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NeuralClothSim: Neural Deformation Fields Meet the Thin Shell Theory

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NEURAL INFORMATION PROCESSING SYSTEMS

4dqv.mpi-inf.mpg.de/NeuralClothSim (inc. source code)

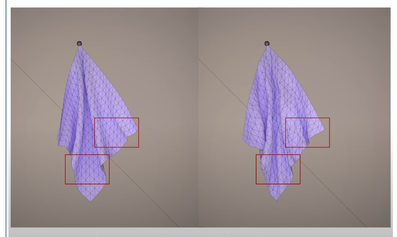
TL;DR

Can cloth simulation benefit from neural fields?
Existing simulators operate on *discrete* surface representations (*e.g.*, meshes).
We propose a *continuous* neural representation and a simulation solver.

NeuralClothSim:
*encodes deformations as a neural deformation field (NDF)
*supervises NDF equilibria relying on non-linear Kirchhoff–Love theory
*uses a non-linear anisotropic material model
*allows material interpolation and simulation editing

NDFs:
*are adaptive: allocate the capacity to the deformation details
*are consistent: allow surface state queries at arbitrary spatial resolutions without retraining

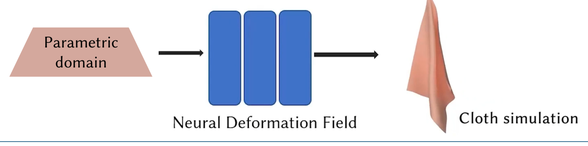
Why NeuralClothSim?



[Liang *et al.*, NeurIPS 2019]

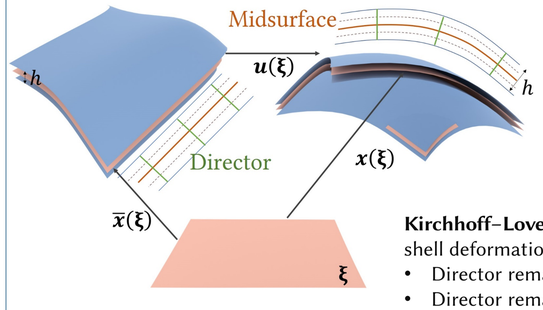
Prior works
- Use discrete surface representation
- Generate inconsistent simulation w.r.t. discretisation
- Are non-adaptive

Our solution: **Continuous** and **Consistent**



Background: Thin Shell Theory

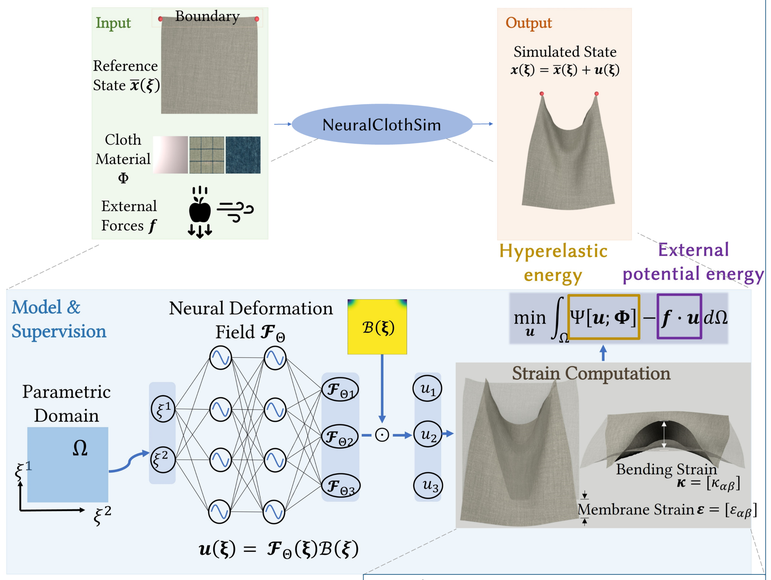
We model cloths as Kirchhoff–Love thin shells, *i.e.*, a volume with reduced kinematic parameterisation as a midsurface and a director



Kirchhoff–Love Hypothesis for shell deformation:
- Director remains straight
- Director remains normal
- Shell thickness does not change

Method: NeuralClothSim

We generate a simulation state at equilibria given a cloth geometry in a reference state, its material properties and external forces



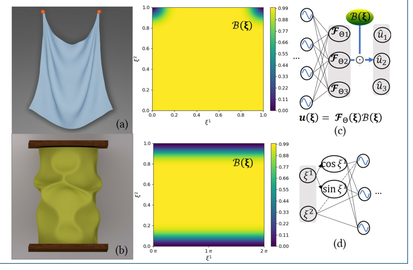
$$\varepsilon_{\alpha\beta} = \frac{1}{2}(\varphi_{\alpha\beta} + \varphi_{\beta\alpha} + \varphi_{\alpha\lambda}\varphi^{\lambda}_{\beta} + \varphi_{\alpha 3}\varphi_{\beta 3}),$$
$$\kappa_{\alpha\beta} = -\varphi_{\alpha 3}|_\beta - \bar{b}^{\lambda}_{\beta}\varphi_{\alpha\lambda} + \varphi^{\lambda}_{3}(\varphi_{\alpha\lambda}|_\beta + \frac{1}{2}\bar{b}_{\alpha\beta}\varphi_{\lambda 3} - \bar{b}_{\beta\lambda}\varphi_{\alpha 3}),$$
where $\mathbf{u}_{,\alpha} = \varphi_{\alpha\lambda}\bar{\mathbf{a}}^{\lambda} + \varphi_{\alpha 3}\bar{\mathbf{a}}^{3}$,
$\varphi_{\alpha\lambda} := u_\lambda|_\alpha - \bar{b}_{\alpha\lambda}u_3$, and $\varphi_{\alpha 3} := u_{3,\alpha} + \bar{b}^{\lambda}_{\alpha}u_\lambda$.

We support multiple material models

Linear Isotropic — Non-linear Orthotropic (Clyde *et al.*)

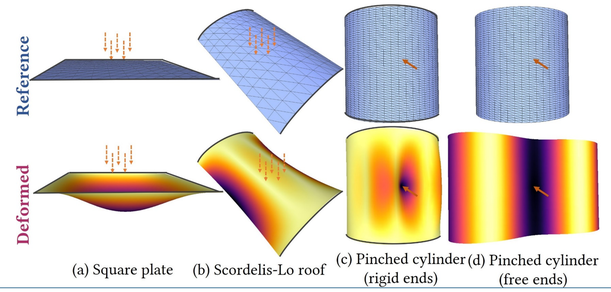
$$\Psi = \frac{1}{2}(DH^{\alpha\beta\lambda\delta}\varepsilon_{\alpha\beta}\varepsilon_{\lambda\delta} + BH^{\alpha\beta\lambda\delta}\kappa_{\alpha\beta}\kappa_{\lambda\delta})$$
$$D := \frac{Eh}{1-\nu^2} \text{ and } B := \frac{Eh^3}{12(1-\nu^2)}$$

We model Dirichlet and periodic boundary conditions as hard constraints



Validation: Belytschko Obstacle Course

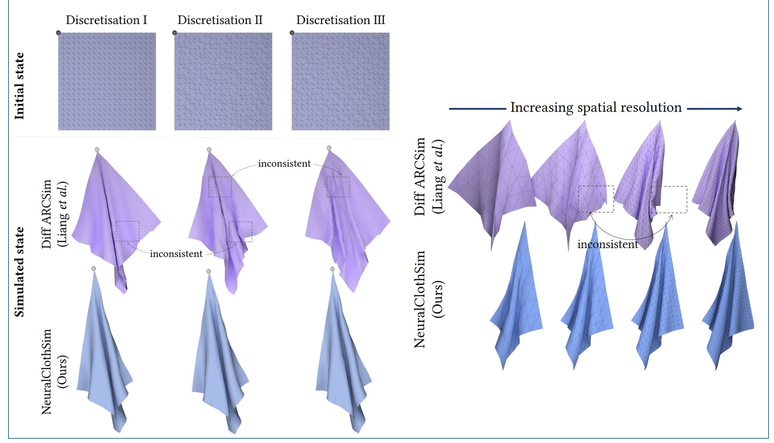
We generate **accurate deformations** on the benchmark obstacle course



Simulation Results

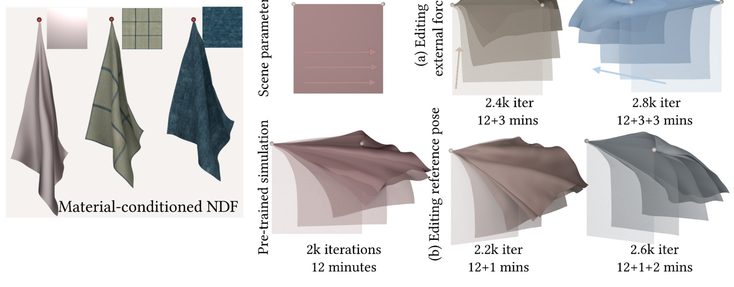
Comparisons to Mesh-based Simulators

NeuralClothSim generates **consistent simulation (*e.g.*, folds and wrinkles)** at different initial discretisations (left) and at multiple resolutions (right)



Applications

NeuralClothSim can incorporate **material priors** (left), and allows **fast editing** of simulations (right)



References

Belytschko (1985). "Stress projection for membrane and shear locking in shell finite elements". In: Computer Methods in Applied Mechanics and Engineering.

Liang al. (2019). "Differentiable cloth simulation for inverse problems." In: Advances in Neural Information Processing Systems (NeurIPS).

Clyde (2017). "Modeling and data-driven parameter estimation for woven fabrics." In: ACM SIGGRAPH/Eurographics Symposium on Computer Animation. 2017.