Animation of 3D surfaces

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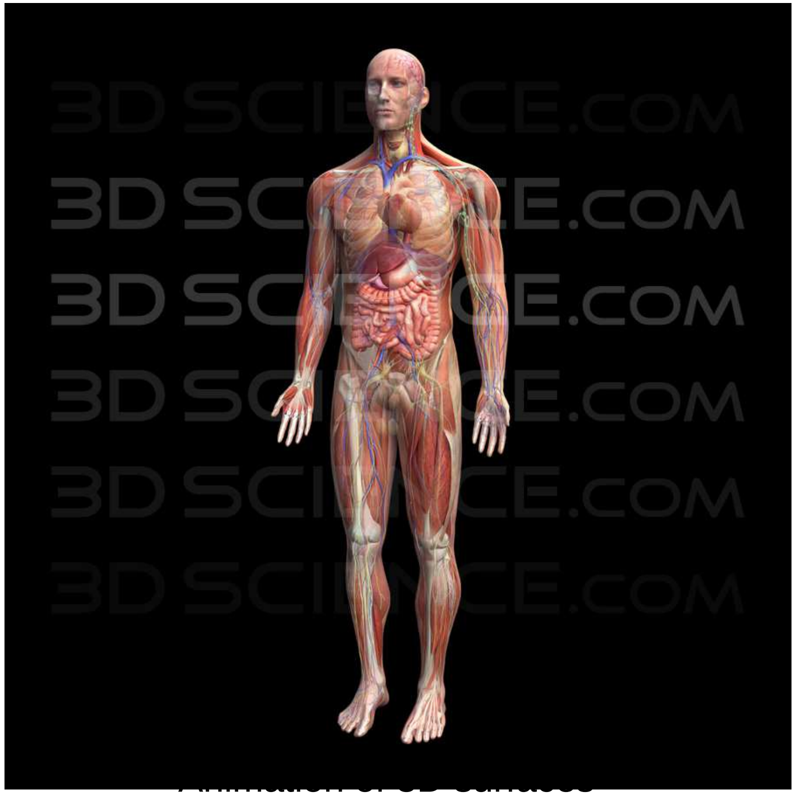
Motivations

- 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

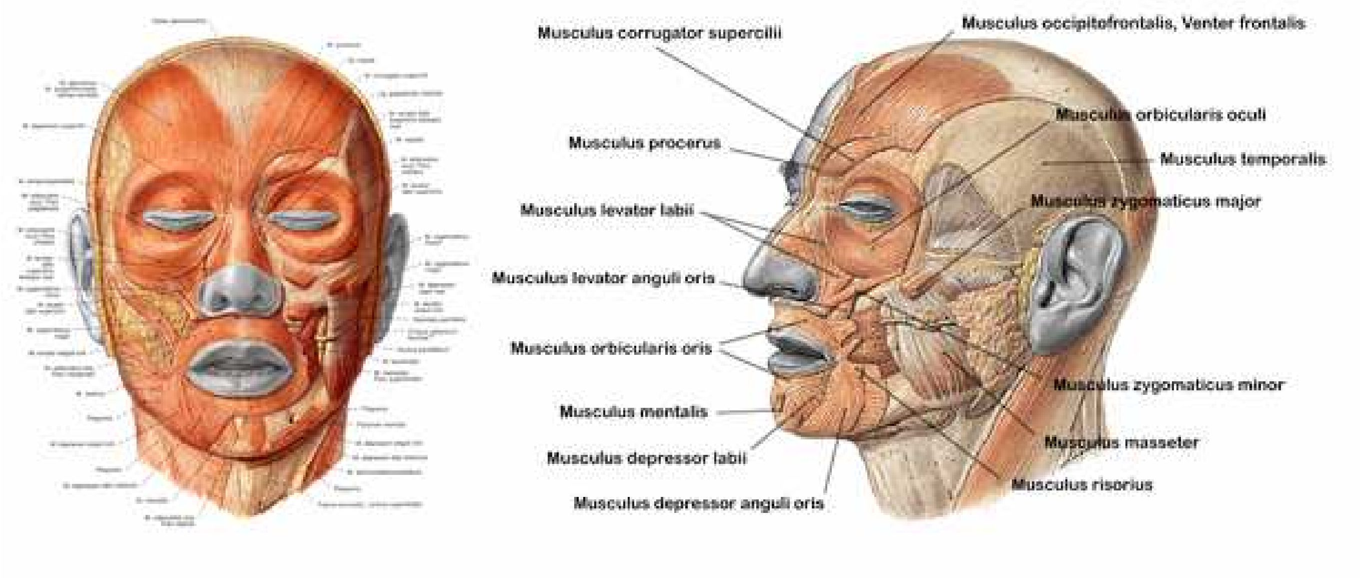
Motivations

- 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

Overview

- **“Skinning”**
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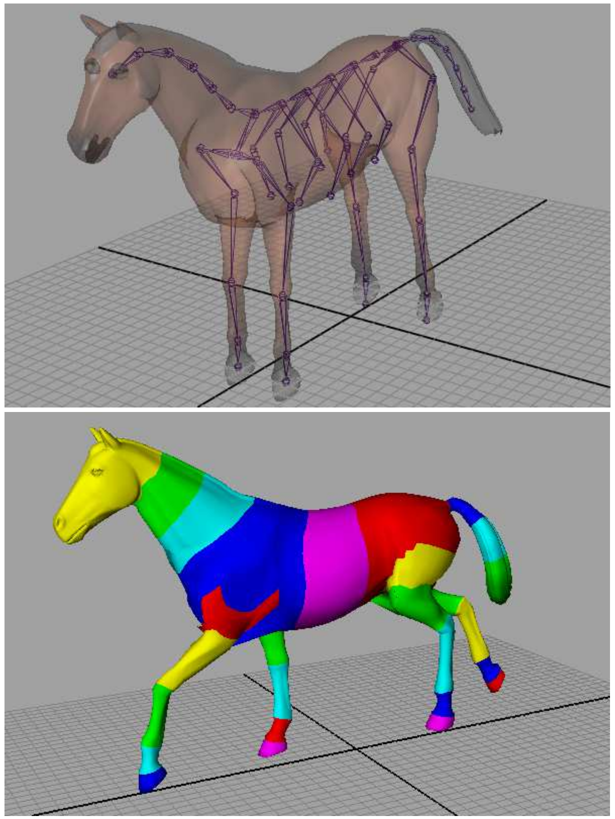
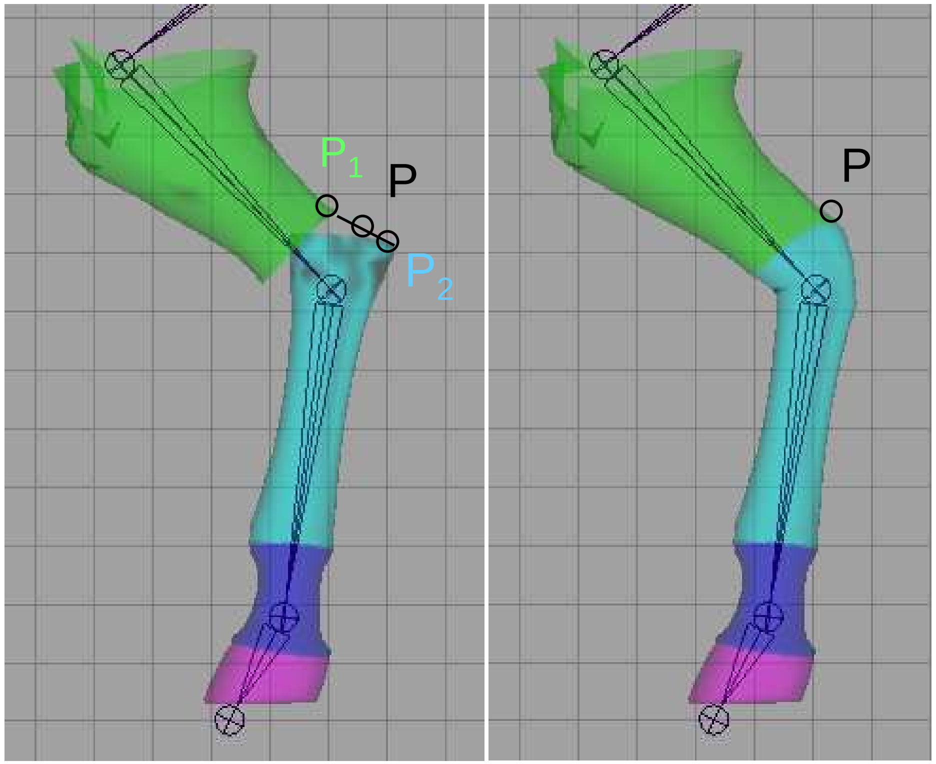
Skinning

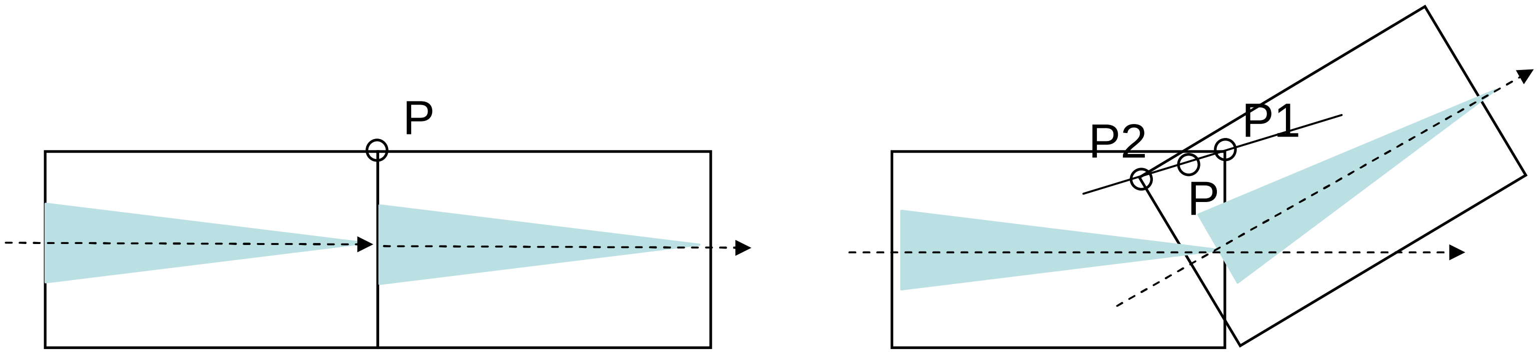
- Goal: bind a skeleton and a shape





Skinning

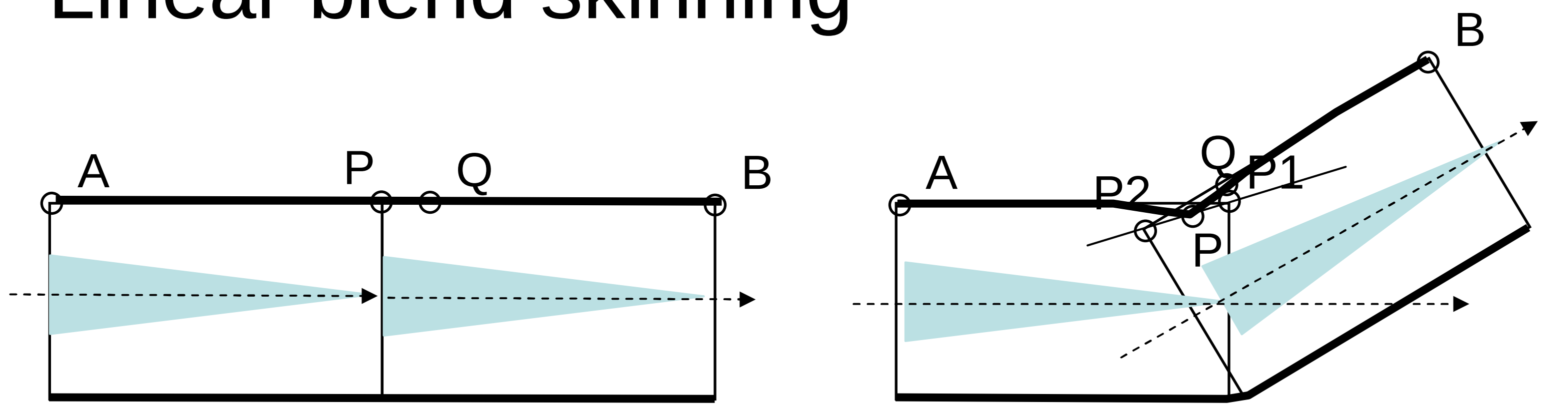
- Linear blend skinning



P = w1***P1** + w2***P2**

Skinning

- Linear blend skinning

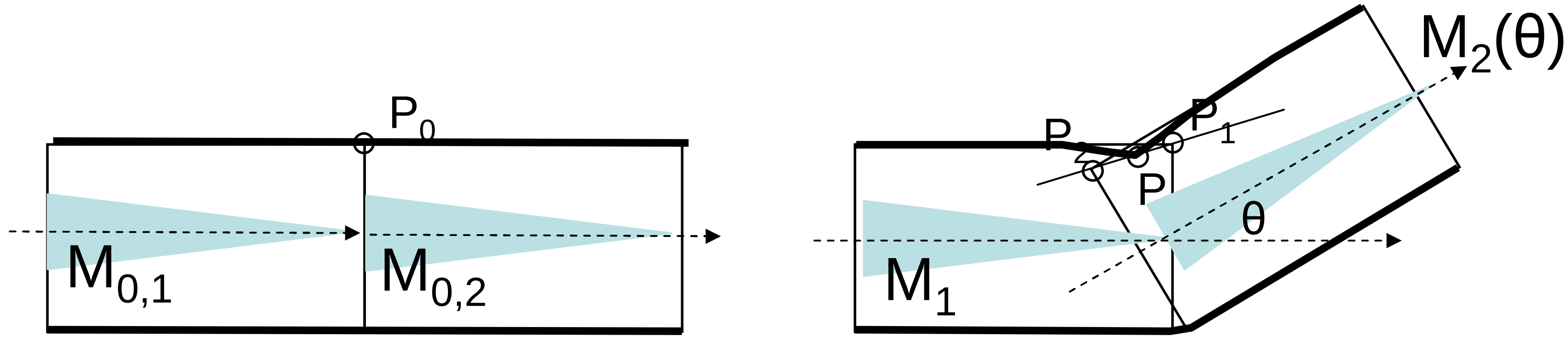


$$\mathbf{P} = w_1 * \mathbf{P1} + w_2 * \mathbf{P2}$$

w_i : [0..1], skin weights

Skinning

- Linear blend skinning



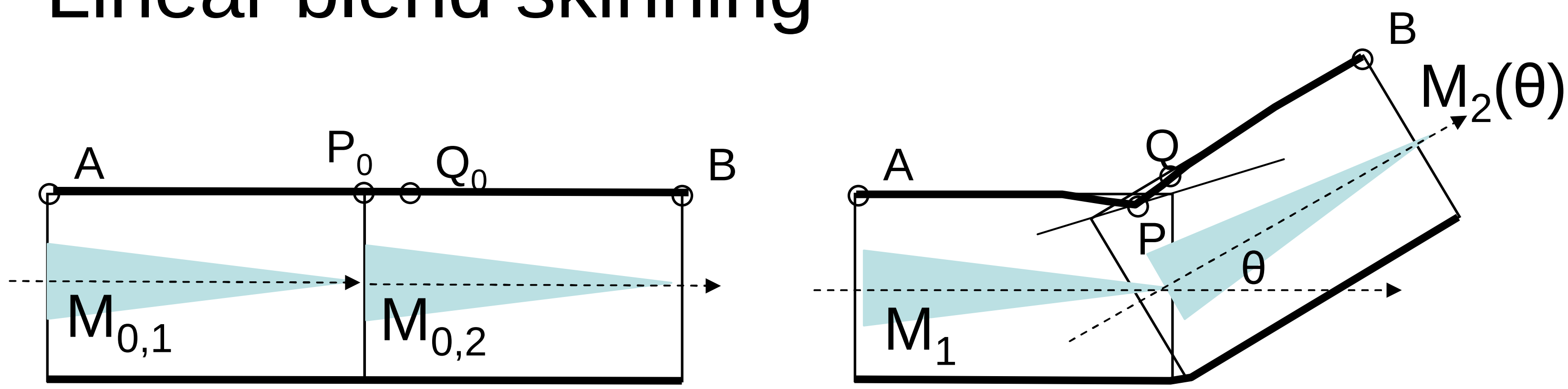
$$\mathbf{P} = w_1 * \mathbf{P}_1 + w_2 * \mathbf{P}_2$$

M : R and T

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

Skinning

- Linear blend skinning

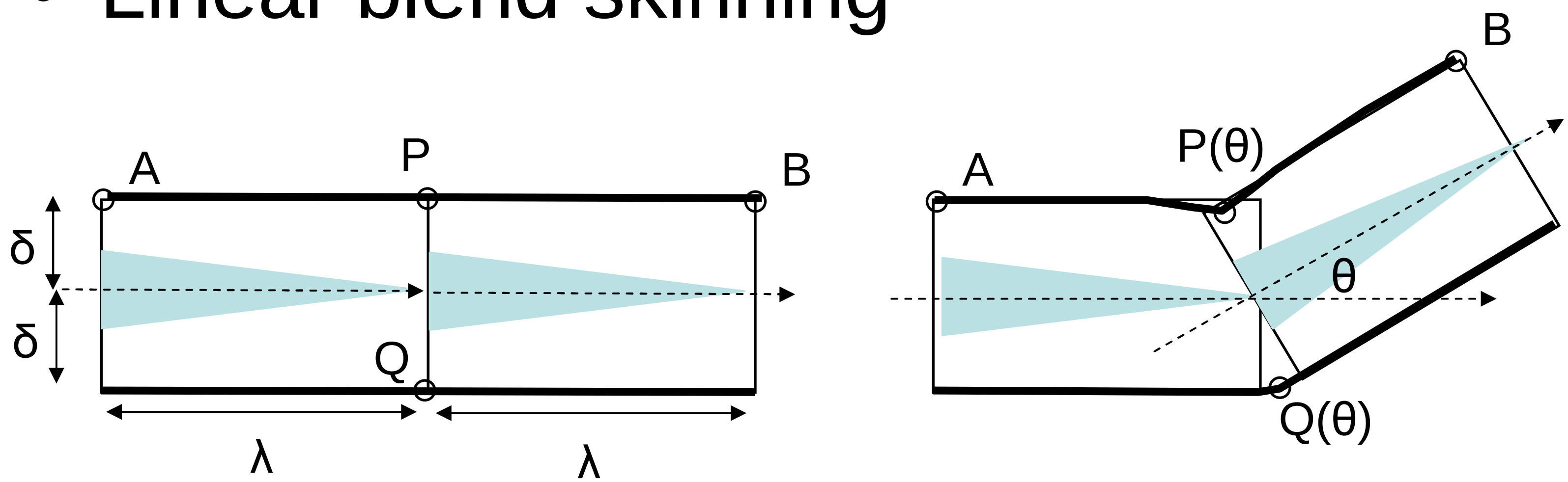


$$\mathbf{P} = \sum_i w_i * M_{0,i}\, M_i(\theta) M^{-1}_{0,i}\, \mathbf{P_0}$$

Implemented as “Skin>Smooth bind” in Maya

Skinning

- Linear blend skinning

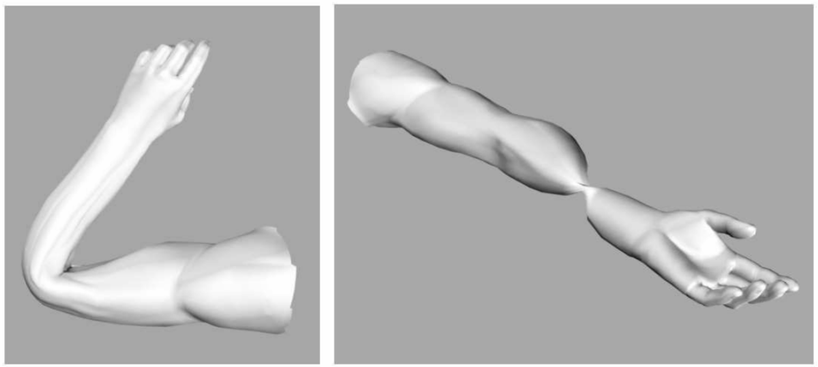


Skinning

- Limitations

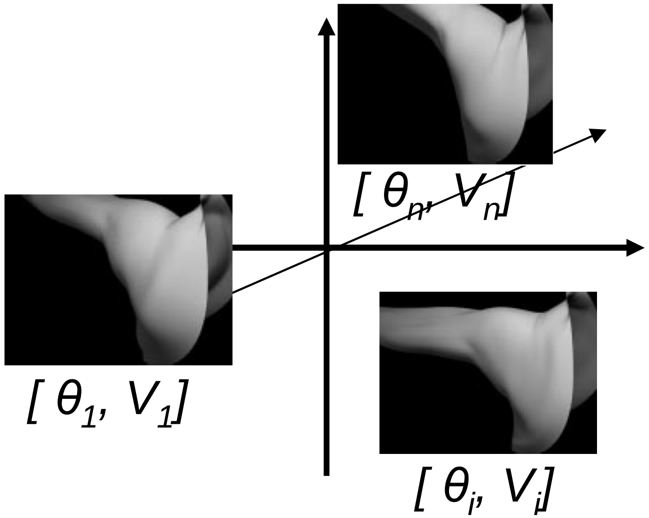
$$\mathbf{P} = \Sigma_{\mathrm{i}}\, \mathrm{w_i}{*}\, M_{0,i}\, M_i\, M^{-1}{}_{0,i}\, \mathbf{P_0}$$
$$= \mathbf{(}\ \Sigma_{\mathrm{i}}\, \mathrm{w_i}{*}\, M_{0,i}\, M_i\, M^{-1}{}_{0,i}\ \mathbf{)}\ \mathbf{P_0}$$

Non-rigid transformation



Skinning

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



$$V = f_a(\theta) = \Sigma_i \, a_i \, f(||\theta - \theta_i||)$$

θ in R^m, with m joints dof
V in R^p, with p mesh vertices
a_i in R^p, n parameters

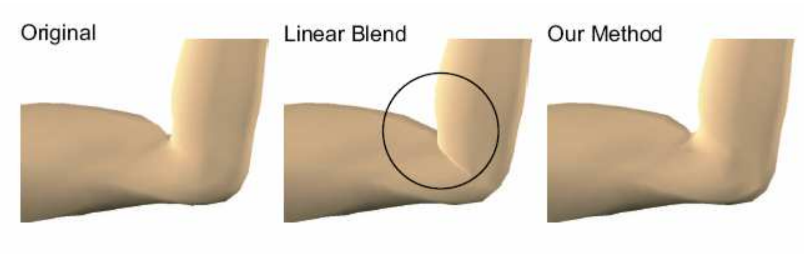
$$a = \text{argmin} \; \Sigma_i \; || \, V_i - f_a(\theta_i) \, ||^2$$

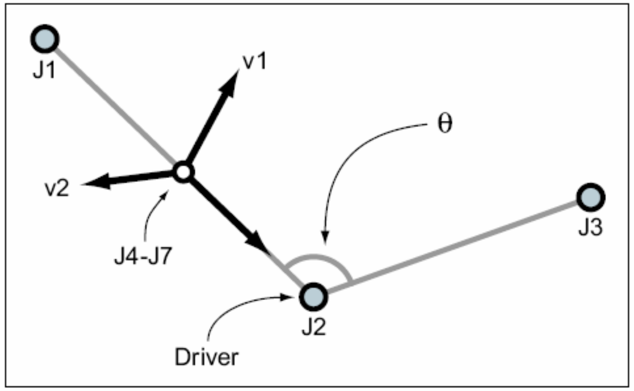
$f_a(\theta) = \Sigma_i \, a_i \, f(||\theta - \theta_i||)$
Radial Basis Function (RBF)

[Lewis et al., 2000]

Skinning

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

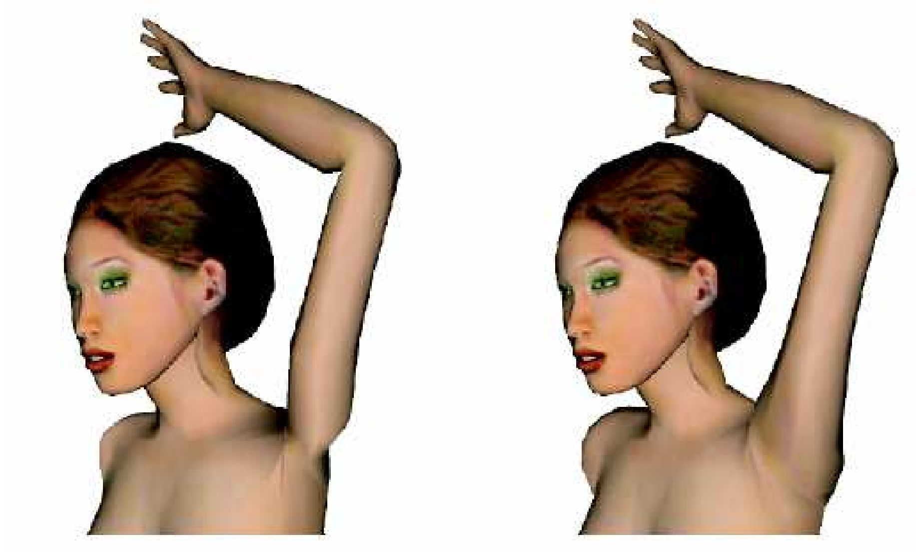




[Mohr et Gleicher, 2003]

Skinning

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



$$\mathbf{P} = \Sigma_i\, w_i{*}\, M_{0,i}\, M_i\, M^{-1}_{0,i}\, \mathbf{P_0}$$
$$\mathbf{= (}\ \Sigma_i\, w_i{*}\, M_{0,i}\, M_i\, M^{-1}_{0,i}\ \mathbf{)\ P_0}$$

[Kavan et al., 2007]

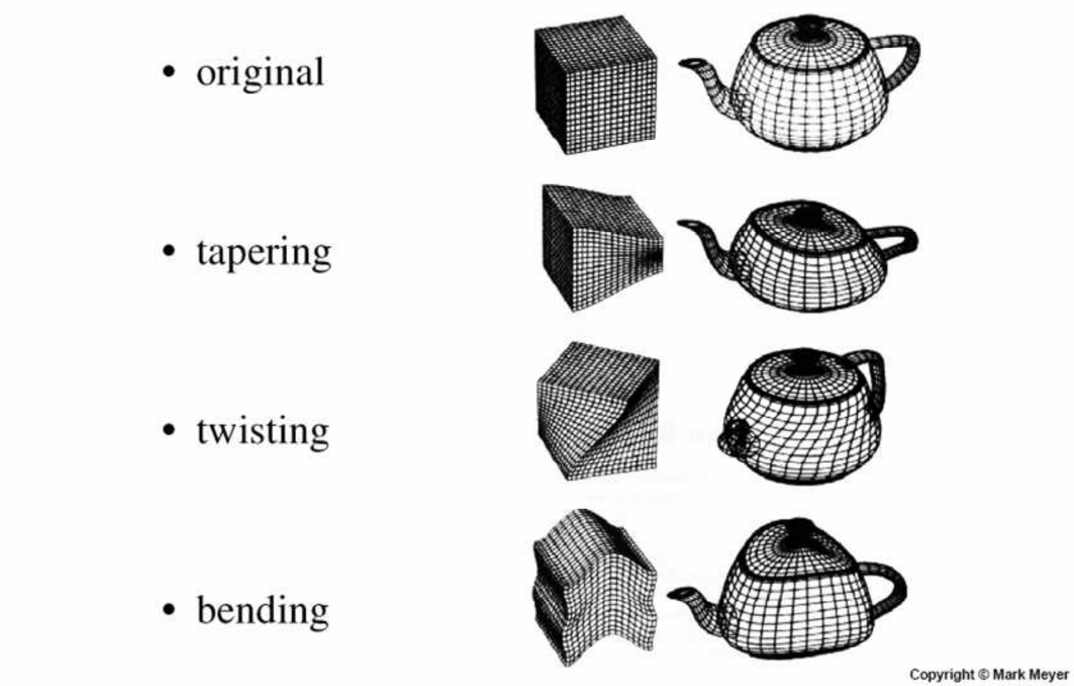
Overview

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

Non-linear deformers

- Global modification of 3D shapes

  the transformation matrix is a function of R^3 point

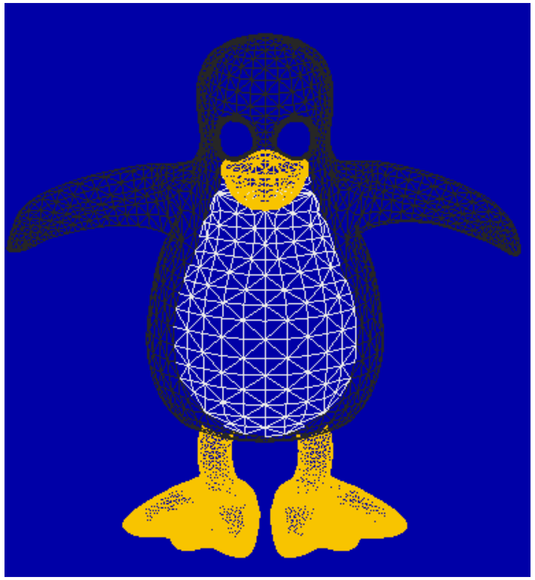


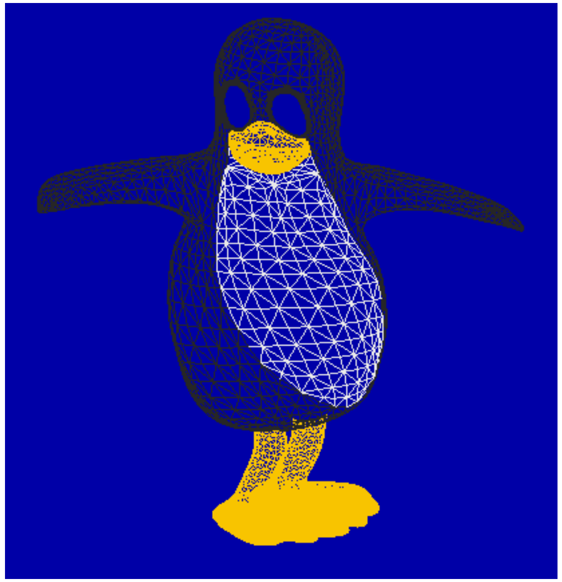
Non-linear deformers

- Non-uniform rotation (twisting)

$$r(z) = \begin{cases} 0 & z \le z_0 \\ \dfrac{z - z_0}{z_1 - z_0}\theta_{\max} & z_0 \le z \le z_1 \\ \theta_{\max} & z_1 \le z_0 \end{cases}$$

$$P' = \begin{bmatrix} \cos(r(p_z)) & -\sin(r(p_z)) & 0 \\ \sin(r(p_z)) & \cos(r(p_z)) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$





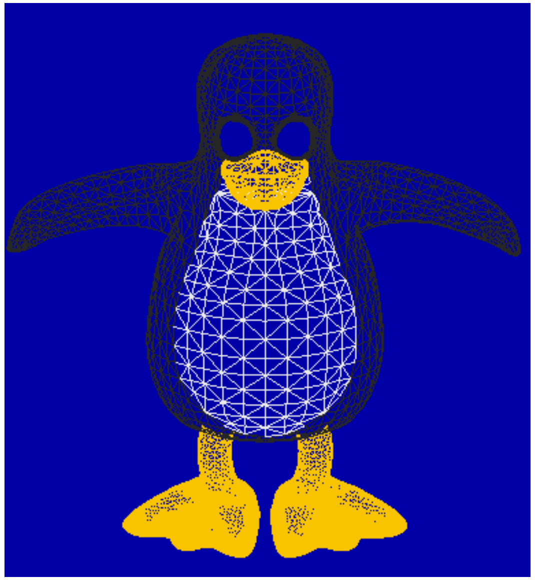
Non-linear deformers

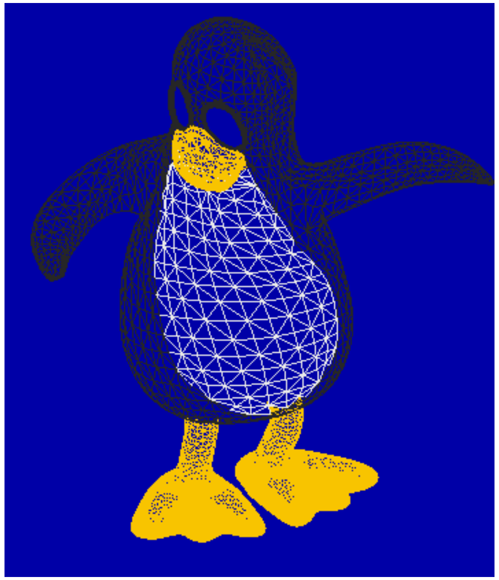
- Vortex

$$r(z)=\begin{cases} 0 & z \le z_0 \\ \dfrac{z-z_0}{z_1-z_0}\theta_{\max} & z_0 \le z \le z_1 \\ \theta_{\max} & z_1 \le z_0 \end{cases}$$

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

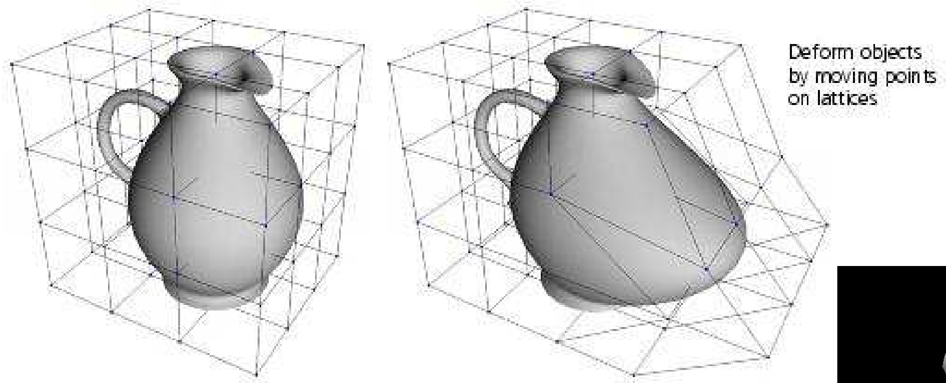
$$P'=\begin{bmatrix} \cos(\alpha(P)) & -\sin(\alpha(P)) & 0 \\ \sin(\alpha(P)) & \cos(\alpha(P)) & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$

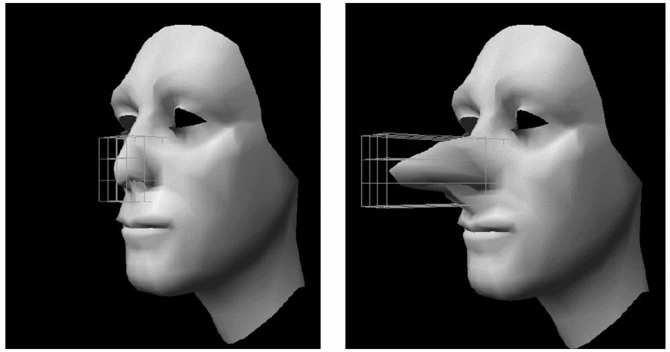




Non-linear deformers

- Free-Form Deformation (FFD)





Object embedded in “3D rubber”

Non-linear deformers

- FFD : Space interpolation

$$s = \frac{\mathbf{T} \times \mathbf{U} \cdot (M - M_0)}{\mathbf{T} \times \mathbf{U} \cdot \mathbf{S}}$$

$$t = \frac{\mathbf{S} \times \mathbf{U} \cdot (M - M_0)}{\mathbf{S} \times \mathbf{U} \cdot \mathbf{T}}$$

$$u = \frac{\mathbf{S} \times \mathbf{T} \cdot (M - M_0)}{\mathbf{S} \times \mathbf{T} \cdot \mathbf{U}}$$

$$P_{ijk} = M_0 + \frac{i}{i_{\max}}\mathbf{S} + \frac{j}{j_{\max}}\mathbf{T} + \frac{k}{k_{\max}}\mathbf{U}$$

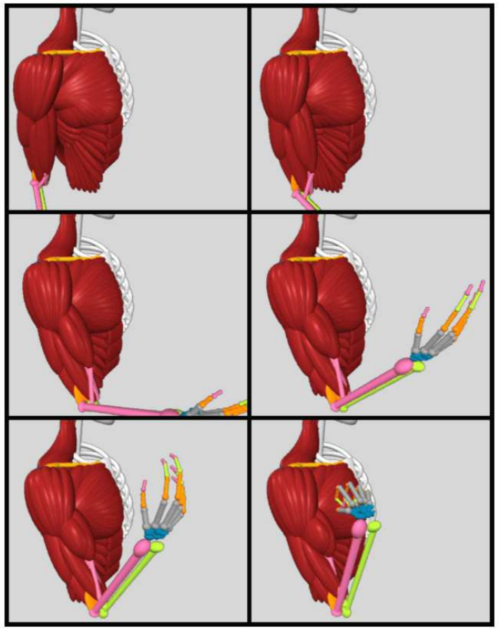
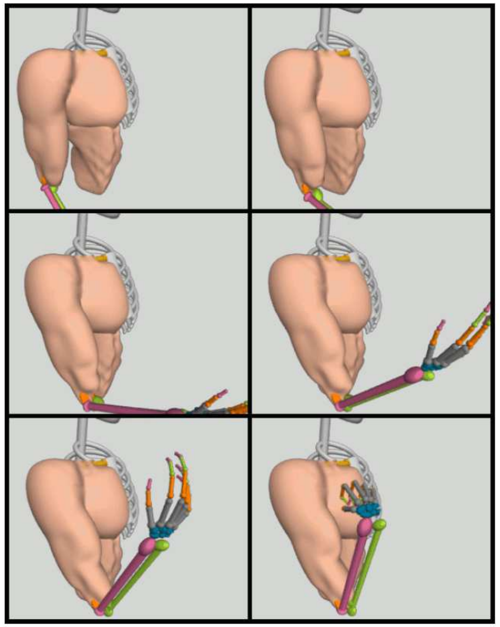
$$M_{FFD} = \sum_{i=0}^{i_{\max}} \sum_{j=0}^{j_{\max}} \sum_{k=0}^{k_{\max}} B_i^{i_{\max}}(s) B_j^{j_{\max}}(t) B_k^{k_{\max}}(u) P_{ijk}$$

Non-linear deformers

- FFD
  - applications to non-characters objects

Non-linear deformers

- Preserving volume

$$V = 4/3\ \pi\ abc$$

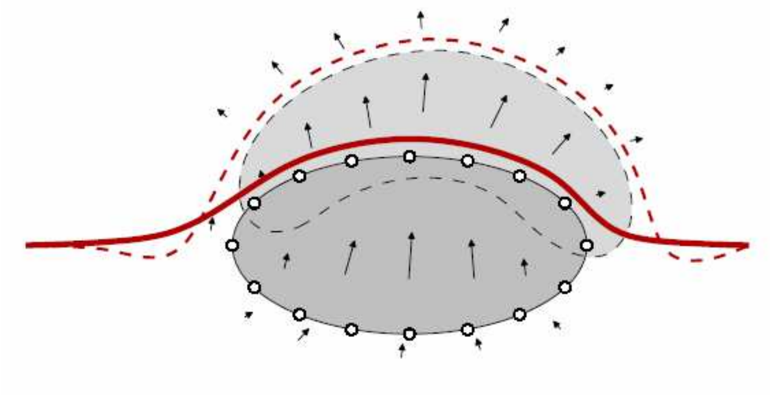
$$b = \tfrac{3}{4}\ V / (\ \pi\ ac)$$

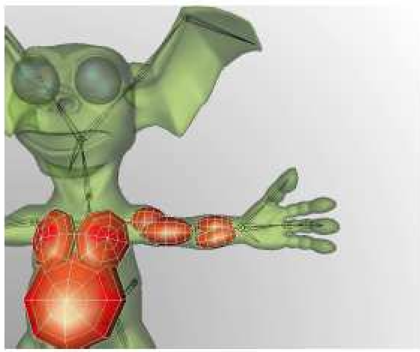
[Scheepers et al., 97]

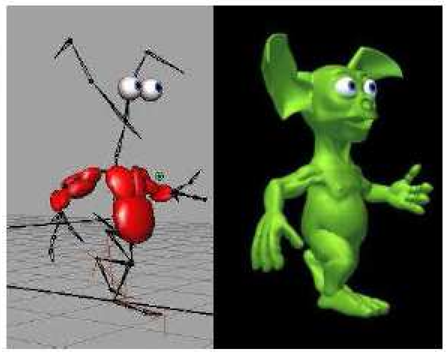
Influence object combined with skinning

Non-linear deformers

- Preserving volume







Motion of “Muscles” induces a displacement field

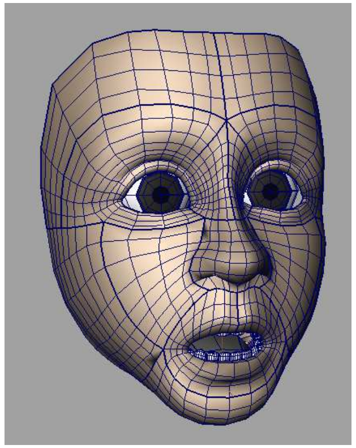
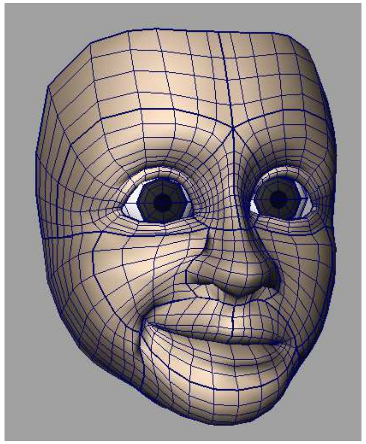
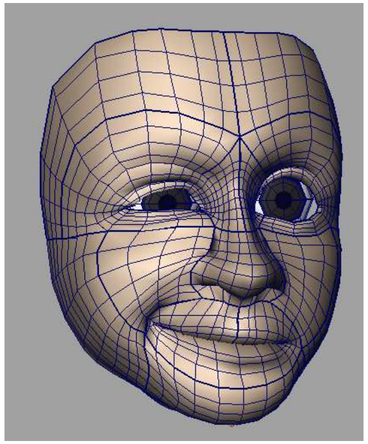
[Angelidis et Singh, 2007]

Overview

- "Skinning"
- Non-linear deformers
- **Shape morphing**
- Mesh edition

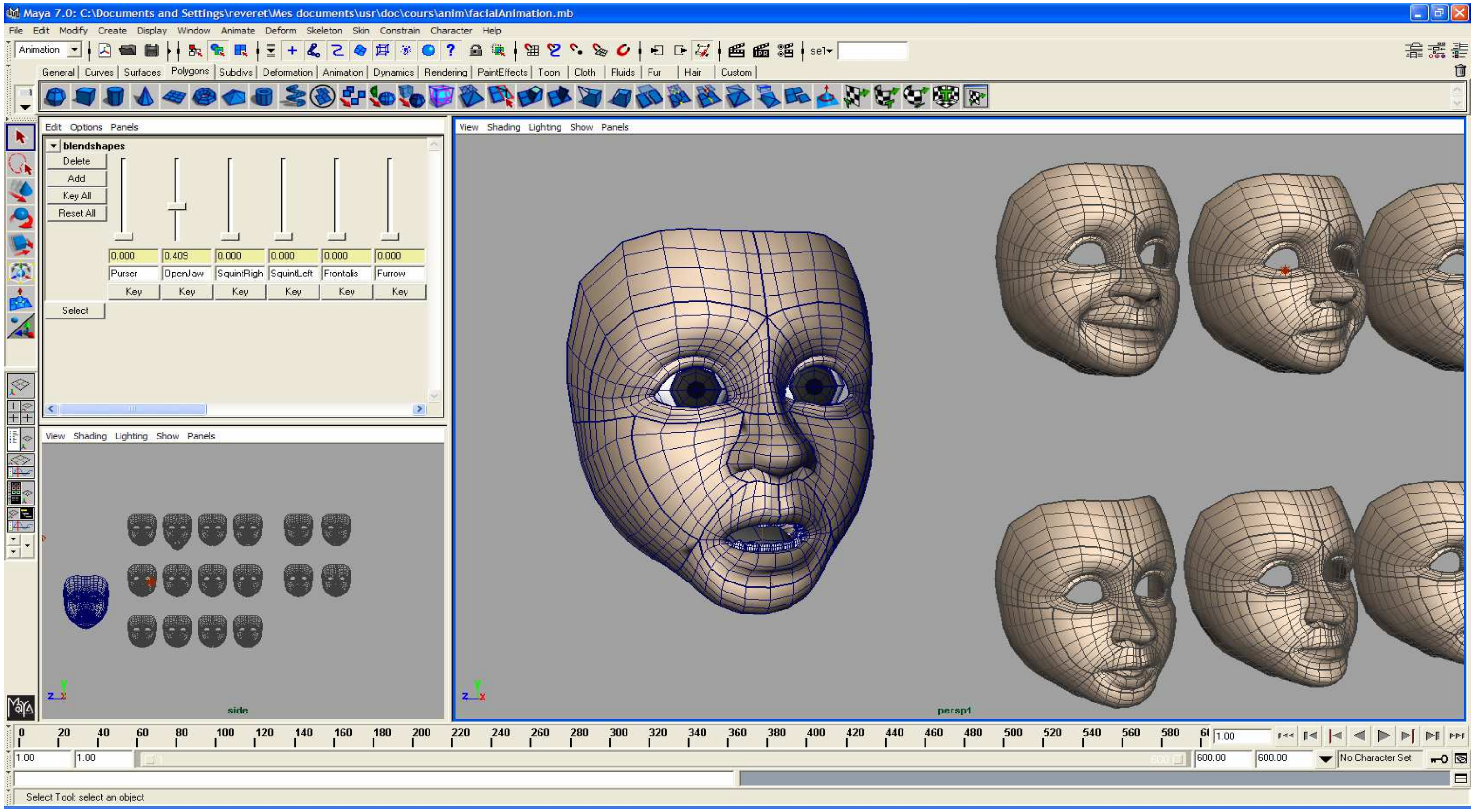
Shape blending

- 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

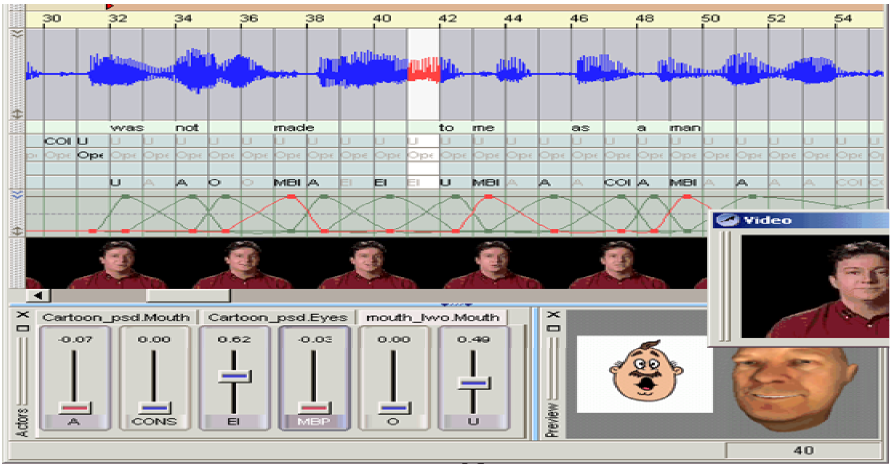
  – Emotion
    - any expression is combination of basic expression: fear, disgust, joy, surprise, anger [Ekman, 75]

  – Talking
    - visual perception of speech production

Lip-synching

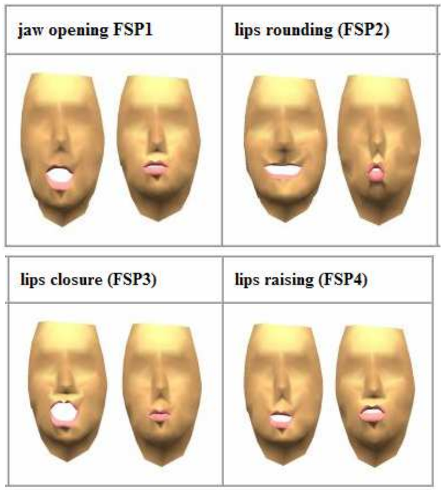
- Difficult task
  – how to post-synchronized video onto audio track
  – one common solution :
    - a phoneme = a 3D shape
    - several visually equivalent phonemes as a “viseme”

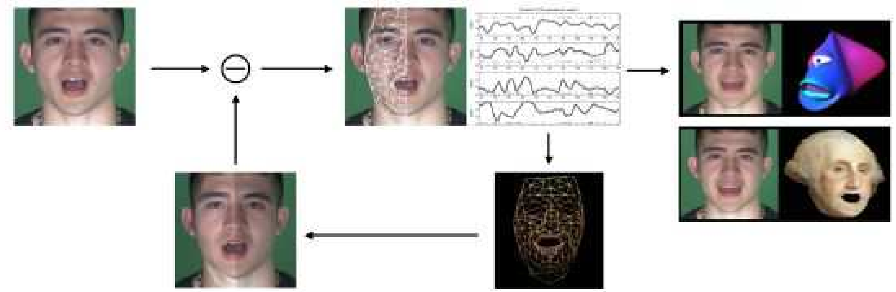
      [p,b,m], [f,v], etc.



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





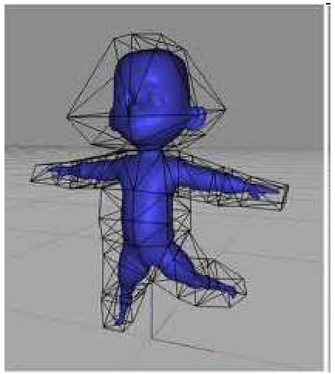
[Reveret et Essa, 2001]

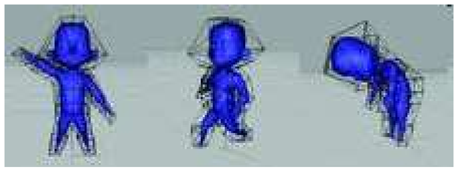
Overview

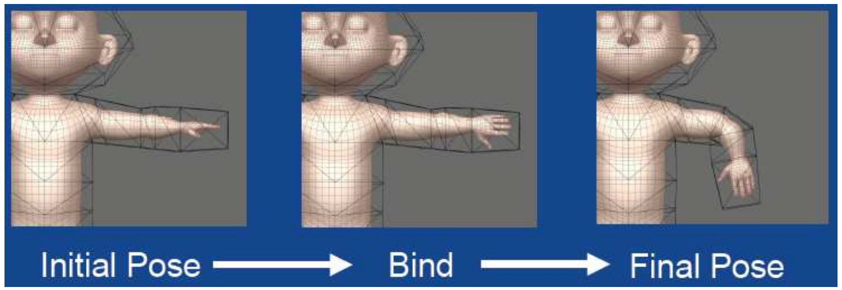
- “Skinning”
- Non-linear deformers
- Shape morphing
- **Mesh edition**

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



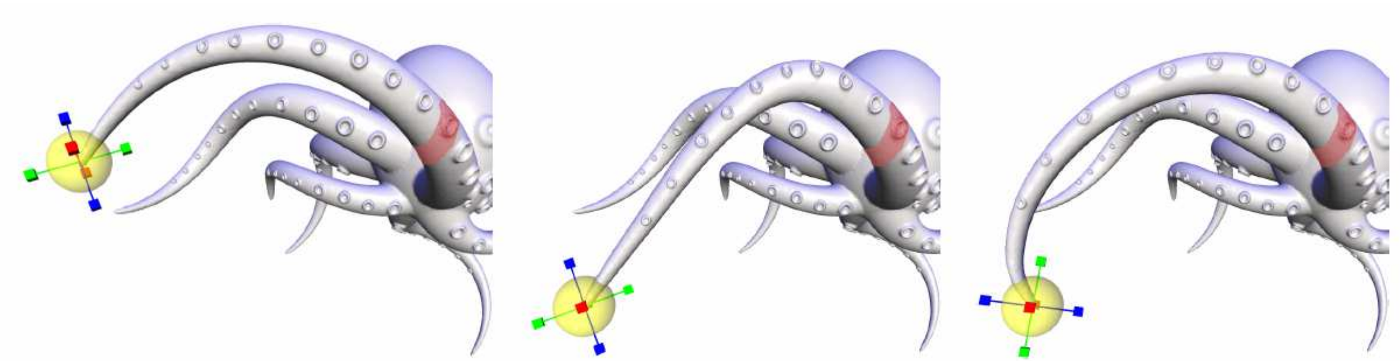




Mean value coordinates,
Harmonic coordinates,
Green coordinates, etc

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 = L V : $d_i = V_i - (1/|N_i|)\Sigma_{k \in Ni} V_k$

- Deformation by adding constrains

  add some rows to L => L* and D => D*

- Reconstruction of V by approximation

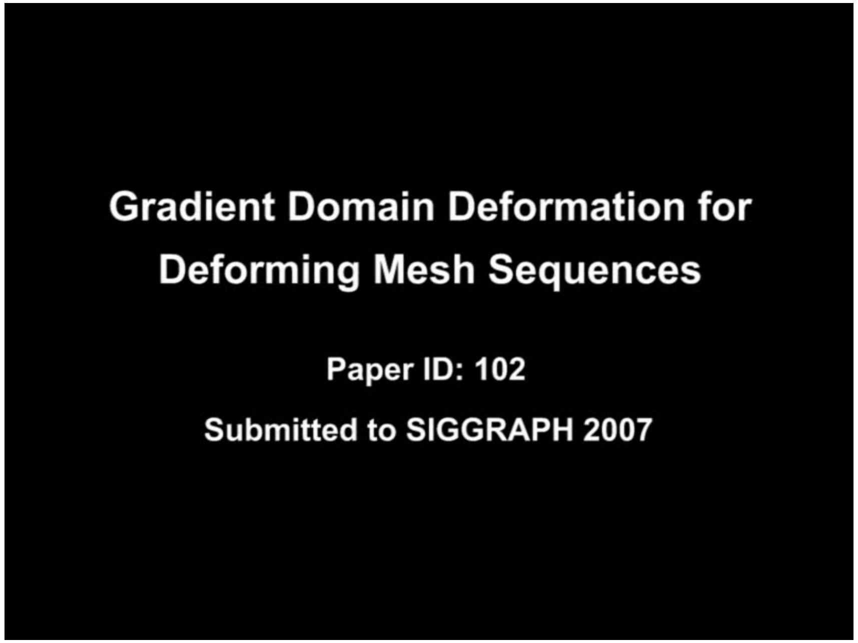
  $V^* = \mathrm{argmin}_V(|| L'V – D' ||)$

  More details on:

  http://igl.ethz.ch/projects/Laplacian-mesh-processing/STAR/STAR-Laplacian-mesh-processing.pdf

Laplacian mesh edition

- Application to key-frame animation



[Xu et al., 2006]