A Convex Formulation of Material Points and Rigid Bodies with GPU-Accelerated Async-Coupling for Interactive Simulation

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https://github.com/g1n0st/drake

Contribution

- An **asynchronous** time-splitting scheme.
- A **convex** weak coupling formulation.
- A **GPU-friendly** quasi-Newton solver.
- We demonstrate **speed**, **accuracy**, and **robustness** across a variety of demos.
- **Open-source** implementation in **Drake.**

Method

Formulation

Update within Δt

Coriolis terms and gravity

$$\mathbf{M}_r(\mathbf{q}_r^n)(\mathbf{v}_r^{n+1}-\mathbf{v}_r^n)=\Delta t\,\mathbf{k}_r(\mathbf{q}_r^n,\mathbf{v}_r^n)+\mathbf{J}_{rr}^T\boldsymbol{\gamma}_r(\mathbf{v}_r^{n+1})$$

Rigid Domain

Symplectic Euler with N substeps

Implicit rigid–rigid coupling

$$+\mathbf{J}_r^T\sum_{k=0}^{N-1}\boldsymbol{\gamma}_d^{n,k}$$

Async-Coupling between MPM and Rigid

MPM Domain

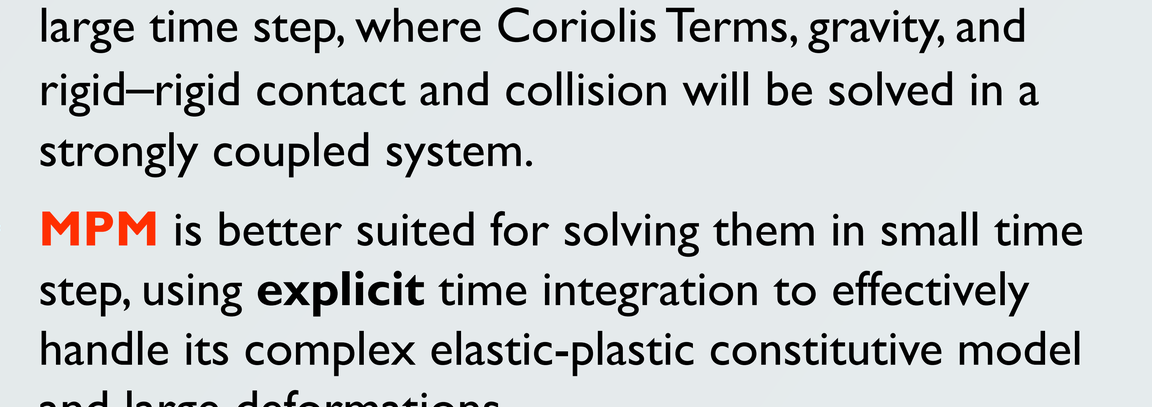
Elastic-plastic and ext. forces

$$\mathbf{M}_d(\mathbf{q}_d^{n,k})(\mathbf{v}_d^{n,k+1}-\mathbf{v}_d^{n,k})=\frac{\Delta t}{N}\mathbf{k}_d(\mathbf{q}_d^n)+\mathbf{J}_d^T\boldsymbol{\gamma}_d^{n,k},$$

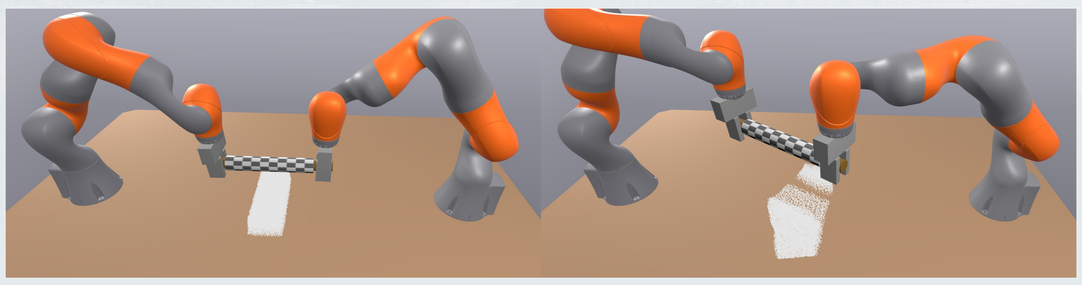
$$\text{for } k=0,\ldots,N-1,\ \text{with } \mathbf{v}_d^{n,0}=\mathbf{v}_d^n,\ \text{and } \mathbf{v}_d^{n,N}=\mathbf{v}_d^{n+1}.$$

- **Rigid body dynamics** can be solved **implicitly** at a large time step, where Coriolis Terms, gravity, and rigid–rigid contact and collision will be solved in a strongly coupled system.
- **MPM** is better suited for solving them in small time step, using **explicit** time integration to effectively handle its complex elastic-plastic constitutive model and large deformations.
- The two domains communicate through the **async-coupling contact impulses** to exchange information efficiently.

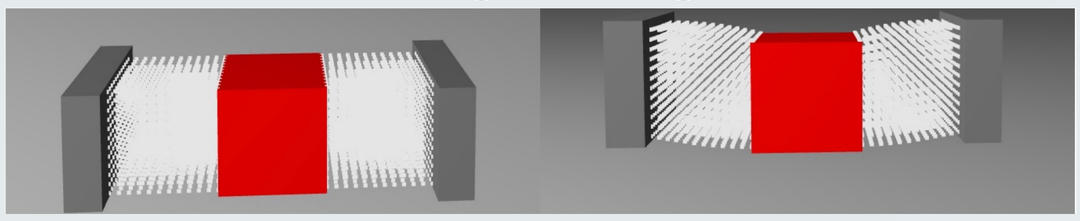
Illustration of async-coupling in a time step



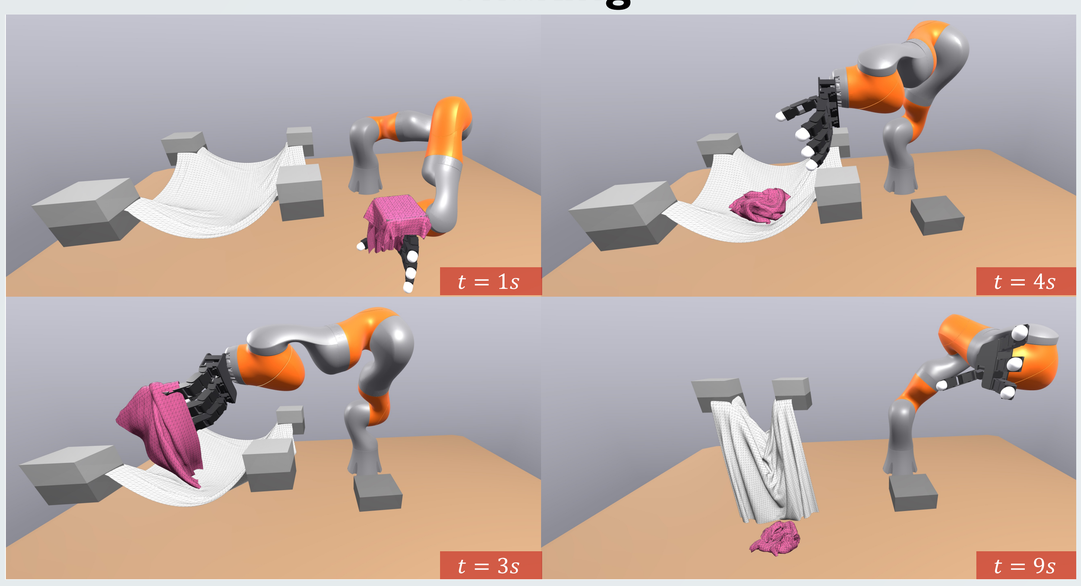
Experimental Results



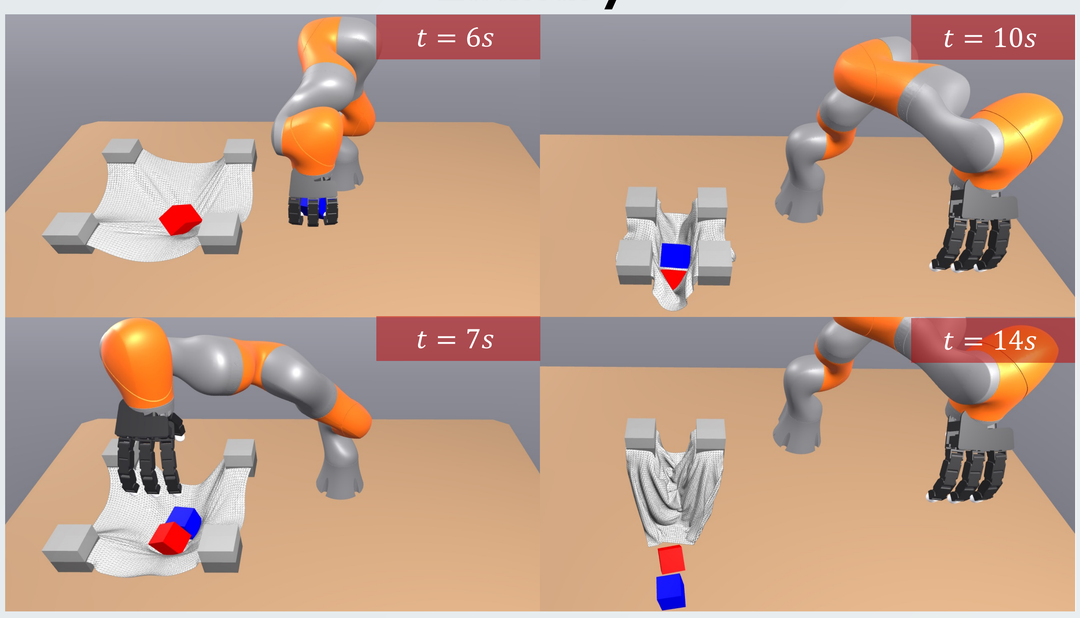
Dough Rolling



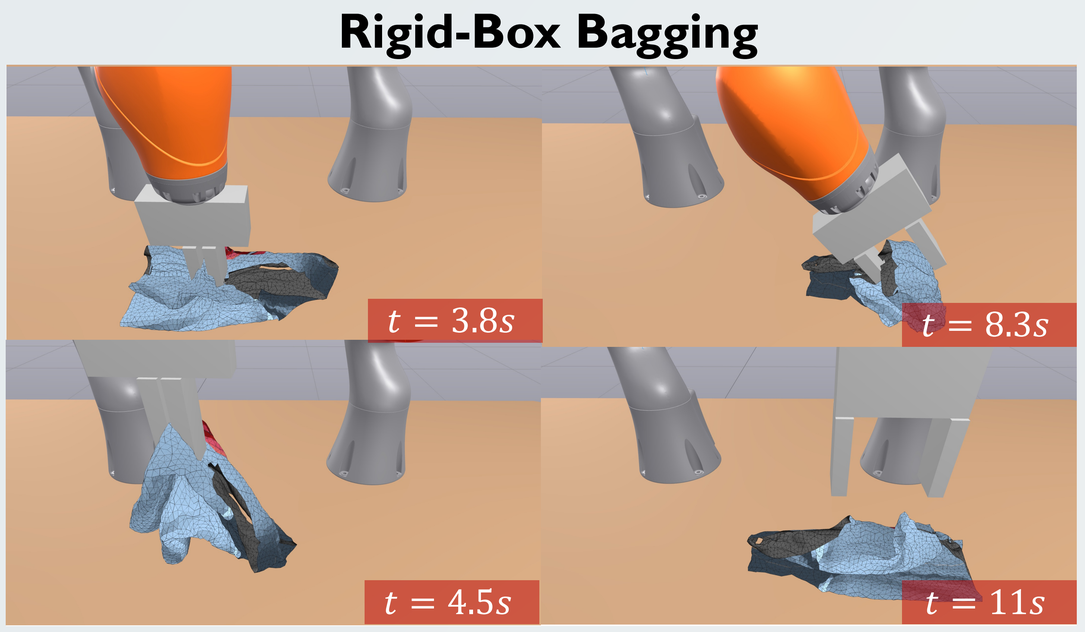
Shaking



Laundry



Rigid-Box Bagging



T-Shirt Folding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IROS HANGZHOU 2025