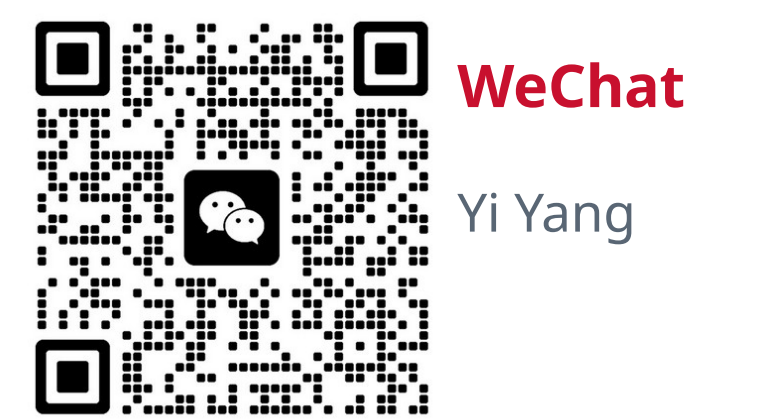
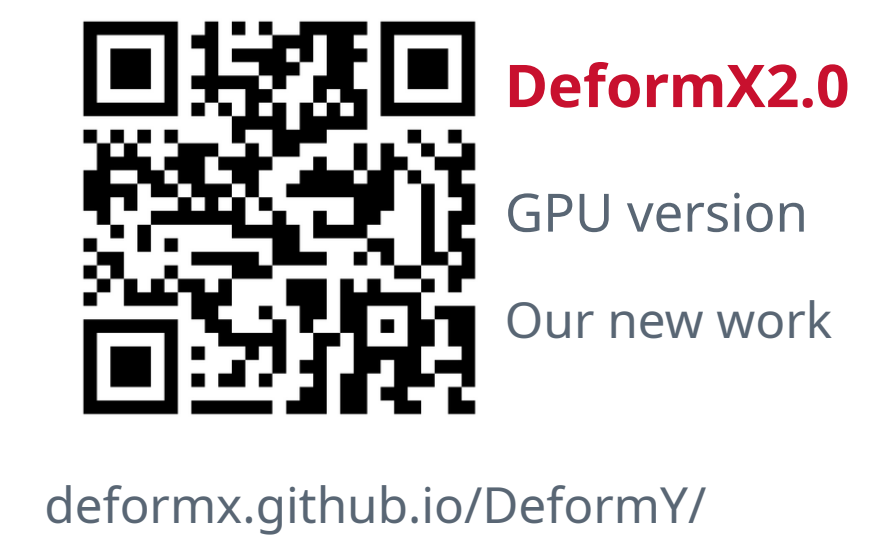


# DeformX: A Versatile Co-Simulation Framework for Deformable Linear Objects

Yi Yang<sup>1,3,4\*</sup> Xiang Fei<sup>1\*</sup> Lehong Wang<sup>1\*</sup> Chenhao Li<sup>2</sup> Zilin Dai<sup>5</sup> Henry Kou<sup>1</sup> Lu Li<sup>1</sup> Howie Choset<sup>1</sup>

<sup>1</sup> The Robotics Institute, Carnegie Mellon University <sup>2</sup> Mechanical Engineering, Carnegie Mellon University

<sup>3</sup> School of Ocean and Civil Engineering, SJTU <sup>4</sup> Zhiyuan College, SJTU <sup>5</sup> Harvard University \* Equal contribution



## Introduction & motivation

Realistic wire simulation can scale perception data and robot learning while reducing real-world trials.

### Why is it difficult?

Slender objects couple stretch, shear, bending and twist with contact and self-interaction.

#### Vision simulators

**Bézier curves / cylinders**

No physically grounded rod dynamics

#### RL simulators

**Rigid links / soft bodies**

Simplified rod mechanics; tuning

#### DeformX

**Cosserat rods + Isaac Sim**

Rod physics + CAD + robot learning

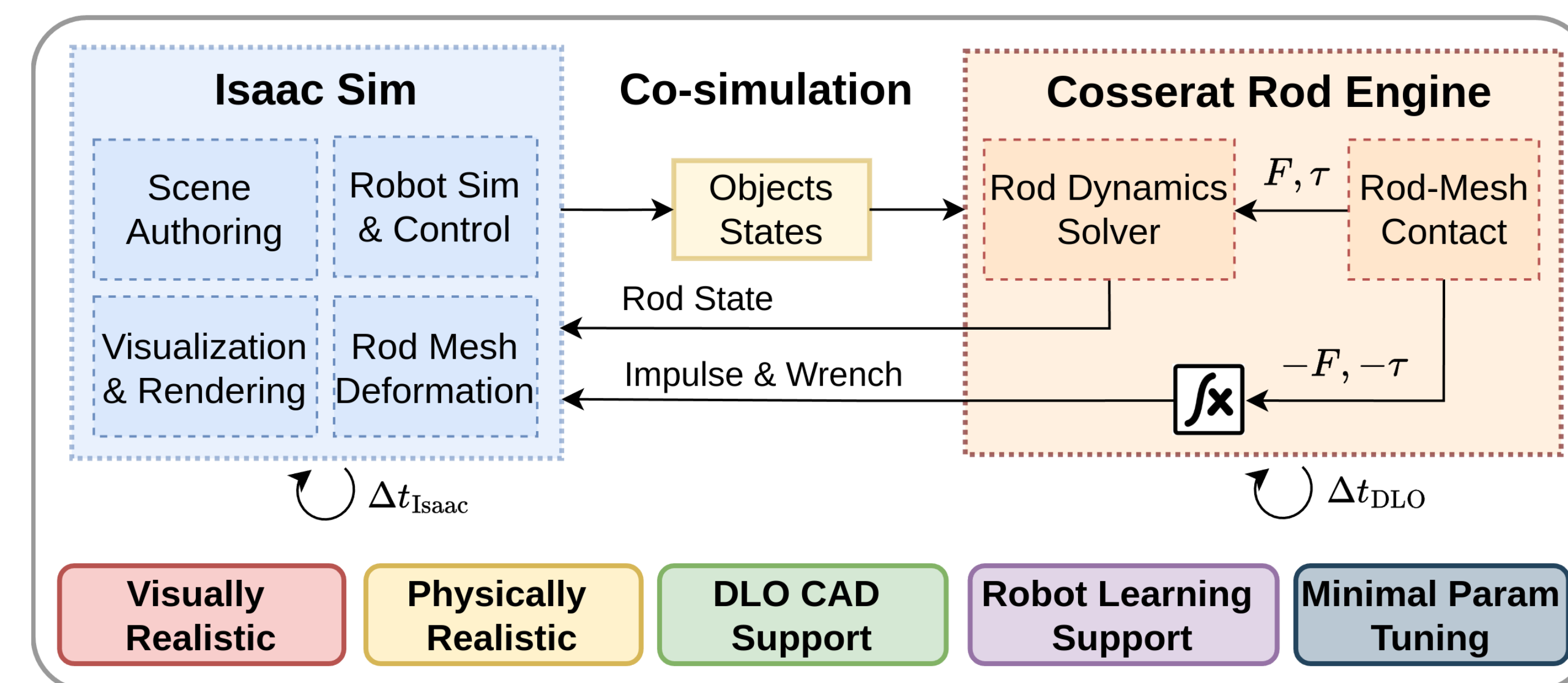
### What is missing?

Existing tools rarely combine accurate rod mechanics, realistic CAD appearance and robot-learning support.

**One framework for physically consistent motion, realistic rendering and robot interaction.**

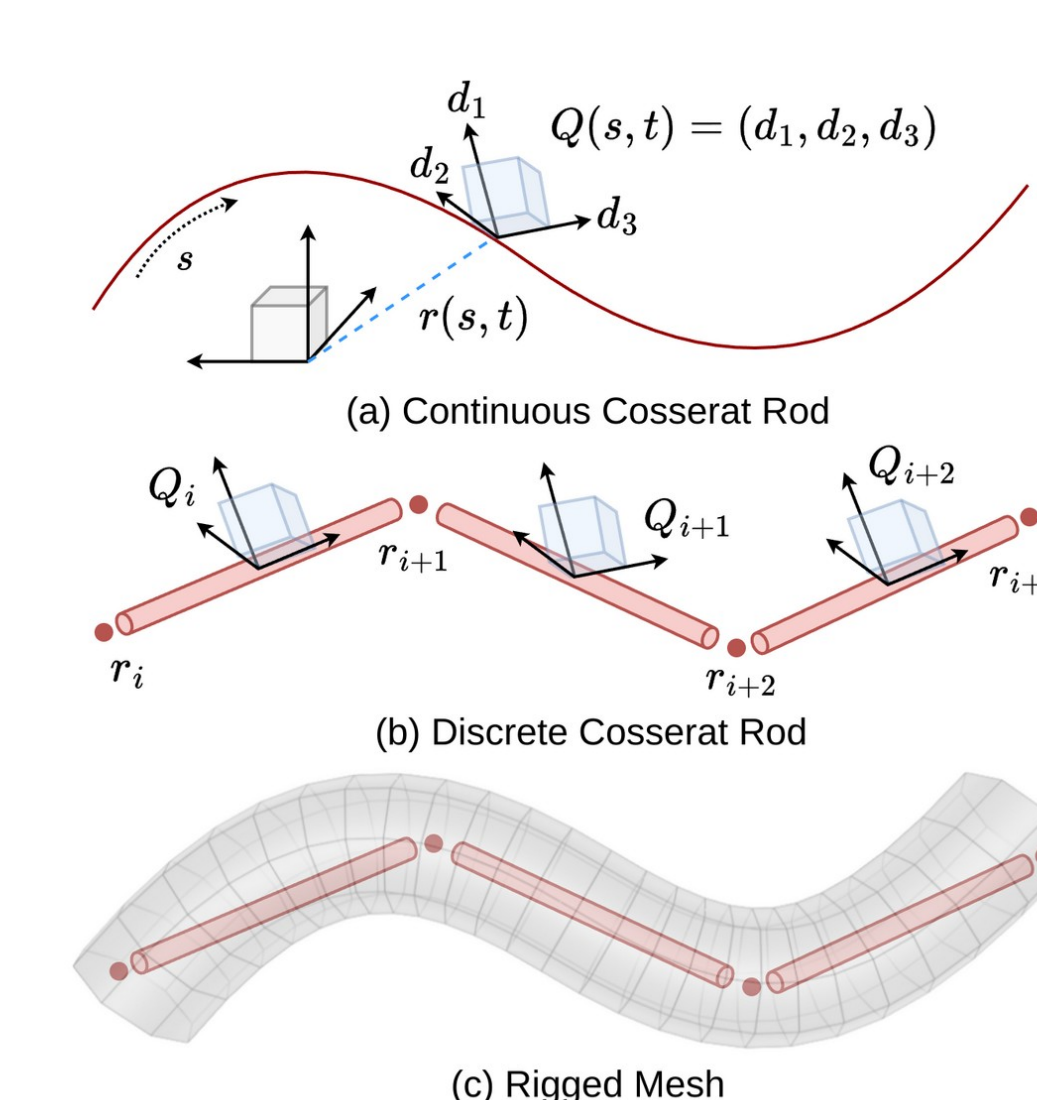
## Framework & method

### Bidirectional co-simulation



Isaac Sim advances robots and rigid bodies. The rod engine substeps deformation and contact, returning reaction impulses and updated rod states.

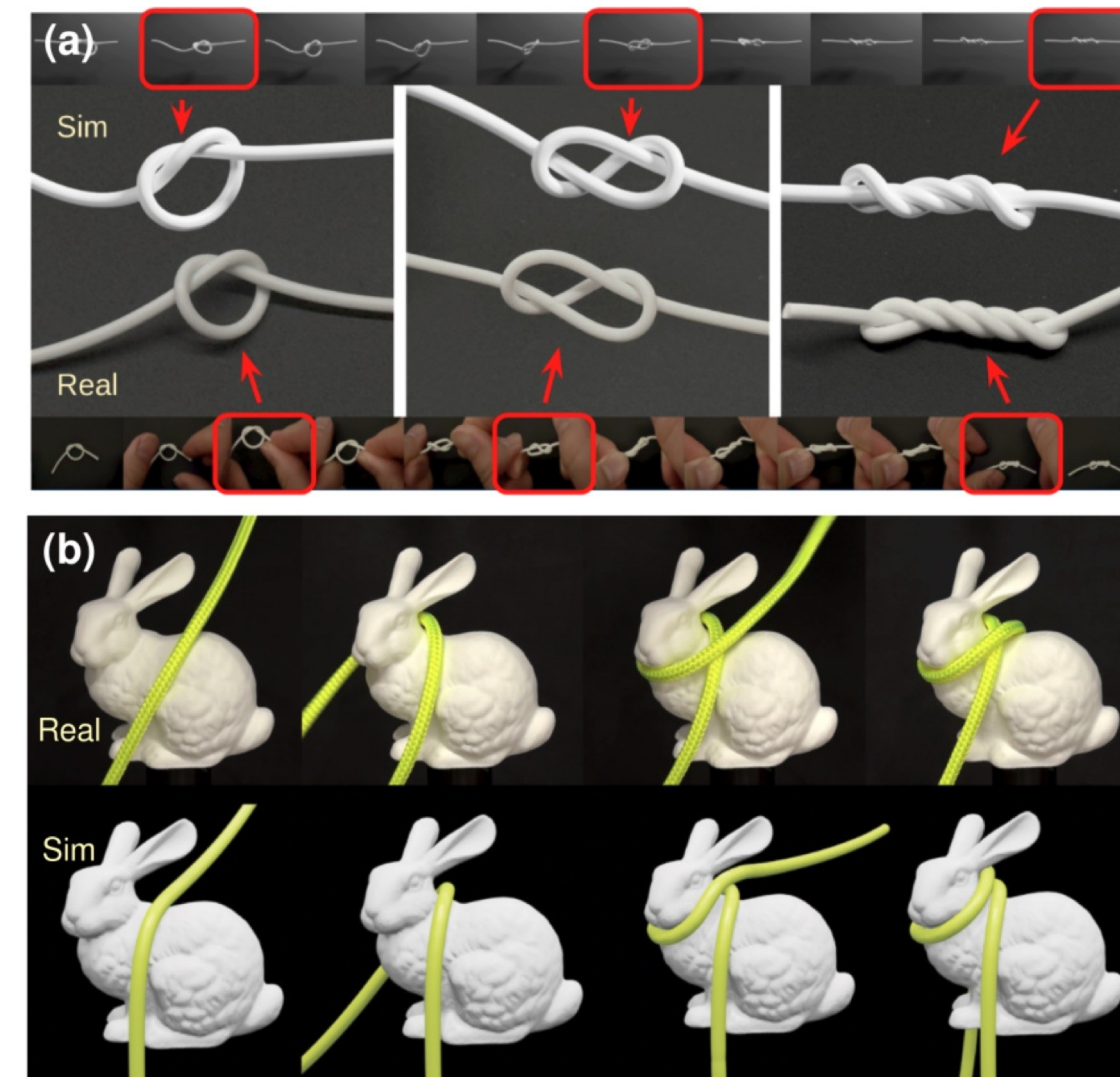
### Rod model & CAD skinning



Stretch, shear, bend and twist follow physical material parameters.

Rod positions and local frames deform an imported CAD mesh for realistic rendering.

## Physical realism



### Twist & bending

Knot experiments reproduce coupled deformation and shape transitions.

### Mesh contact

Sliding and self-contact on free-form geometry.

### Physical inputs

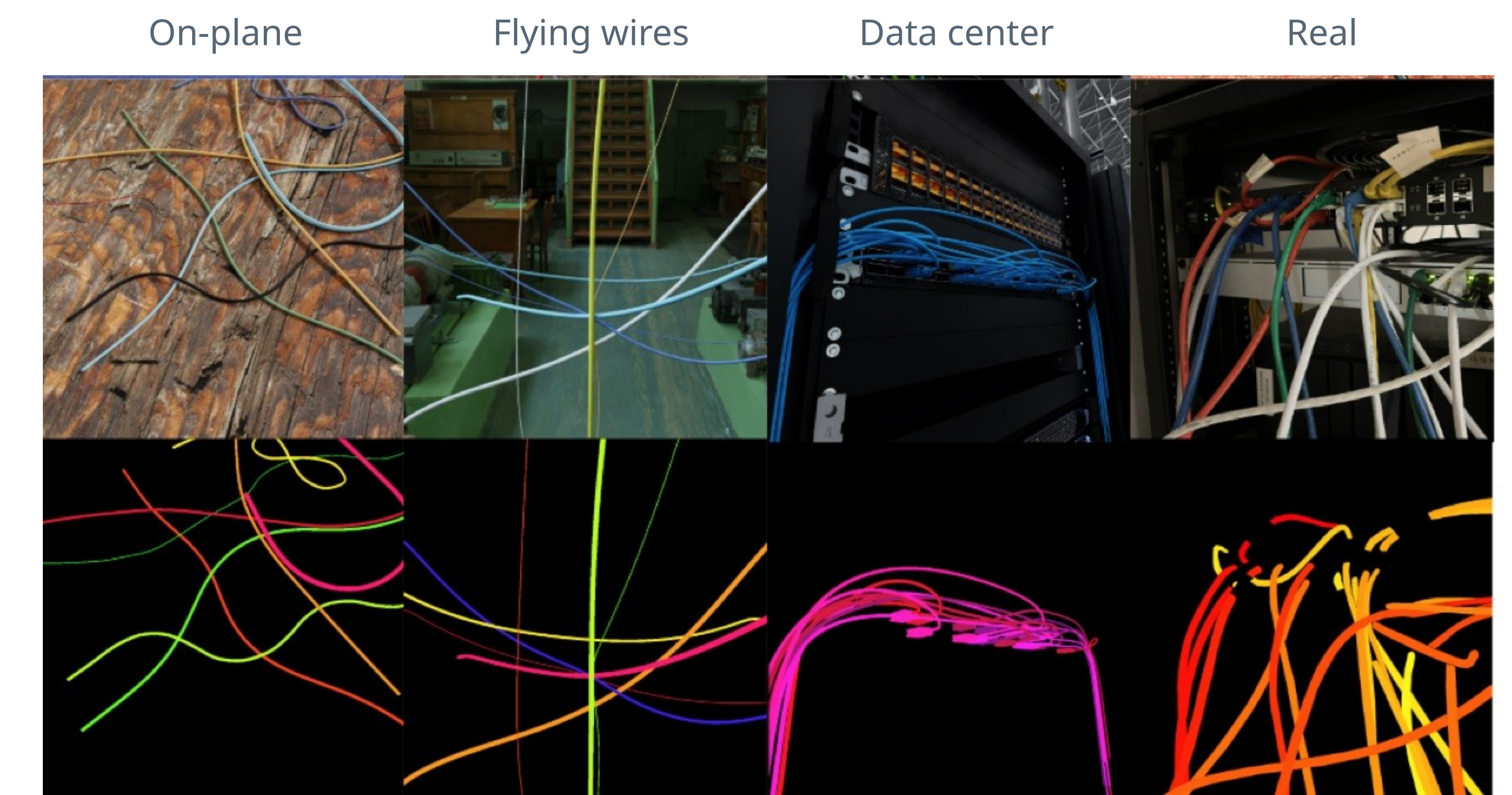
Material values come from physical specifications.

Simulation reproduces real behavior without manual tuning.

## Visual realism

**WireSeg-36k** provides RGB, depth and instance masks.

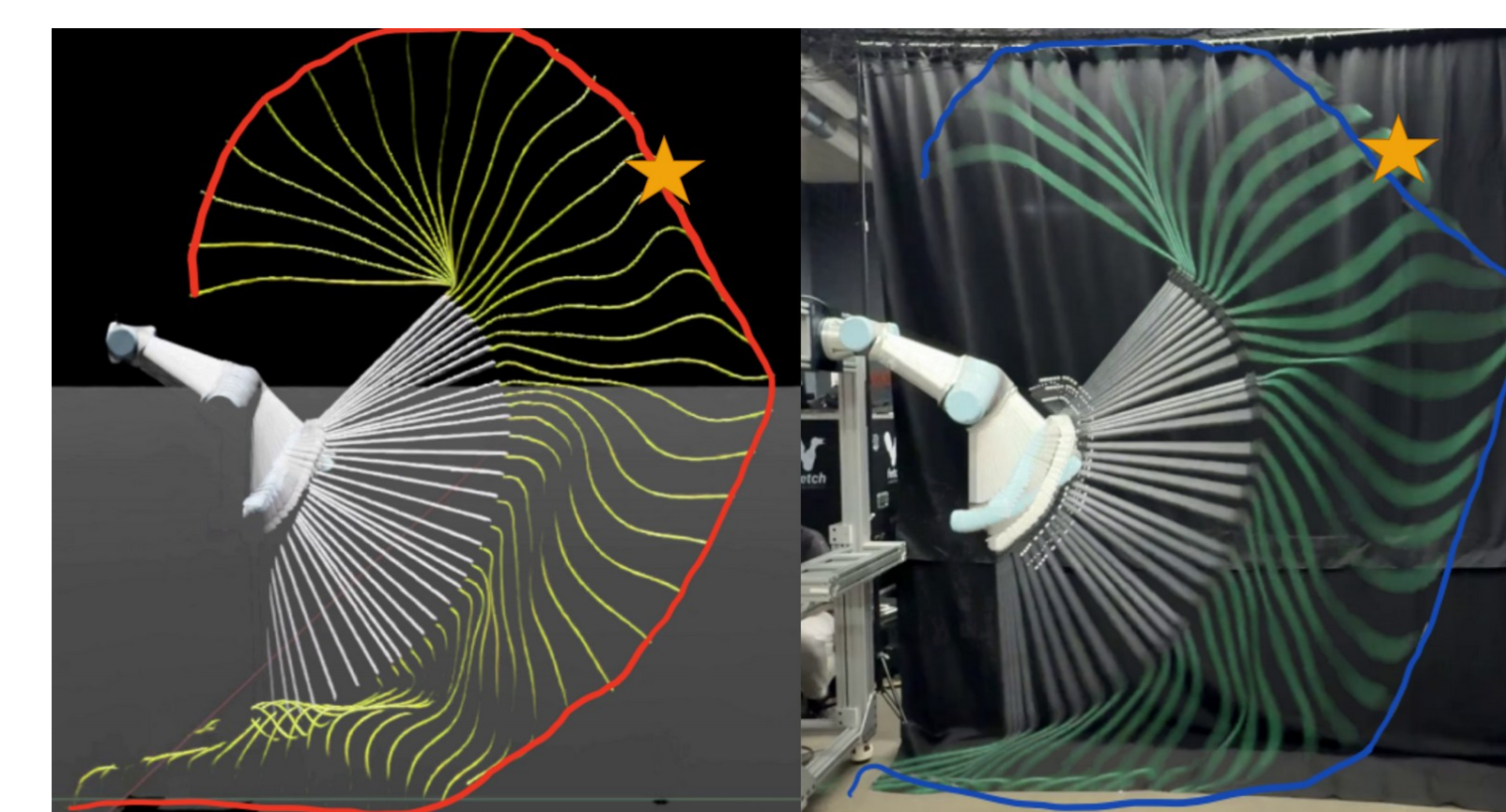
SAM3 LoRA trains only on synthetic scenes with varied wire configurations and appearance. Evaluation uses **300 held-out**, manually annotated real images.



Real mAP@75: SAM3 0.157 **SAM3 + LoRA 0.173**

## Robot learning

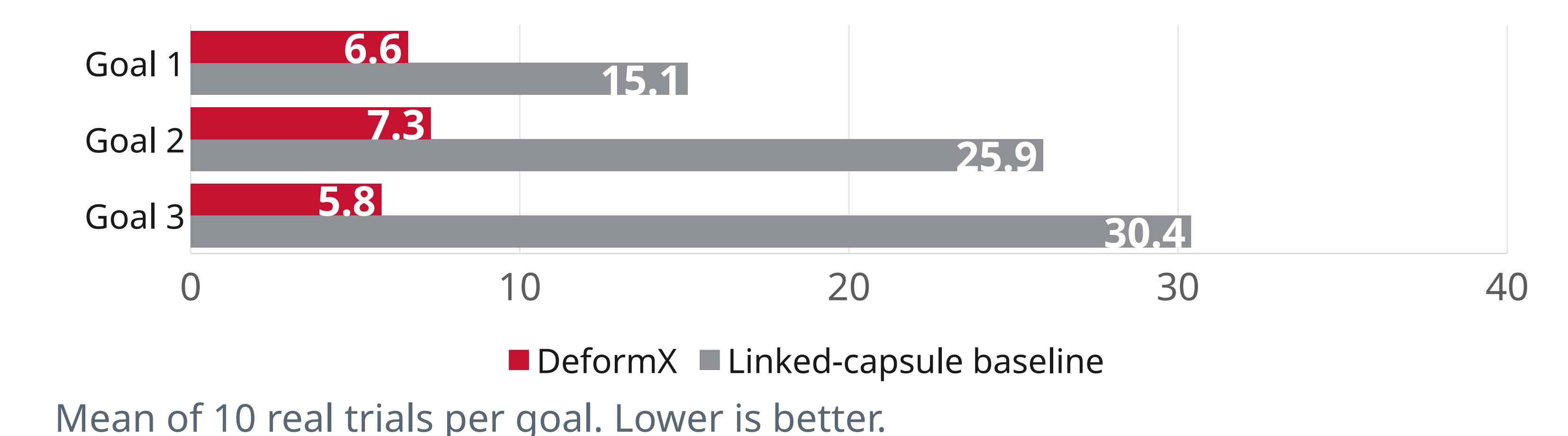
### Rope swinging: sim / real



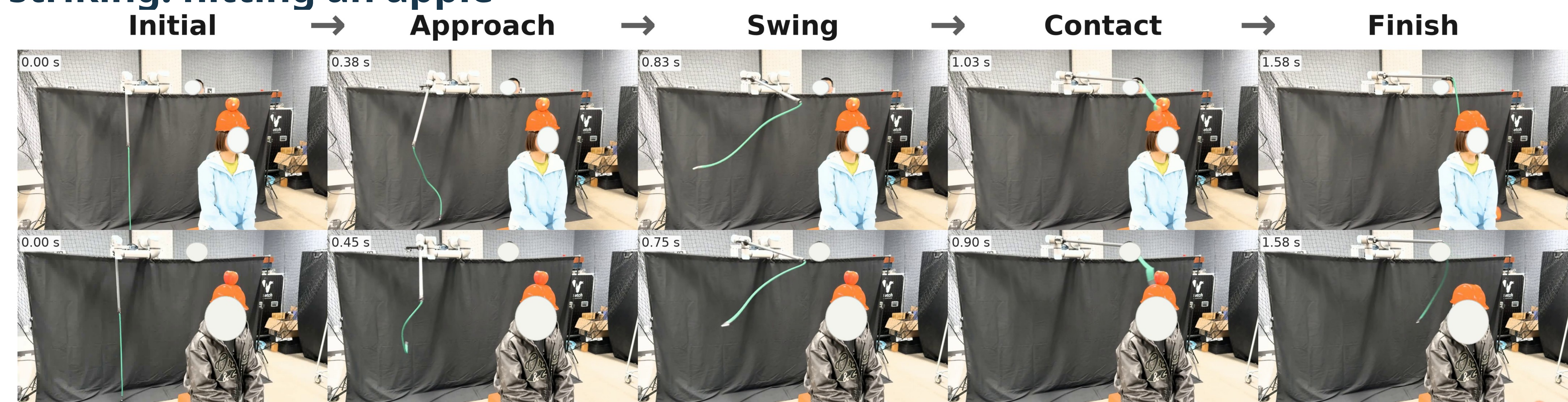
### Controlled comparison

UR5e with a 2 m rope. Both DLO backends use the same calibration motion and PPO setup. Real trials replay policies trained in simulation. **DeformX reaches closer to all three targets in the real world.**

### Real tip-to-goal distance (cm)



### Dynamic striking: hitting an apple



Two real executions of a dynamic striking task. Each row shows a complete approach, swing, contact and finish sequence.