Learning Equivariant Neural-Augmented Object Dynamics From Few Interactions

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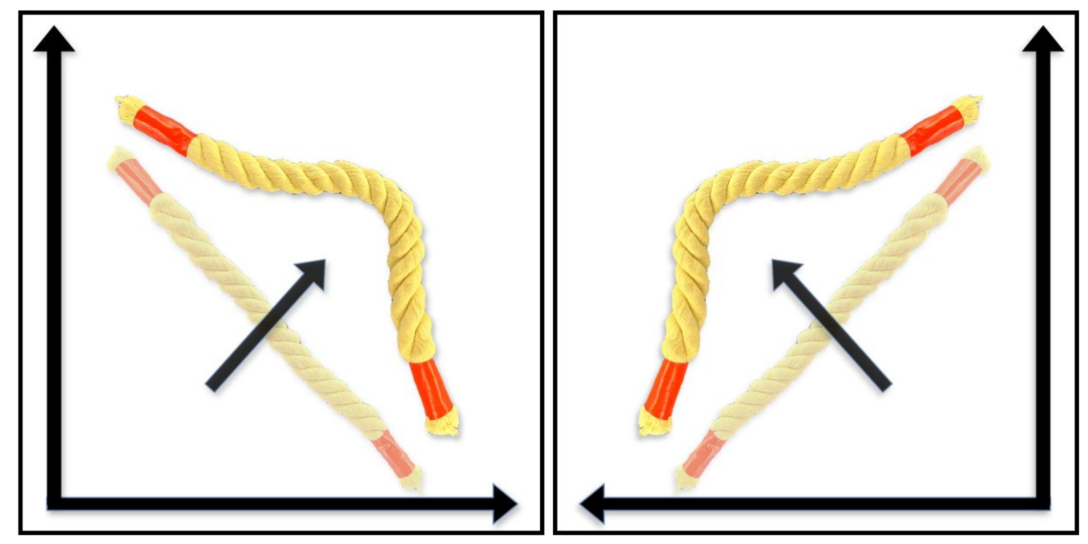
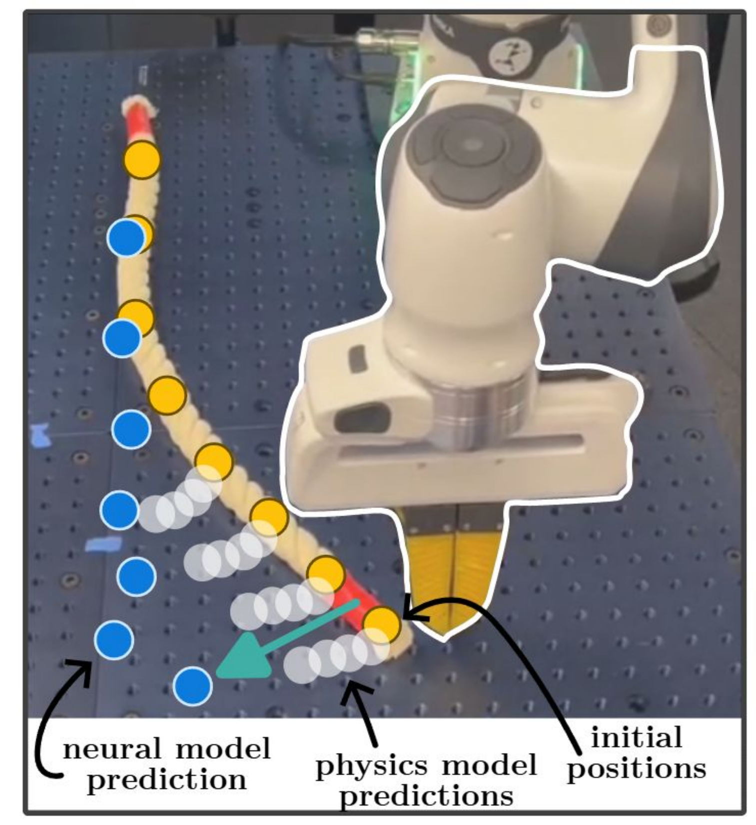
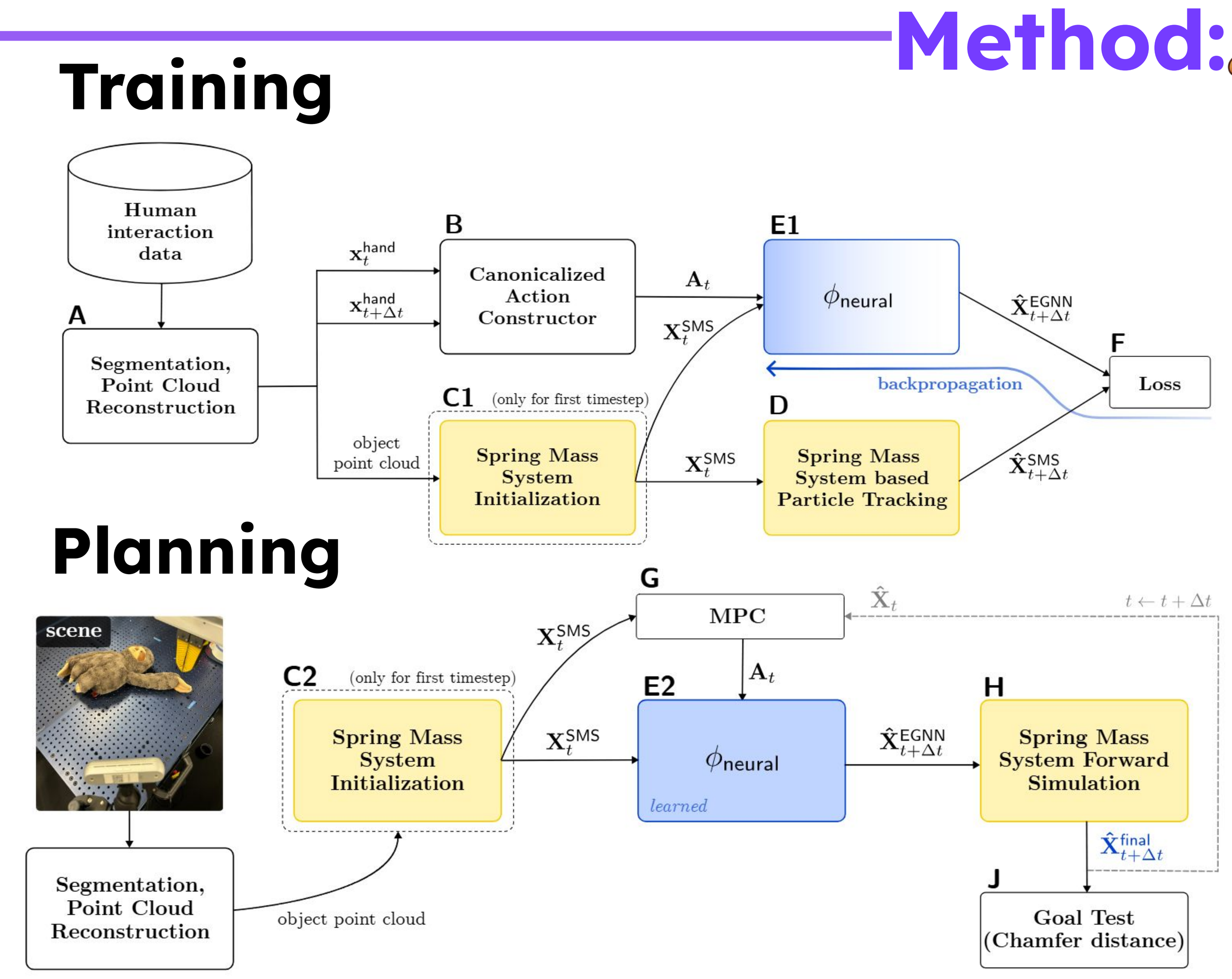
Motivation: Learning Object Dynamics Is Sample Inefficient

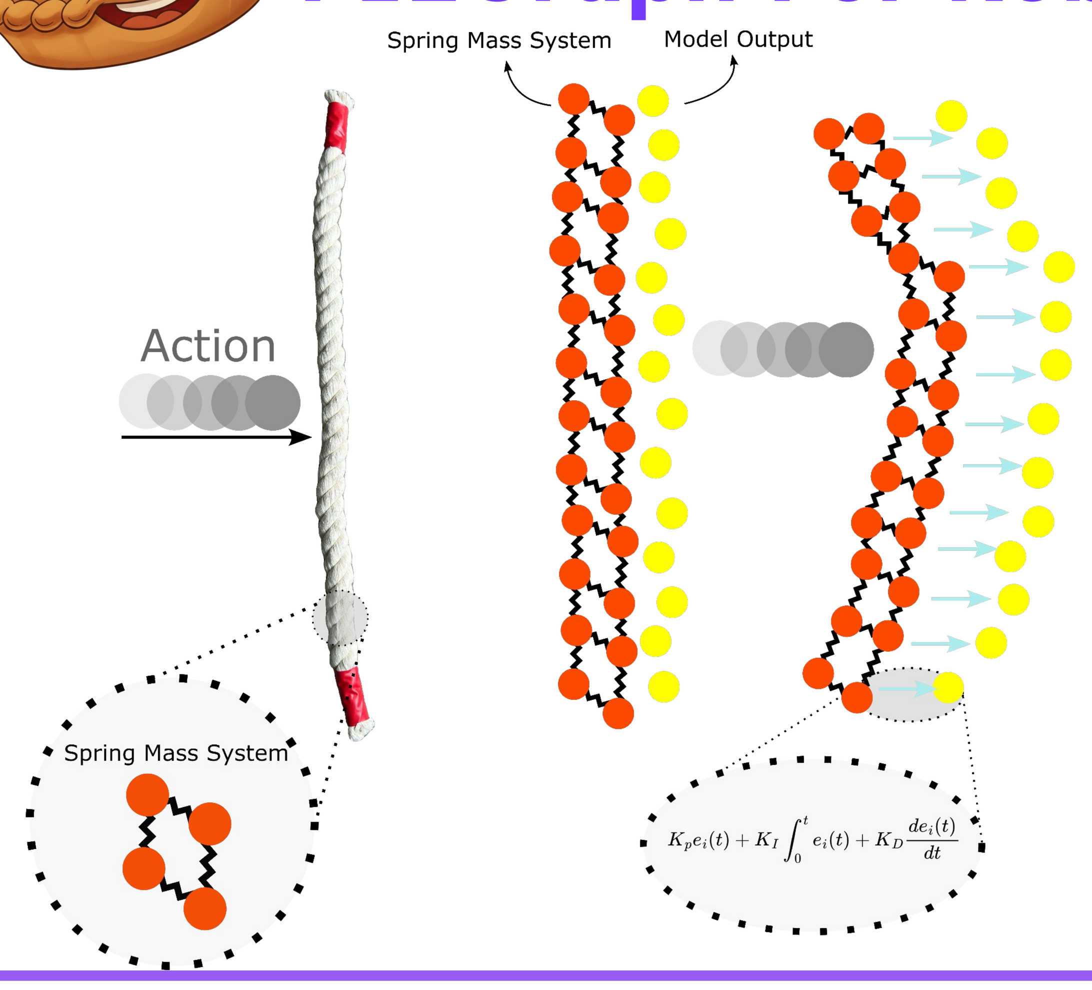
- Learning accurate forward dynamics models for tabletop manipulation require thousands of interactions
- We should exploit symmetries in object dynamics using Equivariance
- Physics simulators provide physical feasibility across long horizons





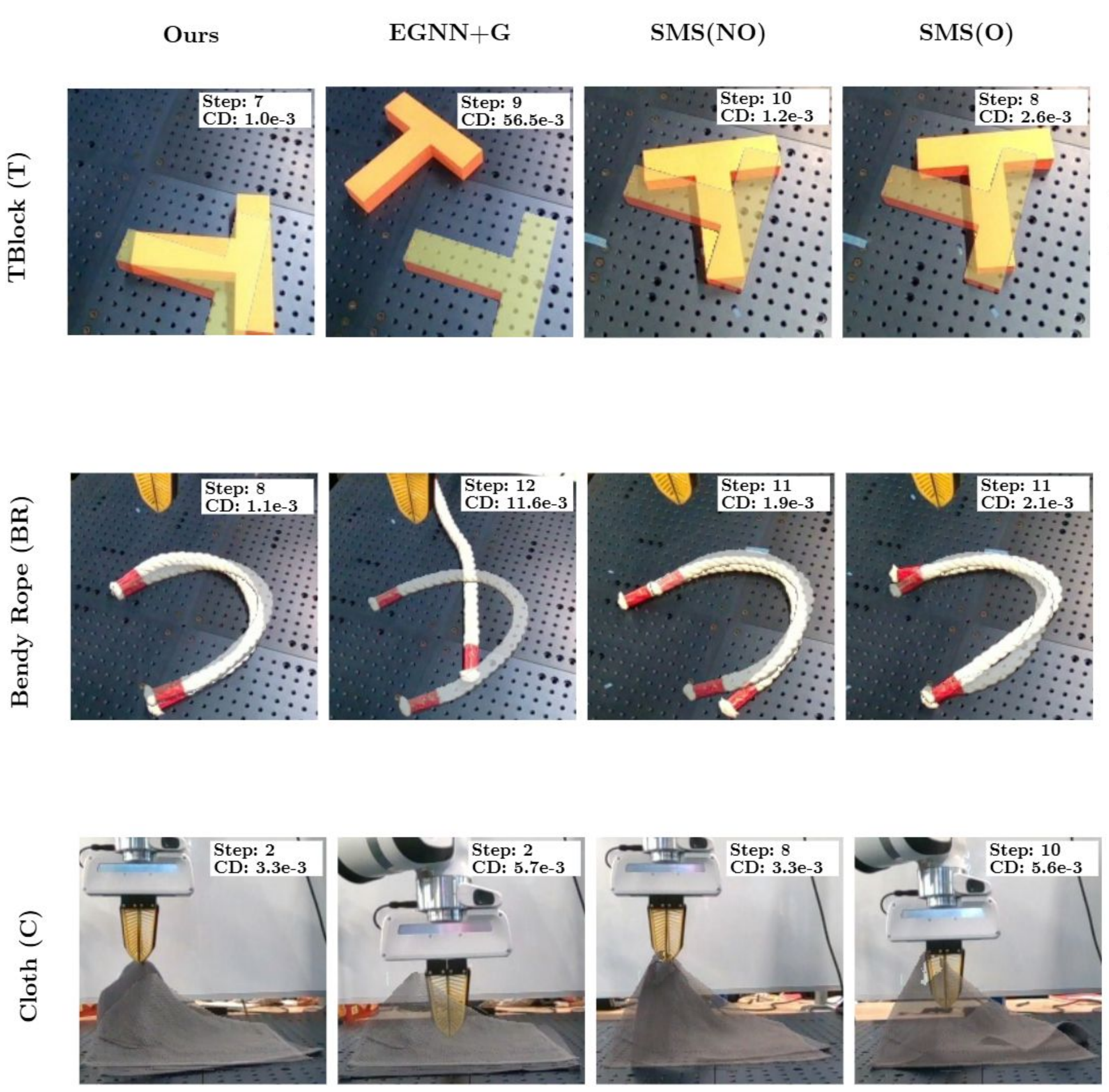
Method: PIEGraph For Robotic Planning

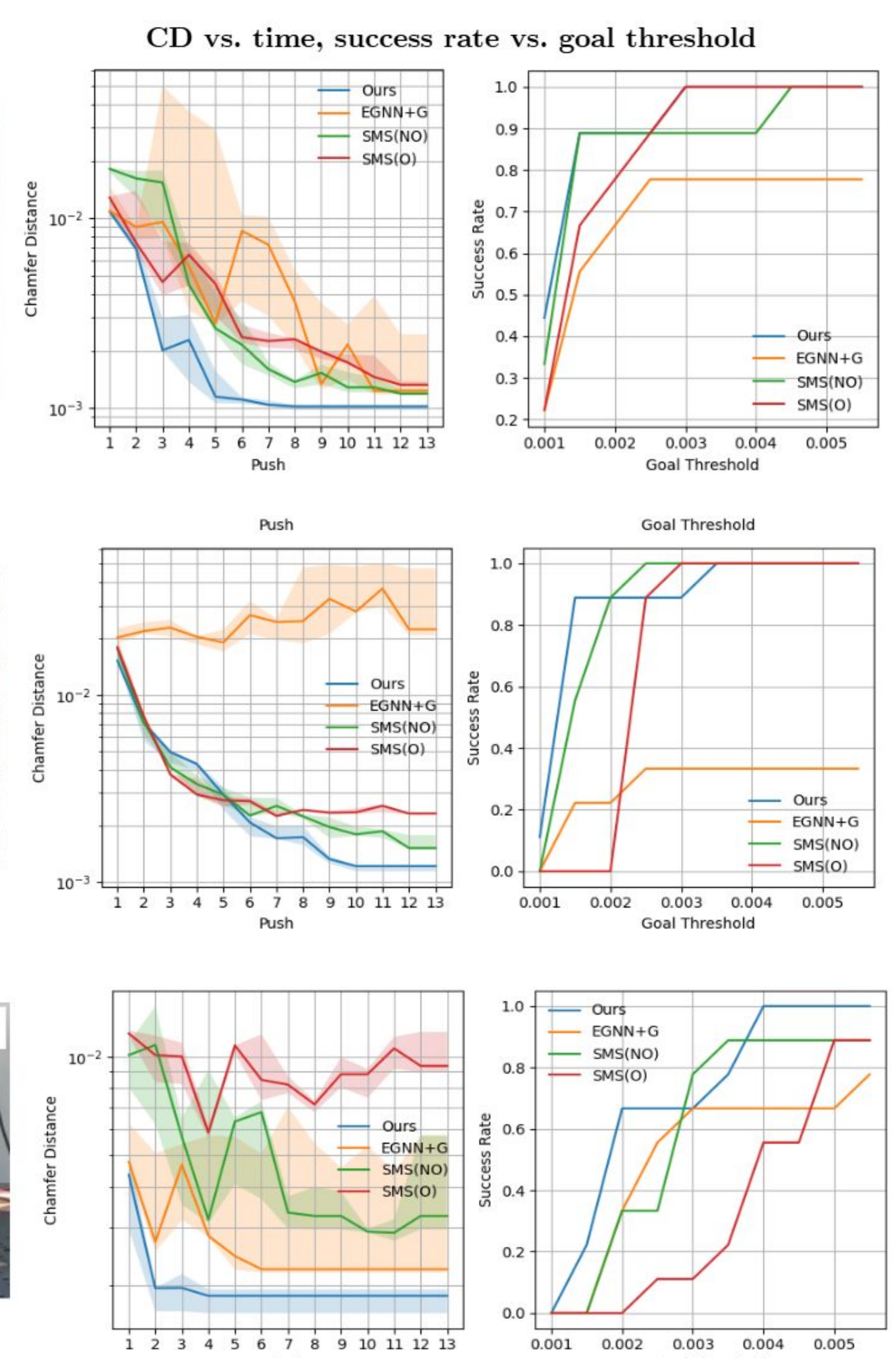




- PIEGraph is a neural-augmented simulator trained on human-object interaction data.
- PIEGraph guides spring mass systems towards equivariant model outputs
- We optimize for action sequences using MPC with 1,000 concurrent simulation trajectories

Results





H	TBlock
1	(0.0073, **0.0029**)
10	(0.0299, **0.013**)
100	(0.0868, **0.0682**)

TABLE I: **Simulated Dynamics Results.** We present average particle distance losses for Propnet and our model respectively — (Propnet, Ours) — for a 2D Tblock for horizon lengths (**H**) 1, 10, and 100. These results are averaged across a single episode of 500 timesteps.

H	TBlock	Stiff Rope	Bendy Rope	Sloth	Cloth
1	(4.1, **1.3**)	(5.1, **2.5**)	(5.5, **2.4**)	(10.9, **6.4**)	(7.2, **2.6**)
2	(9.9, **2.8**)	(11.7, **6.0**)	(13.3, **5.5**)	(26.3, **14.5**)	(15.7, **5.4**)
4	(23.2, **5.7**)	(27.1, **12.8**)	(31.9, **13.8**)	(63.9, **33.7**)	(34.6, **15.7**)

TABLE II: **Real World Dynamics Results.** We present a custom chamfer distance and shape loss metric (**CD+S**) for our neural model without and with guidance respectively — (Ours(NG), Ours) — for tblock, stiff rope, bendy rope, sloth, and cloth for horizon lengths (**H**) 1, 2, 4.

- We outperform explicit simulation with system identification
- We outperform GNNs with 30x less data
- PIEGraph learn deformable object dynamics with only ~1 minute of data
- Ablations show a significant performance increase with a physics informed prior