Biomechanical Simulation and Control of the Face, Neck and Body

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Overview

The Face

- Biomechanical facial modeling
  - *Capturing facial models from data*
- Efficient facial tissue simulation

The Neck

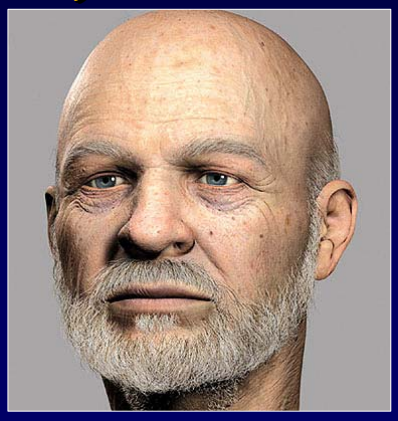
- Biomechanical modeling of the neck-head complex
- Neuromuscular control

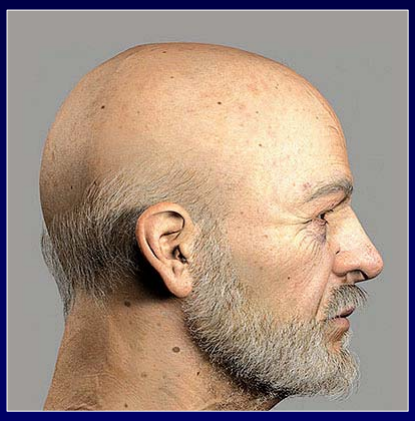
The Body

- Modeling body musculature
- Biomechanical simulation of the upper body

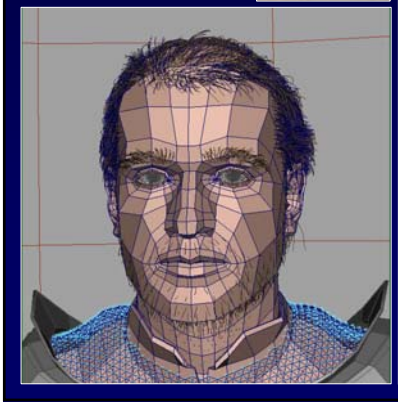
Realistic Facial Modeling

Square Pictures USA (2001)



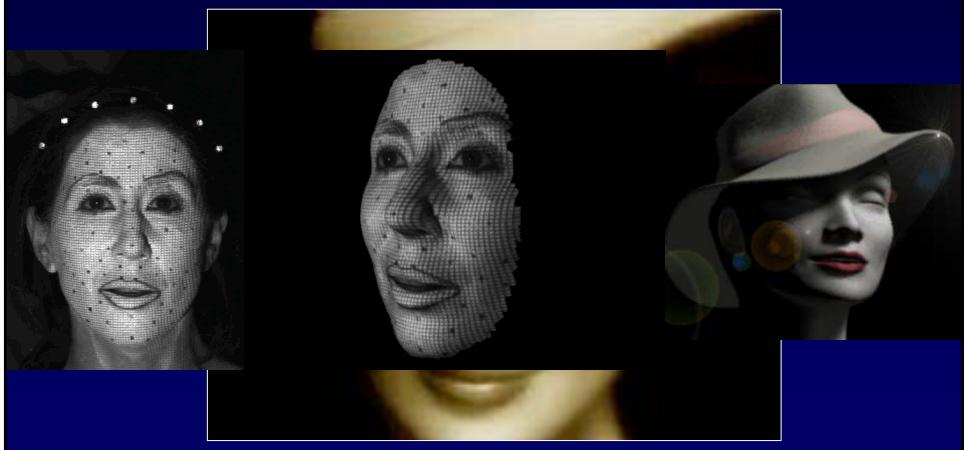


Realistic Facial Modeling

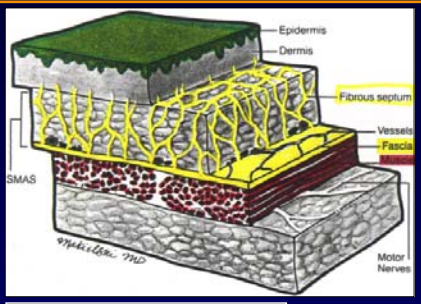


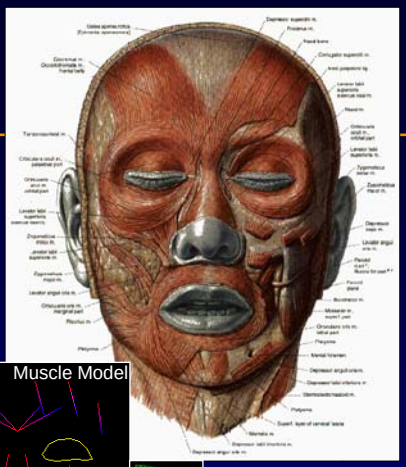
Facial Motion Capture

Virtual Celebrity Productions, LLC

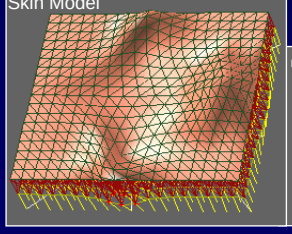


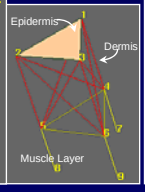
Biomechanical Facial Modeling



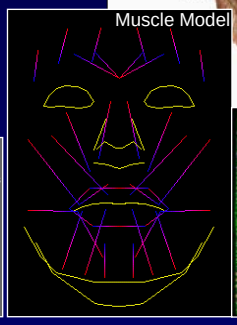


Skin Model





Muscle Model



Real-Time Biomechanical Facial Simulation

Functional Facial Models
Scanned Data ➡ Synthetic Faces

Cyberware Scanner

Range Image

Texture Image

Cyberware Data

Synthesized Expressions

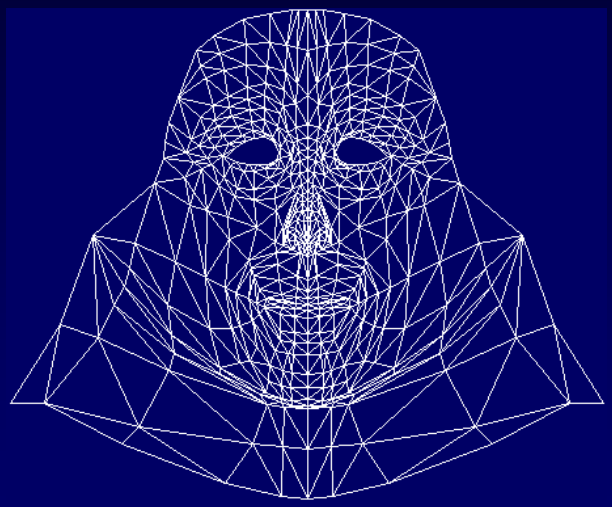
Raw Input Dataset ("Heidi")

From CyberWare 3D Color Digitizer

Range Image

RGB Texture Image

Generic Facial Mesh



Fitting the Generic Mesh

Feature-based image matching algorithm

localizes facial features in:

Processed range image

RGB texture image

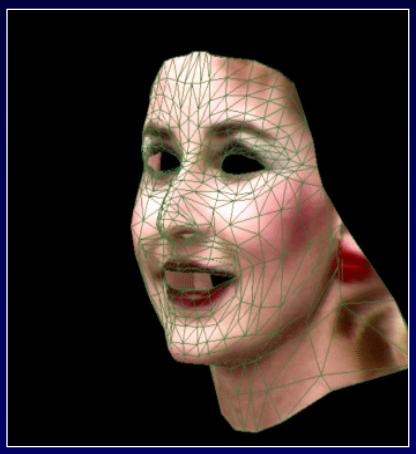
Sampling Facial Shape

Fitted mesh nodes sample range data

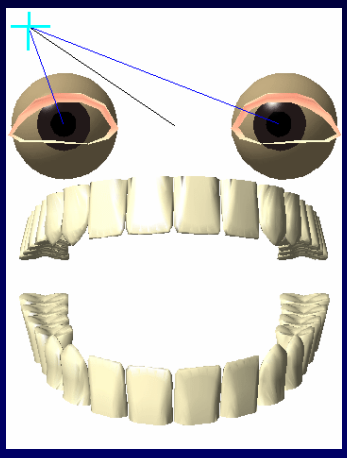
Textured 3D Geometric Model

Texture map coordinates

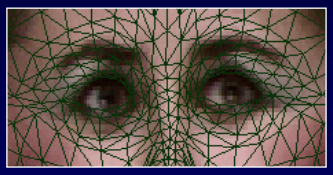
- Positions of fitted mesh nodes in RGB texture image

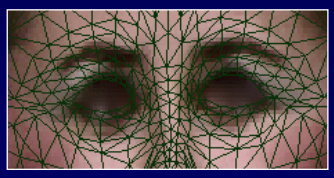


Auxiliary Geometric Models



Eyelid Texture Interpolation



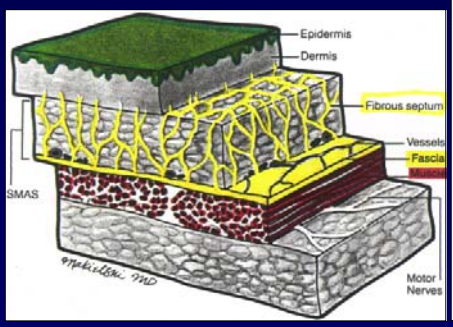


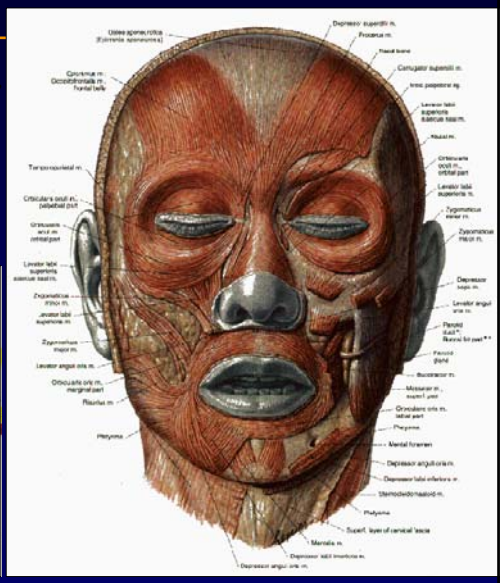
Complete Geometric Model

Neutral expression is estimated

Facial Anatomy

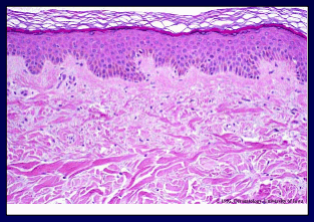
The face: a complex biomechanical structure

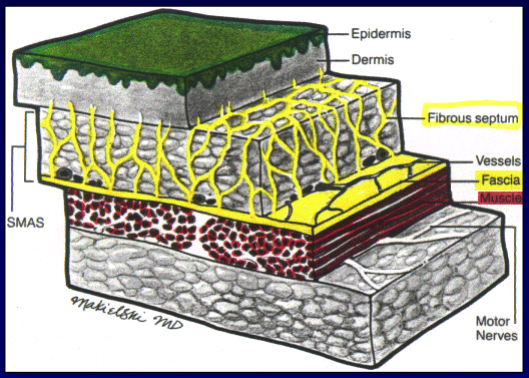




Facial Histology

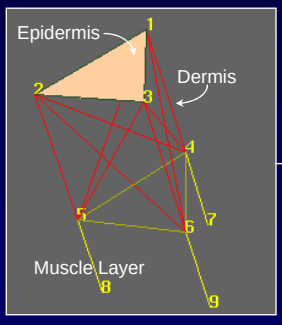
A complex, multilayer structure



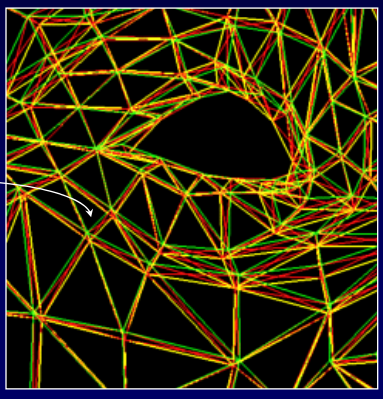


Biomechanical Skin Model

Deformable tissue element

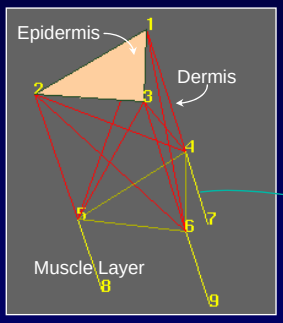


Single Element

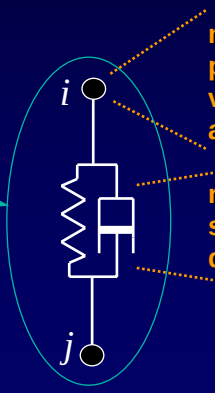


Biomechanical Skin Model

Viscoelastic uniaxial primitive



Single Element



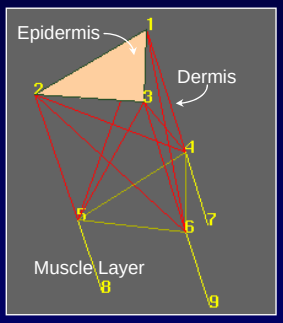
mass m_i
position $\mathbf{x}_i(t)$
velocity $\mathbf{v}_i(t)$
acceleration $\mathbf{a}_i(t)$

rest length l_{ij}
stiffness c_{ij}
damping γ_{ij}

Voigt Viscoelastic Model

Biomechanical Skin Model

Element dynamics

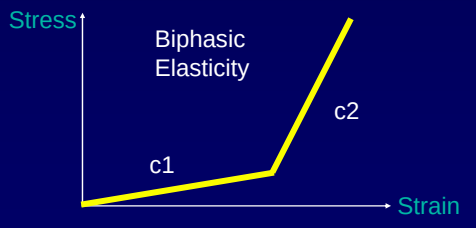


Single Element

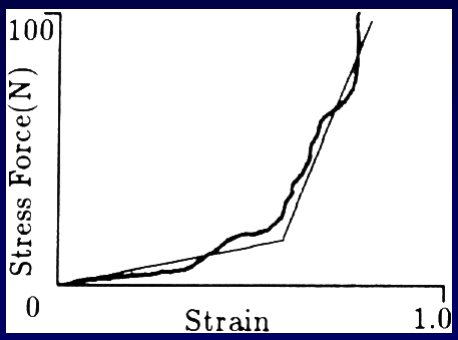
$$\mathbf{r}_{ij} = \mathbf{x}_j - \mathbf{x}_i$$ Span

$$e_{ij} = \|\mathbf{r}_{ij}\| - l_{ij}$$ Deformation

$$\mathbf{f}_{ij}^{e} = (c_{ij} e_{ij} + \gamma_{ij} \dot{e}_{ij}) \frac{\mathbf{r}_{ij}}{\|\mathbf{r}_{ij}\|}$$ Viscoelastic Force

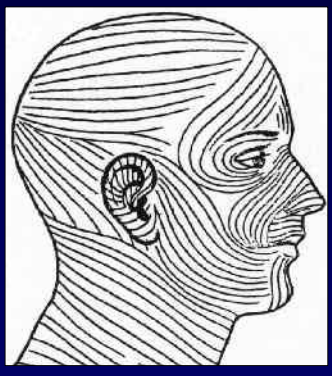


Empirical vs Idealized Stress-Strain Curve



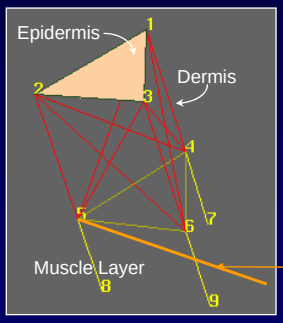
Langer's Lines

Non-isotropic stress-strain characteristics



Biomechanical Skin Model

Element dynamics



Single Element

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$$e_{ij} = \|\mathbf{r}_{ij}\| - l_{ij}$$ Deformation

$$\mathbf{f}_{ij}^{e} = (c_{ij} e_{ij} + \gamma_{ij} \dot{e}_{ij}) \frac{\mathbf{r}_{ij}}{\|\mathbf{r}_{ij}\|}$$ Viscoelastic Force

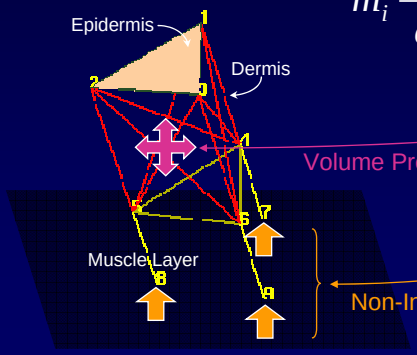
Differential Equations of Motion

$$m_i \frac{d^2 \mathbf{x}_i}{dt^2} + \sum_{j \in N_i} \mathbf{f}_{ij}^{e} = \mathbf{f}_i^{m}$$ Muscle Forces

Biomechanical Skin Model

Element dynamics

$$m_i \frac{d^2 \mathbf{x}_i}{dt^2} + \sum_{j \in N_i} \mathbf{f}_{ij}^{e} = \mathbf{f}_i^{m} + \mathbf{f}_i^{v} + \mathbf{f}_i^{c}$$

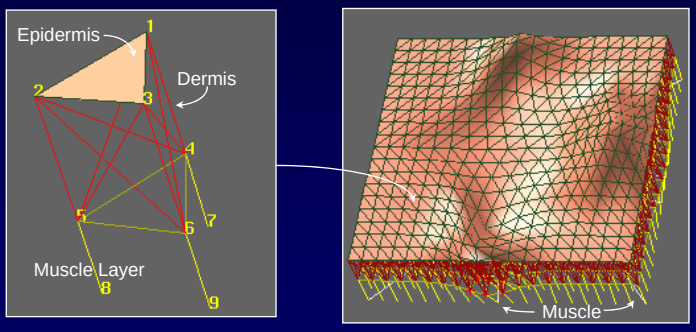


Volume Preservation Constraint

Non-Interpenetration Constraint

Biomechanical Skin Model

Deformable tissue element and patch



Single Element

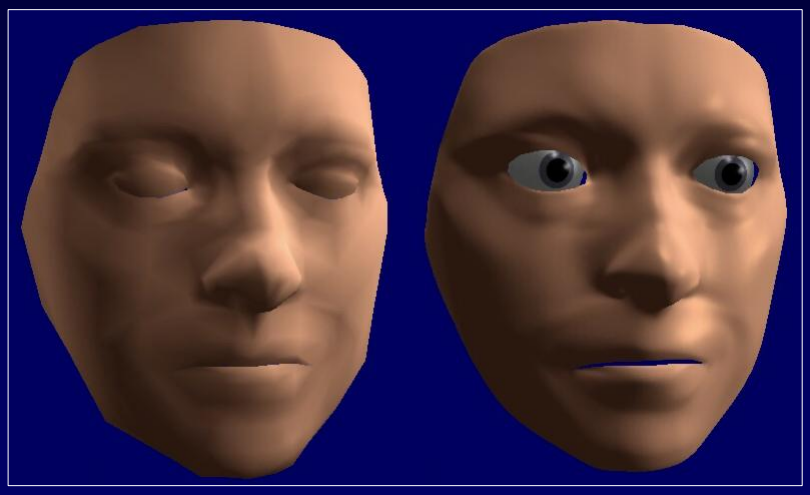
Skin Patch

Explicit Euler Method

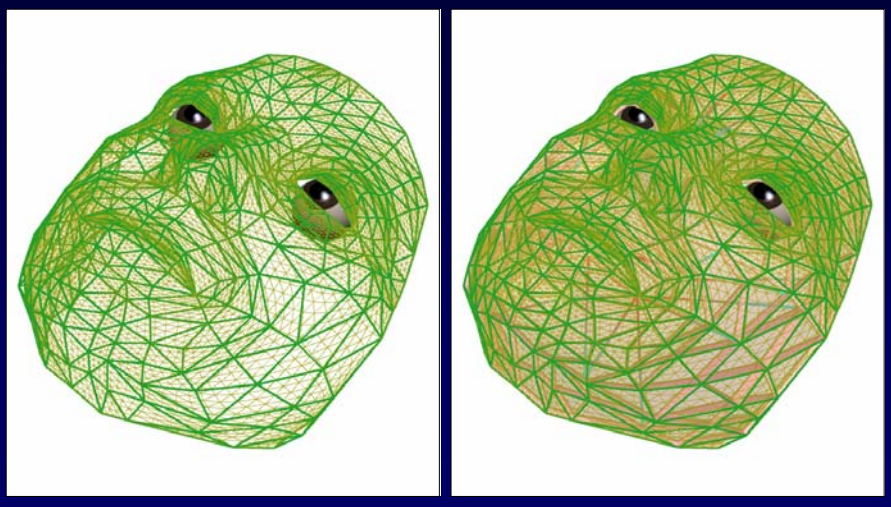
Efficient near-stability limit for moderately deformable biomechanical skin model

$$\begin{cases} \mathbf{a}_i^t = \dfrac{1}{m_i}\left(\sum_{j \in N_i} \mathbf{f}_{ij}^e + \mathbf{f}_i^m + \mathbf{f}_i^v + \mathbf{f}_i^c\right) \\ \dot{\mathbf{x}}_i^{t+dt} = \dot{\mathbf{x}}_i^t + dt\ \mathbf{a}_i^t \\ \mathbf{x}_i^{t+dt} = \mathbf{x}_i^t + dt\ \dot{\mathbf{x}}_i^{t+dt} \end{cases}$$

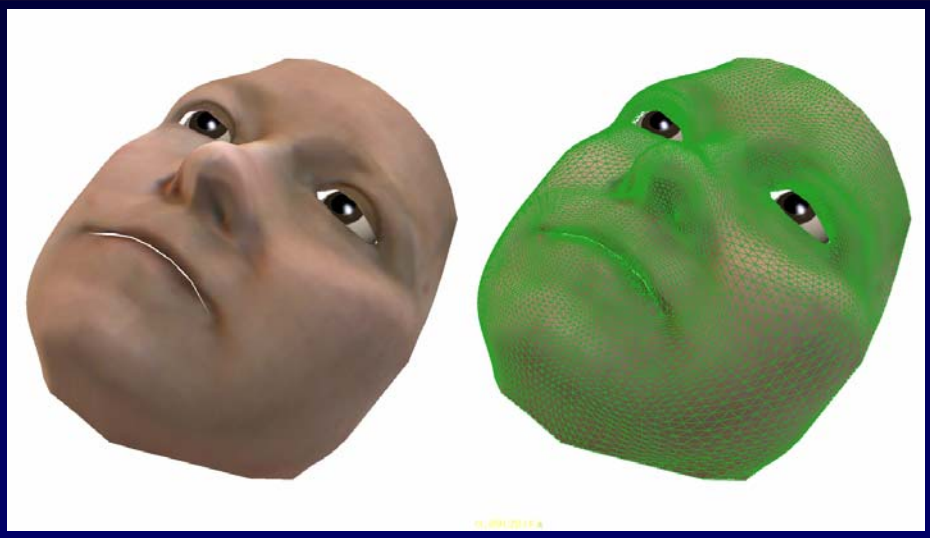
Facial Subdivision Surface



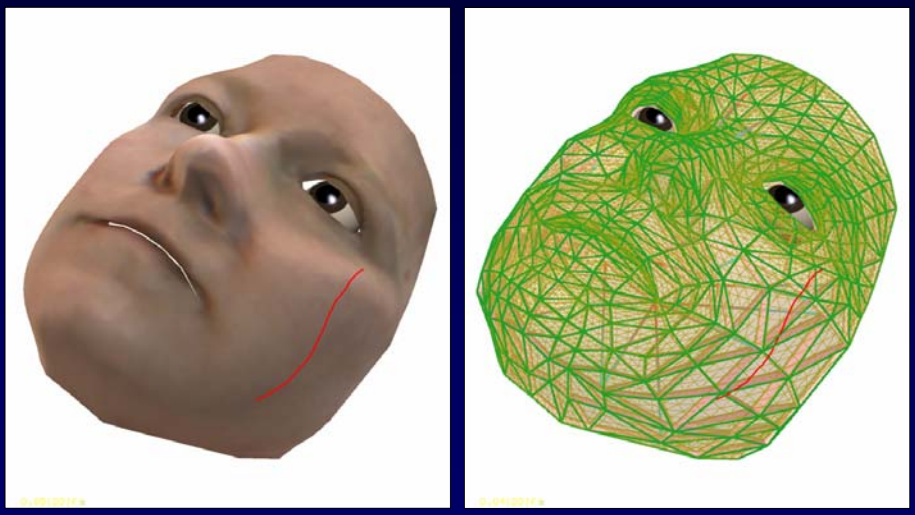
Subdivision Surface with Tissue Model



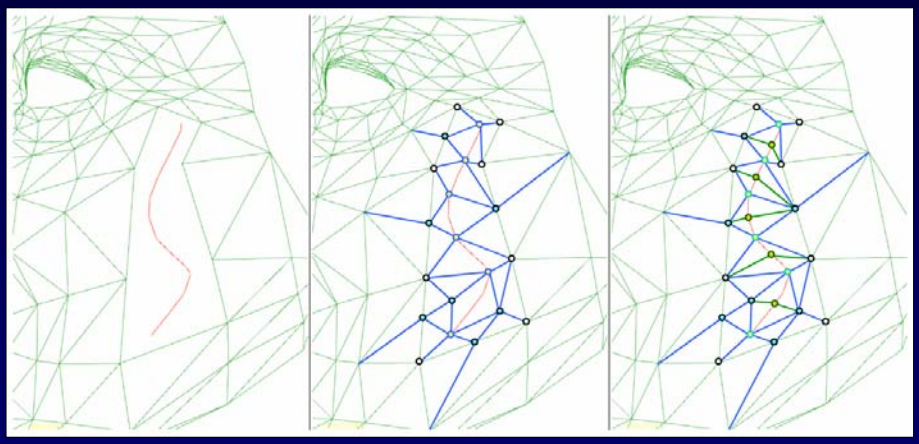
Facial Subdivision Surface



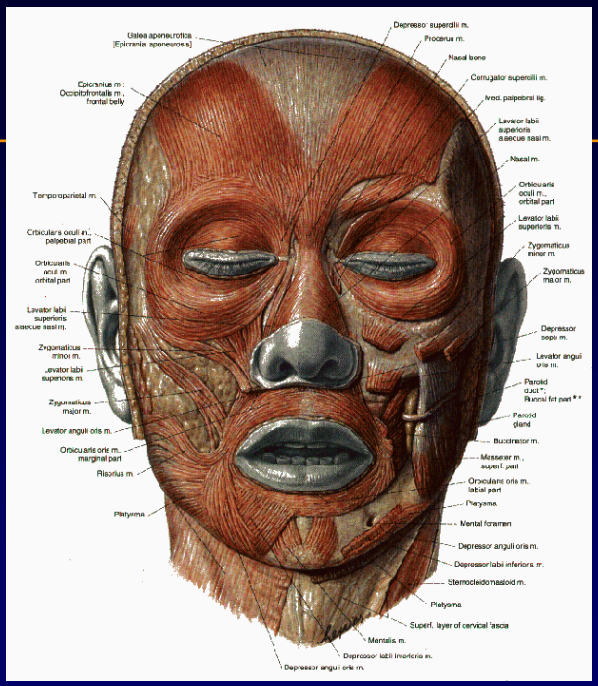
Incision on Facial Mesh



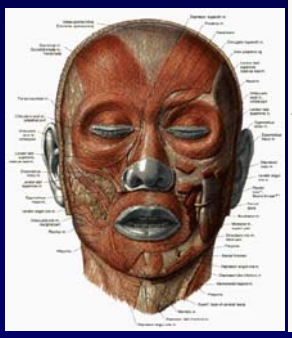
Retriangulation Around Incision

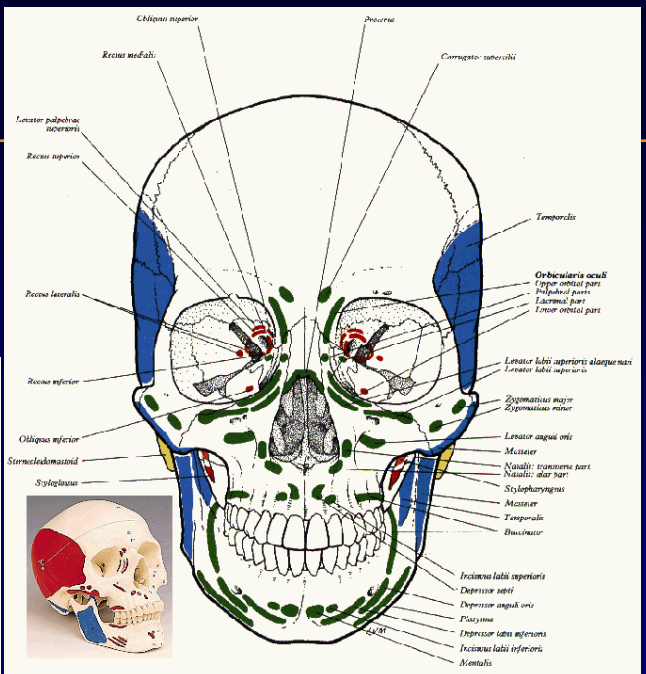


Facial Musculature



Muscles & Insertions





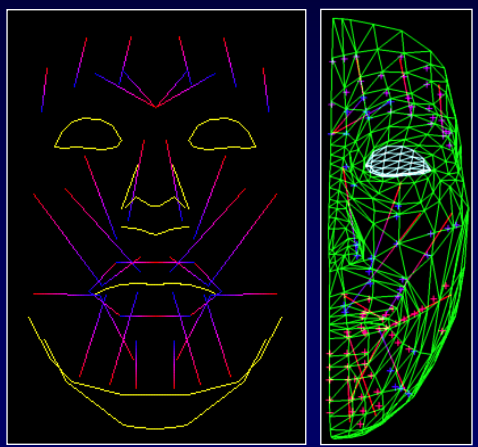
Facial Muscle Model Structure

35 Muscles

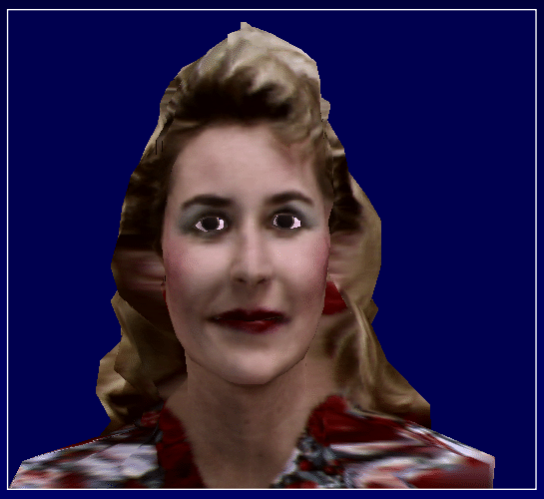
- Levator Oculii
- Corrugators
- Naso-Labial
- Zygomatics
- Obicularis Oris

plus

- Articulate Jaw
- Eyes/Eyelids



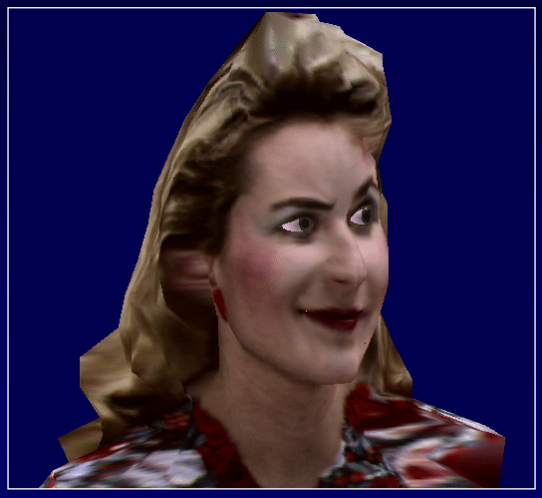
Muscle-Actuated Expressions



Muscle-Actuated Expressions

Muscle-Actuated Expressions

Muscle-Actuated Expressions



Expression Analysis and Resynthesis

Capture expression in video

Analysis

Resynthesis

Transfer it to a synthetic facial model

NN Estimation of Muscle Actions

Trained neural network muscle control

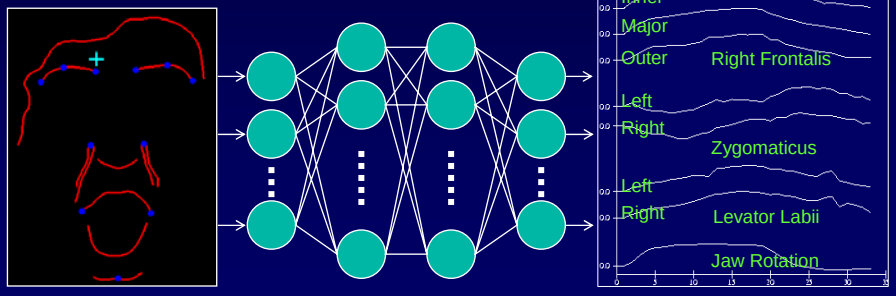


Image Feature Input

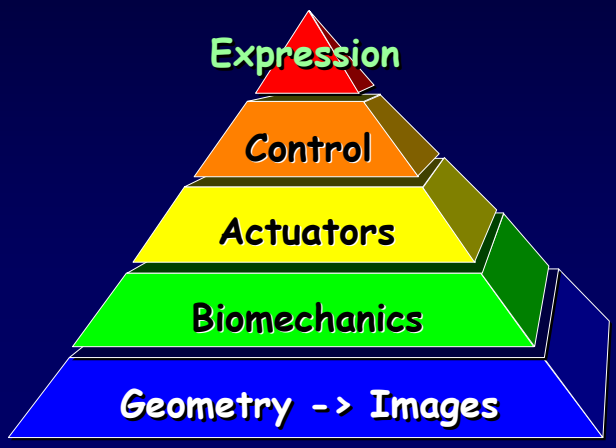
Trained Neural Network Transducer

Muscle Action Output

Expression Analysis and Resynthesis

Hierarchical Facial Model Structure

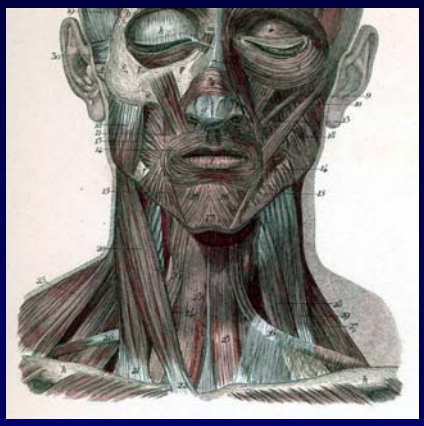
From expression control to images



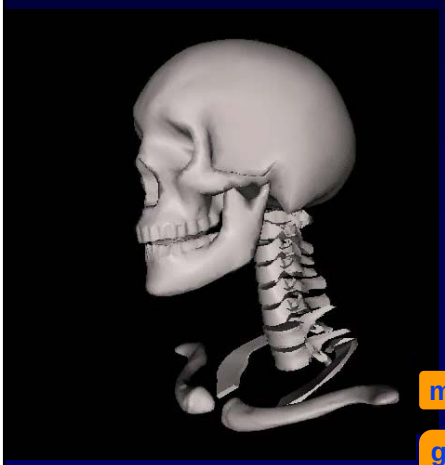
Functional Model of "George"

The Neck

Anatomical Structure of the Neck



Skeleton Model



- 7 cervical vertebrae and a skull coupled by 3-DOF joints
- Ligaments/disks→ passive joint springs
- Equations of motion

$$M(q)\ddot{q} + b(q,\dot{q}) = \Theta(q) f_c(q,\dot{q},a)$$

mass

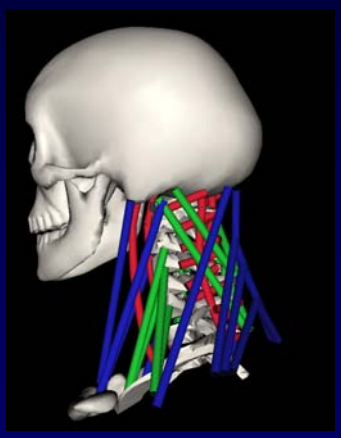
gravity, Coriolis, passive elastic forces

moment arm matrix

active muscle force

neural input

Biomechanical Neck Model



Total of 72 anatomically-based Hill-type muscle actuators in 3 layers

48 *deep* muscles
(16 longus colli, 16 erector, 16 rotator)

6 muscles in each joint increase controllability

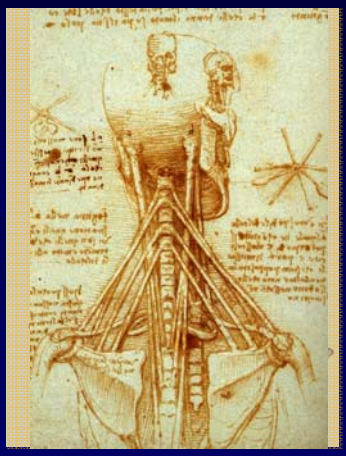
12 *intermediate* muscles
(scalerius: 4 anterior, 4 posterior, 4 capitis)

12 *superficial* muscles
(2 sternomastoid, 2 cleidooccipital, 8 trapezius)

Challenge is actuation and control

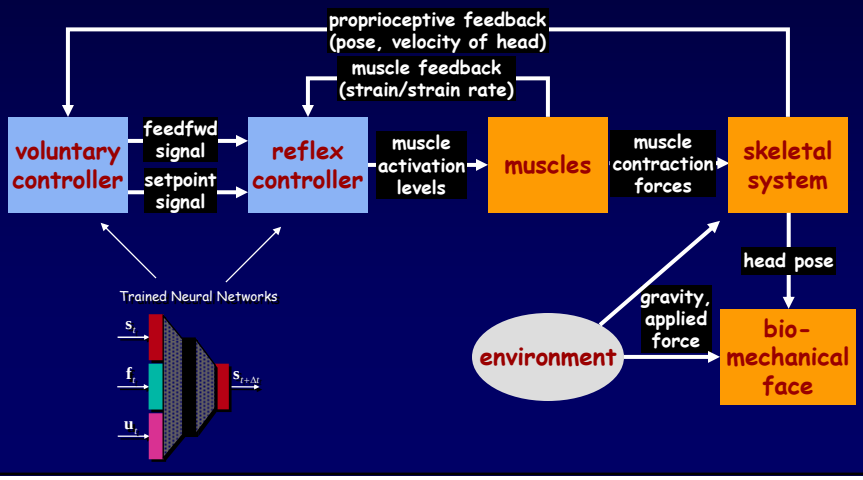
Biomechanical Neck Modeling

What Would Leonardo da Vinci Think of This?

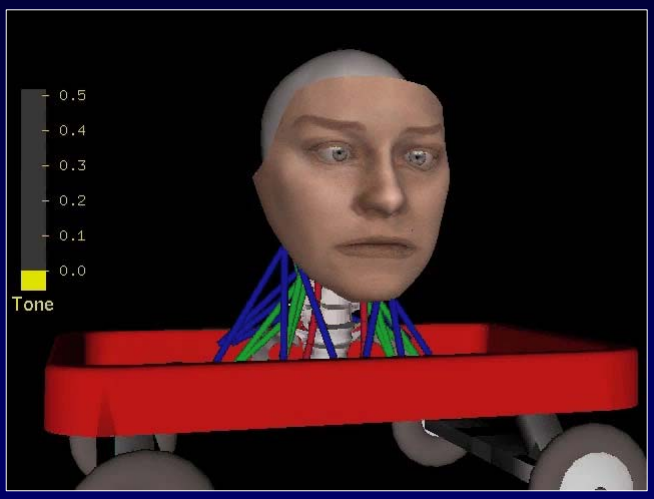


Biomechanical Simulation of the Neck-Head-Face Complex

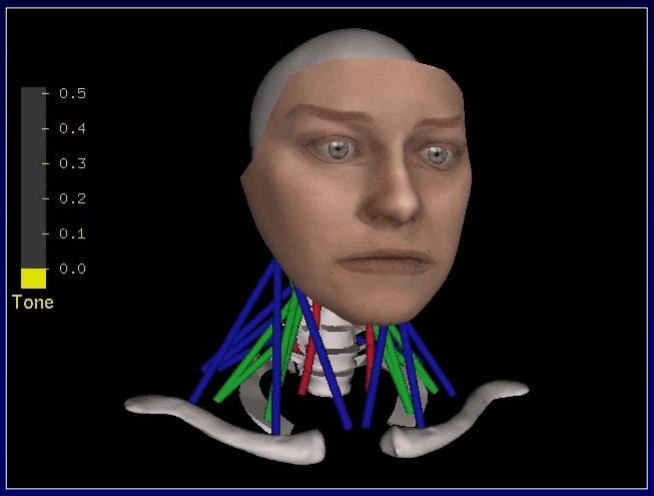
Neuromusculoskeletal model



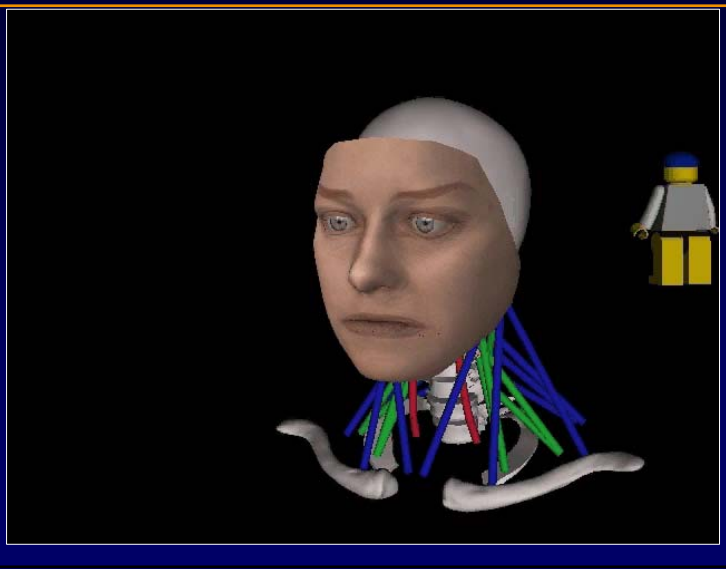
Tension Control



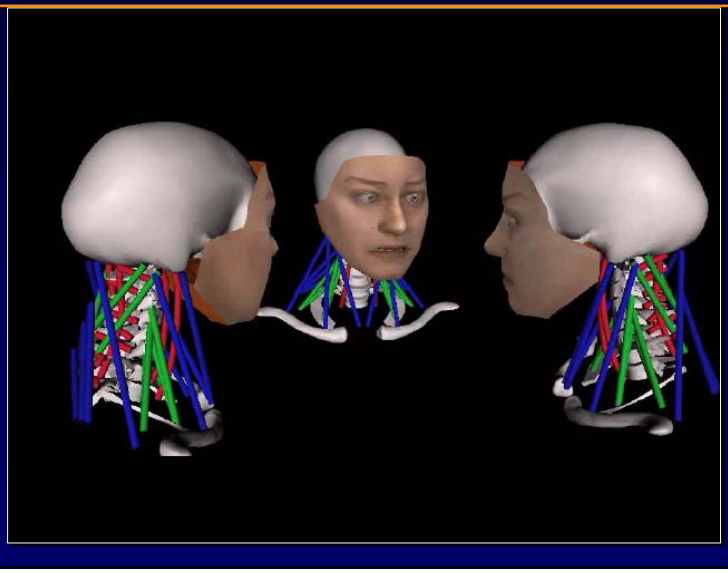
Tension Control



Neck-Head-Face-Eye Behavior



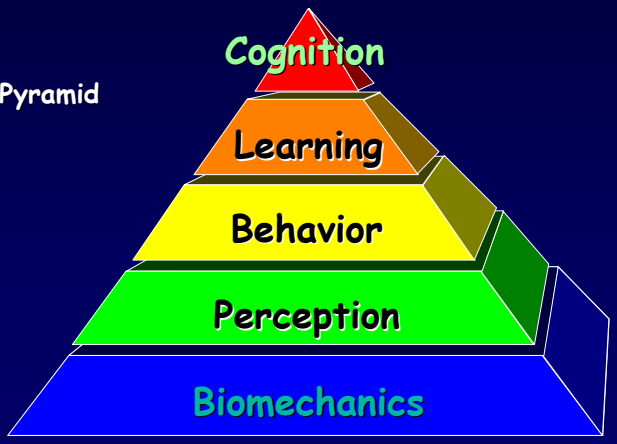
Autonomous Multi-Head Interaction



Artificial Life

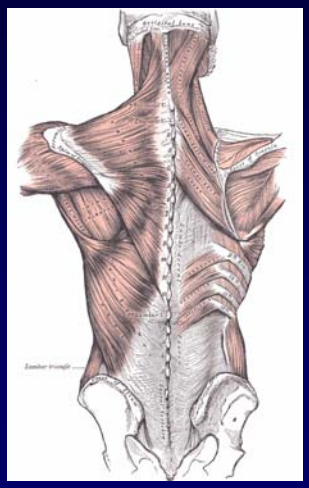
Comprehensive computational model of humans

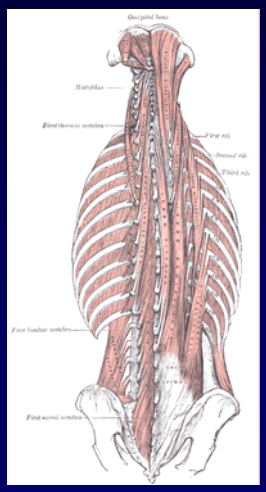
The ALife Modeling Pyramid



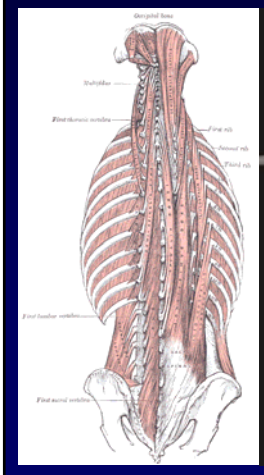
George in "Bureaucrat Too"

Muscles in the Spine



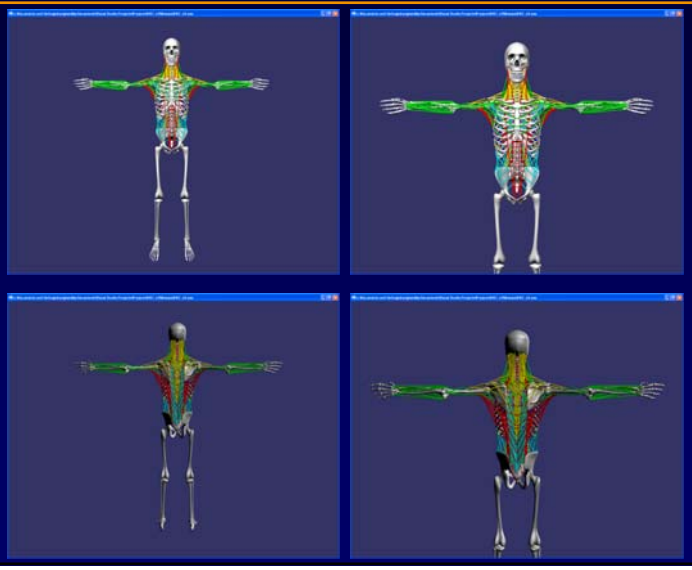


Posterior Muscles in the Deep Layers



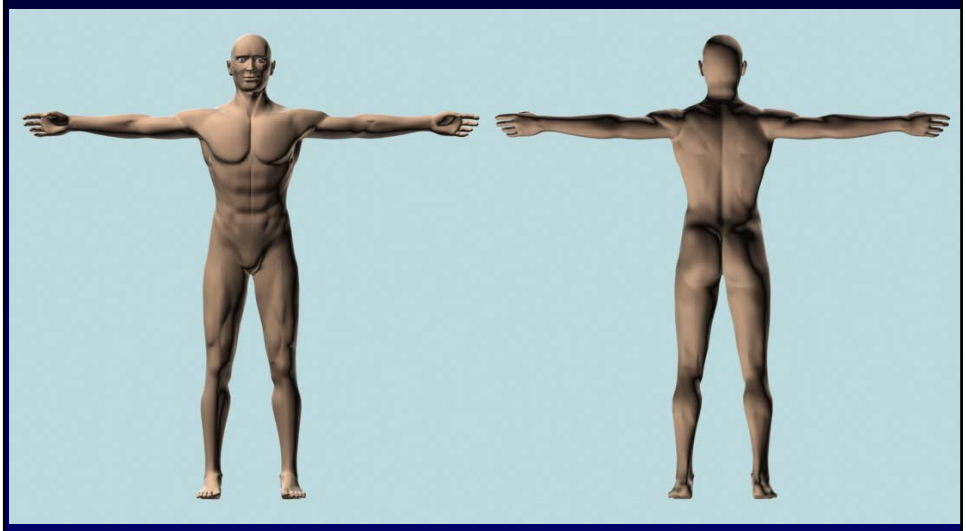
Modeling all the major muscles participating in spinal posture

Full Upper-Body Musculature



3D Muscle Geometry

Skinned Model



A preliminary simulation demo

- flexing_solid.avi
- flexing_transparent.avi

Acknowledgements

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- Sung-Hee Lee — UCLA (neck model)
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Additional info:

deformable.com

Thank You !