Enabling Multiscale and Multiphysics Applications in Fluid Dynamics, Solid Mechanics, and Fluid-Structure Interaction

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Overview

Coupled **fluid-structure systems** are ubiquitous in nature and occur across a broad range of spatial scales:

- writhing and coiling of DNA;
- beating and pumping motions of cilia and flagella;
- flow of blood in the heart and throughout the circulation;
- swimming bacteria and fish, and flying birds and insects;
- fluttering of leaves and dispersal of seeds and pollen by the wind.

The **immersed boundary (IB)** method for **fluid-structure interaction (FSI)** uses:

- an **Eulerian** description of the momentum and incompressibility of the fluid-structure system; and
- a **Lagrangian** description of the structural stresses, forces, and deformations.

The IB approach to FSI:

- facilitates the use of **fast Cartesian grid solvers**;
- reduces or eliminates the need for **dynamic regridding**; and thereby
- enables simulations with **very large** deformations/displacements.

The IB method also implicitly handles **contact** between structures.

IBAMR is software for developing FSI models based on the IB method. ***IBAMR*** currently provides support for Cartesian grid (structured) **adaptive mesh refinement (AMR)**. Support for Lagrangian (unstructured) AMR is planned.

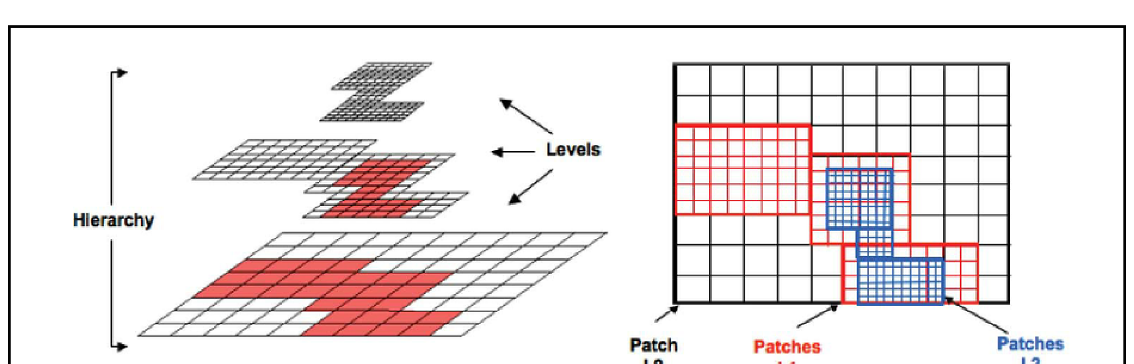

Figure 1: A three-level block-structured AMR grid hierarchy showing grid *levels* and grid *patches*.

IBAMR is built on **SAMRAI**, **PETSc**, **libMesh**, and ***hypre***, and provides **modular structural models**, including finite element mechanics models and methods designed to model material failure (material point methods and *peridynamics*).

Project Goals

- Numerical Methods
- Solver Infrastructure
- User Interface Tools

This work is in the context of applications: *aquatic locomotion*; *cardiac electromechanics*; and *esophageal transport*.

Impact

IBAMR has been used at more than 20 colleges and universities in the U.S. and internationally and at the U.S. *Food and Drug Administration*.

Applications

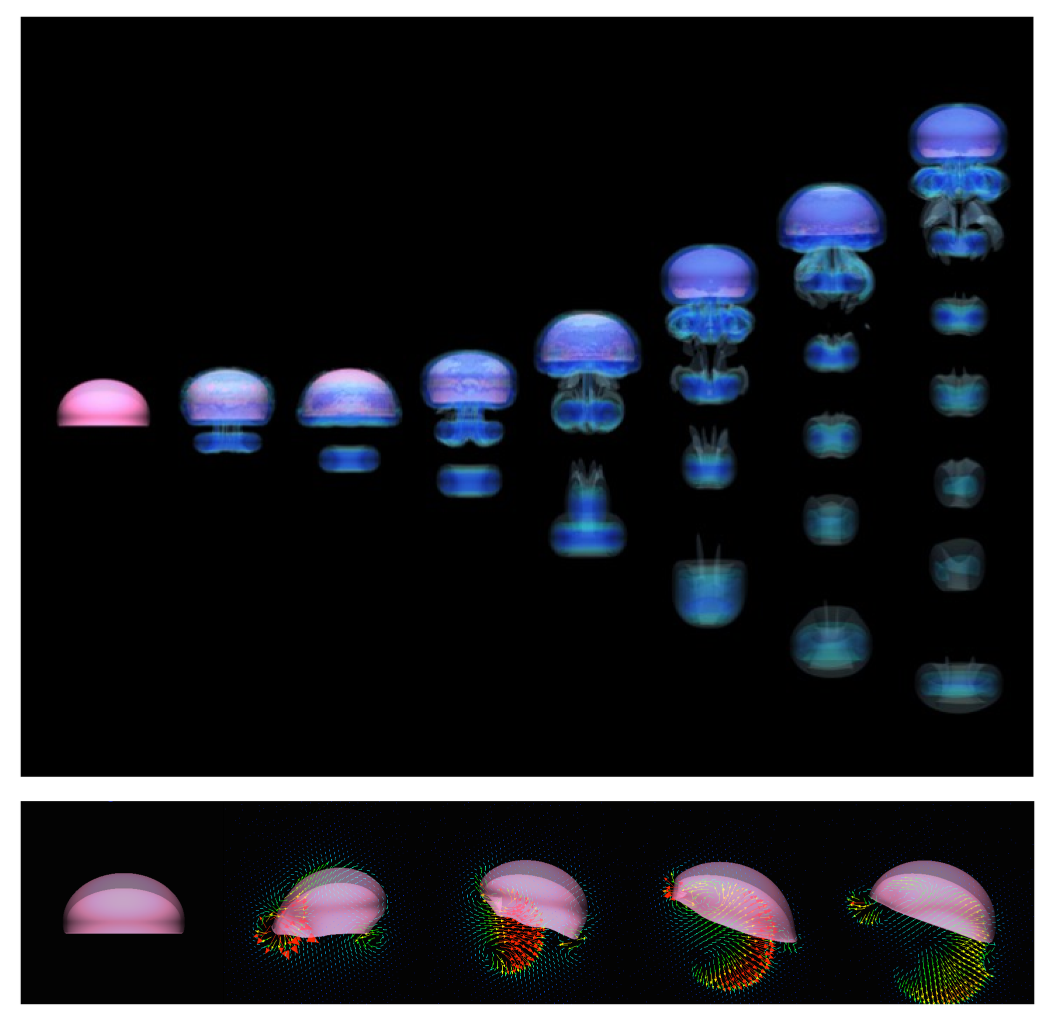

Figure 2: Three-dimensional jellyfish model with bell elasticity and active contraction. (A. Hoover, Tulane, and B.E. Griffith and L.A. Miller, UNC)

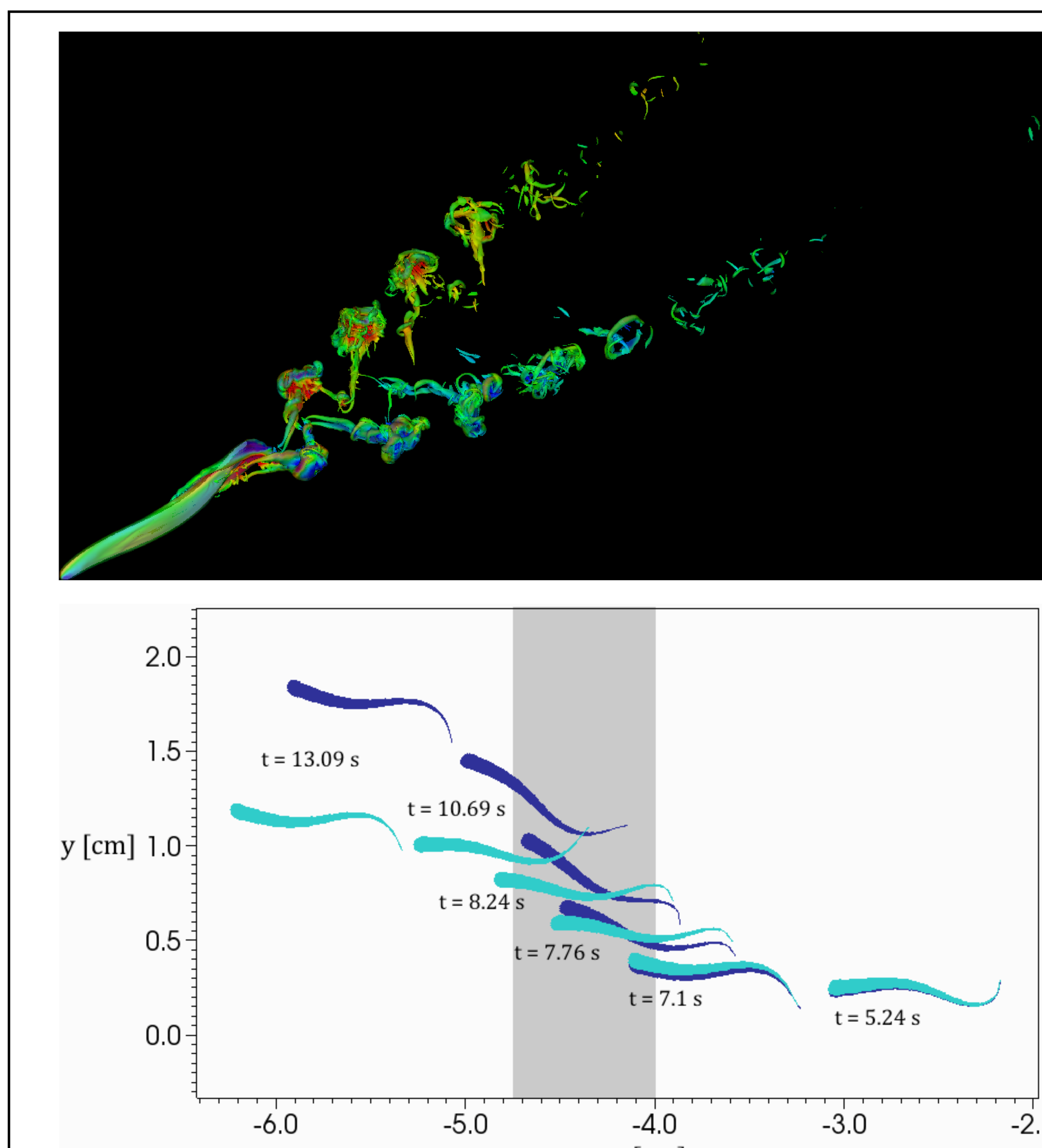

Figure 3: **(Top)** Three-dimensional model of neurally-activated swimming. **(Bottom)** Swimming through an upward jet with (*cyan*) and without (*blue*) neuronal feedback in a two-dimensional model. (N. Patel and N.A. Patankar, Northwestern, and A.P.S. Bhalla, LBNL)

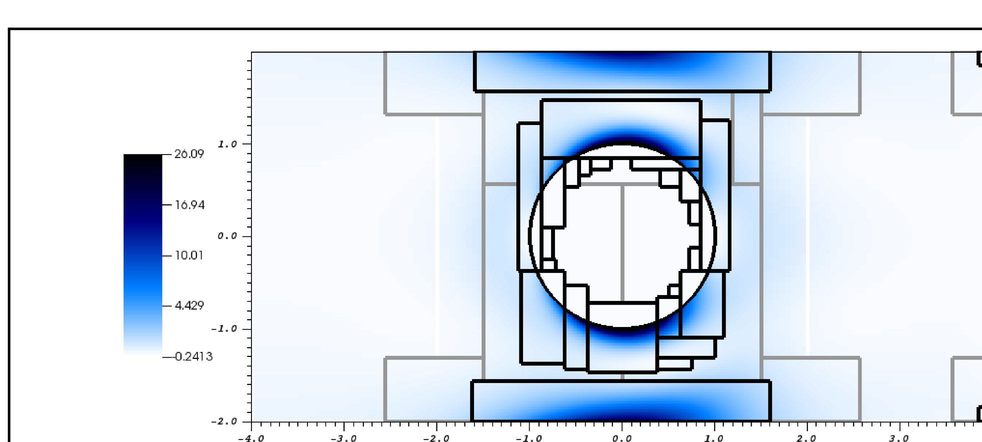

Figure 4: Polymeric stress in an AMR computation of an Oldroyd-B fluid flow past a cylinder using an **immersed interface (II) method** in IBAMR. (A. Barrett and B.E. Griffith, UNC)

Applications (continued)

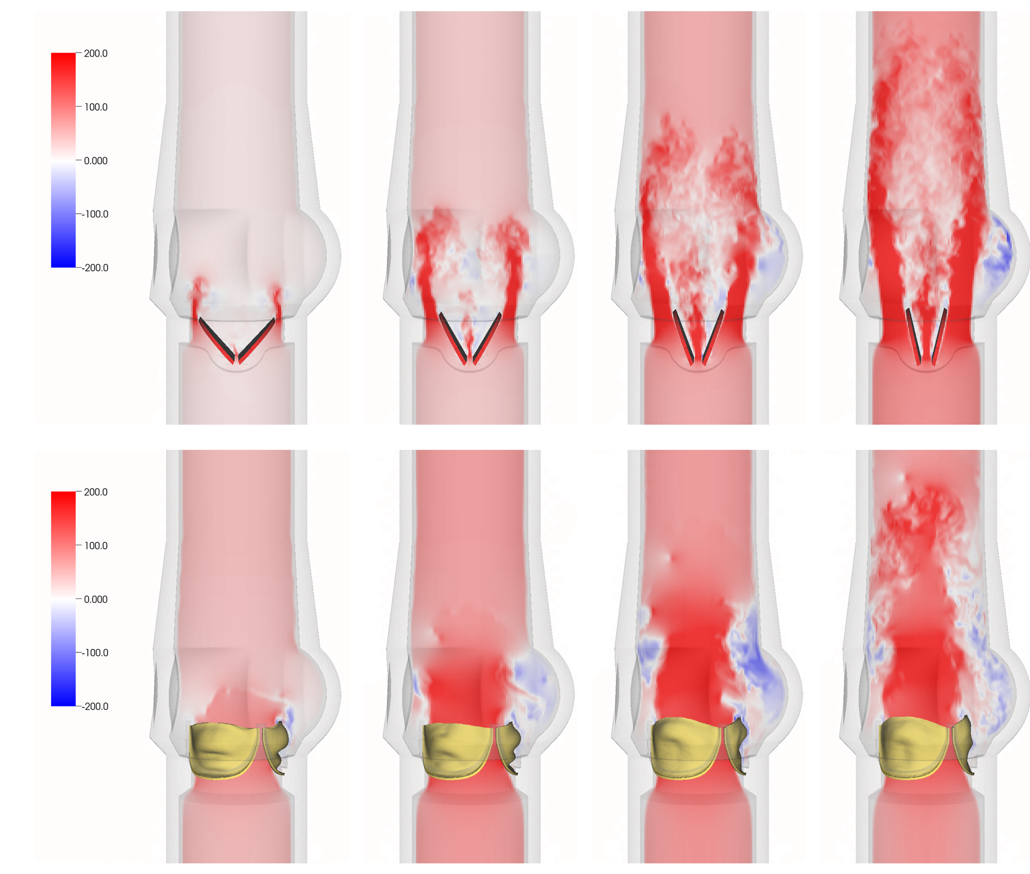

Figure 5: The dynamics of **(top)** rigid mechanical and **(bottom)** flexible bioprosthetic heart valves in the aortic test section of a commercial heart valve testing system. (J.H. Lee, E.M. Kolahdouz, and B.E. Griffith, UNC)

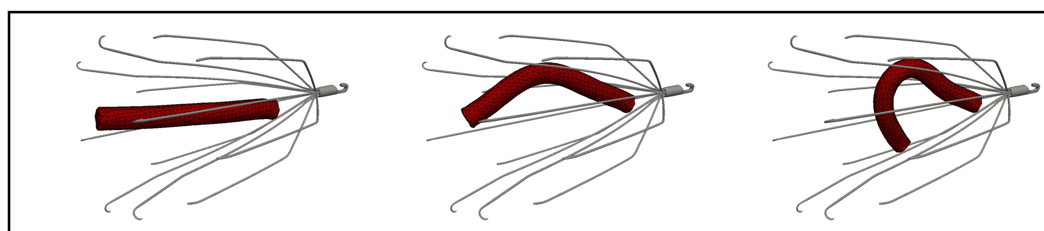

Figure 6: Clot trapping in an idealized model of an **inferior vena cava (IVC)** filter. (B.A. Craven, U.S. FDA.)

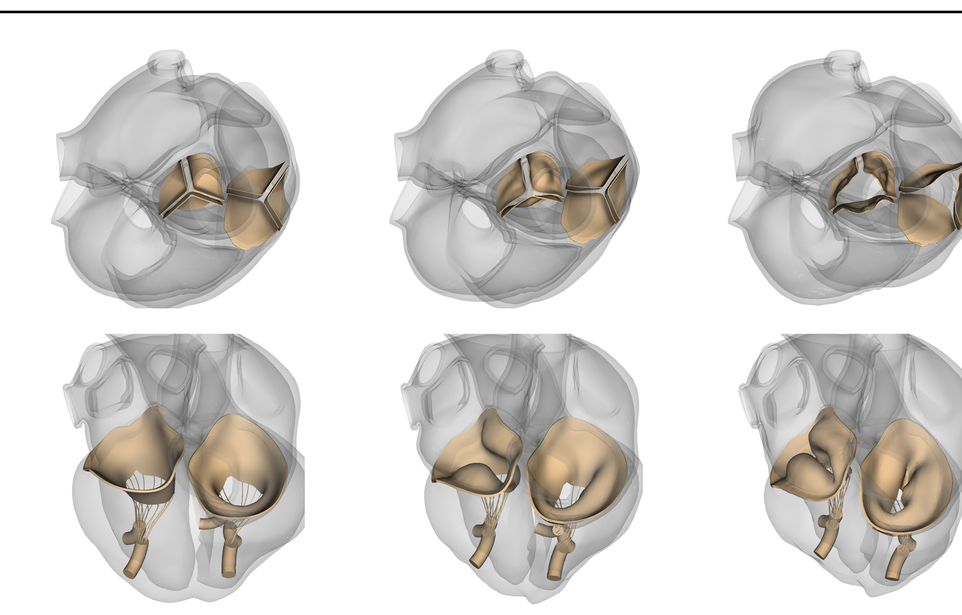

Figure 7: CT-based model of the heart. **(Top)** Opening of the aortic (*middle*) and pulmonic (*right*) heart valves during systolic contraction. **(Bottom)** Closing of the mitral (*left*) and tricuspid (*right*) heart valves at the same times. (C. Puelz, M.A. Smith, S. Rossi, and B.E. Griffith, UNC, and W.P. Segars, Duke)

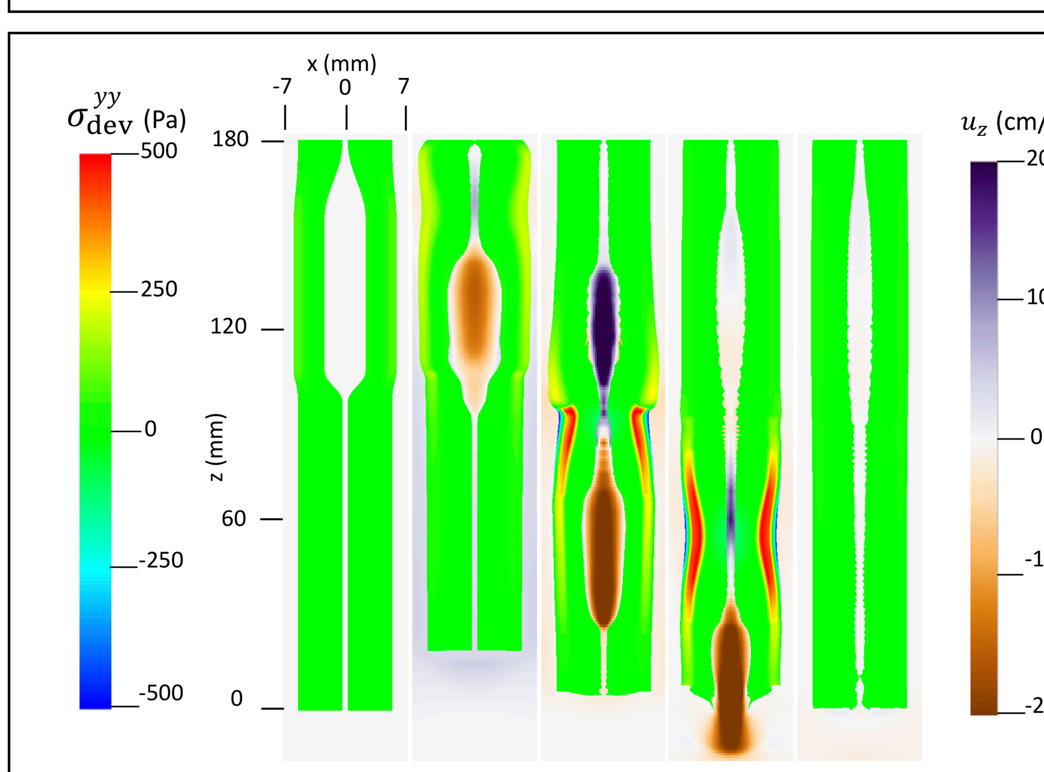

Figure 8: Axial bolus velocity (u_z) and esophageal wall stress (σ^{yy}_{dev}) in a model of esophageal transport. (W. Kou and N.A. Patankar, Northwestern)

Acknowledgements

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