Animation for Computer Games
COMP 477/6311

Prof. Tiberiu Popa

Cloth Animation

Physics-based Animation

- We looked at two types of physics-based animation
  - Springs
  - Fluids
- Can you see a pattern that can serve as a template for other physics-based animations?
- For Lagrangian - yes

Bender, J., Müller, M., Otaduy, M. A., & Teschner, M. (2013, May). Position-based Methods for the Simulation of Solid Objects in Computer Graphics. In *Eurographics (STARs)* (pp. 1-22).

Physics-based Animation

- Lagrangian
  1. Develop the specific equations from F=ma
     1. Derive internal and external forces
     2. Derive acceleration
  2. Find a suitable representation/discretization
  3. Solve the resulting ODE using time integration techniques
  4. ?????

Physics-based Animation

- Lagrangian
  1. Develop the specific equations from F=ma
     1. Derive internal and external forces
     2. Derive acceleration
  2. Find a suitable representation/discretization
  3. Solve the resulting ODE using time integration techniques
  4. Contact and collision (coming soon to a lecture near you!!!)

Cloth Simulation

- Easier said then done
- Cloth is an extremely complex object with very complex behaviour

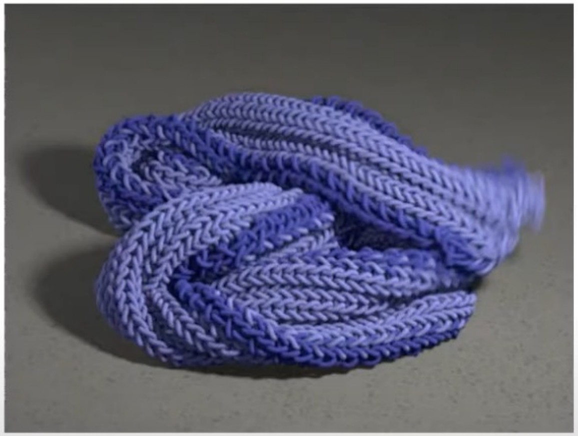
Bridson, R., Fedkiw, R., & Anderson, J. (2002, July). Robust treatment of collisions, contact and friction for cloth animation. In *Proceedings of the 29th annual conference on Computer graphics and interactive techniques* (pp. 594-603).

Cloth Simulation

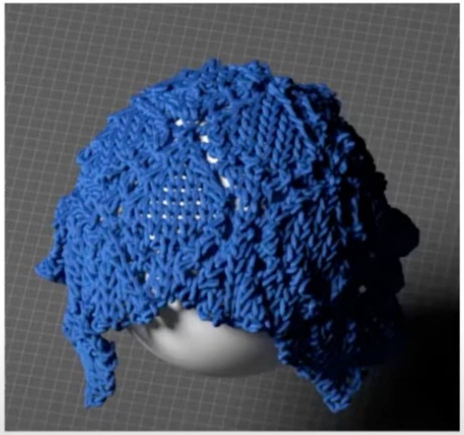
- Divide and conquer
  1. Physical behavior
  2. Collisions and contact

Cloth Simulation

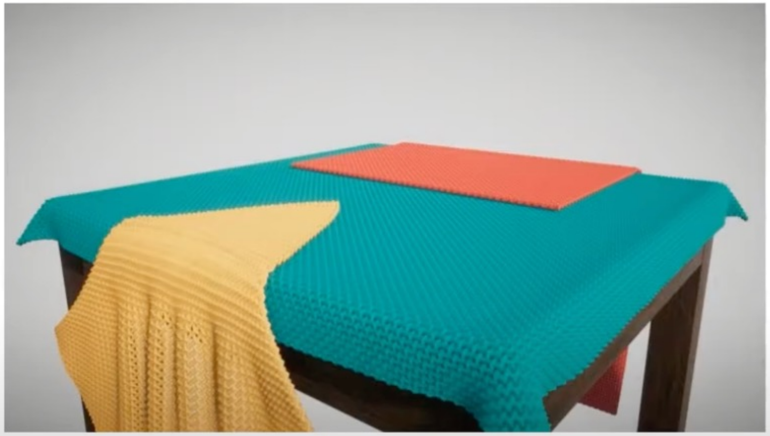
1. Physical behavior
   - Many materials
   - Different physical properties



[Kaldor et al. 2008]



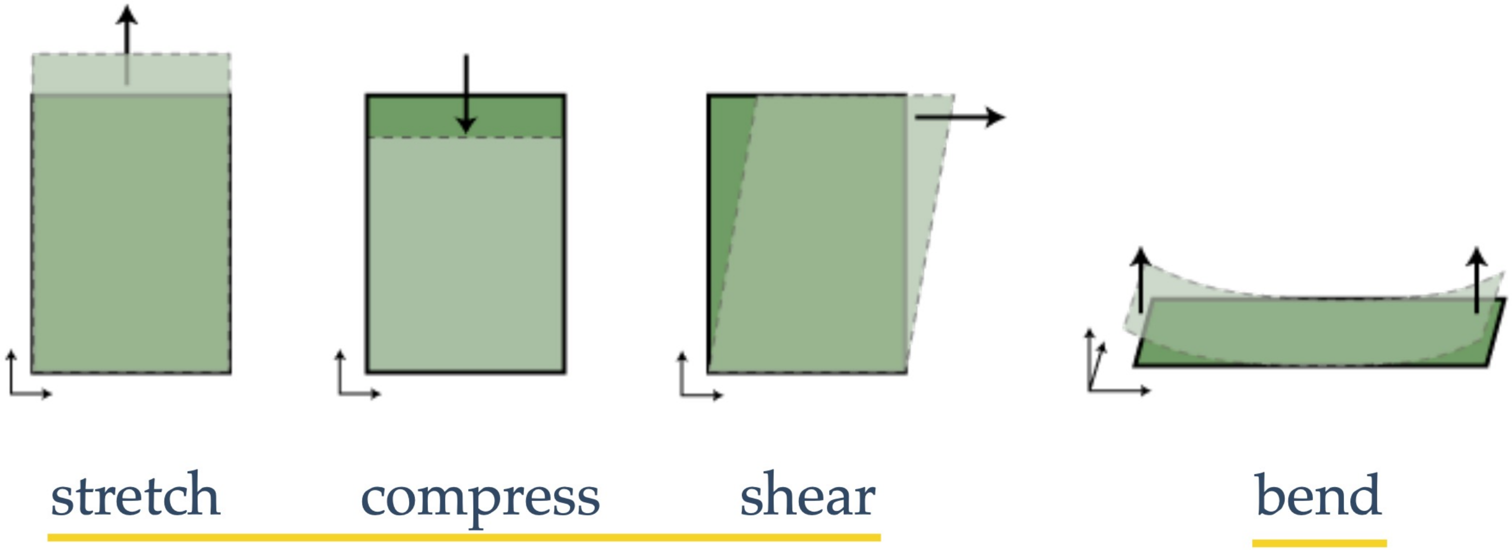
[Cirio et al. 2016]



[Sánchez-Banderas et al. 2020]

Cloth Simulation

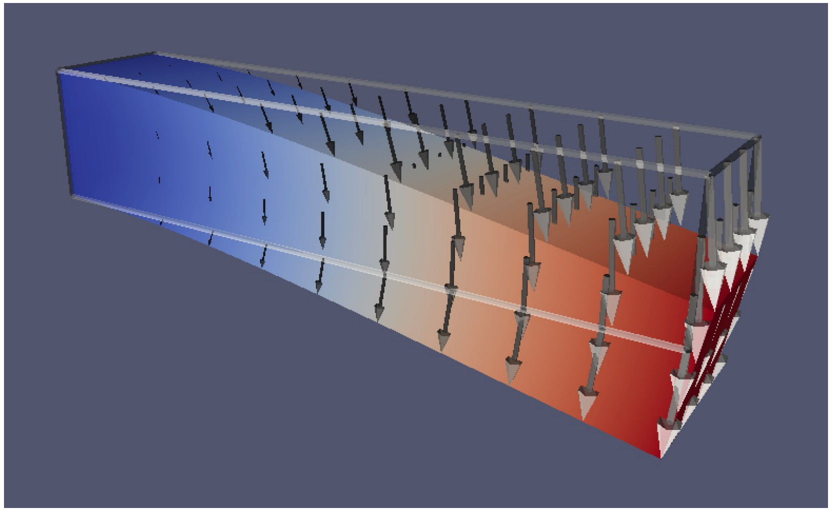
Internal forces of cloth



Cloth Simulation

Elastic objects → tend to return to original shape when deformed
Some internal forces push the object
Where do those forces come from?
Energy → ability of an object to do work
Elastic energy → **stored** in the material

https://www.solarschools.net/knowledge-bank/energy/types/elastic

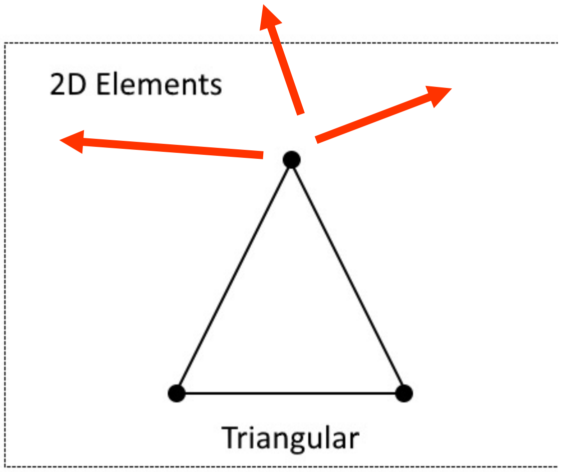


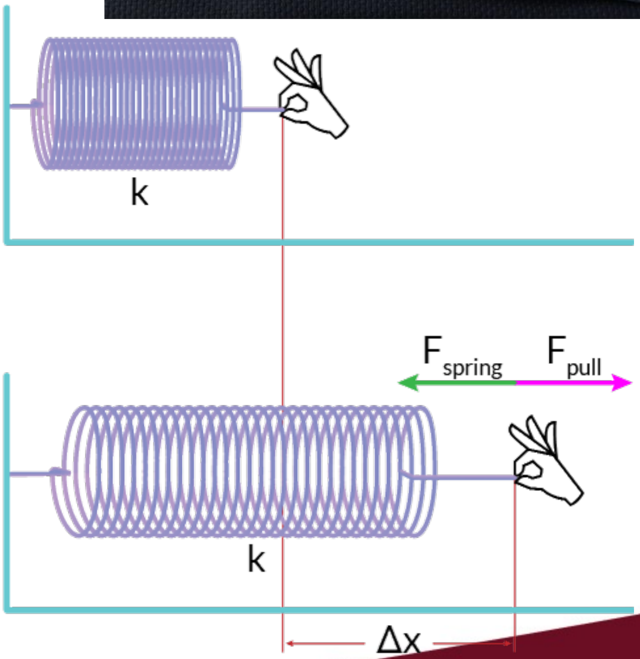
https://fenicsproject.org/pub/tutorial/html/._ftut1008.html

Cloth Simulation

1. Physical behavior

- Elastic behavior
  - Elastic potential energy (E or W)
  - Accumulates when deformed
  - ~sum of all forces at intermediate steps
  - $E = \int F dx$
  - Q1) What kind of function is E?

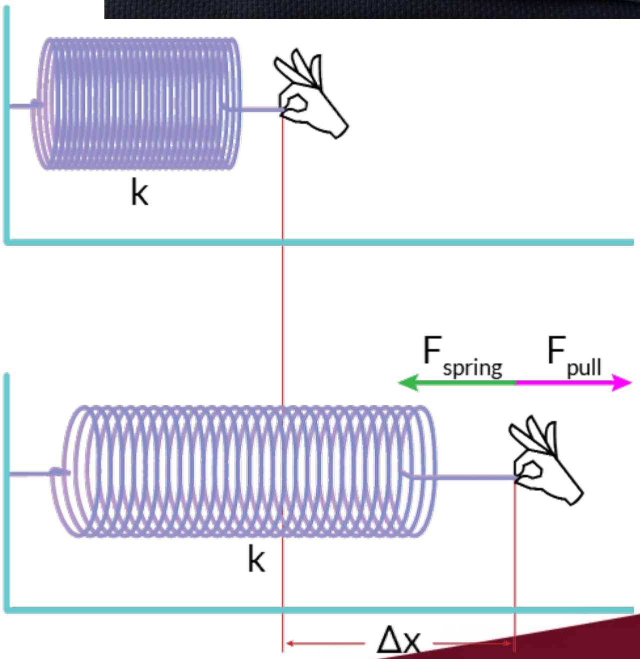


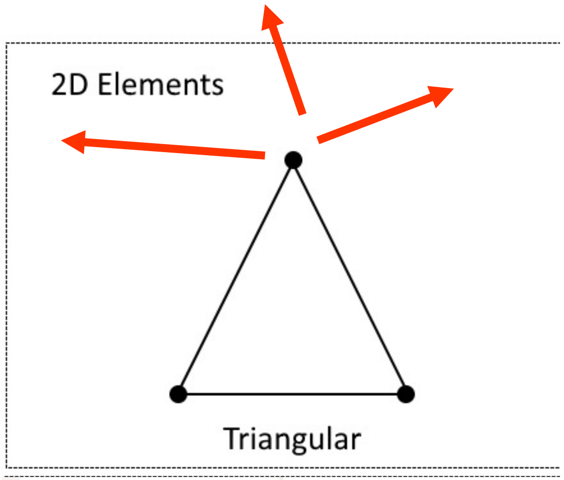


Cloth Simulation

1. Physical behavior

- Elastic behavior
  - Elastic potential energy (E or W)
  - Accumulates when deformed
  - ~sum of all forces at intermediate steps
  - $E = \int F dx$
  - Q2) What does E depend on?

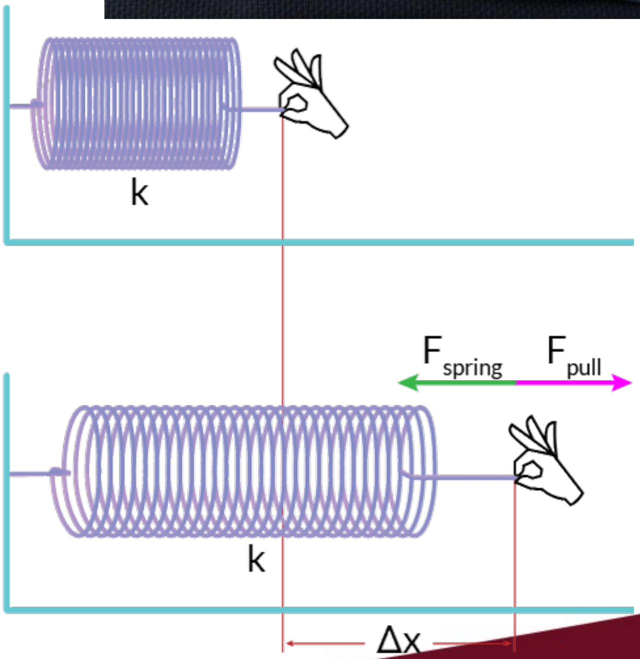


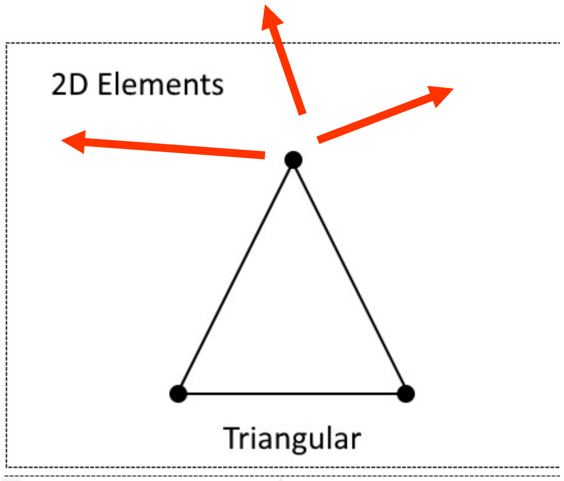


Cloth Simulation

1. Physical behavior

- Elastic behavior
  - Elastic potential energy (E or W)
  - Accumulates when deformed
  - ~sum of all forces at intermediate steps
  - $E = \int F dx$
  - Q3) What kind of function is E?



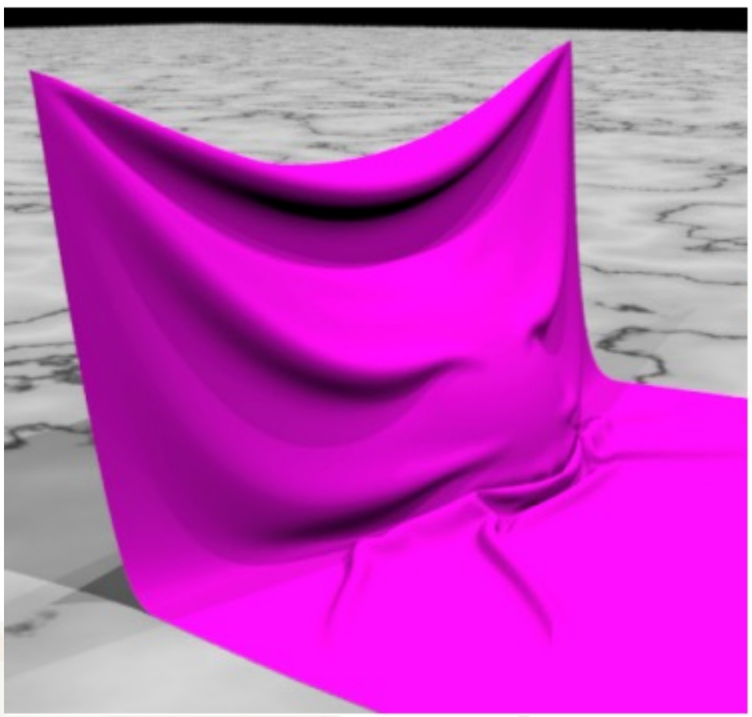


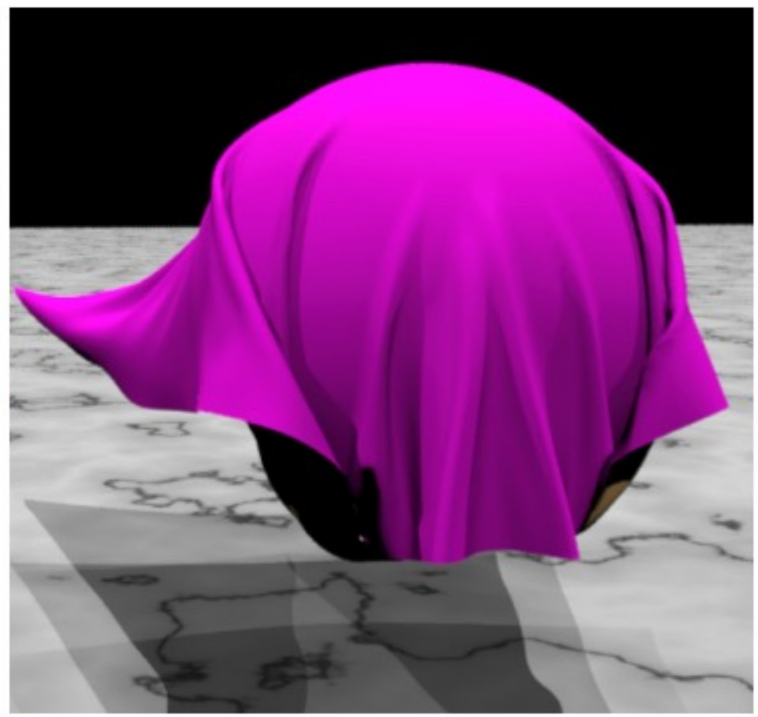
Cloth Simulation

- Ingredients
  - Geometric and Physical model
    - How do I represent the geometry and forces?
    - What are the forces?
  - Time Integration scheme
  - Collision handling
  - Contact handling

Geometric and Physical model

– Triangular mesh
– How do I define the forces?





Geometric and Physical model

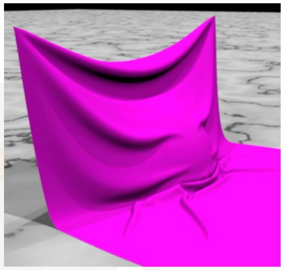
– Forces vs. Energy

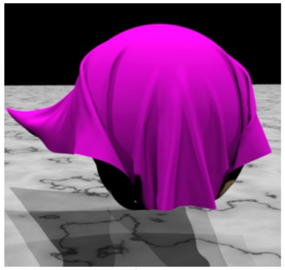
– Energy → scalar field (potential at every point in space)

– $\frac{\partial E}{\partial X} = -F_{int}$

– New equation: $\ddot{X} = M^{-1}(-\frac{\partial E}{\partial X} + F_{ext})$

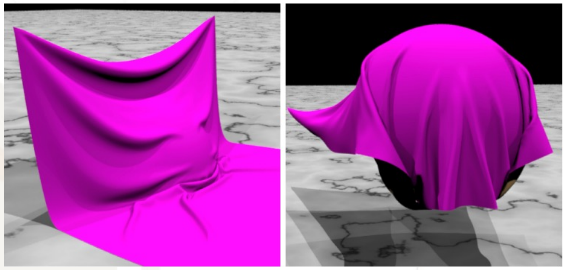
– Why bother?





Geometric and Physical model

- $\ddot{X} = M^{-1}(-\frac{\partial E}{\partial X} + F_e)$
- Acceleration Internal forces External forces
- We can compute/estimate internal energy of the cloth:
- $E = E_{stretch} + E_{shear} + E_{bending}$

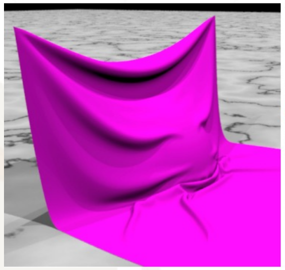


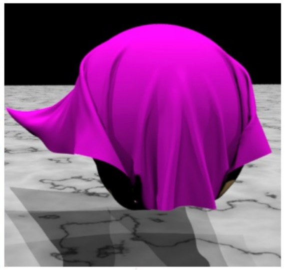
Geometric and Physical model

– We can compute/estimate internal energy of the cloth:

– $E = E_{stretch} + E_{shear} + E_{bending}$

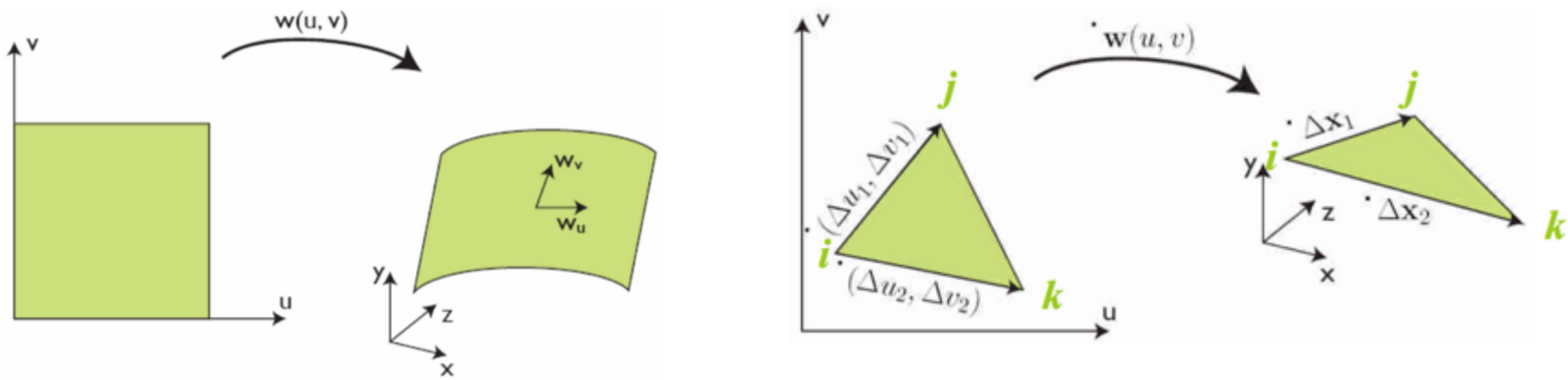
– Properties of energy:
  - Non-negative
  - 0 only in the rest pose





Baraff-Witkin model

– Stretch

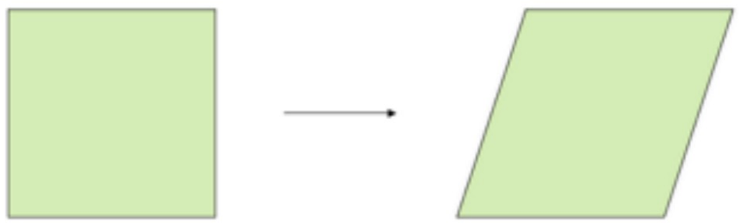


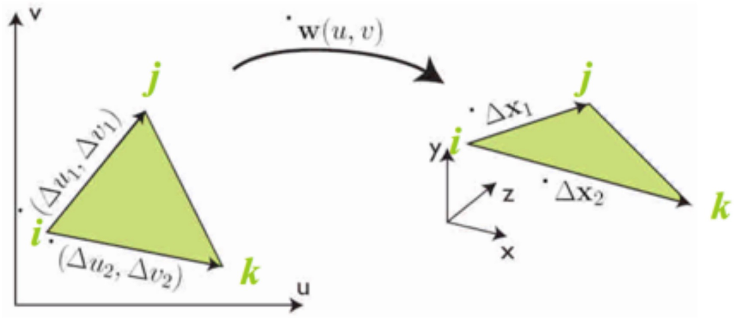
$$\mathbf{w}_u = \partial \mathbf{w}/\partial u \text{ and } \mathbf{w}_v = \partial \mathbf{w}/\partial v$$

$$\mathbf{C}(\mathbf{x}) = a \begin{pmatrix} \|\mathbf{w}_u(\mathbf{x})\| - 1 \\ \|\mathbf{w}_v(\mathbf{x})\| - 1 \end{pmatrix}$$

Baraff-Witkin model

– Shear



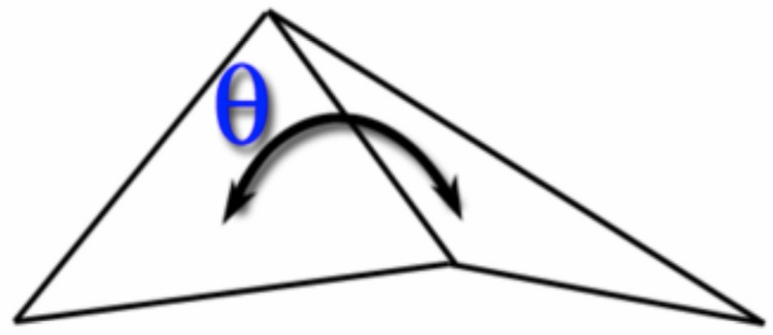


$$\mathbf{w}_u = \partial \mathbf{w}/\partial u \text{ and } \mathbf{w}_v = \partial \mathbf{w}/\partial v$$

$$C(\mathbf{x}) = a\mathbf{w}_u(\mathbf{x})^T \mathbf{w}_v(\mathbf{x})$$

Baraff-Witkin model

- Bending
- Constraint the angle



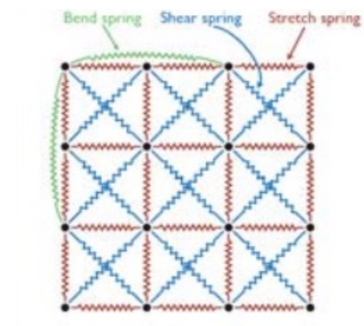
Geometric and Physical model

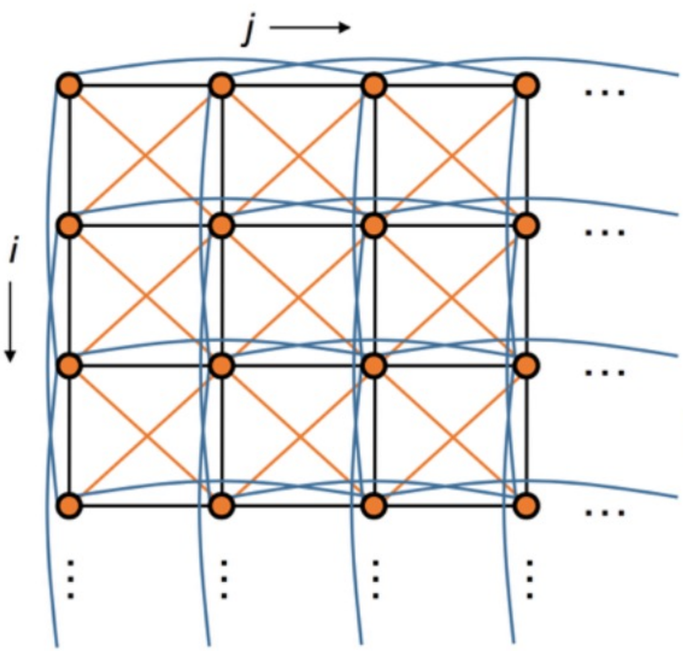
- From constraints to energy
- Take the L2 norm: $||C(x)||_2$
- Is it physically accurate?
- Not always, but often is plausible

Baraff, D., & Witkin, A. (1998, July). Large steps in cloth simulation. In *Proceedings of the 25th annual conference on Computer graphics and interactive techniques* (pp. 43-54).

Geometric and Physical model

– Spring systems and spring forces





Types of springs

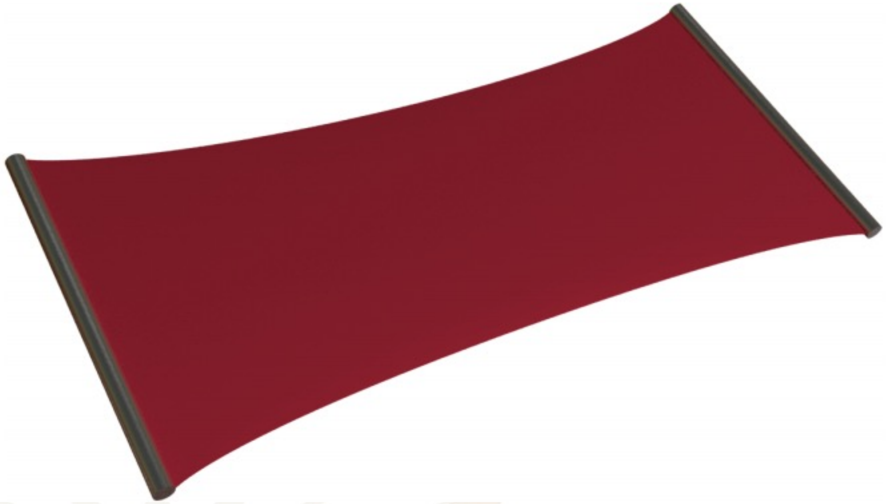
Structural
[i, j]—[i, j + 1]; [i, j]—[i + 1, j]

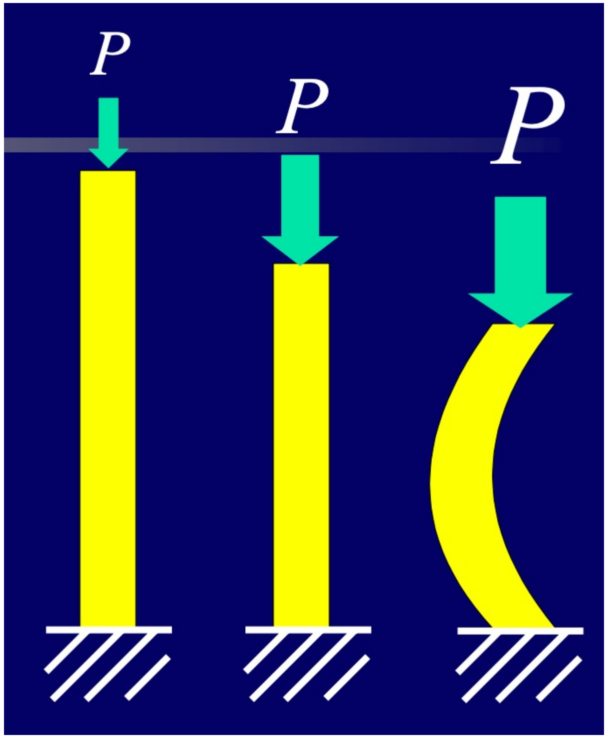
Shear
[i, j]—[i + 1, j + 1]; [i + 1, j]—[i, j + 1]

Flexion (bend)
[i, j]—[i, j + 2]; [i, j]—[i + 2, j]

Cloth Animation

- Explicit Euler does not work
- Implicit methods such as Implicit Euler
- Other problems:
  - Cloth not-really hookian





Choi, K. J., & Ko, H. S. (2005). Stable but responsive cloth. In *ACM SIGGRAPH 2005 Courses* (pp. 1-es).

http://www.tkim.graphics/FEMBW/

Cloth Animation

- Baraff-Witkin (hookian)
  - Shearing term helps achieving wrinkling
  - Numerical problems under compression
    - Hessian of the energies is indefinite under compression
- As Rigid as Possible (ARAP)
  - Energy that explicitly avoids compression
  - Numerically stable
  - Results in stiff clothing
- Superelastic material
  - St. Venant Kirchhoff (StVK)
  - Also has some (other) numerical problems

Choi, K. J., & Ko, H. S. (2005). Stable but responsive cloth. In *ACM SIGGRAPH 2005 Courses* (pp. 1-es).

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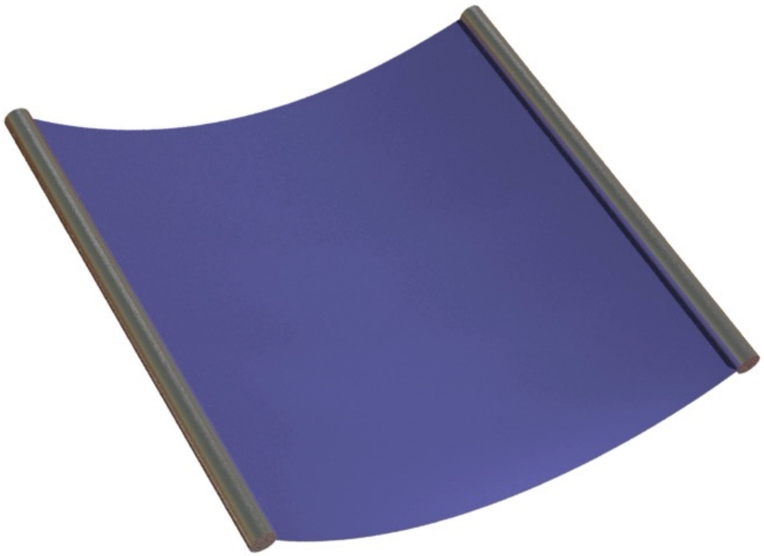
Cloth Animation



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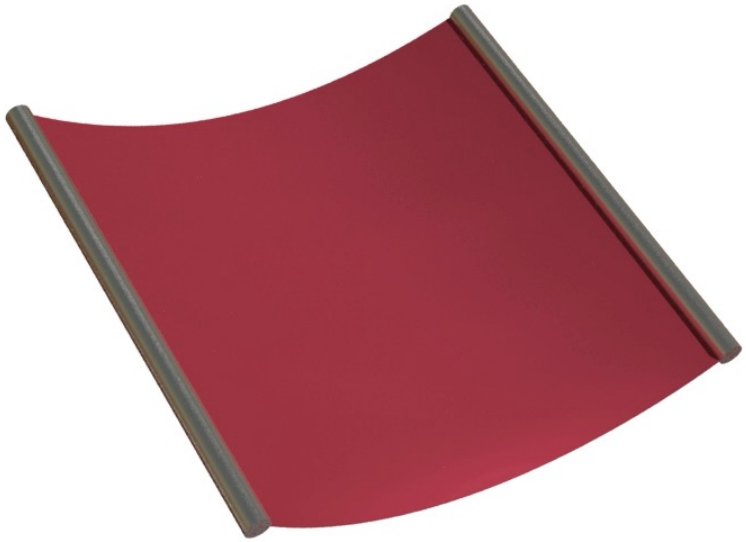
Cloth Animation



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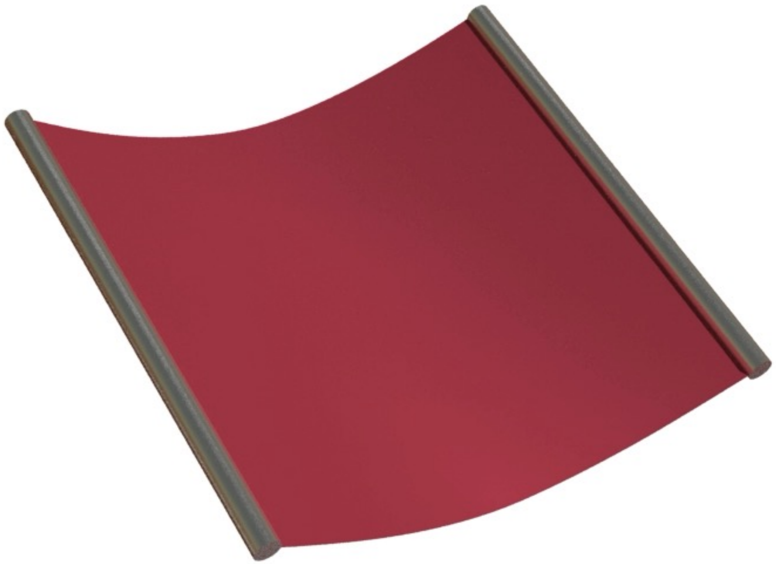

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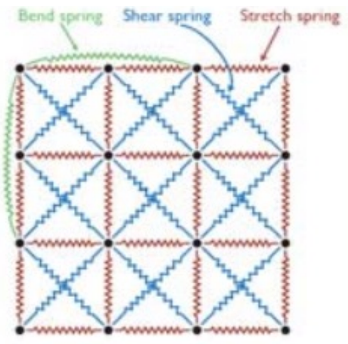
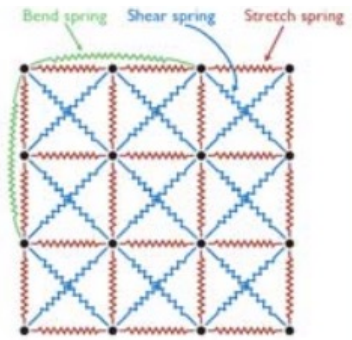


Collision Handling

– Collision detection and handling
  - Penalty method
    – Add “fake” forces
  - Impulse method
    – Change velocities

Time Integration



- Collision detection and handling
  - Penalty method
    - Cons: does not prevent interpenetration
  - Impulse method
    - Numerical instabilities as velocity field is not continuous anymore
  - Repulsion forces
    - Main Idea: slow down particles before they get to the surface
    - Tangential (sliding) motion
    - Add friction forces