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)

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Group 4
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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]
Warp and Weft

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Cloth and Fur Energy Functions

Michael Kass
Stretch (Continuum Version)

\[ S_u = \left\| \frac{\partial \bar{x}}{\partial u} \right\| - 1 \]

\[ E = \frac{1}{2} k \int (S_u^2 + S_v^2) du dv \]
Shear (Continuum Version)

\[ \theta = \cos^{-1} \left( \frac{\hat{x}}{\partial u} \cdot \frac{\hat{x}}{\partial v} \right) \]

\[ E = \frac{1}{2} k \int \theta^2 \, du \, dv \]
Bend (Continuum Version)

\[
E = \frac{1}{2} k \int (\kappa_u^2 + \kappa_v^2) du \, dv
\]
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Resitence To...

- Stretching
- Shearing
- Bending
Basic Model
Warp Strings
Weft Springs
Shear Springs
Bend Springs
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Discretization
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.

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

\[ E_{\text{stretch}} = \frac{1}{2} k (S_u^2 + S_v^2) A \]
Next compute the shear energy. 

\[ \theta = \cos^{-1}(T(\hat{u}) \cdot T(\hat{v})) \]

\[ E_{\text{shear}} = \frac{1}{2} k \theta^2 A \]
Finally compute the bend energy.

\[ \hat{v} \]

\[ \hat{u} \]

\[ \hat{\theta} \]

\[ a \]

\[ b \]

\[ c \]

\[ d \]

\[ \theta \]

\[ \frac{\theta}{l_{perp}} \]

\[ K = \frac{\theta}{l_{perp}} \]

\[ E_{bend} = \frac{k}{2}(\kappa^2)A \]
A Note About Energy

\[ E(x_1, x_2, x_3) \]
\[ E(x_3 - x_2, x_1 - x_2) \]

\[ F_3 = -\frac{\partial E}{\partial x_3} = -D_1E \]
\[ F_1 = -\frac{\partial E}{\partial x_1} = -D_2E \]
\[ F_2 = -\frac{\partial E}{\partial x_2} = D_1E + D_2E \]
• 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)

\[
d = -k_d \dot{C}(x) \frac{\partial C(x)}{\partial x}
\]

where

\[
\dot{C}(x) = \frac{\partial C(x)}{\partial t} = \frac{\partial C(x)}{\partial x} \frac{\partial x}{\partial t}
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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.
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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

Animating Developable Surfaces using Nonconforming Elements

Elliot English & Robert Bridson
University of British Columbia
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.
Developable Surfaces

Animating Developable Surfaces using Nonconforming Elements

Elliot English & Robert Bridson
University of British Columbia
Question

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