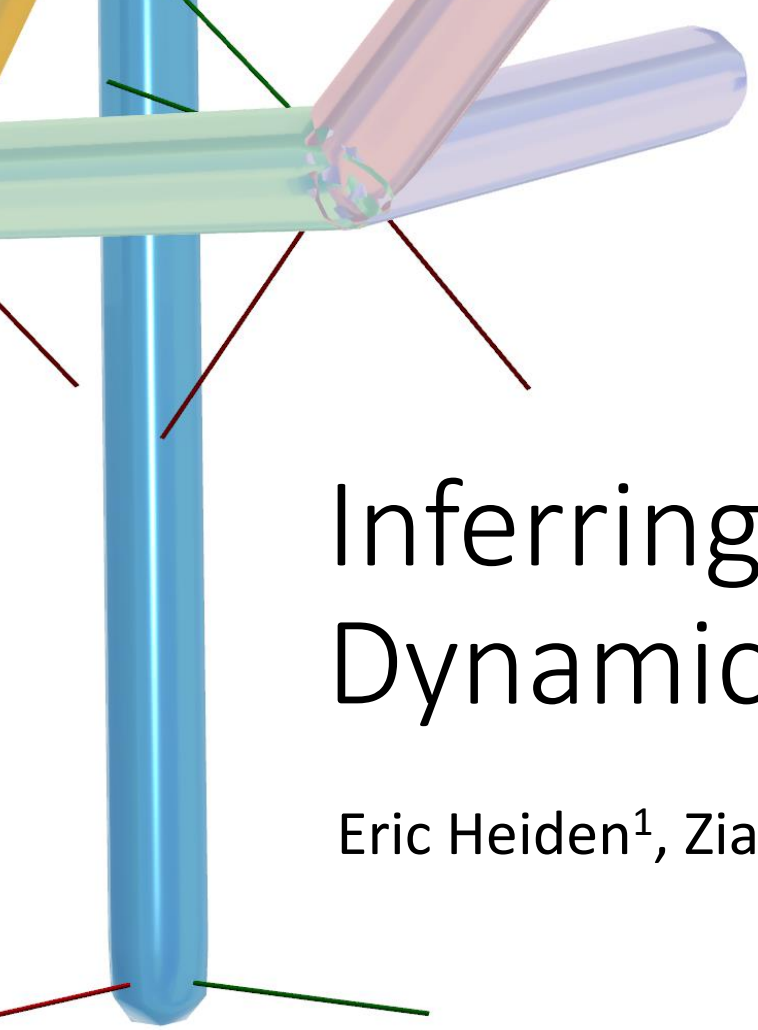

Inferring Articulated Rigid Body Dynamics from RGBD Video

Eric Heiden[1], Ziang Liu[2], Vibhav Vineet[3], Erwin Coumans[1], Gaurav S. Sukhatme[4]

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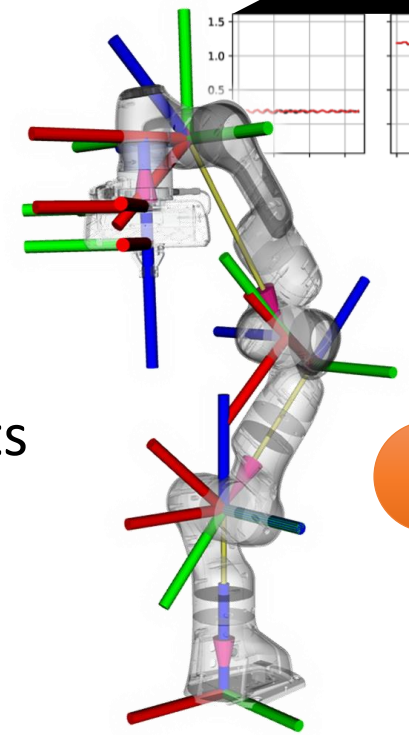
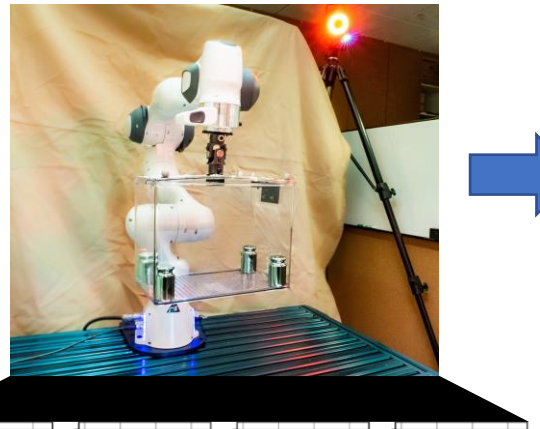
Motivation

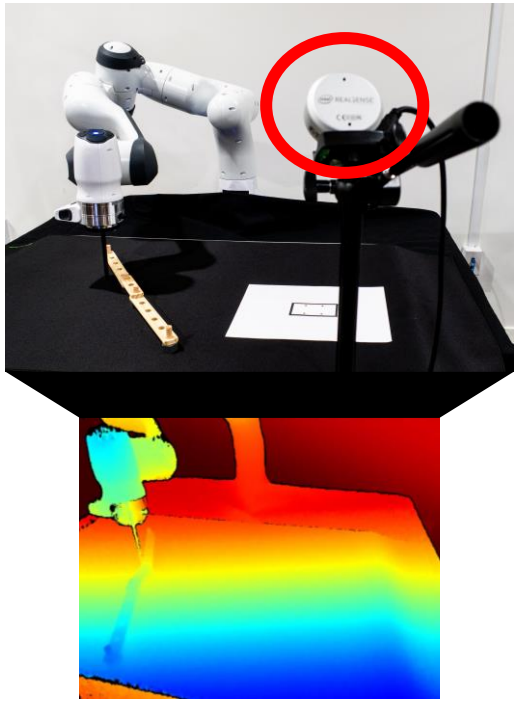
Simulation setup is laborious,
want to automatically generate sim from real system

1. Find kinematic structures of articulated mechanisms
   - URDF model of a system defining the objects and joints connecting them



3. Pixel-based observations

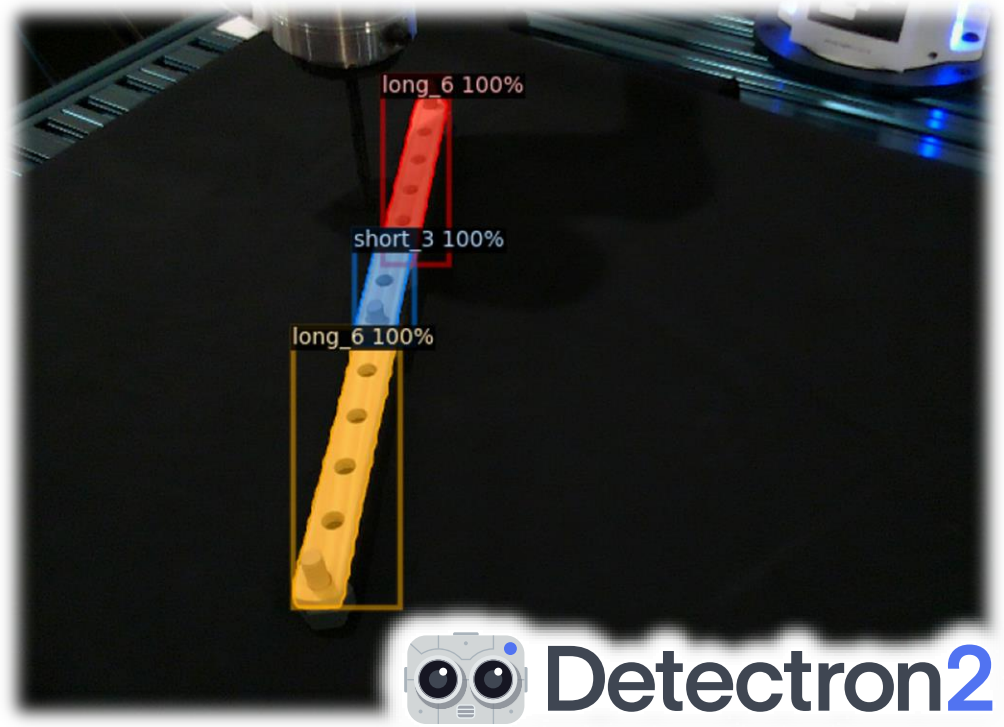


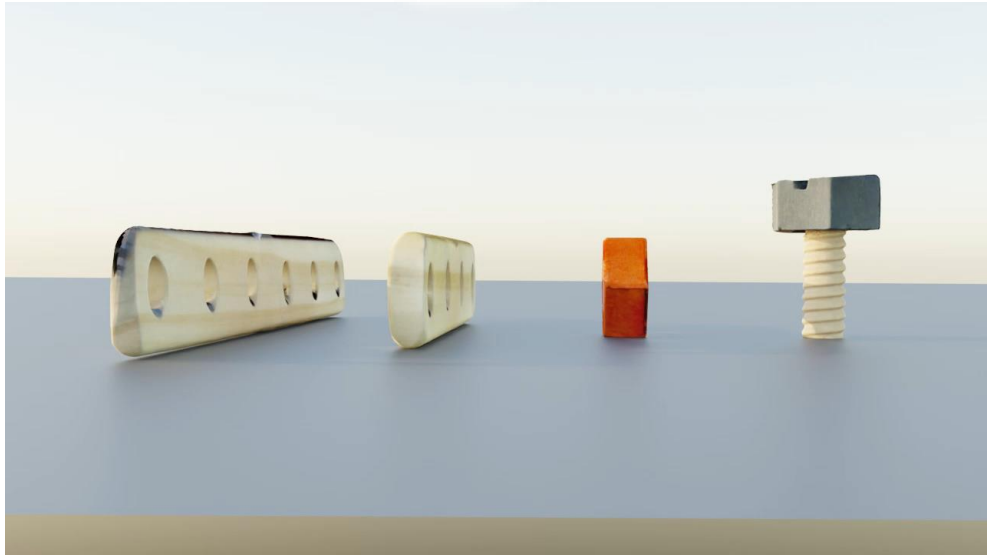


2. Find simulation settings
   - Infer parameters of the simulator automatically

Object recognition

- Find rigid bodies in the first image to initialize simulated scene
- Assume objects in the scene are known
- Detectron2 instance segmentation
- 3D object meshes are scanned via desktop 3D scanner





© EinScan

Detectron2. Wu, Kirillov, Massa, Lo, Girshick. 2019. *https://github.com/facebookresearch/detectron2*

Pose tracking

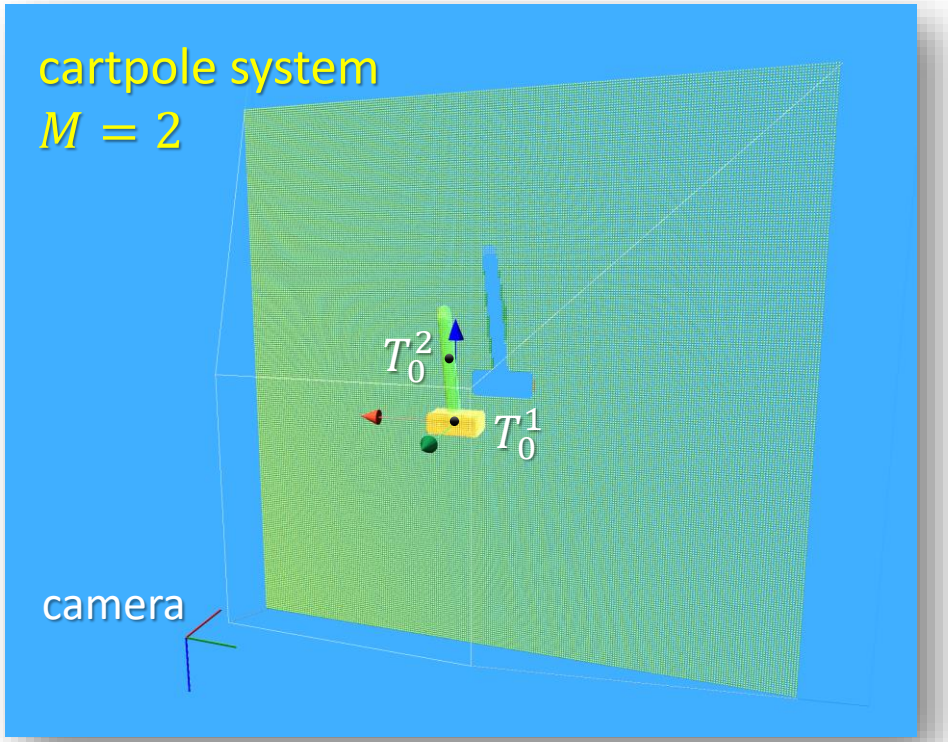
- Set up scene + camera in inverse renderer **nvdiffrast**

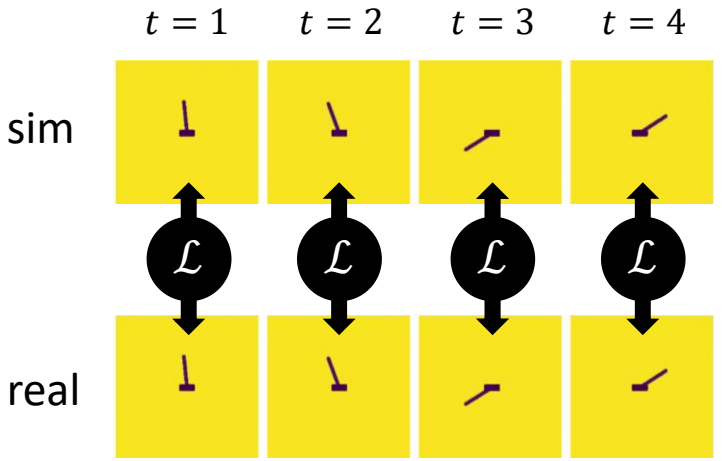
$$f_{\text{rast}}\colon \mathrm{SE}(3)^M \times \mathrm{SE}(3) \to \mathbb{R}^{H\times W\times C}$$

- Find world transforms of rigids bodies in the image via pixel-based loss:

$$\underset{[T_0^1, T_0^2, \ldots, T_0^M]}{\text{minimize}} \left\| f_{\text{rast}}([T_0^1, T_0^2, \ldots, T_0^M], T_0^{\text{cam}}) - \mathbf{x}_{\text{real}} \right\|^2$$

- Optimize from multiple initial pose guesses, warm-started from previous frame

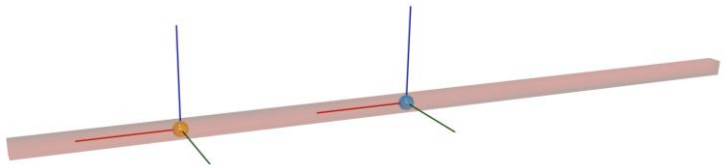




Finding joints and their parameters

Consider relative motion $T_i^j[t]$ between bodies i and j at time t

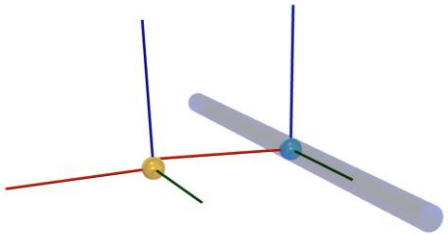
Prismatic joint



$$\Delta r = T_i^j[t+1].r - T_i^j[t].r$$
$$\Delta p = T_i^j[t+1].p - T_i^j[t].p$$

Joint axis: $\frac{\Delta p}{\|\Delta p\|}$

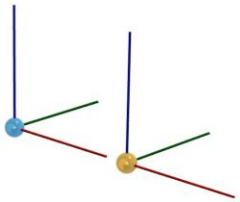
Revolute joint



Joint axis: $\frac{\Delta r}{\|\Delta r\|}$

Pivot point: $T_i^j[t].p + \frac{\Delta r + \Delta p}{\|\Delta r\|^2}$

Static joint



Static transform $T_i^j[t]$

For each joint type, find joint parameters for all time steps via RANSAC

Memorize joint and model error for best candidate in *cost matrix C*

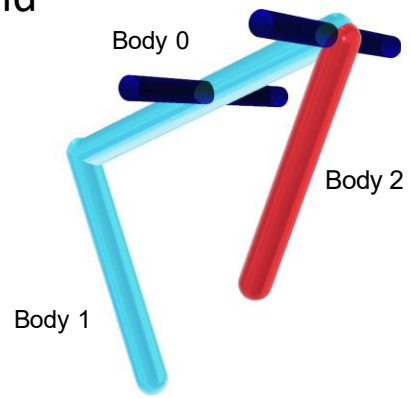
Determine kinematic trees

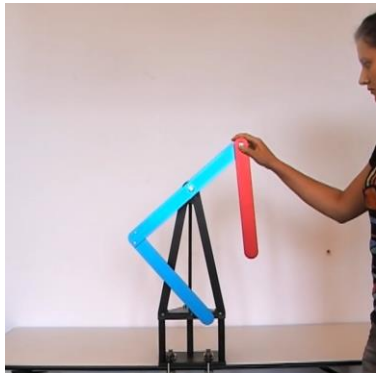
- Each link can only have 1 parent
- Find minimum spanning trees in cost matrix C with root bodies I_{root}
- These spanning trees are the articulated systems in the scene; how are they "attached" to the world?
  - Use RANSAC as before to find best fitting joint for each root link in I_{root}
  - If no joint type is found, assume the system is floating-base

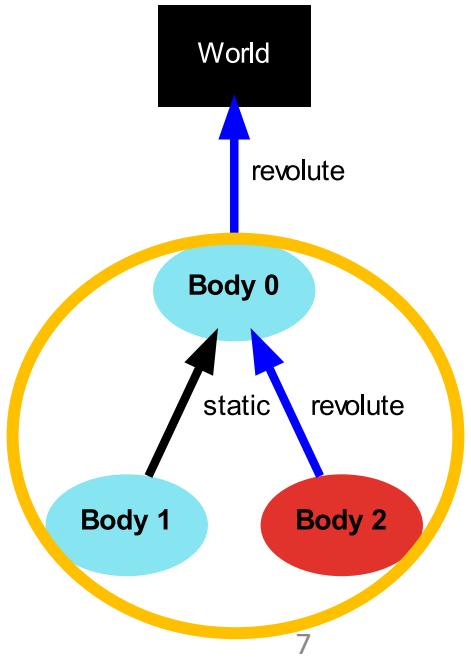
C	Body 0	Body 1	Body 2
Body 0			
Body 1	static 0.01		
Body 2	revolute 0.02	revolute 0.06	

parent

child





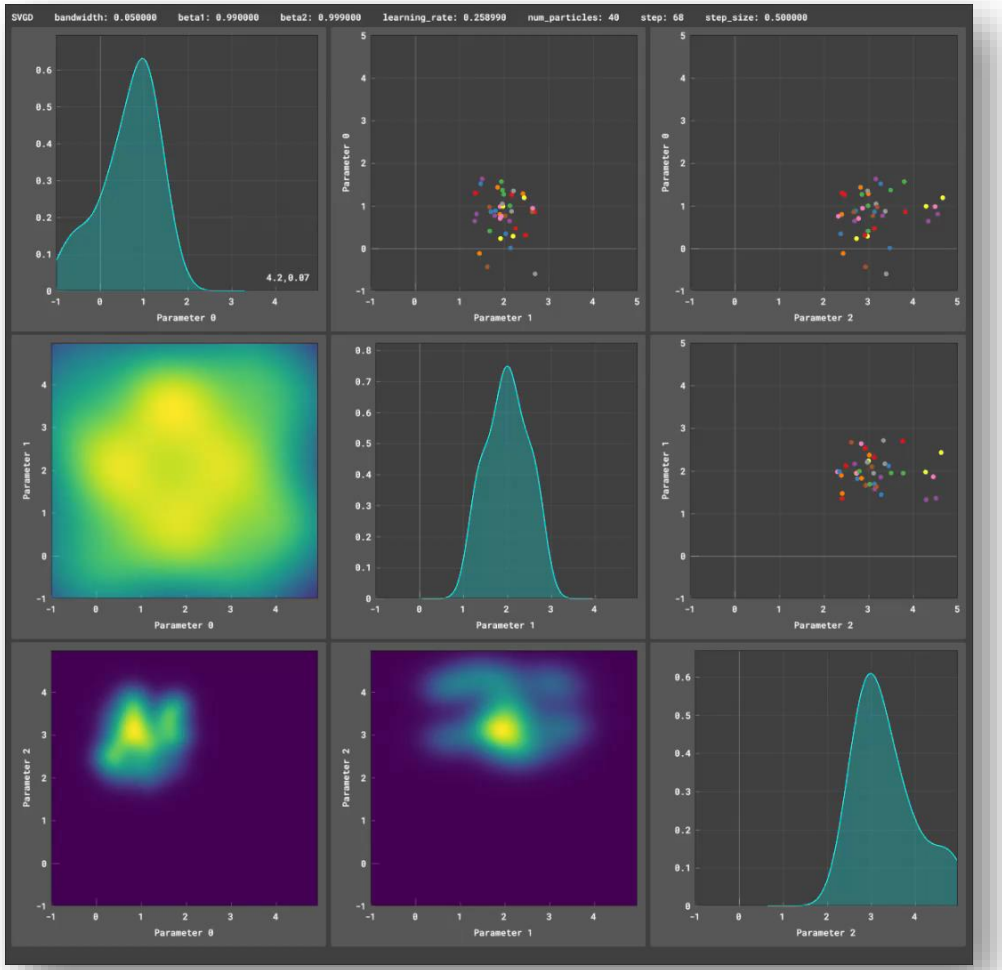


Parameter inference

Infer distributions over simulation parameters via

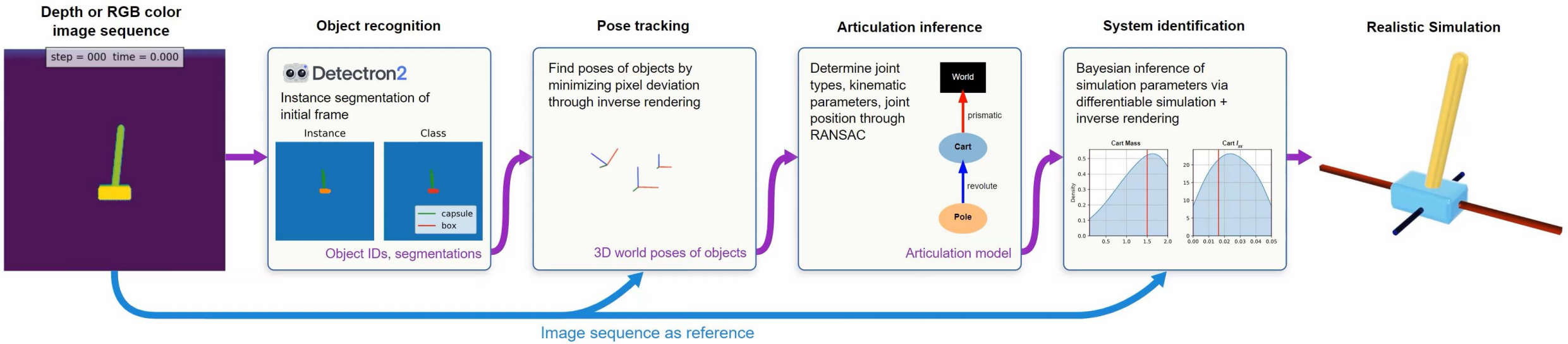
Constrained Stein Variational Gradient Descent (CSVGD)

- Particle-based inference algorithm
- Leverages parallel, differentiable simulation on the GPU
- Uses multiple shooting to improve convergence on long trajectories



Probabilistic Inference of Simulation Parameters via Parallel Differentiable Simulation.
Heiden, Denniston, Millard, Ramos, Sukhatme.
ICRA, 2022.

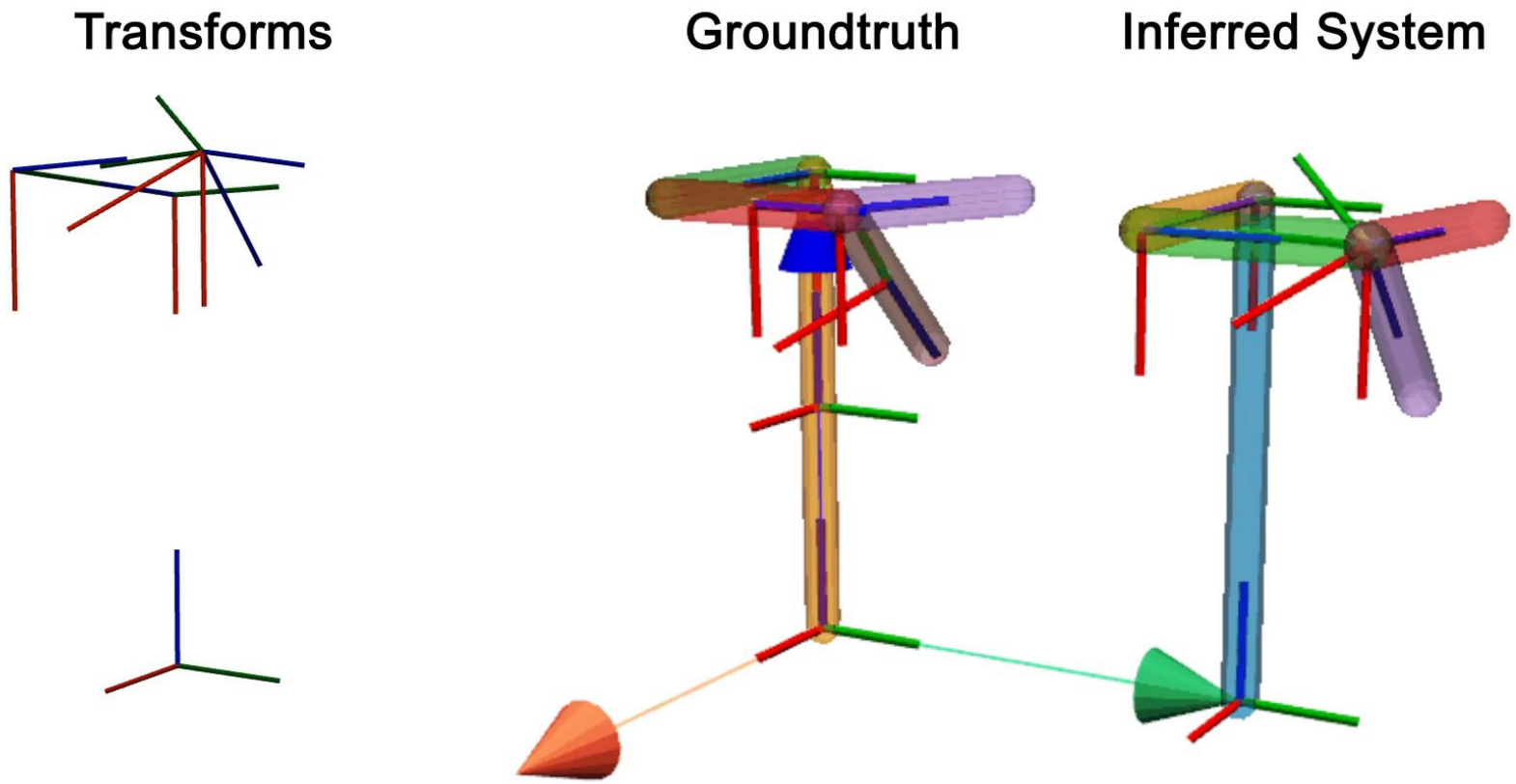
Video2Sim Pipeline



Experiments

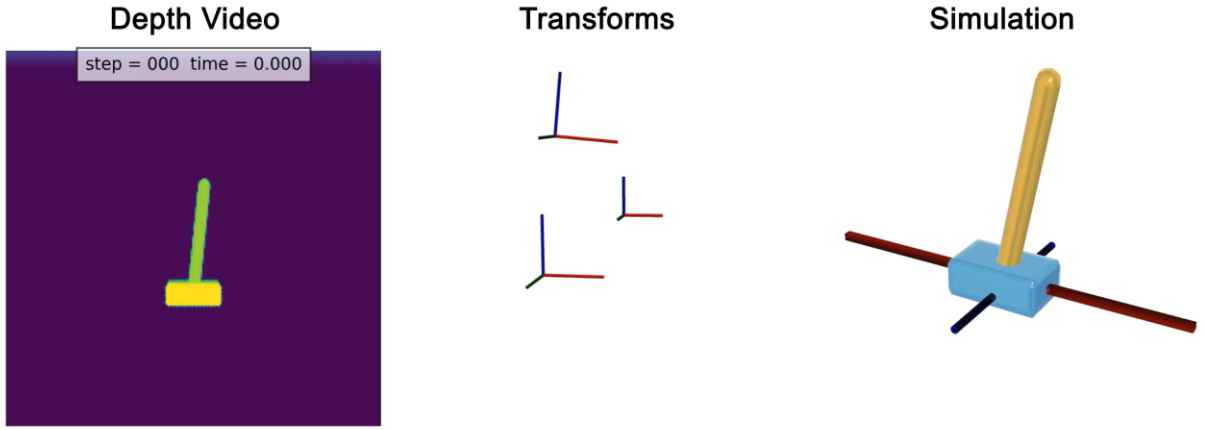
Articulated tree

Mechanism with 2 revolute, 2 static joints



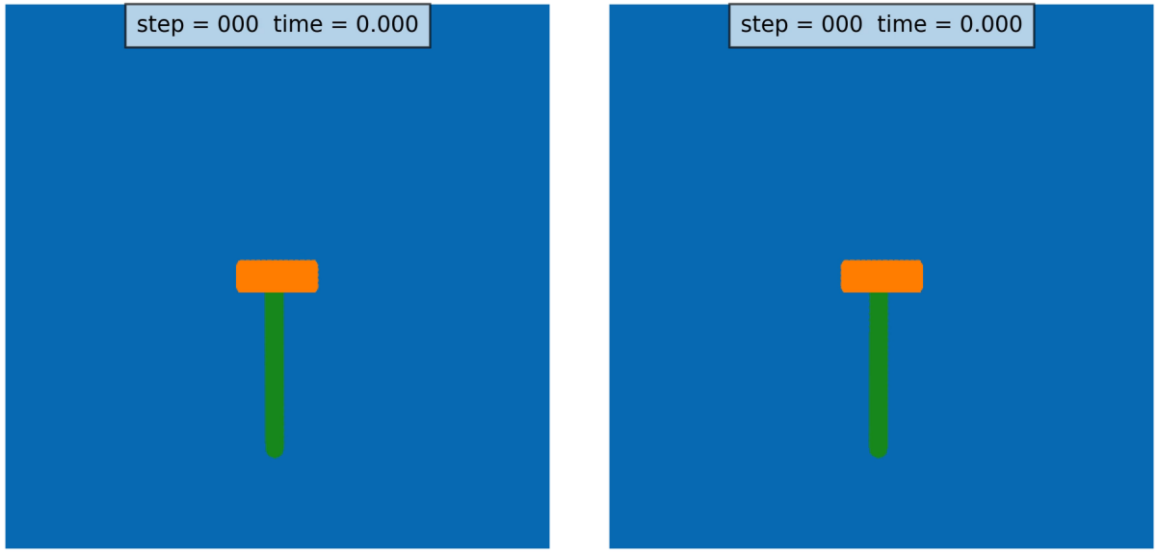
Cartpole in simulation

Recover system from depth video of cartpole simulated in Bullet



Model Predictive Path Integral (MPPI) controller

- uses simulation as dynamics model



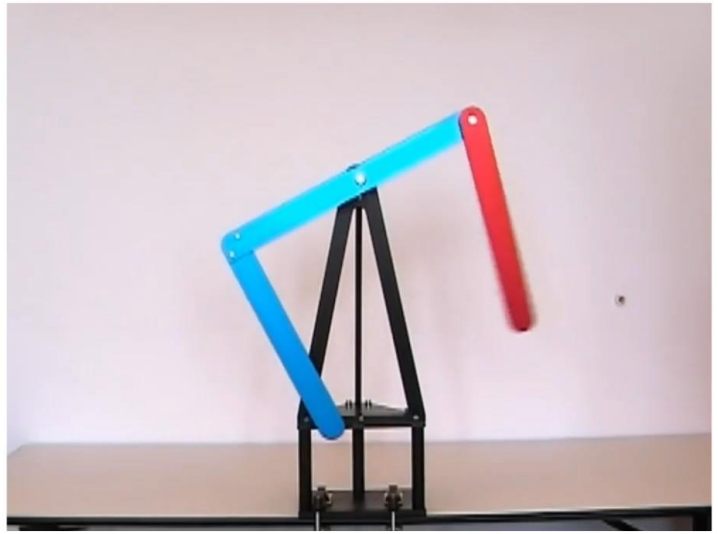
Bullet

Our simulator

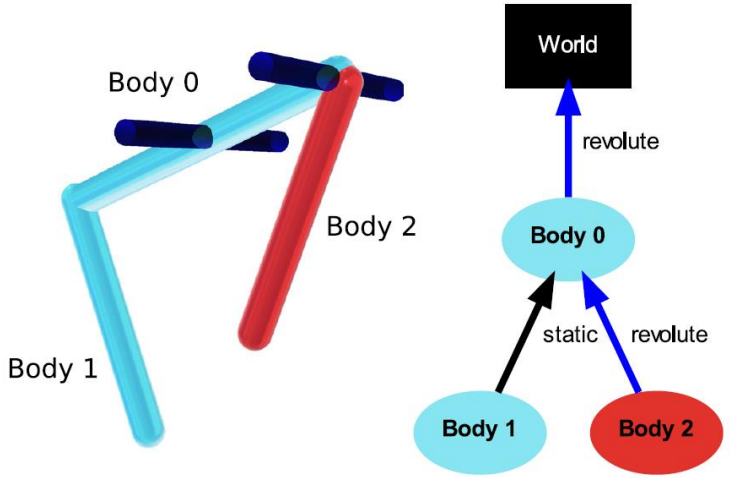
Rott’s pendulum

RGB video of coupled pendulum designed by Nikolaus Rott (1970)

Real

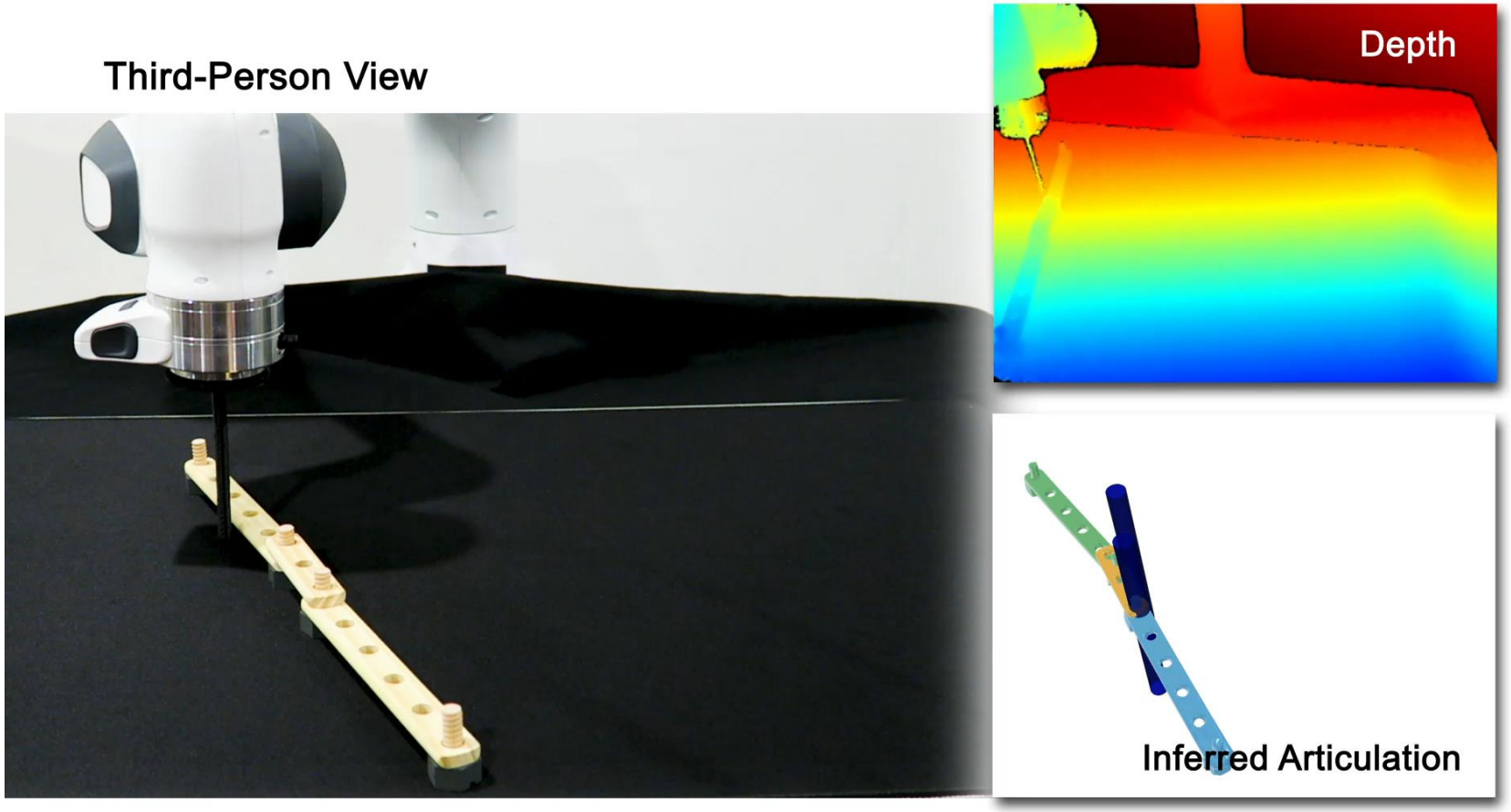


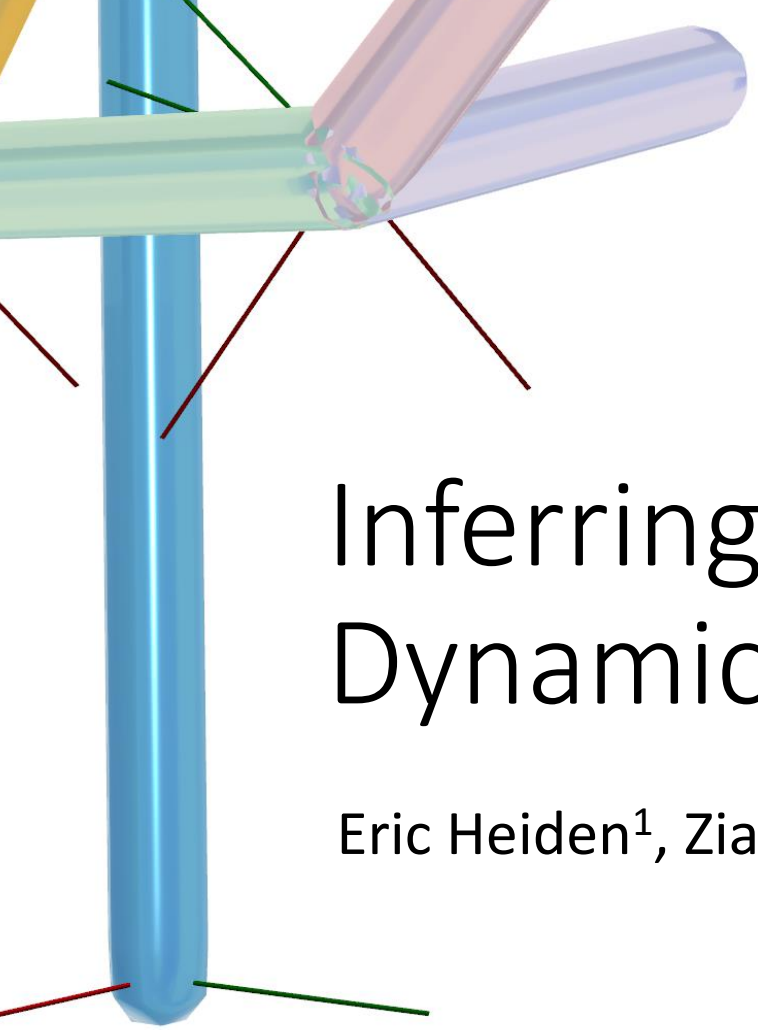
Simulation



Craftsman system

Articulated system of wood parts manipulated by Panda robot arm





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https://eric-heiden.github.io/video2sim

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