Cloth Animation

Outline

- Overview
- Cloth Modeling
  - Static model
  - Dynamic model

Why cloth simulation?

- High demands from
  - Character animation
  - Game industry
  - Fashion industry
  - Textile industry

Challenges of Cloth Simulation

- Realistic cloth
- Interactive cloth
- Stable cloth
- Complex cloth
- Collision detection/handling

Cloth Modeling

- Textile Engineering
  - measuring mechanical properties
  - CAD/CAM and industrial applications
- Computer Graphics
  - Simulating the complex shapes and deformations of fabric and clothing
  - Geometric approaches
  - Physically-based approaches

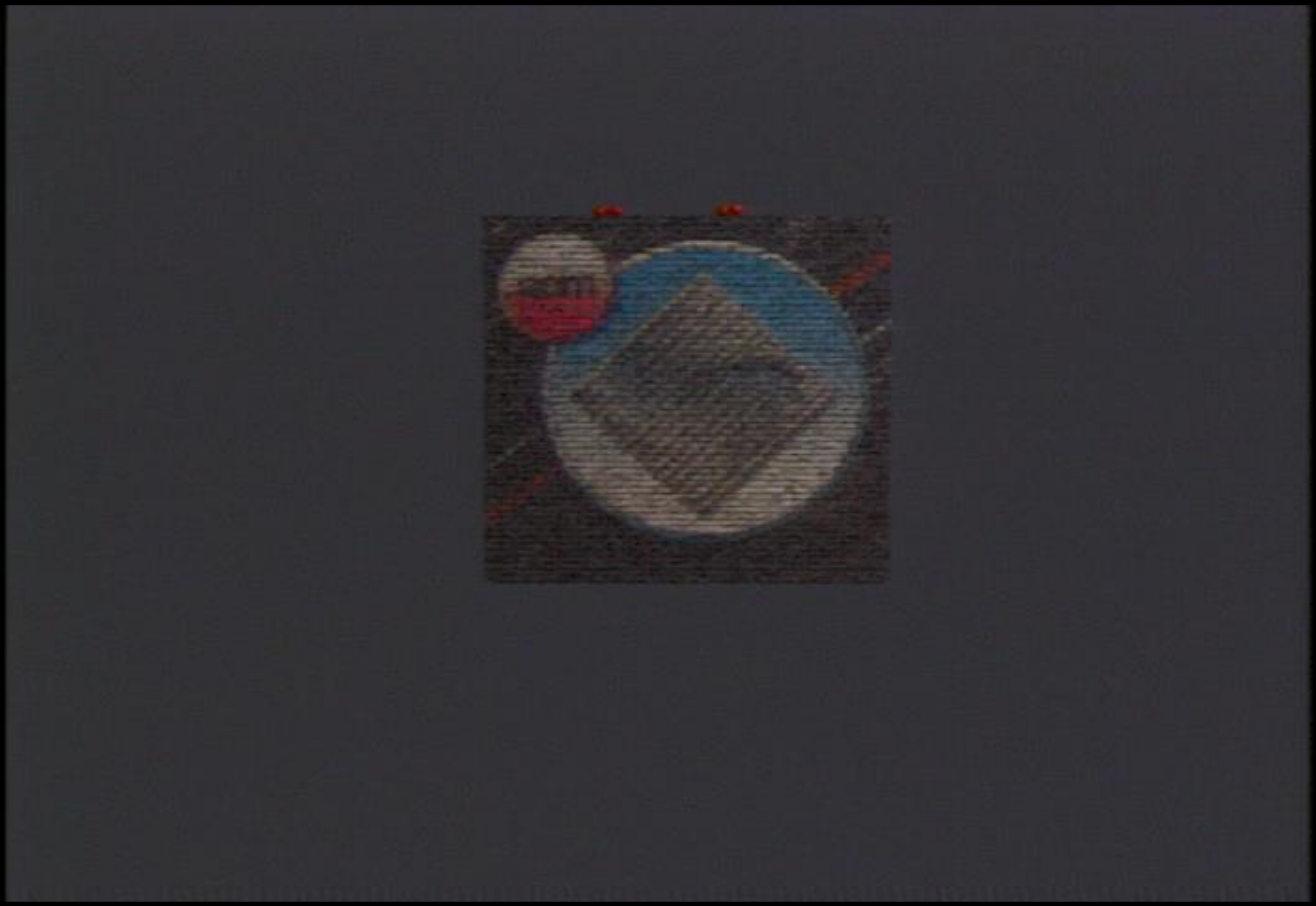
CG Cloth Modeling

- Geometric approaches
  - Weil (1986)
- Continuum approaches
  - Feynman (1986) - minimize strain energy
  - Terzopoulos et al. (1987) - elasticity-based forces
  - Thalmanns (1990 on) – virtual clothing

CG Cloth Modeling (cont.)

- Particle-based approaches
  - Haumann (1987) - Mass-spring model
  - Breen et al. (1991-94) - Particle-based model
  - Baraff & Witkin (SIGGRAPH'98) - Implicit integration
- Misc.
  - Eberhardt et al. (1995) - Modeling knits
  - Ko & Choi (SIGGRAPH'02) - Buckling model
  - Goldenthal et al. (SIGGRAPH'07) - Lagrangian mechanics
  - Kaldor, James, Marschner (SIGGRAPH'08) - yarn level

Terzopoulos et al. Results



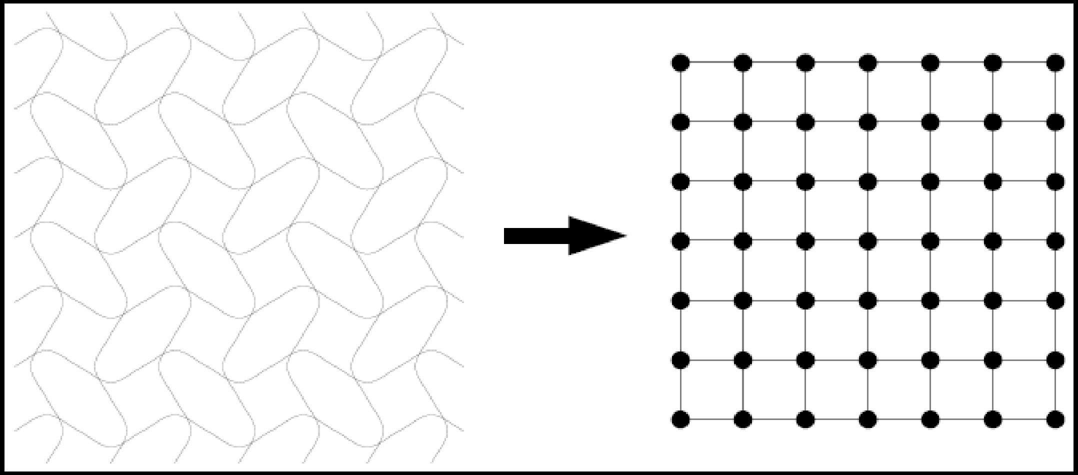
Thalmann et al. Results (2005)

- La Haute Couture Mise en Equations (https://youtu.be/Ekc_9vPDbo8)

Particle-based Approaches

Particle-based Approaches

- Breen, House, Getto, Wozny, 1992-1994
- Macroscopic behavior arises from modeling microscopic structure
- Particles based on thread-level interactions



Breen et al. “A physically-based particle model of woven cloth,” 1992

Breen et al.(1994) – statics

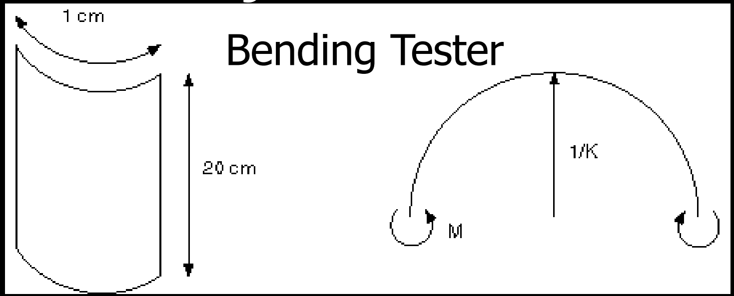
- Energy-based model

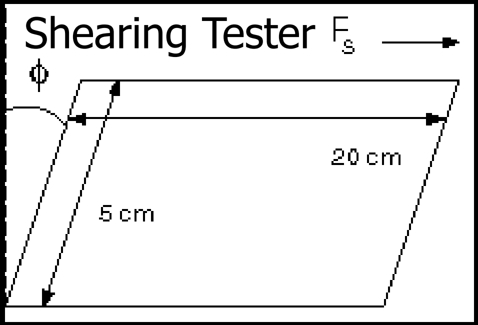
$$U_{total_i} = U_{repel_i} + U_{stretch_i} + U_{bend_i} + U_{trellis_i}$$

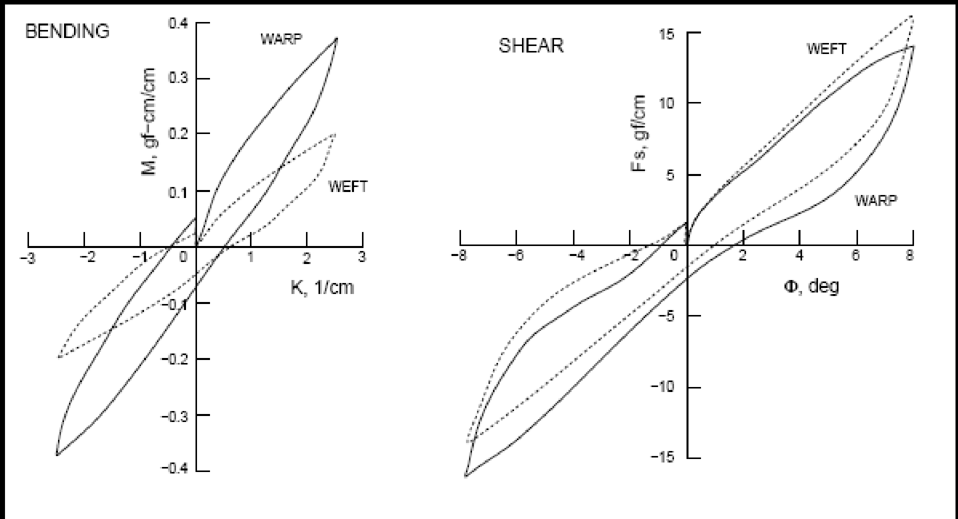
- Compute final draping configuration by minimizing the total energy in the cloth

Breen et al.(1994)

- Tries to make the drape more realistic by measuring from the reality (Kawabata system)
- Fit functions to the measured data
- No dynamics involved

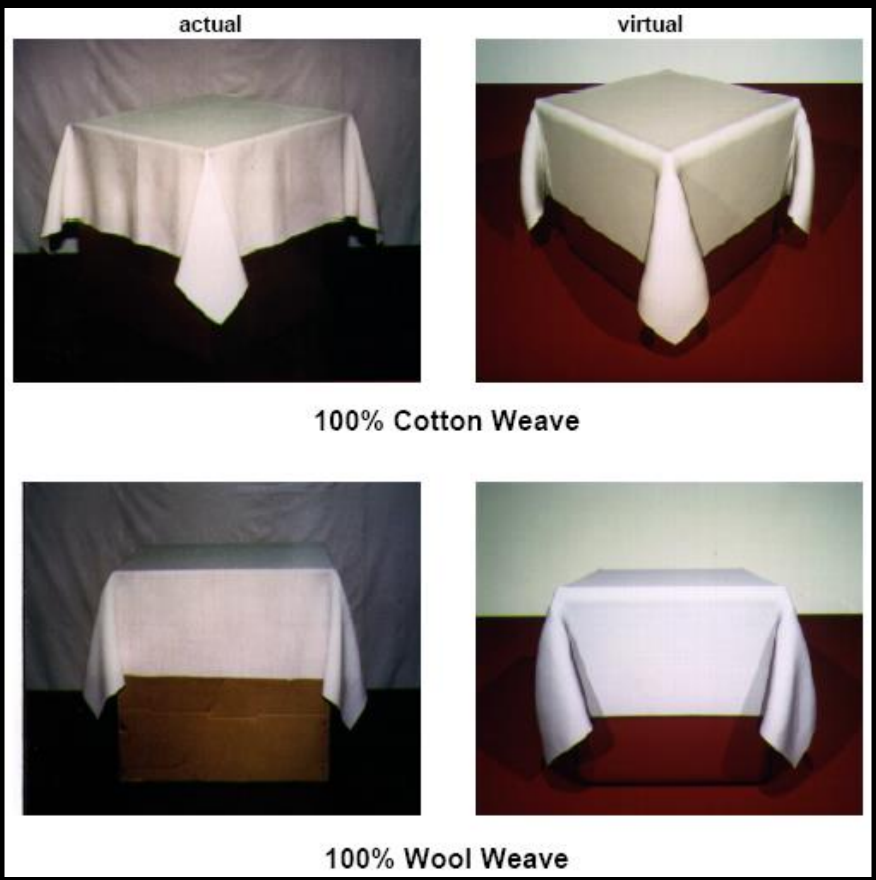


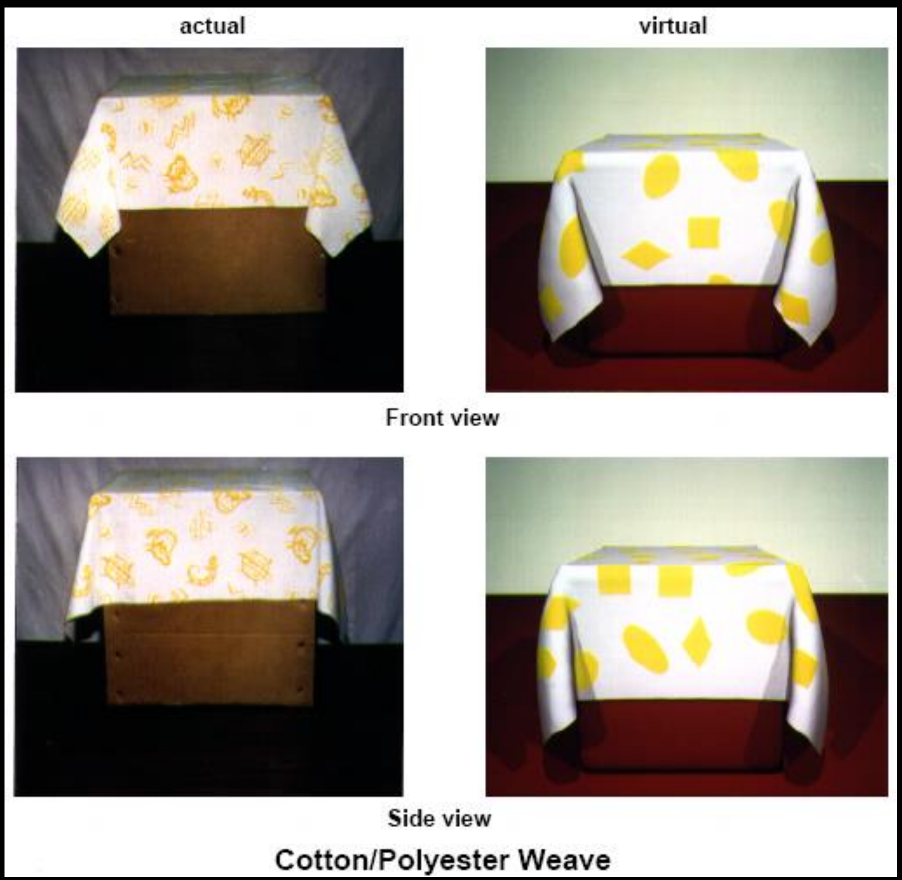




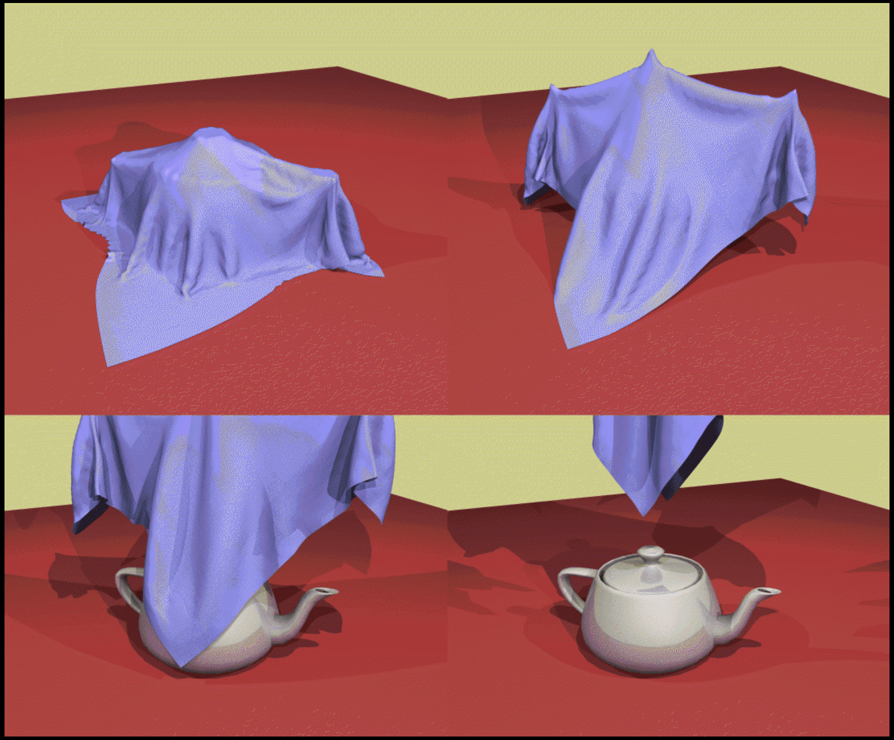
a) 100% cotton

Breen et al. Results



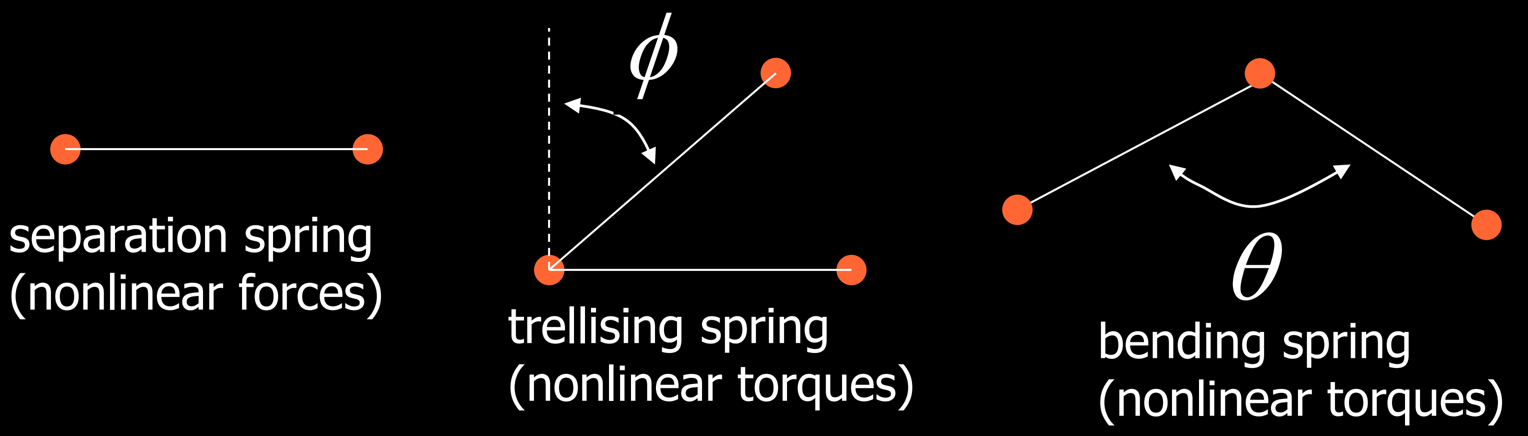


Breen et al. Results



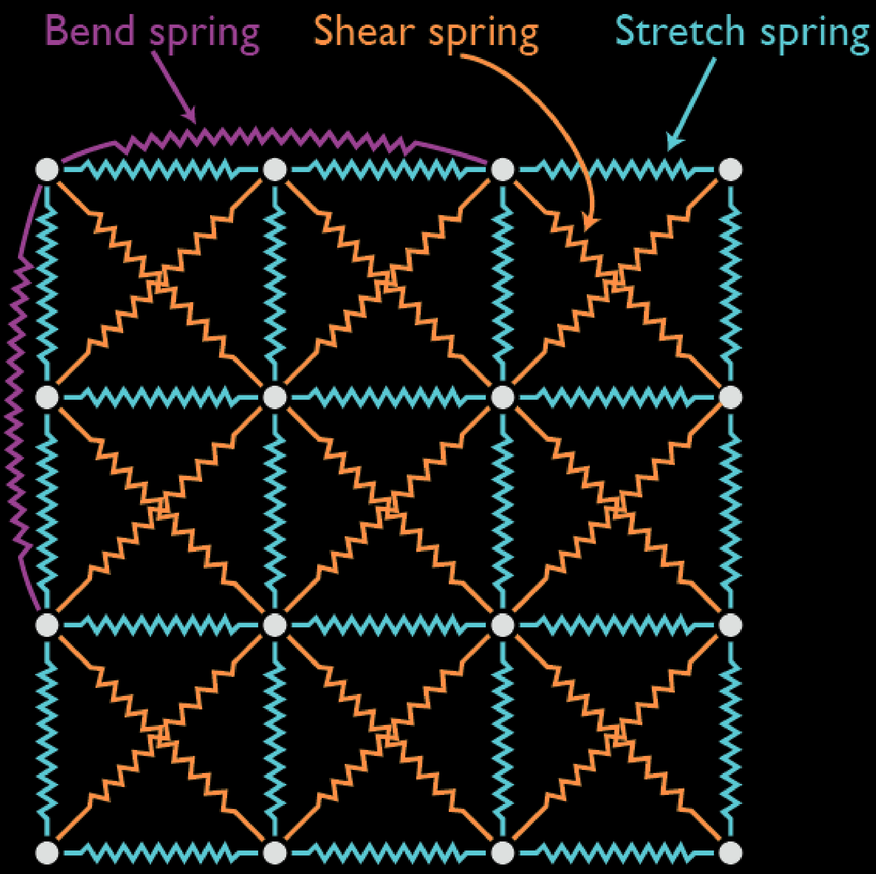
Extend to include dynamics

- Add cloth springs to model
  - Stretch
  - Shearing
  - Bending



Mass-spring Model

- A simple spring-damper system due to Provot (1995)



Courtesy of Chris Twigg

Baraff and Witkin (1998)

- “Large steps in cloth simulation” SIGGRAPH’98
- Rapid cloth simulation with implicit integration
- Larger time steps and faster simulations
- Triangle-based representation
- Exploit sparseness of Jacobian
- Used in Maya Cloth

Baraff and Witkin Results

Newton's 2nd Law of Motion

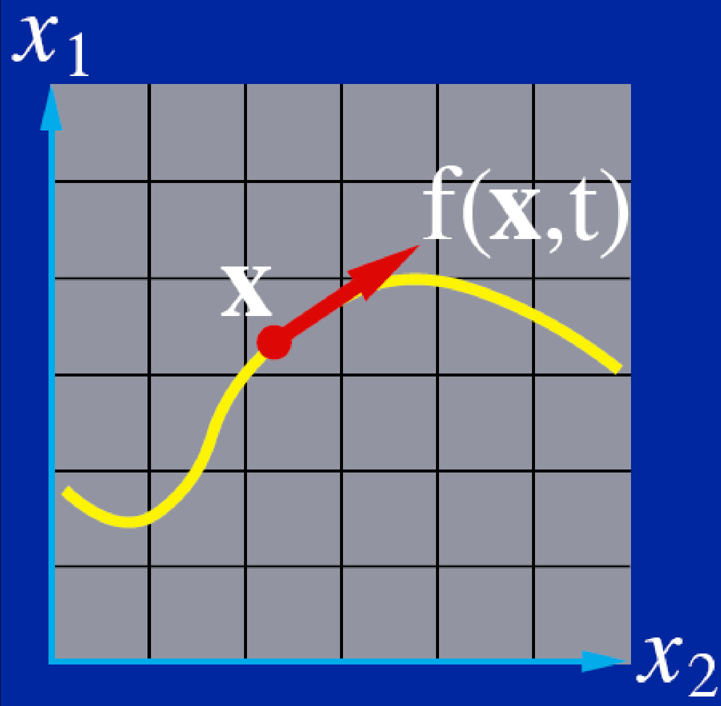
- *n* particles

$$\ddot{\mathbf{x}} = \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \dot{\mathbf{x}})$$

$$\mathbf{x} : 3n \times 1$$

$$\mathbf{M} : 3n \times 3n \quad \text{Diagonal matrix}$$

Different Equation Basics (review)



$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x},t)$$

- $\mathbf{x}(t)$: a moving point.
- $\mathbf{f}(\mathbf{x},t)$: $\mathbf{x}$'s velocity.

$$\ddot{\mathbf{x}} = \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \dot{\mathbf{x}})$$

$$\frac{d}{dt}\begin{pmatrix} \mathbf{x} \\ \mathbf{v} \end{pmatrix} = \begin{pmatrix} \mathbf{v} \\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \mathbf{v}) \end{pmatrix}$$

Explicit Euler (review)

$$\frac{d}{dt}\begin{pmatrix} \mathbf{x} \\ \mathbf{v} \end{pmatrix} = \begin{pmatrix} \mathbf{v} \\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \mathbf{v}) \end{pmatrix}$$

$$\begin{pmatrix} \Delta\mathbf{x} \\ \Delta\mathbf{v} \end{pmatrix} = h\begin{pmatrix} \mathbf{v}_0 \\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}_0, \mathbf{v}_0) \end{pmatrix}$$

Implicit Euler

$$\begin{pmatrix} \Delta\mathbf{x} \\ \Delta\mathbf{v} \end{pmatrix} = h \begin{pmatrix} \mathbf{v}_0 + \Delta\mathbf{v} \\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}_0 + \Delta\mathbf{x}, \mathbf{v}_0 + \Delta\mathbf{v}) \end{pmatrix}$$

Implicit formula for $\Delta\mathbf{x}, \Delta\mathbf{v}$

Usually no close form solution for a nonlinear equation

Approximation using Taylor Series

- Recall that a Taylor series of a real function in two variables is given by

$$f(x+\Delta x, y+\Delta y) = f(x,y) + \frac{\partial f}{\partial x}\Delta x + \frac{\partial f}{\partial y}\Delta y + \ldots$$

- We can approximate **f**(**x**,**v**) as

matrix

vector

$$\mathbf{f}(\mathbf{x}_0 + \Delta\mathbf{x}, \mathbf{v}_0 + \Delta\mathbf{v}) = \mathbf{f}_0 + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\Delta\mathbf{x} + \frac{\partial \mathbf{f}}{\partial \mathbf{v}}\Delta\mathbf{v}$$

Approximation using Taylor Series

$$\mathbf{f}(\mathbf{x}_0 + \Delta\mathbf{x}, \mathbf{v}_0 + \Delta\mathbf{v}) = \mathbf{f}_0 + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\Delta\mathbf{x} + \frac{\partial \mathbf{f}}{\partial \mathbf{v}}\Delta\mathbf{v}$$

$$\begin{pmatrix} \Delta\mathbf{x} \\ \Delta\mathbf{v} \end{pmatrix} = h \begin{pmatrix} \mathbf{v}_0 + \Delta\mathbf{v} \\ \mathbf{M}^{-1}(\mathbf{f}_0 + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\Delta\mathbf{x} + \frac{\partial \mathbf{f}}{\partial \mathbf{v}}\Delta\mathbf{v}) \end{pmatrix}$$

Plug the first row into the second row, we can get:

$$(\mathbf{I} - \mathbf{h}\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{v}} - \mathbf{h}^2\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{x}})\Delta\mathbf{v} = \mathbf{h}\mathbf{M}^{-1}(\mathbf{f}_0 + \mathbf{h}\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\mathbf{v}_0)$$

Solving the Implicit Integration

- To solve for $\Delta\mathbf{x}, \Delta\mathbf{v}$, we need to compute $\frac{\partial \mathbf{f}}{\partial \mathbf{v}}, \frac{\partial \mathbf{f}}{\partial \mathbf{x}}$
- Easy for few springs/dampers
- Difficult for a complex model
- Compute forces from a potential energy function

$$E(\mathbf{x})$$

$$\mathbf{f} = -\frac{\partial E}{\partial \mathbf{x}}$$

Damping force cannot be derived!

An inaccurate but useful interpretation:
Consider work generated by an external force. $w = \mathbf{f}_e \cdot \mathbf{x} \longrightarrow \mathbf{f}_e = \frac{\partial w}{\partial \mathbf{x}}$
For potential energy by internal force, $\mathbf{f}_i = -\mathbf{f}_e = -\frac{\partial U}{\partial \mathbf{x}}$

Solving the Implicit Integration

- To solve for $\Delta\mathbf{x}, \Delta\mathbf{v}$, we need to compute $\dfrac{\partial \mathbf{f}}{\partial \mathbf{x}}, \dfrac{\partial \mathbf{f}}{\partial \mathbf{v}}$

- Compute forces from a special energy function

$$E_C(\mathbf{x}) = \frac{k}{2}\mathbf{C}(\mathbf{x})^T \mathbf{C}(\mathbf{x}) \qquad \mathbf{f} = -\frac{\partial E_C}{\partial \mathbf{x}} = -k\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}}^T \mathbf{C}(\mathbf{x})$$

scalar

vector condition we want to be zero

$$\mathbf{f} \in R^{3n\times 1} \qquad \frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}} \in R^{m\times 3n} \qquad \mathbf{C}(\mathbf{x}) \in R^{m\times 1}$$

Solving the Implicit Integration

- To solve for $\Delta\mathbf{x}, \Delta\mathbf{v}$, we need to compute $\dfrac{\partial \mathbf{f}}{\partial \mathbf{x}}, \dfrac{\partial \mathbf{f}}{\partial \mathbf{v}}$
- Compute forces from a special energy function

$$\underset{\substack{\uparrow\\\text{scalar}}}{E_C}(\mathbf{x}) = \frac{k}{2}\mathbf{C}(\mathbf{x})^T\mathbf{C}(\mathbf{x}) \qquad \mathbf{f} = -\frac{\partial E_C}{\partial \mathbf{x}} = -k\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}}^T\mathbf{C}(\mathbf{x})$$

$$\mathbf{f}_i, \mathbf{x}_j \in R^{3\times 1} \qquad \frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_i} \in R^{m\times 3} \qquad \frac{\partial^2 \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_i \partial \mathbf{x}_j} \in R^{m\times 3}$$

$$\frac{\partial \mathbf{f}_i}{\partial \mathbf{x}_j} = -k\left(\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_i}^T\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_j} + \frac{\partial^2 \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_i \partial \mathbf{x}_j}^T\mathbf{C}(\mathbf{x})\right)$$

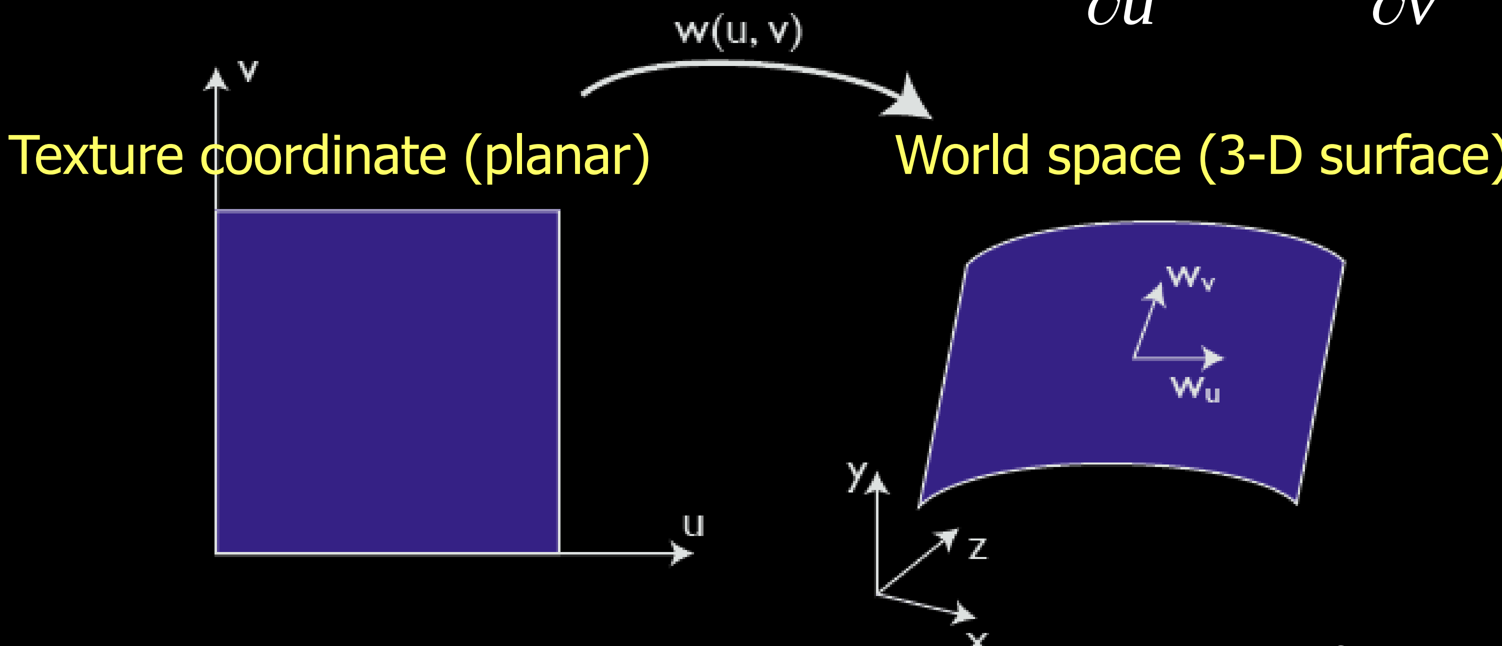
Triangle-based Cloth Model

- Particles are linked like a triangular mesh
- Energy defined over finite regions
- How do we determine stretch and shear on triangles?

$$\mathbf{C}(\mathbf{x}) = ?$$

Basic Idea

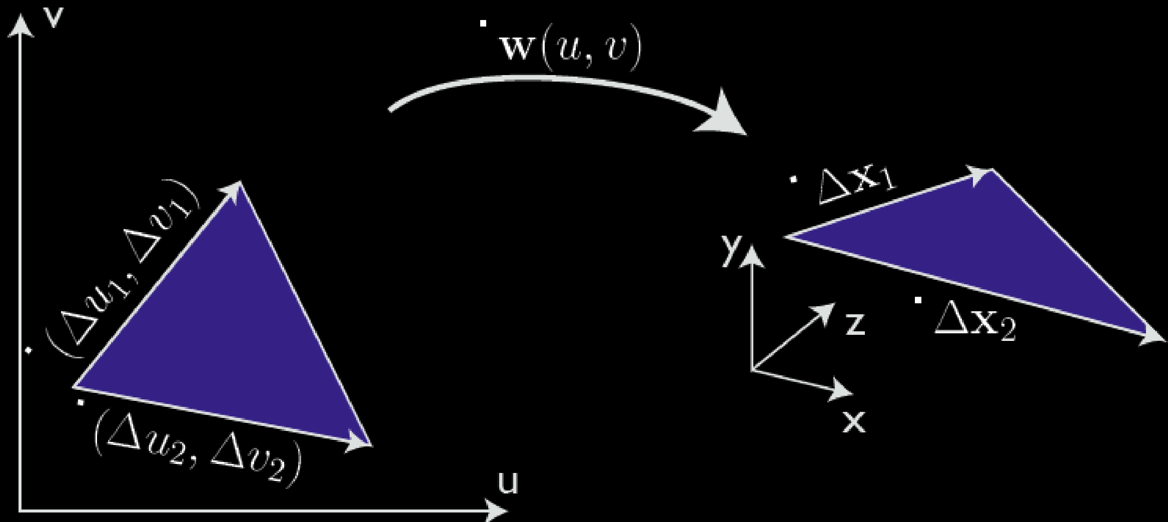
- Represent cloth surface as a triangular surface embedded in 3D
  - Locally linear mapping w(u,v)
- Measure deformation using $\mathbf{w_u} = \dfrac{\partial w}{\partial u}, \mathbf{w_v} = \dfrac{\partial w}{\partial v}$



Courtesy of Chris Twigg

Stretch/Compression Measure

- Represent $(\triangle x, \triangle y, \triangle z)$ using $(\triangle u, \triangle v)$



- Again, we'll use Taylor series!

$$\mathbf{w}(u+\Delta u, v+\Delta v) = \begin{bmatrix} w_x(u+\Delta u, v+\Delta v) \\ w_y(u+\Delta u, v+\Delta v) \\ w_z(u+\Delta u, v+\Delta v) \end{bmatrix} \approx \mathbf{w}(u,v) + \mathbf{J}_{\mathbf{w}}(u,v) \begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix}$$

$$\mathbf{w}(u+\Delta u, v+\Delta v) = \begin{bmatrix} w_x(u+\Delta u, v+\Delta v) \\ w_y(u+\Delta u, v+\Delta v) \\ w_z(u+\Delta u, v+\Delta v) \end{bmatrix} \approx \mathbf{w}(u,v) + \mathbf{J_w}(u,v)\begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix}$$

- The Jacobian is formed by $\mathbf{w_u} = \dfrac{\partial w}{\partial u}, \mathbf{w_v} = \dfrac{\partial w}{\partial v}$

$$\Delta \mathbf{x} = \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \mathbf{w}(u+\Delta u, v+\Delta v) - \mathbf{w}(u,v) \approx \mathbf{J_w}(u,v)\begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix} = \begin{bmatrix} \mathbf{w_u} & \mathbf{w}_v \end{bmatrix}\begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix}$$

- With locally linear assumption,

$$\begin{aligned} \Delta \mathbf{x_1} &= \mathbf{w_u}\Delta u_1 + \mathbf{w_v}\Delta v_1 \\ \Delta \mathbf{x_2} &= \mathbf{w_u}\Delta u_2 + \mathbf{w_v}\Delta v_2 \end{aligned} \Rightarrow \begin{bmatrix} \mathbf{w}_u & \mathbf{w}_v \end{bmatrix} = \begin{bmatrix} \Delta \mathbf{x_1} & \Delta \mathbf{x_2} \end{bmatrix}\begin{bmatrix} \Delta u_1 & \Delta u_2 \\ \Delta v_1 & \Delta v_2 \end{bmatrix}^{-1}$$

Fixed value during simulation

Forces as Energy Functions

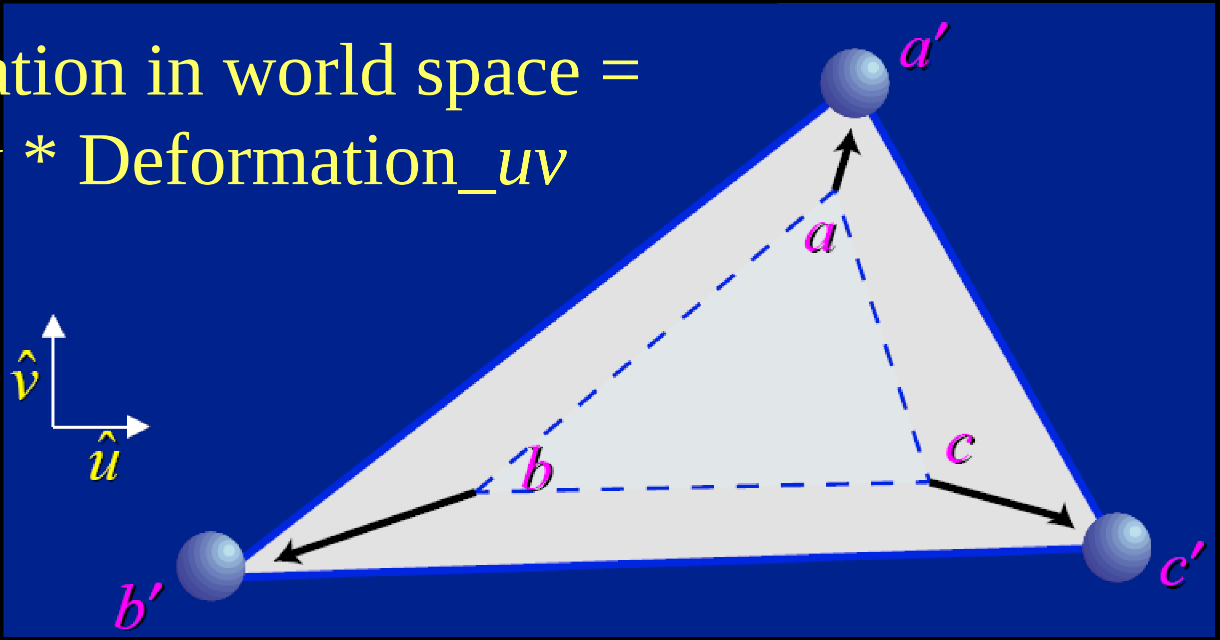
- Condition for stretch forces

triangle's area in *uv* coordinate

rest length

$$C(\mathbf{x}) = a\begin{pmatrix} \|\mathbf{w_u}(\mathbf{x})\| - b_u \\ \|\mathbf{w_v}(\mathbf{x})\| - b_v \end{pmatrix}$$

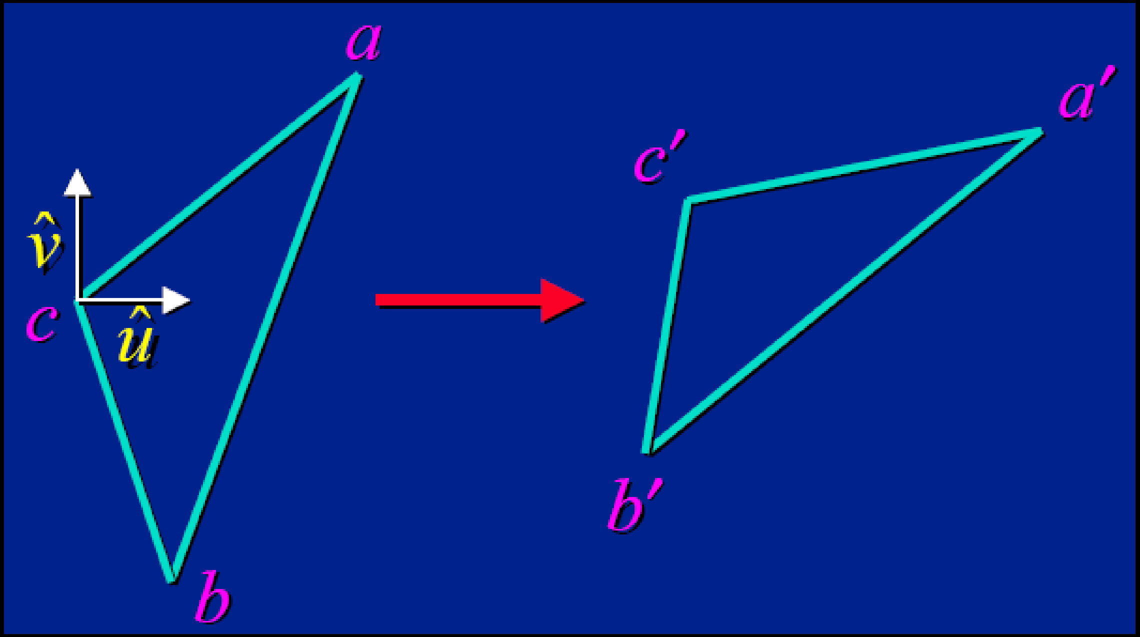
Deformation in world space = Area_uv * Deformation_*uv*



Shear Forces

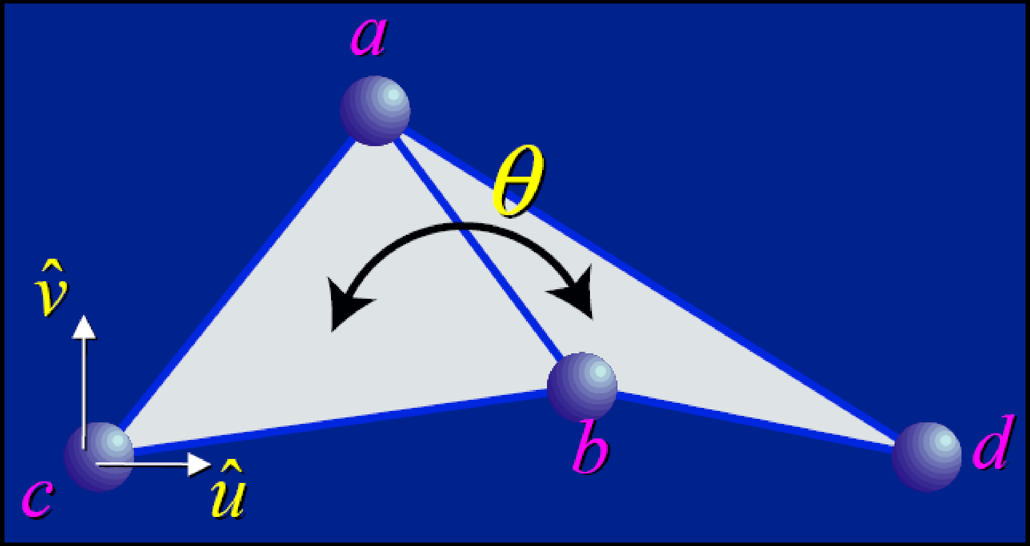
$$C(\mathbf{x}) = a w_u(\mathbf{x})^T w_v(\mathbf{x})$$

measured by the inner product



Bending Forces

$$C(\mathbf{x}) = \theta$$



Damping Forces

- Important both for realism and numerical stability
- Instead of deriving from E,
- Baraff and Witkin differentiate C

$$\frac{dE}{dt} = \left(\frac{\partial E}{\partial \mathbf{x}}\right)^T \frac{d\mathbf{x}}{dt} = 0$$

Gradient of $E = 0$ when E is at its minimum→ damping force is always zero at the rest state!

$$\mathbf{d} = -k_d \underbrace{\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}}}_{\text{direction of force}} \underbrace{\dot{\mathbf{C}}(\mathbf{x})}_{\text{velocity}}$$

- Act in direction of corresponding elastic force
- Proportional to the velocity in that direction

Constraints

- May choose
  - penalty method
    → stiff system
  - Lagrange multipliers
    → need compute constraint force
  - Parametric constraint (reduced coordinate)
    → infeasible for dynamic contact constraints
- Baraff & Witkin introduced a new approach by modifying mass matrix

Zero-acceleration Constraints

- Basic idea:
  Enforcing constraints by mass modification
- e.g. zero acceleration along z-axis

$$\ddot{\mathbf{x}}_i = \begin{pmatrix} \frac{1}{m_i} & 0 & 0 \\ 0 & \frac{1}{m_i} & 0 \\ 0 & 0 & 0 \end{pmatrix} \mathbf{f}_i \rightarrow \ddot{\mathbf{x}}_i = \mathbf{W}_{ii}\mathbf{f}_i$$

$$\mathbf{W}_{ii} = \frac{1}{m_{ii}} \mathbf{S}_i \in R^{3\times 3}$$

Non-axis zero acceleration constraints

- For the *i*th particle

$$\ddot{\mathbf{x}}_i = \mathbf{W}_{ii}\mathbf{f}_i \qquad \mathbf{W}_{ii} = \frac{1}{m_{ii}}\mathbf{S}_i \in R^{3\times 3}$$

$$\mathbf{S}_i = \begin{cases} \mathbf{I} & \text{if } \operatorname{ndof}(i) = 3 \\ (\mathbf{I} - \mathbf{p}_i\mathbf{p}_i^T) & \text{if } \operatorname{ndof}(i) = 2 \\ (\mathbf{I} - \mathbf{p}_i\mathbf{p}_i^T - \mathbf{q}_i\mathbf{q}_i^T) & \text{if } \operatorname{ndof}(i) = 1 \\ 0 & \text{if } \operatorname{ndof}(i) = 0 \end{cases}$$

$$\|\mathbf{p}_i\| = \|\mathbf{q}_i\| = 1 \qquad \mathbf{p}_i \perp \mathbf{q}_i$$

Verification $\mathbf{S}_i = (\mathbf{I} - \mathbf{p}_i \mathbf{p}_i^T)$

- Consider $\mathbf{f}_i = \alpha \mathbf{p}_i$

$$\ddot{\mathbf{x}}_i = \mathbf{W}_{ii} \mathbf{f}_i = \frac{1}{m_i}(\mathbf{I} - \mathbf{p}_i \mathbf{p}_i^T)\alpha \mathbf{p}_i$$

$$\|\mathbf{p}_i\| = 1 = \mathbf{p}_i^T \mathbf{p}_i$$

$$= \frac{\alpha}{m_i}(\mathbf{p}_i - \mathbf{p}_i \mathbf{p}_i^T \mathbf{p}_i) = 0$$

Particle i is constrained to be moved perpendicular to $\mathbf{P}_i$

Arbitrary Velocity Constraints

- No constraints

$$(\mathbf{I} - h\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{v}} - h^2\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{x}})\Delta\mathbf{v} = h\mathbf{M}^{-1}(\mathbf{f}_0 + h\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\mathbf{v}_0)$$

- With constraints

$$(\mathbf{I} - h\mathbf{W}\frac{\partial \mathbf{f}}{\partial \mathbf{v}} - h^2\mathbf{W}\frac{\partial \mathbf{f}}{\partial \mathbf{x}})\Delta\mathbf{v} = h\mathbf{W}(\mathbf{f}_0 + h\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\mathbf{v}_0) + \mathbf{z}$$

Mass-modified matrix for constraints

$$\mathbf{W}_{ii} = \frac{1}{m_{ii}}\mathbf{S}_i$$

Arbitrary velocity constrain

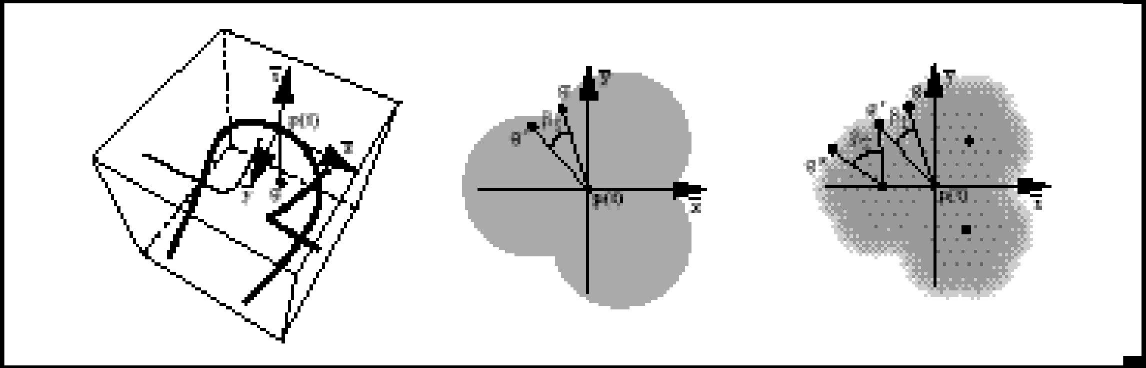
Higher-order implicit methods

- Implicit Euler has only first-order accuracy
- 2nd-order implicit method is used in
  - Ko & Choi, SIGGRAPH’02
  - Bridson, Marino, & Fedkiw, SCA’03 (mixed explicit / implicit method)

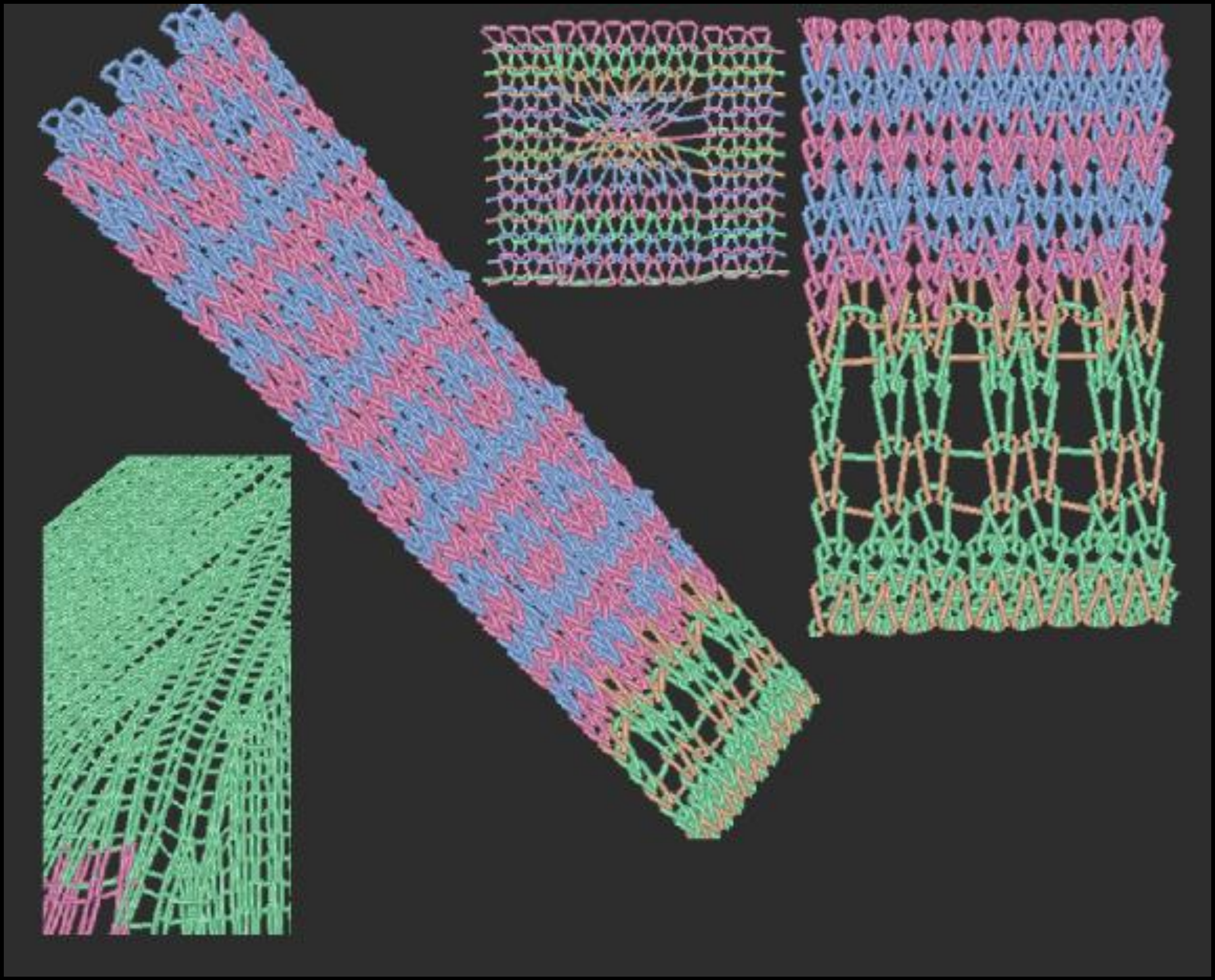
Miscellaneous Approaches

Eberhardt et al. (1995)

- Focus on knits, instead of woven cloth
- Particle system with measured energies
- Volumetric approach to rendering knits
  - Represent microstructure
  - Sweep density distributions along yarns

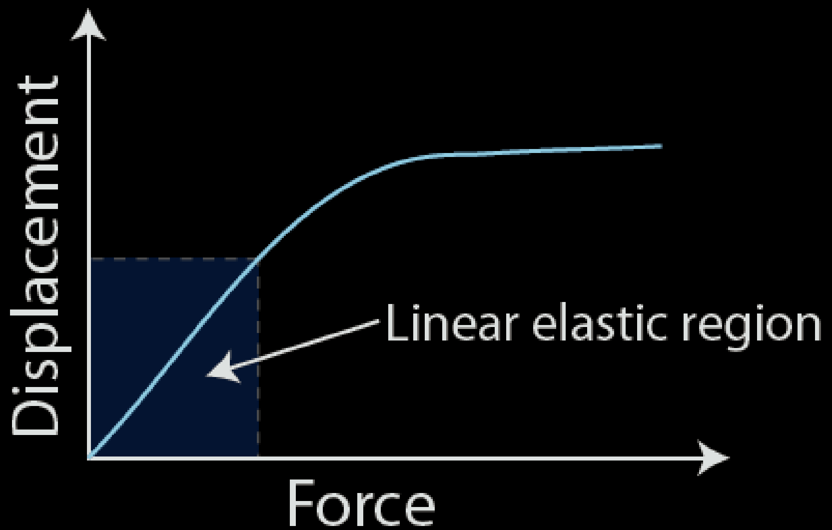


Eberhardt et al. Results



Avoiding Stiffness

- Apply only non-stiff spring forces and then “fix” the solution at the end of time step
  - Provot (1995)
  - Desbrun et al. (1999)
  - Bridson et al. (2002)
- Popular for interactive applications

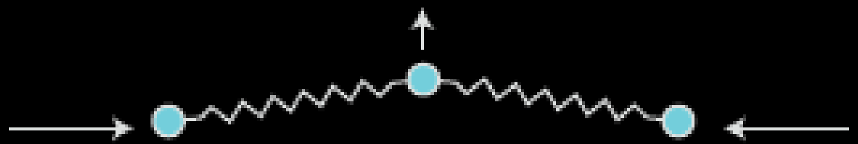


From Desbrun, Meyer, Barr [2000]

Ko, Choi (SIGGRAPH 2002)

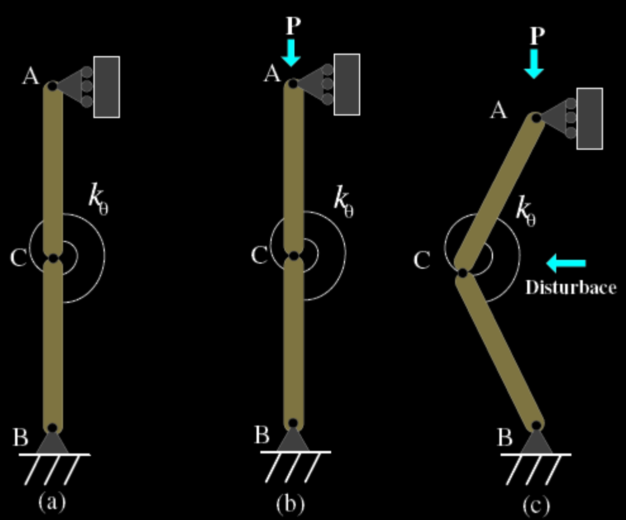
- Cloth property
  - Weak resistance to bending
  - Strong resistance to tension

- Problem in spring-mass model
  - Stiff system for non-stretch
  - Need large compression forces for out-of-plane motion

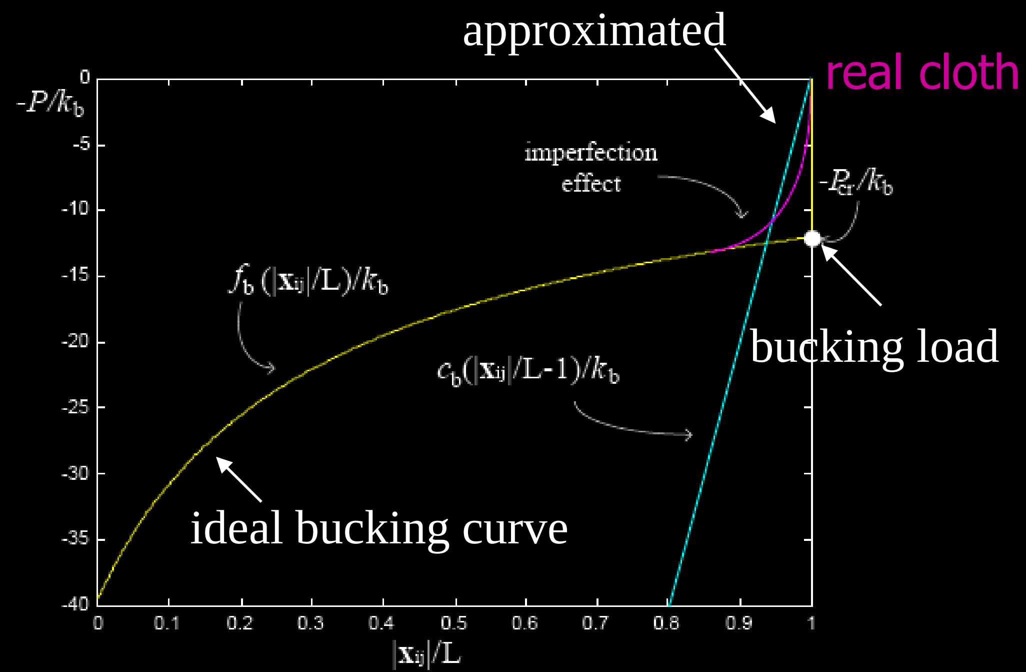


Ko, Choi (2002)

- Use column buckling as their basic model
- Replace bend and compression forces with a single nonlinear model



column bucking



Ko and Choi results

https://www.youtube.com/watch?v=u6hHrkMQNZs

Cloth Model Based on Constrained Lagrange Mechanics

- Goldenthal et al., “Efficient Simulation of Inextensible Cloth,” SIGGRAPH’07
- Inextensibility is important for cloth animation!

- An alternative to implicit integration for stiff system—reformulate it as constraints.

Quick Tutorial on Lagrangian Mechanics

- Lagrangian mechanics is just another form of Newtonian mechanics
- Newtonian mechanics describes motion in Cartesian coordinate (vector) → coordinate transformation is hard
- Lagrangian mechanics describes motion via energy → coordinate transformation is easy
  - generalized coordinate

Quick Tutorial on Lagrangian Mechanics

- Reformulation of classical mechanics
- *Lagrangian* of a dynamical system

$$L(\mathbf{x},\mathbf{v}) = \text{Kinetic Energy} - \text{Potential Energy}$$
$$= T(\mathbf{x},\mathbf{v}) - V(\mathbf{x},\mathbf{v})$$

- The equation of motion is defined as

$$\frac{d}{dt}\frac{\partial L}{\partial \mathbf{v}} - \frac{\partial L}{\partial \mathbf{x}} = 0$$

Cloth Model Based on Constrained Lagrange Mechanics

- Augment Lagrange equation with constraints

Constraints

$$\mathbf{L}(\mathbf{x}, \mathbf{v}) = \frac{1}{2}\mathbf{v}^T \mathbf{M}\mathbf{v} - V(\mathbf{x}) - \mathbf{C}(\mathbf{x})^T \boldsymbol{\lambda}$$

Lagrange Multipliers

Potential energy: stretch, bending, shear

- Constrained dynamics equation

$$\mathbf{M}\dot{\mathbf{v}} + \nabla V(\mathbf{x}) + \nabla \mathbf{C}(\mathbf{x})^T \boldsymbol{\lambda} = 0$$

$$\mathbf{C}(\mathbf{x}) = 0$$

Hybrid Scheme ODE solver

$$\mathbf{M}\dot{\mathbf{v}} + \nabla V(\mathbf{x}) + \nabla \mathbf{C}(\mathbf{x})^T \boldsymbol{\lambda} = 0 \qquad \mathbf{C}(\mathbf{x}) = 0$$

- Potential and constraint equations may be integrated using different explicit or implicit schemes
- Implicit Constraint Direction (ICD) scheme

$$\mathbf{v}^{n+1} = \mathbf{v}^n - h\mathbf{M}^{-1}\left(\nabla V(\mathbf{x}^n) + \nabla \mathbf{C}(\mathbf{x}^{n+1})^T \boldsymbol{\lambda}^{n+1}\right)$$

$$\mathbf{x}^{n+1} = \mathbf{x}^n + h\mathbf{v}^{n+1} \ ,$$

$$\mathbf{C}(\mathbf{x}^{n+1}) = \mathbf{0} \ .$$

Step and Project (SAP)

- Solving ICD is computationally expensive
  - needs to find roots of an equation of 5N variables
  - N is the number of vertices
- Alternative
  - Step forward only the potential forces to unconstrained position $\mathbf{x}_0^{n+1}$
  - Enforce the constraints by projecting $\mathbf{x}_0^{n+1}$ onto the constraint manifold $\{\mathbf{x}^{n+1} \mid \mathbf{C}(\mathbf{x}^{n+1}) = \mathbf{0}\}$, i.e., find $\mathbf{x}^{n+1}$ that is close to $\mathbf{x}_0^{n+1}$

Efficient Simulation of Inextensible Cloth

- Video (https://youtu.be/B2t6x-D6Om0)

Subspace clothing simulation using adaptive bases

- Siggraph 2014 (https://youtu.be/uADrduZWX74)
- Simulation using low-dimensional linear subspaces with temporally adaptive bases

A perceptual control space for garment simulation, Siggraph 2015

- Provide intuitive and art-directable control
- Learned mapping from common descriptors to simulation parameters
- https://youtu.be/LJ_zxvsdcrw