Fine-grained differentiable physics: A Yarn-level Model for Fabrics

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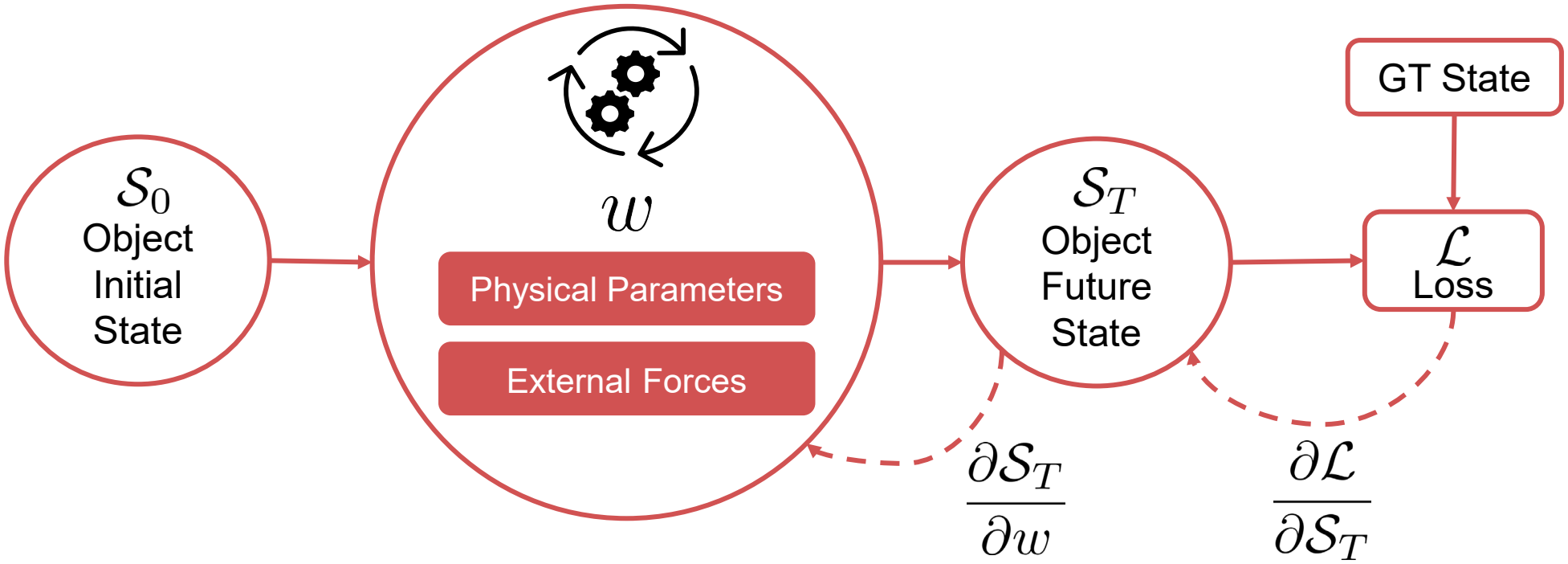
Background

- Differentiable physics model combines physical-based simulator with machine learning.

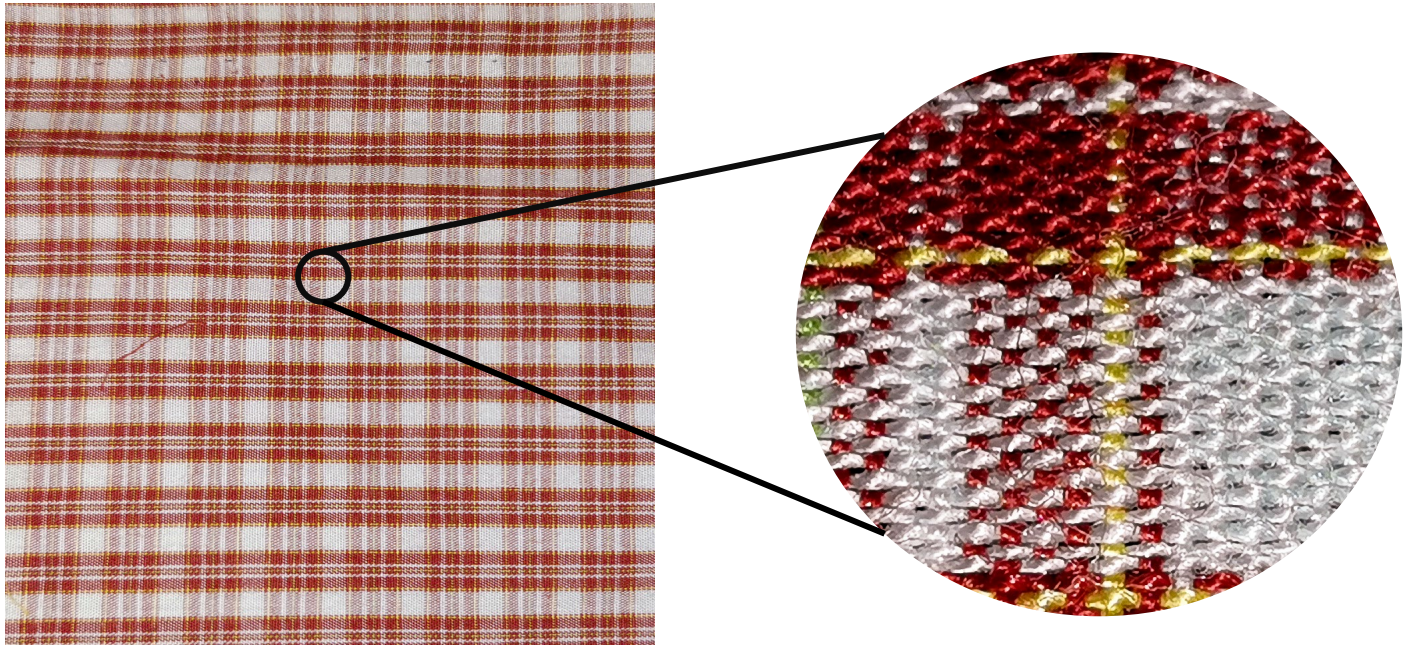


Introduction

- Current problems
  - Too general for cloth.
- The First Fine-grained for Woven cloth
  - Yarn-level modeling, different woven pattern, blend woven
  - More explainable physical parameters, high data efficiency, and accurate prediction

Real Cloths have Complex Microstructure

- Microstructure affects dynamics (Vassiliadia et al., 2011).
- Previous work used simplified elastic sheet model.



Vassiliadis, S., Kallivretaki, A., Domvoglou, D. and Provatidis, C., 2011. Mechanical analysis of woven fabrics: The state of the art.

Cloth Modeling

- The same as real cloth, the simulator models a piece of cloth as perpendicular yarns.

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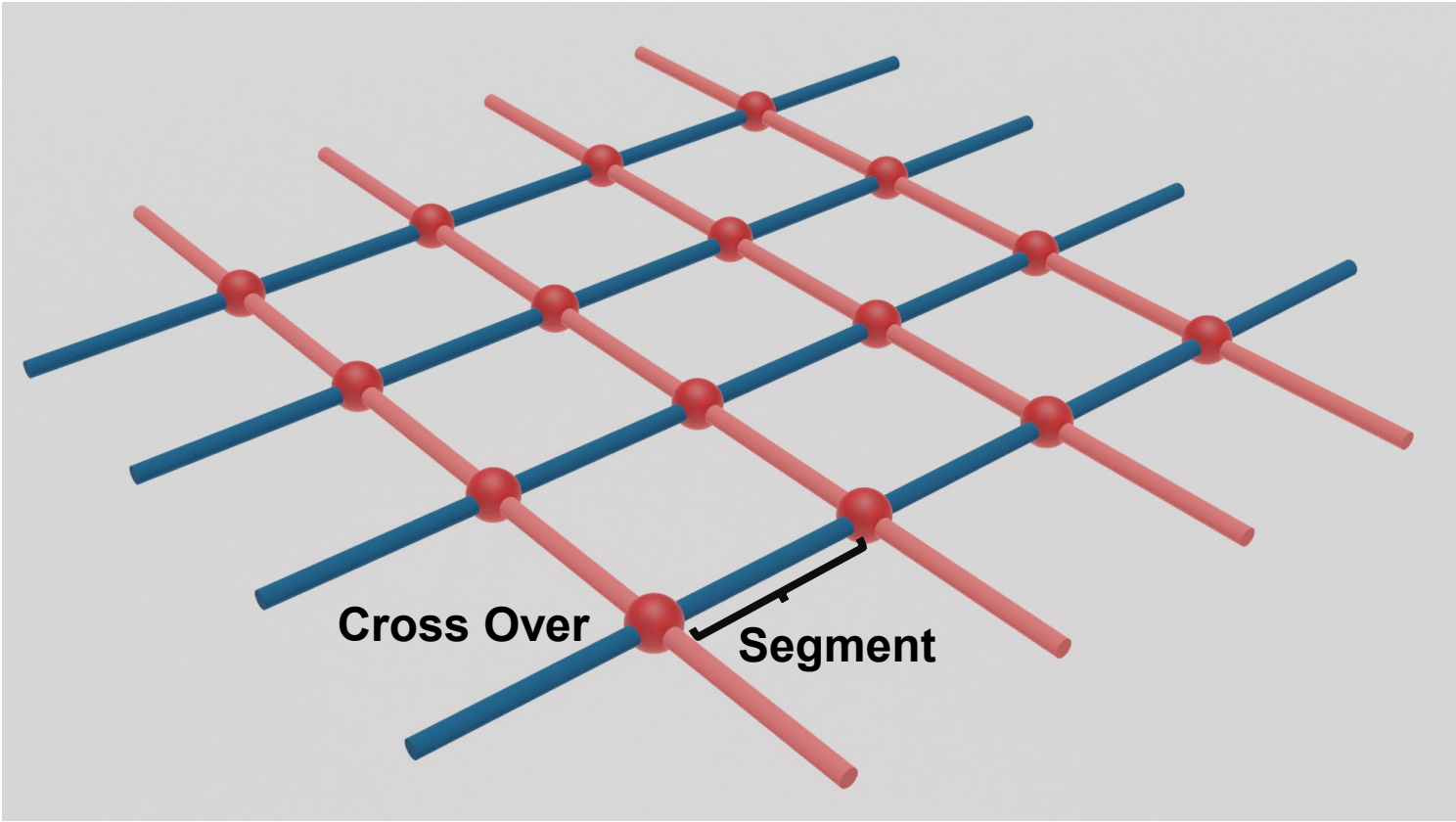

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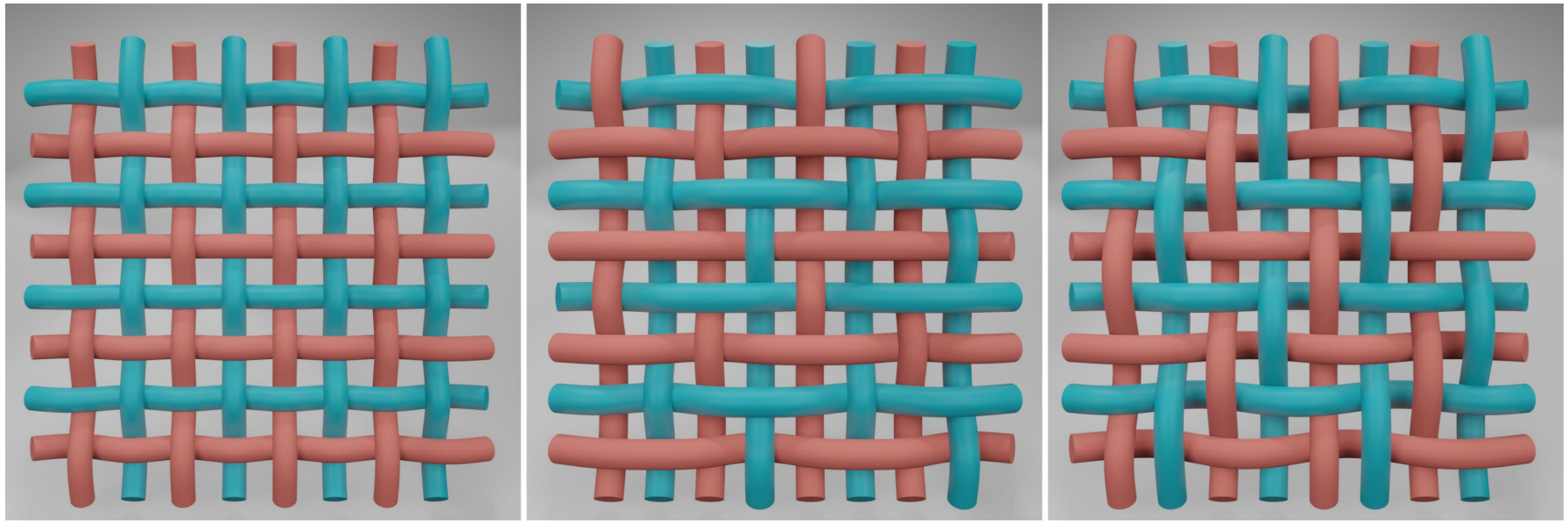


Plain Satin Twill

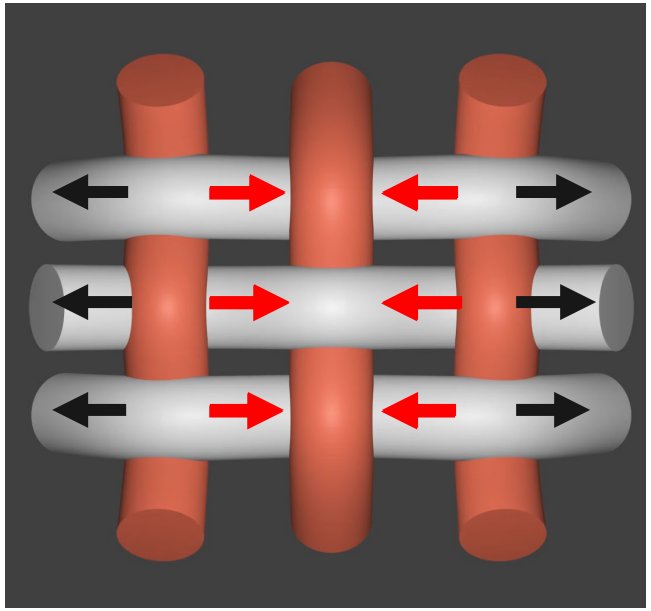
Forces

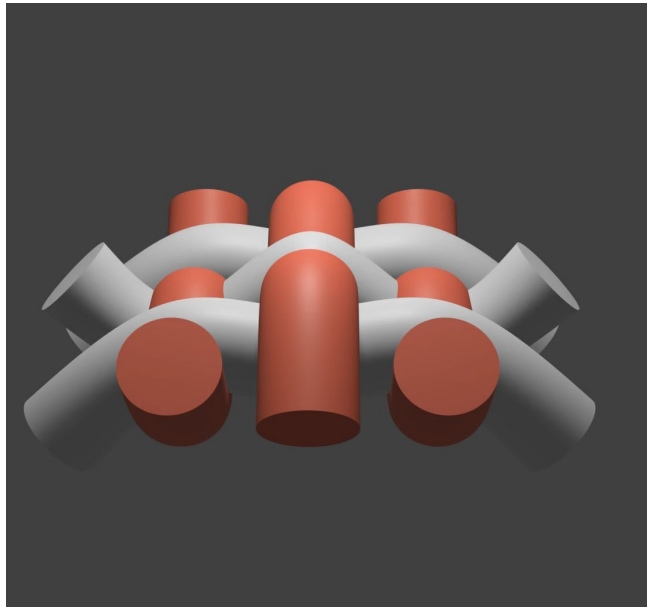
Internal force: Stretching and Bending

- Resistant to deformation along segments' axis.
- Bending appears when the angle between two adjacent segments is no equal to zero.

$$V = \frac{1}{2} Y \pi R^2 \Delta u (\|\mathbf{w}\| - 1)^2$$

$$V = B \pi R^2 \frac{\theta^2}{u_1 - u_2}$$

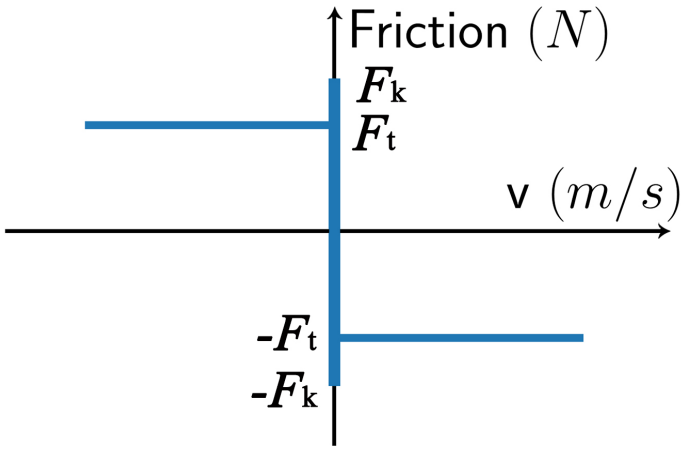




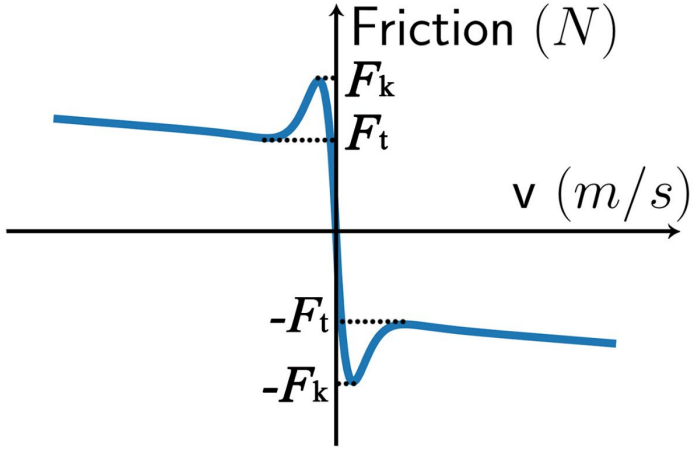
Internal force: Slide friction

- Prohibit the relative sliding at cross overs.

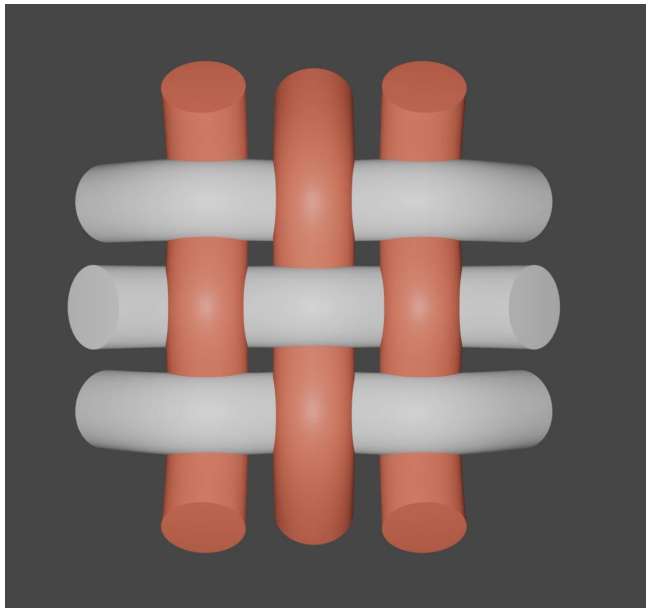
$$F_{Slide} = -\left(\frac{k_f \delta u - K(\delta u)\ \mu\ F_n}{2} K(\mu F_n - F_u) + \frac{k_f \delta u + K(\delta u)\ \mu\ F_n}{2}\right) - d_f \dot{u}_0$$



Indifferentiable Coulomb model



Our differentiable friction model

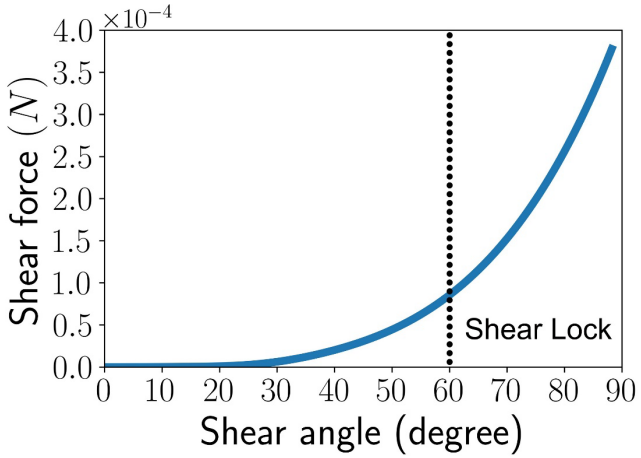


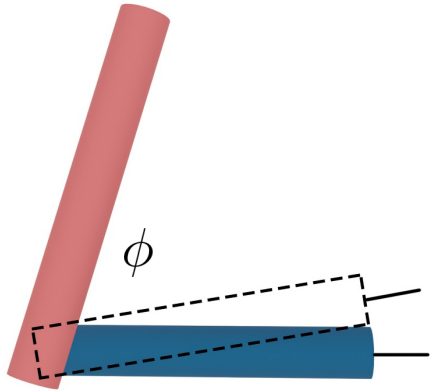
Internal force: Shearing

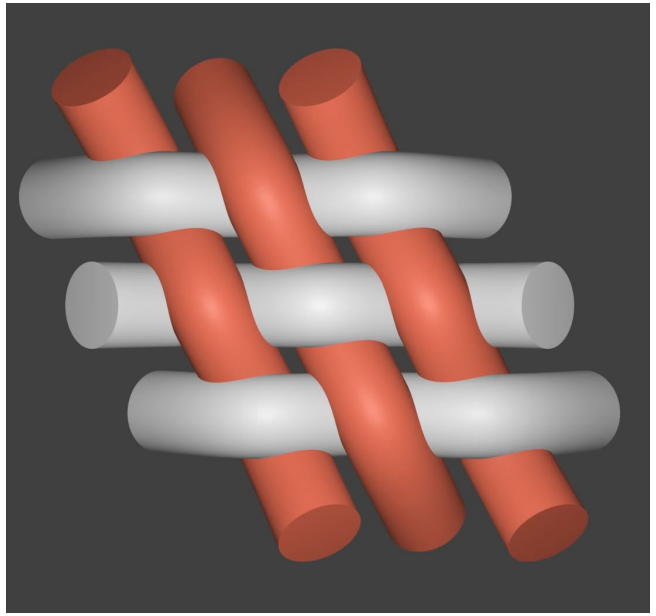
- Resisting relative rotation between two perpendicular segments.

$$k_s = \frac{1}{2}(F_n + 1)\, S\, \pi R^2 \left((1+\gamma^c) + (1-\gamma^c) \tanh\left(\frac{\bar{\phi}^5(\phi - \phi_l)}{(\phi(\phi-\phi_l)(\phi-\bar{\phi}))^2 + \bar{\phi}^4\sigma^2} \right) \right)$$

$$V = \frac{1}{2} k_s L(\phi - \bar{\phi})$$







Forces: External Forces

- Gravity $V = \rho \Delta \mathbf{g}^\top \frac{\mathbf{x}_0 + \mathbf{x}_1}{2}$
- Wind Force
- Control $\mathbf{F}_{ctrl}$
- Collision

Trained Parameters

- Physical Parameters
  - Stretching Stiffness: Y
  - Bending Stiffness: B
  - Friction Coefficient: μ
  - Shearing Stiffness: S
  - Density: ρ
- Control Force $\mathbf{F}_{ctrl}$

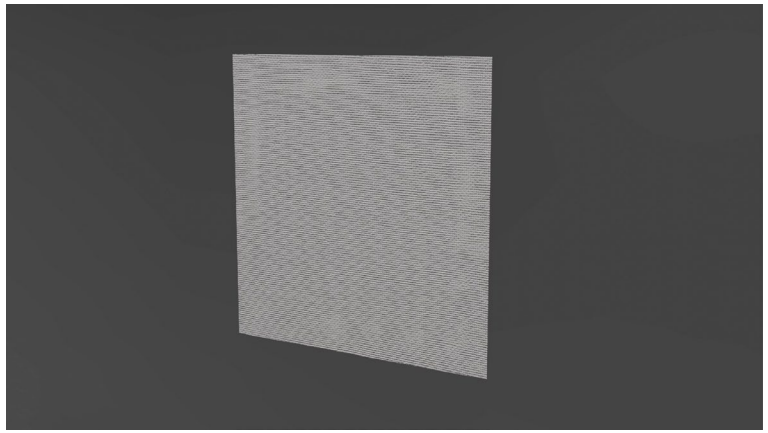
More EXPLAINABLE than existing cloth simulator (Liang et al., 2019; Wang et al., 2010).

Liang, J., Lin, M. and Koltun, V., 2019. Differentiable cloth simulation for inverse problems. Advances in Neural Information Processing Systems, 32.
Wang, H., O'Brien, J.F. and Ramamoorthi, R., 2011. Data-driven elastic models for cloth: modeling and measurement. ACM transactions on graphics (TOG), 30(4), pp.1-12.

Experiments

Experiments: Parameter Estimation

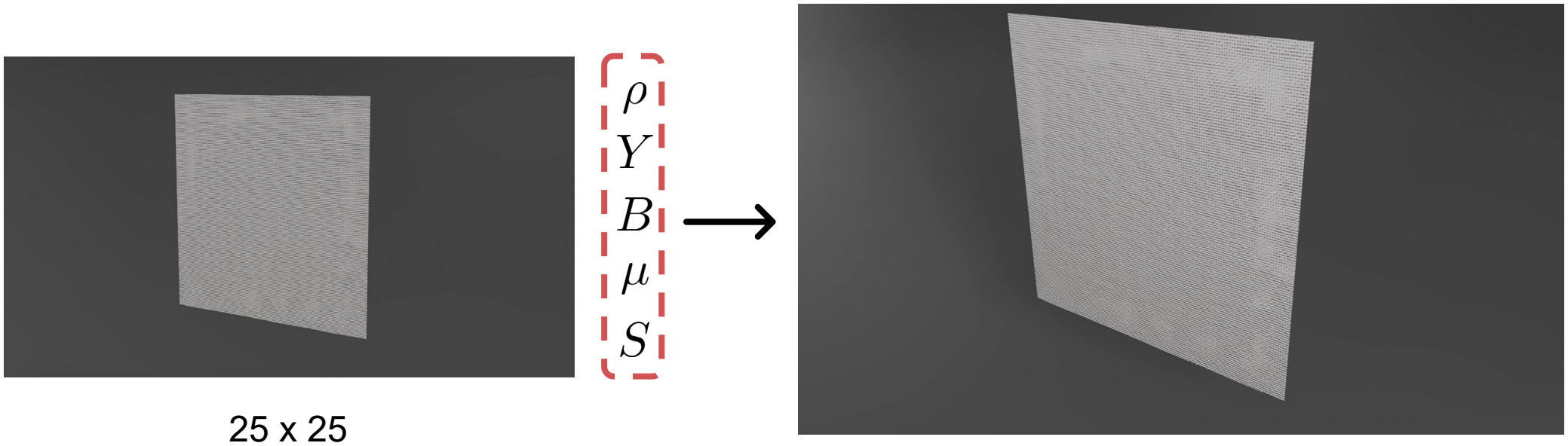
- Train Data: 25 frames simulated cloth of various sizes blown by wind(shown in error percentage. The smaller, the better).



Size	Shear	Friction	Yarn	Density	Stretch	Bend
5 x 5	5.10%	12.60%	1	1.40%	4.10%	0.93%
			2	2.00%	1.72%	1.09%
10 x 10	6.80%	9.00%	1	0.45%	3.06%	5.36%
			2	2.08%	2.26%	6.73%
17 x 17	5.30%	19.60%	1	1.55%	1.08%	5.50%
			2	2.40%	0.77%	6.00%
25 x 25	8.70%	24.00%	1	3.45%	2.04%	6.29%
			2	2.28%	2.31%	9.18%

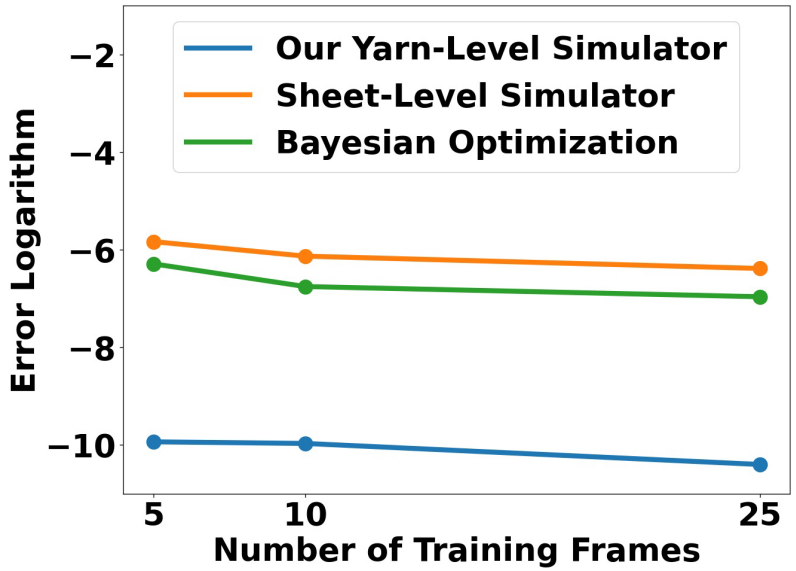
Experiments: Parameter Estimation

Scaled simulation with the parameters learned on small cloths



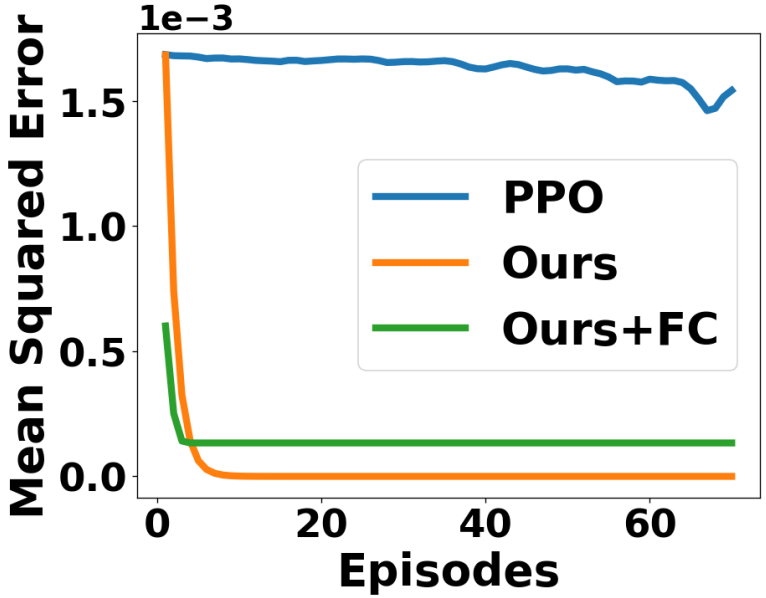
Experiments: Comparison

- Compare our model with sheet-level and Bayesian Optimization in physical parameter estimation.
- The initial 5, 10, and 25 frames from 50 frames are used for training. All 50 frames are used for evaluation.



Experiments: Control Learning

- Learning the needed forces to throw the cloth to the bin.



Thank you

More details can be found at:
http://drhewang.com/pages/diffcloth.html

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