Solid-Fluid Interaction with Surface-Tension-Dominant Contact

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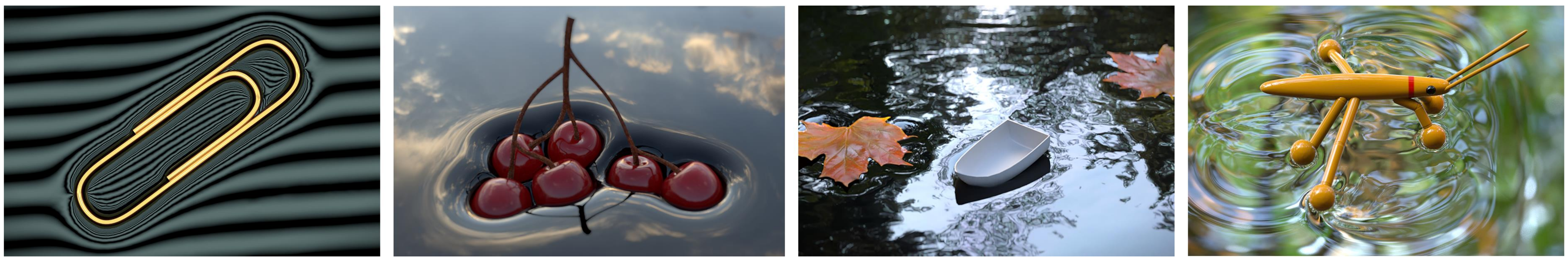
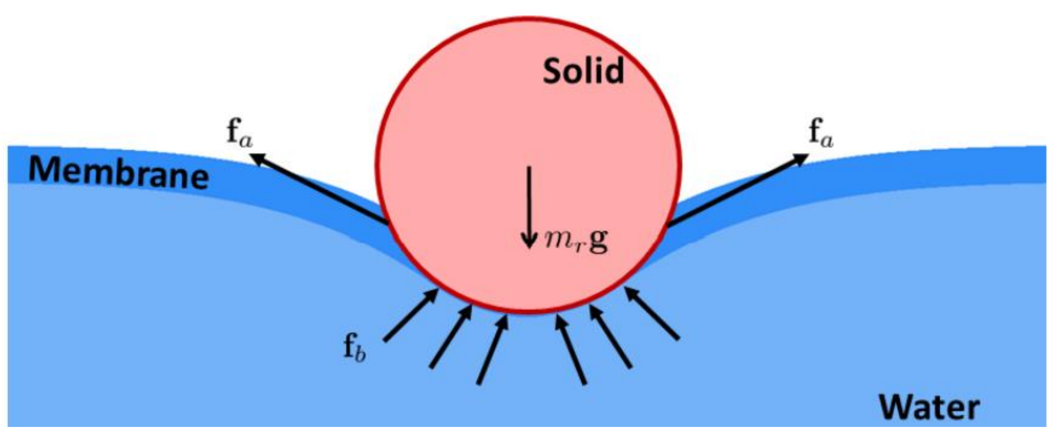


Introduction

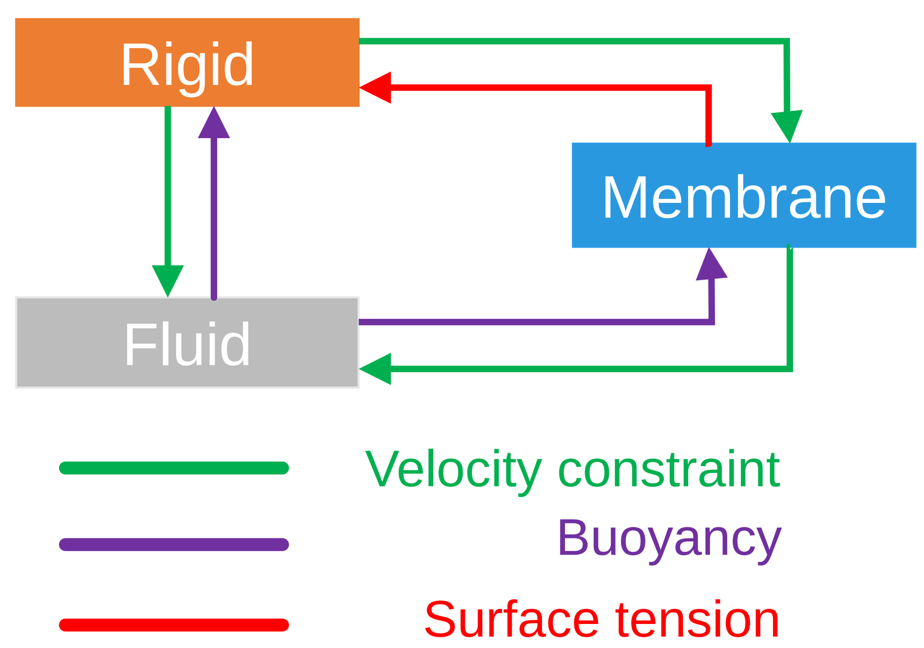
Interactions between solids and fluids driven by the strong interfacial capillary forces are seen ubiquitously. From a computational perspective, accurately modeling the surface tension interacting with the gravity and the buoyancy requires proper treatment of three subsystems — the liquid, the solid, and the strongly-tensioned liquid interface between them.

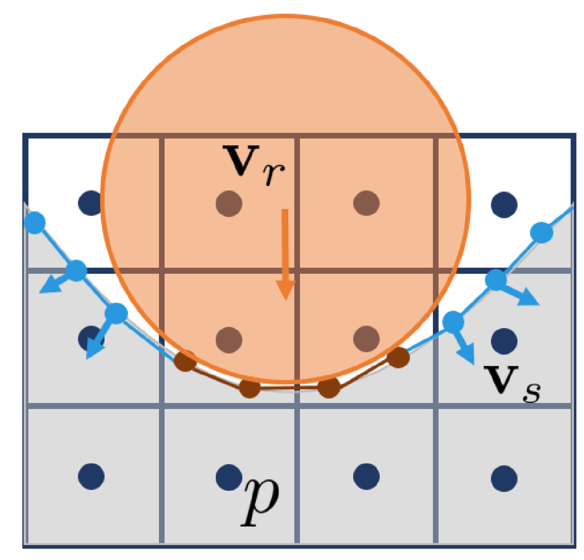


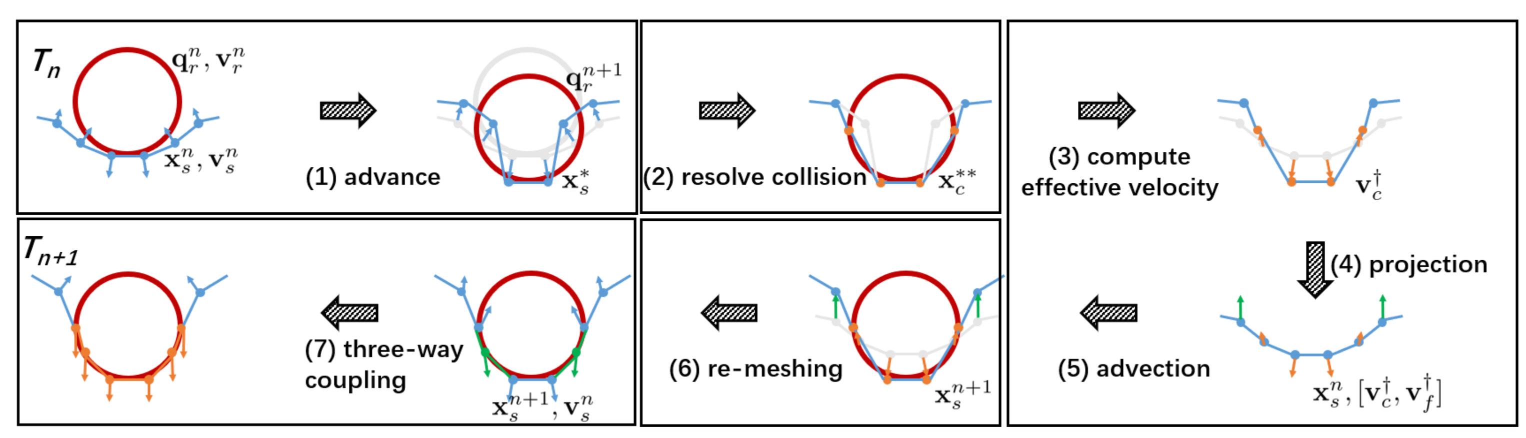
The mainstream numerical paradigms of using an implicit level-set method to model the free-surface flow [Robinson-Mosher et al. 2008] suffer from **limitations** of accurately capturing the liquid-solid **contact perimeter** and fine-scale **capillary waves**. To tackle these computational challenges, we propose a novel "**three-way**" coupling mechanism by adding a **Lagrangian thin membrane** between the fluid and the solid.

Methods

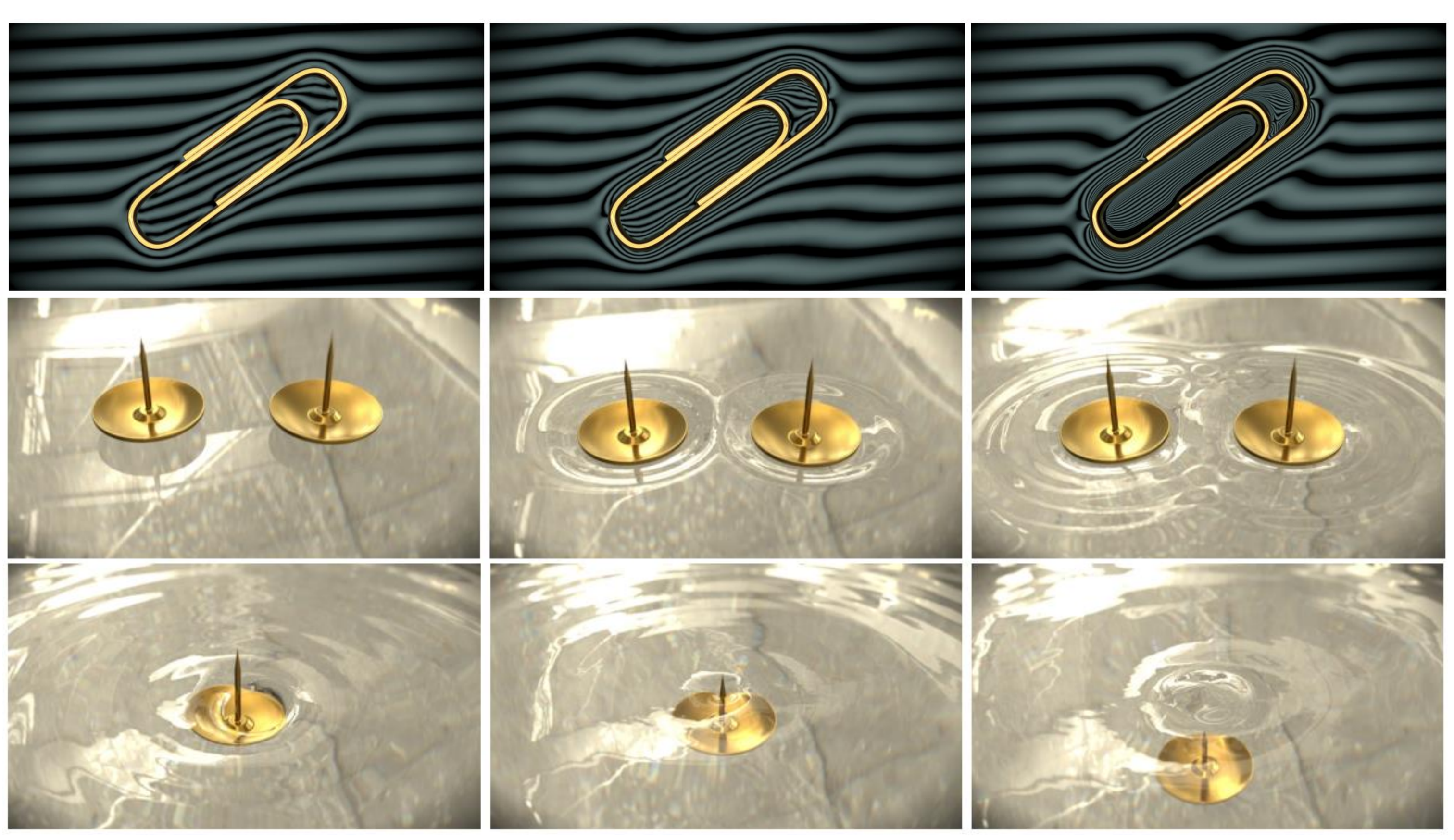
$$\begin{bmatrix} \frac{V}{\rho}\mathbf{G}^T\mathbf{G} & -V\mathbf{G}^T\mathbf{W} & -V\mathbf{G}^T\mathbf{J}_r \\ -\mathbf{W}^T\mathbf{G}V & -\tilde{\mathbf{M}}_s & -\mathbf{K}_{c,r}\Delta t^2 \\ -\mathbf{J}_r^T\mathbf{G}V & -\mathbf{K}_{a,s}\Delta t^2 & -\tilde{\mathbf{M}}_r \end{bmatrix} \begin{bmatrix} \hat{\mathbf{p}} \\ \mathbf{v}_s^{n+1} \\ \mathbf{v}_r^{n+1} \end{bmatrix} = \begin{bmatrix} V\mathbf{G}^T\mathbf{u}^* \\ -\mathbf{M}_s\mathbf{v}_s^n - \tilde{\mathbf{f}}_c\Delta t - \mathbf{W}^T\mathbf{M}\mathbf{u}^* \\ -\mathbf{M}_r\mathbf{v}_r^n - \tilde{\mathbf{f}}_a\Delta t - \tilde{\mathbf{f}}_r\Delta t - \mathbf{J}_r^T\mathbf{M}\mathbf{u}^* \end{bmatrix}$$







Results



Discussion

We demonstrate the efficacy of our method through an array of rigid-fluid contact simulations dominated by strong surface tension, which enables the faithful modeling of a host of new surface-tension-dominant phenomena. But there are several limitations of our current method:

1. the three-way coupled system is **not symmetric positive definite**, which affects the solver's performance when solving large-scale problems.
2. Our explicit mesh representation, though exhibiting outstanding performance on handling contact, **cannot** handle the **large topological evolution** of complex liquid surfaces efficiently.
3. Regarding the physical model, our current solver does **not** support **hydrophilic materials** and **contact angles** which limits its scope of applications.

Conclusion

We develop a novel numerical method to simulate surface-tension-dominant solid-fluid coupling:

1. In stead of using level set, we use a **Lagrangian membrane** to represent the fluid surface and discretize surface tension on it.
2. We then involve the membrane into the fluid-rigid system, constructing a **three-way coupling system**.
3. At last we design a **prediction-correction time scheme** to handle the collision between the membrane and the rigid.

Reference

[Robinson-Mosher et al. 2008] Avi Robinson-Mosher, Tamar Shinar, Jon Gretarsson, Jonathan Su, and Ronald Fedkiw. 2008. Two-way coupling of fluids to rigid and deformable solids and shells. ACM Trans. on Graphics 27, 3 (2008), 1–9.