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RESEARCH & COLLABORATION PROFILE | FSAI

KEY WORDS: Immersed Boundary Method, Fluid-Structure Interaction, Vesicle & Foam Dynamics, Energy-Stable Schemes, Scientific Machine Learning



Research Snapshot. Prof. Seol develops numerical methods and mathematical models for moving-interface and fluid-structure interaction problems. His work centers on the immersed boundary method and its extensions to vesicles, biological cells, foams, bubbles and soap films, surfactant-laden interfaces, and non-Newtonian fluids, together with energy-stable and structure-preserving schemes, spectrally accurate mesh control, and, more recently, physics-aware graph neural networks that embed high-order numerical methods into data-driven models. His current projects apply these tools to improving the efficiency of renewable energy harvesting.

RESEARCH EXPERTISE

- **Immersed boundary methods:** development of immersed boundary and immersed boundary projection methods for fluid-structure and fluid-rigid body interaction, including three-dimensional incompressible interfacial flows.
- **Interfacial and multiphase flows:** simulation of vesicles and biological cells, dry and wet foam, bubbles, soap films and minimal surfaces, insoluble surfactant transport, and viscoelastic or non-Newtonian suspending fluids.
- **Structure-preserving numerical analysis:** energy-stable finite difference schemes, semi-implicit semi-Lagrangian time integration, spectrally accurate point redistribution and remeshing, and discrete geometry for evolving curves and surfaces.
- **Scientific machine learning:** graph neural networks informed by high-order numerical discretizations, applied to weather forecasting and to surrogate modeling of partial differential equations.

RECENT RESEARCH HIGHLIGHTS

- **Physics-aware graph networks (Knowl.-Based Syst. 2024):** built a graph neural network that embeds high-order numerical methods in its message passing, improving accuracy and stability over purely data-driven weather forecasting models.
- **High-inertia immersed boundaries (Appl. Math. Comput. 2023):** introduced a semi-implicit semi-Lagrangian scheme that remains stable and efficient for immersed boundary motion under strong inertia and elasticity.
- **Fluid-rigid body interaction (J. Comput. Phys. 2022):** developed an immersed boundary projection method for fluid-rigid body interaction, extending an earlier projection framework for 3D incompressible interfaces.

POTENTIAL COLLABORATION WITH FSAI

Best-fit collaborator areas: computational fluid dynamics and FSI | interface numerics | scientific machine learning | renewable energy

- **1. Joint development of numerical methods:** co-design of energy-stable and spectrally accurate schemes for moving-interface problems, with stability and convergence analysis.
- **2. Soft matter and biological flows:** simulation of vesicles, cells, foams and surfactant-laden interfaces with experimental and biological groups.
- **3. Scientific machine learning:** hybrid numerical-neural solvers and graph-network surrogates for PDEs, weather and climate data.
- **4. Renewable energy harvesting:** modeling and simulation of energy-harvesting devices, linking FSI computation with device design (NRF and G-LAMP projects).

SELECTED RECENT PUBLICATIONS

- **Knowl.-Based Syst. 2024, 300, 112158 -** Physics-aware graph network using high-order numerical methods for weather forecasting.
- **Appl. Math. Comput. 2023, 459, 128269 -** A semi-implicit semi-Lagrangian method for immersed boundary motion under high inertia and elasticity.
- **J. Comput. Phys. 2022, 466, 111367 -** An immersed boundary projection method for solving fluid-rigid body interaction problems.
- **SIAM J. Sci. Comput. 2020, 42(5), A3030-A3054 -** Spectrally accurate algorithm for point redistribution on closed curves.

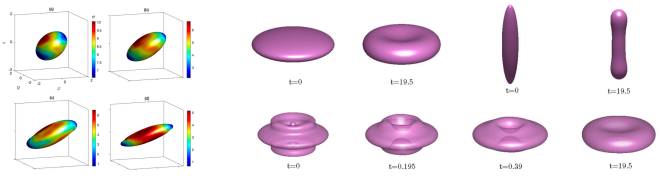
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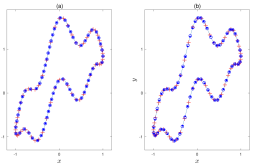
https://sites.google.com/site/yunchangseol/

REPRESENTATIVE RESEARCH FIGURES / SCHEMES

Vesicle as an Incompressible Surface with Bending



Point Remesh/Redistribution



Efficient Numerical Scheme

Theorem 5. *System (3.18) is exactly equivalent to the following 2-by-2 block matrix system*

$$\begin{bmatrix} \mathbf{H} & -\mathbf{PS} \\ -\hat{\mathbf{S}} & \frac{3}{2\Delta t}\mathbf{I} \end{bmatrix} \begin{bmatrix} \boldsymbol{u}^{n+1} \\ \boldsymbol{X}^{n+1} \end{bmatrix} = \begin{bmatrix} \mathbf{Pr}_1 \\ \mathbf{r}_2 \end{bmatrix},$$

where $\mathbf{P}$ *denotes the block matrix of the discrete projection operator* $\mathcal{P}_h$ *defined in Eq. (3.6). If a solution exists, we have*

$$\begin{bmatrix} \boldsymbol{u}^{n+1} \\ \boldsymbol{X}^{n+1} \end{bmatrix} = \begin{bmatrix} \mathbf{H}^{-1} + \mathbf{H}^{-1}(\mathbf{PS})\mathbf{C}^{-1}\hat{\mathbf{S}}\mathbf{H}^{-1} & \mathbf{H}^{-1}(\mathbf{PS})\mathbf{C}^{-1} \\ \mathbf{C}^{-1}\hat{\mathbf{S}}\mathbf{H}^{-1} & \mathbf{C}^{-1} \end{bmatrix} \begin{bmatrix} \mathbf{Pr}_1 \\ \mathbf{r}_2 \end{bmatrix},$$

Physics-aware Graph Networks

