Seeking Efficiency for the Accurate Draping of Digital Garments in Production

Supplementary Material

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A Derivation of the Bending Damping Energy

Here we derive the damping energy for the bending model by using the method of Sánchez-Banderas et al. [2].

We start from the expression of the bending energy from Tamstorf and Grinspun [3]:

$$\Phi_b = k_b 3 \frac{|\bar{\mathbf{e}}_0|^2}{\bar{A}} (\varphi - \overline{\varphi})^2 \tag{1}$$

We set $\Phi_b = w\Psi_e(\varepsilon)$, with w as the product of all constant values in (1), and the energy density Ψ_e as $\Psi_e = \varepsilon^2$ with $\varepsilon = \varphi - \overline{\varphi}$. Then, we can define our dissipation potential $\Psi_d(\dot{\varepsilon})$ by using the strain rate instead of the strain:

$$\Psi_d(\dot{\varepsilon}) = \dot{\varepsilon}^2 = \left(\frac{\partial \varepsilon}{\partial \mathbf{x}}^T \mathbf{v}\right)^2 \tag{2}$$

Tamstorf and Grinspun [3] formulate the derivative of the strain with respect to the positions using the chain rule:

$$\frac{\partial \varepsilon}{\partial \mathbf{x}} = \frac{\partial \varphi}{\partial \theta} \frac{\partial \theta}{\partial \mathbf{x}} \tag{3}$$

which we apply to the derivative of (2) with respect to the positions to obtain the force:

$$\mathbf{F}_d = -2w \frac{\partial \varepsilon}{\partial \mathbf{x}}^T \mathbf{v} \frac{\partial \varepsilon}{\partial \mathbf{x}} \tag{4}$$

We then obtain the damping hessians by taking the derivative of the damping force with respect to positions and velocities. For positions, we discard the non-symmetric term [2]. The general expressions are given below:

$$\frac{\partial \mathbf{F}_d}{\partial \mathbf{x}} = 2w \frac{\partial^2 \varepsilon}{\partial \mathbf{x}^2} \frac{\partial \varepsilon}{\partial \mathbf{x}}^T \mathbf{v} \tag{5}$$

$$\frac{\partial \mathbf{F}_d}{\partial \mathbf{v}} = 2w \frac{\partial \varepsilon}{\partial \mathbf{x}} \frac{\partial \varepsilon}{\partial \mathbf{x}}^T \tag{6}$$

The small angle problem described by Sánchez-Banderas et al. for yarns does not affect our hinge bending energy since it is well defined in that range of deformation, and there is no need to do any special treatment.

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B Mechanical Parameters

In this appendix, mechanical parameters of the materials of the different simulated scenes are presented. In Table 1, the materials of the real scenes presented in the main article are shown alongside the corresponding scene identifier and their names. In the same fashion, Table 2 shows the two different materials of the synthetic scenes. In Table 3 we provide the resolution and material parameters for all the scenes used in the comparison against C-IPC.

C Generalization to More Scenes

To evaluate the generalization of the conclusions reached using the original 10 garments, we have performed drape simulations with all the proposed features for a validation set composed of 60 additional garments, shown in Figure 1, with varied properties in terms of wear (from very loose to very tight), size (from 46698 to 344799 DoFs) and material stiffness (from very elastic knits to heavy, stiff wovens).

From all the simulations we have gathered comparable quantitative metrics. Aside from the computation time per DoF per garment and the average early exit values, shown in the main document, we have also gathered system matrix bandwidth after reordering, ranging from 313 to 1195 for the validation set scenes, well aligned with the [496,1202] range in the original garments. Regarding the average time step size, both sets yield similar values of $\overline{h} = 9.67\text{e}{-4}$ms for the original garments and $\overline{h} = 9.83\text{e}{-4}$ms for the validation set, suggesting an equally low use of the time-splitting scheme.

D Simulator Comparisons

In this Appendix, we provide the renders of the garments and scenes generated in Section 7.2, which compares our simulator to a real-time PBD simulator (Figure 2) and the C-IPC [1] simulator (Figure 3).

References

[1] M. Li, D. M. Kaufman, and C. Jiang. Codimensional incremental potential contact. ACM Trans. Graph., 40(4), 2021. doi: 10.1145/3450626.3459767 1, 3

[2] R. M. Sánchez-Banderas and M. A. Otaduy. Strain rate dissipation for elastic deformations. Computer Graphics Forum (Proc. of the ACM SIGGRAPH / Eurographics Symposium on Computer Animation), 37(8):161–170, 2018. 1

[3] R. Tamstorf and E. Grinspun. Discrete Bending Forces and Their Jacobians. Graph. Models, 75(6):362–370, Nov. 2013. doi: 10.1016/j.gmod.2013.07.001 1

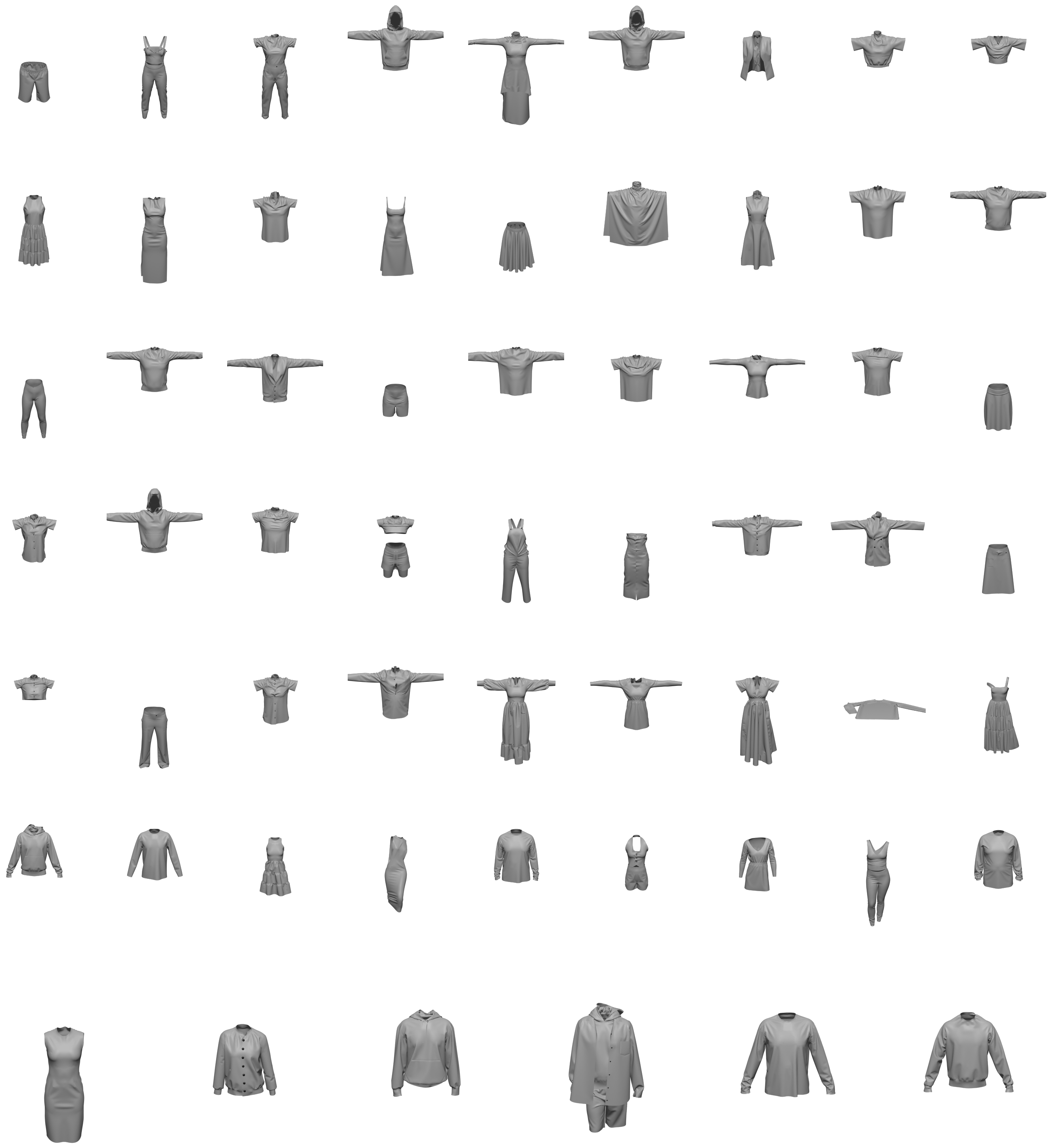

Fig. 1: Renders of the 60 garments in the validation set. The set contains varied garment styles, with different sizes and fabric types.

Garment	Fabric Name	Density	Stretch Weft	Stretch Warp	Stretch Bias	Bending Weft	Bending Warp	Bending Bias
1)	Rib 1x1 Mix - Black	0.439	33.64	356.14	275.78	$1.00 \cdot 10^{-5}$	$6.26 \cdot 10^{-7}$	$1.88 \cdot 10^{-6}$
1)	Twill PL - Beige	0.21	209.42	326.60	270.86	$1.50 \cdot 10^{-6}$	$6.84 \cdot 10^{-7}$	$9.13 \cdot 10^{-7}$
2)	Rib 1x1 CO - Navy	0.206	15.30	307.07	107.81	$2.79 \cdot 10^{-7}$	$1.39 \cdot 10^{-6}$	$9.89 \cdot 10^{-7}$
2)	Single Jersey VI/EA - Fucsia Pink	0.193	46.74	66.27	43.27	$6.68 \cdot 10^{-8}$	$1.02 \cdot 10^{-7}$	$5.90 \cdot 10^{-8}$
3)	Rib Mix - Blue	0.418	33.64	307.07	143.86	$1.26 \cdot 10^{-6}$	$3.44 \cdot 10^{-6}$	$2.02 \cdot 10^{-6}$
3)	Rib Mix - Mint Green	0.279	53.17	111.76	45.27	$2.20 \cdot 10^{-7}$	$1.36 \cdot 10^{-6}$	$5.94 \cdot 10^{-7}$
4)	Twill TN - White	0.157	1097.66	1000.00	104.88	$3.25 \cdot 10^{-7}$	$1.44 \cdot 10^{-6}$	$1.20 \cdot 10^{-6}$
4)	Rib Mix - Mint Green	0.279	53.17	111.76	45.27	$2.20 \cdot 10^{-7}$	$1.36 \cdot 10^{-6}$	$5.94 \cdot 10^{-7}$
4)	Brushed Back Fleece PC/VI - Pale Pink	0.228	57.27	140.82	82.47	$3.46 \cdot 10^{-7}$	$5.36 \cdot 10^{-7}$	$4.28 \cdot 10^{-7}$
5)	Single Jersey CO - Gray Melange	0.196	170.35	307.07	177.11	$5.31 \cdot 10^{-8}$	$3.95 \cdot 10^{-7}$	$6.24 \cdot 10^{-7}$
6)	French Terry PL/CO - Blue	0.367	66.27	170.35	41.37	$3.85 \cdot 10^{-7}$	$4.48 \cdot 10^{-7}$	$9.91 \cdot 10^{-7}$
6)	Rib Mix - Orange	0.422	43.64	268.01	153.67	$9.38 \cdot 10^{-7}$	$2.78 \cdot 10^{-6}$	$2.23 \cdot 10^{-6}$
6)	French Terry CO/EA - Mustard Yellow	0.231	170.35	160.35	121.53	$5.28 \cdot 10^{-7}$	$3.88 \cdot 10^{-7}$	$9.30 \cdot 10^{-7}$
7)	Rib Mix - Gray Melange	0.422	57.27	326.60	182.01	$2.92 \cdot 10^{-6}$	$5.50 \cdot 10^{-6}$	$6.73 \cdot 10^{-6}$
7)	Twill 2x1 Mix - Creme	0.21	668.44	1595.94	241.56	$1.44 \cdot 10^{-6}$	$1.00 \cdot 10^{-5}$	$2.04 \cdot 10^{-6}$
7)	Brushed Back Fleece PL/CO - Green	0.27	278.01	209.42	163.39	$1.26 \cdot 10^{-6}$	$2.21 \cdot 10^{-6}$	$1.02 \cdot 10^{-6}$
8)	Twill Tartan Mix - Wine Red/Black	0.202	550.31	609.38	88.28	$3.53 \cdot 10^{-7}$	$1.20 \cdot 10^{-6}$	$1.08 \cdot 10^{-6}$
8)	Rib Mix - Mint Green	0.279	53.17	111.76	45.27	$2.20 \cdot 10^{-7}$	$1.36 \cdot 10^{-6}$	$5.94 \cdot 10^{-7}$
8)	Twill CLY - Terracota Orange	0.207	395.20	502.39	62.81	$6.80 \cdot 10^{-7}$	$1.05 \cdot 10^{-6}$	$9.18 \cdot 10^{-7}$
9)	Plain Weave Windowpane WO - Navy	0.174	804.69	550.78	72.66	$1.07 \cdot 10^{-6}$	$6.17 \cdot 10^{-7}$	$5.65 \cdot 10^{-7}$
10)	Single Jersey CO - Gray Melange	0.196	170.35	307.07	177.11	$5.31 \cdot 10^{-8}$	$3.95 \cdot 10^{-7}$	$6.24 \cdot 10^{-7}$
10)	Rib Mix - Gray Melange	0.422	57.27	326.60	182.01	$2.92 \cdot 10^{-6}$	$5.50 \cdot 10^{-6}$	$6.73 \cdot 10^{-6}$
10)	Brushed Back Fleece CO/PL - Navy	0.431	385.20	424.26	239.61	$3.22 \cdot 10^{-6}$	$3.99 \cdot 10^{-6}$	$3.65 \cdot 10^{-6}$

Table 1: Mechanical parameters for every fabric used in the set of production garments. Units are kg/m^2 for density, N/m for stretch stiffness and $N \cdot m$ for bending stiffness.

Material Category	Density	Stretch Weft	Stretch Warp	Stretch Bias	Bending Weft	Bending Warp	Bending Bias
Soft	0.11	10	27	30	$14.0 \cdot 10^{-8}$	$4.4 \cdot 10^{-8}$	$8.6 \cdot 10^{-8}$
Stiff	0.23	400	530	110	$2.0 \cdot 10^{-6}$	$3.0 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$

Table 2: Mechanical parameters for the synthetic scenes. Units are kg/m^2 for density, N/m for stretch stiffness and $N \cdot m$ for bending stiffness.

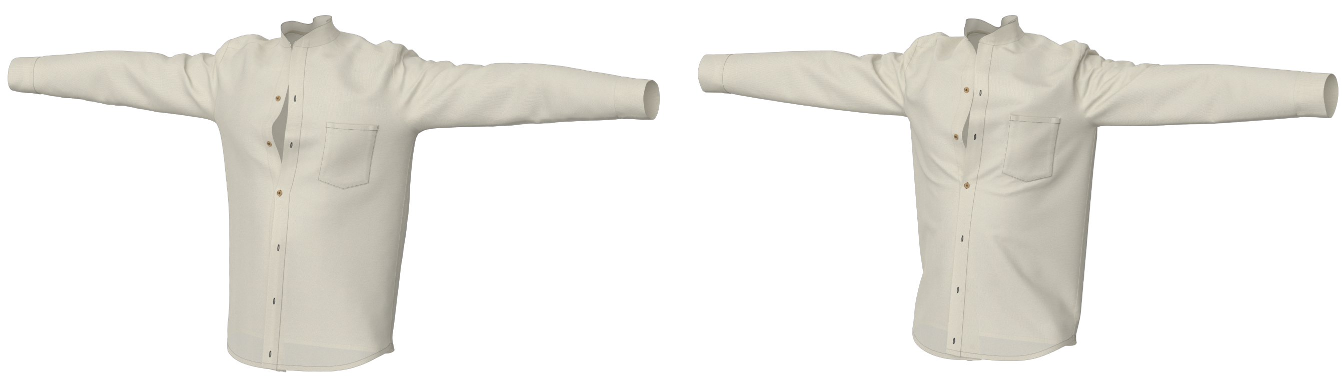

Fig. 2: Comparison of a shirt draped with the real time simulator (left) and our proposed simulator (right). The more realistic stiffness treatment of the latter leads to the appearance of tension wrinkles around the buttons, as well as a more realistic gathering of fabric at the shoulders due to the raised arms.

Multiplier	Coarse	Stiff Stretch	Compliant Bending	Stiff Bending	2 stack	3 stack
resolution	1.45	1	1	1	1.45	1.45
stretch	1	10	1	1	1	1
bending	1	1	0.1	10	1	1

Table 3: Multiplier values applied to the resolution, the stretch stiffness and the bending stiffness of the adjusted baseline materials for both C-IPC and our simulator. The baseline resolution is 3.5mm for both simulators. For C-IPC, the baseline material parameters are those of Section 6.1 of C-IPC [1], i.e. density: 472kg/m^3, E: 821000 Pa, ν: 0.243, thickness: 0.318mm. We then apply a multiplier of 0.01 for stretch and 0.1 for bending to get the adjusted baseline material, following C-IPC's own *"cloth_on_rotating_sphere"* example. For our simulator, the material parameters are chosen to match the mechanical behavior of the C-IPC adjusted baseline material. We used density: 0.158kg/m^2, stretch: 31N/m (all 3 directions), bending: $1.7 \cdot 10^{-6}$ $N \cdot m$ (all 3 directions).

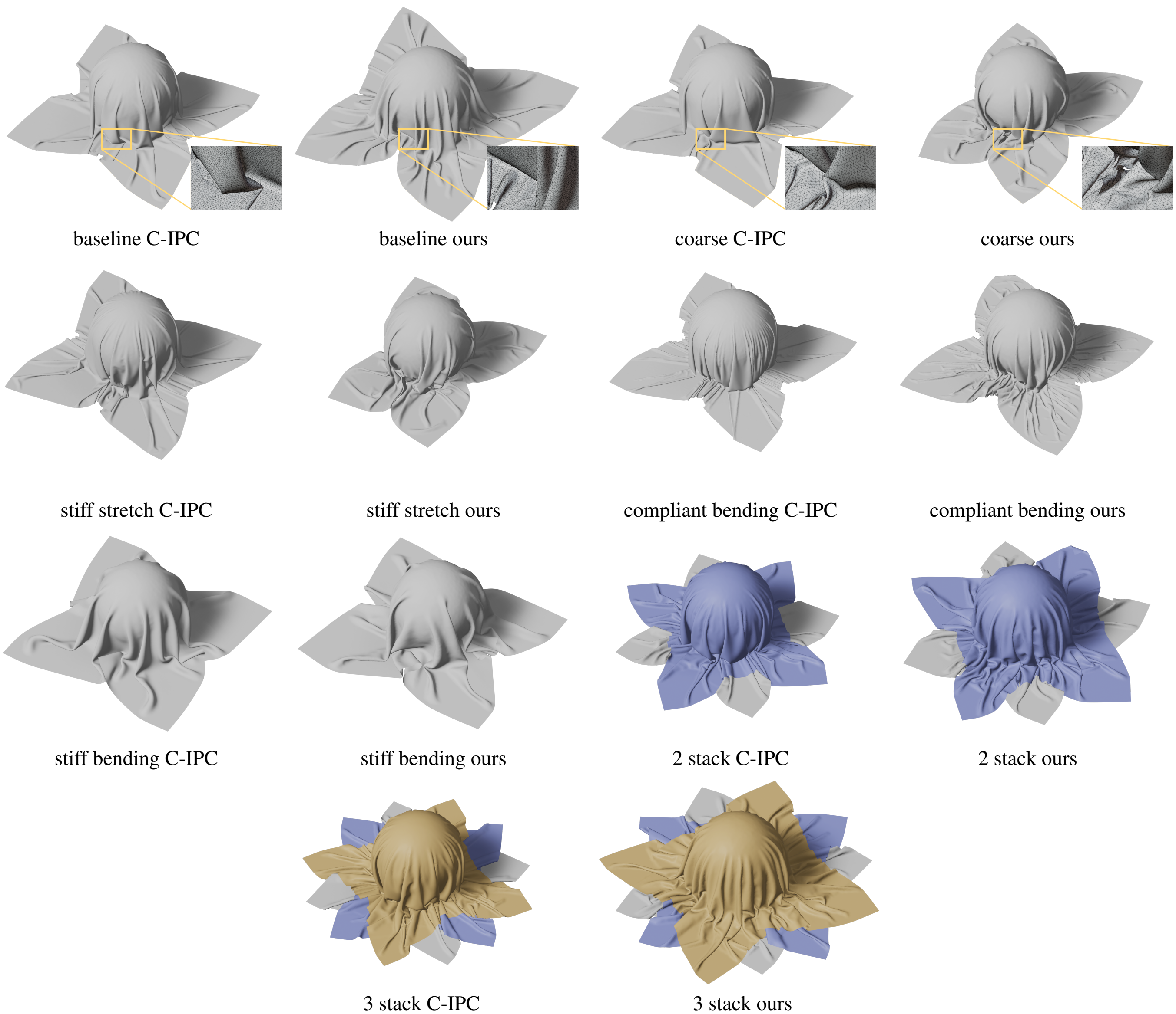

Fig. 3: Draping comparisons of our simulator with the C-IPC simulator for different scenes. Starting from a baseline scene of a patch of fabric falling onto a sphere, we alternately modify the discretization resolution, the stretch stiffness, the bending stiffness and the number of stacked patches to test different conditions. The inset figures show triangulation details for the baseline and coarse meshes. We encourage the reader to zoom into the figures for greater detail.