Simulation of rigid and soft robots

Robotix Academy Roadshow

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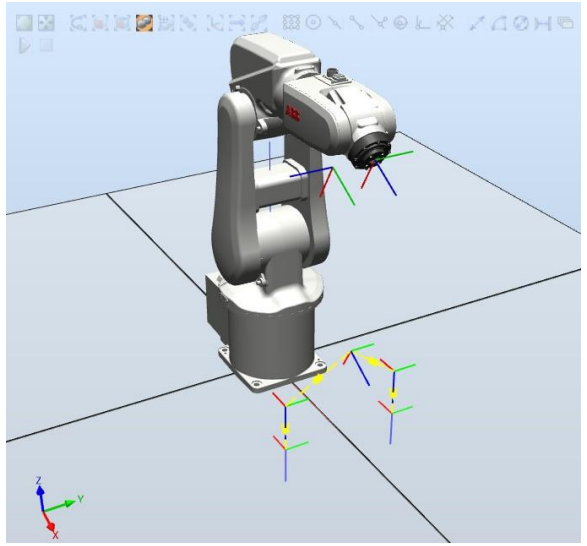
Motivation: robot simulator

- **Robot simulators** are useful for several tasks
  - **Trajectory** planning
  - **Robot cell** design
  - **Virtual testing**
  - …
- They can also be used as **digital twins** giving **remote** information on the cell **current status**

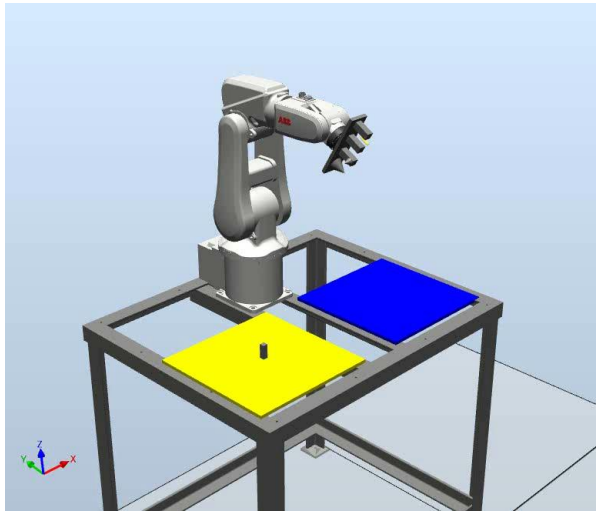
What can be represented?

Robot

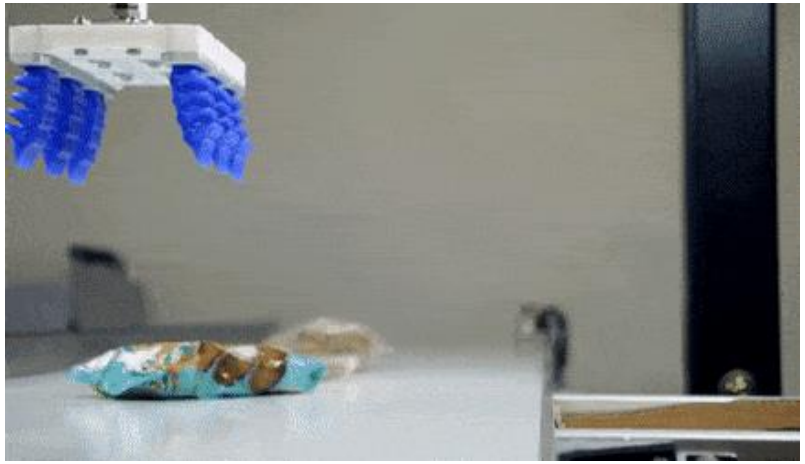
	$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q},\dot{\mathbf{q}})\dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}) = \boldsymbol{\tau}$$	 [Lismonde, 2020]
Geometry and motion	Rigid dynamics	Flexible dynamics

What can be represented?

Robot and its environment

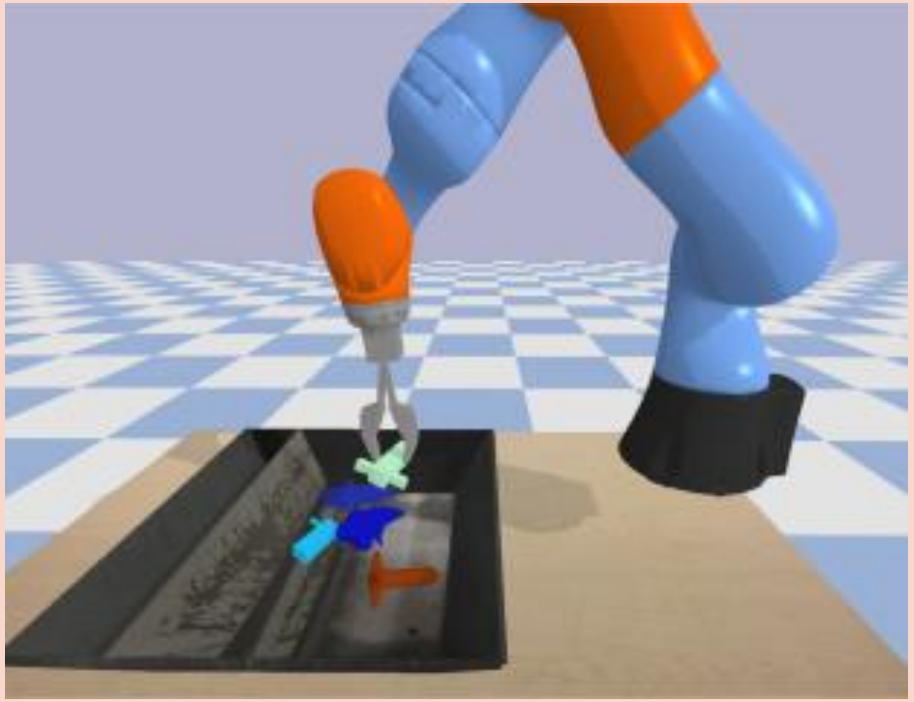
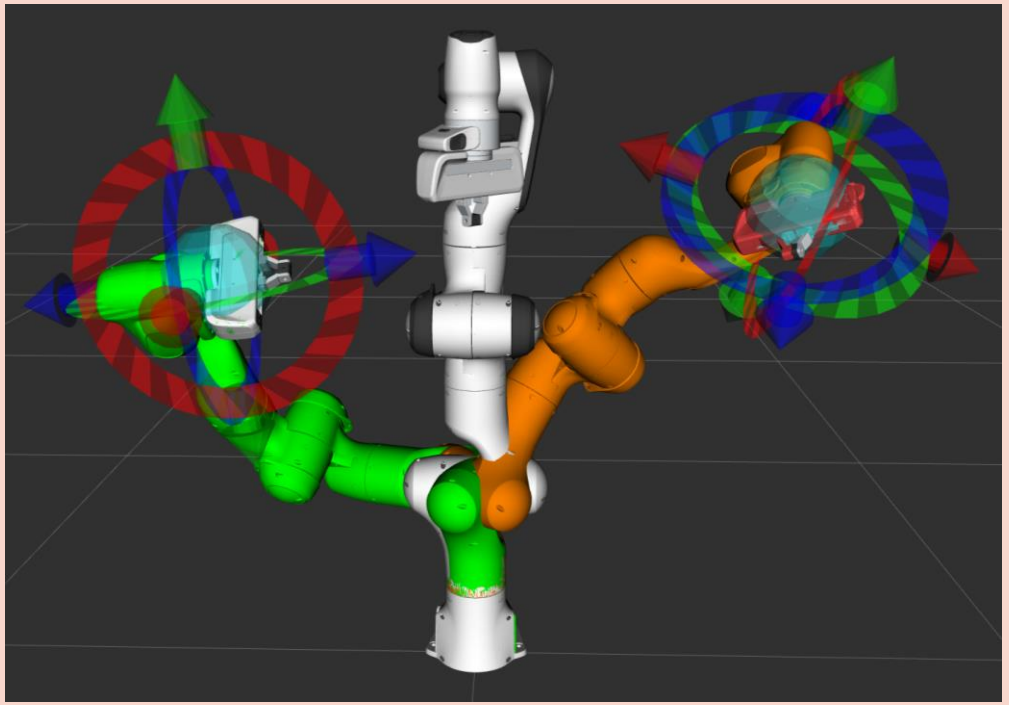


[Marlier, 2021]

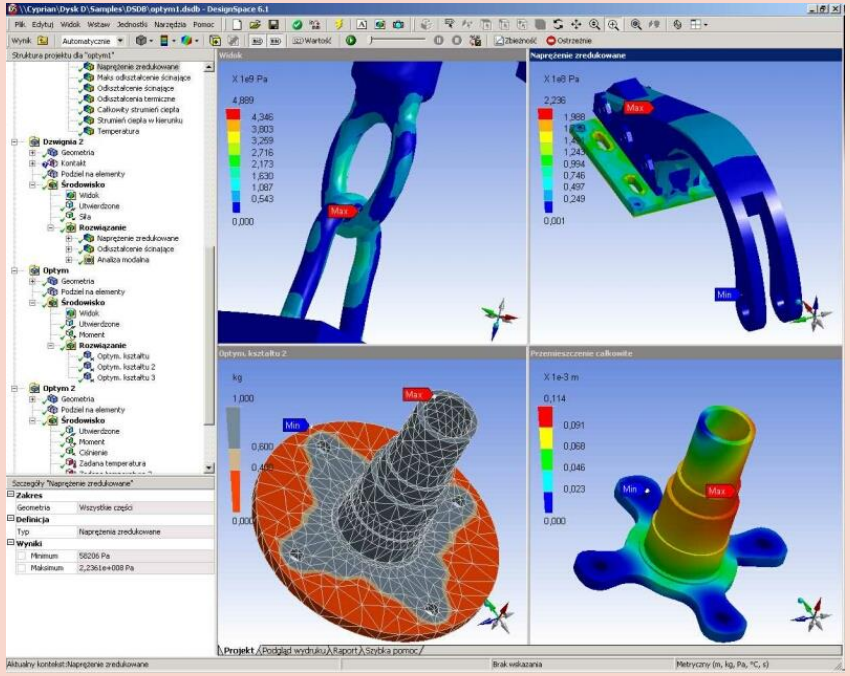


Geometry and motion	Rigid dynamics	Flexible dynamics

Simulation tools focused on geometry, motion and rigid dynamics

PyBullet	Gazebo and MoveIt
	
• Developed by the **computer graphics** community • **Limited** capabilities for **flexible** dynamics	• Developed by the **robotics** community • **Physics engine**: PyBullet, ODE, DART,…

Simulation tools focused on flexible dynamics

Simcenter Mecano	ANSYS
	

- Developed by the **computational mechanics** community
- Simulator based on **the finite element method**
- **Frictional contact** models are **regularized,** i.e. replaced by smooth approximations

Development of Odin simulator

Flexible bodies

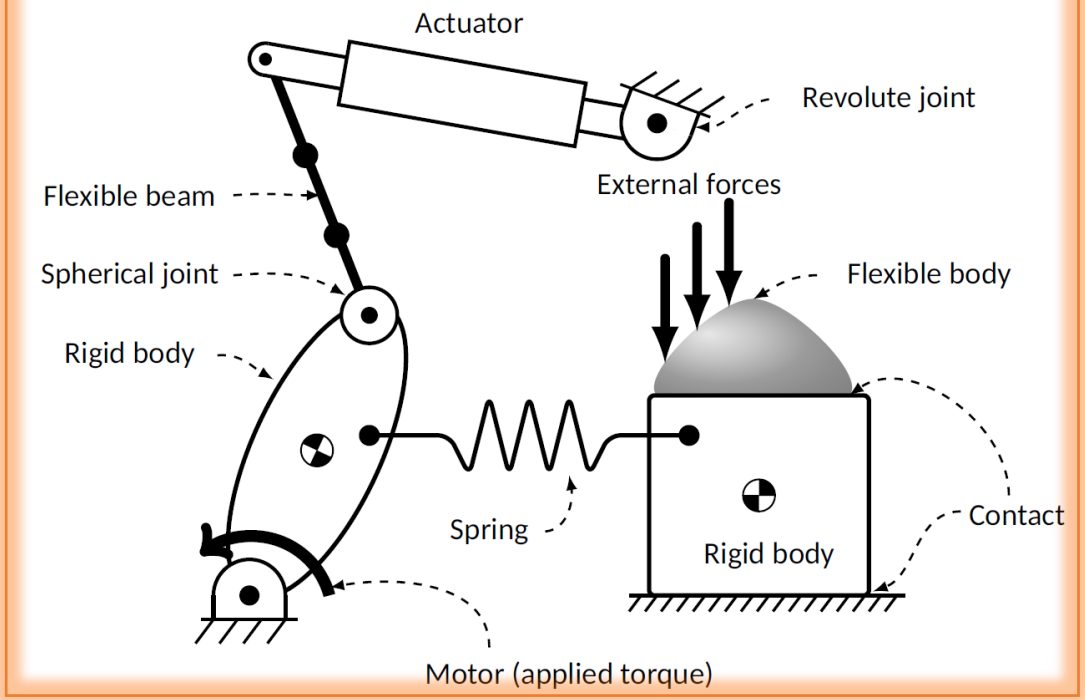
- Be rigorous in the modeling of highly flexible systems
- Use of a consistent approach for geometric nonlinearities

Contact and friction

- Represent non-penetration conditions and stick-slip transitions without regularization
- Use of state-of-the-art nonsmooth solvers

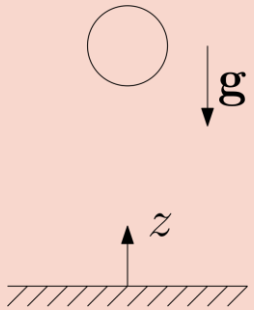
Odin:

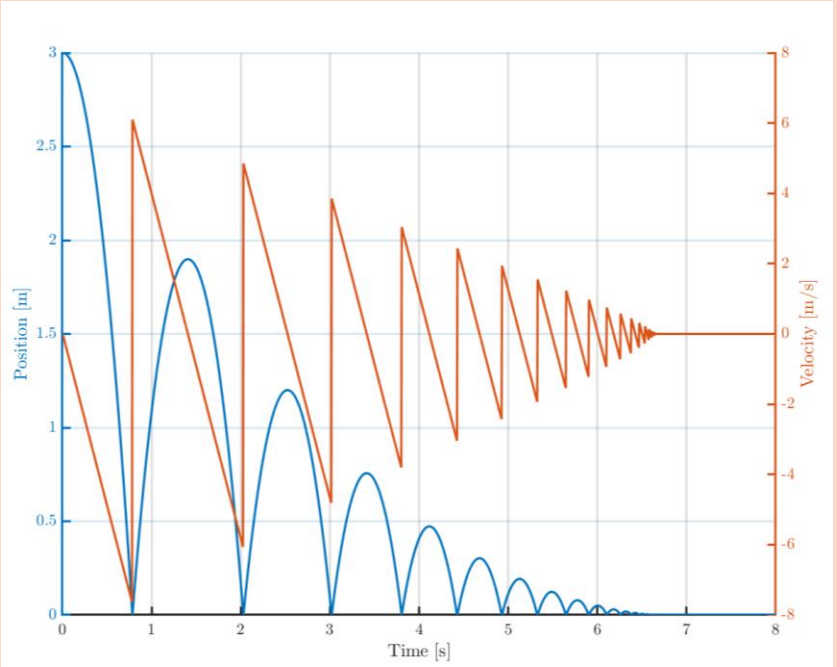
Based on a multibody finite element approach



Nonsmooth basics

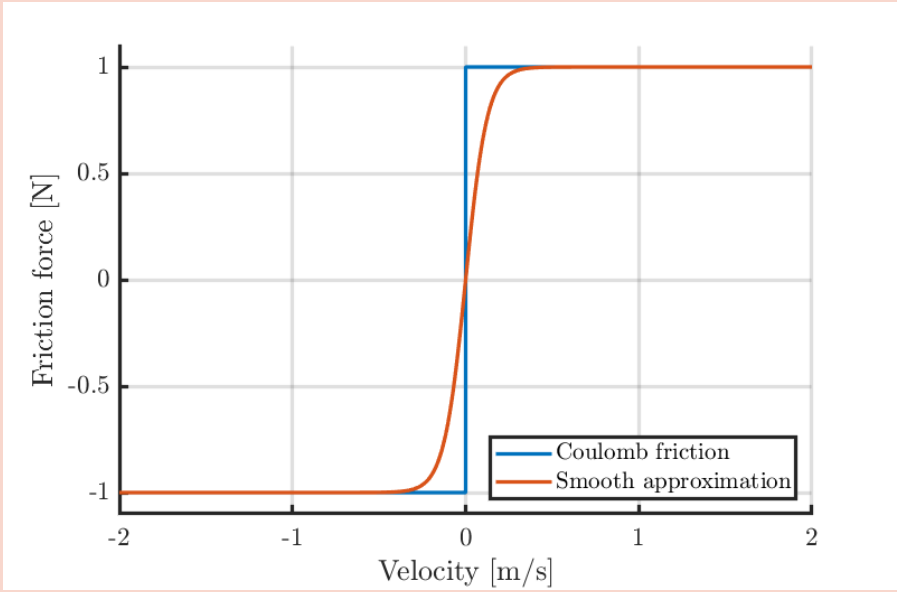
Bouncing ball

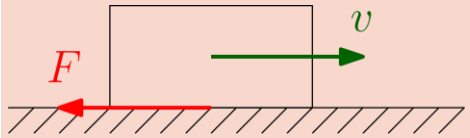




- At each impact on the ground, there is a **velocity jump**
- This jump is instantaneous => **nonsmooth** transition

Coulomb friction





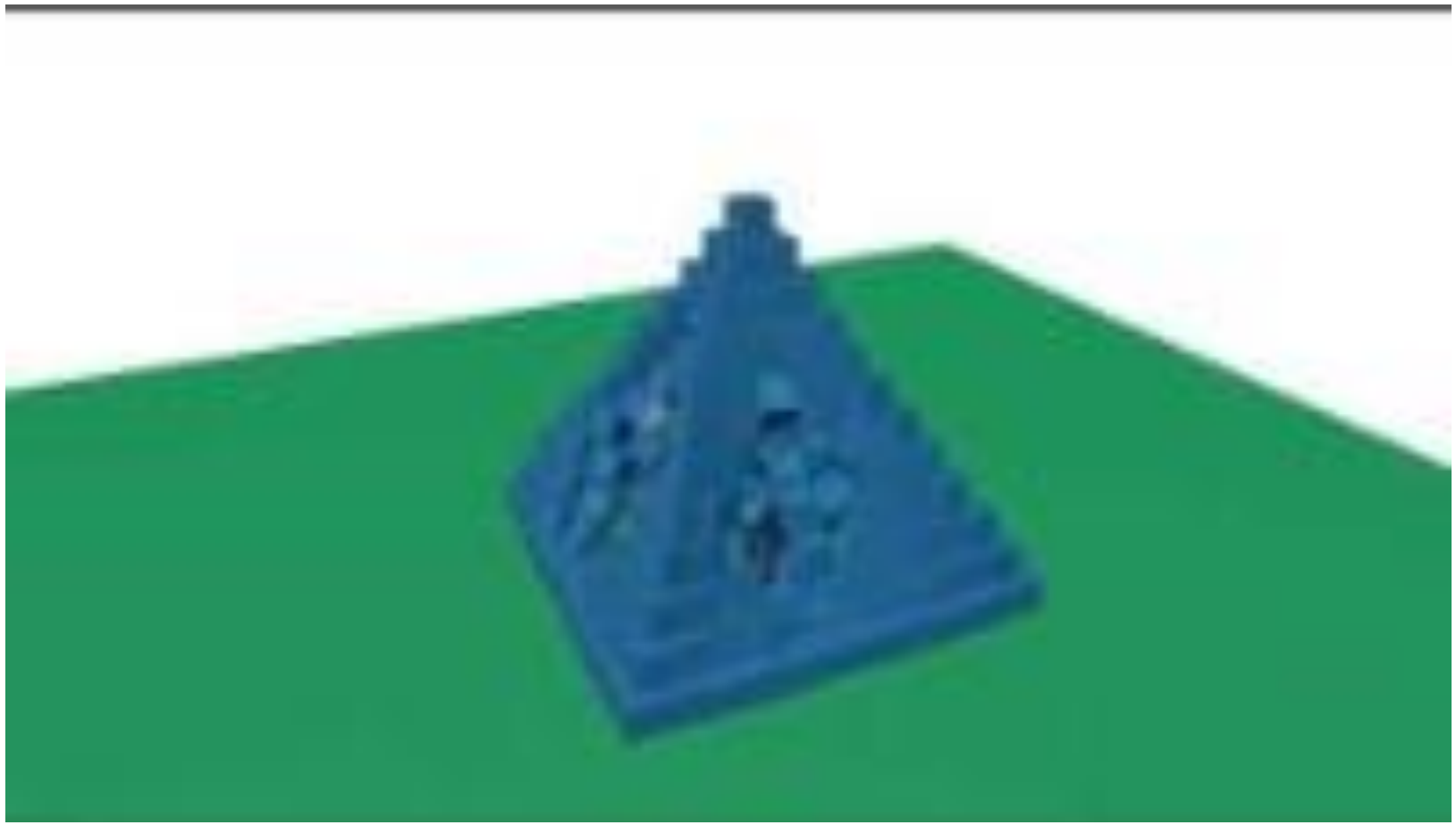
- Due to static friction, a certain force is needed to move => **nonsmooth friction law**
- **Smooth** approximations **cannot represent** correctly the **sticking** phase

Nonsmooth contact modeling

- In a multibody system, **bilateral constraints** represent the **rigidity** or the **joints** and **unilateral constraints** represent the **contact** conditions
- Most numerical formulations only verify the constraints **at position OR velocity level** (e.g., Jean-Moreau formulation)

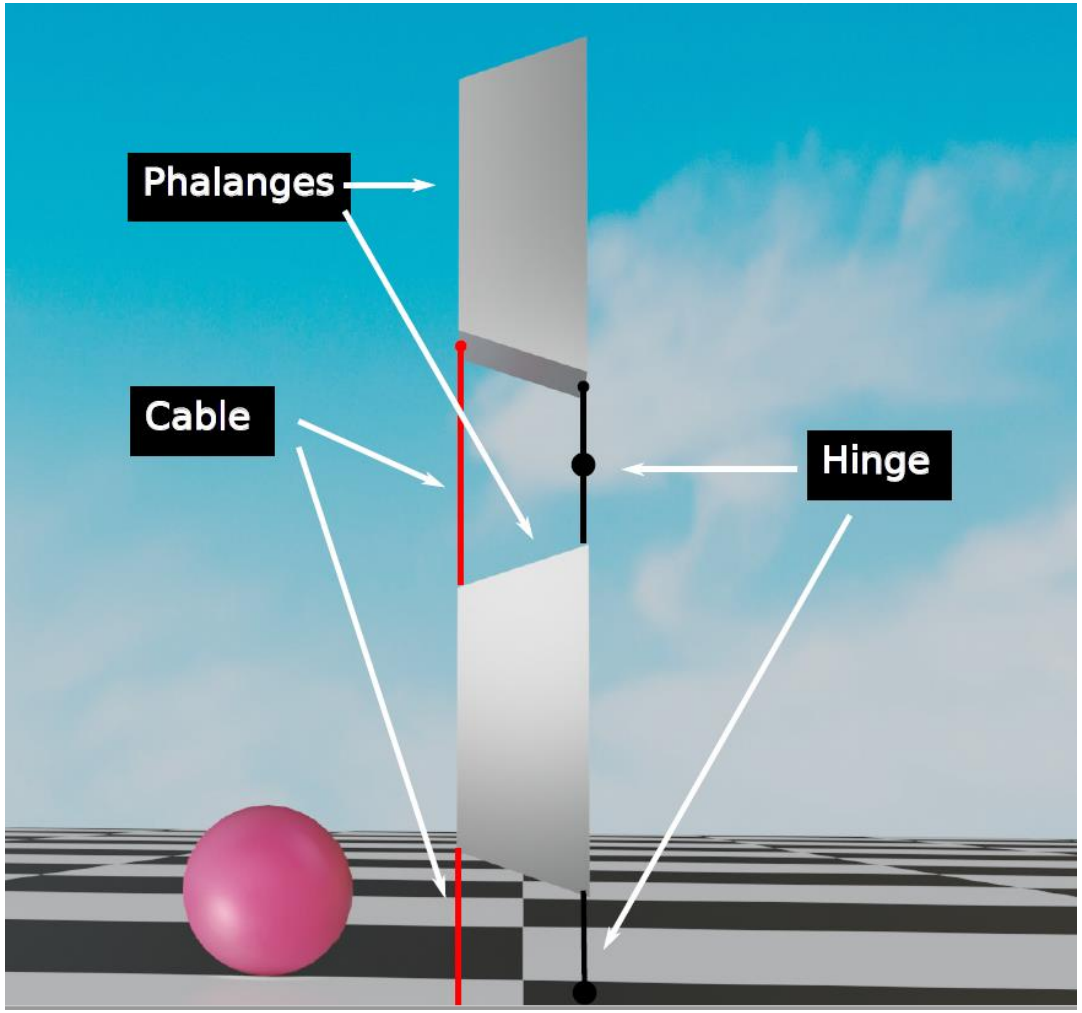
  → **velocity drift, penetration** of the objects
- Our formulation, combined with the **nonsmooth generalized-α** solver, verifies the constraints at **position**, **velocity** and **acceleration** level

Odin examples: several impacts with friction

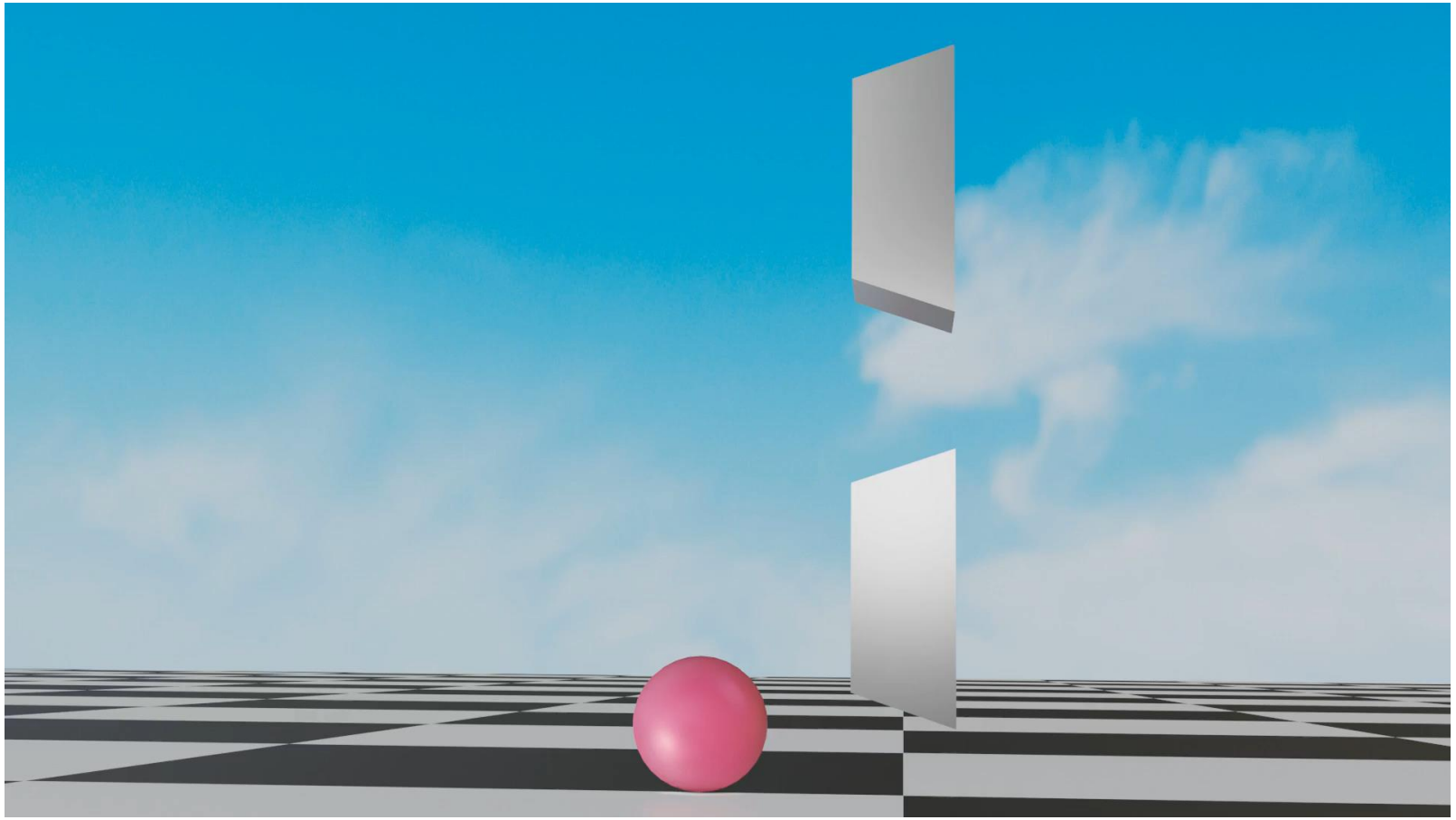


Collision of a hollow pyramid of cubes.

Odin examples: soft finger model

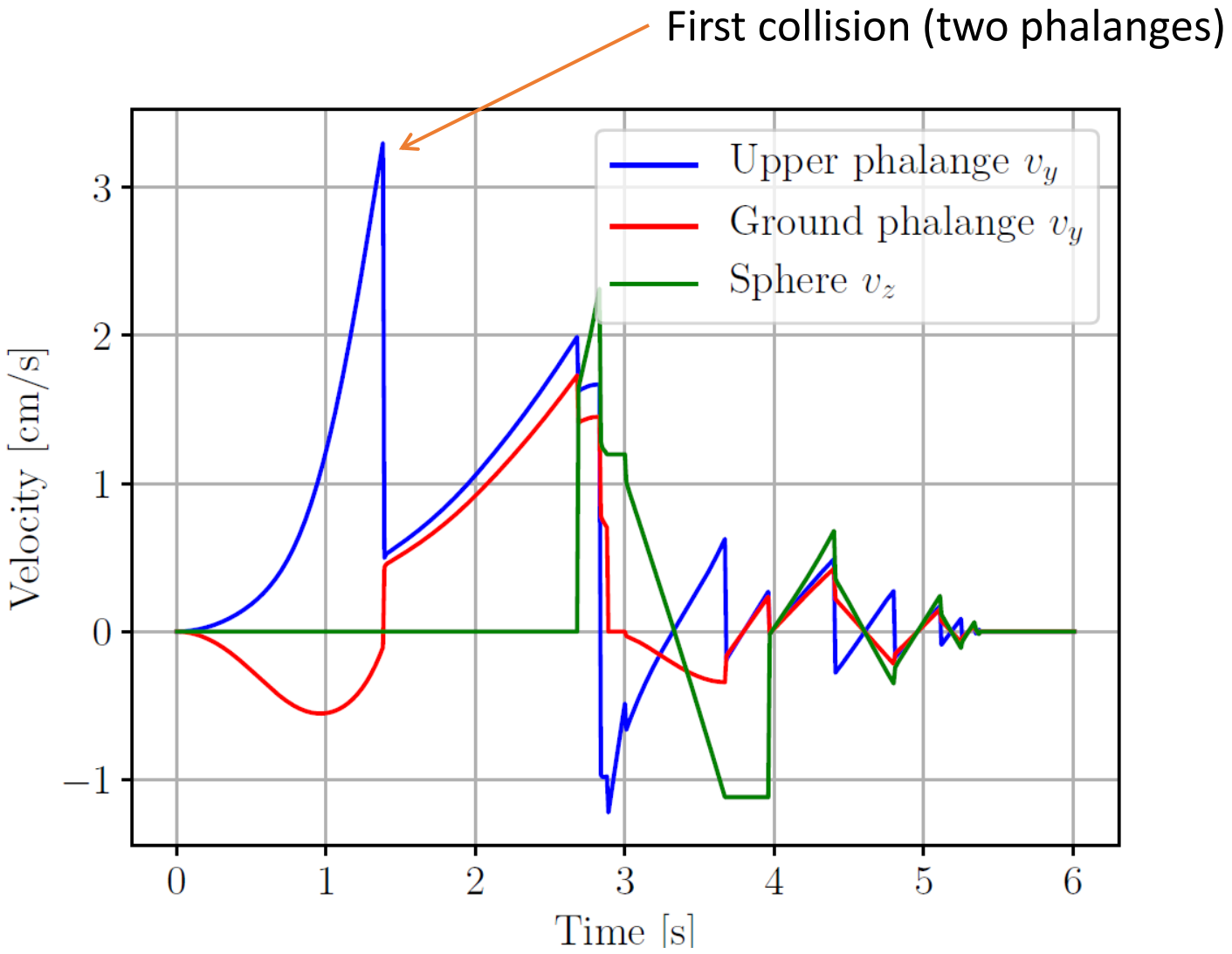


Odin examples: soft finger model

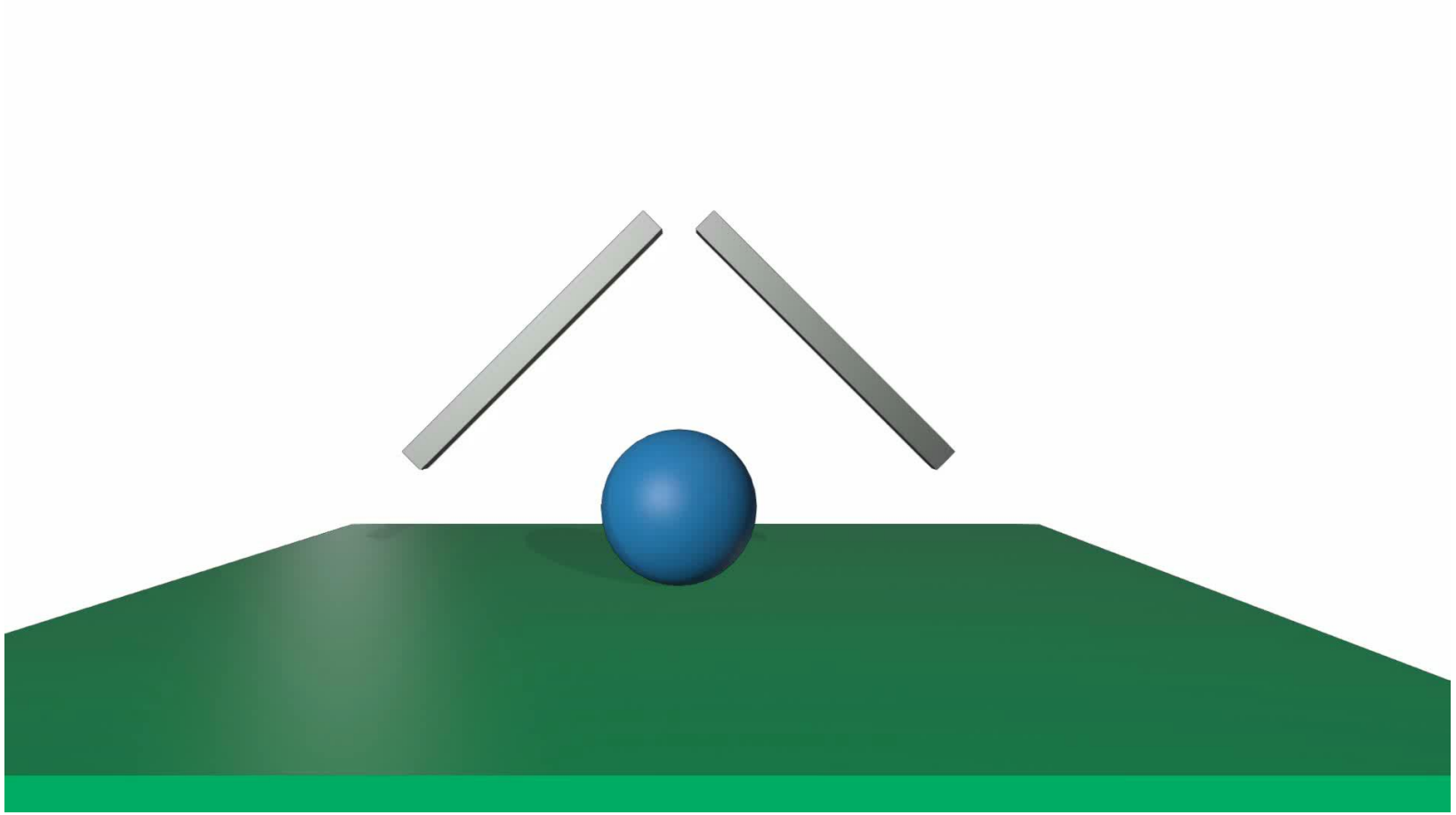


Soft finger model interacting with a sphere,

Odin examples: soft finger model



Odin examples: grasping with friction



Simulation of manipulators grasping objects.

Flexibility modeling

- Approach based on the finite element method
  - ➢ A rigid body can be represented as a single node
  - ➢ A flexible body is represented by a mesh
- All equations are formulated in the local frames of the node
- Interesting properties:
  - Invariance of the equations of motion, strain measures,…
  - Reduced nonlinearities

Odin examples: flexible beams

Line contact formulation for flexible beams.

Conclusions and perspectives

Conclusions

- Odin code to be released in open-source in the coming months
- Rigorous treatment of contact and flexibility

Targeted robotics applications

- Soft robot modeling
- Manipulation of flexible objects