



Realistic Multi-Material Interaction Simulation Pipeline

Final Presentation

Advanced Computer Graphics

Yiyang Lu*, Xiangchen Tian*

IIIS, Tsinghua University

{luyyy24,txc23}@mails.tsinghua.edu.cn

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清华大学
Tsinghua University



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Overview

1 Introduction

- Implement a collision simulation system for rigid, fluid and cloth materials, as well as smoke simulation.
- The simulation part is implemented in Python, especially Taichi, a high-performance acceleration library.
- Surface reconstruction is implemented by Splashsurf, automated offline rendering is done through Blender.
- About 3k lines of code in Python.



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2 Method

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Rigid 2 Method

- Simply use position and orientation as state

$$\mathbf{F} = \sum_i \mathbf{f}_i \quad \mathbf{M} = \sum_i (\mathbf{p}_i - \mathbf{r}) \times f_i$$

$$\frac{dv}{dt} = \mathbf{a} = \frac{\mathbf{F}}{m} \quad \frac{d\omega}{dt} = \boldsymbol{\alpha} = \mathbf{I}^{-1} \mathbf{M}$$

- Support rigid simulation of any mesh



Fluid

2 Method

- Lagrangian particle-based method: SPH

$$A(x) = \int A(x') W(x - x', h) dV$$

- Three SPH solvers: WCSPH, DFSPH and PCISPH.
 - WCSPH handles high-pressure gradients efficiently by allowing slight compressibility
 - DFSPH enforces incompressibility and divergence-free velocity fields directly, leading to highly stable
 - PCISPH accelerates pressure convergence through predictive-corrective iterations
- Use space hash to accelerate the neighbor search ($O(n^2) \rightarrow O(n)$)



Rigid-Fluid Coupling

2 Method

- Rigid bodies modeled as point clouds, behave similarly as fluid.
- Transfer forces between fluid and rigid body
- Minor changes to ensure accurate dynamic interactions between fluids and rigid bodies in simulations, e.g. change factor α_i in DFSPH

$$\alpha_i = \frac{\rho_i}{\sum_{j \in \text{fluid}} |m_j \nabla W_{ij}|^2 + |\sum_{j \in \text{fluid and rigid}} m_j \nabla W_{ij}|^2}$$

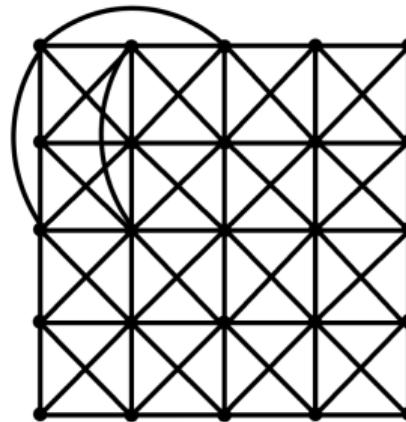


Cloth 2 Method

- Mass-Spring System Method.
- Three kinds of springs: structural spring, shear spring, and bend spring.

$$\mathbf{F}_{\text{internal}} = k_{\text{struct}} \Delta \mathbf{x}_{\text{struct}} + k_{\text{shear}} \Delta \mathbf{x}_{\text{shear}} + k_{\text{bend}} \Delta \mathbf{x}_{\text{bend}}$$

- Space hash to detect collision.



Mass-Spring System



Cloth-Rigid Coupling

2 Method

- Support both fixed rigid & movable rigid.
- Transfer of forces between the cloth and the rigid body by accumulated impulse.

$$\mathbf{I}_{\text{total}} = -M\mathbf{g}\Delta t + \sum_{i \in \text{cloth}} \mathbf{I}_i$$

- Real-time interaction GUI! You can try it yourself.



Smoke 2 Method

- Goal: Solve the incompressible Euler equations

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} = -(\mathbf{u} \cdot \nabla) \mathbf{u} - \nabla p + \mathbf{f}$$

- Involves solving the Poisson equation about pressure field p with pure Neumann boundary condition $\frac{\partial p}{\partial \mathbf{n}} = 0$.
- Other trick includes vorticity confinement, semi-Lagrange method, etc.



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3 Demo

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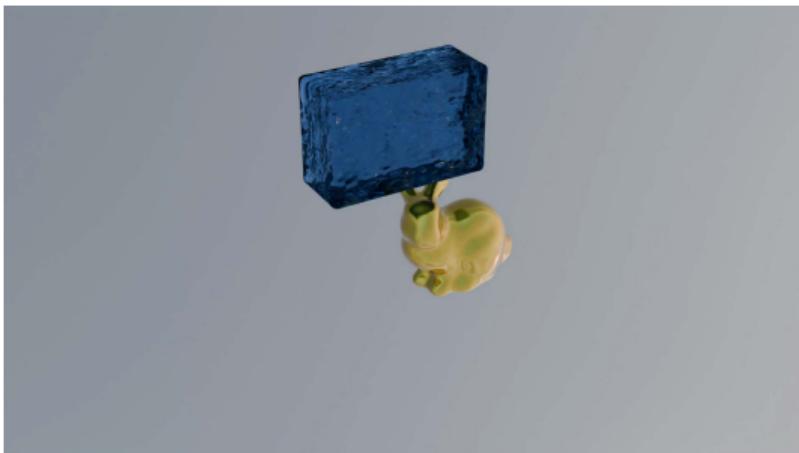
► Method

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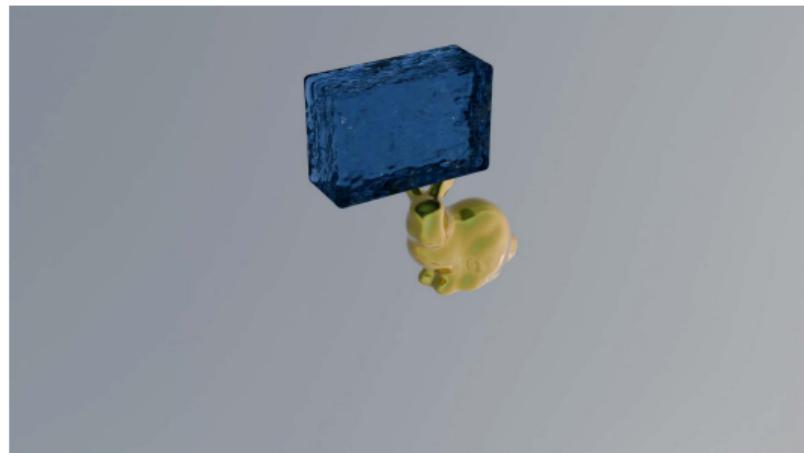


Rigid-Fluid Coupling

3 Demo



WCSPH

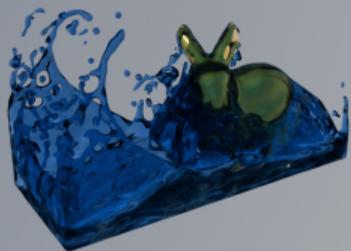


DFSPH

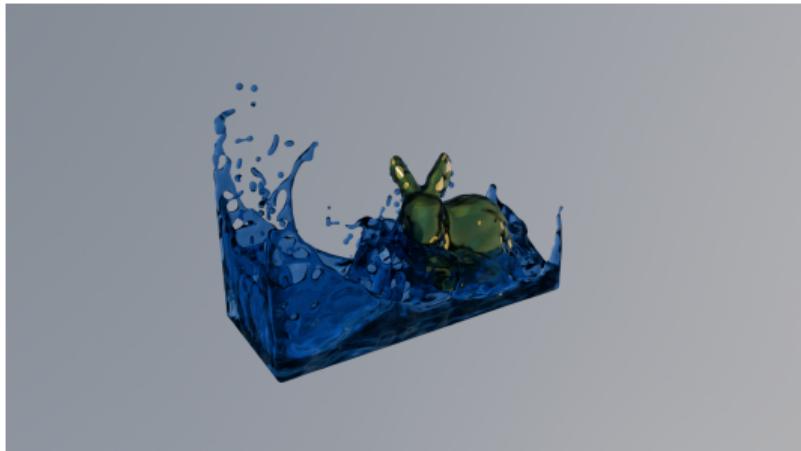


Rigid-Fluid Coupling

3 Demo



WCSPH



DFSPH

DFSPH has lower energy dissipation compared to WCSPH



Rigid-Fluid Coupling

3 Demo

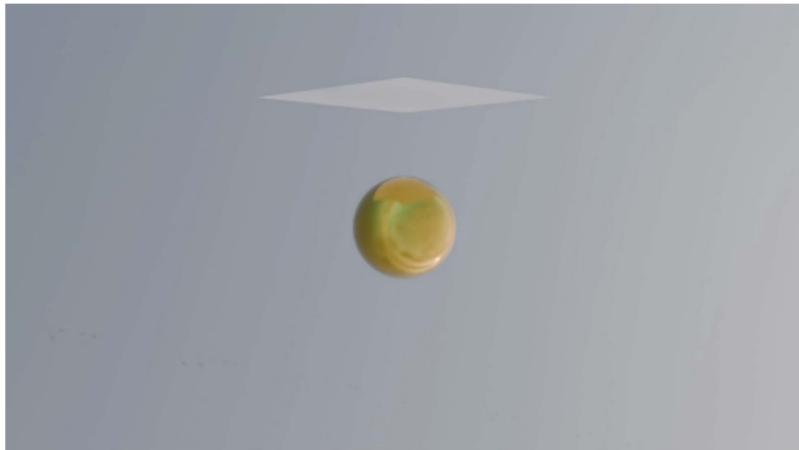


Two-way Rigid-Fluid Coupling



Cloth-Rigid Coupling

3 Demo



Cloth

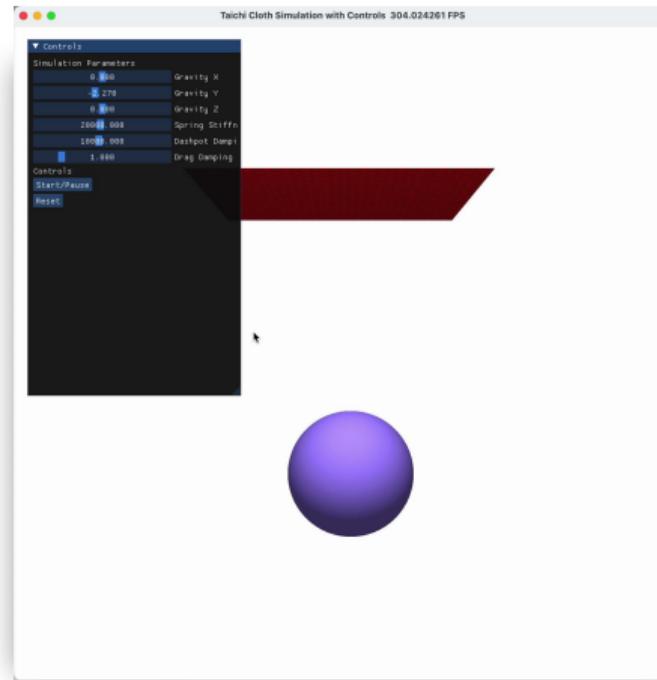


Cloth-Rigid



Real-time Interaction

3 Demo



Real-time Cloth-Rigid Coupling



Smoke

3 Demo



Smoke



Acknowledge

3 Demo

- Sincerely thank Prof. Yi and TA for their guidance and help.
- Thanks to the authors of Taichi, Splashsurf, and Blender.



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Yiyang Lu*, Xiangchen Tian*

*Thank you for listening!
Any questions?*