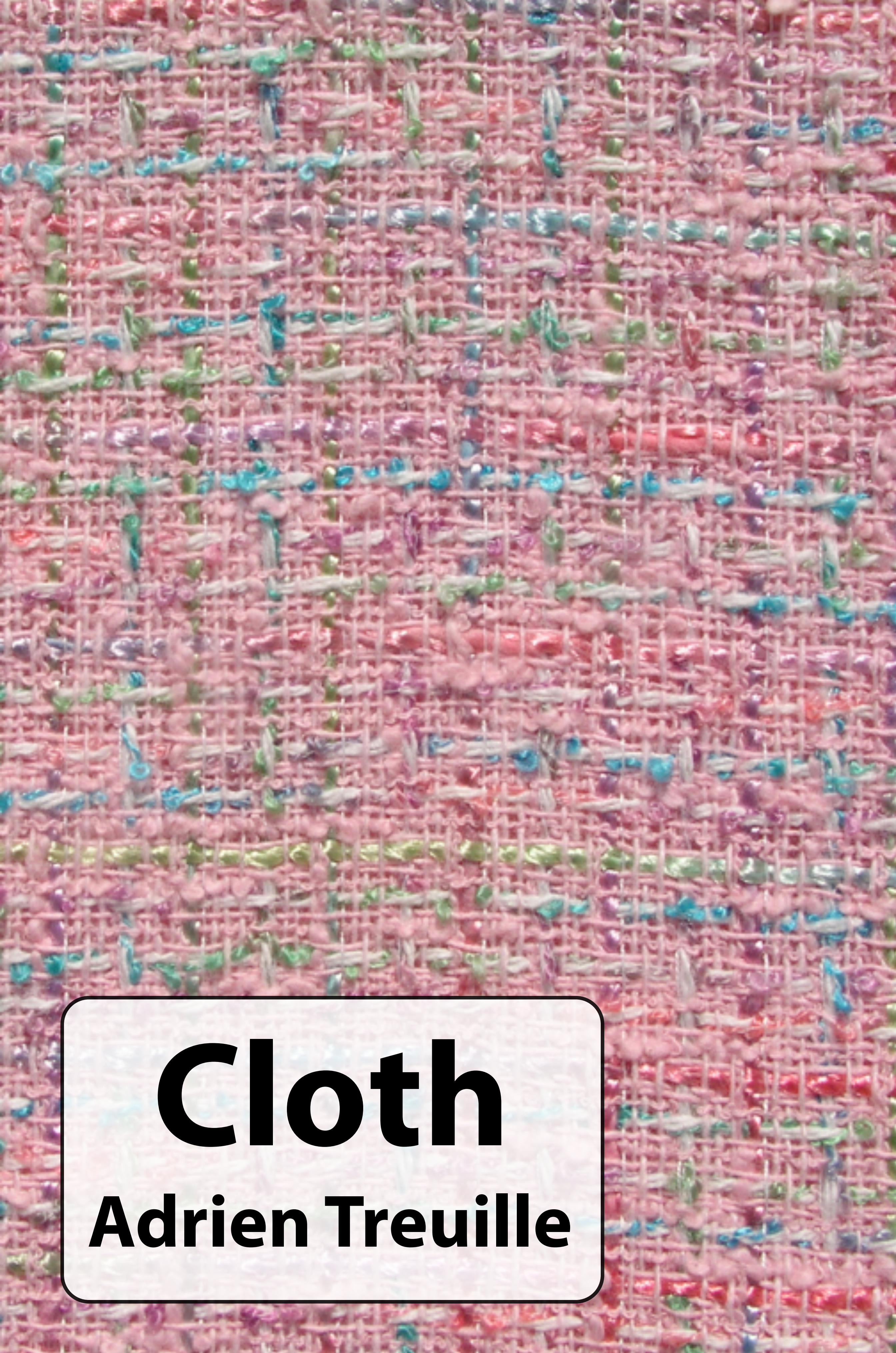
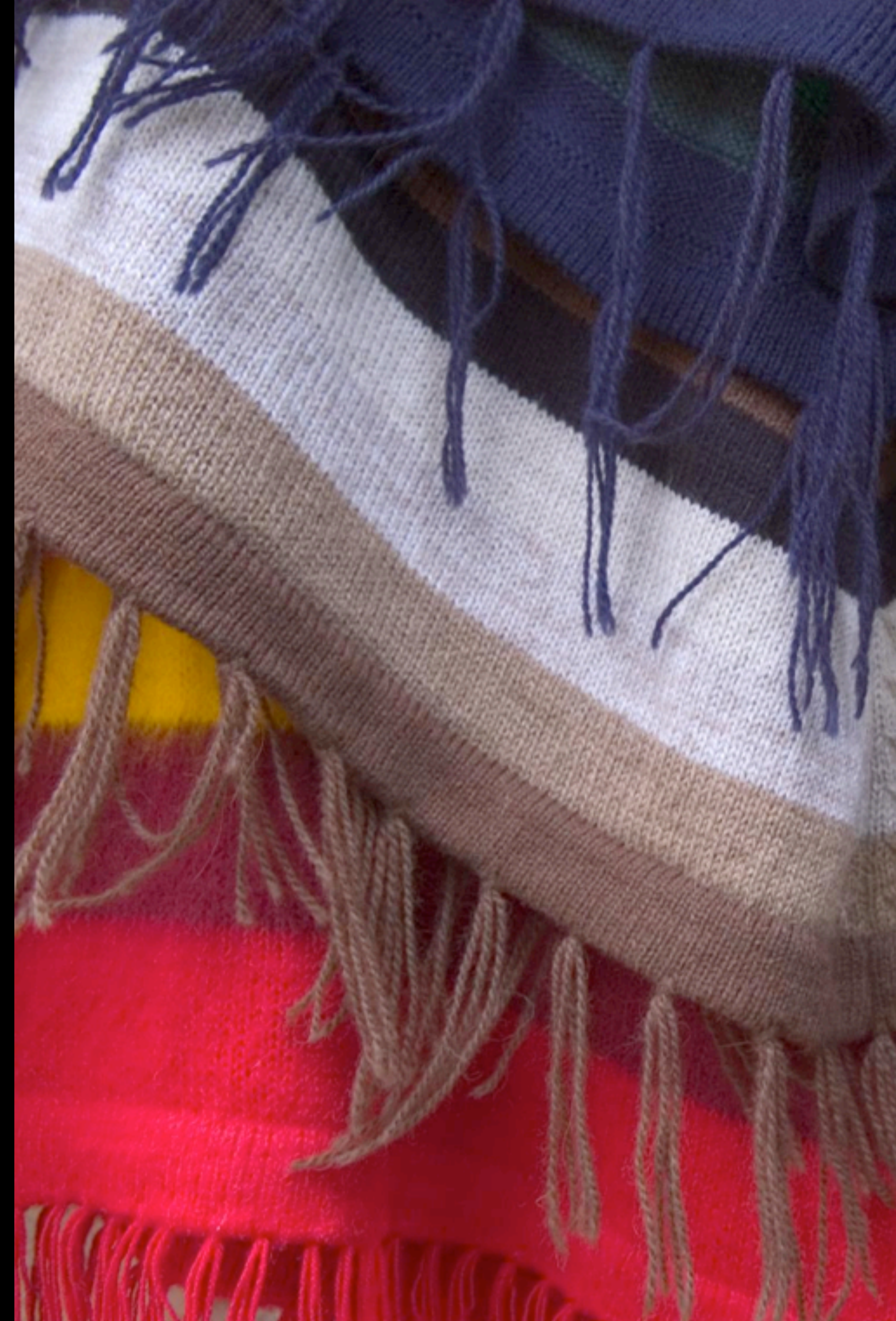
Cloth

Adrien Treuille





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- Real Cloth
- Springs
  - Spring-based Cloth
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  - Hamiltonian Cloth
- Inextensible Cloth
- “Creating” cloth.
- Collisions
- QUESTIONS

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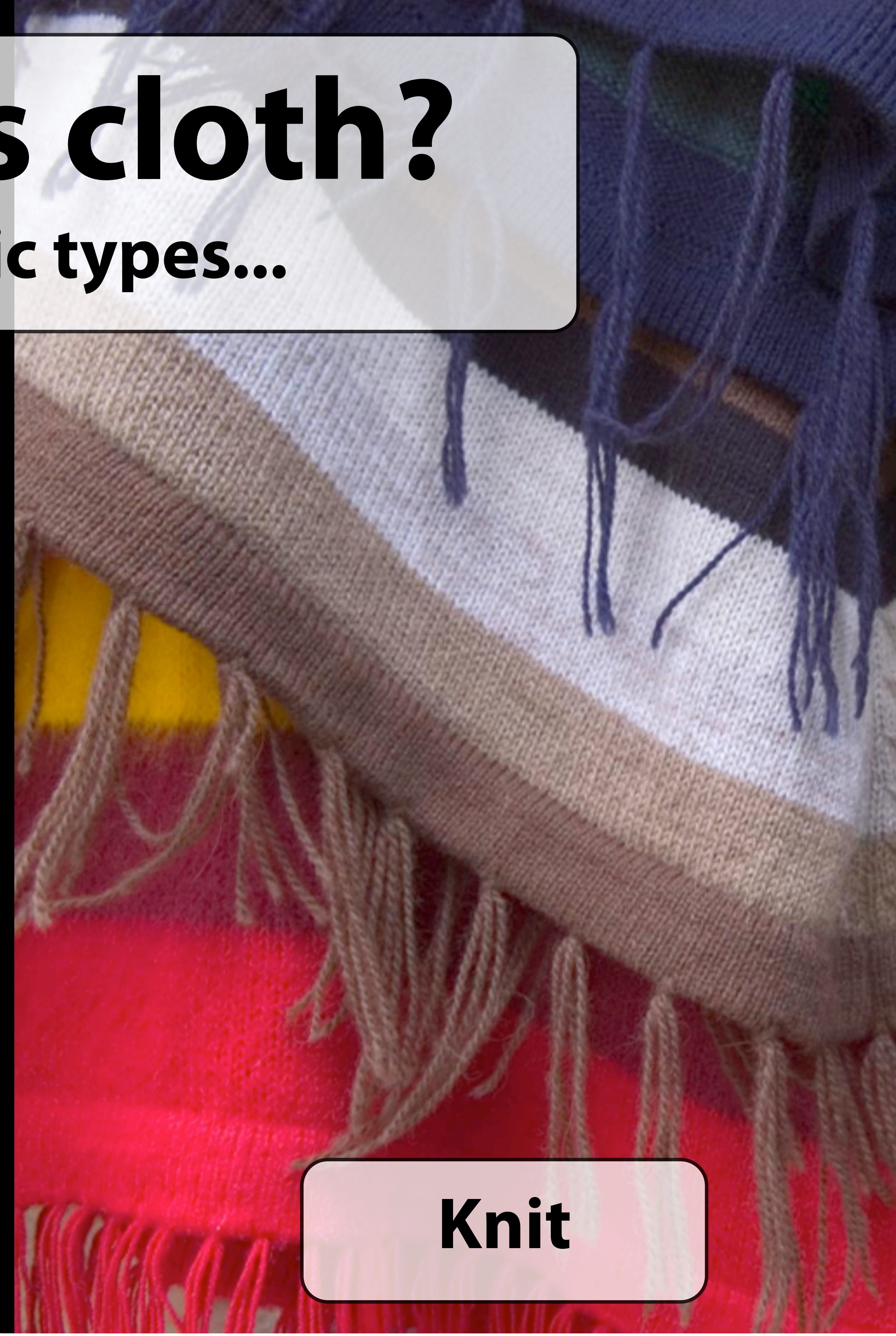
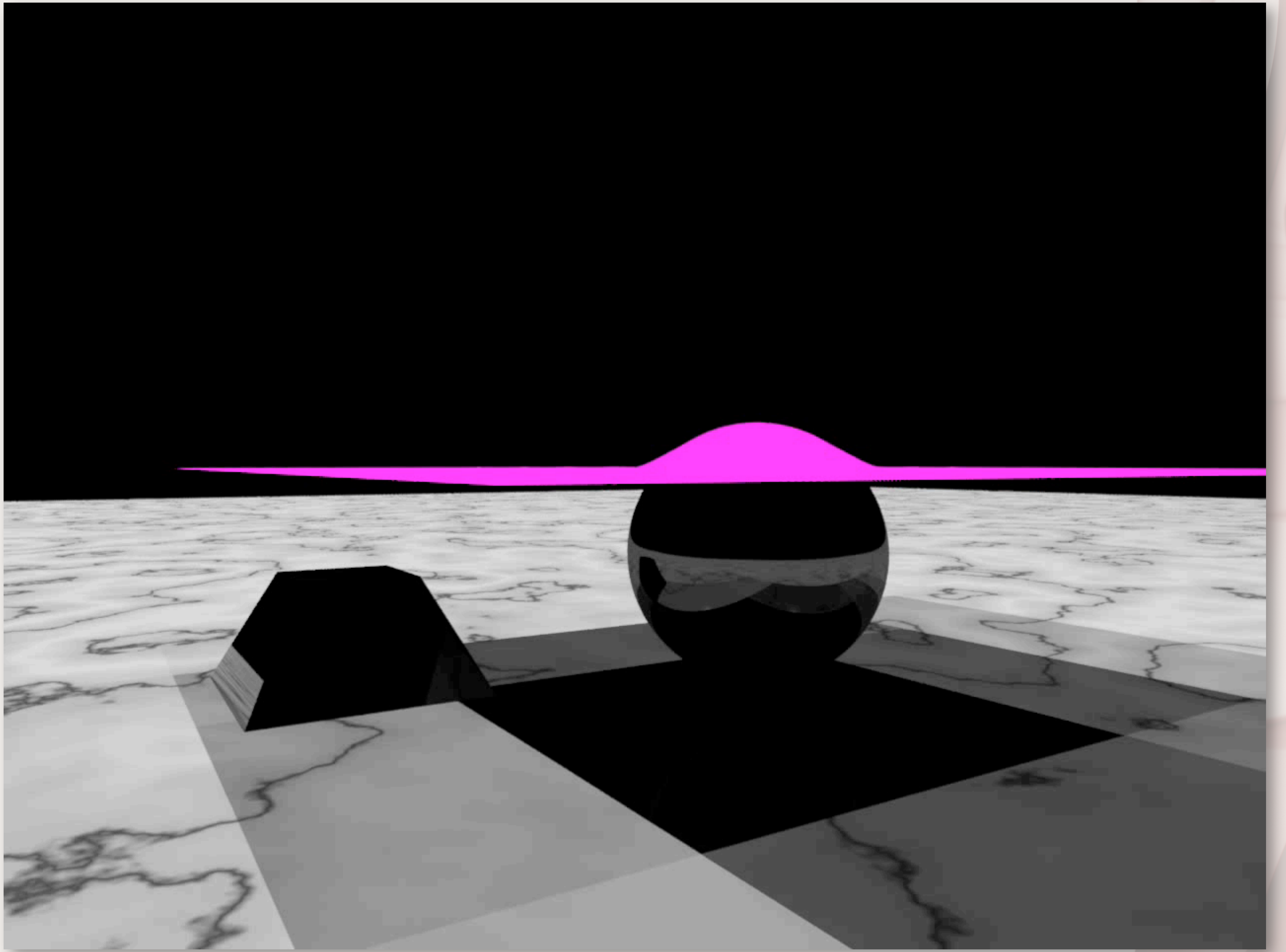
What is cloth?

Two basic types...



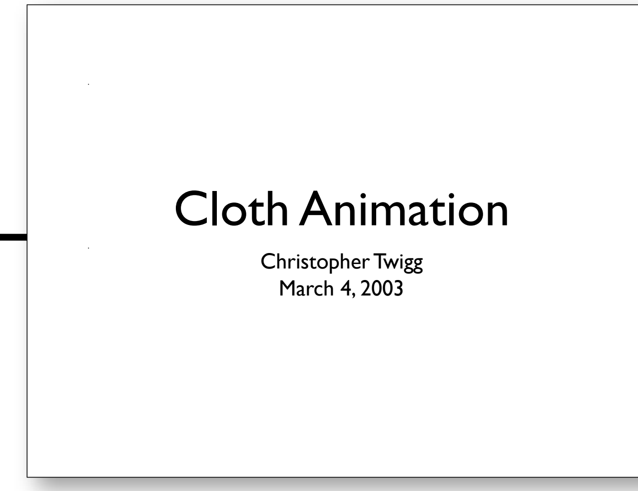
Woven Cloth



Bridson, R., Marino, S. and Fedkiw, R., "Simulation of Clothing with Folds and Wrinkles", ACM SIGGRAPH/Eurographics Symposium on Computer Animation (SCA), edited by D. Breen and M. Lin, pp. 28-36, 2003.

Knit Cloth

Jonathan Kaldor, Doug L. James, and Steve Marschner. Simulating Knitted Cloth at the Yarn Level. SIGGRAPH 2008.



What is cloth?

- 2 basic types: woven and knit
- We’ll restrict to woven
  - Warp vs. weft

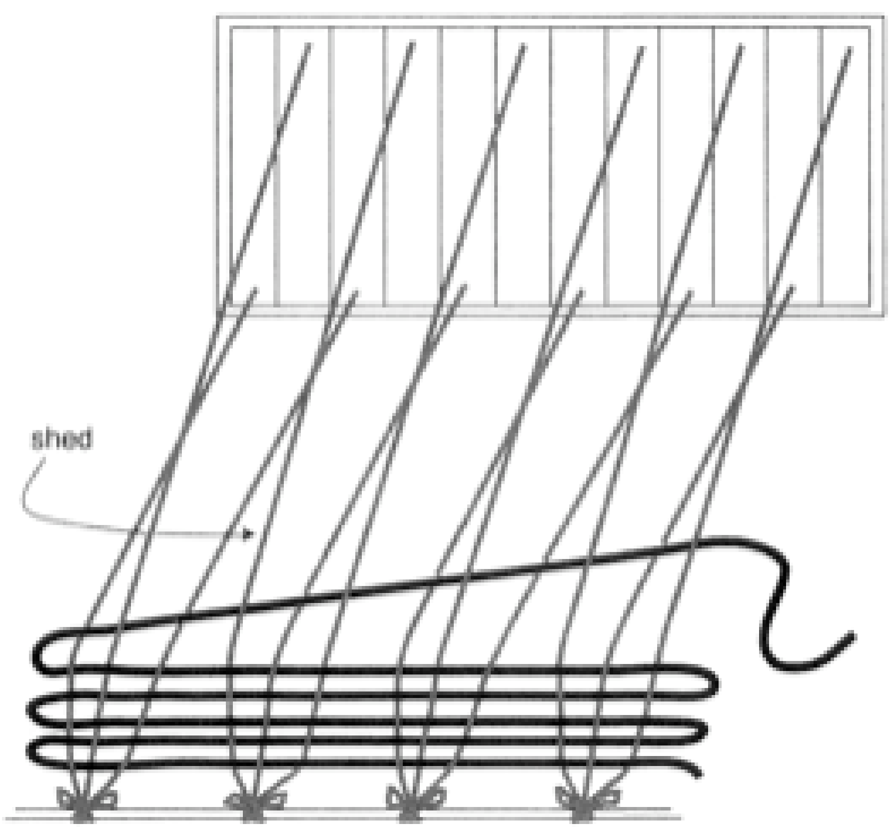
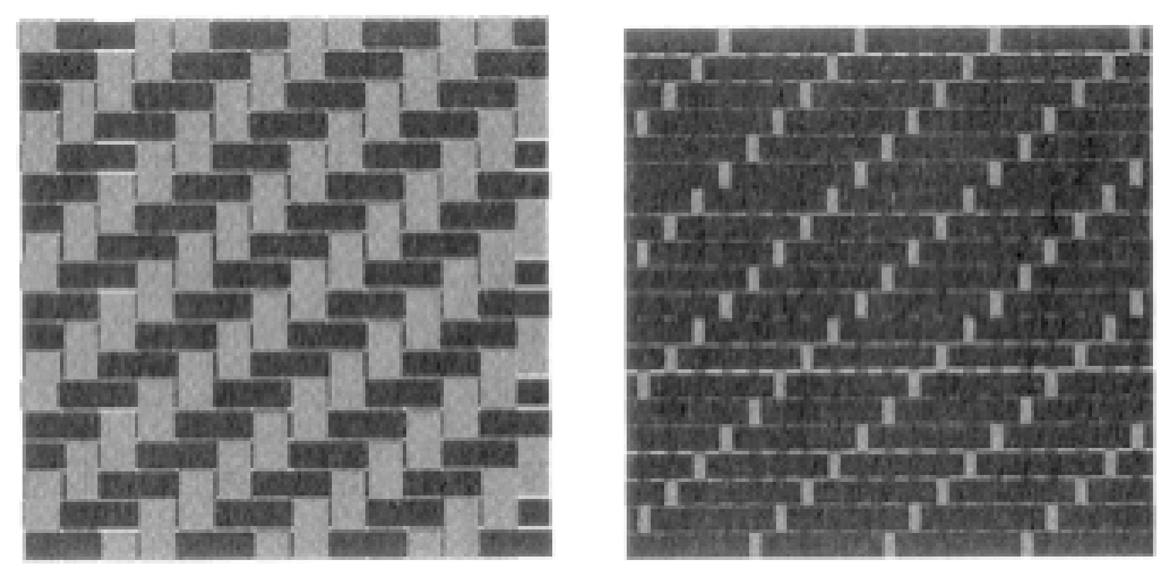


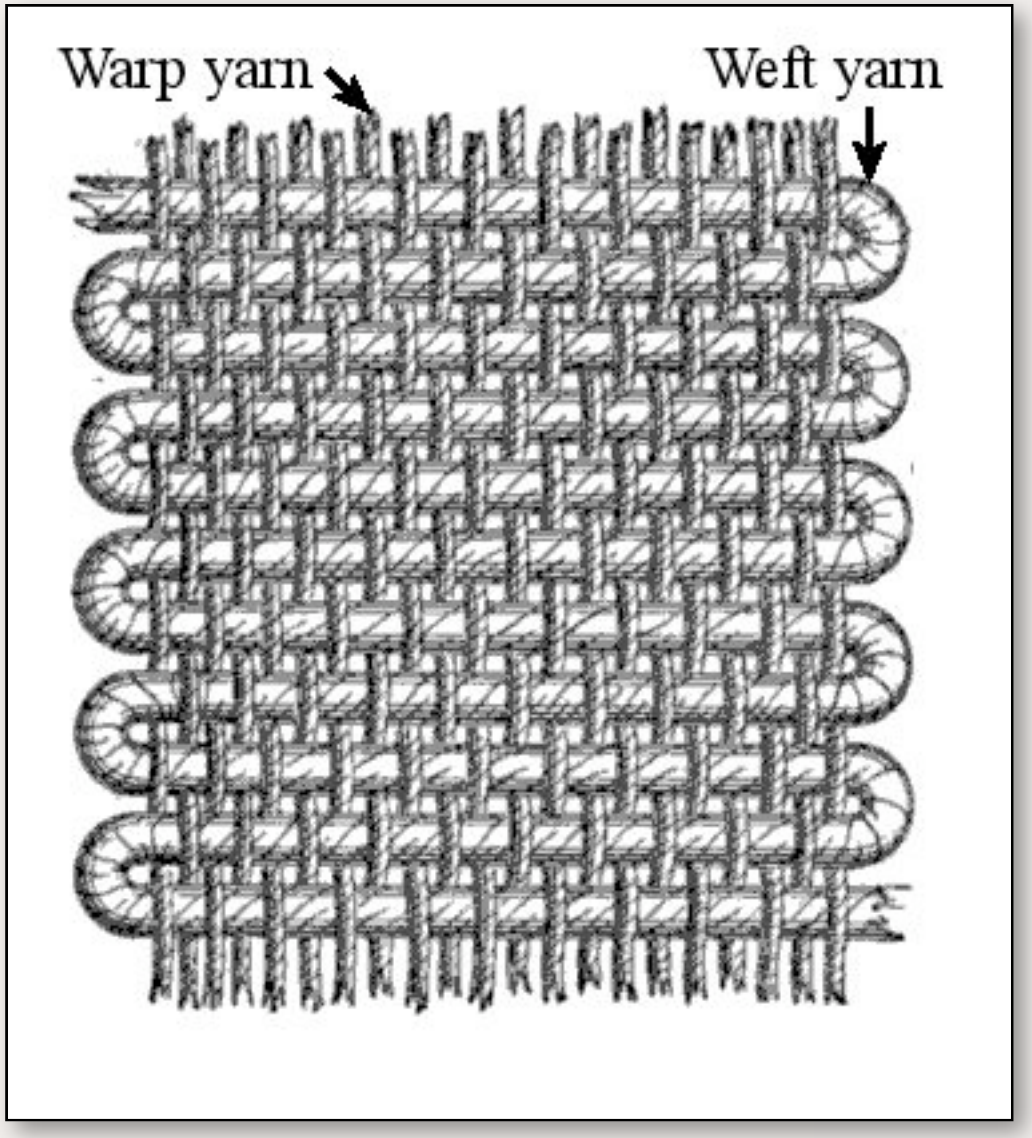
Figure 1.8. The weaving process.

House, Breen [2000]



b) twill   c) satin

Warp and Weft



source: Wikipedia

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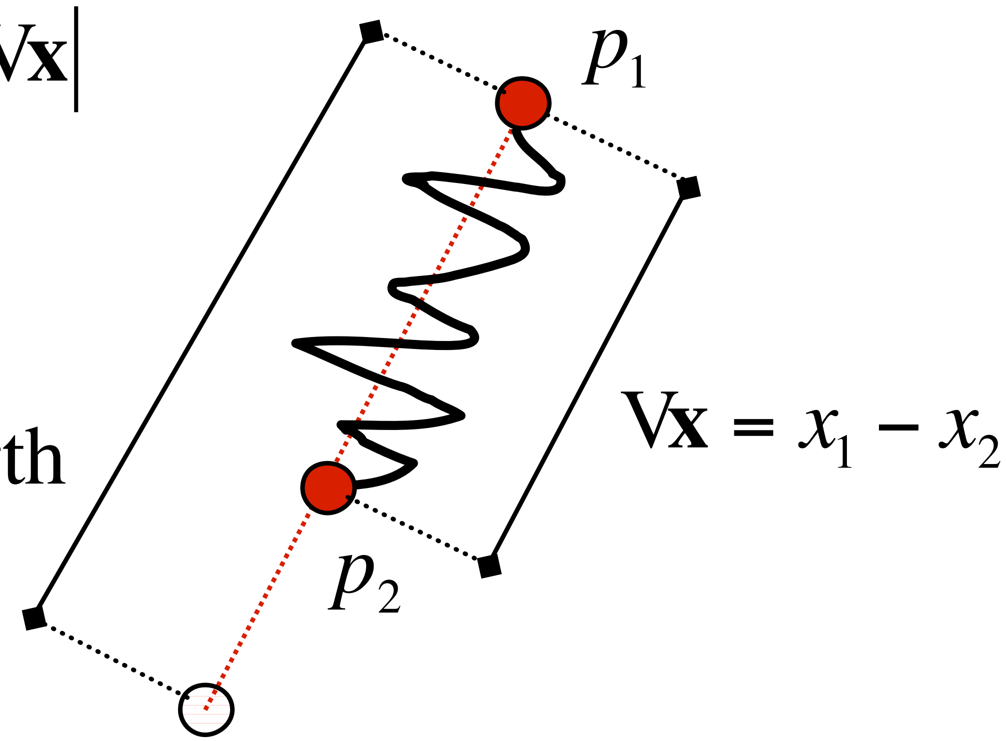
Damped spring

Force law:

$$\mathbf{f}_1 = -\left[k_s\left(\left|\mathrm{V}\mathbf{x}\right| - \mathbf{r}\right) + k_d\left(\frac{\mathrm{V}\mathbf{v}\mathrm{V}\mathbf{x}}{\left|\mathrm{V}\mathbf{x}\right|}\right)\right]\frac{\mathrm{V}\mathbf{x}}{\left|\mathrm{V}\mathbf{x}\right|}$$

$$\mathbf{f}_2 = -\mathbf{f}_1$$

$\mathbf{r}$ = rest length



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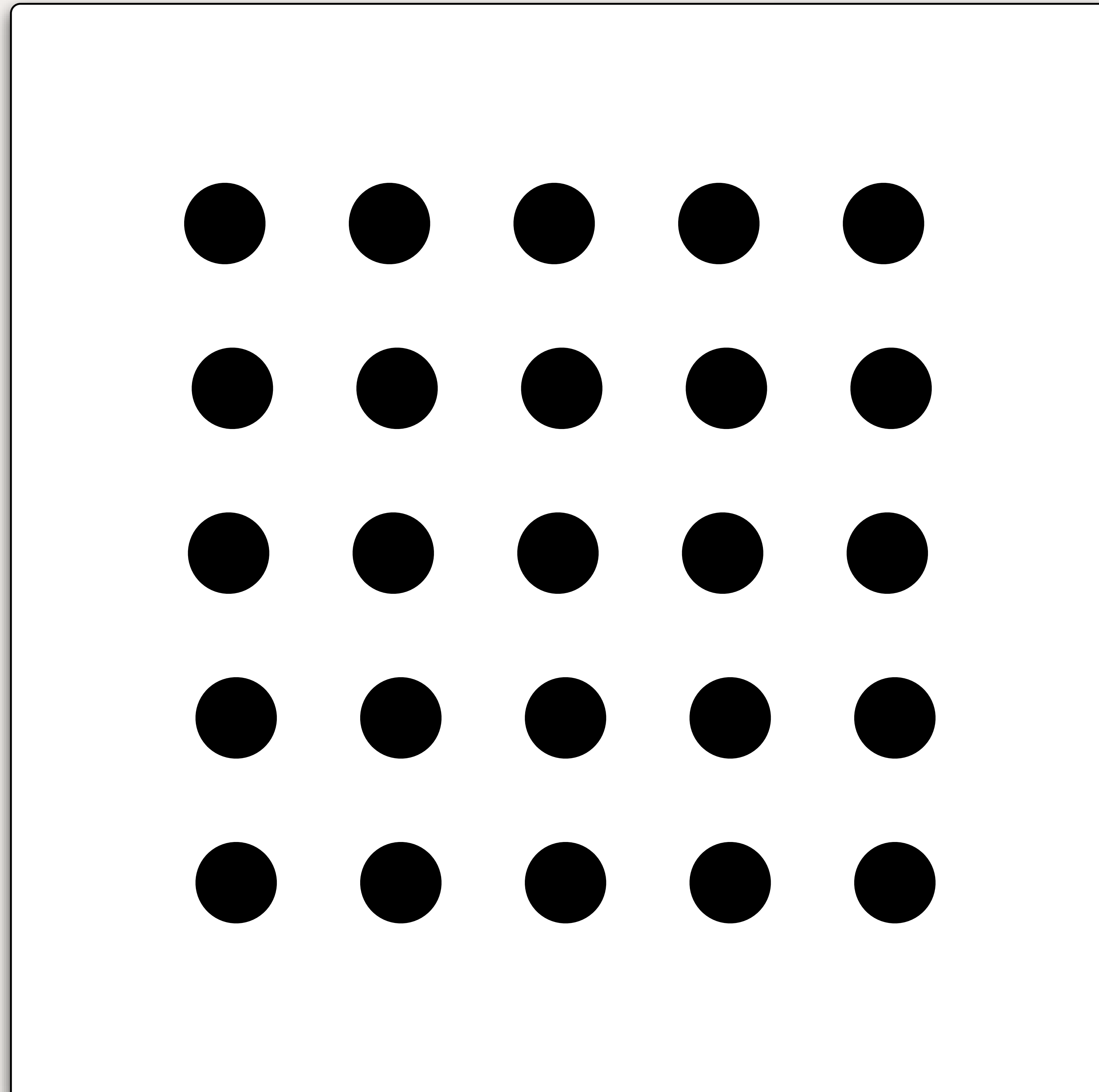
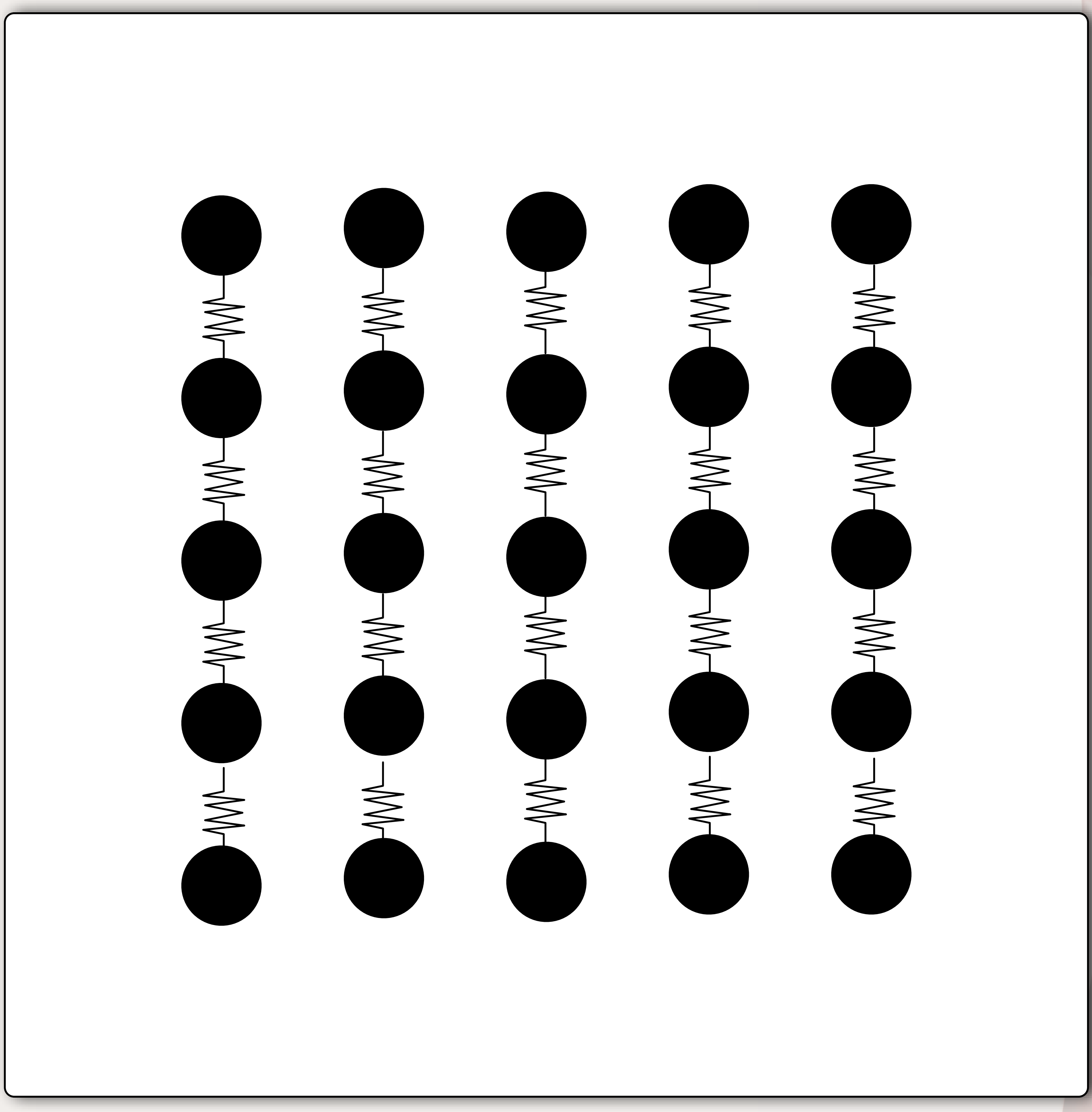
Resistance To...

- Stretching
- Shearing
- Bending

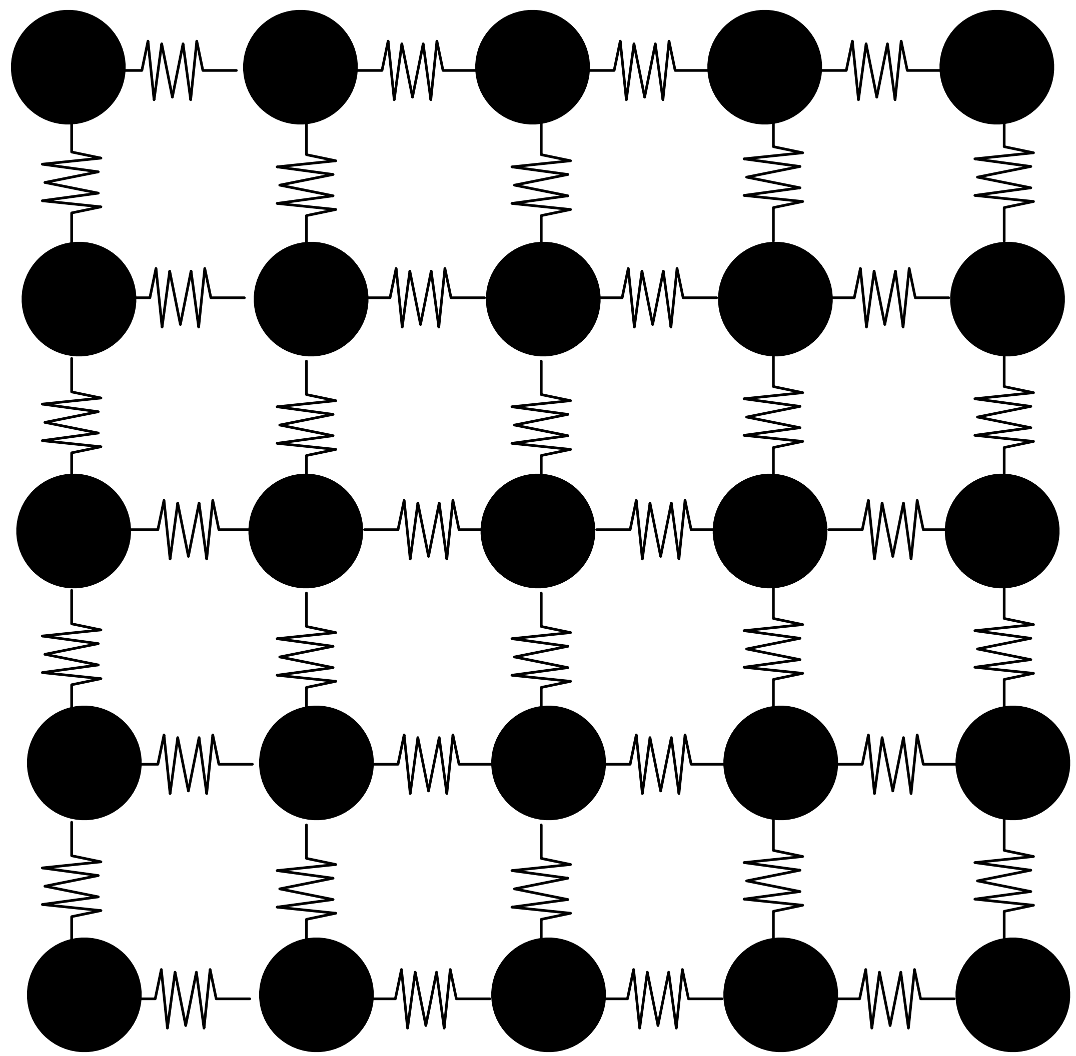
Basic Model



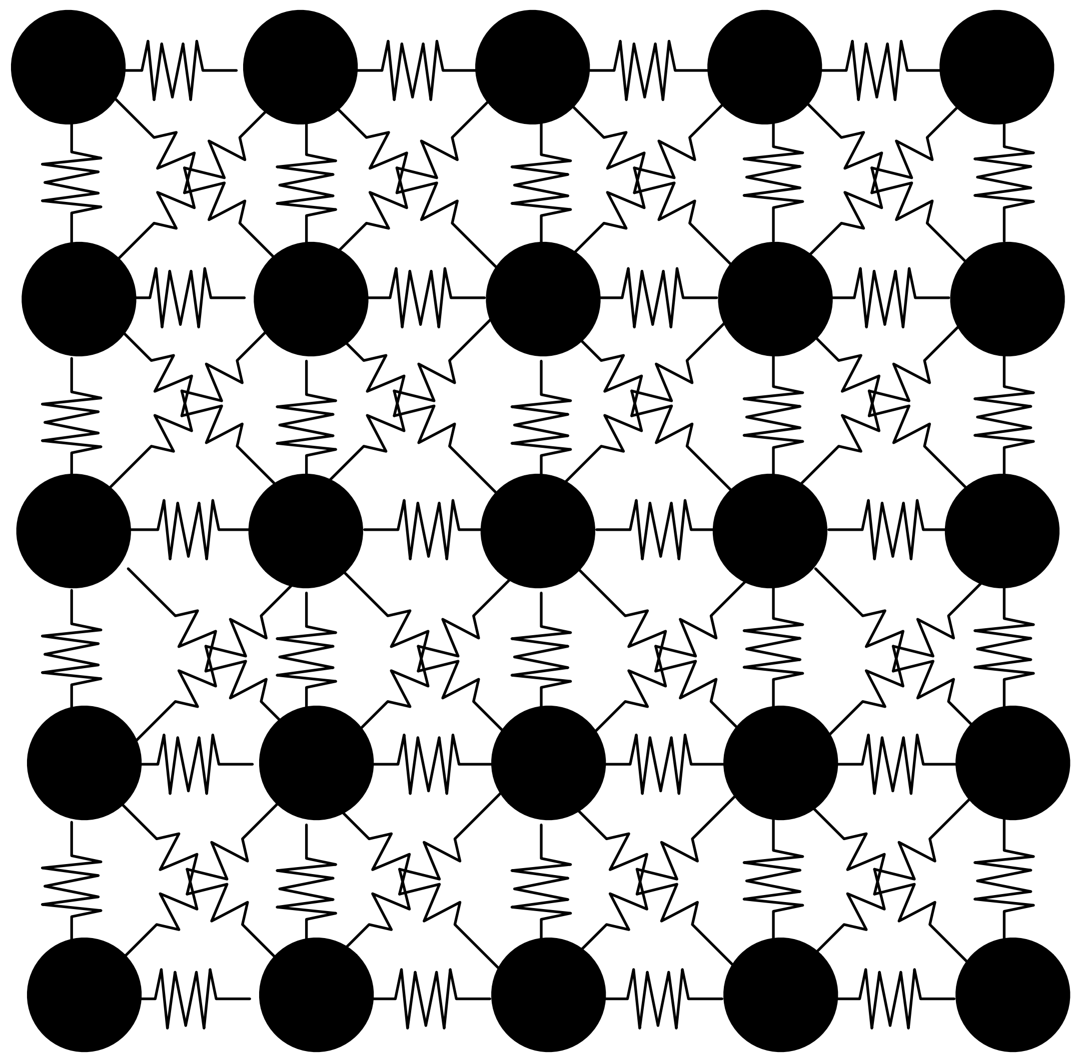
Warp Srings



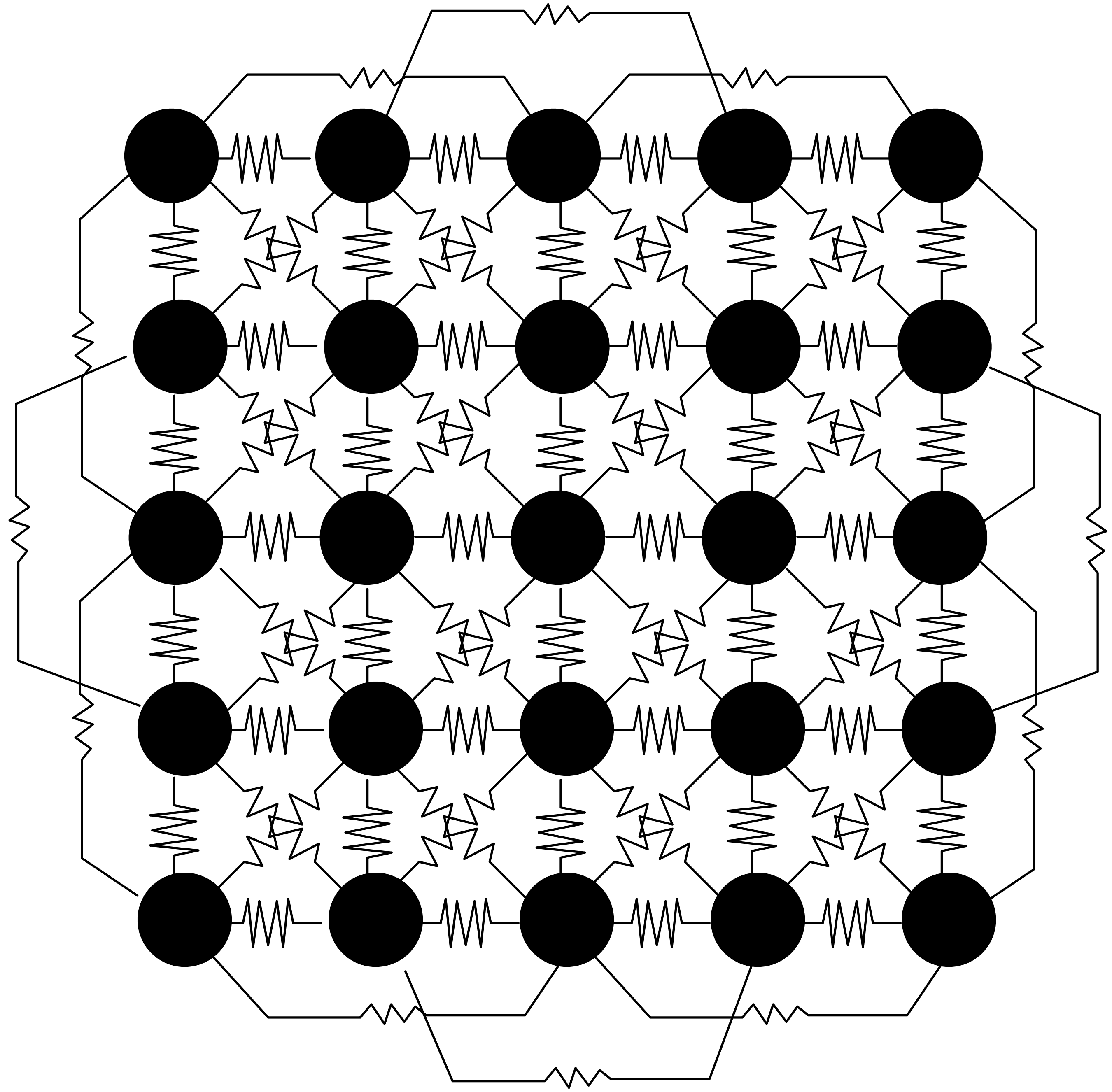
Weft Springs



Shear Springs



Bend Springs



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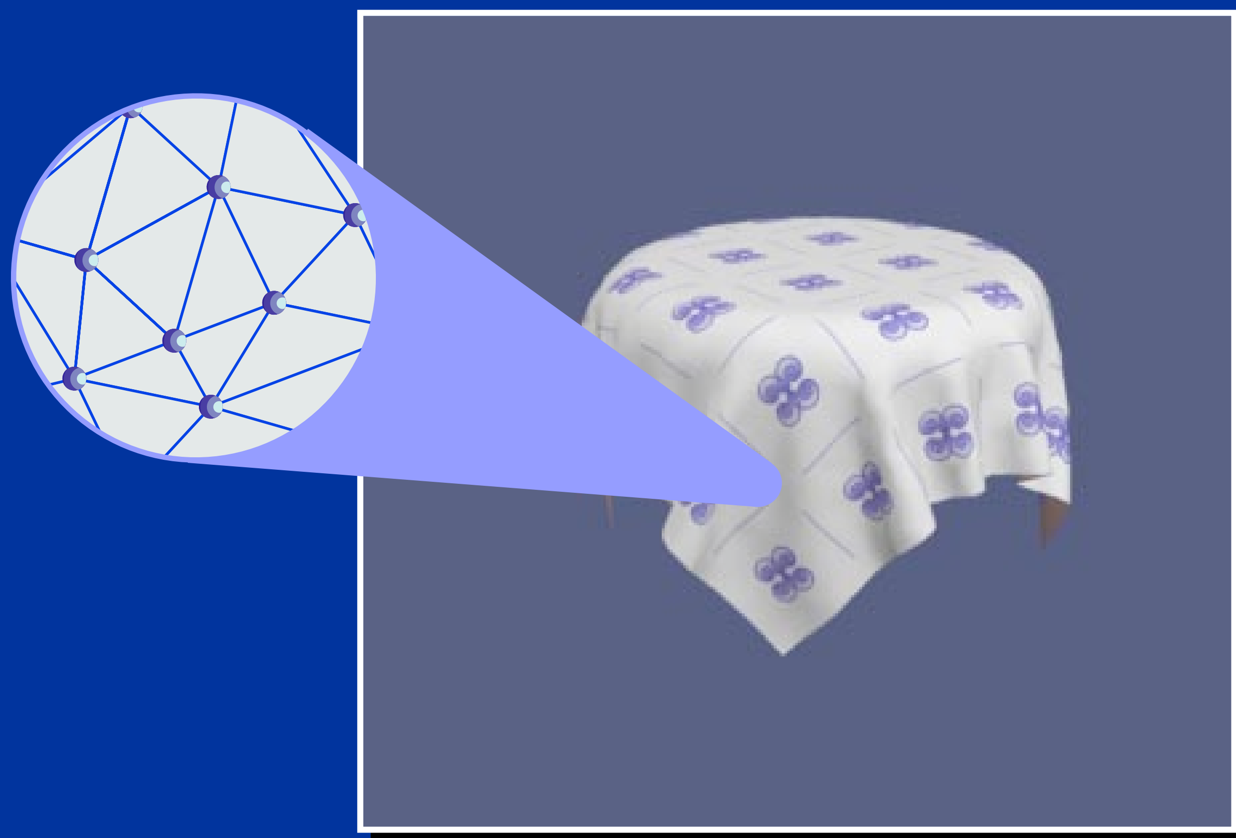
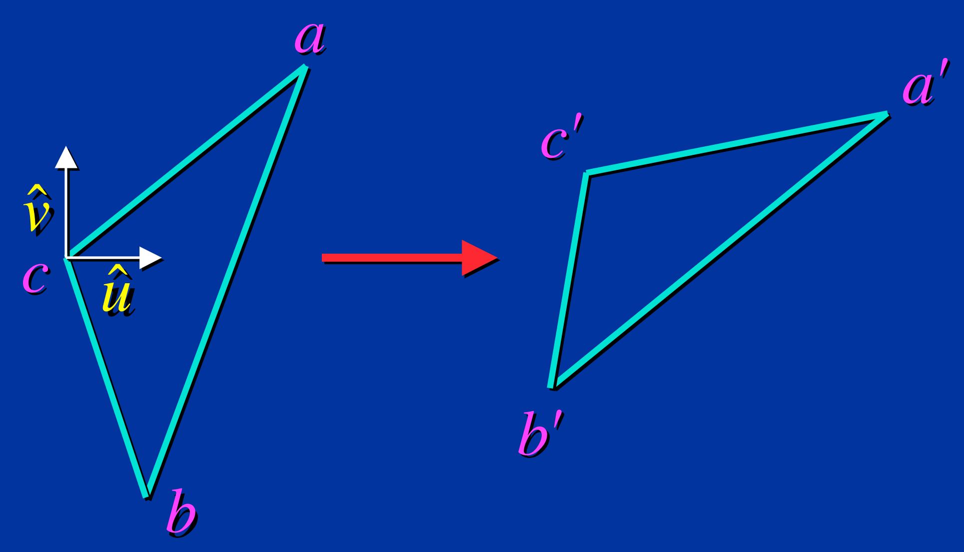
Discretization



Triangle Energy

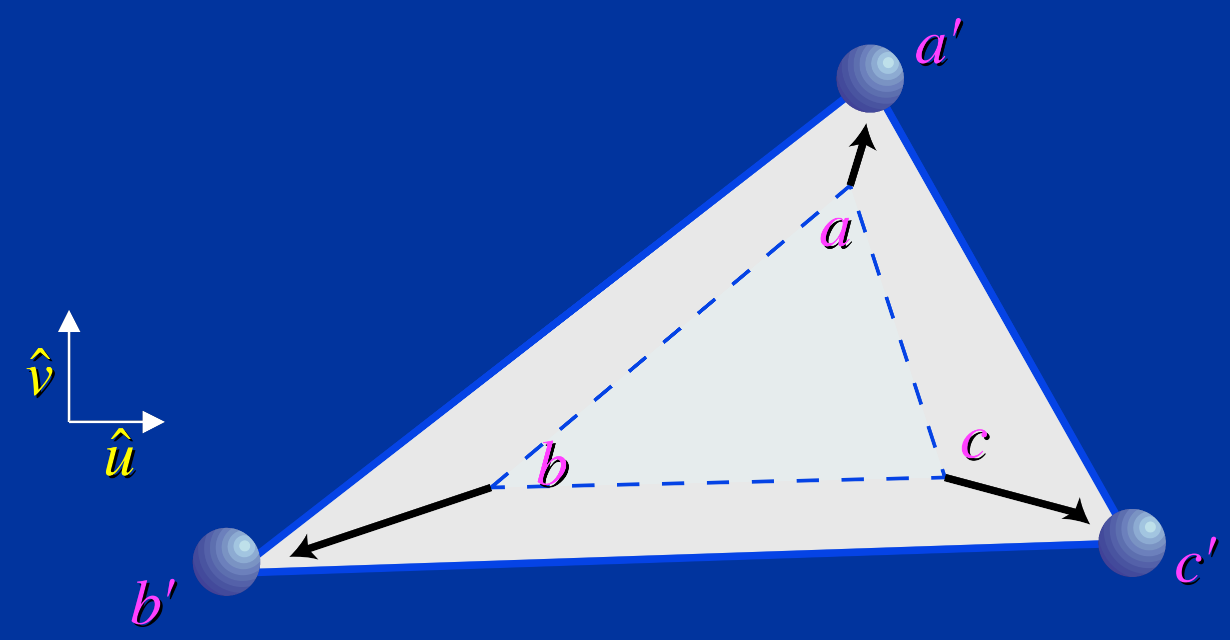


First, compute the affine transformation T that maps: $T : a \rightarrow c'$

$$b \rightarrow b'$$

$$c \rightarrow c'$$

Triangle Stretch Energy

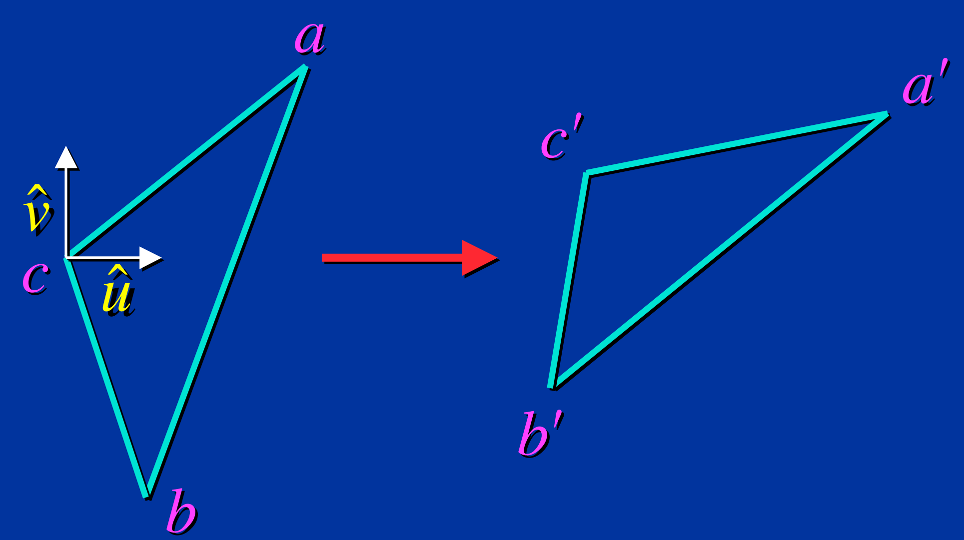


Now compute the stretch energy.

$$S_u = \|T(\hat{u})\| - 1$$

$$E_{\text{stretch}} = \tfrac{1}{2}k(S_u^2 + S_v^2)A$$

Triangle Shear Energy

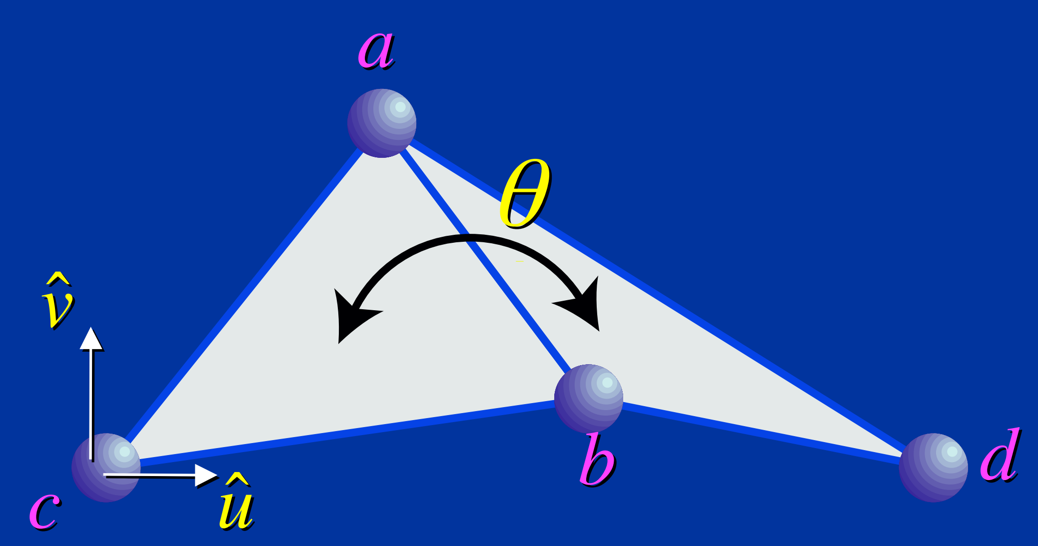


Next compute the shear energy.

$$\theta = \cos^{-1}(T(\hat{u}) \bullet T(\hat{v}))$$

$$E_{\text{shear}} = \frac{1}{2} k \theta^2 A$$

Triangle Bend Energy



$$\kappa = \frac{\theta}{l_{perp}}$$

Finally compute the bend energy.

$$E_{\text{bend}} = \frac{k}{2}(\kappa^2)A$$

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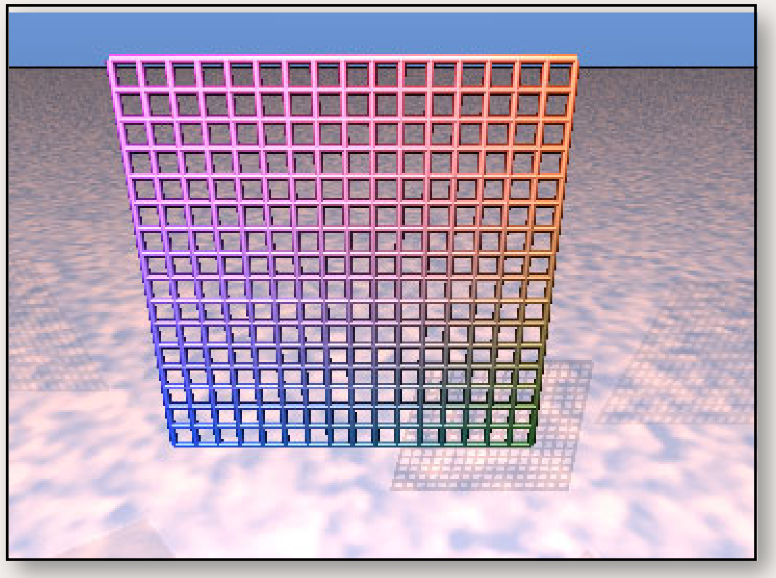
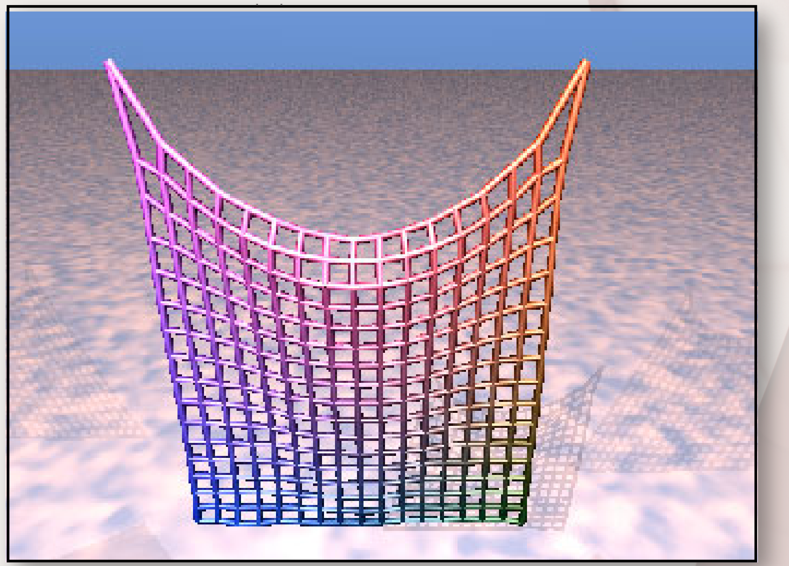
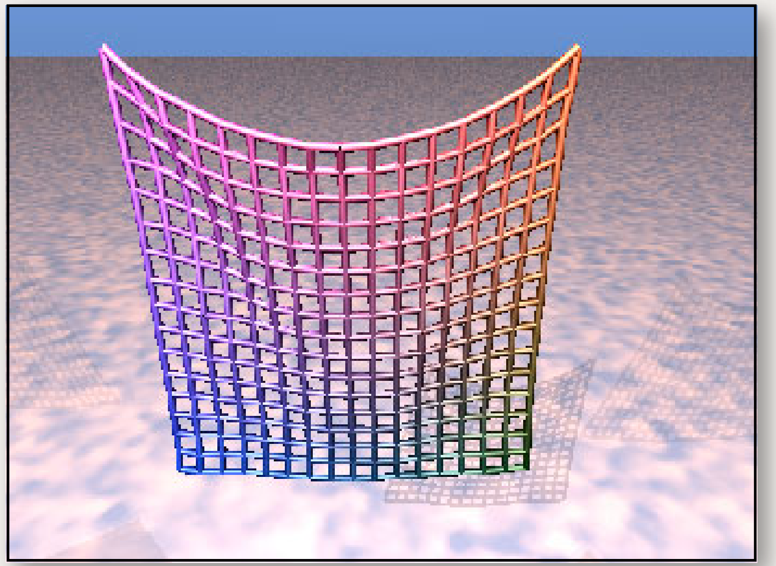
Springs vs. Constraints



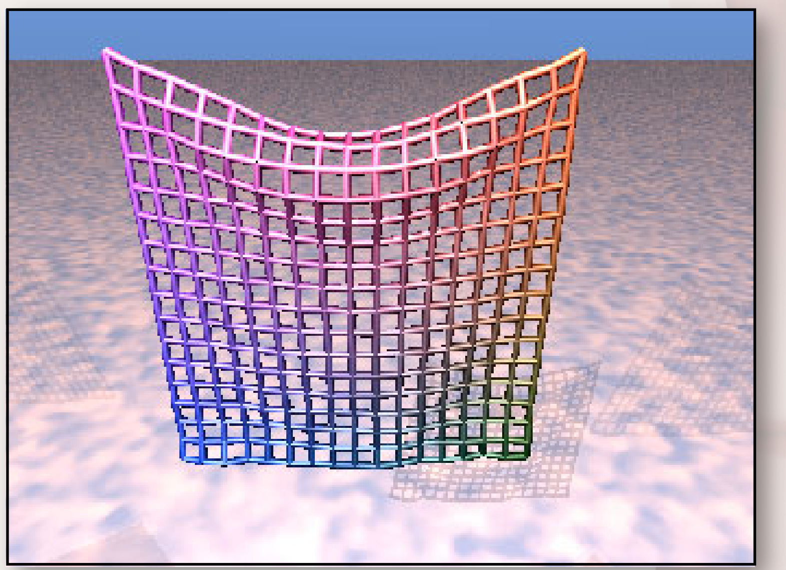
Before Simulation



Only Springs



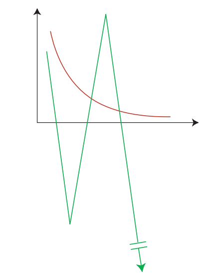
Stretch Constraints

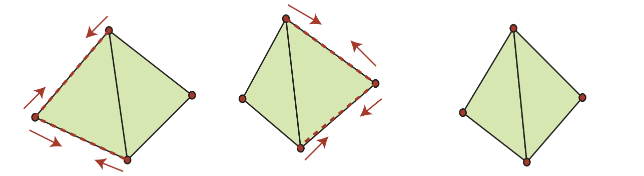


Stretch+Shear Constraints

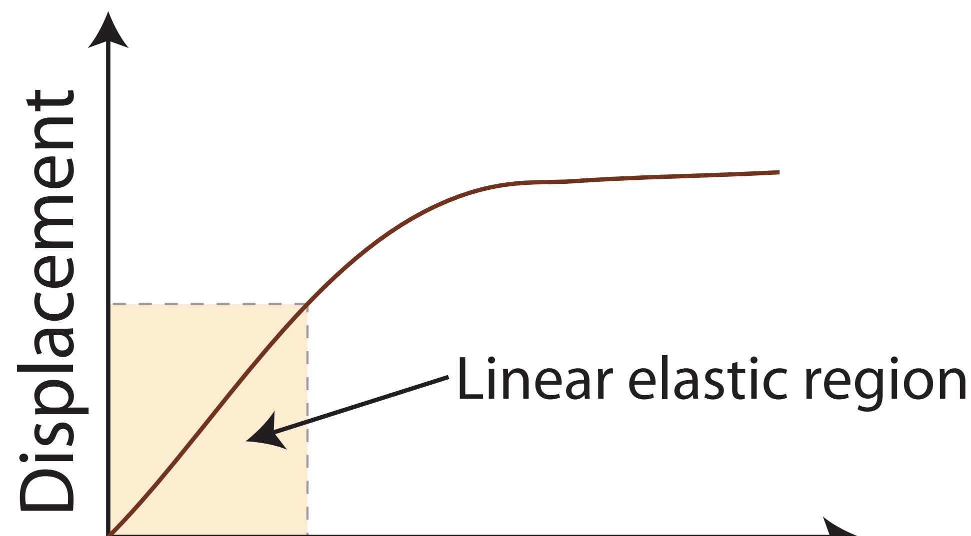
Source: Xavier Provot
Deformation Constraints in a Mass-Spring Model to Describe Rigid Cloth Behavior

Avoiding stiffness (2)

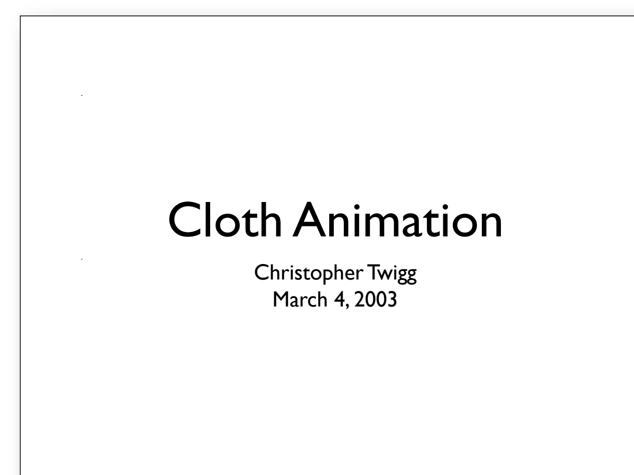




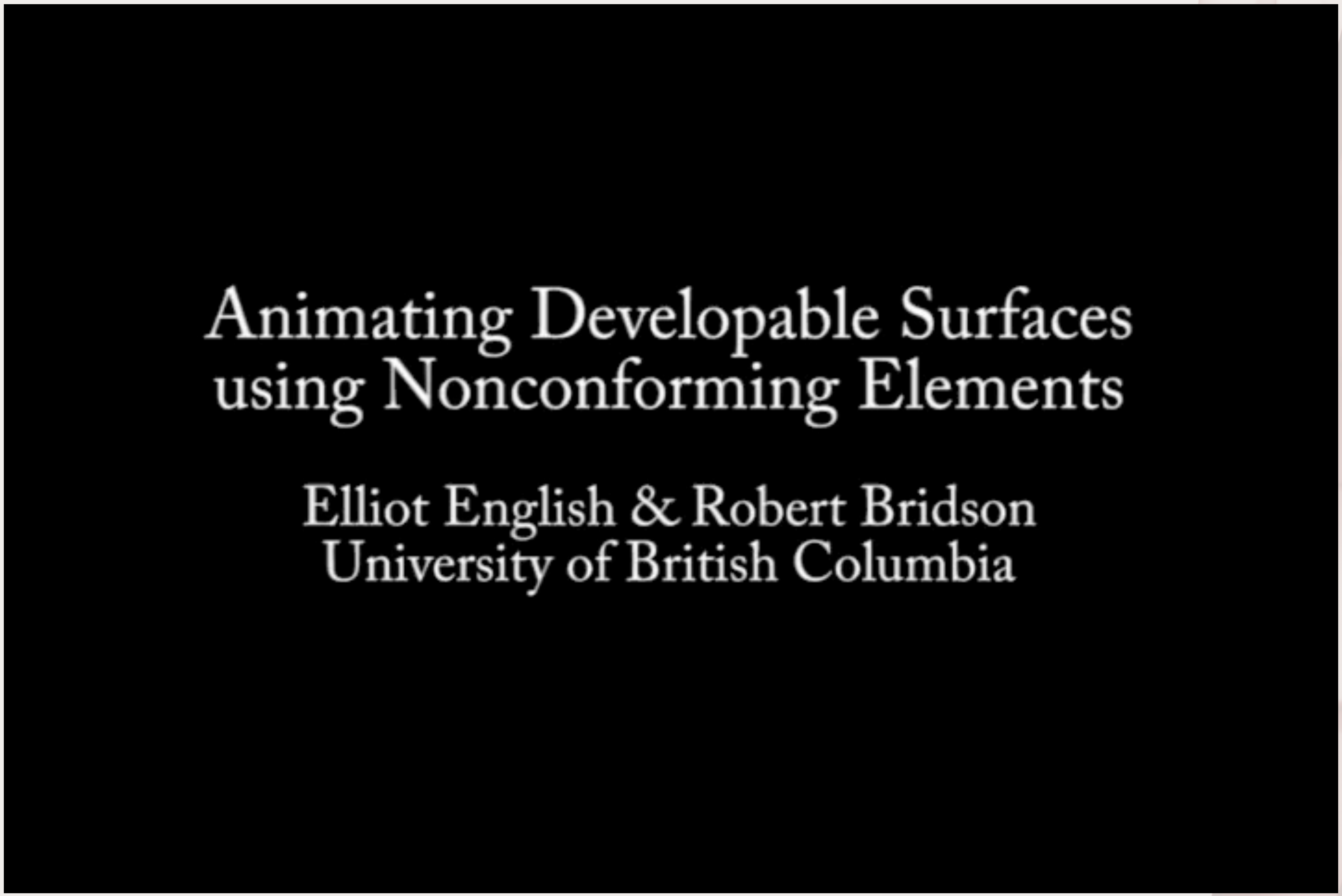
- Popular for interactive applications
- Justification
  - Biphasic spring model
  - Plausible dynamics



From Desbrun, Meyer, Barr [2000]



Developable Surfaces



Developable Surfaces

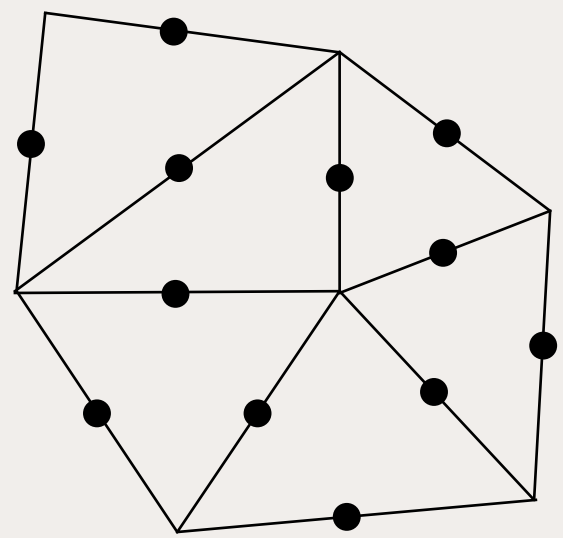
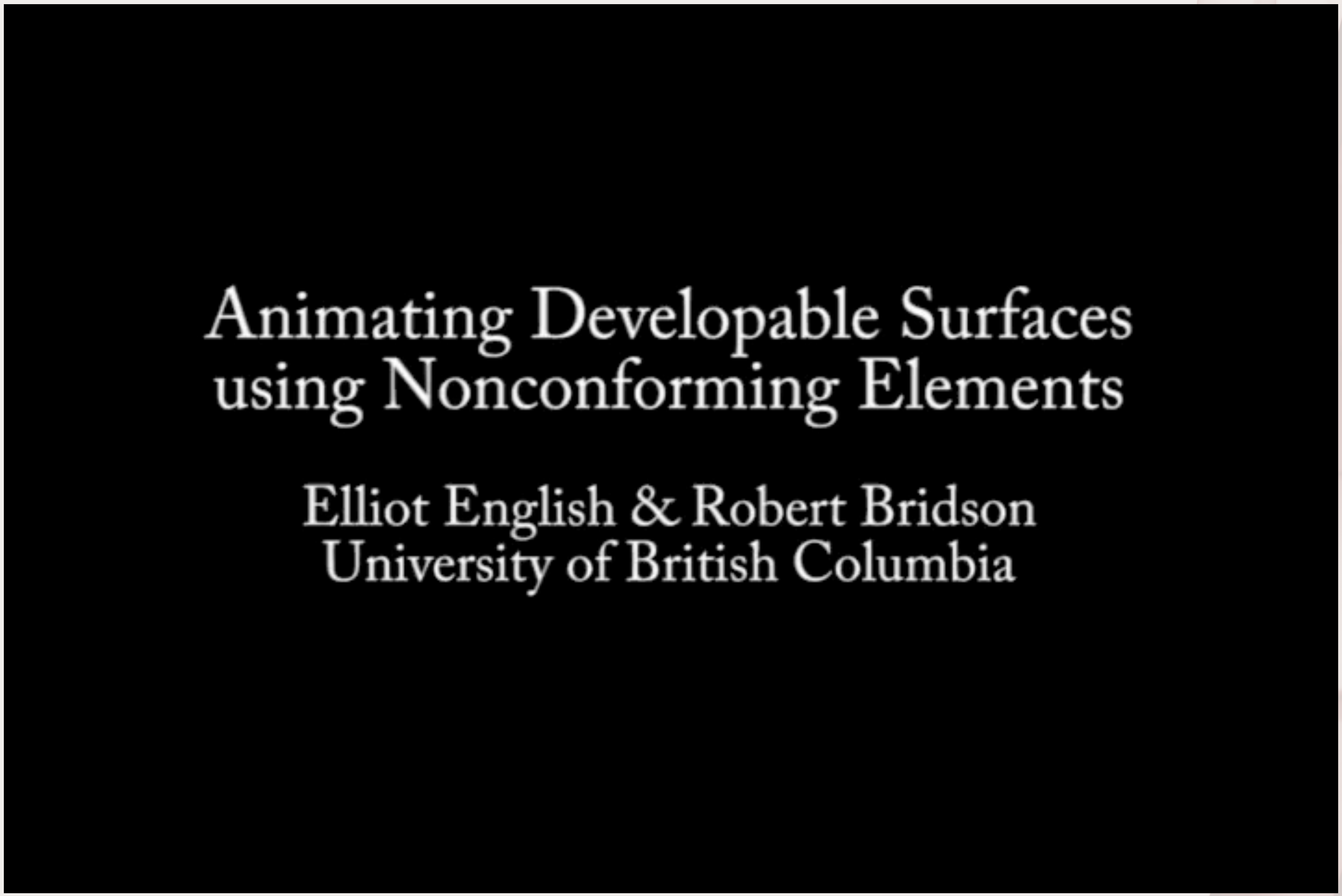


Figure 2: *Schematic of nonconforming variables, located at midpoints of edges between triangles. While continuous at these points, the surface may be discontinuous along the rest of each edge.*

Elliot English*
University of British Columbia

Robert Bridson†
University of British Columbia

Developable Surfaces



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Creating Clothes

- How could we create the 3D model the clothes for a character?

Non-flat Cloth

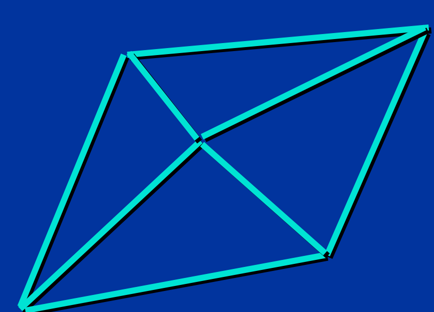
Non-flat cloth is strange stuff:

A baseball with no seams?

Wrinkles give strength?

Clothing cut out of a volume?

Convexities that pop?



Even 4 Triangles are over-constrained:
16 rest angles, 8 rest lengths.
24 constraints on 15 dofs.
Must be consistent!

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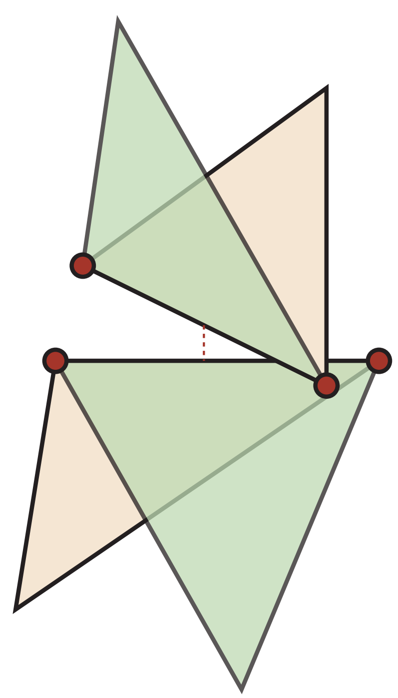
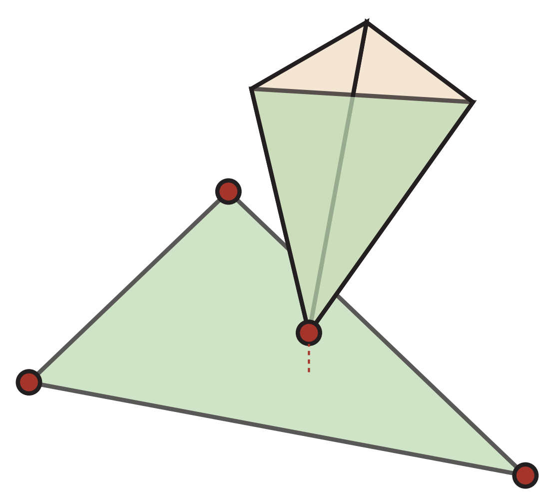
Collision detection

- We already covered this for deformable bodies
- Many of the same methods work, especially acceleration methods
- Generally need to do triangle-triangle collision checks:

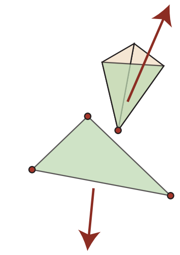


Edge-edge collision



Point-face collision

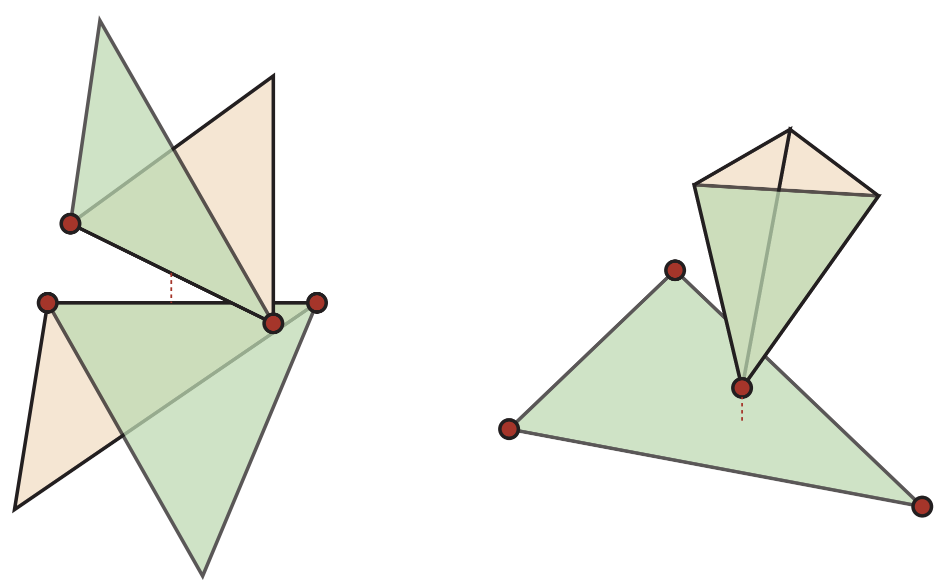
Robust collision detection



If triangles are moving too fast, they may pass through each other in a single timestep.

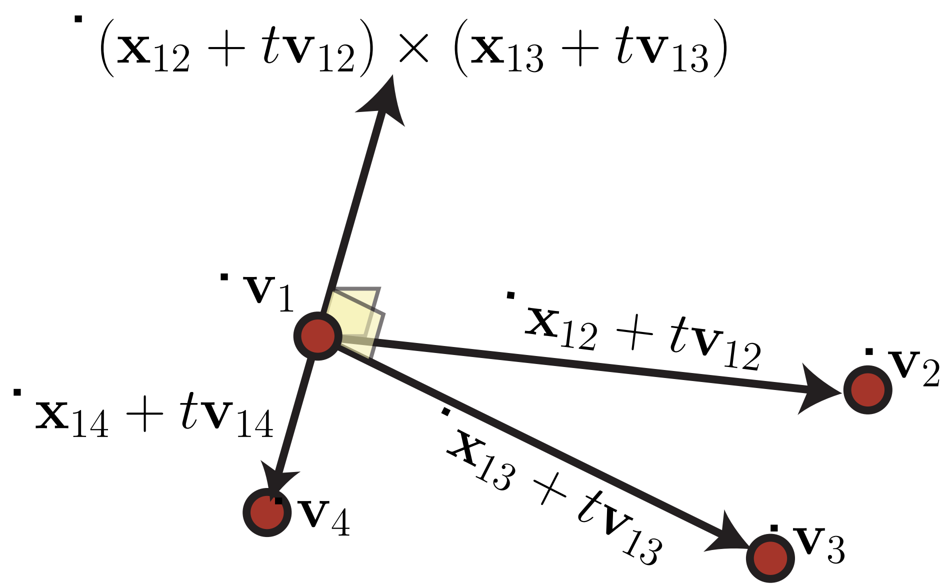
We can prevent this by checking for *any* collisions during the timestep (Provot [1997])

Note first that both point-face and edge-edge collisions occur when the appropriate 4 points are *coplanar*



Robust collision detection (2)

Detecting time of coplanarity - assume linear velocity throughout timestep:



So the problem reduces to finding roots of the cubic equation

$$\big((\mathbf{x}_{12} + t\mathbf{v}_{12}) \times (\mathbf{x}_{13} + t\mathbf{v}_{13})\big) \cdot (\mathbf{x}_{14} + t\mathbf{v}_{14})$$

Once we have these roots, we can plug back in and test for triangle adjacency.

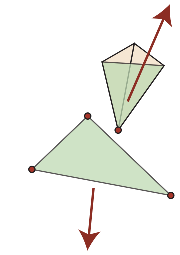
Collision Response

Cloth Animation

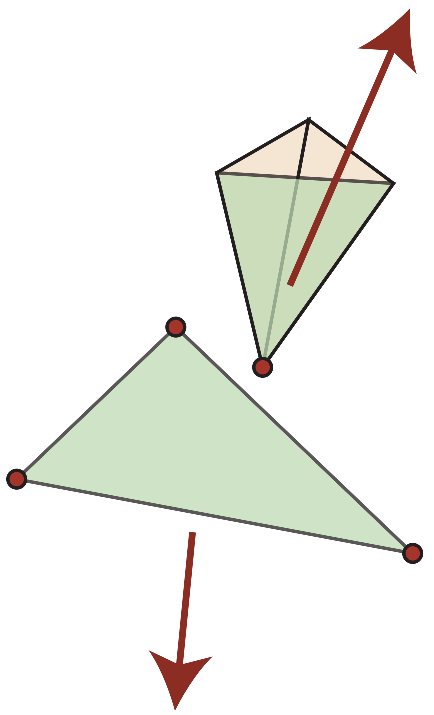
Christopher Twigg

March 4, 2003

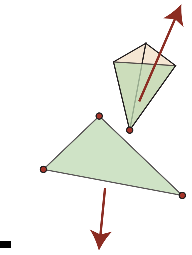
Collision response



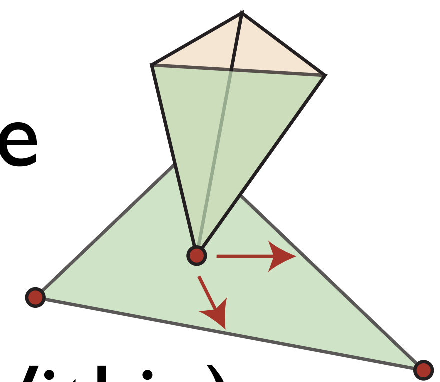
- 4 basic options:
  - Constraint-based
  - Penalty forces
  - Impulse-based
  - Rigid body dynamics (will explain)



Constraint-based response



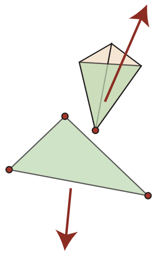
- Assume totally inelastic collision
- Constrain particle to lie on triangle surface
- Benefits:
    - Fast, may not add stiffness (e.g., Baraff/Witkin)
    - No extra damping needed
- Drawbacks
    - Only supports point-face collisions
    - Constraint attachment, release add discontinuities (constants hard to get right)
    - Doesn't handle self-collisions (generally)
- Conclusion: a good place to start, but not robust enough for heavy-duty work



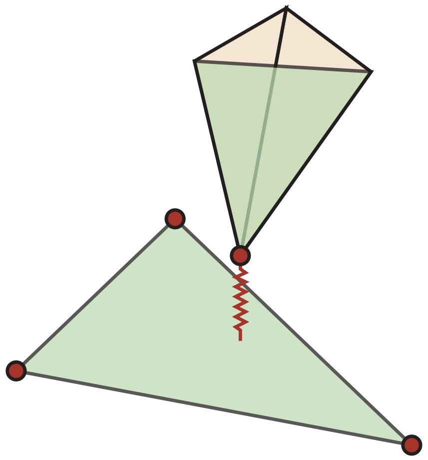
Constraint-based response (4)

- Must keep track of constraint forces in the simulator -- that is, the force the simulator is applying to maintain the constraint
- If constraint force opposes surface normal, need to release particle

Penalty forces



- Apply a spring force that keeps particles away from each other
- Benefits:
  - Easy to fit into an existing simulator
  - Works with all kinds of collisions (use barycentric coordinates to distribute responses among vertices)



- Drawbacks:
  - Hard to tune: if force is too weak, it will sometimes fail; if force is too strong, it will cause the particles to “float” and “wiggle”

Penalty forces (2)

- In general, penalty forces are not inelastic (springs store energy)
- Can be made less elastic by limiting force when particles are moving away
- Some kind of additional damping may be needed to control deformation rate along surface

Impulses

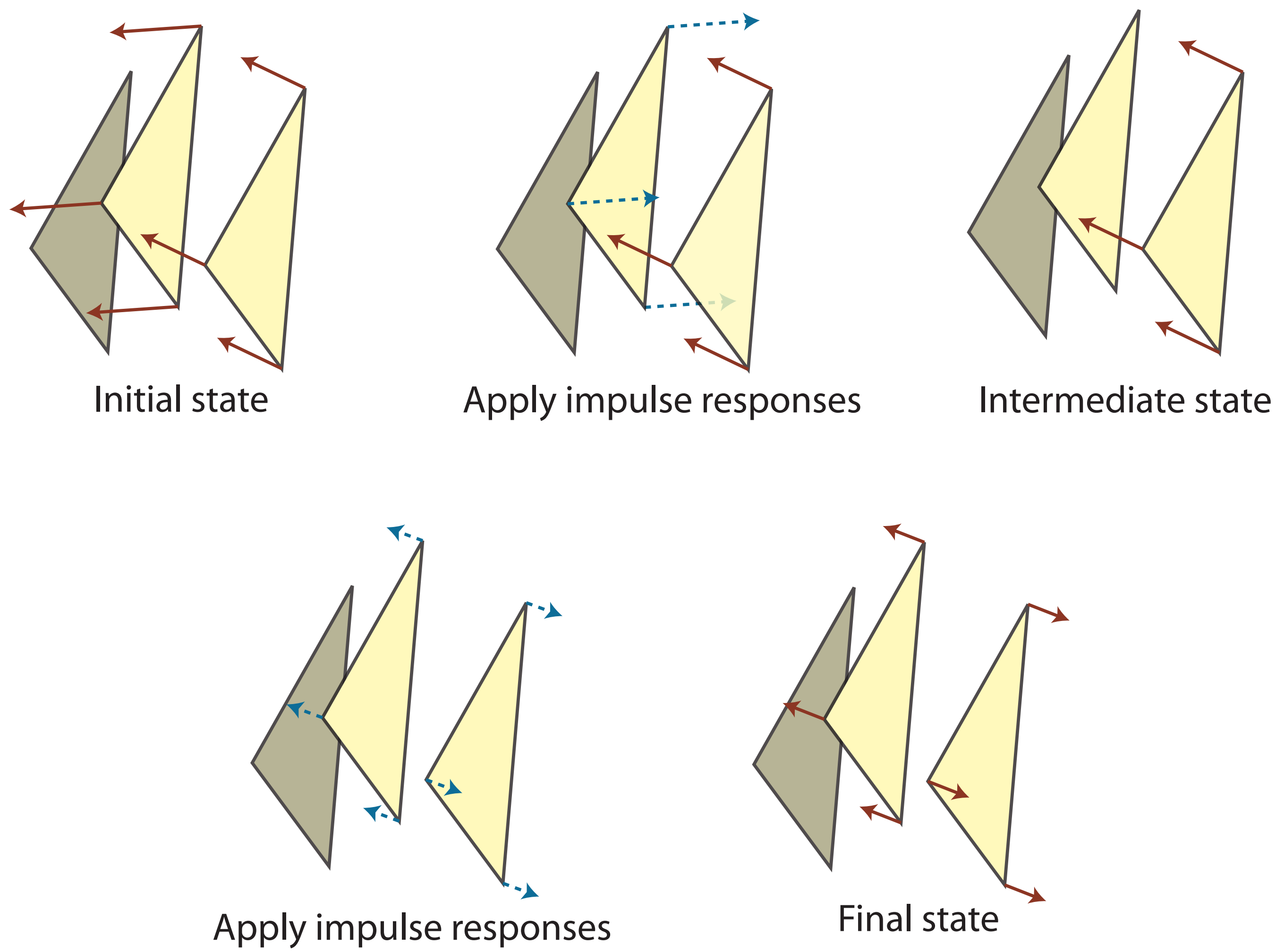
- "Instantaneous" change in momentum

$$\mathbf{J} = \int_{t_i}^{t_f} \mathbf{F}\, dt = \mathbf{p}_f - \mathbf{p}_i$$

- Generally applied outside the simulator timestep
- Benefits
  - Correctly stops all collisions (no sloppy spring forces)
- Drawbacks
  - Can have poor numerical performance
  - Handles persistent contact poorly

Impulses (2)

Iteration is generally necessary to remove all collisions.



Convergence may be slow in some cases.

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Question

- What are the relevant properties of crowds?
- Can crowds be modeled as particles?
- How?
- What phenomena does your algorithm capture, what doesn't it?

Student Answers

- "social forces" - it's all about forces
  - NOT just usual spring forces (people don't oscillate, usually)
  - attractive forces between friends
  - attracted to certain physical locations
  - constraints: a kid has to be near her parent
  - repelling force when someone gets all up in your grill
  - group force
  - steering force
- how could we model group motion
  - a leader-follower model
  - some kind of "group dynamics"
- inhomogeneity of individuals in a crowd
- pure particles may be insufficient
  - need to take into account direction someone is facing
- the _really_ important phenomena:
  - lane formation ("striping") when people cross one another but don't intersect
  - compute an "energy" for each person, and the optimal velocity is that which decreases energy
- avoidance
  - for avoidance, people will *predict* where others will be