Sensitive Couture for Interactive Garment Editing and Modeling

Nobuyuki Umetani (Univ. Tokyo)
Danny Kaufman (Columbia Univ.)
Takeo Igarashi (Univ. Tokyo, JST ERATO)
Eitan Grinspun (Columbia Univ.)
Plan for Today

- Next Lab Session
- Demo of Paper from Last Lecture
- Sensitive Couture: Interactive Design of Clothing
  - Finite Elements for Cloth Simulation
  - How to make simulations run at INTERACTIVE RATES!
But First!

- Demo!
Lab Session

- Who would like another lab session this or next Friday
- AM or PM?
Creating New Patterns is Difficult

Drawing a pattern

2D

Fitting on a mannequin

3D
Especially for “strange” characters

Can we design clothing for the Armadillo?
Interaction is essential for problem solving
Design Cycle

Design

Test

Prototype
Design Cycle

Design

Test

3D Printing
Integrated Design, Simulation and Interaction

- Design
- Test
- Simulation
- Fabricate
Integrated Design, Simulation and Interaction

Diagram:

- Design
  - Test
  - FEM
  - Fabricate
Continuum Mechanics

World \mathbf{x} = \text{World Body } \phi \left( q, \text{Body } \mathbf{x} \right)
Continuum Mechanics

- Let’s define our mapping (Finally!)

\[ \text{World}_x = \text{World}_{\text{Body}} \phi\left(\mathbf{q}, \text{Body}_x\right) \]
Finite Elements
Finite Elements
Finite Elements

Reference

World
Finite Elements

Change Design in Reference Space

Reference  World
Finite Elements

Change Design in Reference Space

Reference

World
Finite Elements

Change Design in Reference Space

Reference

Simulation

World
Finite Elements for Thin Shells
Finite Elements for Thin Shells

Images copyright Rahul Narain, Armin Samii, and James F. O'Brien.
Finite Elements for Shells

• How do we compute forces on this 2D to 3D mapping?
Let’s define our mapping (Finally!)

\[
\text{World} \ x = \text{World}_\text{Body} \ \phi (q, \text{Body}_x)
\]
Continuum Mechanics

- Let’s define our mapping (Finally!)

\[ \text{World } x = \text{World Body } \phi (q, \text{Body } x) \]
Finite Elements for Thin Shells

• For solids we consider “deformation”

\[ \frac{1}{2} (F^T F - I) \]

• But for cloth we need two types of deformation
Finite Elements for Thin Shells: Stretching

Computed in a similar fashion to 2D FEM
Finite Elements for Thin Shells: Bending

Proportional to angle between normals
Examples of Cloth Simulation

Gray Interlock
Examples of Cloth Simulation
So Far …

• We can simulate cloth
• How About Design?
Interactive Garment Design

P. Volino and N. Magnenat-Thalmann [2005]
Interactive Garment Design

Marvelous Designer [2013]
All assume a fixed clothing pattern
What does it take to enable interactive simulation and design for high-resolution meshes?
Integrated Design, Simulation and Interaction

Design

Test

FEM

Fabricate
Integrated Design, Simulation and Interaction

Design

Test

FEM

Has to be very VERY FAST!!!!

Fabricate
What kind of simulation should we run?

- We want the final rest shape of the clothing
What kind of simulation should we run?

- We want the final rest shape of the clothing = STATICS
What kind of simulation should we run?

- We want the final rest shape of the clothing = STATICS
- How do we update the simulation results when we change the design?
Attempt #1: Dynamic Simulation Fails

Clothing pattern

Naïve standard
Dynamic simulation

Wrinkle artifacts
Slow response

Ground truth
(static cloth shape)
Last Lecture: Sensitivity Analysis

Suggestion Candidate #1

Suggestion Candidate #2

First order approximation: Sensitivity analysis [Umetani et al. '11]
Suggestion for Toppling

Contact force space
• Here we’re going to use sensitivity analysis for something different

• We’ll use it to accelerate cloth simulation
We need to relate changes in the design to changes in cloth shape
We need to relate changes in the design to changes in cloth shape

Changes in design = changes in mouse position = 2D Space 😊
Attempt #2: Sensitivity Analysis is Promising

Mouse position → Derivative → Static cloth shape

\[ \Delta \approx \frac{\partial}{\partial} \Delta \]

Linear approximation

Sensitivity mode
Sensitivity Analysis

- Studied in engineering
- Used mainly in offline optimization
- Linear

[Keulen05, Kuang-Hua95, Jeff97, Dailey89, Sobieszczanski90, Seonho00]

[Gleicher and Witkin 91]  [Smith et al. 05]  [Alexandre et al. 10]
A Geometric Interpretation of Static Equilibrium

Reference

World

Internal Forces + External Forces = ?
A Geometric Interpretation of Static Equilibrium

Internal Forces + External Forces = 0
Static Equilibrium

\[ f_{\text{internal}} (x^*, X) + f_{\text{external}} = 0 \]
Static Equilibrium

\[ \mathbf{R}(x, X) = 0 \]
Static Equilibrium

2D cloth pattern \rightarrow 3D cloth shape

\[ R(\mathbf{x}, \mathbf{x}) \rightarrow 0 \]

Fixed Solve

R=0 : Static equilibrium
Equilibrium Shape is Function of Cloth Pattern

3D cloth shape

Newton’s Iteration

Equilibrium \( R=0 \)

2D cloth pattern
Linear Sensitivity Analysis

• What does this derivative tells us about our surface?

\[ \frac{\partial \text{red surface}}{\partial \text{red curve}} = ? \]
Linear Sensitivity Analysis

3D cloth shape

Sensitive response

Equilibrium
R=0

2D cloth pattern
2D Pattern Mesh Movement with Mouse

\[ \frac{\partial \text{pattern}}{\partial \text{mouse}} = \left( \frac{\partial \text{pattern}}{\partial \text{mouse}} \right) \cdot \left( \frac{\partial \text{pattern}}{\partial \text{mouse}} \right) \text{ constant} \]

linear
We Remesh and/or Remap Current Mesh

Remap with positive mean value coordinates
[Lipman et al. 07]

We occasionally perform remeshing
Sensitivity Modes

Horizontal

Vertical
Linear sensitivity is not enough for large mouse movement.

Rest shape  Linear sensitivity  Ground truth

Linearization artifact
Nonlinear Approximation - During Mouse Drag

Cached solutions & sensitivities

Merge

Nonlinear Approximation
Newton’s iteration with the sensitivity approximation

3D cloth shape

Newton’s iteration

Equilibrium

Mouse position

Converged solution
Nonlinear Augmentation

Interpolation: Generalized Moving Least Squares (GMLS)

Cached solution & sensitivity

3D cloth shape

GMLS interpolation

Sensitive Response

Mouse position

Interpolation: Generalized Moving Least Squares (GMLS)
Hermite Spline
Hermite Spline

Point
Hermite Spline

Tangent Vector
Progressive Nonlinear Augmentation

Mouse click

Cached solution & sensitivity
Result of Nonlinear Augmentation

- Rest shape
- GMLS sensitivity
- Cached solutions
- Ground truth
Sensitivity for Contact & Friction

**Friction:** constant

**Contact linear w.r.t. penetration depth**

Human Body

Cloth
A variety of cloth pattern designs is possible with our system.
Live Demo
Paper Craft

x5
FUTURE WORK
Self Contact

Flicker photo by “Nemo's great uncle”

Flicker Photo by “Tomas Fano”
More Materials

- Hair
- 3D solid
- Elasto-plastic material
- Fluid
Now is the time for IDSI

Integrated Design
Simulation Interaction

numerical method
hardware
interaction technique
Acknowledgement

We would like to thank:
- Charles Han & Suzanna Kim
- Brandon Michael Arrington
- Anonymous Reviewers

Funded by:
- FUNAI Oversea Scholarship
- JST ERATO
- JSPS
- NSF
Thank You!!
Nobuyuki Umetani (Univ. Tokyo)
Danny Kaufman (Columbia Univ.)
Takeo Igarashi (Univ. Tokyo, JST ERATO)
Eitan Grinspun (Columbia Univ.)
Standard Finite Element Method

Solve 3D cloth shape assuming fixed 2D cloth pattern

\[ R(X, x) = r \]

\[ \frac{\partial R}{\partial x} \Delta x = r \]

\[ \Delta x = \left( \frac{\partial R}{\partial x} \right)^{-1} r \]

Fixed residual

Equilibrium \( R = 0 \)

Newton’s Iteration

3D cloth shape

2D cloth pattern
Linear Sensitivity Analysis

Compute response to changing cloth pattern

\[ R(X,x) = 0 \]

\[ \frac{\partial R}{\partial x} \Delta x = -\frac{\partial R}{\partial X} \Delta X \]

\[ \Delta x = -\left( \frac{\partial R}{\partial x} \right)^{-1} \frac{\partial R}{\partial X} \Delta X \]

\( X \): input 2D cloth pattern

\( \hat{X} \): output 3D cloth shape
Customized Cloth Design

We can design clothes for our dogs!!