CS 231

Deformation simulation (and faces)
Deformation BODY Simulation

Deformation function $r(a, t)$

Time $t$

Reference state

Deformation at time $t$

$r(a, t)$: 3D position of $a$ at time $t$

- $r(a, 0) = r^0(a) =$ position when body is in its natural rest state.
Discretization

Spring-mass models
  difficult to model continuum properties
  Simple & fast to implement and understand

Finite Element Methods
  general, versatile and more accurate
  computationally expensive and mathematically sophisticated
Cloth Simulation – deformable surface model

Represent cloth model as a triangular or rectangular grid

Points of finite mass as vertices

Forces or energies of points on the grid are calculated in relations to other points
Cloth Simulation – deformable surface model

Energy-based

\[ \ddot{x} = M^{-1} \left( -\frac{\partial E}{\partial x} + F \right) \]

Internal Energy (potential energy), \( E \)
- stretch
- shear
- bending
Cloth Simulation – deformable surface model

Stretch

Shear

Bending

Original dihedral angle

Bending along the edge that changes dihedral angle

\[
\begin{align*}
|l_1 & = |v_2 - v_1| \\
|l_2 & = |v_3 - v_2| \\
|l_3 & = |v_3 - v_1| 
\end{align*}
\]
Cloth Simulation – deformable surface model

100% Cotton Weave

100% Wool Weave
Cloth Simulation – deformable surface model

Seams and pattern making
Finite Element Methods

FEM approximates a continuous function with internal force expression due to deformation.

Object is divided into elements and tracks the continuous equilibrium (internal force) equations over each element.

The solution is subject to the constraints at the node points and element boundaries, so that continuity between elements is achieved.
Finite Element Methods

Subdivide the object into elements

For each element, derive the equilibrium equations (and *interpolation functions*) for the element displacements

Combine the set of equations for all the elements into a single system and solve the system for the node displacements for the *whole* object

Use the node displacements and the interpolation functions of a particular element to calculate displacements (or other quantities) for points *within* the element
Stress

Stress Vector \( T_\nu = \frac{dF}{dS} \) (roughly) where \( \nu \) is the normal direction of the area \( dS \).

Normal stress, say \( \sigma_{xx} \), acts on a cross section normal to the x-axis and in the direction of the x-axis. Similarly for \( \sigma_{yy} \).

Shear stress \( \tau_{xy} \) is a force per unit area acting in a plane cross section \( \perp \) to the x-axis in the direction of the y-axis. Similarly for \( \tau_{yx} \).
Strain

Consider a string of an initial length $L_0$. It is stretched to a length $L$.

The ratio $\lambda = \frac{L}{L_0}$ is called the stretch ratio.

The ratios $(L - L_0)/L_0$ or $(L - L_0)/L$ are strain measures.

There are other strain measures, e.g.

$$\varepsilon = \frac{(L^2 - L_0^2)}{2L^2} \quad \varepsilon = \frac{(L^2 - L_0^2)}{2L_0^2}$$
Stress and Strain

For an infinitesimal strain in stretching has a relation

\[ \sigma = E e \]

where \( E \) is a constant called \textit{Young’s Modulus}, is valid within a certain range of stresses.

Hooke’s Law: material subjected to an infinitesimal shear strain is

\[ \tau = G \tan \alpha \]

where \( G \) is another constant called the \textit{shear modulus} or \textit{modulus of rigidity}. 
Basic Steps of Solving

1. Find deformation.
2. Find strain.
3. Approximate the stress.
4. Find the stiffness matrix $K$.
5. $F = K (x - x_0)$
\[ \sigma = E \frac{\Delta l}{l} \quad \sigma = E \left[ \frac{\Delta l}{l} + \left( \frac{\Delta l}{l} \right)^2 \right] \]

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σ = E Δl/l, Δl/l < d_{max}
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“real”
Stiffness for FEM

Stiffness is high dimensional
Linear stiffness is much easier

\[ f_{\text{elastic}} = K \cdot (x - xo) \]

However, linear stiffness suffers from rotation:
Stiffness warping – for stable real-time deformation (Muller et al 02)

\[ f_{\text{elastic}} = K \cdot (x - x_0) \quad \Rightarrow \quad f_{\text{elastic}} = R_e K \cdot (R_e^{-1} x - x_0) \]
Video Break
Ongoing Research

Validation of physically accurate deformation
tissue, fabrics, material properties

Achieving realistic & real-time deformation of complex objects

Exploiting hardware & parallelism, hierarchical methods, dynamics simplification, etc.

Integrating deformable modeling with interesting “real” applications
various constraints & contacts, collision detection
Modeling and animating faces
Animating faces

Important but difficult

Complex structure, soft and hard

Area of study for 20+ years

*Computer Facial Animation*  
by Parke and Waters  
is a good reference
People fixate on the face, it must appear real or no one will believe what they are seeing.

Animation first requires a model for structure - and motion.
What is good enough?
What is good enough?
Anatomy of the face

- Bones
- Cartilage
- Muscle
- Nerves
- Blood vessels
- Glands
- Fatty tissue
- Connective tissue
- Skin
- Hair
Studying faces in ‘the real world’

Expressions - Movement for faces have identifiable motion characteristics

optical flow
Facial animation techniques

- Interpolation for key-framed
- Direct parameterization
- Performance (data) driven
- Pseudo-muscle based
- Muscle-based
Parameterized facial animation

Build deformation examples from same mesh and add sliders to move between key postures
Common interface, with speech
Modeling faces from ‘the real world’

Direct measure of color and shape (Cyberware)
Facial modeling
plaster cast
Model types for facial structure

- Depends on application
  - final fantasy vs. quake monster

- What they do?
  - constrain motion and/or provide rules for animation

- Examples:
  - Mesh-based
  - Volume/3D-data based
  - Image-based
  - Muscle
Data-driven face model
Data-driven face model

Cyberware scans for 200 subjects

Controlled conditions (lighting, bathing cap)

Build database finding correspondence for vertex positions and rgb color information

Average to determine neutral face, build parametrized database from there
Solving for 3D from 2D using database
3D from a single image
Data-driven and video based approaches

Cloning animation

Video Rewrite

Motion capturing faces

Voice puppetry
Video rewrite

Build Visual-Phoneme (Viseme) apriori from video source footage
Video rewrite

Diagram:
- Video Model
- Background Video
- Speech Labeling
- Select
- Stitch
Video rewrite

Mask face to add smoothly the re-written mouth smooth blend
Video rewrite

Results
Data-driven and video based approaches

Many markers

Combine with character model skin
With mocap - Cao, Faloutsos, Pighin (2003)

Similar approach based on motion snippets, this time using motion capture points

Analyze motion capture data, resynthesize from new sound tracks, control emotional style
With mocap - Blend shapes
Pseudo - muscles based facial animation

Connect skin mesh with points

No underlying bone structure

Control displacement and angle
Layered - muscles based facial animation

Muscles attach skin to bone

Skin is modeled as spring mesh

point of insertion

attachment point

bone

muscle

skin
Layered - muscles based facial animation
Data-driven and video based approaches

Can we combine?

Muscle and skin with mocap?
Animation of hair and eyes

People are sensitive to these

Hair is difficult because of numbers, look and feel

Eyes modeled with statistical model (Badler 2002)
Record video of person talking
Segment eye motion
Determine correlation with voice and eye motion
Move eyes with same characteristics
(Performed user study to assess)
Hair model

Cantilever or spring-based guide hairs

Interpolated rendered hair

[Images of hair models and a character from a animated movie]
Guide hair model
Hair rendering
Conclusions

Facial models can be complex

Caricature can be simpler

Realism taken from real data