Scalable Infrastructure and Multiphysics Applications in Fluid Dynamics, Solid Mechanics, and Fluid-Structure Interaction

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Overview

Purpose

Develop new algorithms and software for solving biology problems arising from the interaction of a flexible structure with an incompressible fluid.

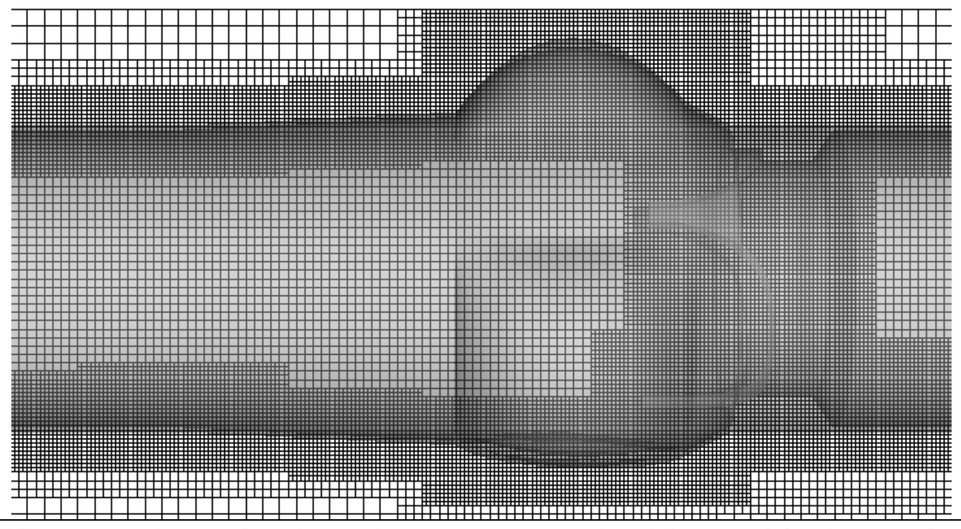
Methods

- Model biological structures as elastic, neutrally buoyant solids
- Model fluids with the incompressible Navier-Stokes equations
- Couple structures and fluids with the Immersed Boundary (IB) method

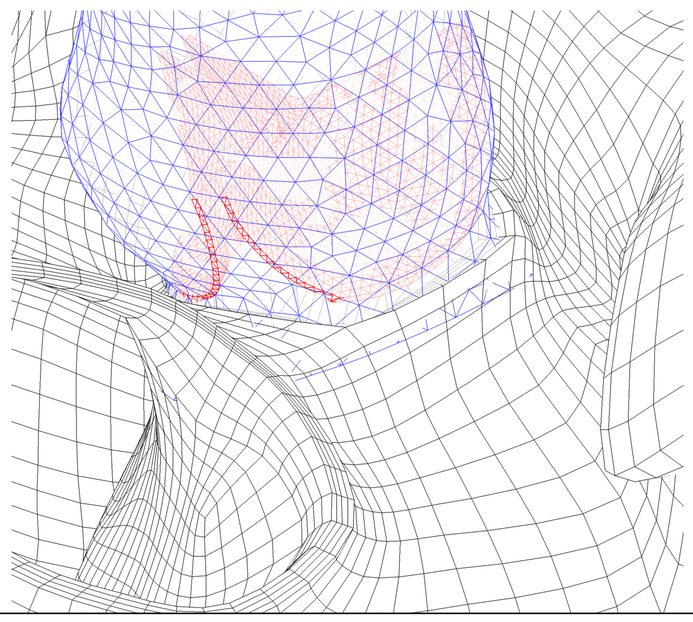
Results

- Comparisons between experiments and simulations of porcine valves[1]
- Models of esophageal transport[2]
- Swimming jellyfish models[3]
- Comparison of chordae models[4]
- New Immersed Interface Method (IIM) discretization[5]

Efficient Fluid & Solid Discretizations

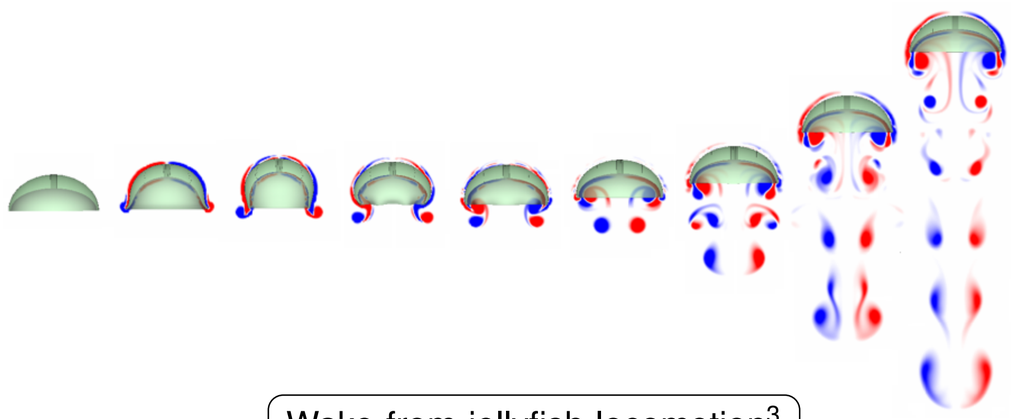


AMR around a valve housing: structured grids enable fast solvers

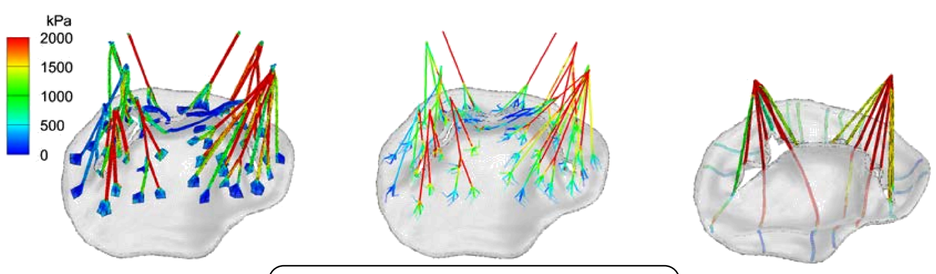


Overlapping finite element grids for discretizing complex geometries

Realistic Interaction Dynamics

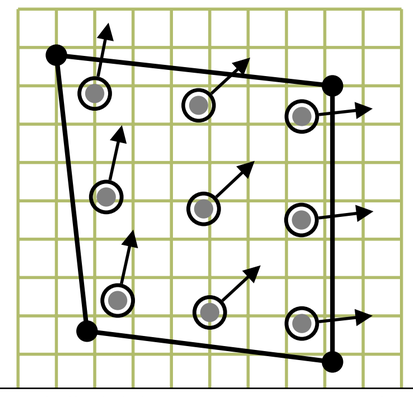


Wake from jellyfish locomotion[3]



Mitral chordae stresses[4]

Coupling With Immersed Boundaries



Structure and fluid interact at quadrature points

Fluid to Structure: Velocity Projection

$$\frac{\partial}{\partial t}\chi(\mathbf{X},t) = \mathbf{U}(\mathbf{X},t) \text{ where}$$

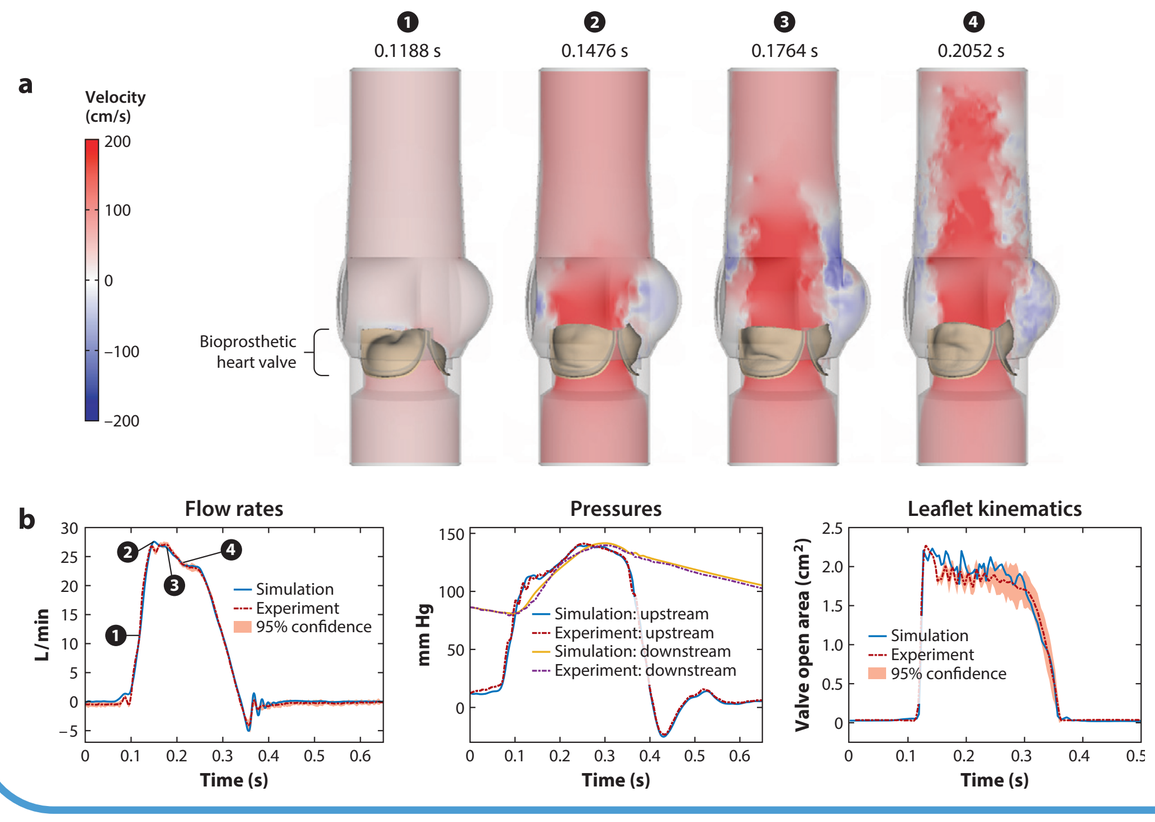
$$\int_U \mathbf{U}(\mathbf{X},t)\phi(\mathbf{X})d\mathbf{X} = \int_U \mathbf{V}(\mathbf{X},t)\phi(\mathbf{X})d\mathbf{X}, \forall \phi \in X^h(U)$$

$$\mathbf{V}(\mathbf{X},t) = \sum_{i,j,k} \mathbf{u}_{i,j,k}\delta_h(\mathbf{x}_{i,j,k} - \chi(\mathbf{X},t))\Delta\mathbf{x}_{i,j,k}$$

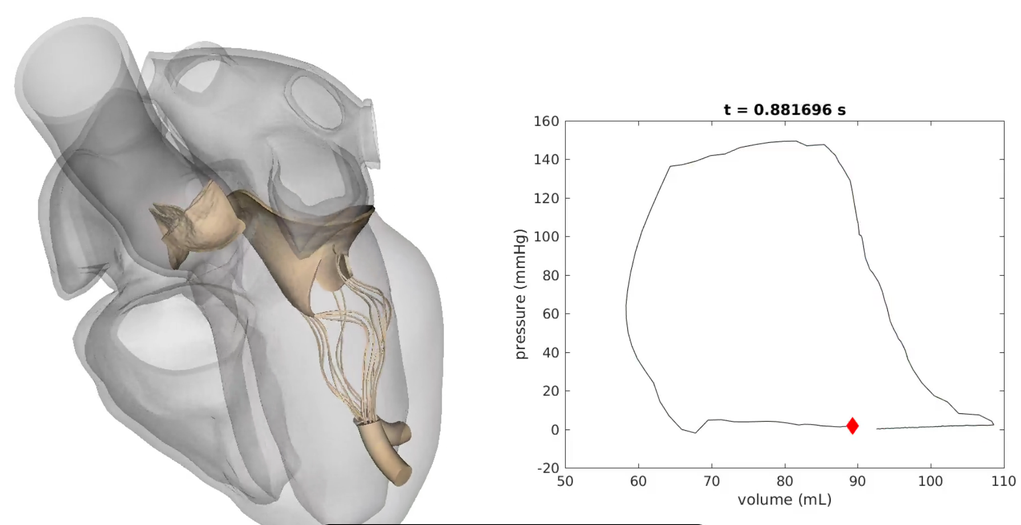
Structure to Fluid: Force Spreading

$$\mathbf{f}(\mathbf{x}_{i,j,k},t) = \int_U \mathbf{F}(\mathbf{X},t)\delta_h(\mathbf{x}_{i,j,k} - \chi(\mathbf{X},t))d\mathbf{X}$$

Experimentally Verified Valve Models[1]



Physiologically Accurate Heart Modelling



Cardiac cycle PV loops

References

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3. A. P. Hoover, B. E. Griffith, L. A. Miller. *Quantifying performance in the medusan mechanospace with an actively swimming three-dimensional jellyfish model.* J Fluid Mech, v.813, 2017.
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