Cloth

The Animation of Natural Phenomena

Adrien Treuille

Overview

- Real Cloth
  - Properties of Real Cloth
- Cloth Simulation
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
      - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- Cloth Collisions
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- Advanced
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

Overview

- Real Cloth
  - Properties of Real Cloth
- Cloth Simulation
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
    - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- Cloth Collisions
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- Advanced
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

What is cloth?

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

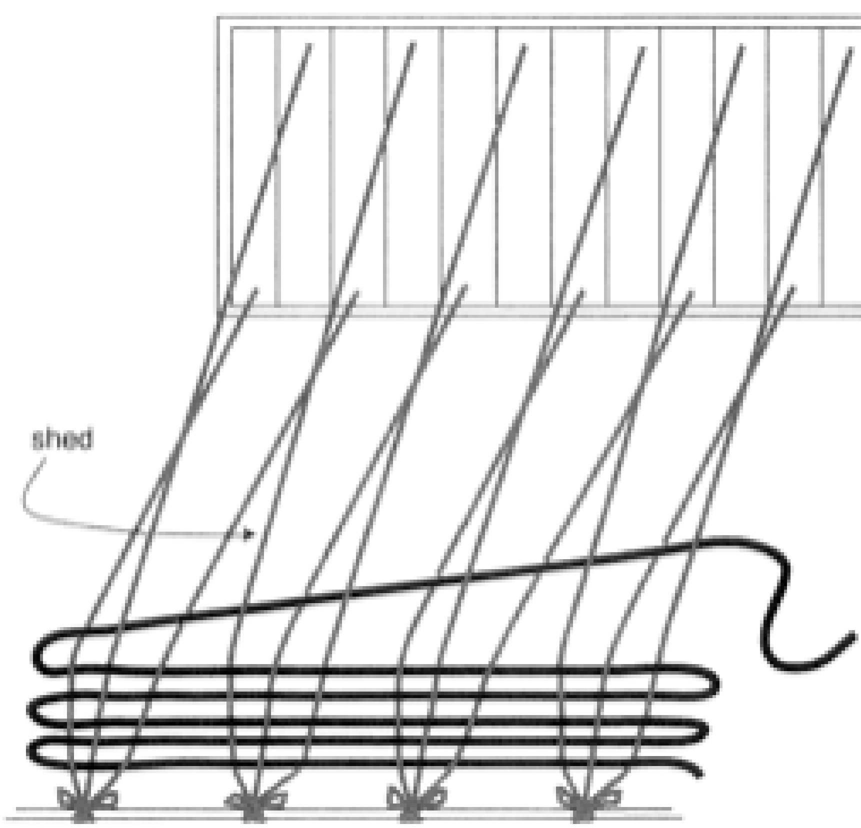
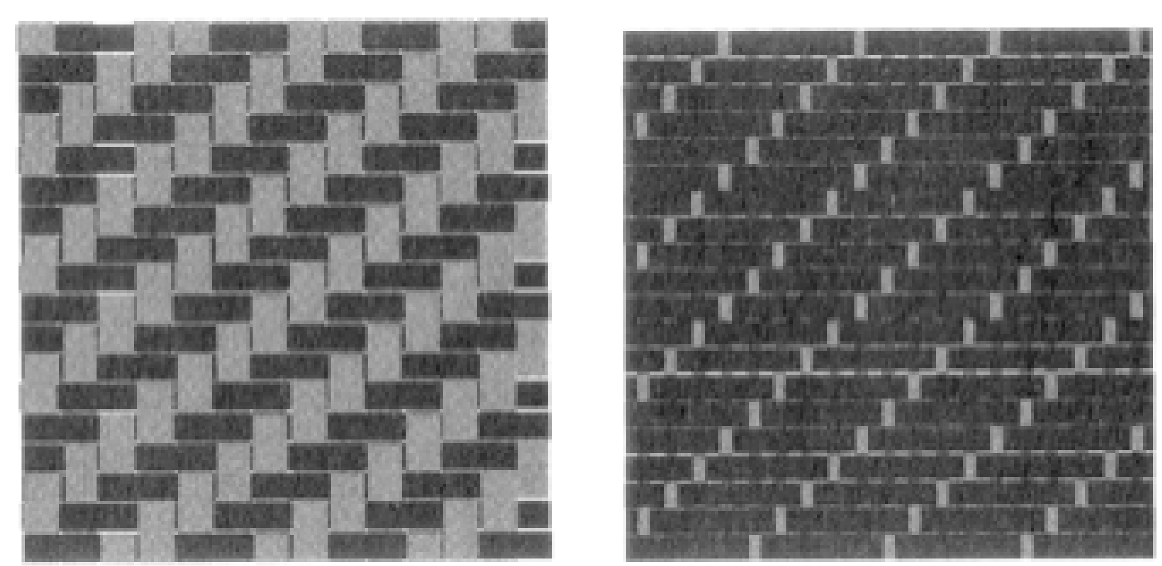


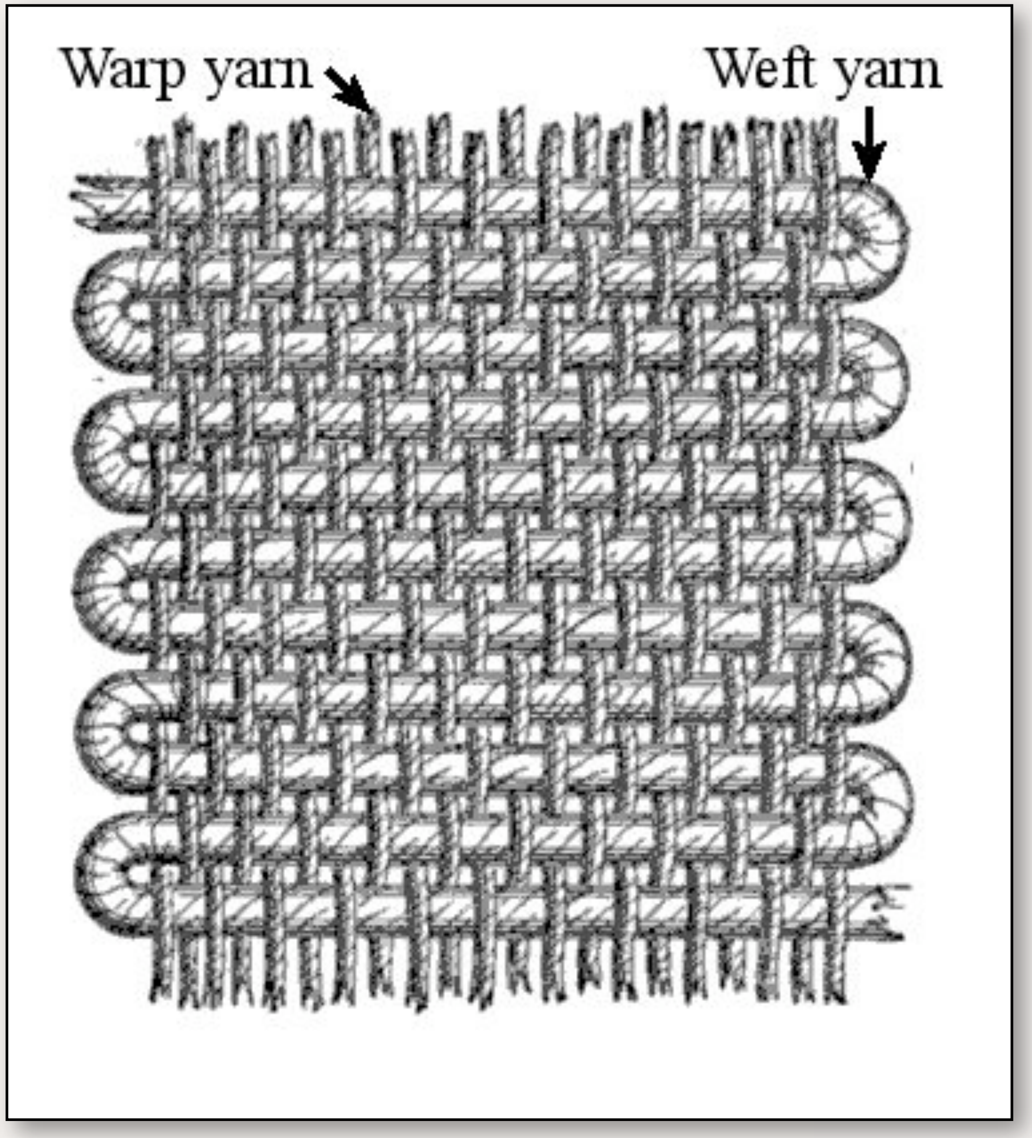
Figure 1.8. The weaving process.



b) twill c) satin

House, Breen [2000]

Warp and Weft



source: Wikipedia

Overview

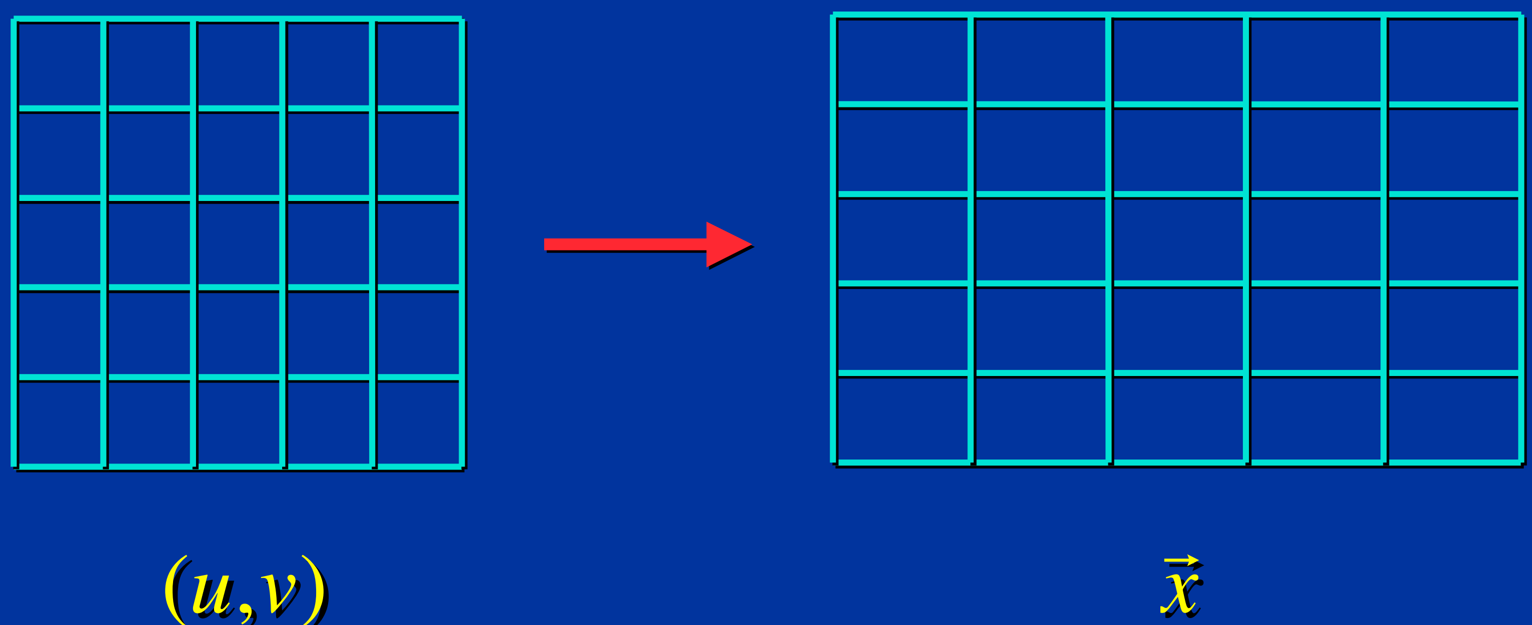
- **Real Cloth**
  - Properties of Real Cloth
- **Cloth Simulation**
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
    - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- **Cloth Collisions**
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- **Advanced**
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

Cloth and Fur Energy Functions

Michael Kass

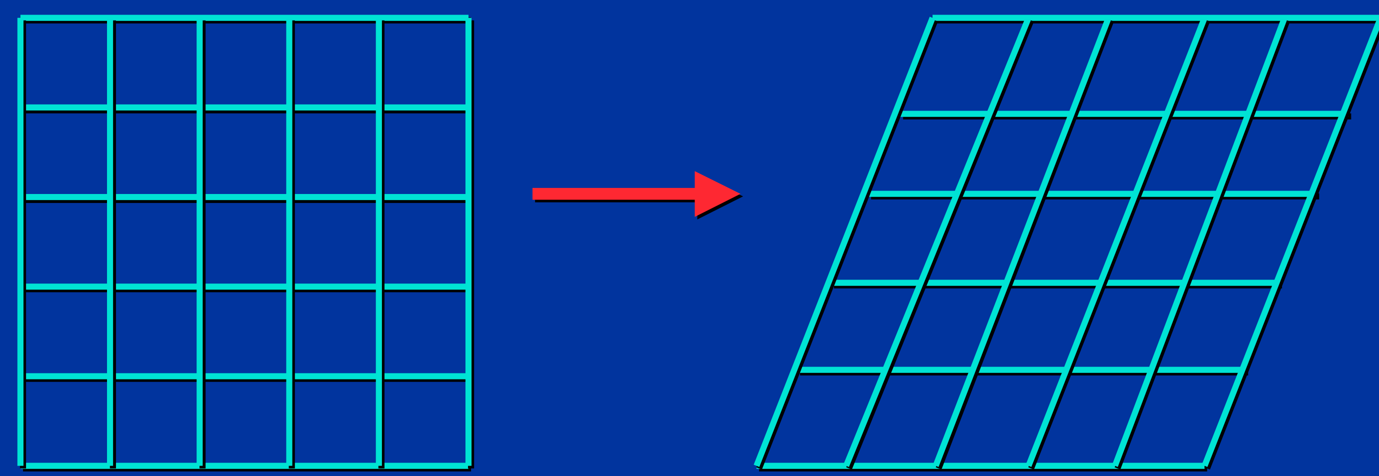
Stretch (Continuum Version)



$$S_u = \left\| \frac{\partial \vec{x}}{\partial u} \right\| - 1$$

$$E = \frac{1}{2} k \int (S_u^2 + S_v^2)\, du\, dv$$

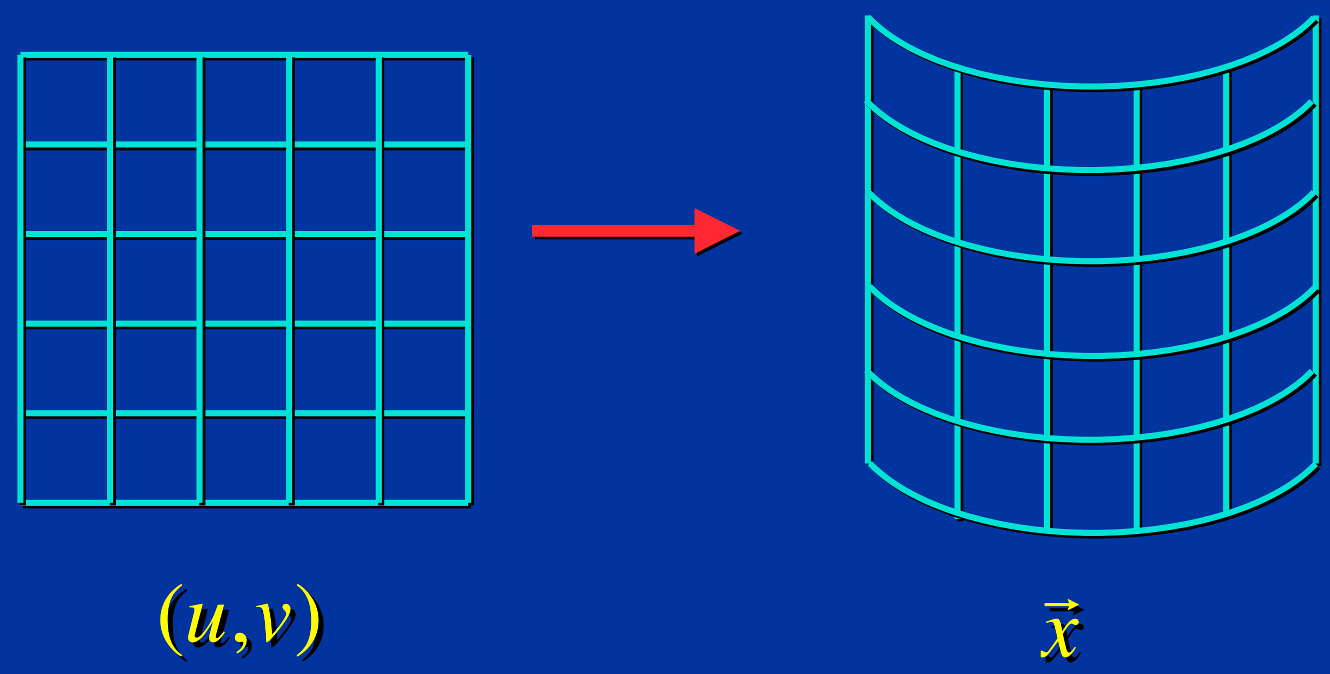
Shear (Continuum Version)



(u,v) $\vec{x}$

$$\theta = \cos^{-1}\left(\frac{\widehat{\partial \vec{x}}}{\partial u} \bullet \frac{\widehat{\partial \vec{x}}}{\partial v} \right) \qquad E = \frac{1}{2}k\int \theta^2 \, du \, dv$$

Bend (Continuum Version)



$$E = \frac{1}{2} k \int (\kappa_u^2 + \kappa_v^2)\, du\, dv$$

Overview

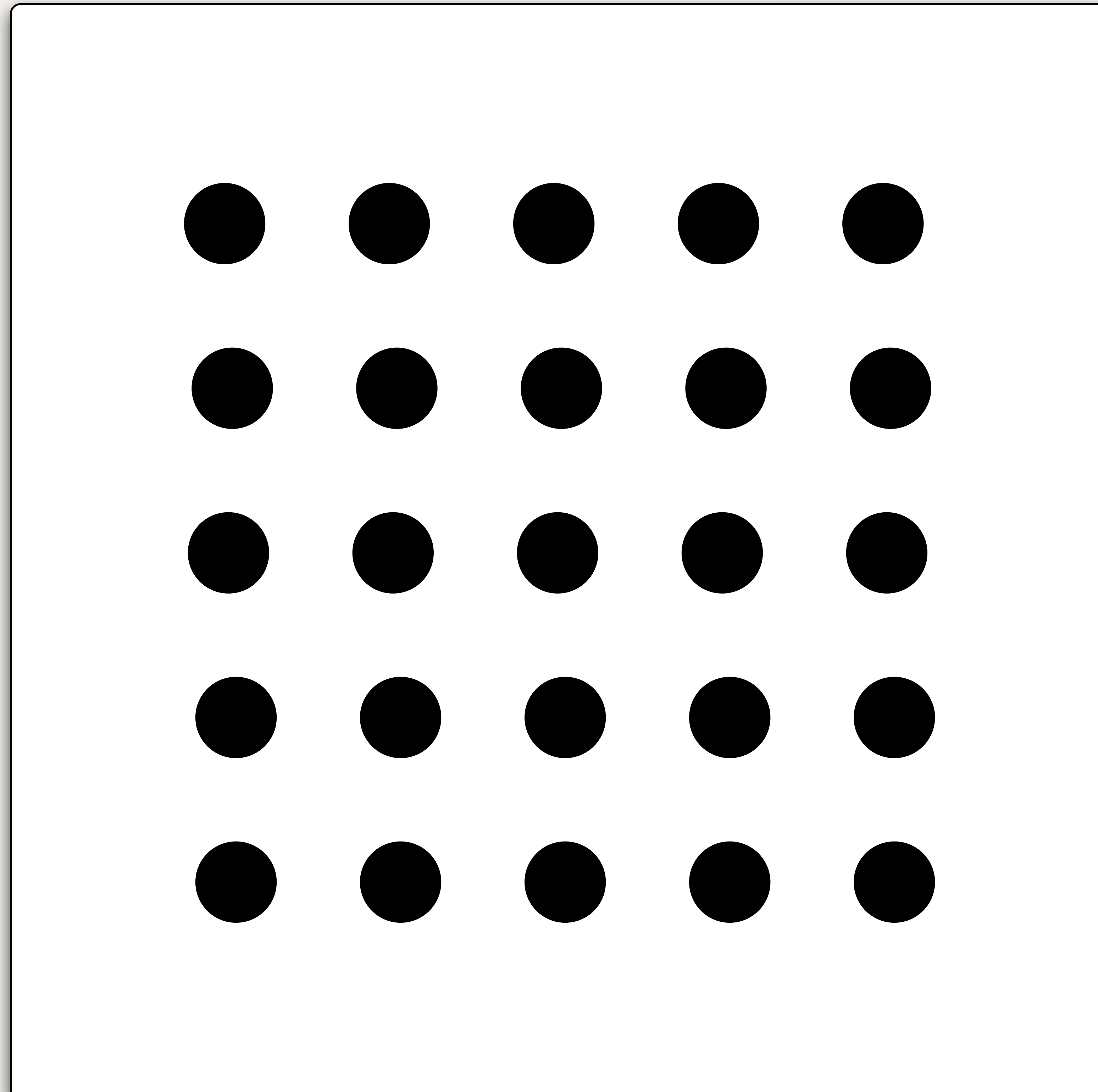
- Real Cloth
  - Properties of Real Cloth
- Cloth Simulation
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
    - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- Cloth Collisions
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- Advanced
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

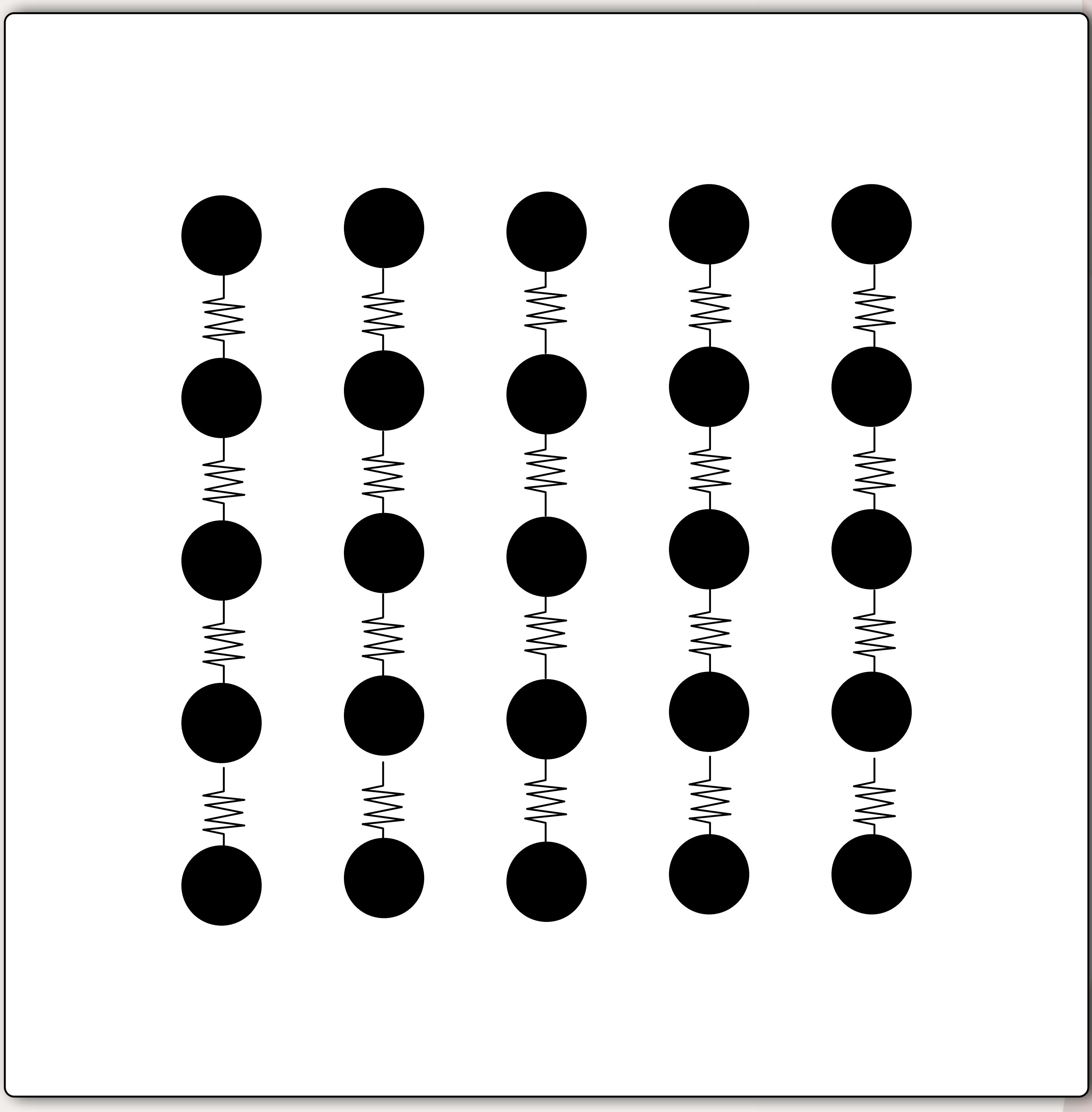
Resitence To...

- Stretching
- Shearing
- Bending

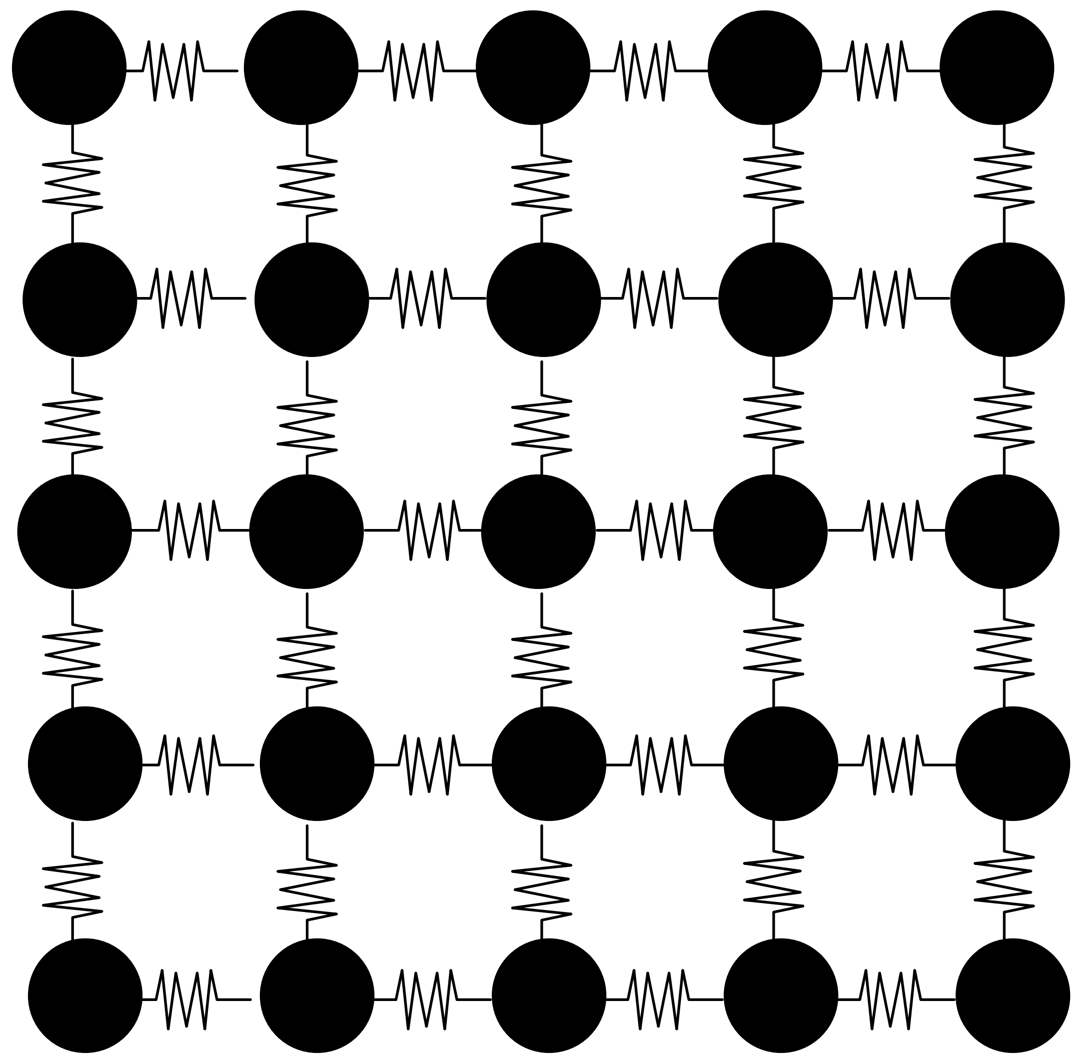
Basic Model



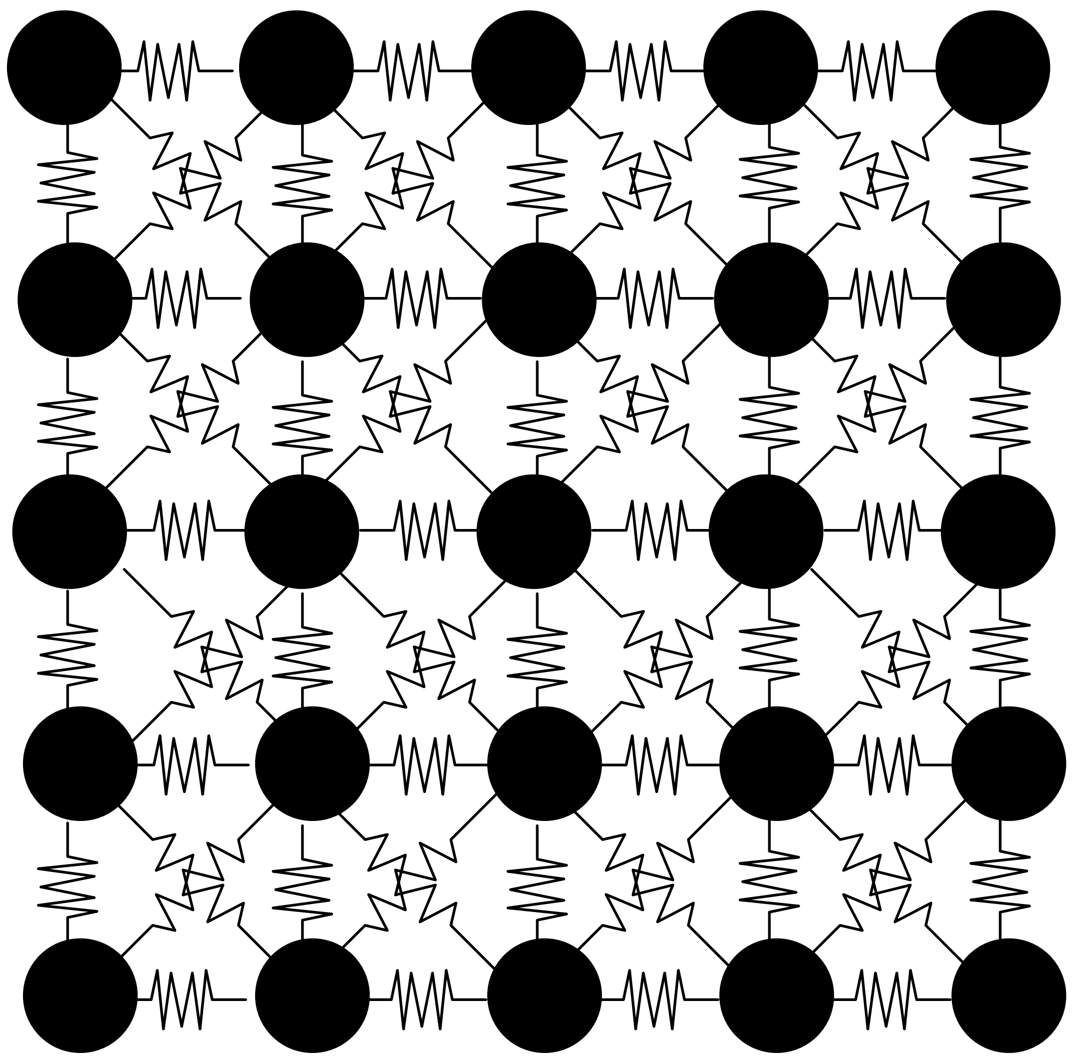
Warp Srings



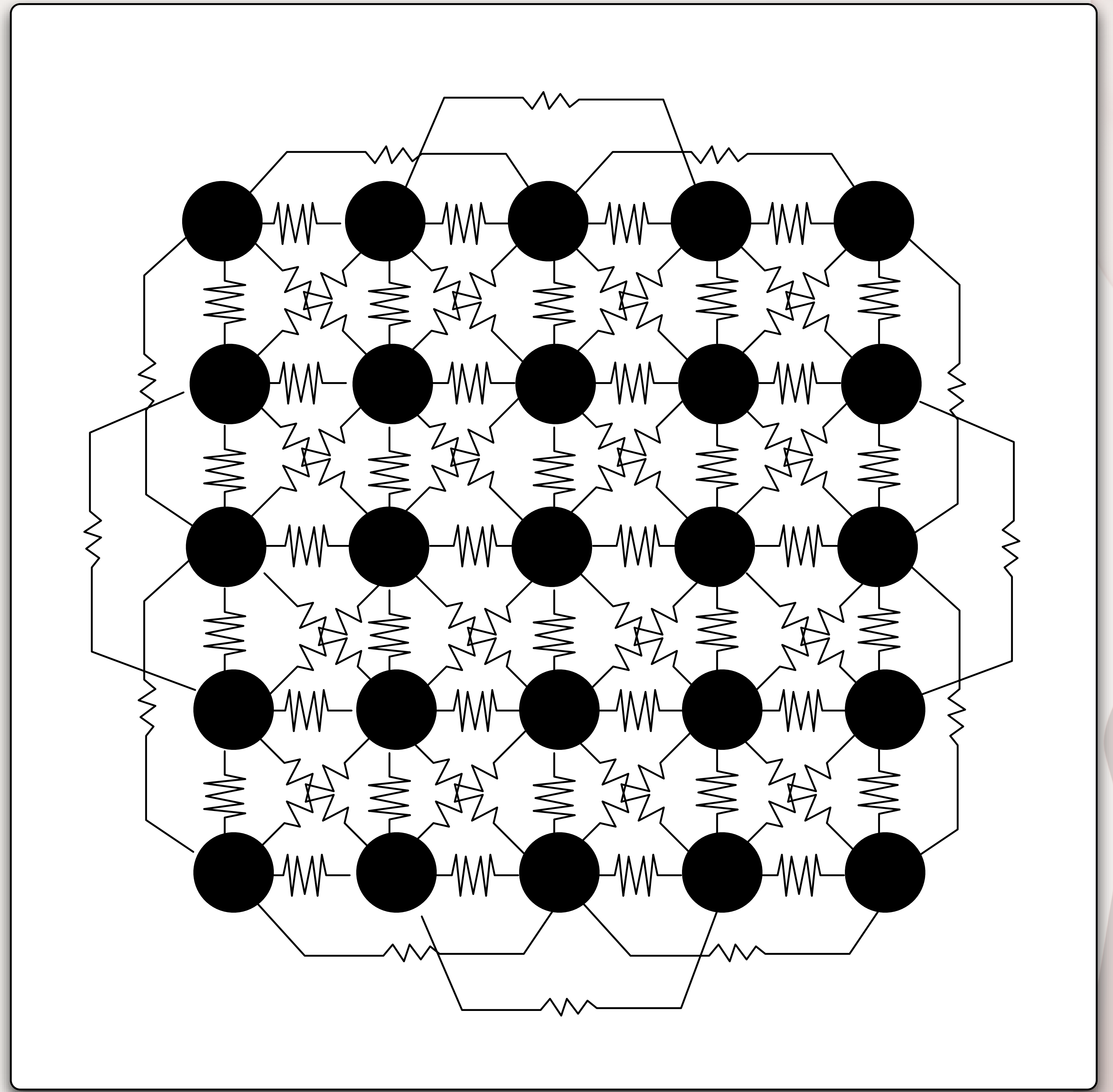
Weft Springs



Shear Springs



Bend Springs

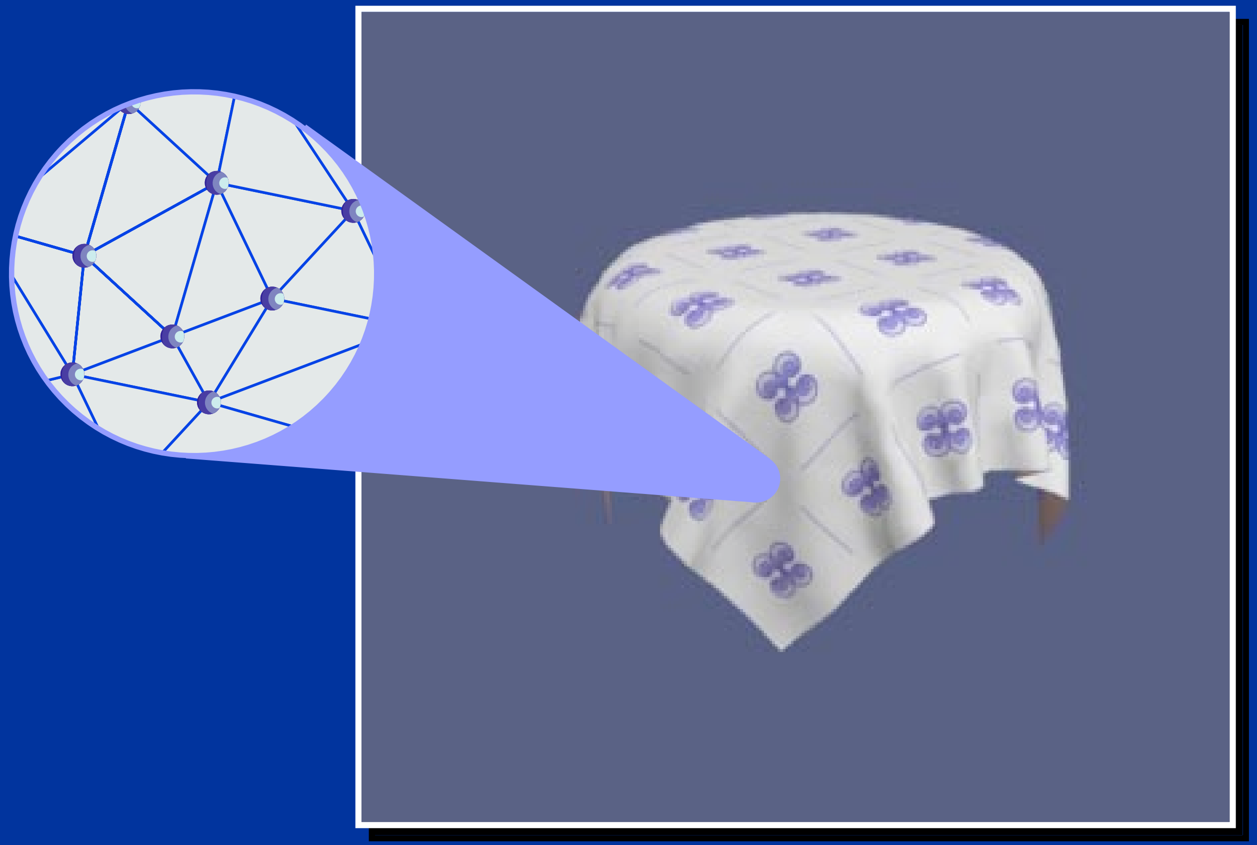


Overview

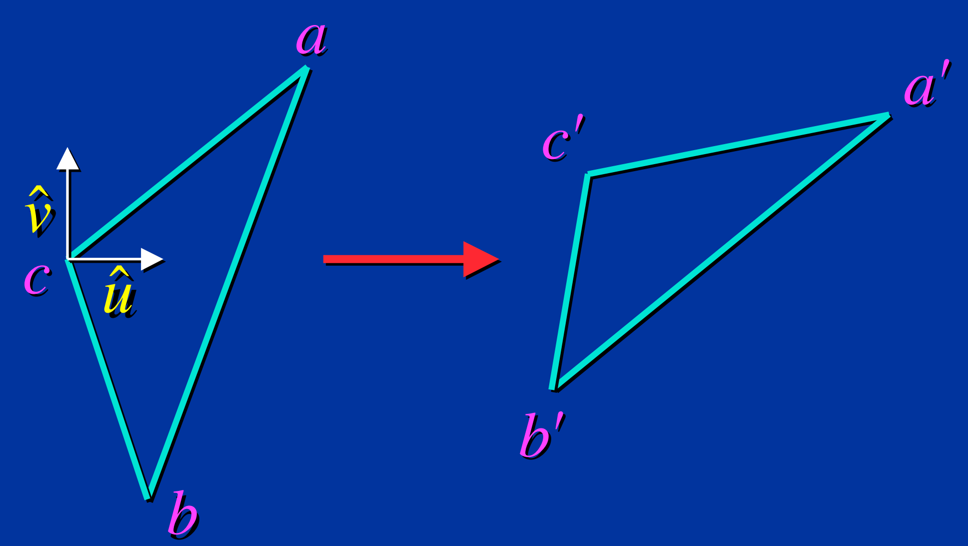
- Real Cloth
  - Properties of Real Cloth
- Cloth Simulation
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
      - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- Cloth Collisions
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- Advanced
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

Discretization



Triangle Energy

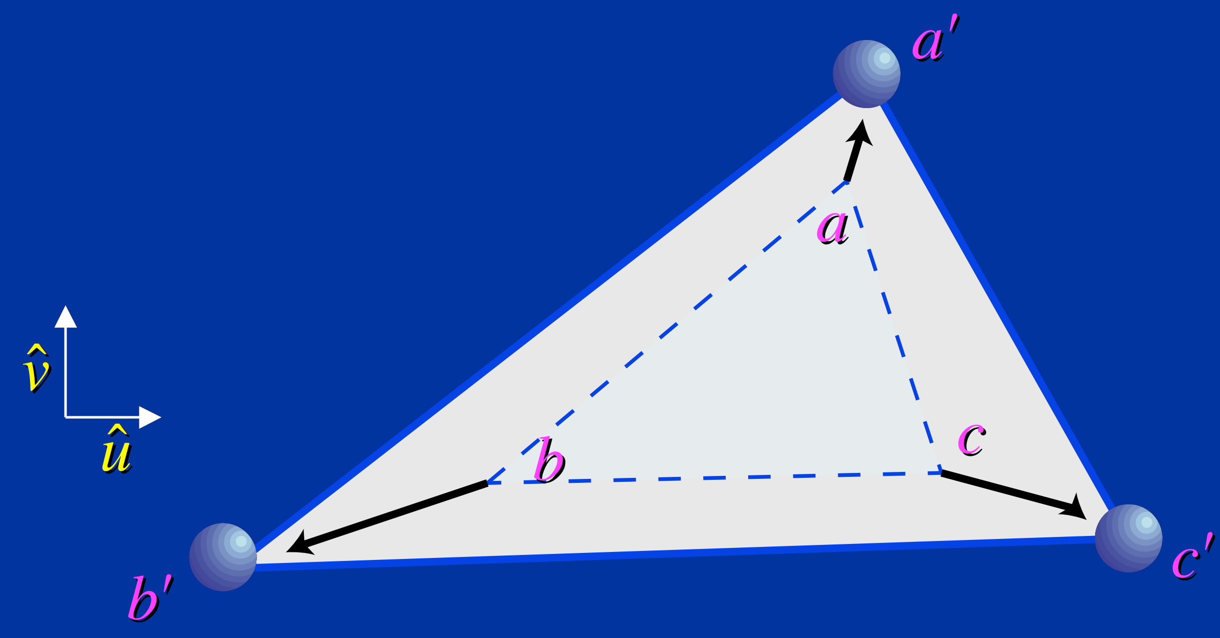


First, compute the affine transformation T that maps: $T: a \rightarrow c'$

$$b \rightarrow b'$$

$$c \rightarrow c'$$

Triangle Stretch Energy

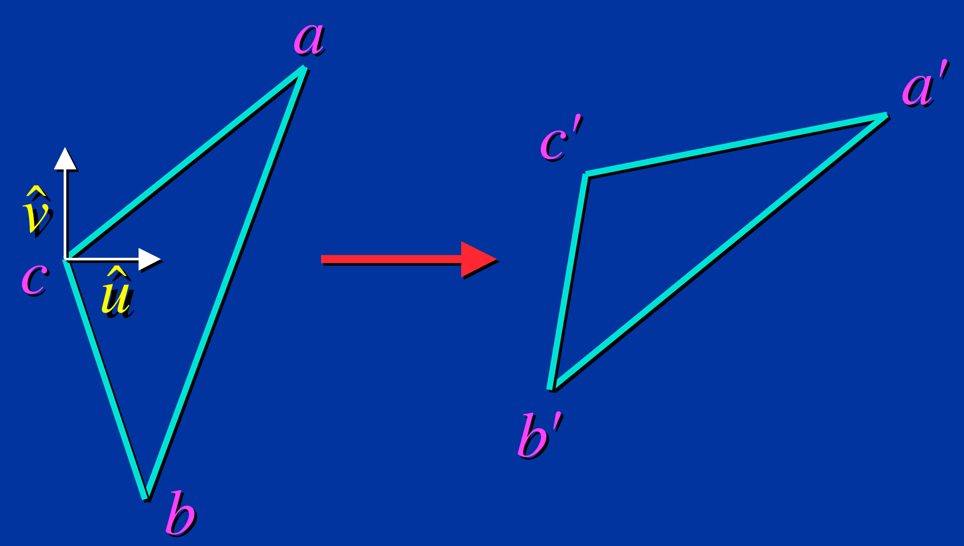


Now compute the stretch energy.

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

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

Triangle Shear Energy

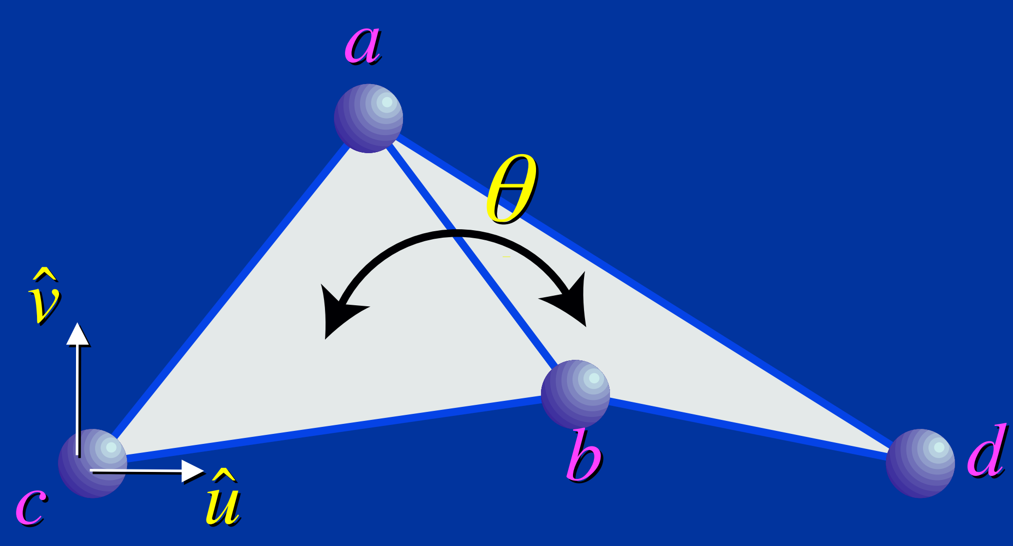


Next compute the shear energy.

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

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

Triangle Bend Energy

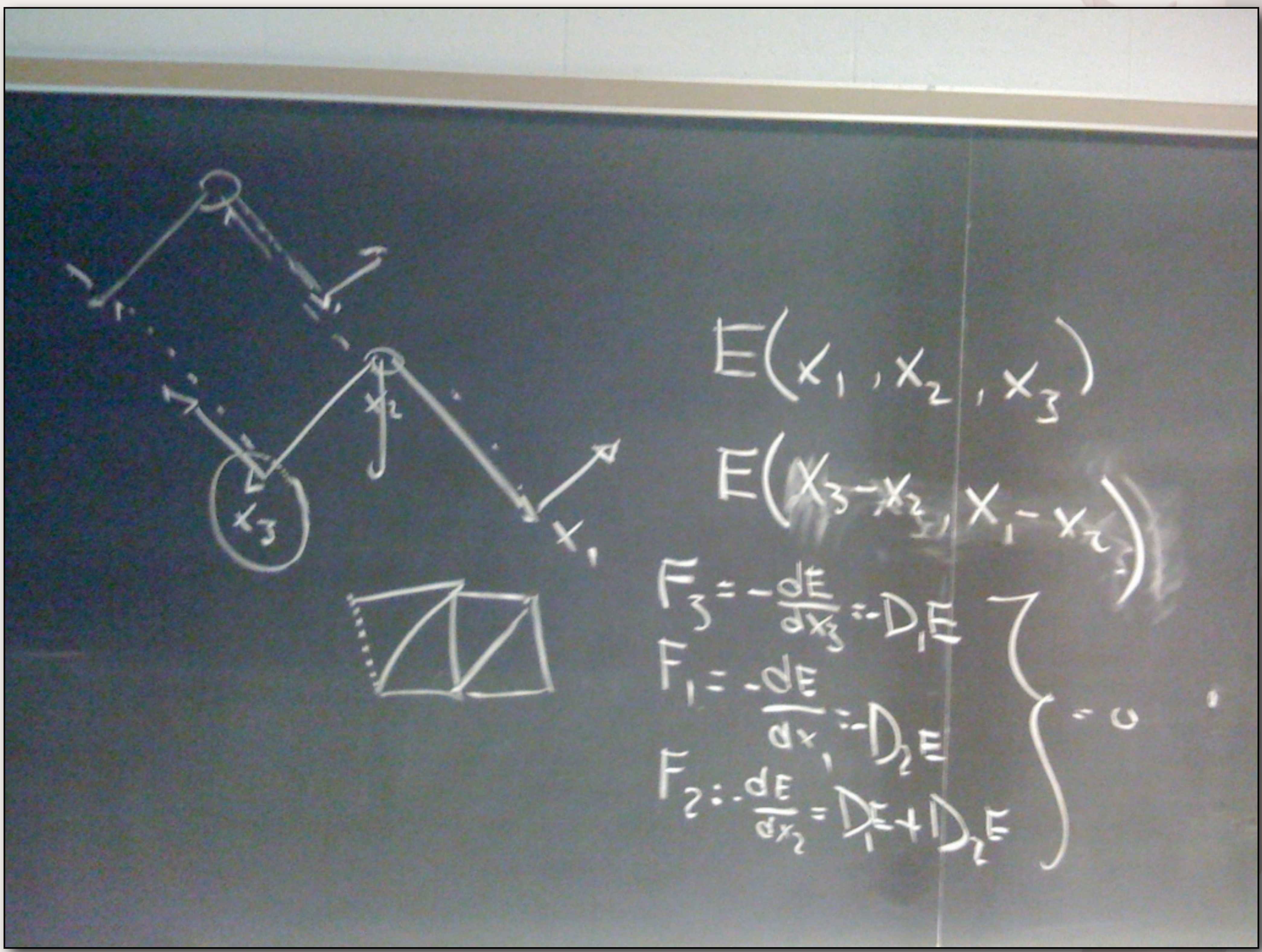


$$\kappa = \frac{\theta}{l_{perp}}$$

Finally compute the bend energy.

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

A Note About Energy



Baraff, Witkin [1998] (5)

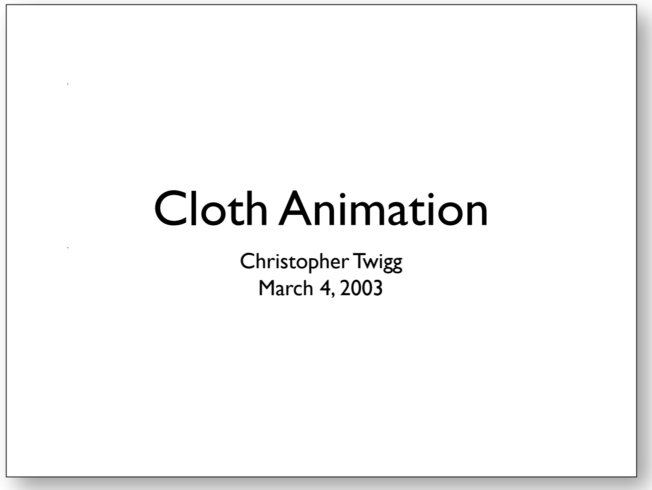
- Damping forces turn out to be important both for realism and numerical stability
- Damping forces should
  - Act in direction of corresponding elastic force
  - Be proportional to the velocity in that direction

Hence, we derive (this should look familiar)

$$\mathbf{d} = -k_d \dot{\mathbf{C}}(\mathbf{x}) \frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}}$$

where

$$\dot{\mathbf{C}}(\mathbf{x}) = \frac{\partial \mathbf{C}(\mathbf{x})}{\partial t} = \overbrace{\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}}}^{\text{Direction of force}} \frac{\partial \mathbf{x}}{\partial t}$$



Overview

- **Real Cloth**
  - Properties of Real Cloth
- **Cloth Simulation**
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
    - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- **Cloth Collisions**
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- **Advanced**
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

Parameters

- Given stretch, shear, and bending constants...
- **How would you make a wrinkly t-shirt, thick cloth, or non-uniform cloth?**

Creating Clothes

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

Non-flat Cloth

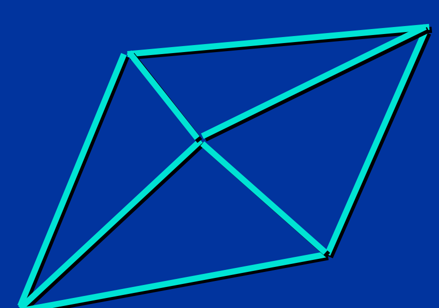
Non-flat cloth is strange stuff:

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!

Rest Mesh Options

Model in 3D

- Clothing already on characters.
- Can directly craft desired 3D shape.
- Annotate warp/weft directions.
- Clothing probably will not locally flatten.

Model in 2D

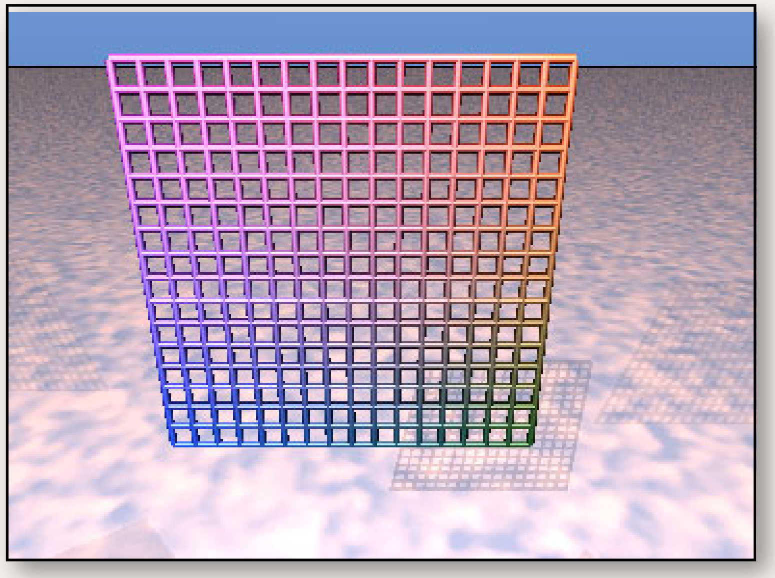
- Must put clothing on characters
- Hire a tailor to get the pattern right.
- Sew parts together.
- Clothing guaranteed to flatten locally.
- Greater realism.

Overview

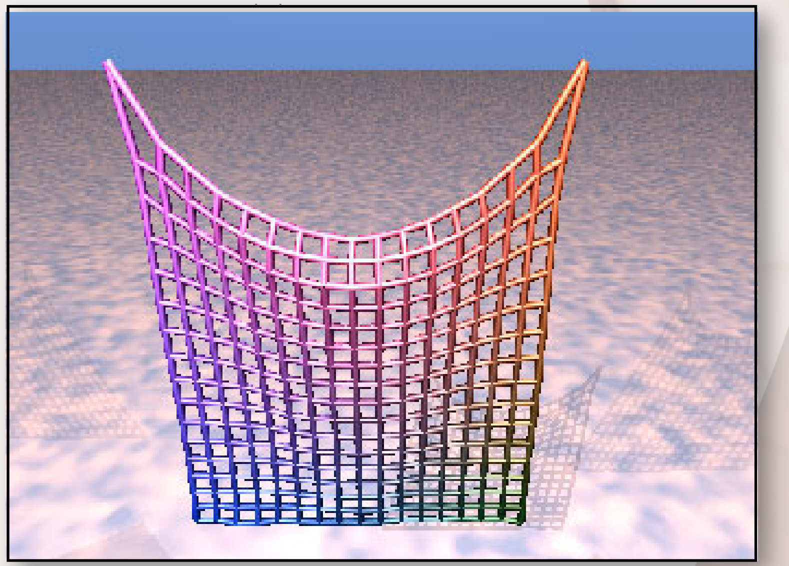
- Real Cloth
  - Properties of Real Cloth
- Cloth Simulation
  - Properties of Cloth
    - sheet of fabric (4)
    - parameter for stretching (1) (4)
    - parameter for shearing (4)
    - parameter for bending (4)
    - how to set these properties
      - wrinkles and crinkles (4)
      - thickness (4)
      - non-uniform (4)
  - Spring-based Simulation
      - mesh of springs (1) (2)
  - Energy-based
    - various forms of triangle energy
  - Developable Surfaces
- Cloth Collisions
  - interactions w/ itself (1) (2) (3) (4)
  - interactions w/ rigid bodies (1) (3)
  - friction (4)
- Advanced
  - fluid flow affecting cloth (3)
  - rendering / texturing of cloth (3)
  - tearing (3)

Group 1
Group 2
Group 3
Group 4
New!

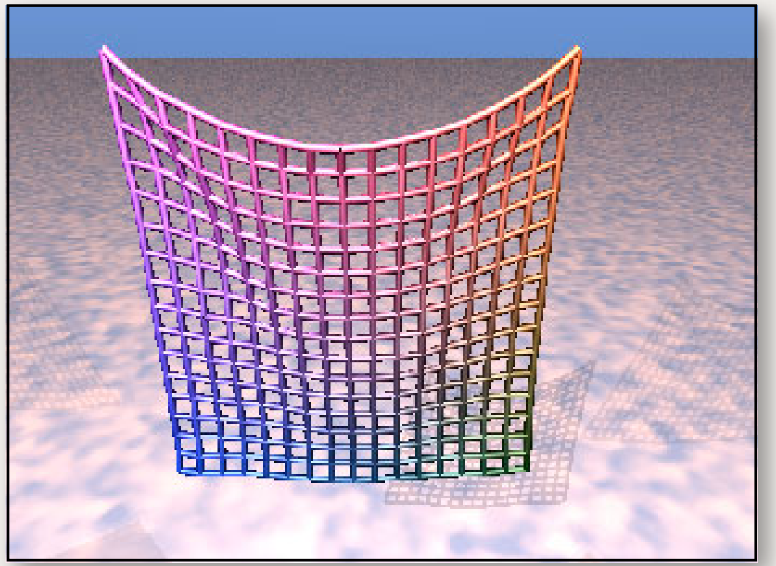
Springs vs. Constraints



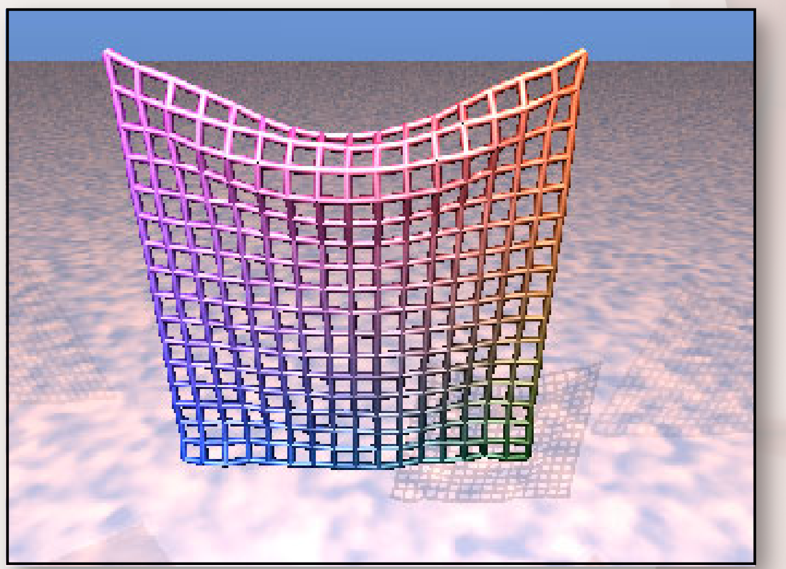
Before Simulation



Only Springs



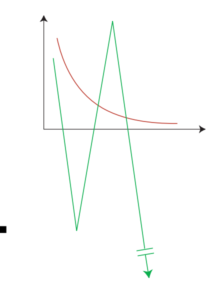
Stretch Constraints

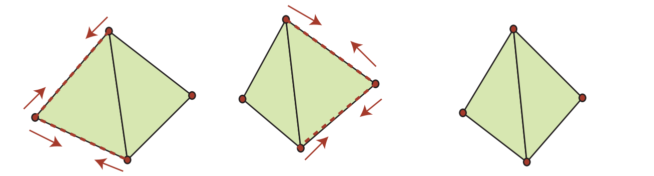


Stretch+Shear Constraints

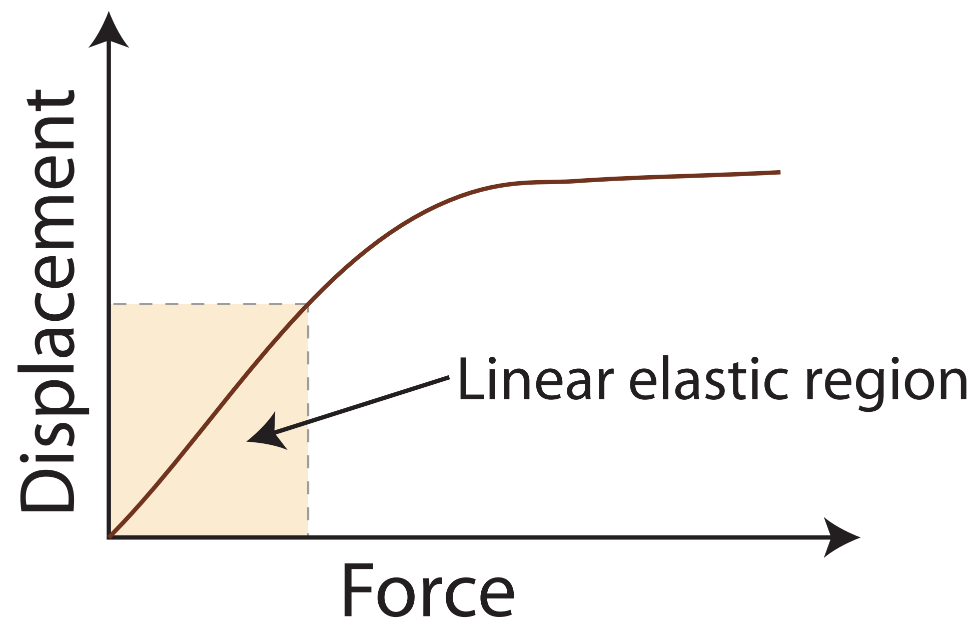
Source: Xavier Provot
Deformation Constraints in a Mass-Spring Model to Describe Rigid Cloth Behavior

Avoiding stiffness (2)



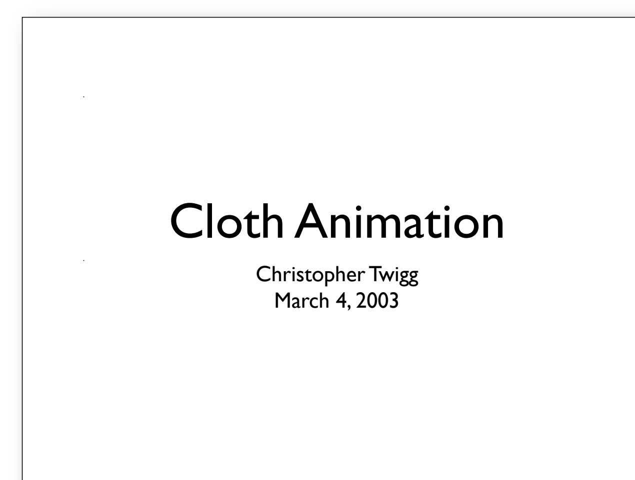


- Popular for interactive applications
- Justification
  - Biphasic spring model

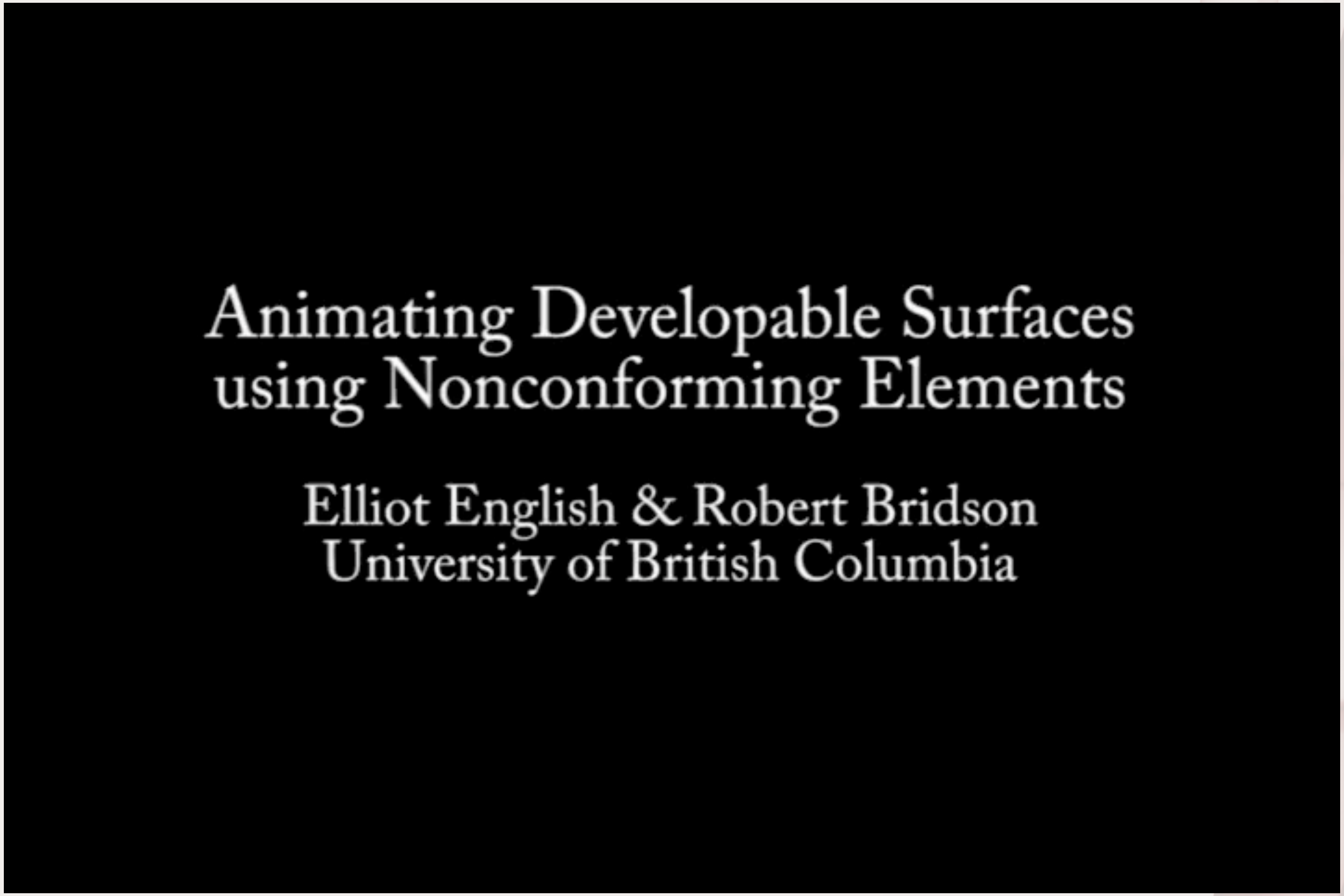


From Desbrun, Meyer, Barr [2000]

  - Plausible dynamics



Developable Surfaces



Developable Surfaces

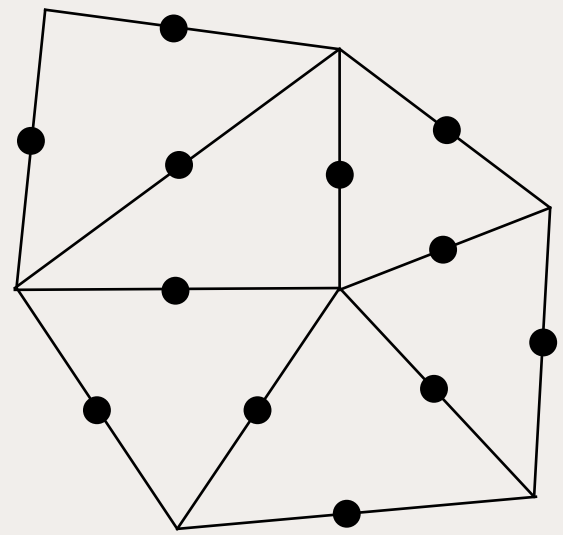
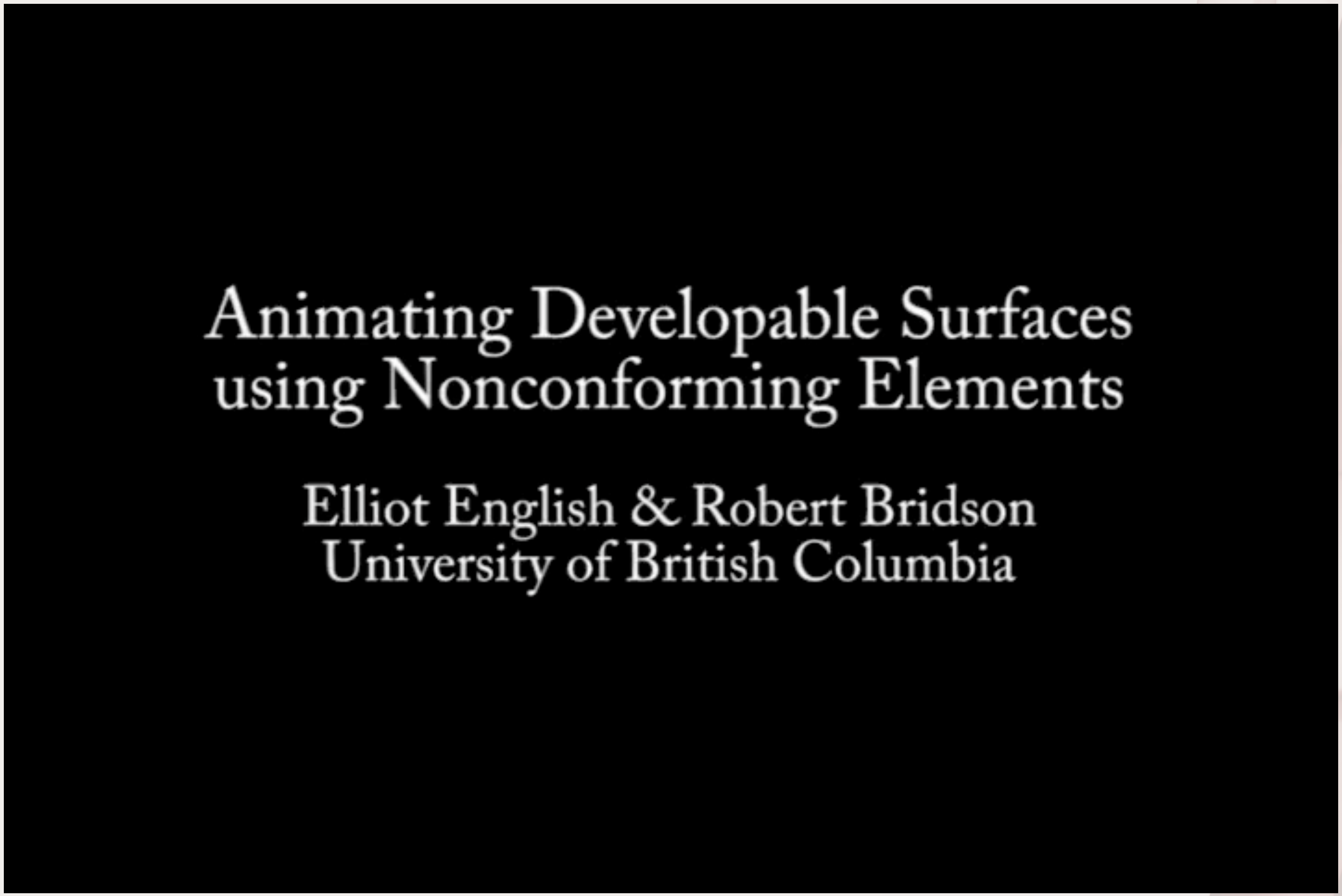


Figure 2: *Schematic of nonconforming variables, located at mid-points of edges between triangles. While continuous at these points, the surface may be discontinuous along the rest of each edge.*

Elliot English*
University of British Columbia

Robert Bridson†
University of British Columbia

Developable Surfaces



Question

- Cloth *and* Hair..
- How can we detect collisions?
  - Data structures?
  - Algorithms?
- How do we handle collisions?

Course Evaluations