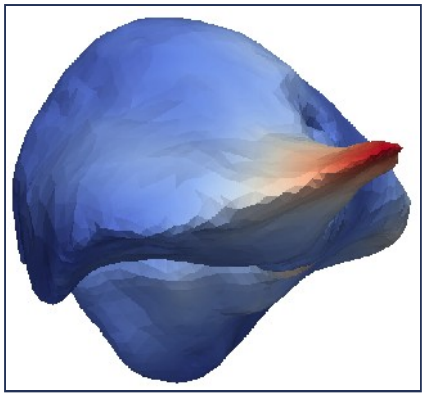
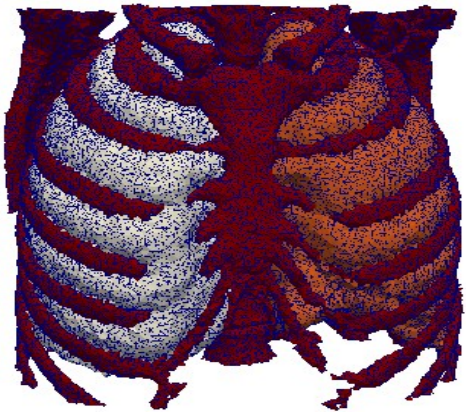




# Impact on OR / Clinic Environment

## Software Development



Software Platform Interface Project:

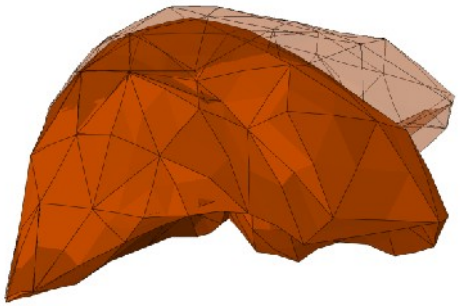
**'*Medical Simulation Markup Language (MSML)*':**

- Simplify biomechanical modeling workflow
- Act as middleware between all tools used in the modeling pipeline

➔ XML-based modeling scheme/alphabet.

➔ Python-based implementation (including interpreter/executor).

→ HiFlow$^3$-MSML-Exporter allows for feeding HiFlow$^3$-based simulations with flexible surgery-motivated modelling situations.

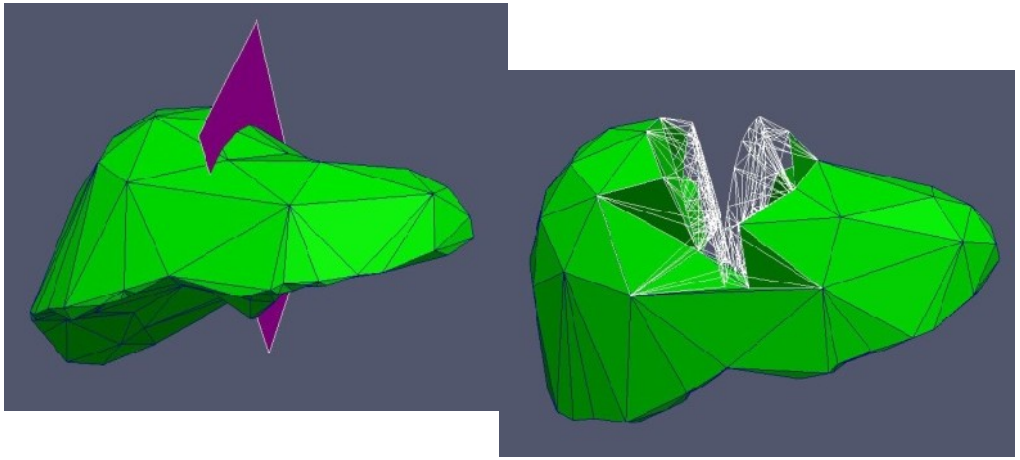


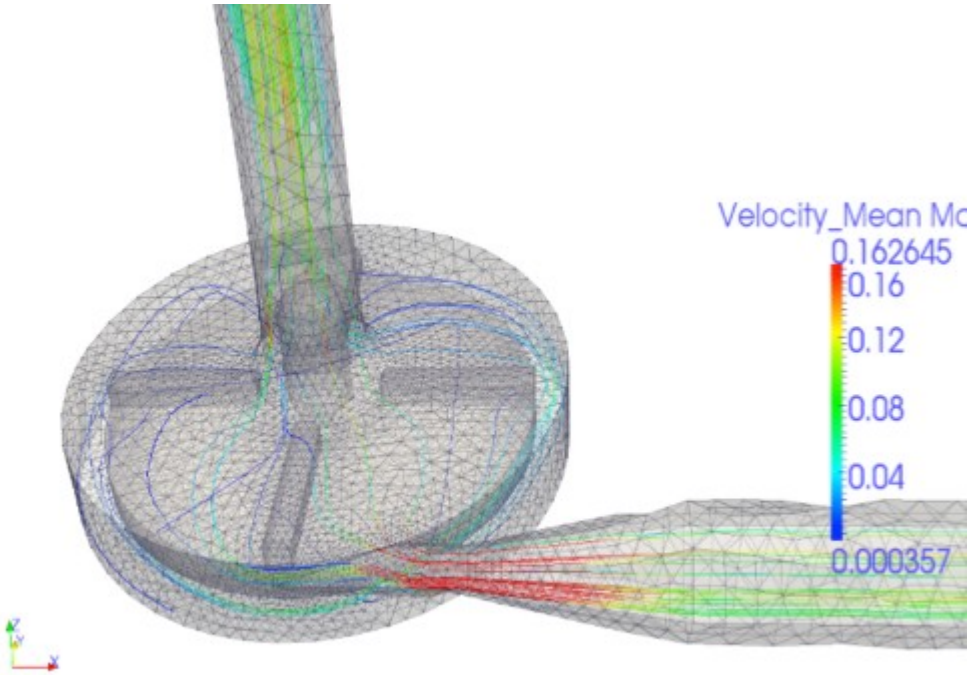
Conference Contribution and Publication:

S. Suwelack, M. Stoll, S. Schalck, N. Schoch, R. Dillmann, R. Bendl, V. Heuveline, and S. Speidel
"*The medical simulation markup language (MSML) – simplifying the biomechanical modeling workflow*"
@ Medicine Meets Virtual Reality, MMVR2014.

# Outlook
## HiFlow³ medical applications

- X-FEM capabilities
  for Soft Tissue Cutting Simulation
- Knowledge-based, intelligent
  Biomechanical Simulations
  in Surgery Workflow
- Preconditioners for complex blood
  flows
- Fluid-Structure Interaction
- Uncertainty Quantification for
  reliable medical simulation results





**Thank you for your attention!**