GranularGym: High Performance Simulation for Robotic Tasks with Granular Materials
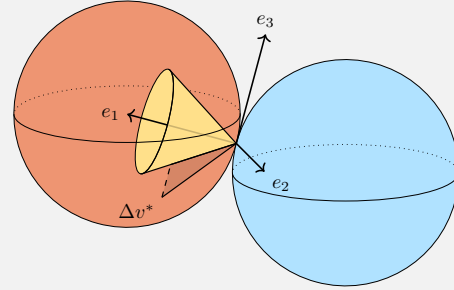
David Millard* (dmillard@usc.edu), Daniel Pastor[†], Joseph Bowkett[†], Paul Backes[†], Gaurav S. Sukhatme*

University of Southern California*, NASA Jet Propulsion Laboratory[†]

Overview

- Simulation of hundreds of thousands of particles at realtime speeds on a single commodity GPU.

- Implicit timestepping formulation of inter-particle contact using a parallelized projected Jacobi algorithm.

- One-way coupling with rigid bodies of arbitrarily complex geometry using Signed Distance Functions (SDFs).

- Open source, portable implementation across (multithreaded) CPUs, NVIDIA GPUs, Apple Metal GPUs, (more soon!)

Franka Emika Panda Simulation

50000 particles, running at realtime on a single NVIDIA GeForce RTX 3080 Ti.

Implicit Rigid Body Contact

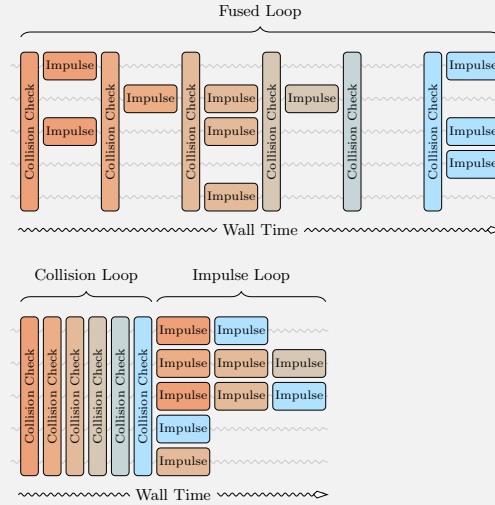$$c^{(k+1)} = \underbrace{JM^{-1}J^T}_{A}\Delta v + \underbrace{J(v^{(k)} + M^{-1}\Delta t F_{ext})}_{b}$$

$$\text{s.t.} \quad 0 \leq \Delta v \cdot e_1 \perp (A\Delta v + b) \cdot e_1 \geq 0$$

$$||\text{proj}_{e_2 e_3}\Delta v||_2 \leq \mu \Delta v \cdot e_1$$
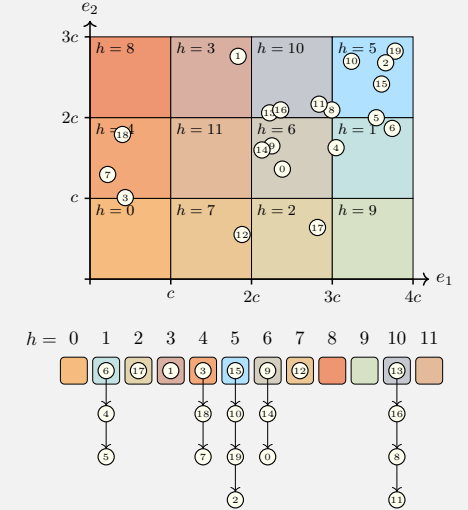
Algorithm 1: Projected Jacobi Algorithm

1 $\Delta v \leftarrow 0$;
2 **foreach** iteration from 1 to n **do**
3   **foreach** contact pair (i, j, ψ) **do**
4        $b \leftarrow J_{i,j}^T(v_i^{(k)} - \gamma v_j^{(k)} + \Delta t F_{ext,i} + \Delta v_i)$;
5        $b[1] \leftarrow \max(b[1] + \frac{\alpha\psi}{\Delta t}, 0)$;
6   **if** $||b[2:3]||_2 > \mu b[1]$ **then**
7           $b[2:3] \leftarrow \mu b[1]\frac{b[2:3]}{||b[2:3]||_2}$;
8   **end if**
9        $\Delta v_i \leftarrow \Delta v_i + J_{i,j}b$;
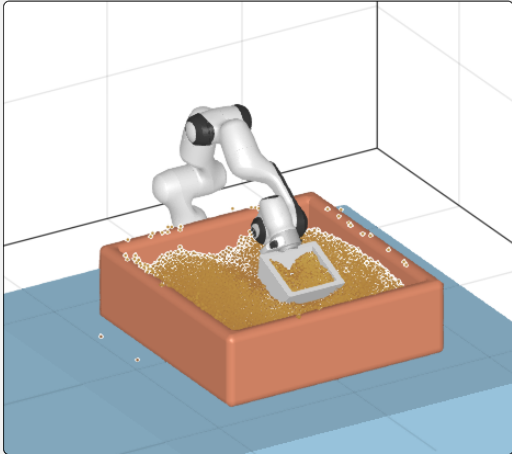10   **end foreach**
11 **end foreach**

Warp Divergence Mitigation

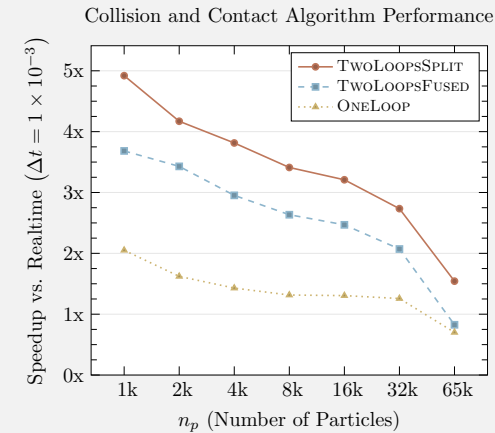## Parallel Broadphase Collision Check

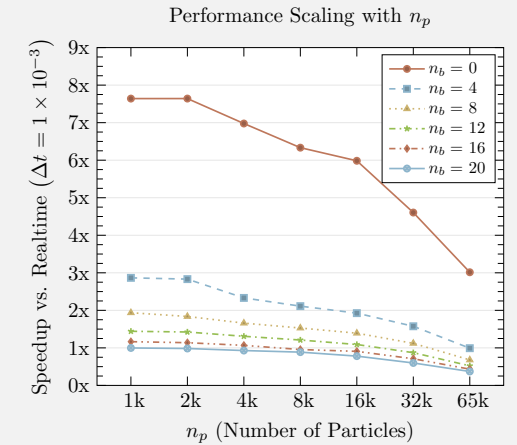## Warp Divergence Mitigation Performance

Collision and Contact Algorithm Performance

Performance Scaling

Performance Scaling with n_p