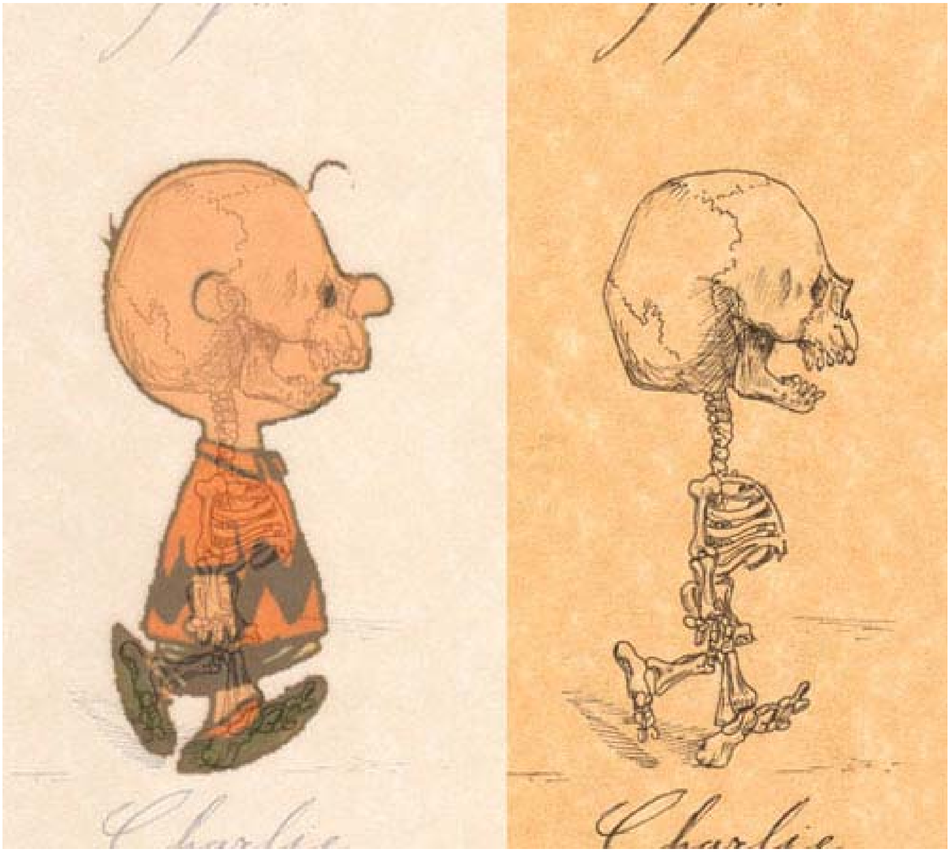
BODY DEFORMATION

Winter 08
888 presentation
Ying Wei



Outline

- Overview
- Related works
- Important papers
- Discussion

Overview

- During dynamic activities, the surface of the human body moves in many subtle but visually significant ways: bending, bulging, jiggling, and stretching.
- Realistic animation needs more than natural behavior of skeletons
- Human are sensitive to familiar objects like body.

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Related works

- Surface model
  - Deformed by skeletal structure
  - “Candy wrapper” effect because the volume of the body is not preserved.
  - Cannot show dynamic effects such as jiggling of the flesh or muscle bulging due to exertion.
  - Remain common in real-time application like games or virtual environments.
  - Skinning by Example
    - Creation from pose interpolation
- Multi-layered approach
  - Model the complex anatomy
  - Simulate functionality (breathing)

Special Case: hands and face

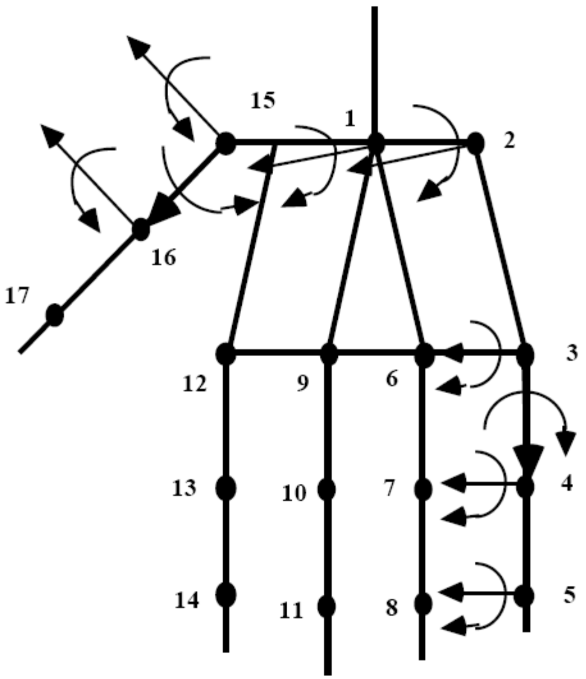
- Face
  - Many different parts of the face and head work together to convey meaning.
  - Facial anatomy is both structurally and physically complex and motions cannot be approximated by rigid body motion
  - Motion capture using dense marker sets (do not include significant occlusion)
  - Ben's presentation covers this part in detail
- Hands:
  - Bony anatomical structure makes them more amenable to anatomical modeling
  - Detailed geometry required

More about simulation techniques

- SSD
- FFD
- Mass-Spring
- FED
- Gradient Domain
- BEM
- Meshless Particle System

Skeletal Subspace Deformation (SSD)

- move the hand and grasp objects
- compute the deformations of the hands: rounding at joints and muscle inflations.
- Motion is specified by giving key values for each joint angle.
- Semi-automatic hand grasping



JOINT-DEPENDENT LOCAL DEFORMATIONS
FOR HAND ANIMATION AND OBJECT GRASPING

Nadia Magnenat-Thalmann Richard Laperrière Daniel Thalmann
MIRALab, HEC/IRO
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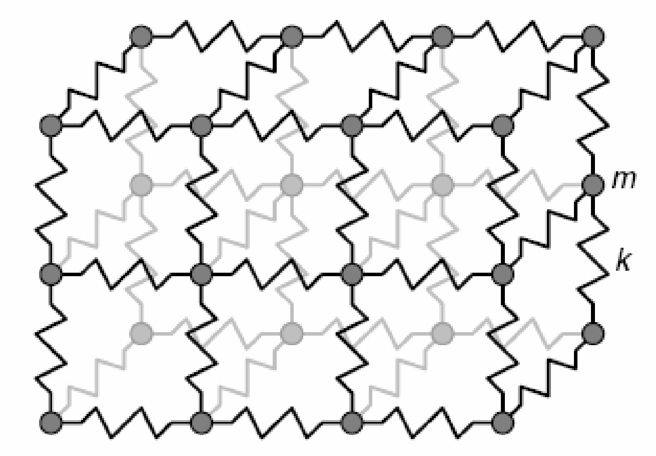
Free Form Deformation (FFD)

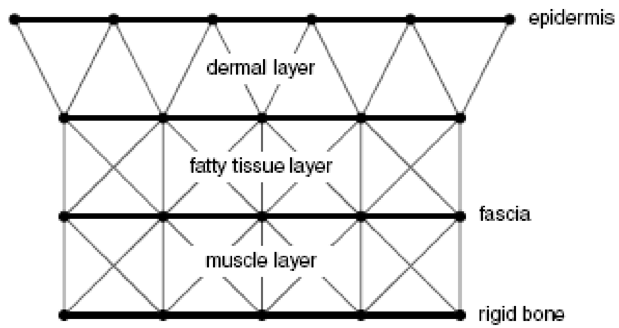
- FFD's change the shape of an object by deforming the space in which the object lies.
  - Barr's early work in this area examined deformation in terms of geometric mappings of three-dimensional space. [Barr84]
    - Limited deformation
    - Non-intuitive user control
  - Sederberg and Parry embedded object in a lattice of grid points of some standard geometry, such as a cube or cylinder. [SP86]
  - Coquillart provides a toolkit of lattices with different sizes, resolutions and geometries [Coq90].
  - Hsu et. al. allow direct manipulation of surface or curve points by converting the desired movement of these points to equivalent grid point movement. [HHK92].

Mass-Spring Models

- An object is modeled as a collection of point masses connected by springs in a lattice structure
- Used widely in facial animation
- Newton's Second Law:

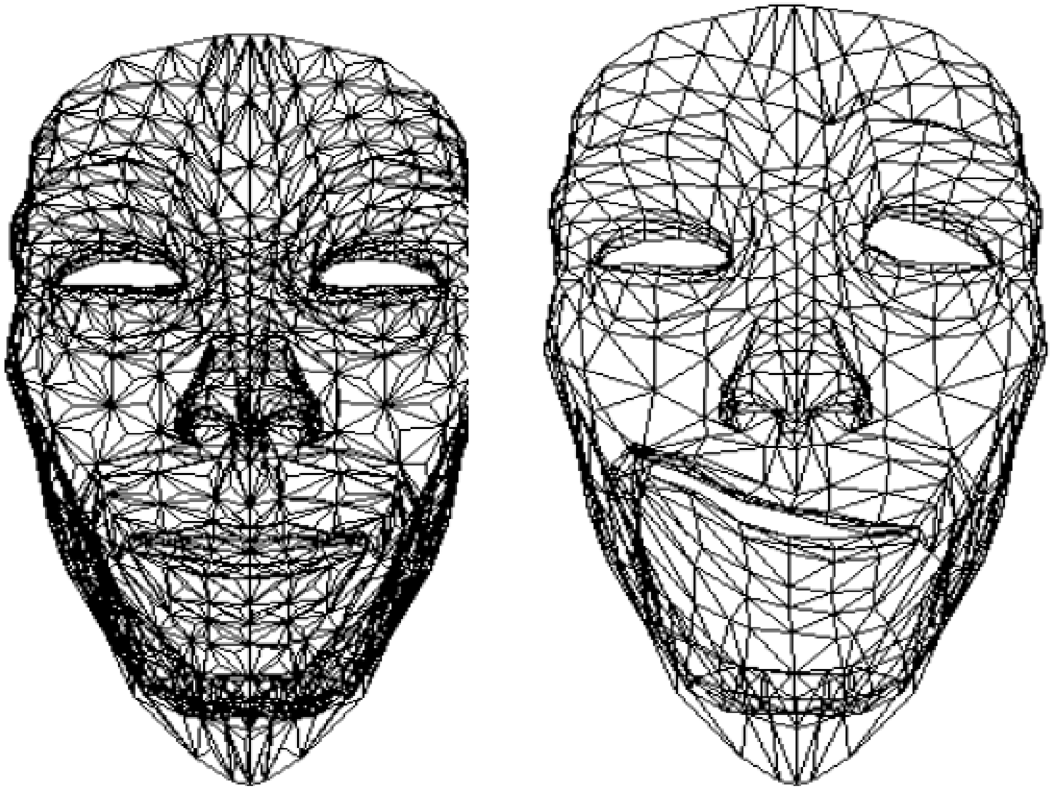
$$m_i \ddot{\mathbf{x}}_i = -\gamma_i \dot{\mathbf{x}}_i + \sum_j \mathbf{g}_{ij} + \mathbf{f}_i.$$





The three-layer skin mesh used by Terzopoulos and Waters.

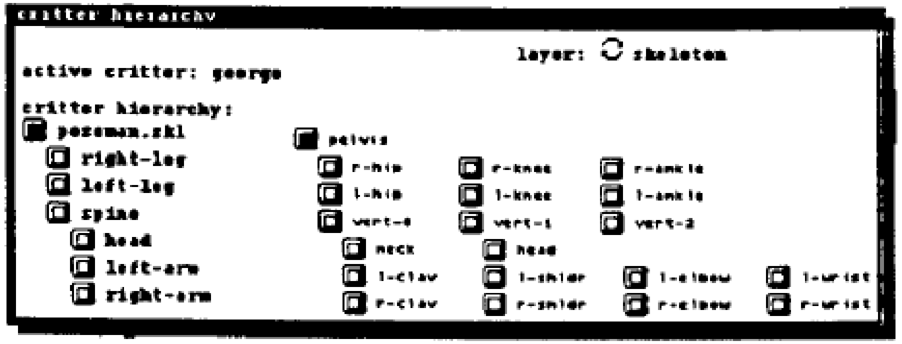
- Terzopoulos and Waters were the first to apply dynamic mass-spring systems to facial modeling [TW90].



- Chadwick et. al. combined mass-spring models with free form deformations to animated muscles in human character animation.
- The muscles are embedded in a lattice of 8-node mass-spring elements and deformed by applying forces to the lattice node points.
- The dynamic deformation of the muscle model is calculated by interpolating the motion of the lattice points [CHP89].

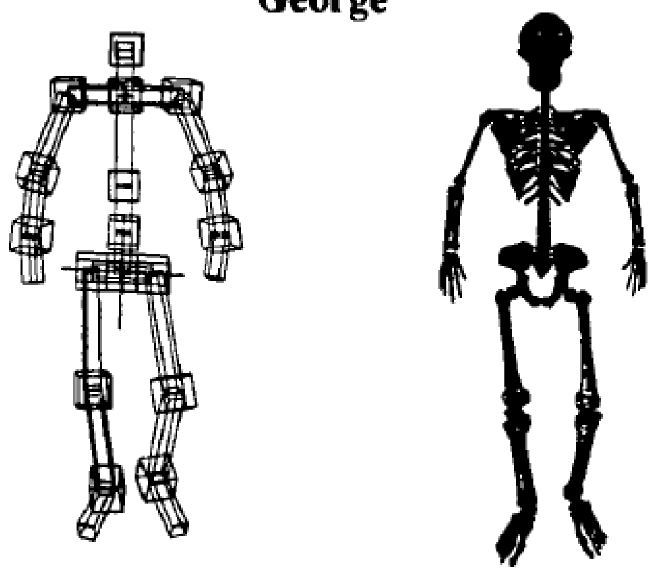
- Motion specification
  - (behavior layer in the critter system)
- Motion Foundation, articulated armature
  - (critter skeleton layer)
- Shape transition, squash and stretch
  - (critter muscle and fatty tissue layer)
- Surface description, surface appearance and geometry
  - (critter skin, clothing and fur layer)

several bones (critter skin) are mapped to a simplified articulated critter skeleton.

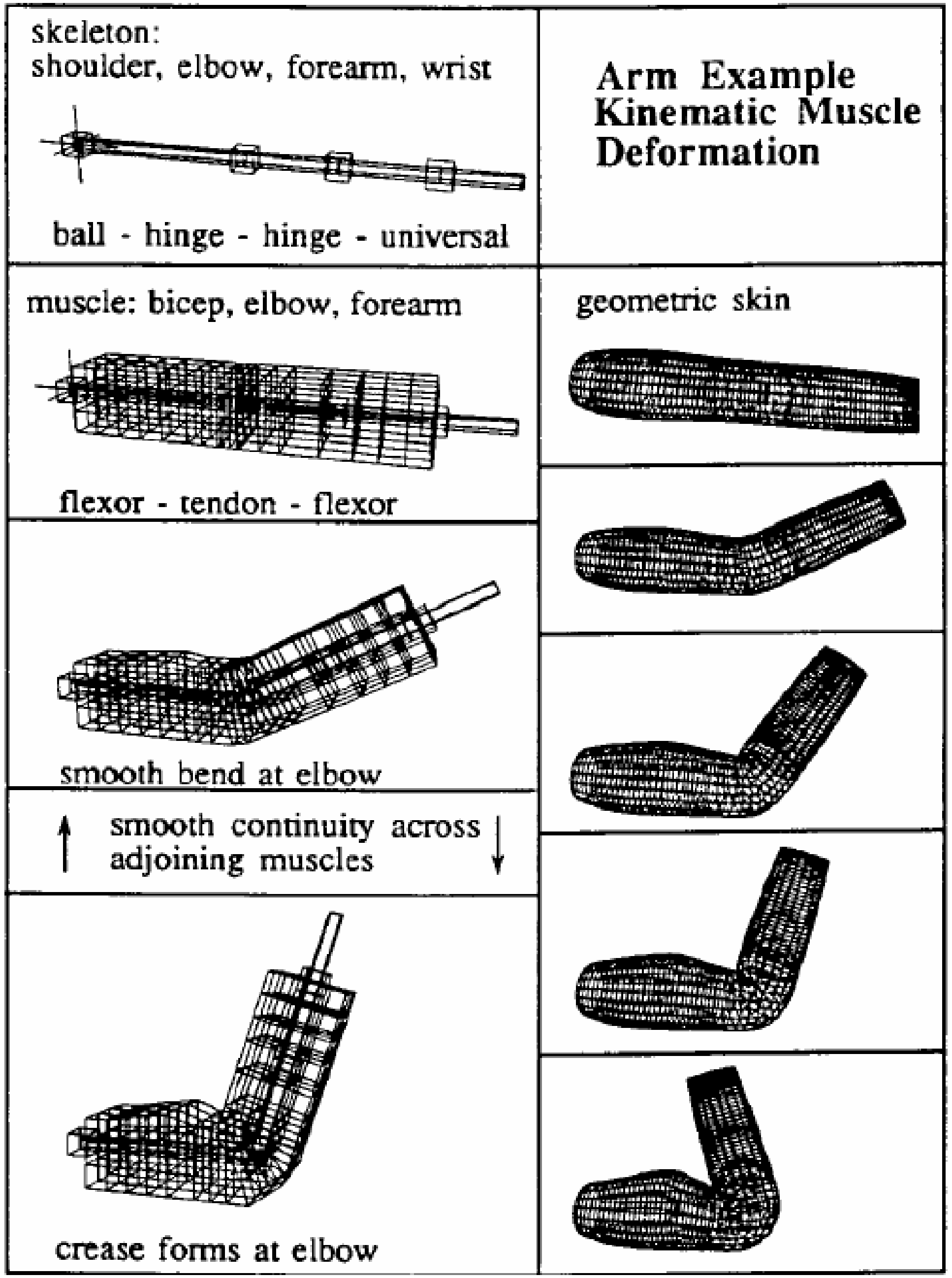


Panel selection of various layers & parts
Visual hierarchical display

George



Skeleton "Skin"


skeleton:
shoulder, elbow, forearm, wrist
ball - hinge - hinge - universal
Arm Example
Kinematic Muscle
Deformation
muscle: bicep, elbow, forearm
flexor - tendon - flexor
geometric skin
smooth bend at elbow
smooth continuity across
adjoining muscles
crease forms at elbow

- Terzopoulos et. al. describe a mass-spring model for melting objects by associating each node with a temperature and a position [TPF89].
  - spring stiffnesses dependent on temperature.
  - discretized form of the heat equation computed the diusion of heat through the material, and the changes in nodal temperatures.

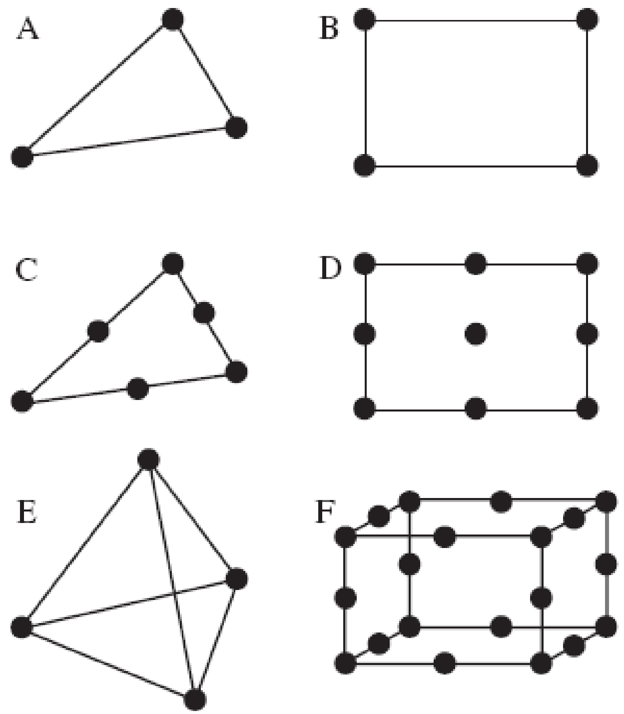
Finite Element Method (FEM)

- The full continuum model of a deformable object considers the equilibrium of a general body acted on by external forces.
- The object deformation is a function of these acting forces and the object's material properties.
- The object reaches equilibrium when its potential energy is at a minimum.

$$\Pi = \Lambda - W,$$

- FEM divides object into a set of elements and approximate the continuous equilibrium equation over each element.

Common FEM Elements



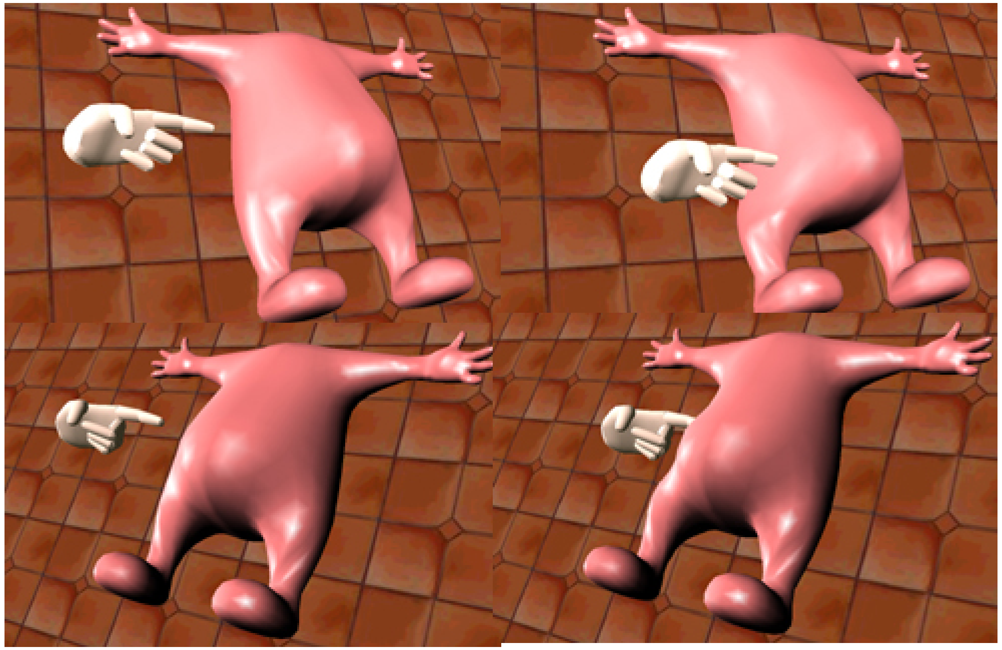
element type	# nodes	interpolation equation	interpolation functions
linear triangular area A	3	$\Phi = a_1 + a_2 x + a_3 y$	$h_1 = [(x_2 y_3 - x_3 y_2) + (y_2 - y_3)x + (x_3 - x_2)y]/2A$ $h_2 = [(x_3 y_1 - x_1 y_3) + (y_3 - y_1)x + (x_1 - x_3)y]/2A$ $h_3 = [(x_1 y_2 - x_2 y_1) + (y_1 - y_2)x + (x_2 - x_1)y]/2A$
bilinear rectangular width w height h area A	4	$\Phi = a_1 + a_2 x + a_3 y + a_4 xy$	$h_1 = (w + x_1 - x)(h + y_1 - y)/A$ $h_2 = (x - x_1)(h + y1 - y)/A$ $h_3 = (w + x_1 - x)(y - y_1)/A$ $h_4 = (x - x_1)(y - y1)/A$
quadratic triangular	6	$\Phi = a_1 + a_2 x + a_3 y$ $+ a_4 xy + a_5 x^2 + a_6 y^2$	*see FEM text*
Lagrangian	9	$\Phi = a_1 + a_2 x + a_3 y$ $+ a_4 xy + a_5 x^2 + a_6 y^2$ $+ a_7 x^2 y + a_8 y^2 x + a_9 x^2 y^2$	*see FEM text*
tetrahedral	4	$\Phi = a_1 + a_2 x + a_3 y + a_4 z$	*see FEM text*
20-node brick	20	*see FEM text*	*see FEM text*

Gradient Domain Methods

- Deformation: an energy minimization problem.
  - Energy function contains both a term for a detail-preserving constraint and a term for a position constraint
  - The detail-preserving constraint is nonlinear
  - For computational efficiency, existing techniques convert this nonlinear constraint into a linear one
    - local linearization of transformation
    - transformation interpolation from handles
    - the decomposition of rotation and scaling computation
  - The price: suboptimal deformation results.

Boundary Element Method (BEM)

- [James and Pai 1999]



Meshless Particle System

- First introduced for simulating cosmological fluids: Smoothed Particle Hydrodynamics (SPH)
- Define smoothed particles as samples of mass smeared out in space
- Level set: extract implicit surface from smooth particles
- [Desbrun and Cani 1996], [Tonnesen 1998], [M ¨ uller et al. 2004]
- **Demo** : Sig05 Meshless Deformations Based on Shape Matching
  - input is a set of particles with masses *mi* and an initial configuration

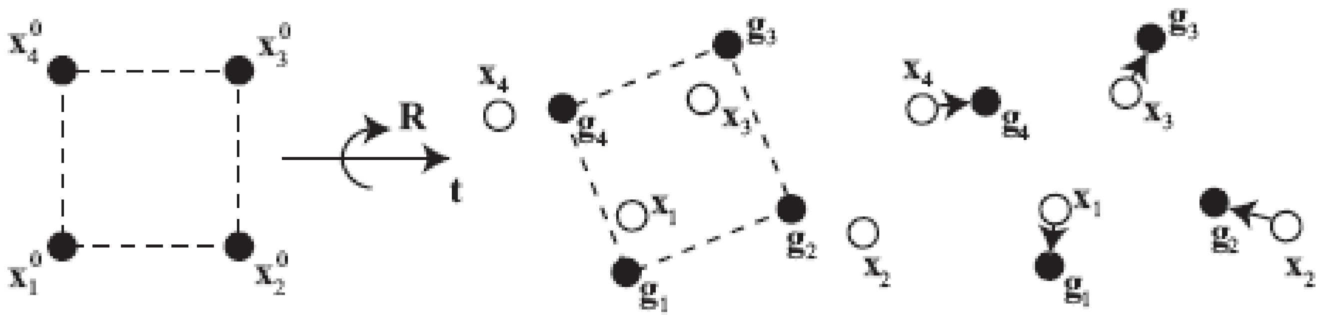


Figure 3: First, the original shape $\mathbf{x}_i^0$ is matched to the deformed shape $\mathbf{x}_i$. Then, the deformed points $\mathbf{x}_i$ are pulled towards the matched shape $\mathbf{g}_i$.

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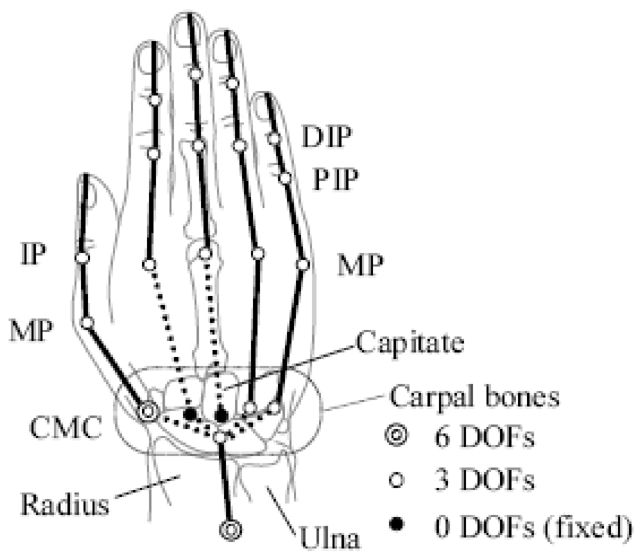
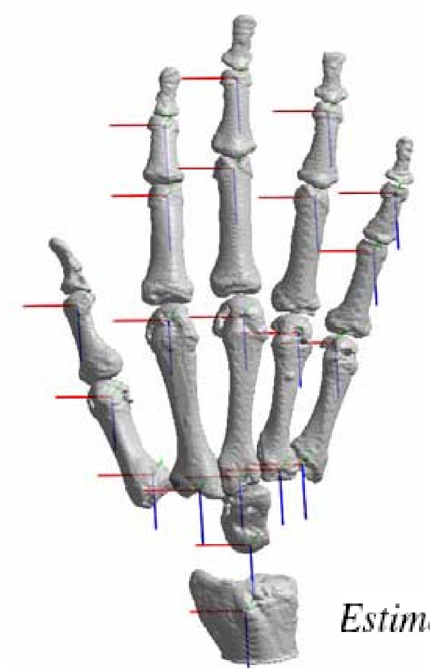
Skeleton-driven; pose interpolation





Estimated rotation center of joint.

Modeling Deformable Human Hands from Medical Images

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Digital Human Research Center, National Institute of Advanced Industrial Science and Technology, Tokyo, Japan

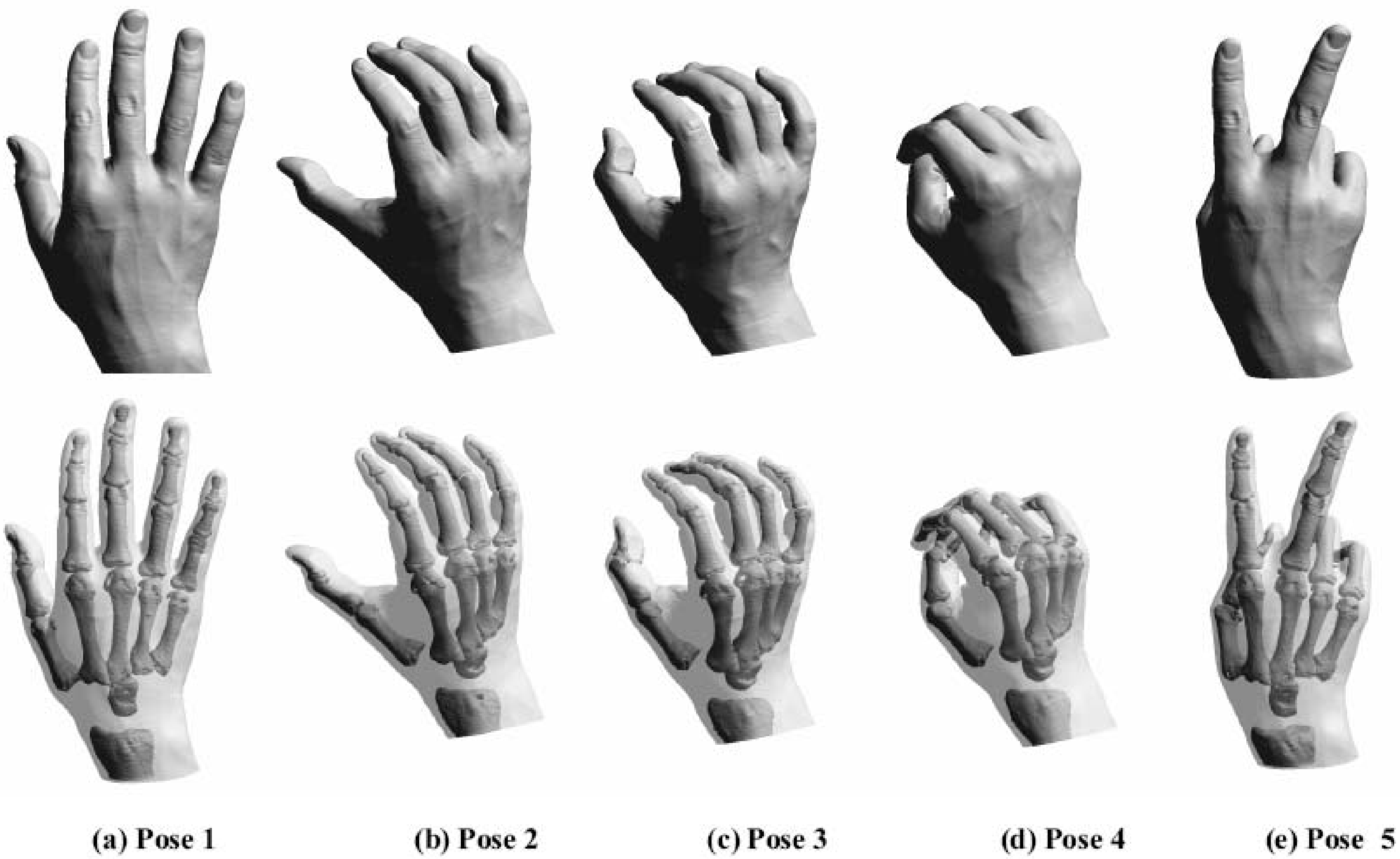
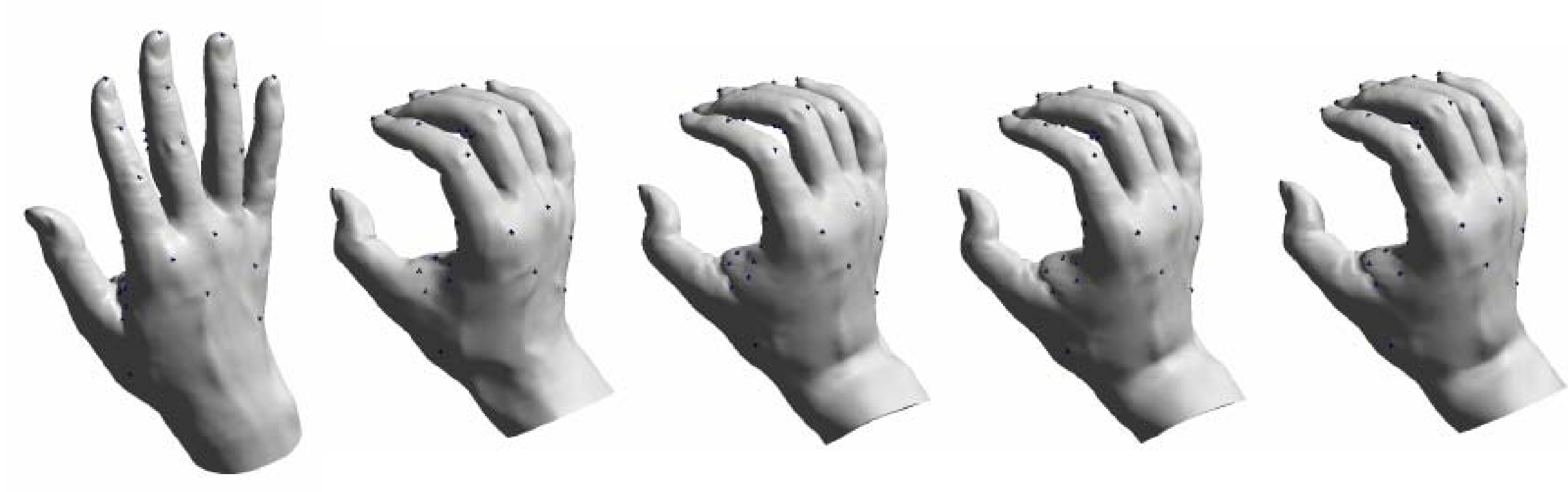


Figure 2: *Skin shape and bone shape reconstructed from CT images.*

- precise estimation of the rotation centers <= CT data
- example-based skin deformation with detailed measured surfaces.

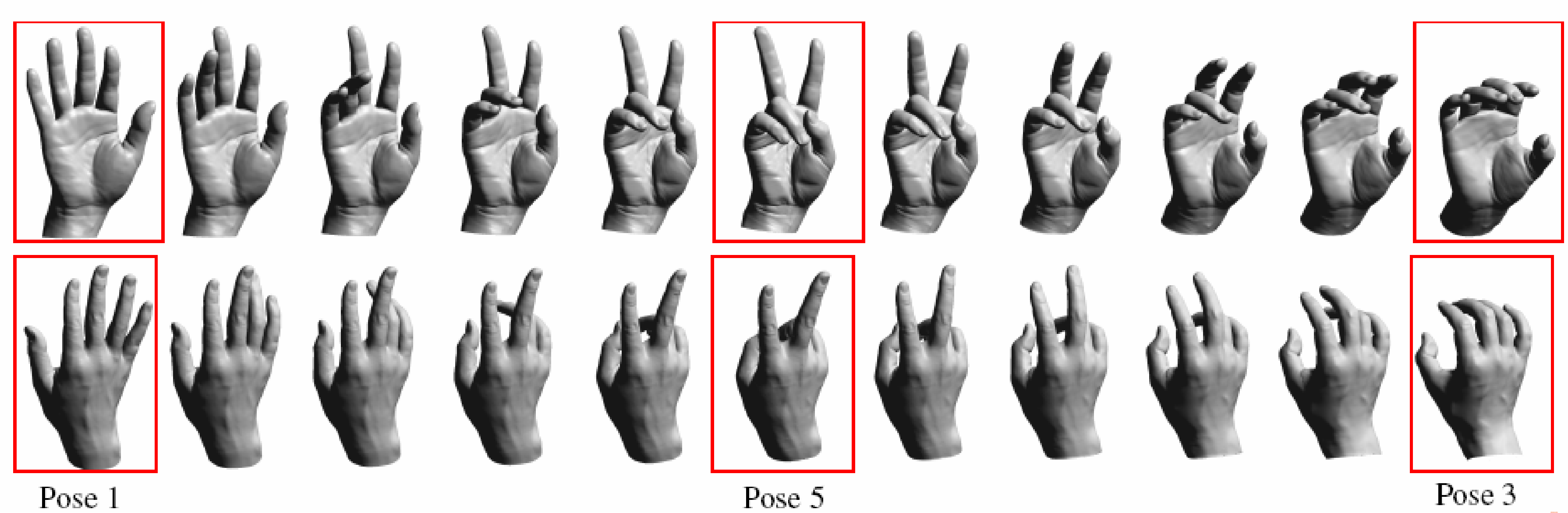


(a) Base mesh $\mathbf{S}_0$ (b) Measured mesh $\mathbf{T}_i$ (c) Mesh $\mathbf{S}_i^s$ deformed using SSD (d) Mesh $\mathbf{S}_i^r$ deformed using RBF (e) Fitted mesh $\mathbf{S}_i^f$

Figure 6: *Fitting process.*

1. Derive the centers of rotation and poses from bone shapes
2. Transform the skin surfaces of all poses into mutually consistent meshes
3. Implement skeleton-driven deformation by using weighted pose space deformation.

- Bone and skin surfaces were generated as isosurfaces using the marching cubes algorithm


Pose 1
Pose 5
Pose 3

SSD

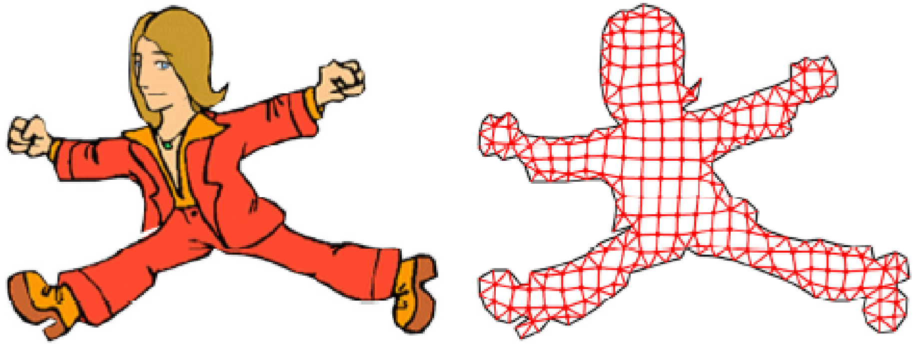
- A framework for real time detail-preserving mesh manipulation
- Builds upon traditional rigging by optimizing skeleton position and vertex weights in an integrated manner.
- New poses and animations are created by specifying constraints on vertex positions, balance of the character, length and rigidity preservation, joint limits, and/or self-collision avoidance.
- **Demo**

Mesh Puppetry:

Cascading Optimization of Mesh Deformation with Inverse Kinematics

Xiaohan Shi∗ Kun Zhou† Yiying Tong‡ Mathieu Desbrun‡ Hujun Bao∗ Baining Guo†

Gradient Domain

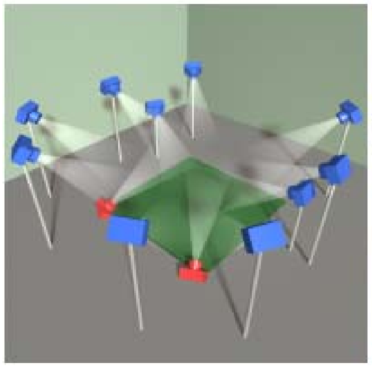


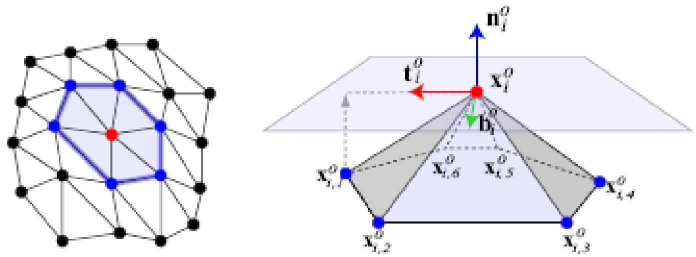
- Interactive 2D shape deformation based on nonlinear least squares optimization.
- Two local shape properties are preserved:
  - Laplacian coordinates of the boundary curve
  - Local area of the shape interior
- Demo (silent)

2D Shape Deformation Using
Nonlinear Least Squares Optimization
Yanlin Weng · Weiwei Xu · Yanchen Wu
Kun Zhou · Baining Guo

Data-driven

- Motion capture with approximately 350 markers to obtain not only the motion of the skeleton but also the motion of the surface of the skin
- A high-res subject-specic surface model is used
- Demo





(a) (b)

Capturing and Animating Skin Deformation in Human Motion

Sang Il Park Jessica K. Hodgins.
School of Computer Science
Carnegie Mellon University

Point-based example

- Modeling and animating a wide spectrum of volumetric objects
- Material properties ranging from stiff elastic to highly plastic.
- Both the volume and the surface representation are point based
- Demo

Point Based Animation of Elastic, Plastic and Melting Objects

M. Müller[1], R. Keiser[1], A. Nealen[2], M. Pauly[3], M. Gross[1] and M. Alexa[2]

[1] Computer Graphics Lab, ETH Zürich

[2] Discrete Geometric Modeling Group, TU Darmstadt

[3] Stanford University

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Discussion

- FFD
  - Simple, easy, fast
  - Does not take into account the natural way in which shapes features are controlled.
- Skeleton-based deformation
  - Intuitive control
  - Appropriate weight selection is a painful process
- Physically-based simulations
  - Mass-spring
    - Simple, fast, suited for parallel computation
    - Tuning spring constants are not always easy
    - Certain constraints not naturally expressed. eg. incompressibility
- FEM: computational expensive
- Gradient Domain methods
  - Conversion to linear problem causes sub-optimal solution

- Validation of physically accurate deformation
  - surgical simulation
- Real-time performance
- User Interaction
- Integration into broader simulation contexts
  - Interaction with objects, environment, human, etc.