Animation of 3D surfaces

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Motivations

• When character animation is controlled by “skeleton”…
  – set of hierarchical joints
  – joints oriented by rotations

• the character shape still needs to be visible:
  – visible = to be rendered as a continuous shape
  – typically, a surface is rendered
Motivations

• visible shape is made of organic tissues
Motivations

• visible shape is made of organic tissues
Motivations

• What is the goal of 3D animation?
Motivations

- 3D animation workflow
Motivations

• Animation of 3D surface is actually the most “practical” thing:
  – direct connection with modeling phase
    • shape and texture
  – light structure, easy to animate
    • possibly real-time
  – works will be focused on workarounds to cope with this approximation of reality
Overview

- “Skinning”
- Non-linear deformers
- Shape morphing
- Mesh edition
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Skinning

• Goal: bind a skeleton and a shape
Skinning

• Linear blend skinning

\[ P = w_1 \cdot P_1 + w_2 \cdot P_2 \]
Skinning

• Linear blend skinning

\[ P = w_1 \times P_1 + w_2 \times P_2 \]

\( w_i : [0..1], \text{ skin weights} \)
Skinning

• Linear blend skinning

\[ P = w_1 * P_1 + w_2 * P_2 \]

with \( P_i = M_{0,i} M_i(\theta) M_{i}^{-1} 0,i P_0 \)

\[ M : R \text{ and } T \]
Skinning

• Linear blend skinning

\[ P = \sum_i w_i^* \, M_{0,i} \, M_i(\theta)M^{-1}_{0,i} \, P_0 \]

Implemented as “Skin>Smooth bind” in Maya
Skinning

• Linear blend skinning
Skinning

• Limitations

\[
P = \sum_i w_i^* M_{0,i} M_i M_{0,i}^{-1} P_0
\]

\[
= ( \sum_i w_i^* M_{0,i} M_i M_{0,i}^{-1} ) P_0
\]

Non-rigid transformation
Skinning

- **Improvements**
  - Skinning as a prediction function from joint configuration to 3D shapes

\[
V = f_a(\theta) = \sum_i a_i f(||\theta - \theta_i||)
\]

\[
\theta \text{ in } \mathbb{R}^m, \text{ with } m \text{ joints dof}
\]

\[
V \text{ in } \mathbb{R}^p, \text{ with } p \text{ mesh vertices}
\]

\[
a_i \text{ in } \mathbb{R}^p, \text{ n parameters}
\]

\[
a = \arg\min \sum_i ||V_i - f_a(\theta_i)||^2
\]

\[
f_a(\theta) = \sum_i a_i f(||\theta - \theta_i||)
\]

Radial Basis Function (RBF)

[Lewis et al., 2000]
Skinning

- **Improvements**
  - Incorporate user-defined examples of shapes and automatically add some joints and weights in LBS

[Mohr et Gleicher, 2003]
Skinning

- Improvements
  - Compute the matrix interpolation while maintaining correct rotations, using dual quaternions

\[ P = \sum_i w_i^* M_{0,i} M_i M_{0,i}^{-1} P_0 \]
\[ = \left( \sum_i w_i^* M_{0,i} M_i M_{0,i}^{-1} \right) P_0 \]

[Kavan et al., 2007]
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Non-linear deformers

- Global modification of 3D shapes
  the transformation matrix is a function of $R^3$ point

- original
- tapering
- twisting
- bending
Non-linear deformers

- Non-uniform rotation (twisting)

\[ r(z) = \begin{cases} 
0 & z \leq z_0 \\
\frac{z-z_0}{z_1-z_0} \theta_{\text{max}} & z_0 \leq z \leq z_1 \\
\theta_{\text{max}} & z_1 \leq z_0 
\end{cases} \]

\[
P' = \begin{bmatrix} \cos(r(p_z)) & -\sin(r(p_z)) & 0 & p_x \\
\sin(r(p_z)) & \cos(r(p_z)) & 0 & p_y \\
0 & 0 & 1 & p_z \end{bmatrix}
\]
Non-linear deformers

- Vortex

\[ r(z) = \begin{cases} 
0 & z \leq z_0 \\
\frac{z-z_0}{z_1-z_0} \theta_{\text{max}} & z_0 \leq z \leq z_1 \\
\theta_{\text{max}} & z_1 \leq z_0 
\end{cases} \]

\[ \alpha(P) = r(p_z)e^{-(p_z^2+p_x^2)} \]

\[ P' = \begin{bmatrix} 
\cos(\alpha(P)) & -\sin(\alpha(P)) & 0 & p_x \\
\sin(\alpha(P)) & \cos(\alpha(P)) & 0 & p_y \\
0 & 0 & 1 & p_z 
\end{bmatrix} \]
Non-linear deformer

- Free-Form Deformation (FFD)

Object embedded in “3D rubber”
Non-linear deformers

• FFD : Space interpolation

\[
\begin{align*}
  s &= \frac{T \times U \cdot (M - M_0)}{T \times U \cdot S} \\
  t &= \frac{S \times U \cdot (M - M_0)}{S \times U \cdot T} \\
  u &= \frac{S \times T \cdot (M - M_0)}{S \times T \cdot U}
\end{align*}
\]

\[
P_{ijk} = M_0 + \frac{i}{i_{\text{max}}} S + \frac{j}{j_{\text{max}}} T + \frac{k}{k_{\text{max}}} U
\]

\[
M_{\text{FFD}} = \sum_{i=0}^{i_{\text{max}}} \sum_{j=0}^{j_{\text{max}}} \sum_{k=0}^{k_{\text{max}}} B_i^{i_{\text{max}}} (s) B_j^{j_{\text{max}}} (t) B_k^{k_{\text{max}}} (u) P_{ijk}
\]
Non-linear deformers

- FFD
  - applications to non-characters objects
Non-linear deformers

• Preserving volume

\[ V = \frac{4}{3} \pi abc \]

\[ b = \frac{3}{4} V / (\pi ac) \]

Influence object combined with skinning

[Scheepers et al., 97]
Non-linear deformers

• Preserving volume

Motion of “Muscles” induces a displacement field

[Angelidis et Singh, 2007]
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Shape blending

• a 3D shape is a linear combination of reference shapes
  – a linear interpolation for each vertex,
    • $S = S_0 + \Sigma_i w_i(S_i - S_0)$
    • animation is controlled by blend coefficient $w_i$
  – typical application is facial animation
Shape blending

• Blend Shapes
Shape blending

• Facial animation : two main domains

  – Emotion
    • any expression is combination of basic expression: fear, disgust, joy, surprise, anger [Ekman, 75]

  – Talking
    • visual perception of speech production
Lip-synching

- Difficult task
  - how to post-synchronized video onto audio track
  - one common solution:
    - a phoneme = a 3D shape
    - several visually equivalent phonemes as a “viseme”
      [p,b,m], [f,v], etc.
Lip-synching

- Problem of the co-articulation effect
  - audio-visual speech signal is continuous
  - audio and visual are not synchronized by nature (anticipation and latency)
  - gesture vs shape

[Reveret et Essa, 2001]
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Barycentric coordinates

- Low-resolution « cage » controlling a high-resolution mesh
  - each vertex is a linear combination w.r.t cage vertices and normals => local coordinates or weights
  - difficulty: getting the right weights, leading to little artefacts

Mean value coordinates, Harmonic coordinates, Green coordinates, etc
Laplacian mesh edition

- Character animation without a skeleton
- Group of vertices are locally deformed while preserving surface details
- Based on discrete differential geometry

[Sorkine et al., 2004]
Laplacian mesh edition

• Each vertex coordinate is replaced by the difference to the average of its neighbors

\[ D = LV \quad : \quad d_i = V_i - \left( \frac{1}{|N_i|} \right) \sum_{k \in N_i} V_k \]

• Deformation by adding constrains
  add some rows to L => L* and D => D*

• Reconstruction of V by approximation

\[ V^* = \arg\min_V ( \| L'V - D' \| ) \]

More details on:
Laplacian mesh edition

- Application to key-frame animation

[Gradient Domain Deformation for Deforming Mesh Sequences]
Paper ID: 102
Submitted to SIGGRAPH 2007

[Xu et al., 2006]