中国科学技术大学
University of Science and Technology of China

GAMES 102在线课程

几何建模与处理基础

刘利刚
中国科学技术大学

中国科学技术大学

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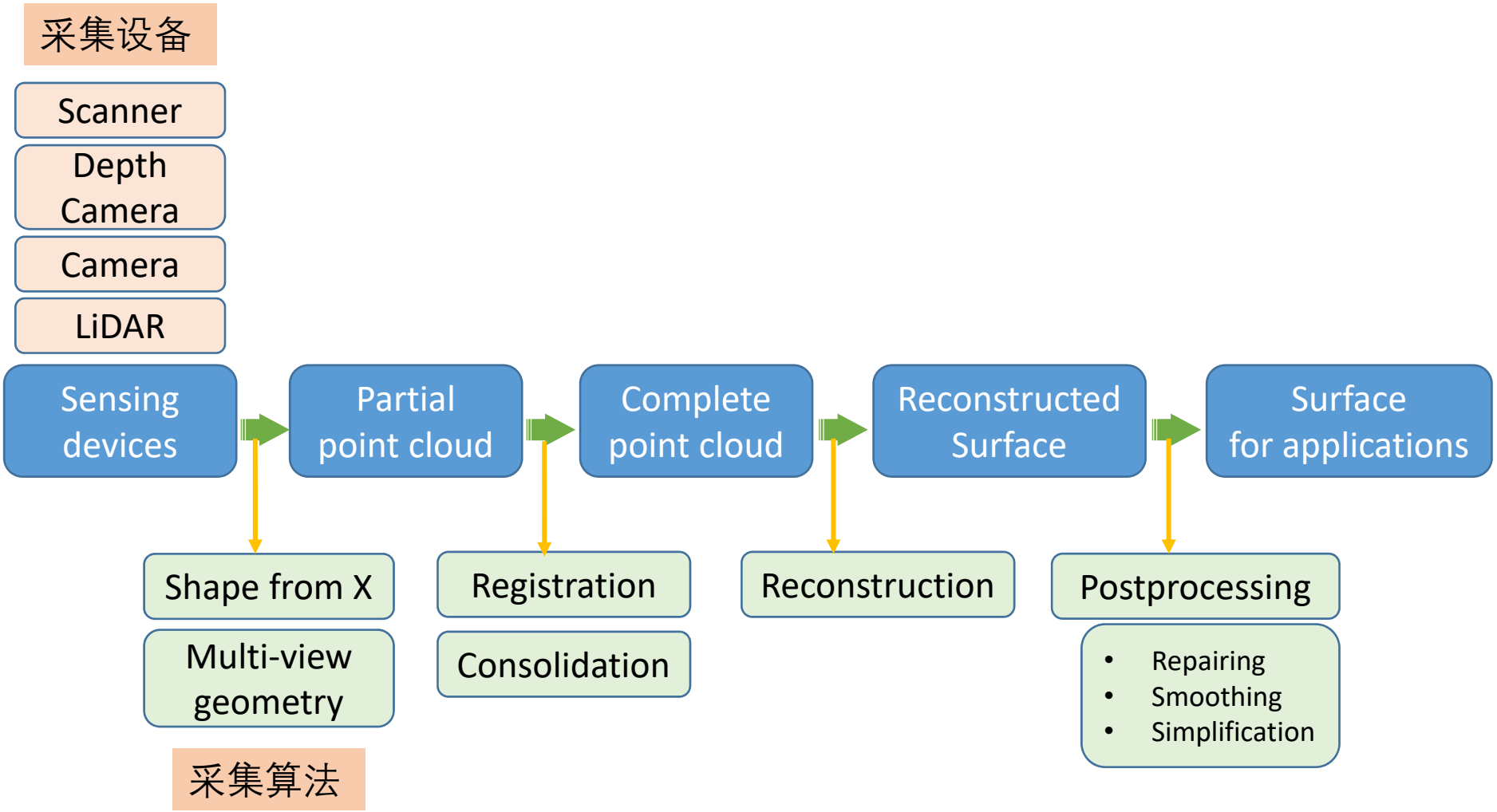
GAMES 102在线课程：几何建模与处理基础

几何建模

回顾：曲面重建


采集设备
Scanner
Depth Camera
Camera
LiDAR
Sensing devices
Partial point cloud
Complete point cloud
Reconstructed Surface
Surface for applications
Shape from X
Multi-view geometry
Registration
Consolidation
Reconstruction
Postprocessing
Repairing
Smoothing
Simplification
采集算法

建模(modeling)：设计与重建

- 曲面设计(Design)
  - 不存在的物体：通过人工交互凭空设计出新的物体
    - CAGD (NURBS)、mesh modeling
  - 存在的物体：通过人工交互编辑修改构建出新的物体
    - Editing, deformation
- 曲面重建(Reconstruction)
  - 存在的物体：对其采集并进行数字化构建
  - 也称为：逆向工程、扫描重建
    - Reverse engineering, scanning

Design Modeling

- Design from zero
  - Create a shape by a set of 3D design operators such as extrusion or revolution etc.

- Design from a given shape
  - Select a base shape
  - Select editing elements and editing operators
  - Deform the shape to obtain a new shape

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- Design from a given shape
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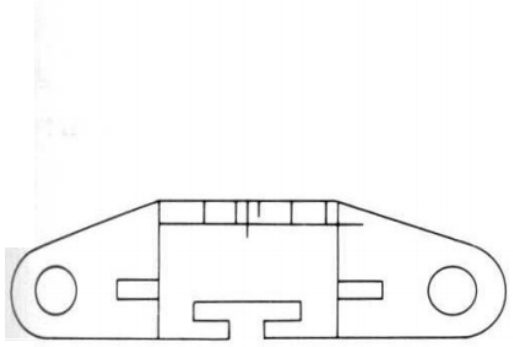
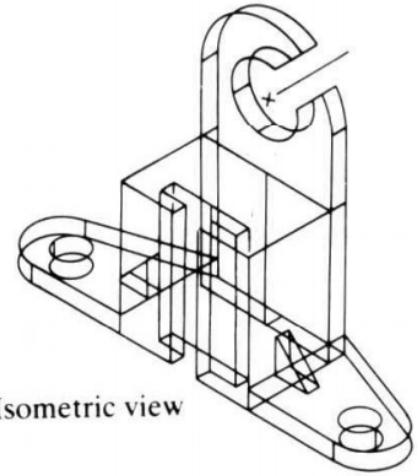
Geometric Modeling Techniques

- Wireframe Modeling
- Surface Modeling
  - Analytical Surface
  - Free-form, Curved, Sculptured Surface
- Solid Modeling Solid Modeling
  - Parametric Modeling
  - Feature Based Modeling
  - Constructive Solid Geometry (CSG)
  - Boundary Representation (B-Rep)

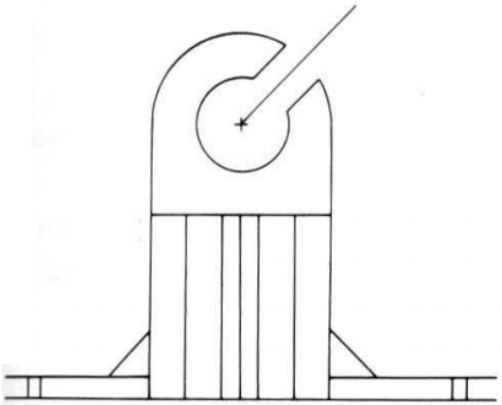
Wireframe Modeling （工程制图）



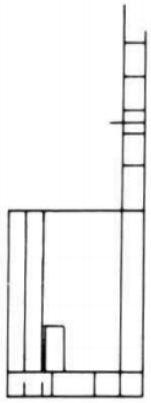
Top view



Isometric view

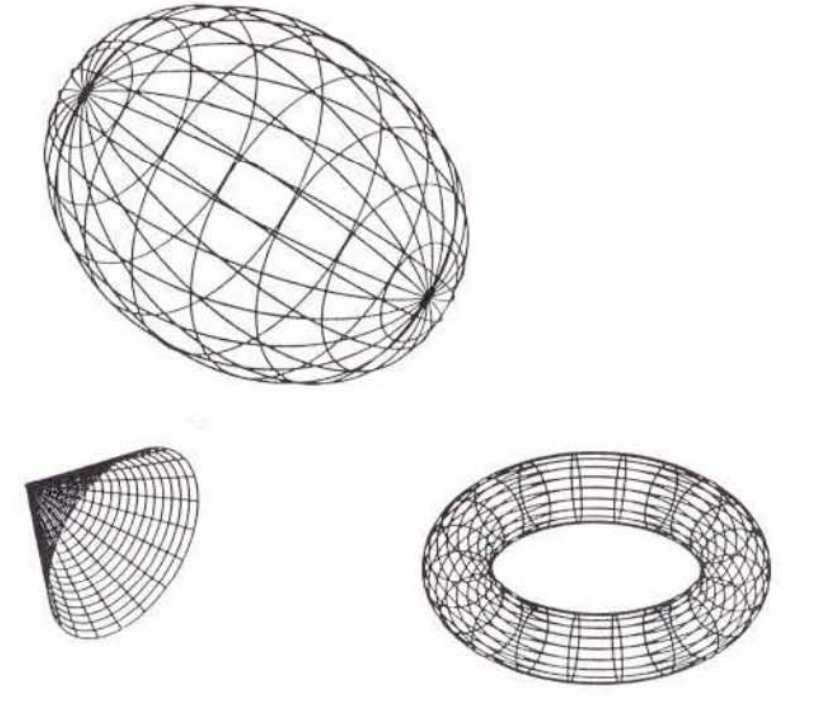


Front view

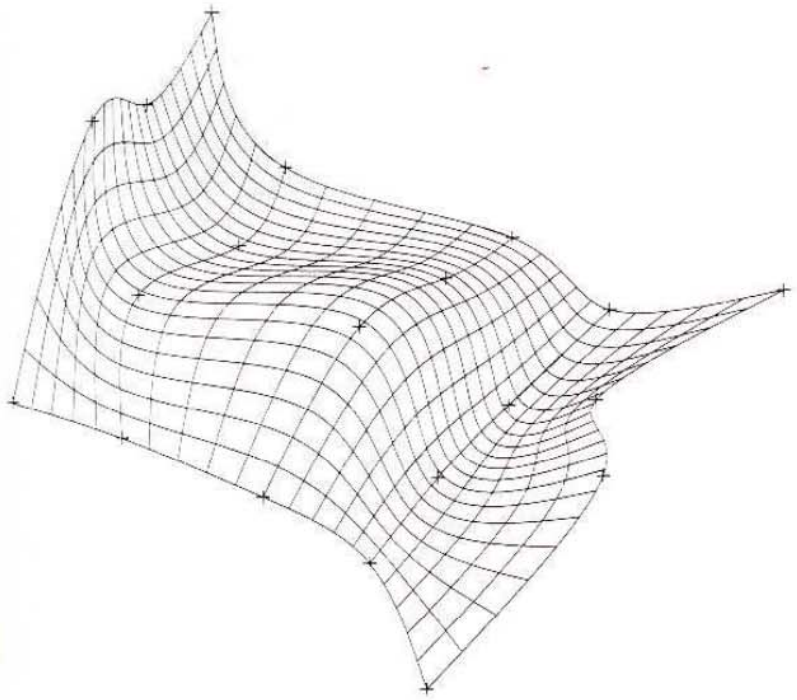


Right view

Surface Modeling (NURBS)



Analytical Surfaces



Free-form, Curved, or
Sculptured Surface

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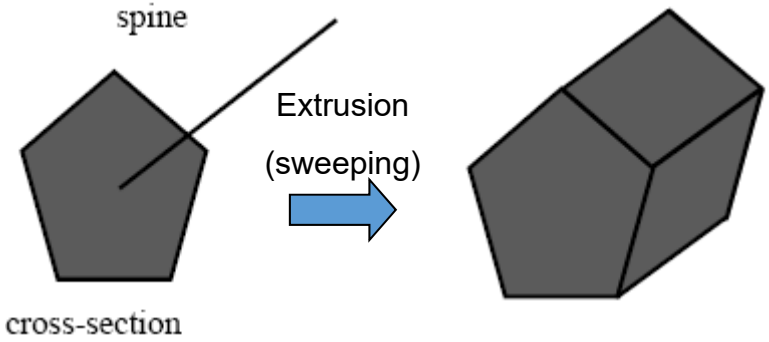
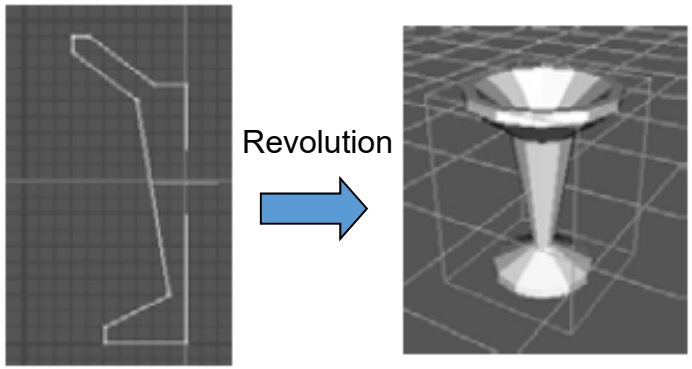
Solid Modeling

Solid Modeling

- Modeling by a set of geometric operators
  - Geometric operators: extrusion, revolution, sweeping, lofting, etc.
  - Parametric: various semantic parameters
  - Feature-based: various components such as holes, grooves, fillets, and chamfers.





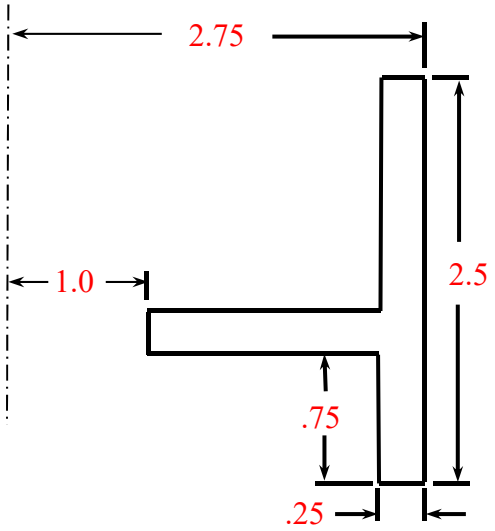
- Commercial software
  - SolidWorks, Creo (PTC), Inventor & Fusion 360 by Autodesk, Unigraphics, Catia, …..

Concepts of Parametric Modeling

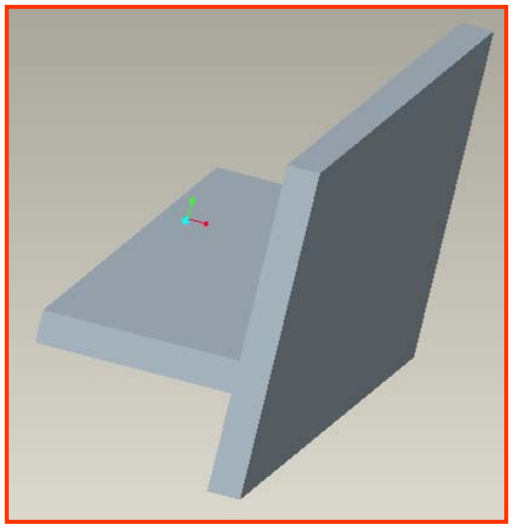
- Sketching
  - Take the word sketch literally. A sketch should be just that, a sketch.
  - When sketching it is not necessary to create geometry with accuracy. Lines, arcs, and additional geometry need not be created with exact dimensions in mind.
- Dimensioning
  - When dimensions are added, the sketch will change size and shape. This is the essence of Parametric Modeling.
- Features
  - Create a 2D sketch and dimension it.
  - Create a feature from the sketch by extruding, revolving, sweeping, and lofting.

Extruding and revolving

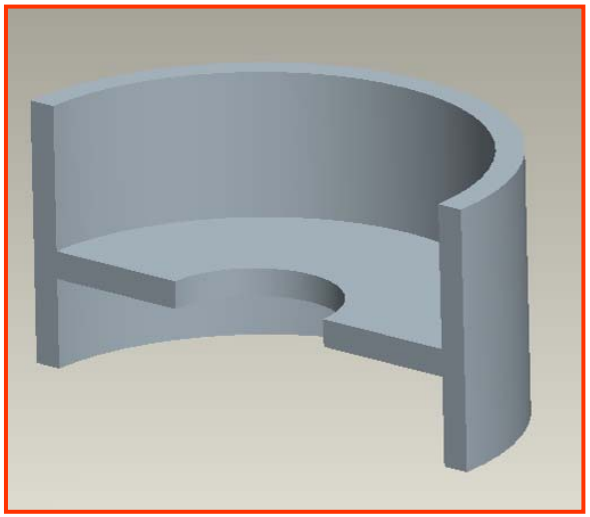
- Extrusion: 平移，沿直线段挤出（扫掠sweeping）
- Revolution: 旋转曲面，沿圆弧挤出



Sketching: profile



Extruding

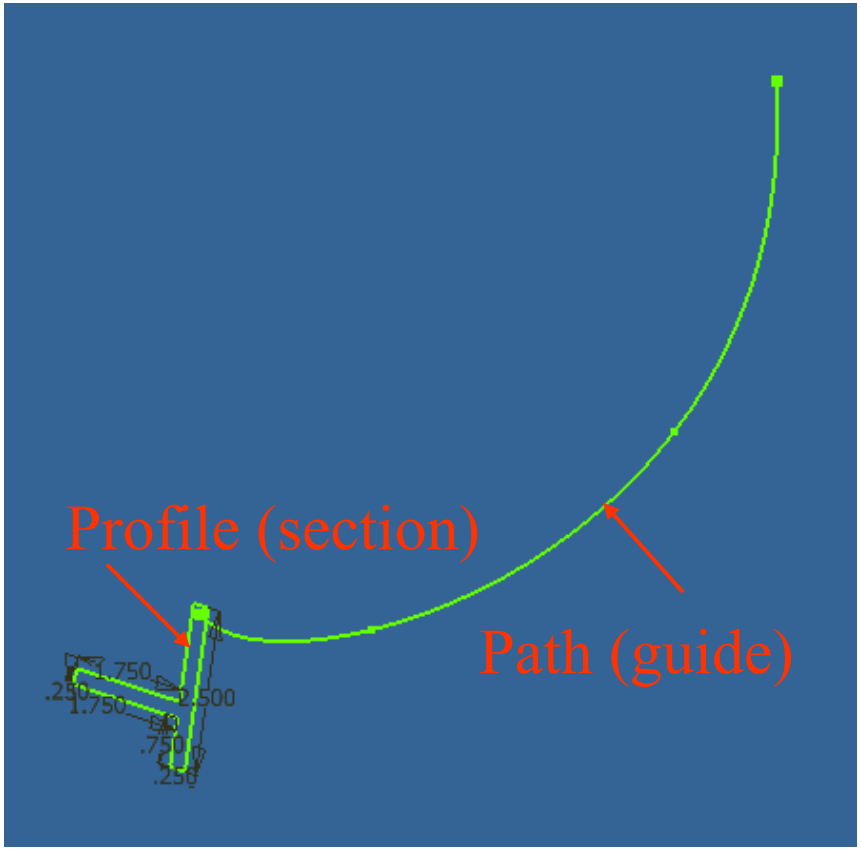


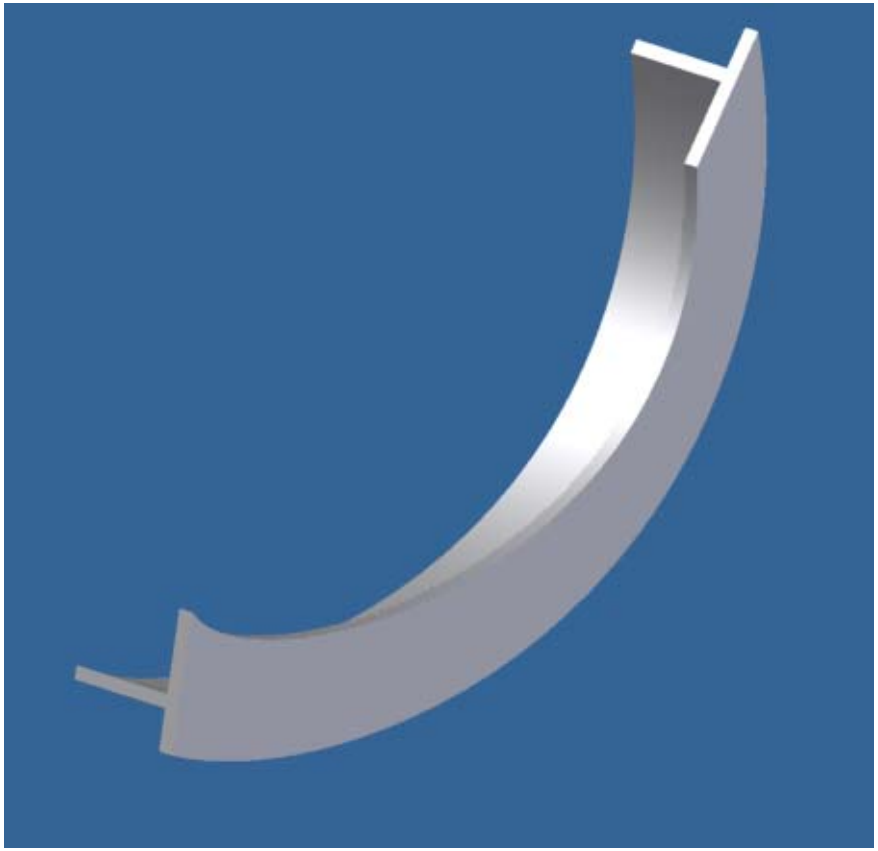
Revolving

Courtesy of Ken Youssefi

Sweeping

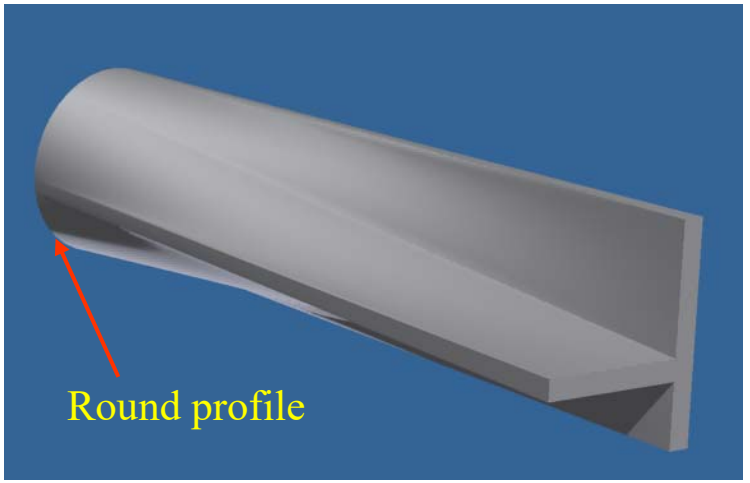
- A sweep feature requires a profile and a path. The profile will follow the path to create the solid.

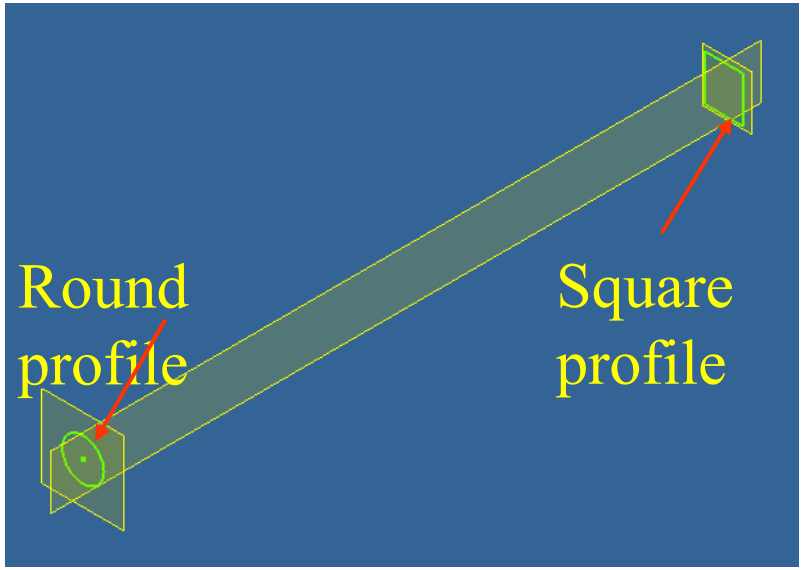


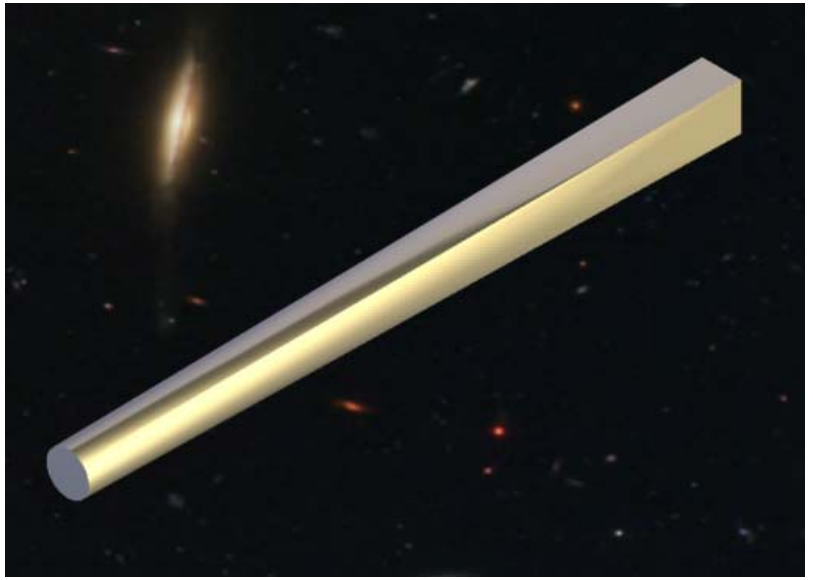


Lofting

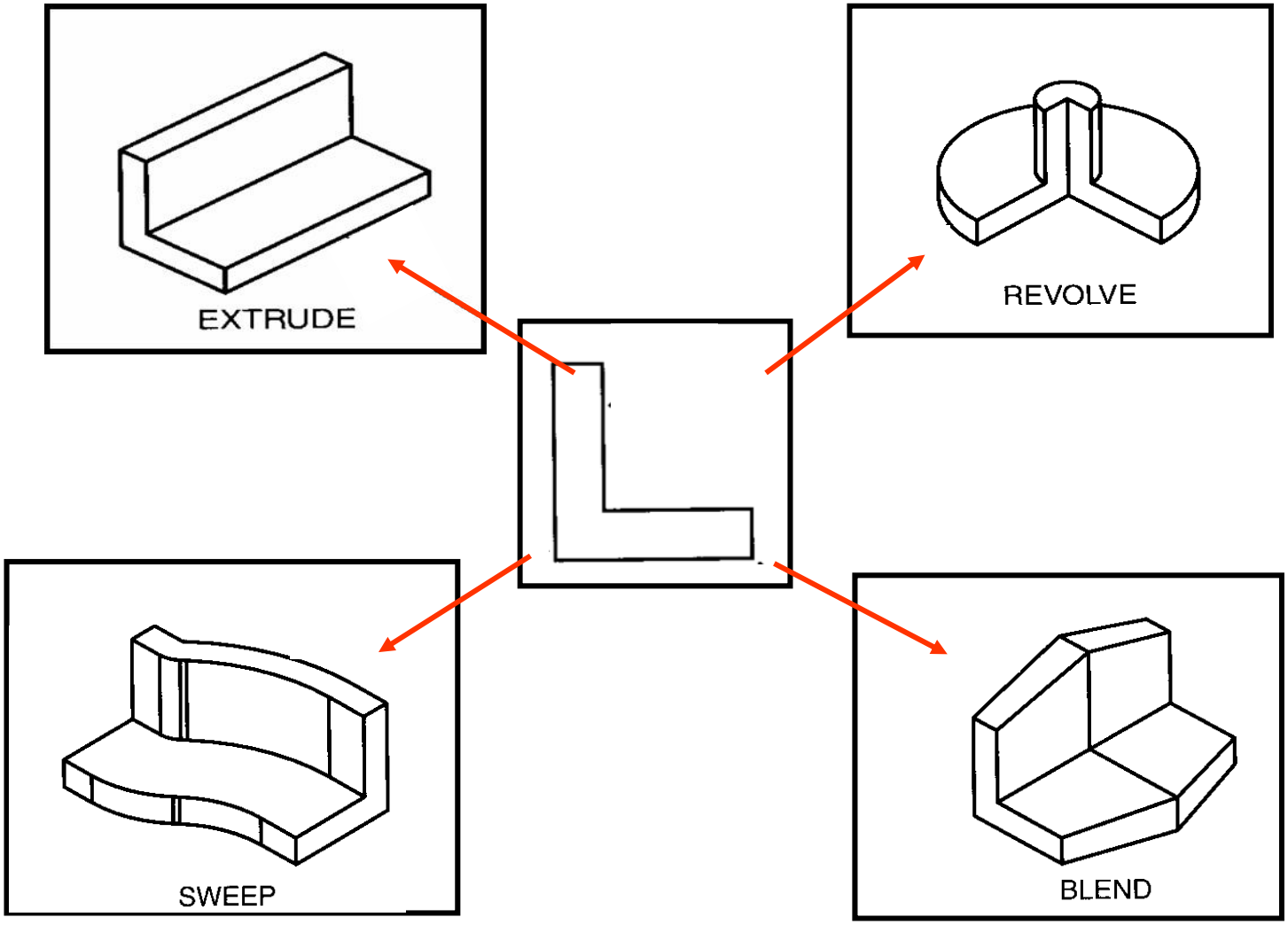
- Sweeping with different profiles
  - Sections (profiles) do not have to be sketched on parallel planes
  - All sections must be either closed or open







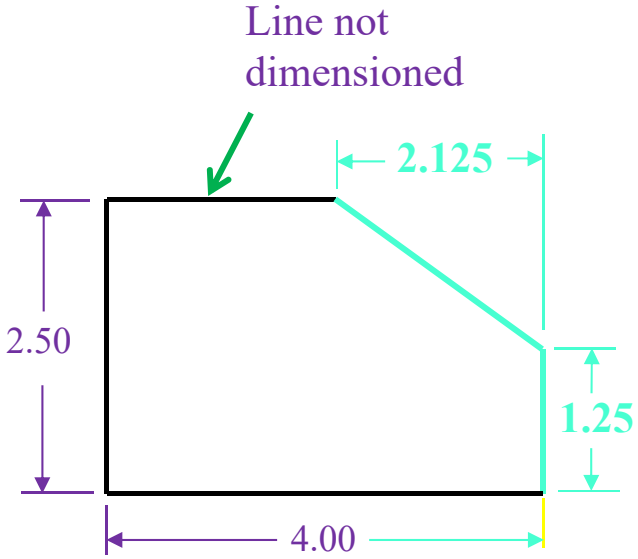
Creating Features from Sketches

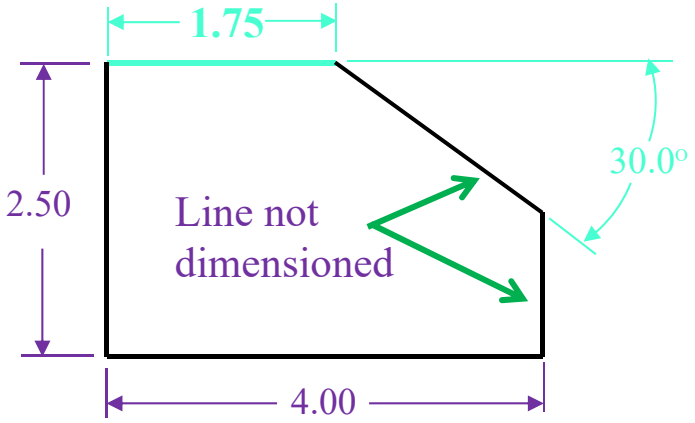


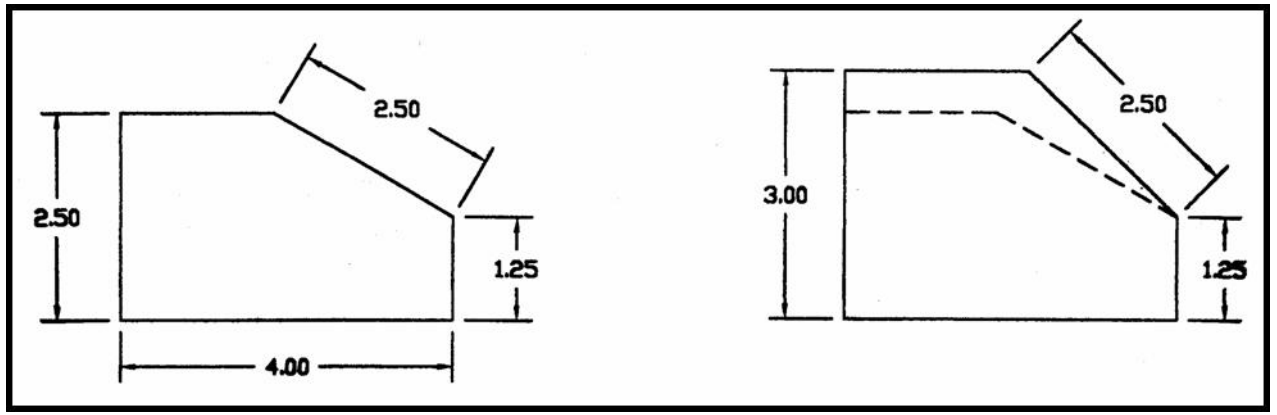
Loft in SolidWorks

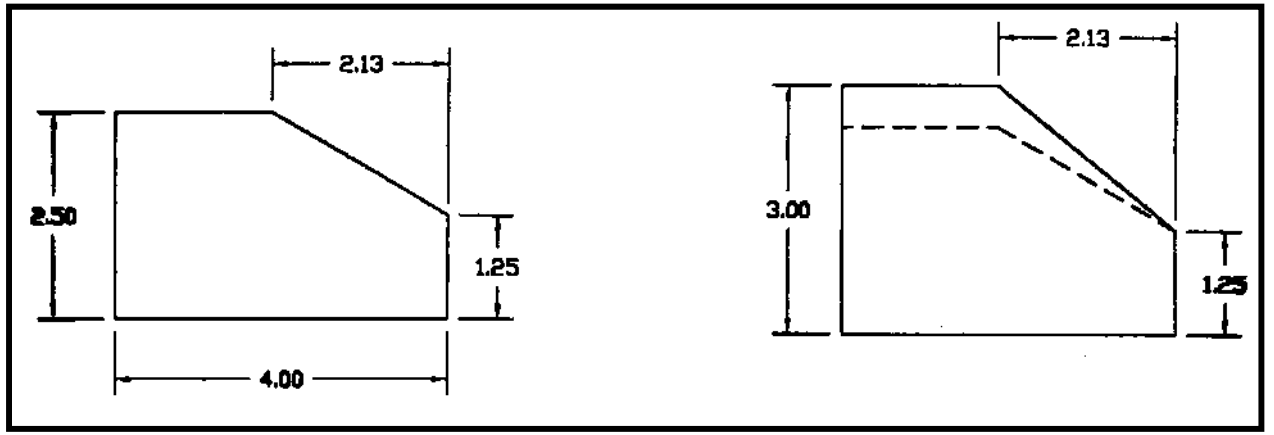
Design Intent (constraints)

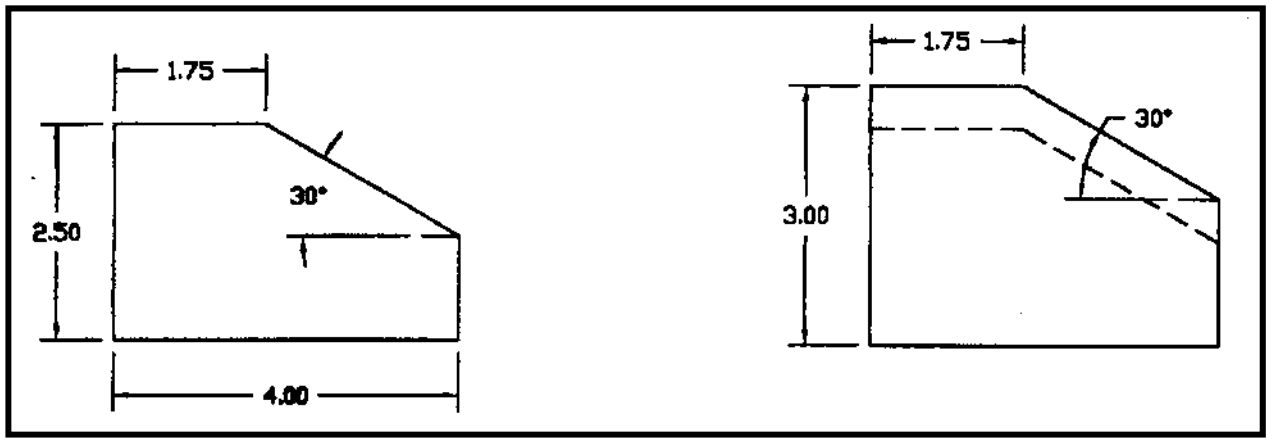
- How your model will react when dimension values are changed?





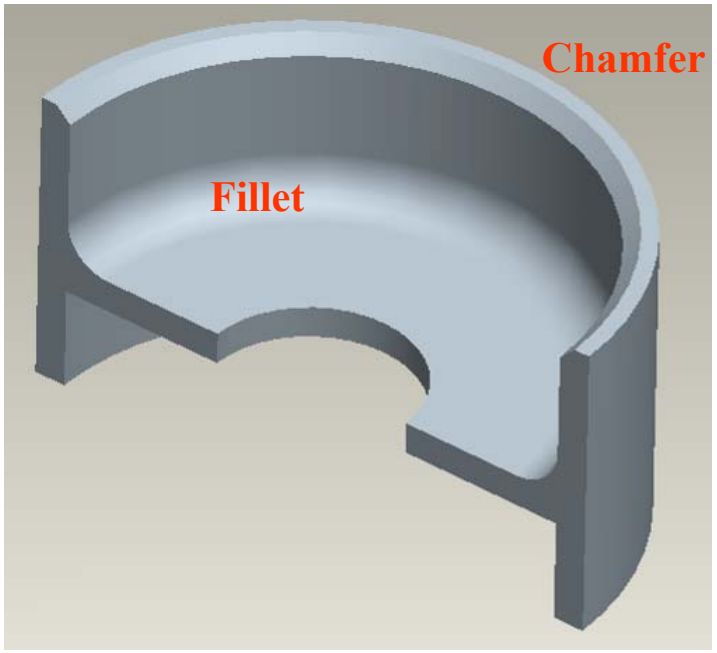

2.50
2.50
1.25
4.00
2.50
3.00
1.25

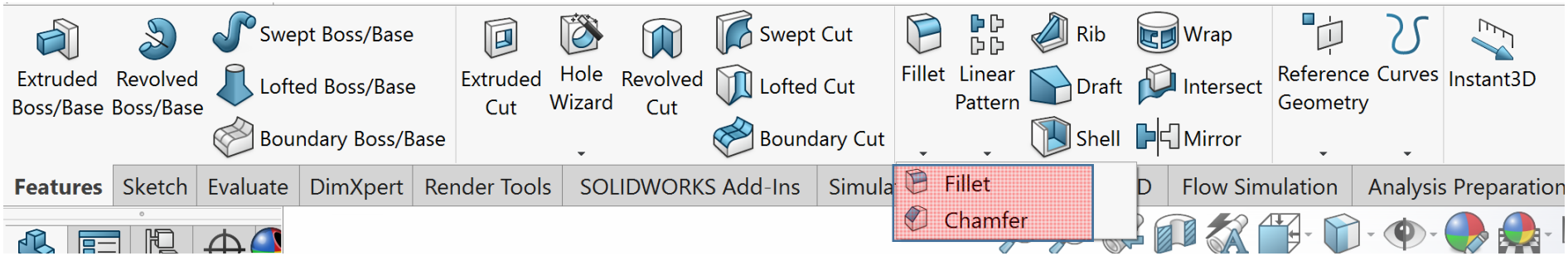

2.13
2.50
1.25
4.00
2.13
3.00
1.25


1.75
30°
2.50
4.00
1.75
30°
3.00

Applied Feature: Chamfer and Fillet

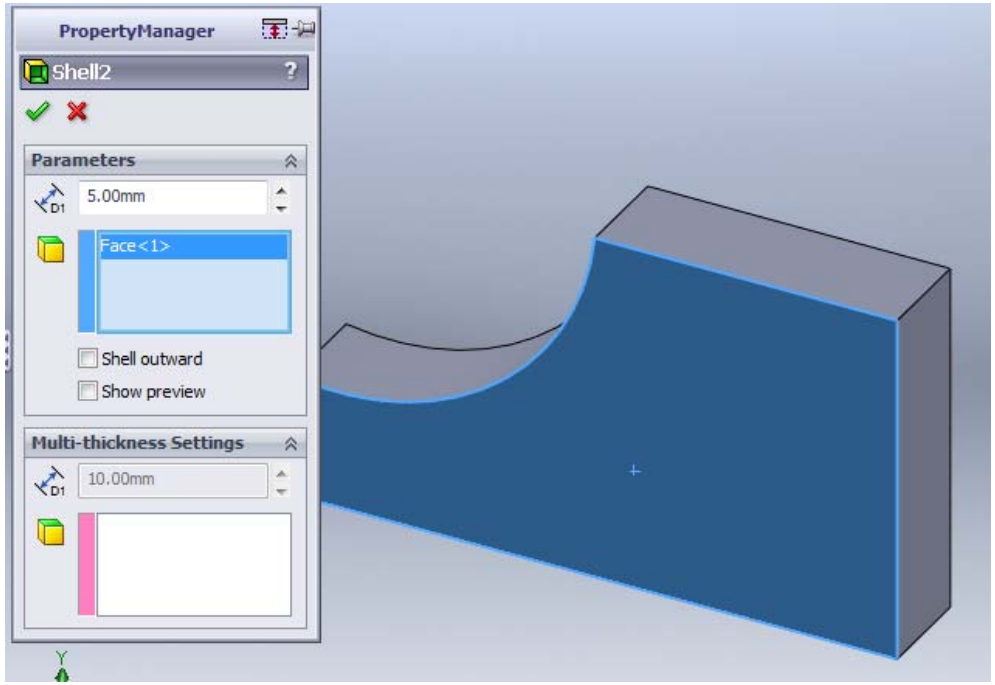
- Applied feature does not require a sketch.
- It is applied directly to the model.

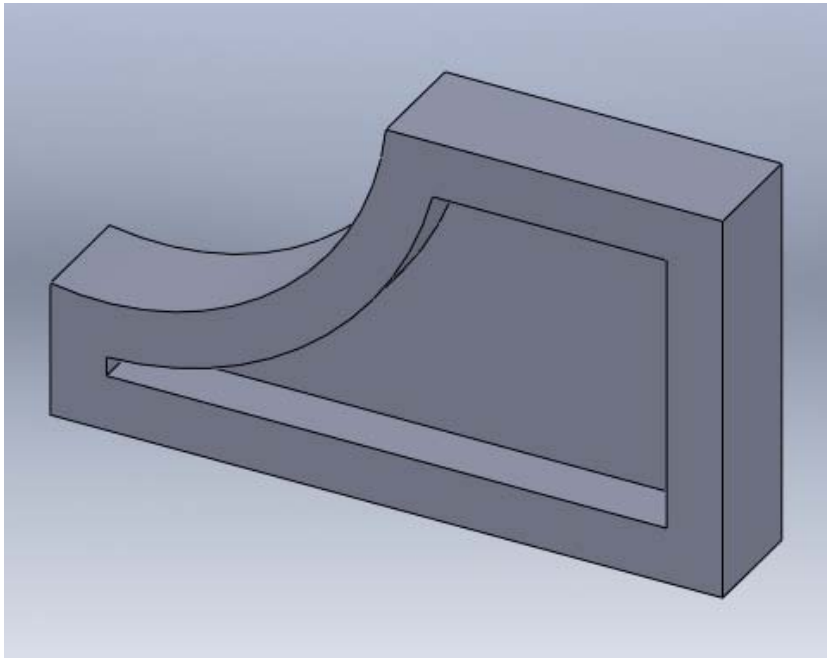


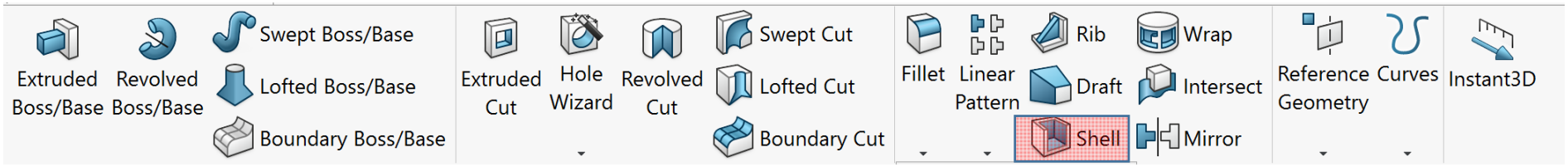


Applied Feature: Shell

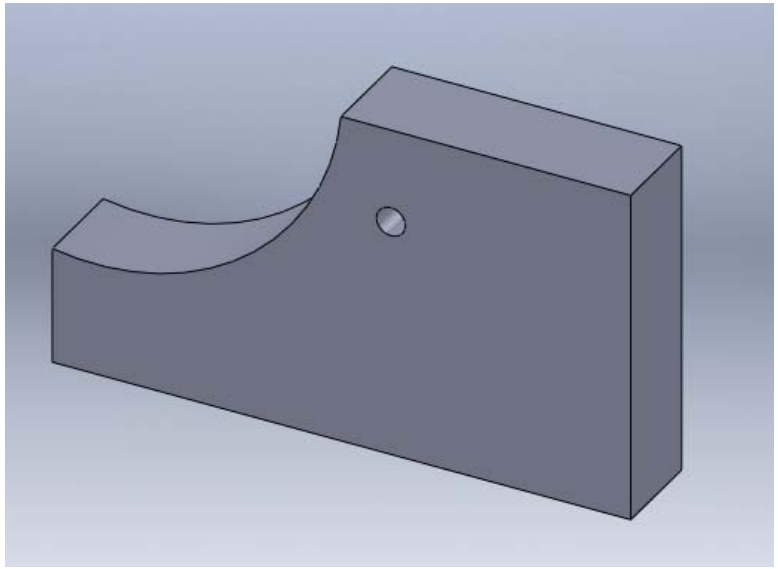
- Shell – hollowing out a solid



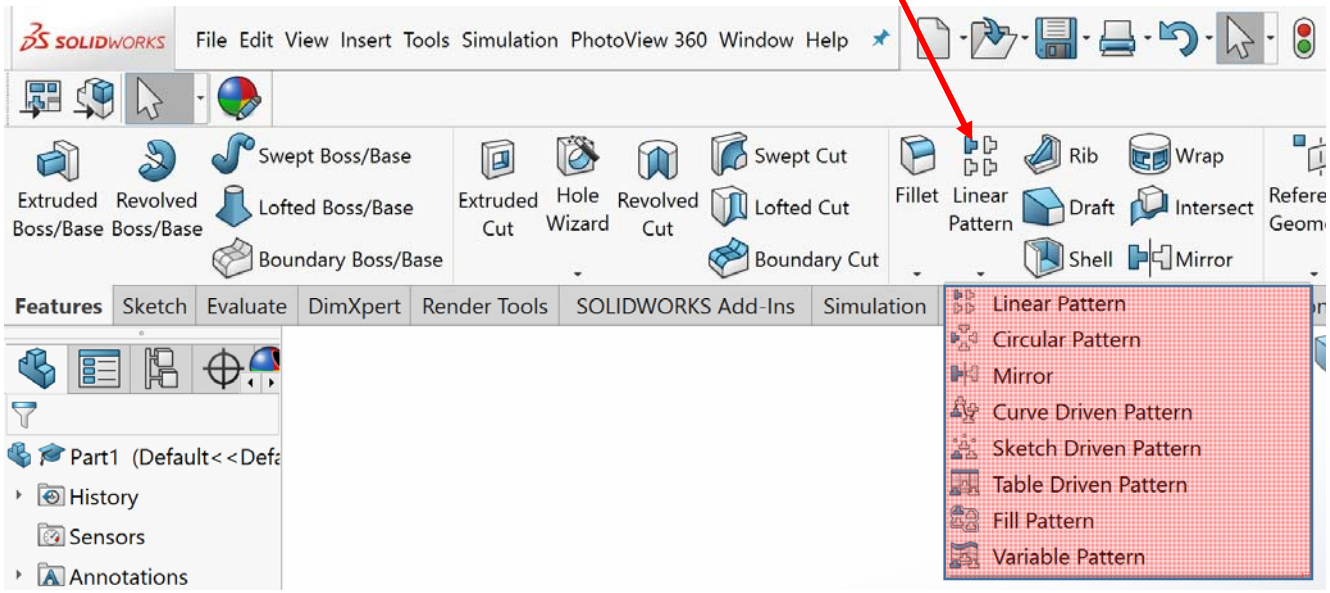




Applied Feature: Patterns



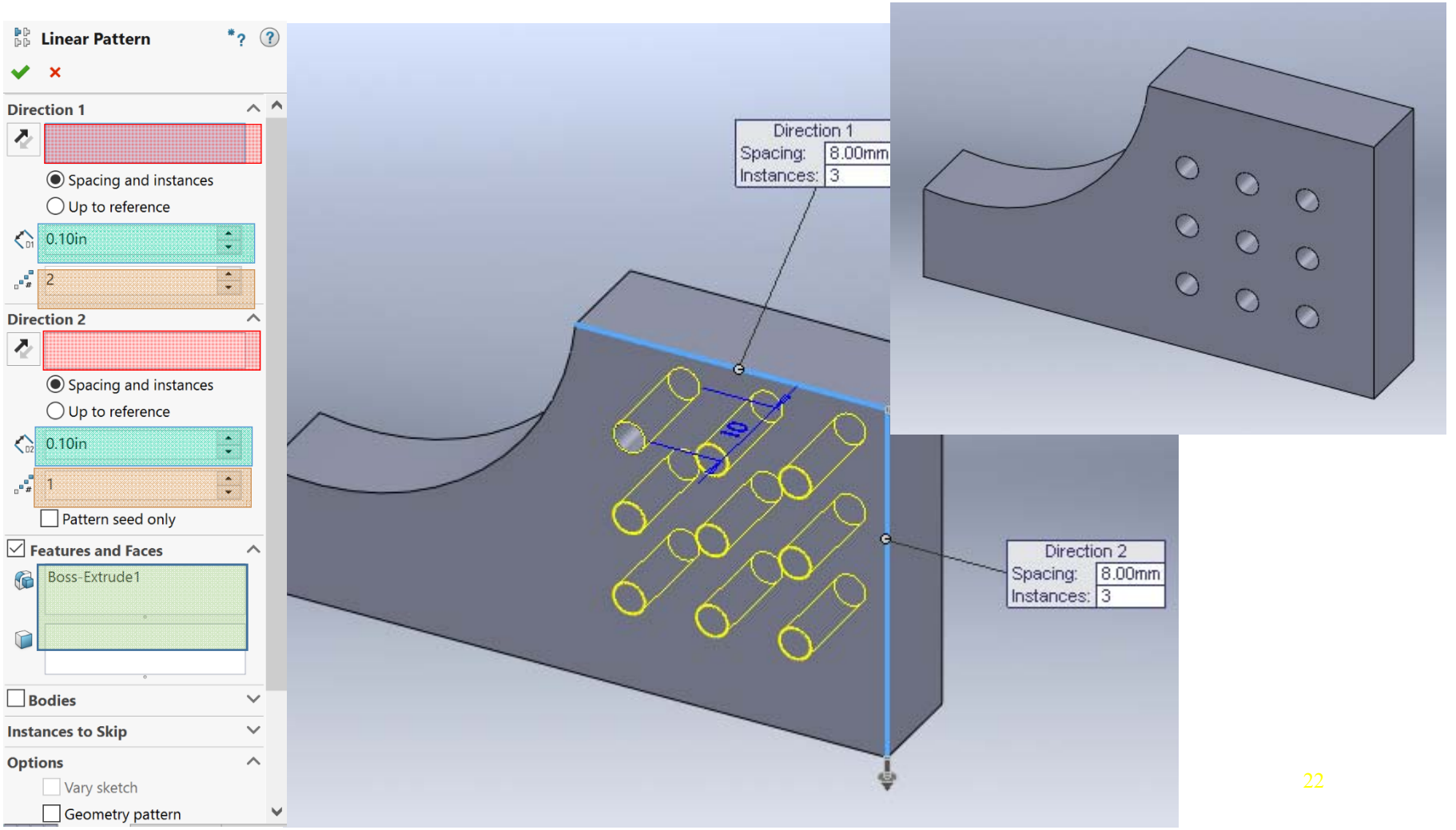
Linear (rectangular) pattern



Applied Features - Patterns

Linear (rectangular) pattern

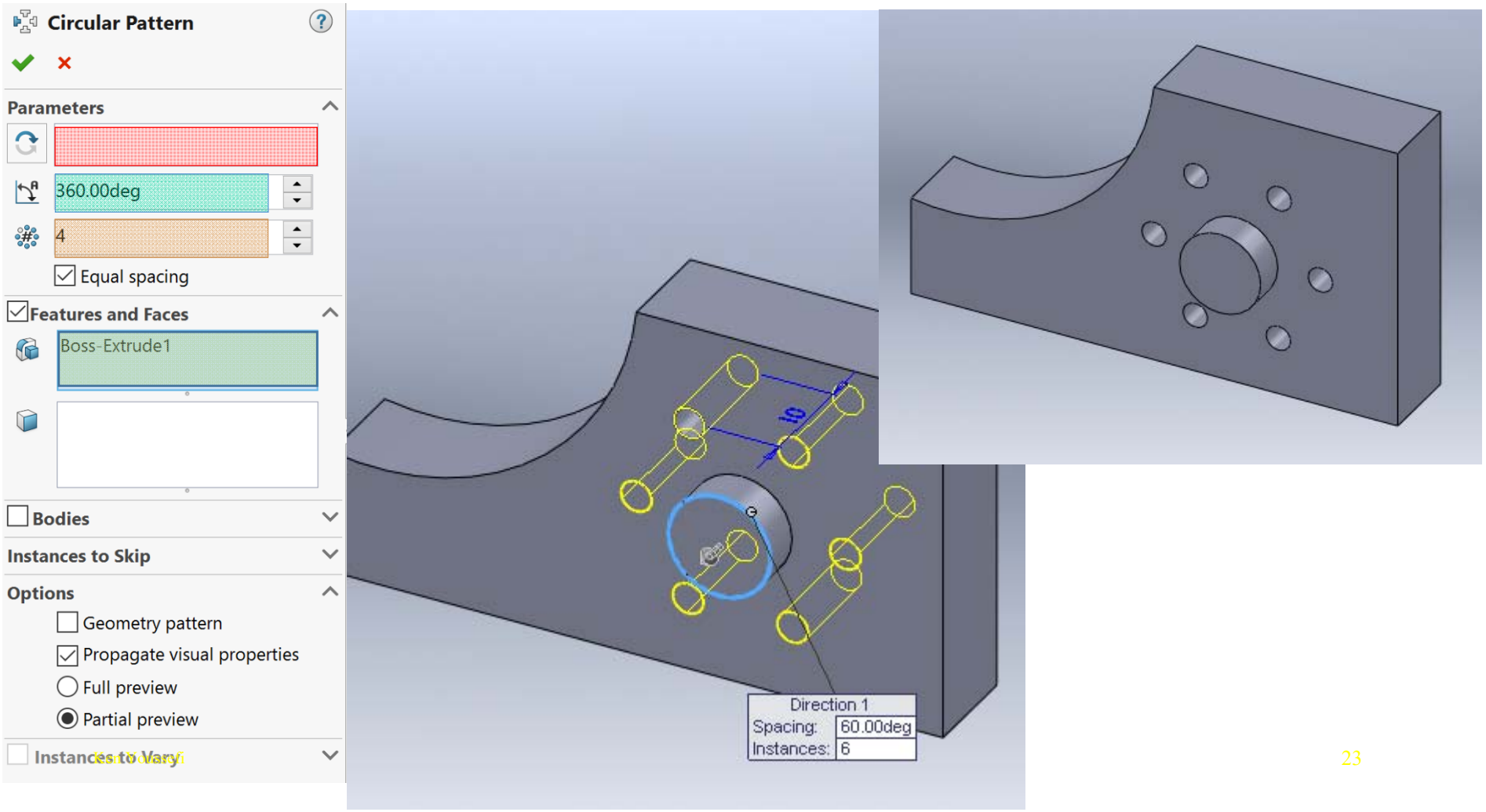
1. Select direction 1 and 2
2. Select spacing in dir. 1 and 2
3. Select # of features in dir. 1 and 2
4. Select feature to pattern



Applied Features - Patterns

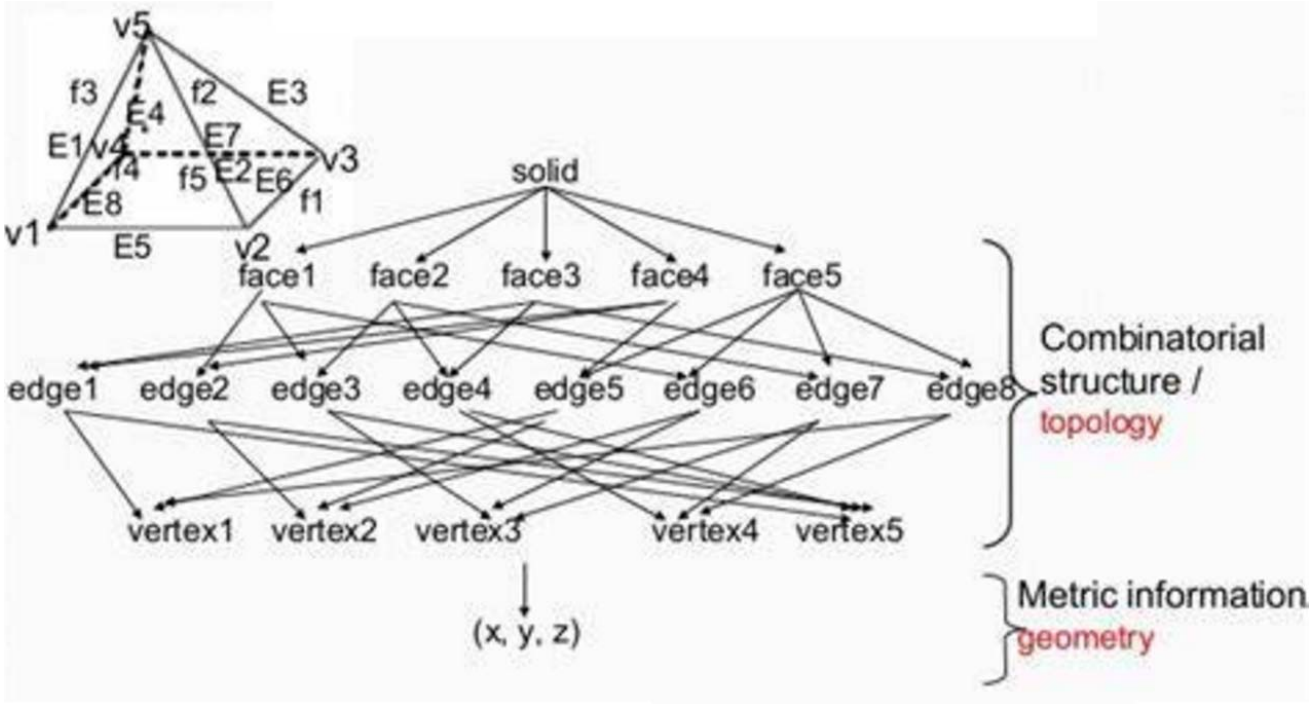
Circular (polar) pattern

1. Select axis of rotation
2. Select spacing between features
3. Select # of features
4. Select feature to pattern



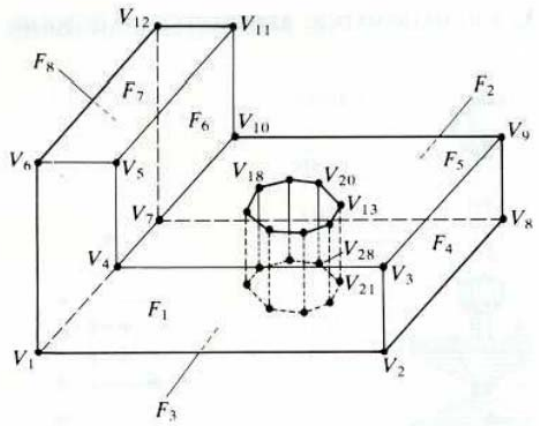
Boundary Representation (B-Rep) Modeling

- BREP defines an object by their spatial boundaries.
  - Topology: faces, edges, and vertices.
  - Geometry: surfaces, curves, and points.
- Data structure: 0bject list, surface list, polygon list, boundary list, line list, point list...

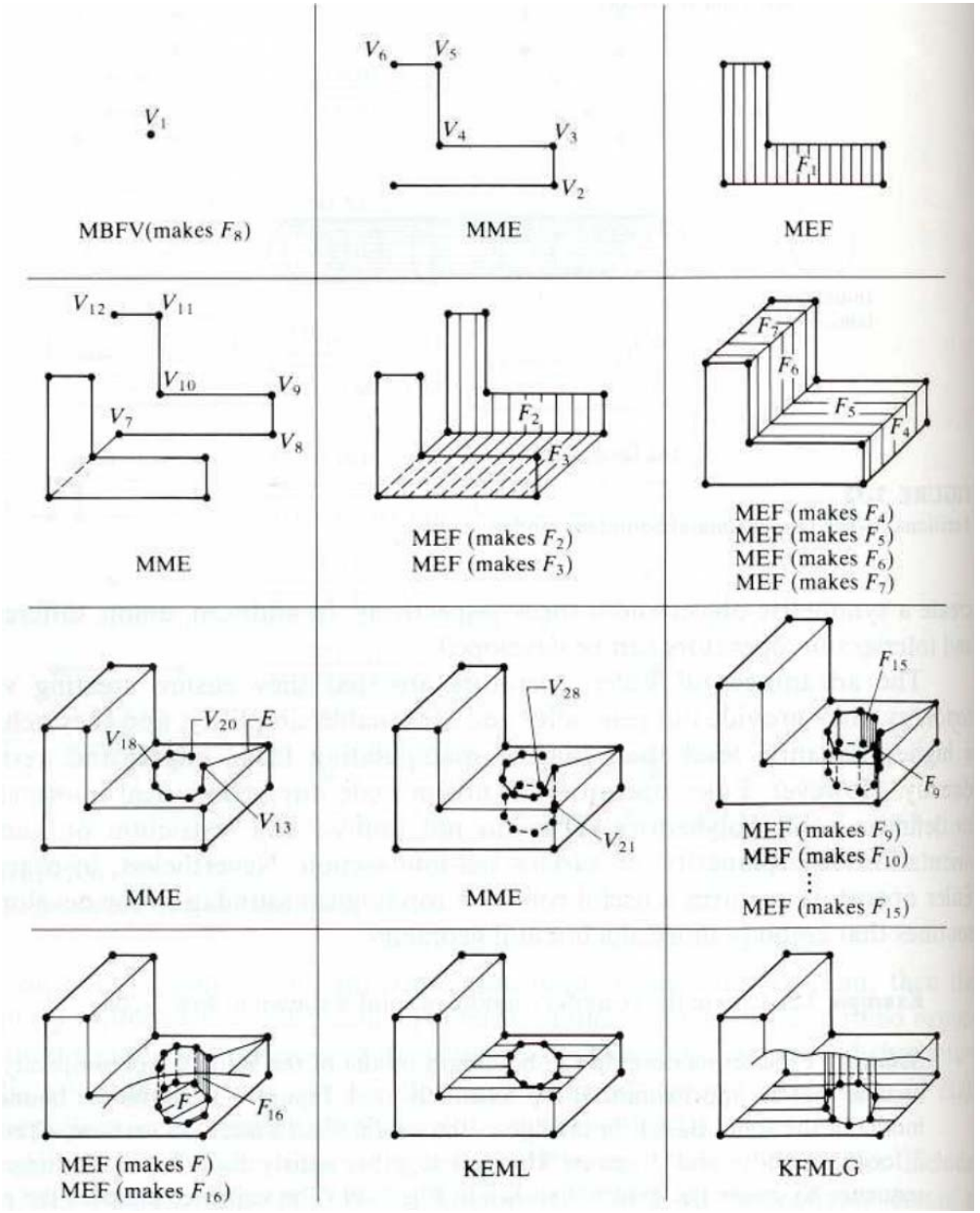


B-Rep

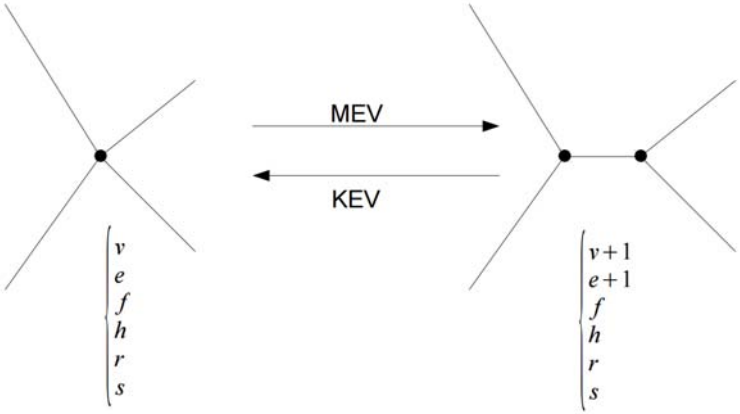
- Euler operators
  - MBFV: Make body, face, vertex
  - MME: Make multi edges
  - MEF: Make edge, face
  - KEML: Kill edge, make loop
  - KFMLG: Kill face, make loop, genus
- Validity Check: V – E + F = 2

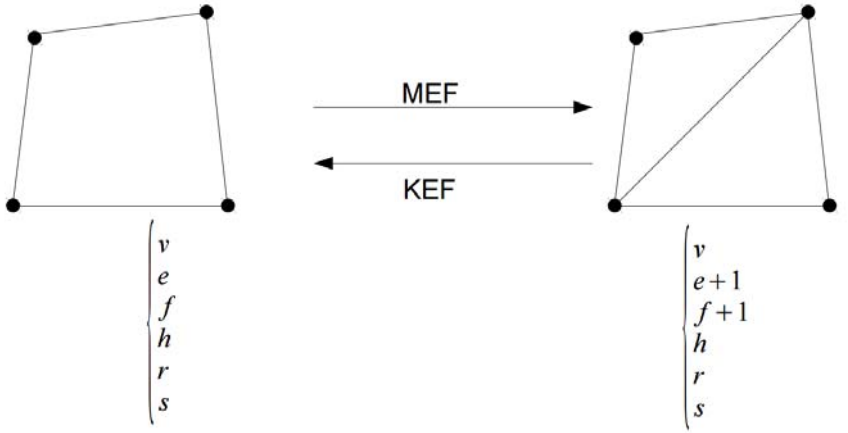


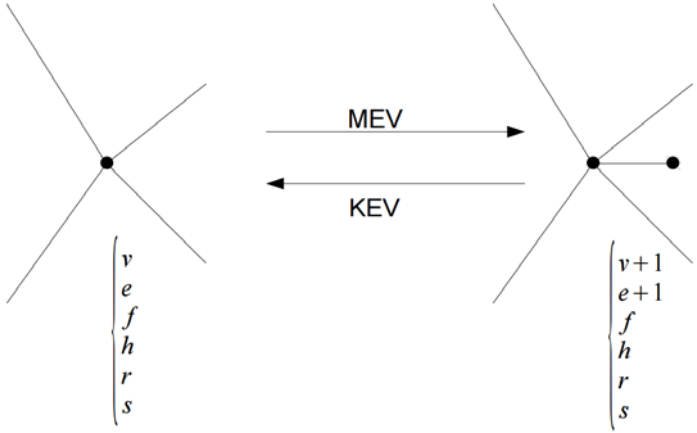
Body, Face, Polygon
(Edge Loop), Edge, Vertex

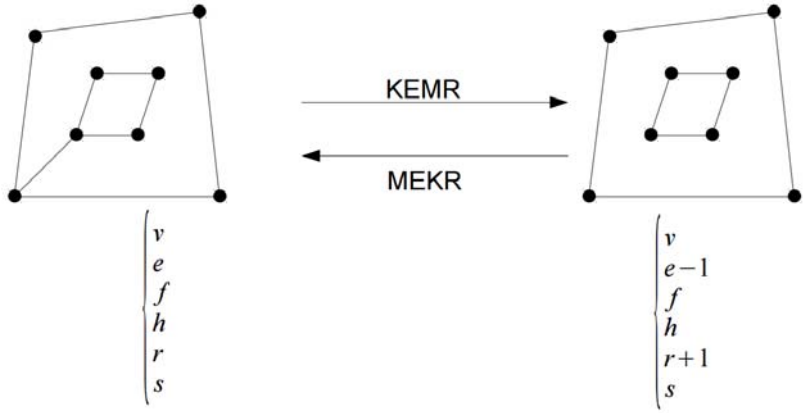


Examples of Euler Operators



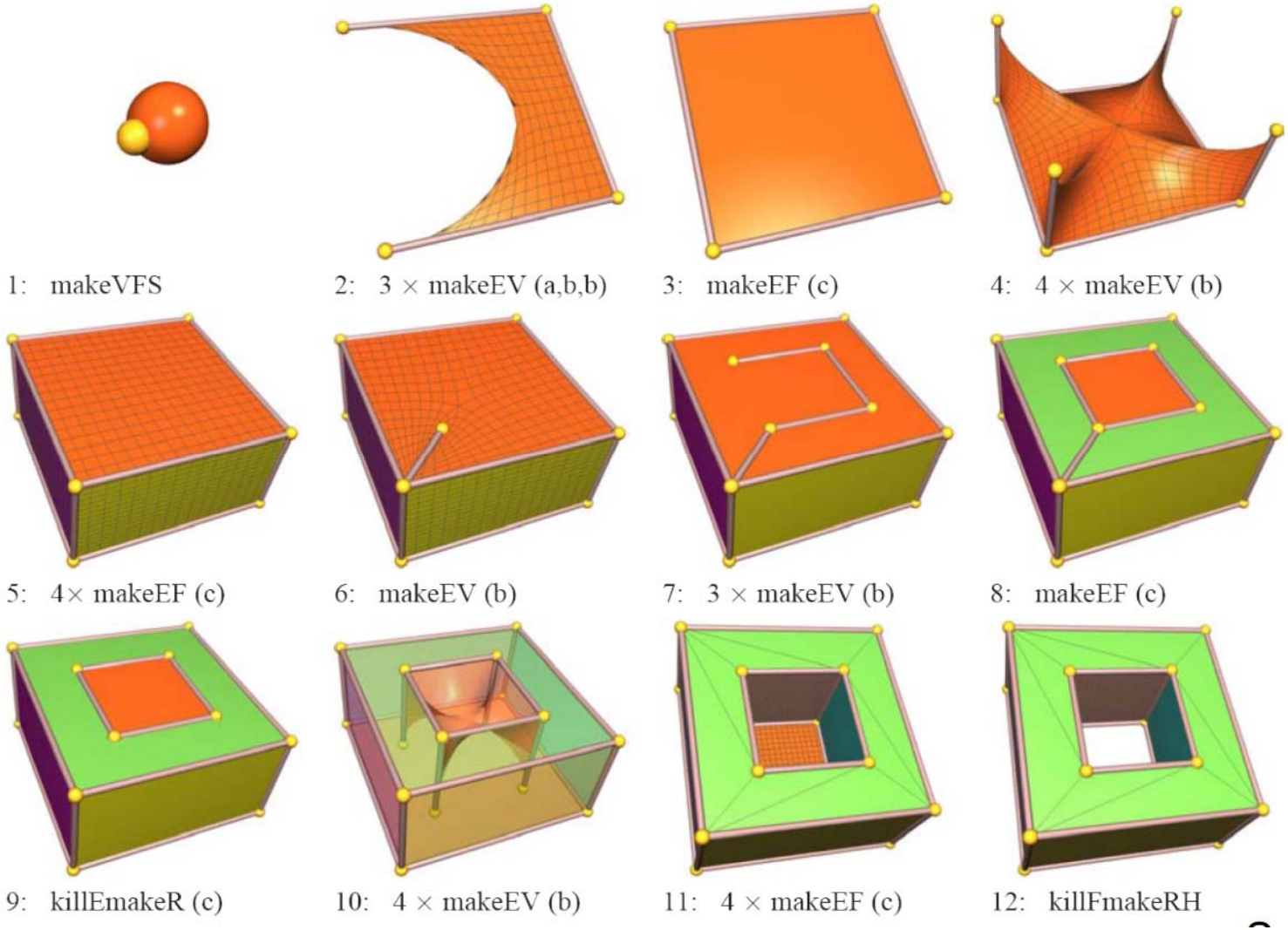






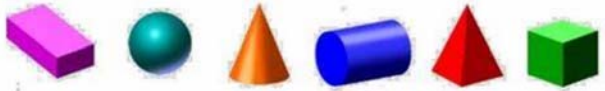
http://www.cgeo.ulg.ac.be/CAO/CAD_07.pdf

Modeling Example of using Euler operators

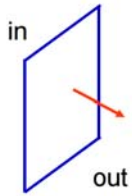


Constructive Solid Geometry (CSG) Modeling

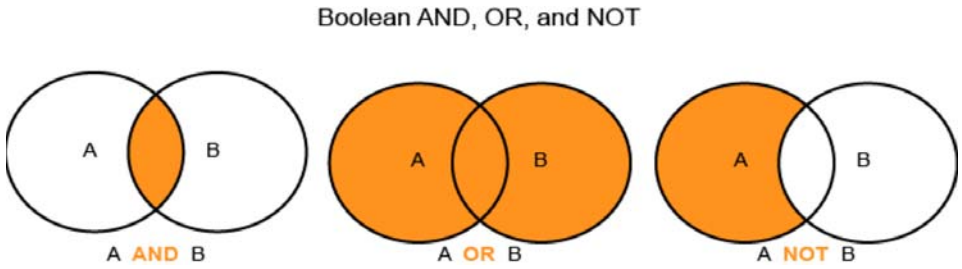
- Predefined primitive objects: cuboids, cylinders, prisms, pyramids, spheres, and cones.

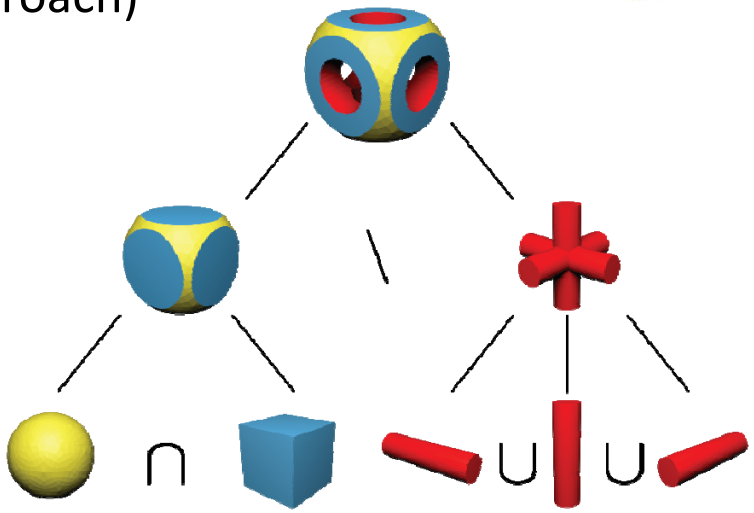


- Boolean operations: union, intersection, difference (subtraction)
- Two types
  - Primitive based CSG: It is a popular CSG scheme which is based on bounded solid primitives, R-sets.
  - Half-space based CSG: This CSG scheme uses unbounded **half-spaces**.

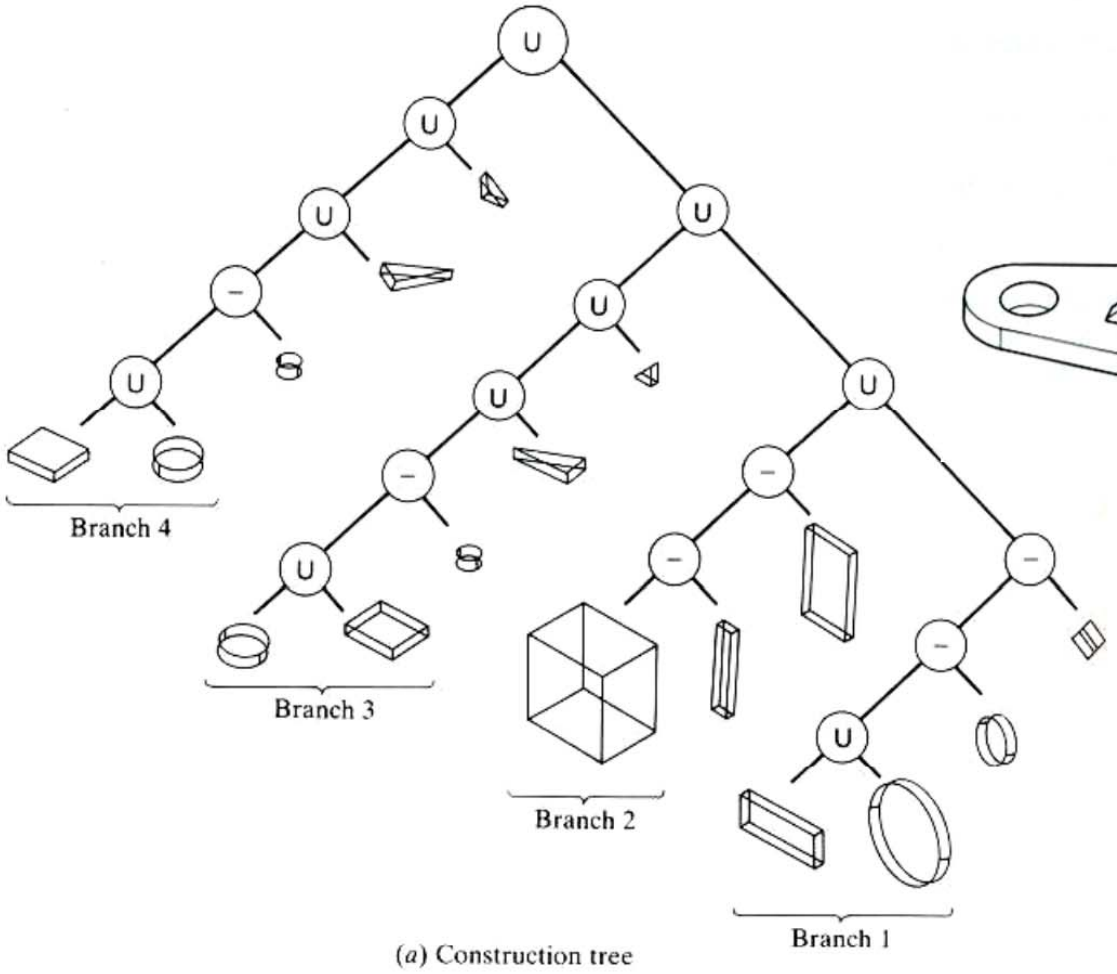


- CSG tree structure (building process/approach)

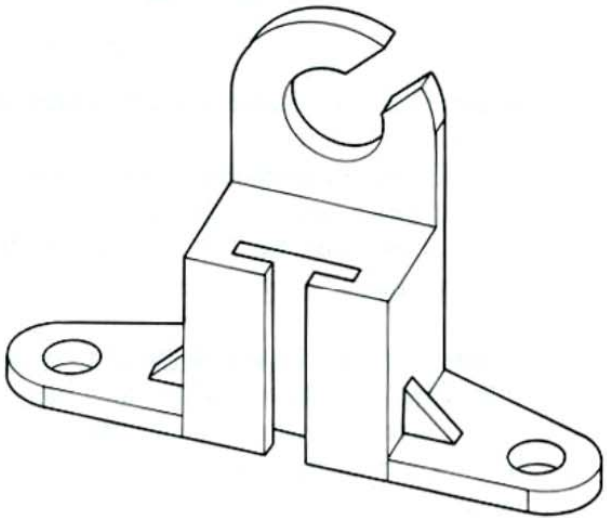




A CSG model



(*a*) Construction tree

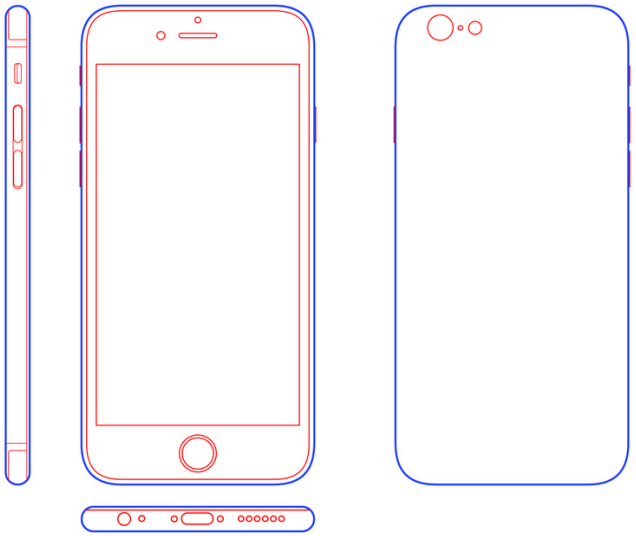


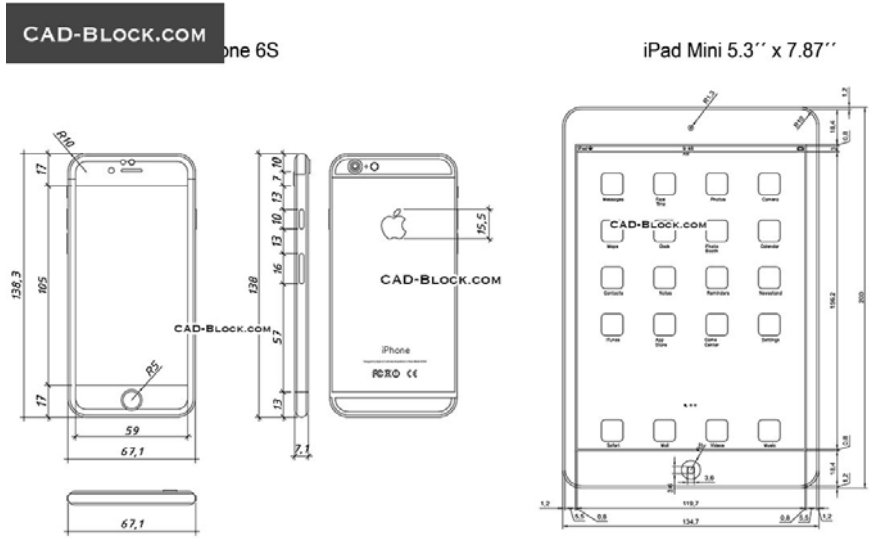
A lengthy, lousy process

B-Rep VS. CSG

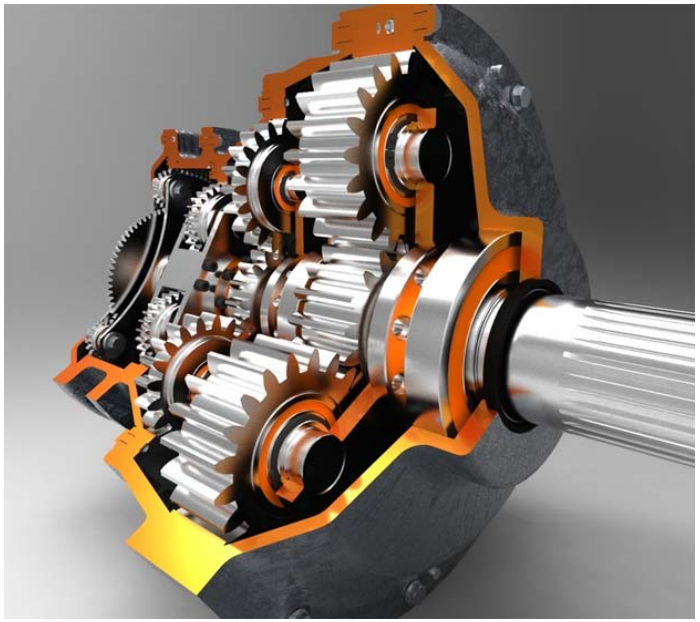
Boundary Representation (BREP)	Constructive Solid Geometry (CSG)
BREP describes only the oriented surface of a solid as a data structure composed of vertices, edges, and faces.	A solid is represented as a set of Boolean expression of primitive solid objects, of a simpler structure.
A BREP object is easily rendered on a graphic display system.	A CSG object is always valid in the sense that its surface is closed and orientable and encloses a volume, provided the primitives are authentic in this sense.
For B-rep, we review the possible surface types, the winged-edge representation schema, and the Euler operators.	For CSG, The basic operations include classifying points, curves, and surfaces concerning a solid; detecting redundancies in the representation; and approximating CSG objects systematically.

CAD Design Example

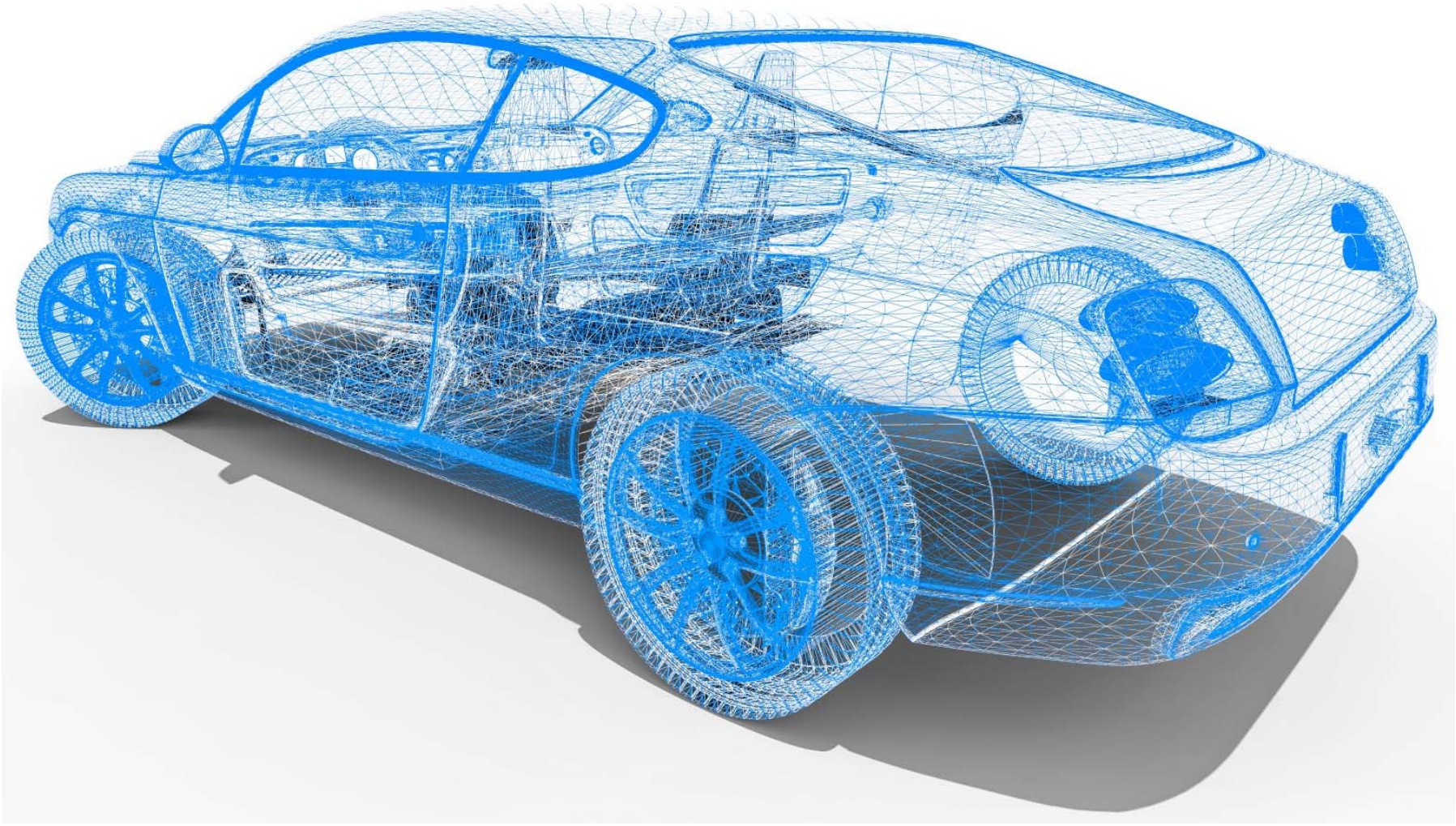




Examples of CAD models



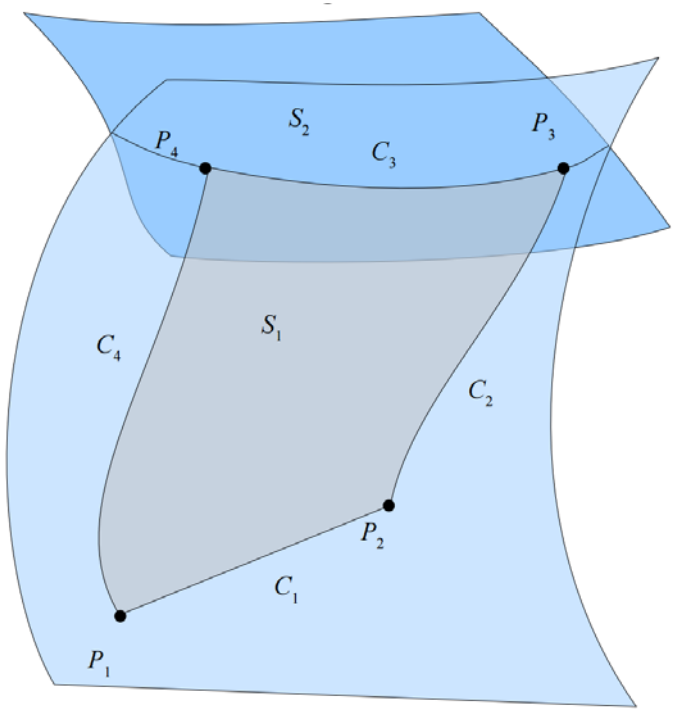
Examples of CAD models

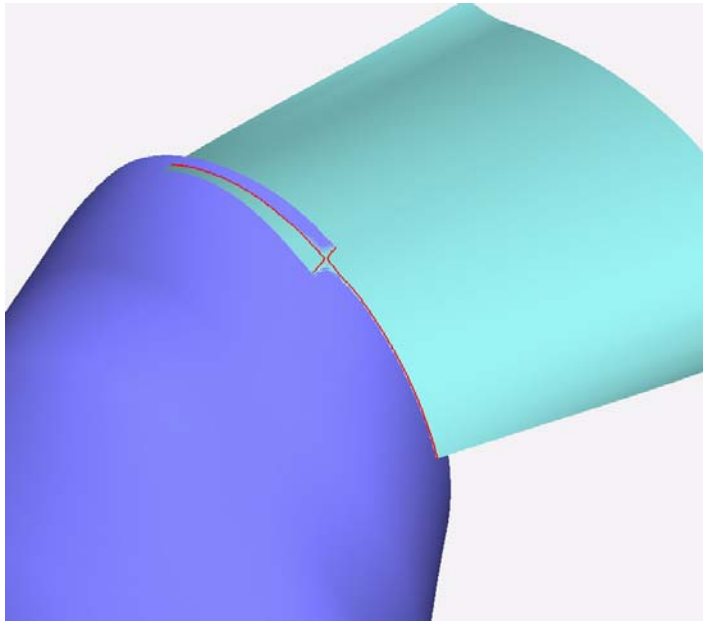


Examples of CAD models

Challenges in CAD systems

- Intersections & Topology robustness/precision
- Parametric design: non-linear optimization





从“中国制造”到“中国智造”

制造业是国民经济的主体，是立国之本、兴国之器、强国之基





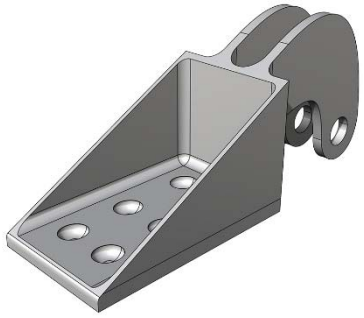
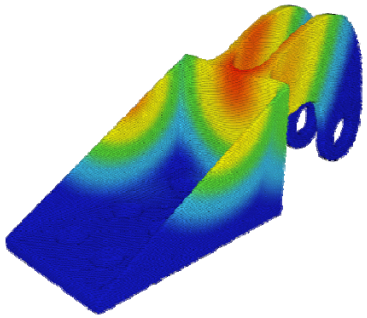
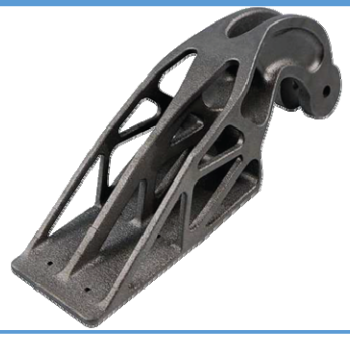
国务院2015：《中国制造2025》

- 设计顶层规划及战略目标
- 制定“三步走”路线图

- ✓ 第一步到2025年，迈入世界制造强国行列
- ✓ 第二步到2035年，达到世界制造强国中等水平
- ✓ 第三步到2049年，进入世界制造强国前列

挑战：国产自主工业设计软件

工业制造的核心要素是工业设计软件

计算机辅助设计(CAD)	计算机辅助分析(CAE)	计算机辅助制造(CAM)
		
CAD 软件 ➢ AutoCAD ➢ SolidWorks	CAE 软件 ➢ Ansys ➢ Abaqus	CAM 软件 ➢ MasterCAM ➢ Pro/NC
几何设计	性能分析	加工制造

- **立志：国产自主工业设计软件**
- **破解：“卡脖子”难题！**

中国科学技术大学

University of Science and Technology of China

GAMES102

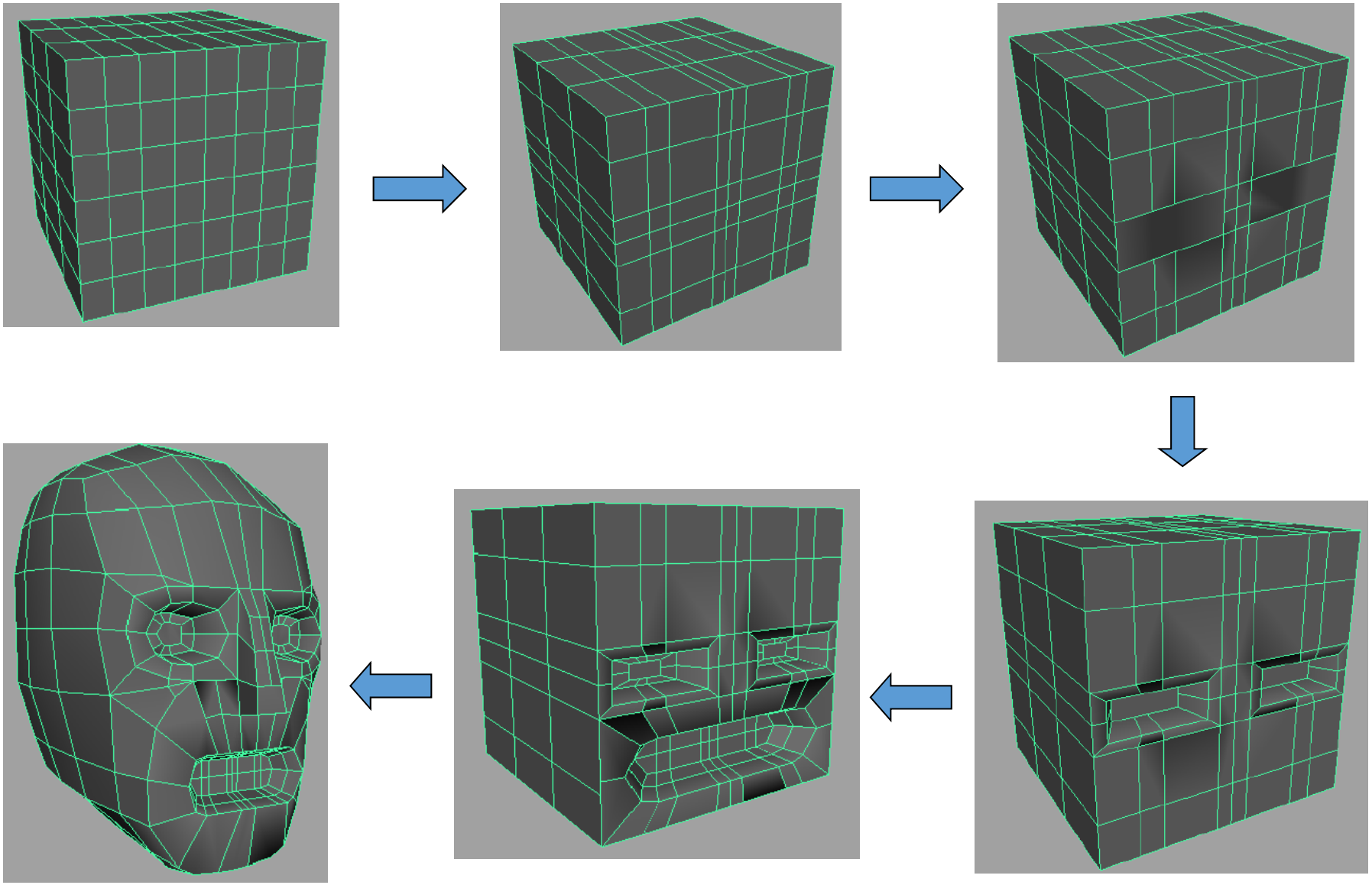
Surface Editing

Design Modeling

- Design from zero
  - Create a shape by a set of 3D design operators such as extrusion or revolution etc.

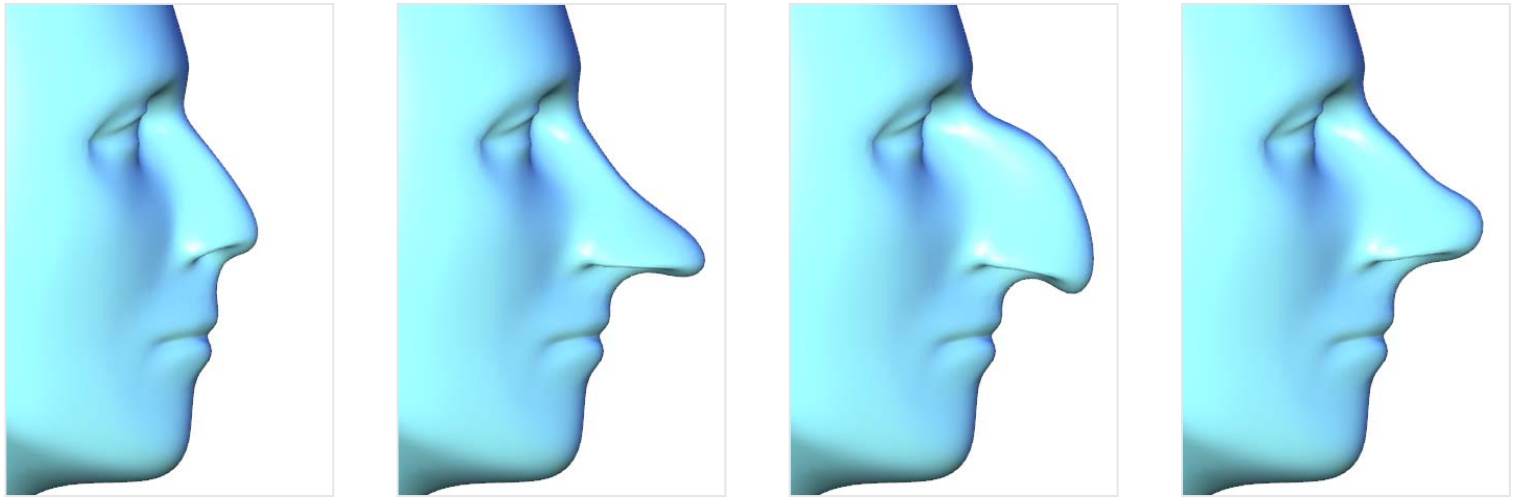
- Design from a given shape (Mesh editing)
  - Select a base shape
  - Select editing elements and editing operators
  - Deform the shape to obtain a new shape

Mesh Surface Editing



Interactive shape modeling

- Modeling is an interactive, iterative process
  - Tools need to be intuitive (interface and outcome)
  - Allow quick experimentation
  - Preserve shape properties

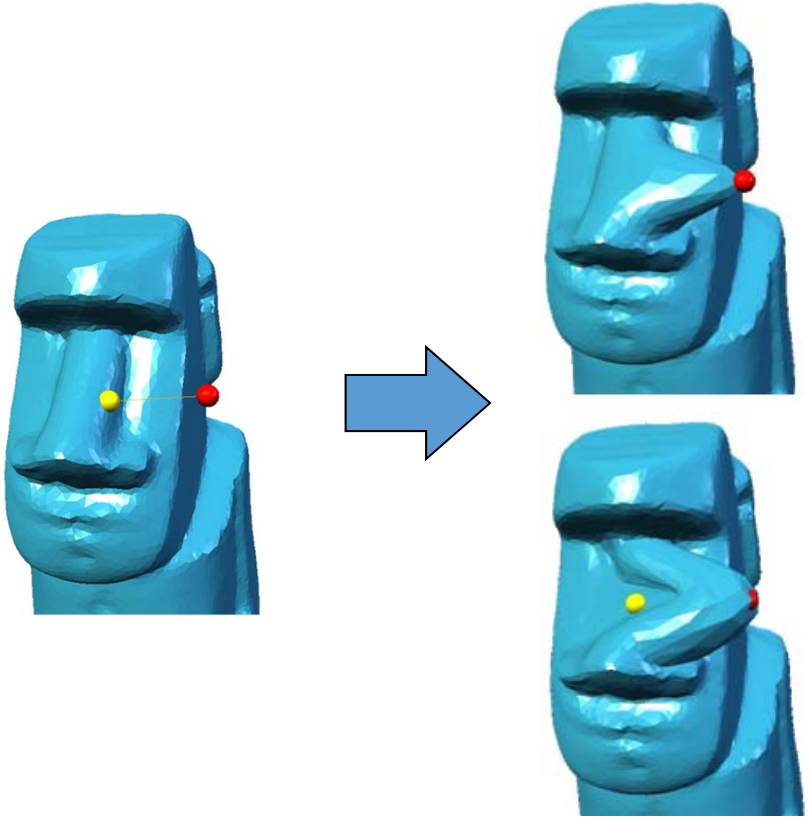


User Interaction (UI)

- User specifications: Intuitive, easy-to-use
  - Dragging handles -- vertices, features, ROI, …
- Deformed shape: adapt to user intents

Challenges:

- Operations
- Preservation of properties
- Semantics



Methodology

- Set a proxy P for the input shape S
  - P is simpler/easier/more semantic than S
  - Find a map between P and S: S=*g*(P)
    - *g* is also called an embedded space
- User interacts and deforms the proxy P to P’
  - Find a deformation map: P’=*h*(P)
- Compute a new shape S’ from P’: S’=*g*(P’)

Key Problem:

- find a good map *g*

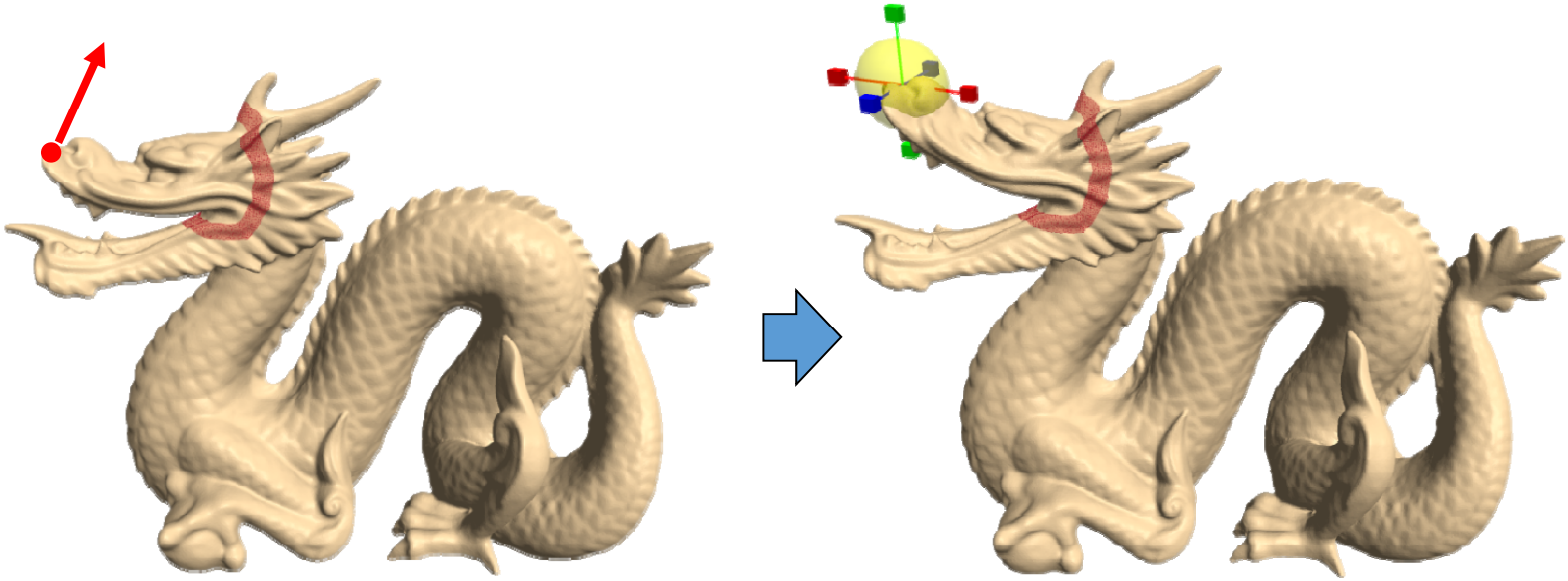
Proxy Shapes (handles)

- Points
  - Points, vertices, …
- Lines/Curves
  - Sketches, skeletons, silhouettes, wires, …
- Meshes
  - Bezier nets, lattices, cages, …
- Other shapes
  - Deformation transfer: learning deformation from other shapes

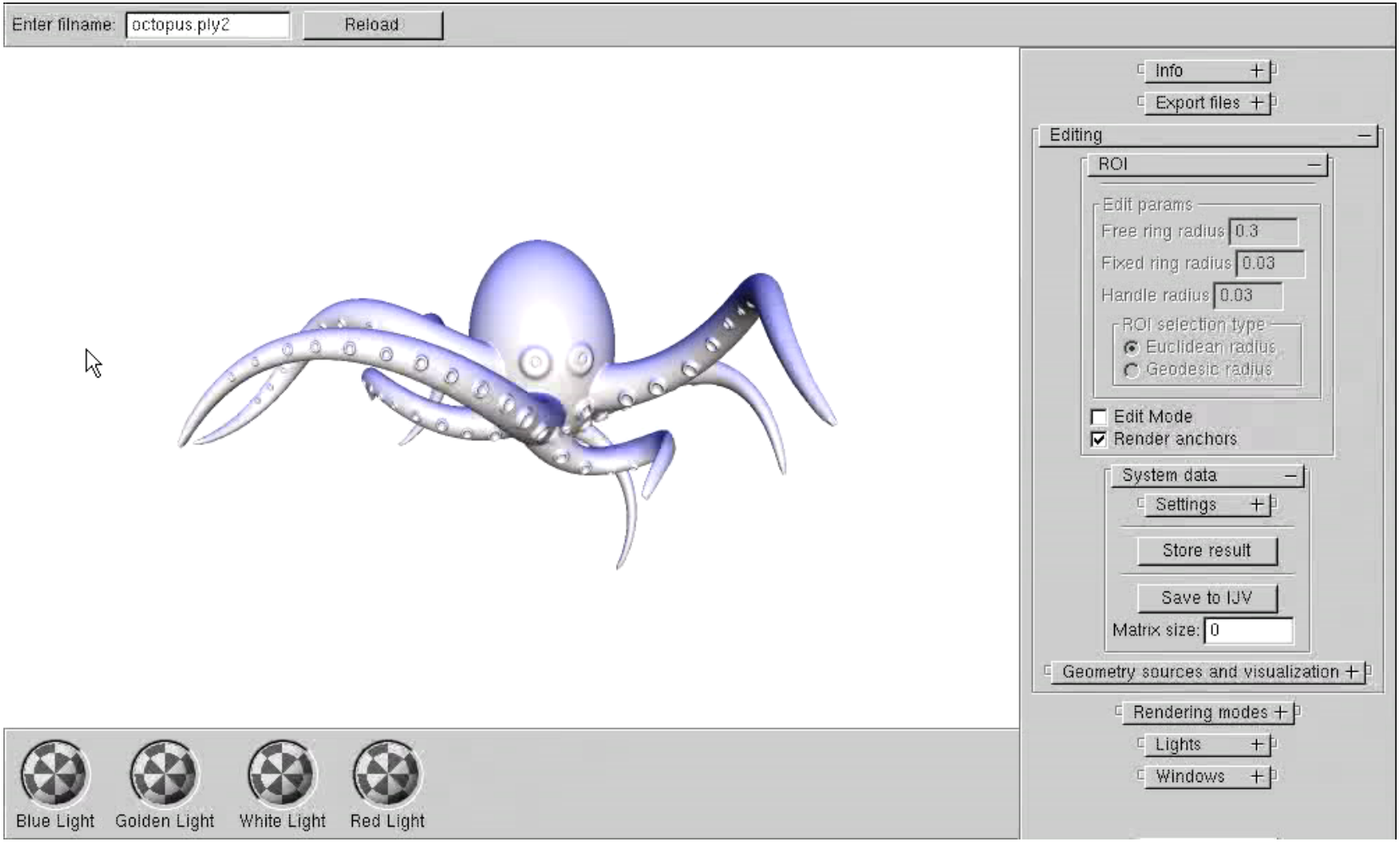
1. Point Proxy

Point based editing

- Fix some vertices
- Drag one or more vertices

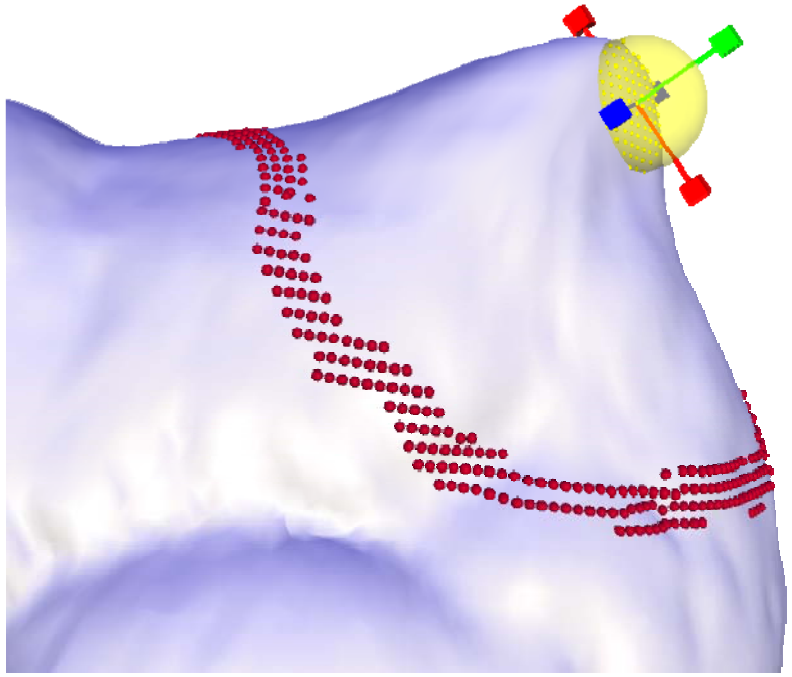


User Interfaces



User Interfaces

- ROI is bounded by a belt (static anchors)
- Manipulation through handle(s)

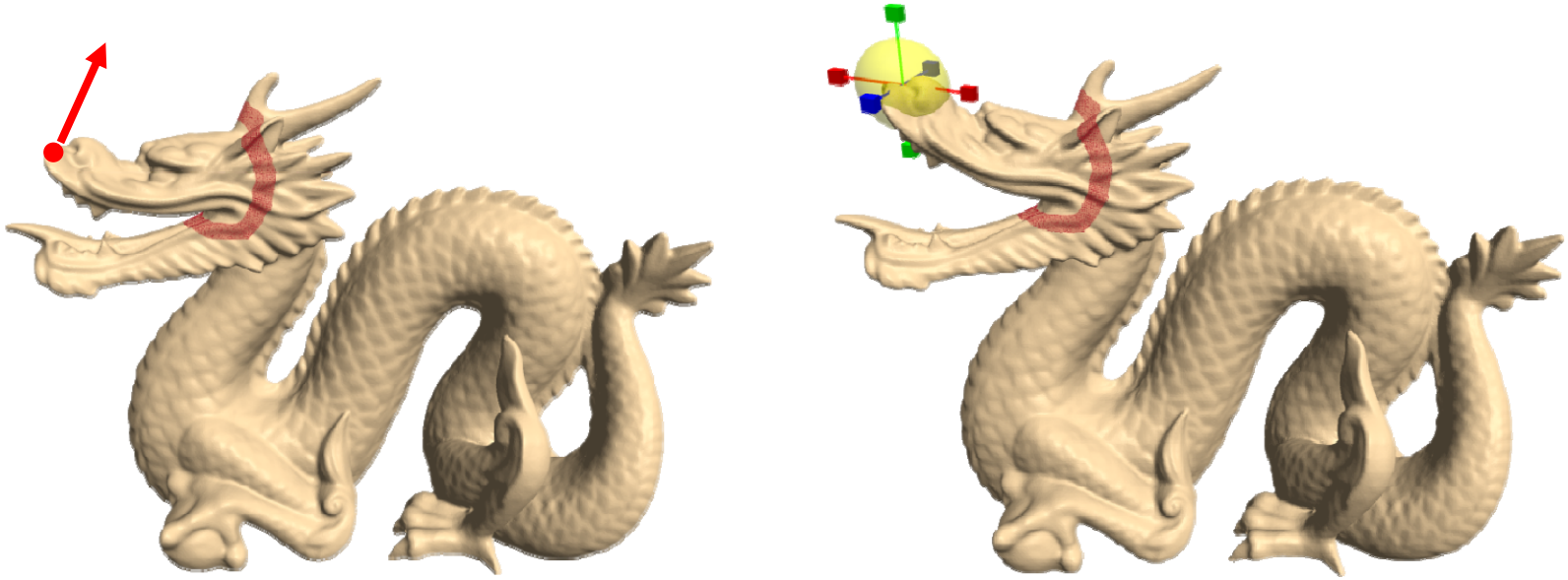


本质数学问题：数据插值问题

Interpolation Problem

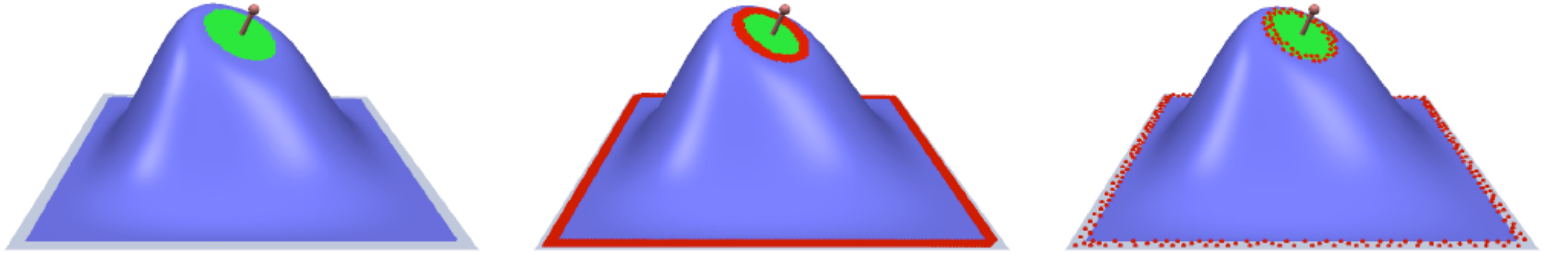
$$minE(f)$$

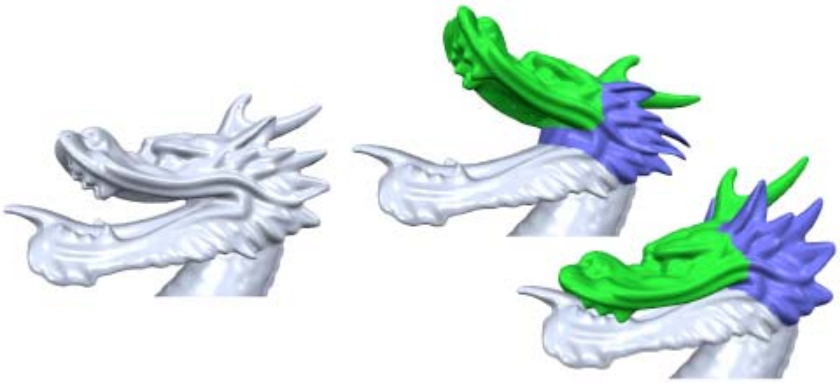
$$\text{s.t.} \quad f(x_i) = y_i, i = 1,2, \dots, n$$

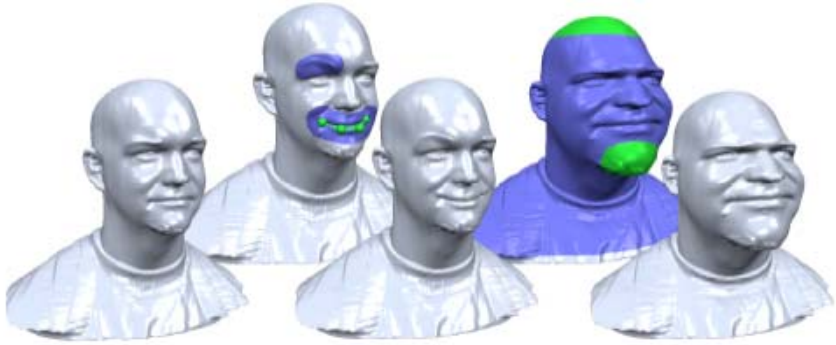


1.1 RBF-based Editing

[2005]

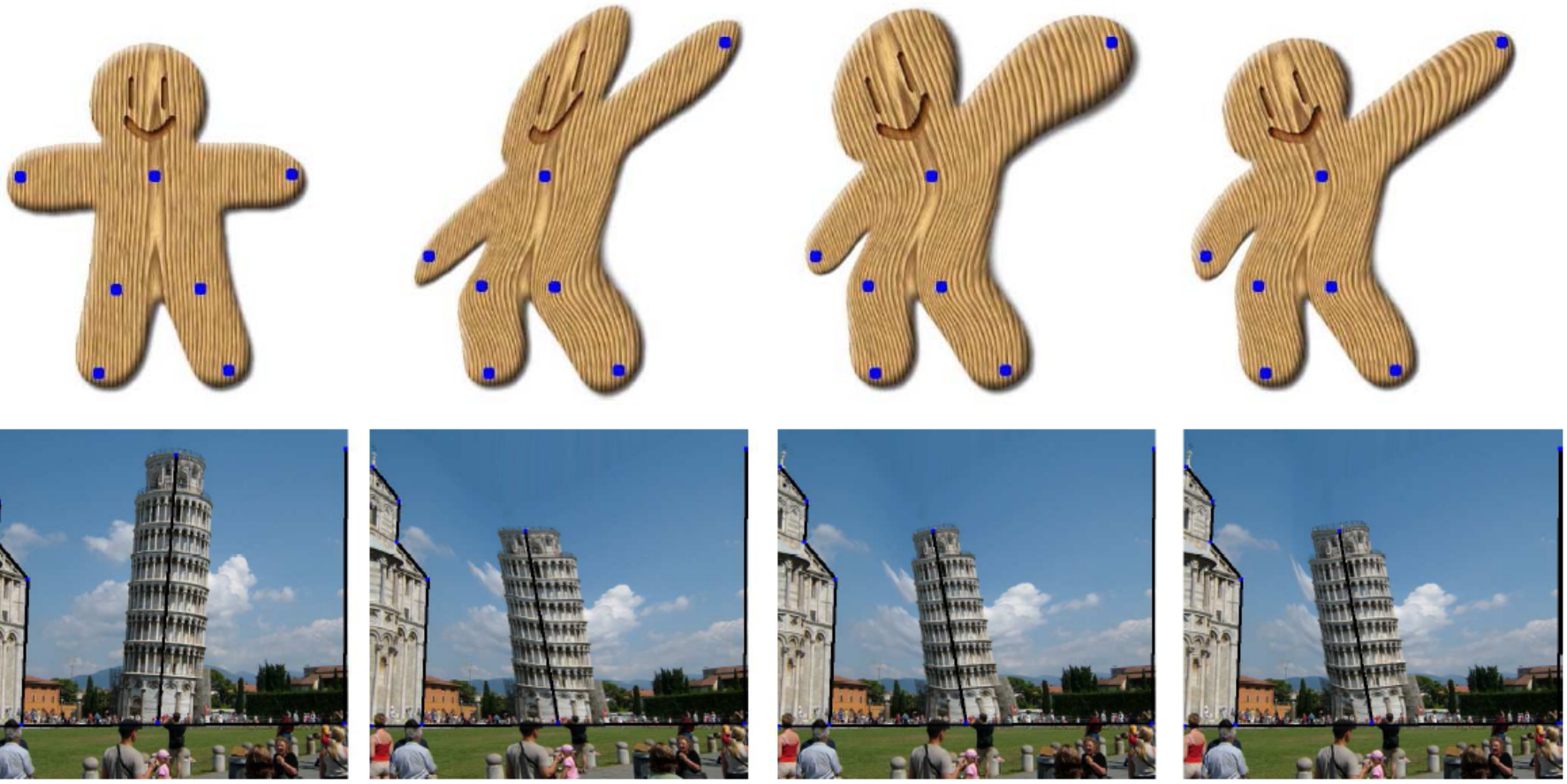






1.2 Moving Least Squares Method

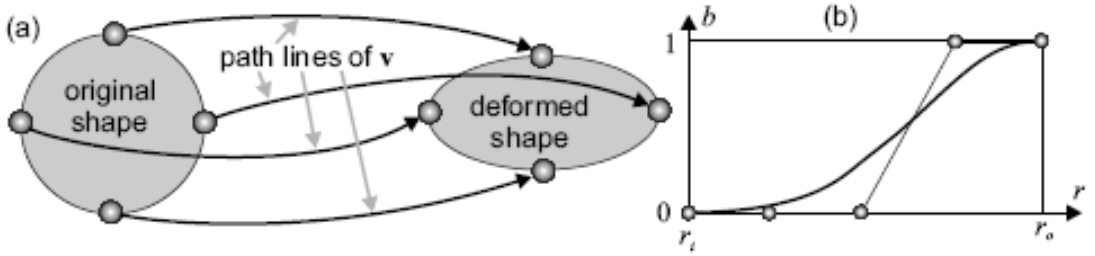
[Siggraph 2006]



1.3 Vector Field Based Deformations

[Siggraph 2006]

- Basic model: Moving vertex along the deformation orbit – defined by the path lines of a vector field v.



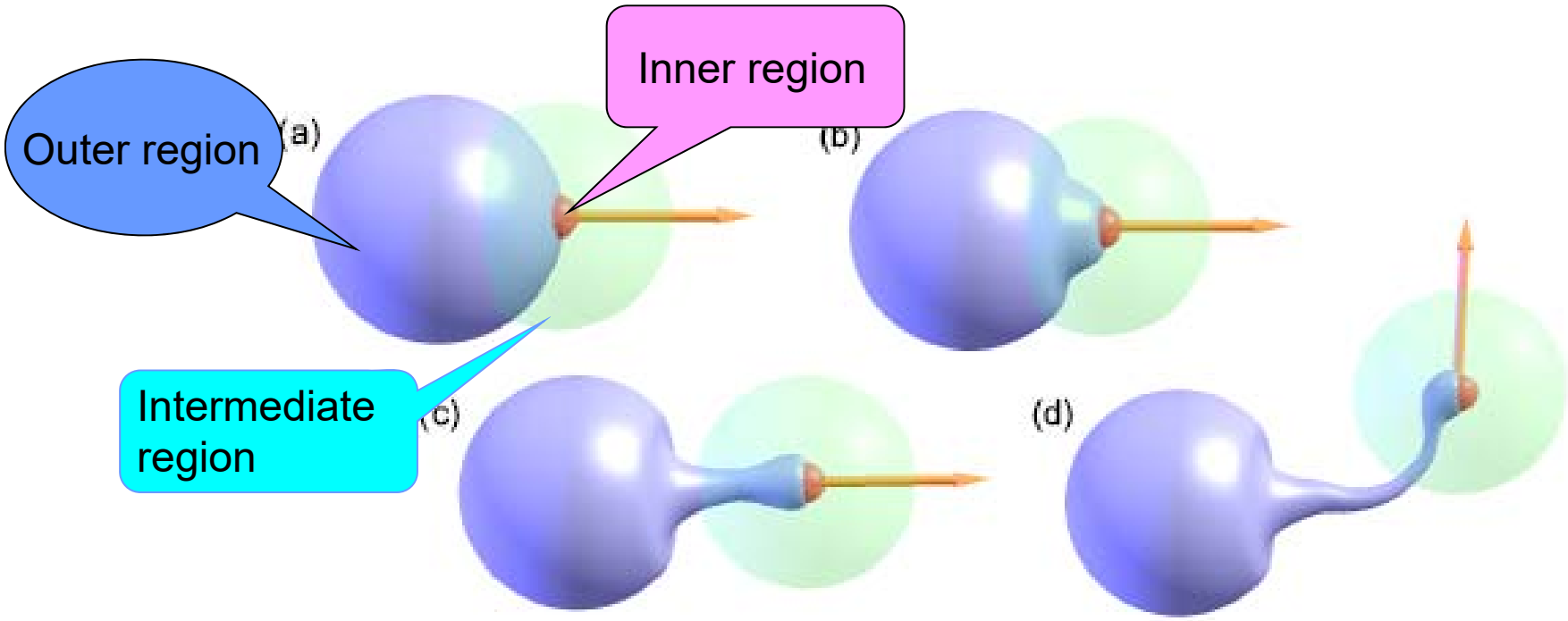
- Given a time-dependent vector field **V**(**X**, t), a *Path Line* **X**(t) in space is an integral.

Vector Field Selection

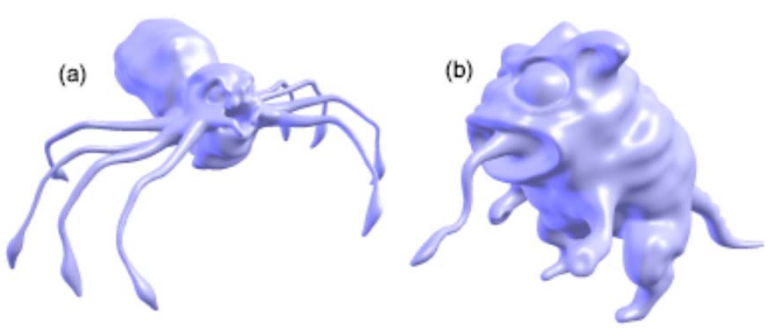
- Deformation Request:
  - No self-intersection
  - Volume-preserving
  - Details-preserving
  - Smoothness of shape in deformation
- Divergence-free Vector Field: $\boldsymbol{V}=(V_1, V_2, V_3)$

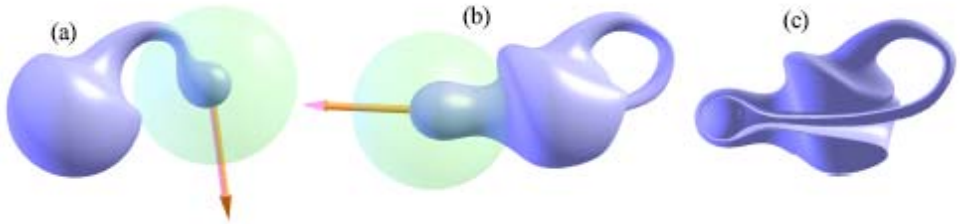
$$div\,\boldsymbol{V} = \frac{\partial V_1}{\partial x} + \frac{\partial V_2}{\partial y} + \frac{\partial V_3}{\partial z} = 0$$

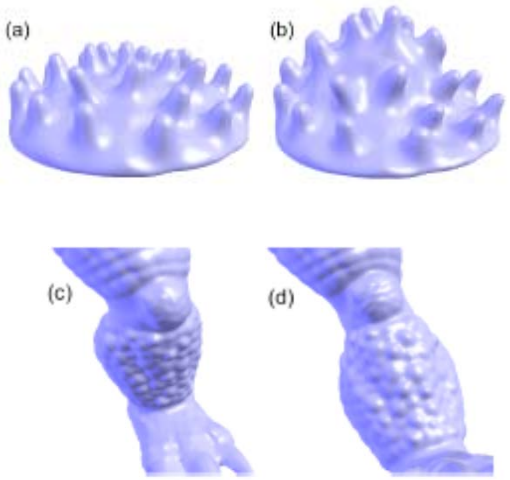
Piecewise Field for Deformation

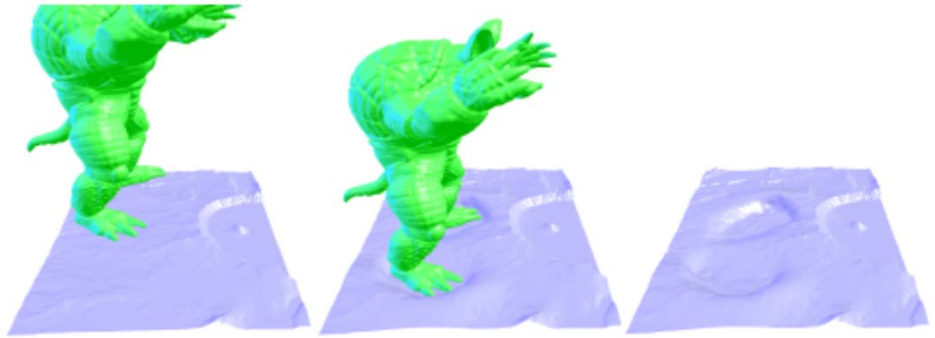


Examples





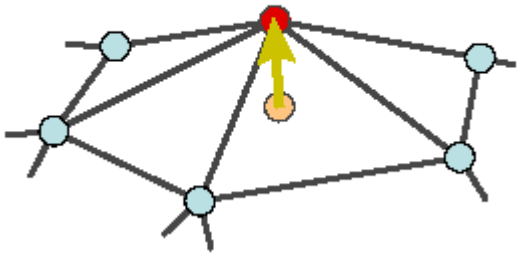


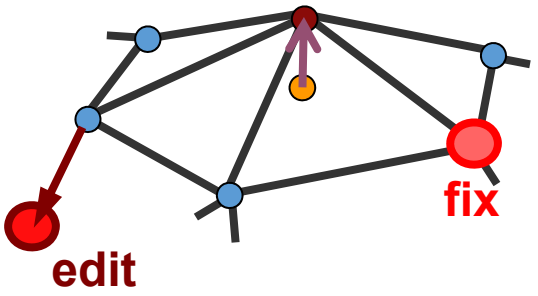


1.4 Laplacian Editing

[Sorkine et al. SGP 2004]

- Preserve local detail – Laplacian coordinates
- Representation with sparse matrices
- Efficient linear surface reconstruction





$$v_i = \sum_{j \in N(i)} w_j v_j + \delta_i$$

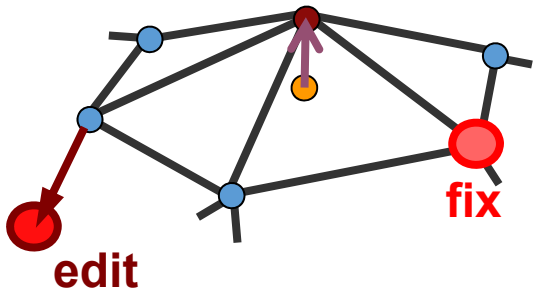
Variational Viewpoint

- Laplacian Approximation

$$\tilde{\mathbf{x}} = \underset{\mathbf{x}}{\operatorname{argmin}} \left(\|L\mathbf{x} - \delta^{(x)}\|^2 + \sum_{j \in C} \omega^2 \|x_j - c_j\|^2 \right).$$

- Gradient Approximation

$$\min_{\phi} \int \int_{\Omega} \|\nabla \phi - \mathbf{w}\|^2 dA,$$



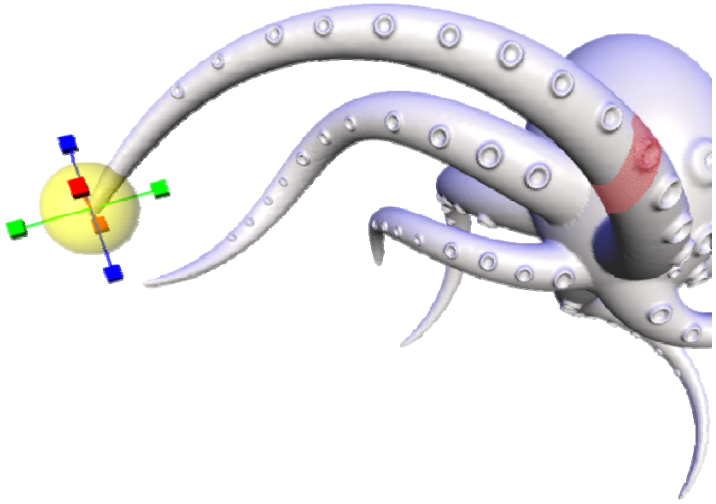
Editing framework

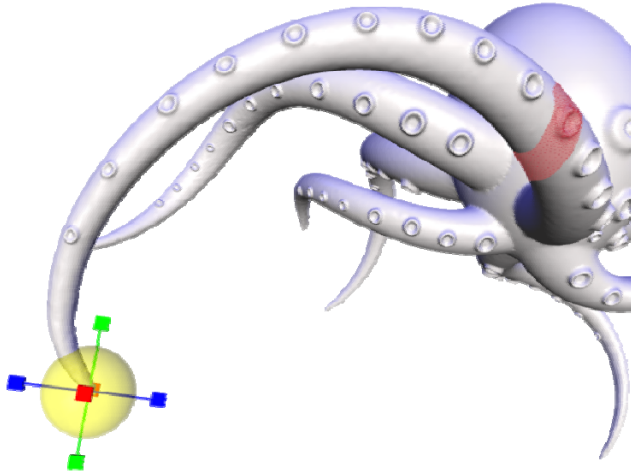
- The spatial constraints will serve as modeling constraints
- Reconstruct the surface every time the modeling constraints are changed

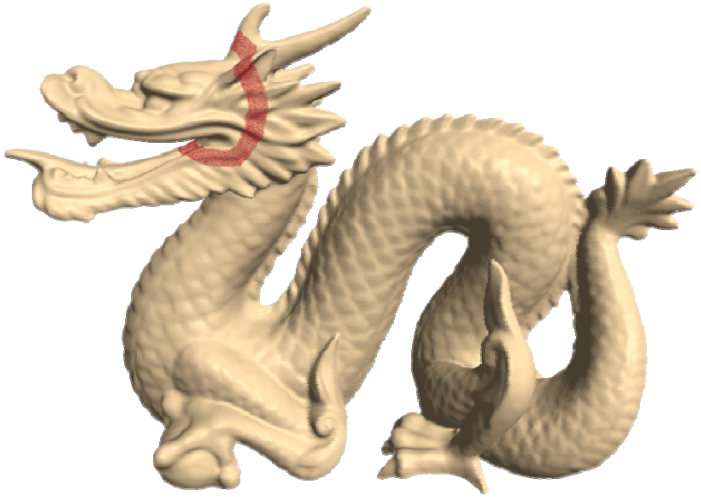
Detail constraints: $L\mathbf{x} = \boldsymbol{\delta}$

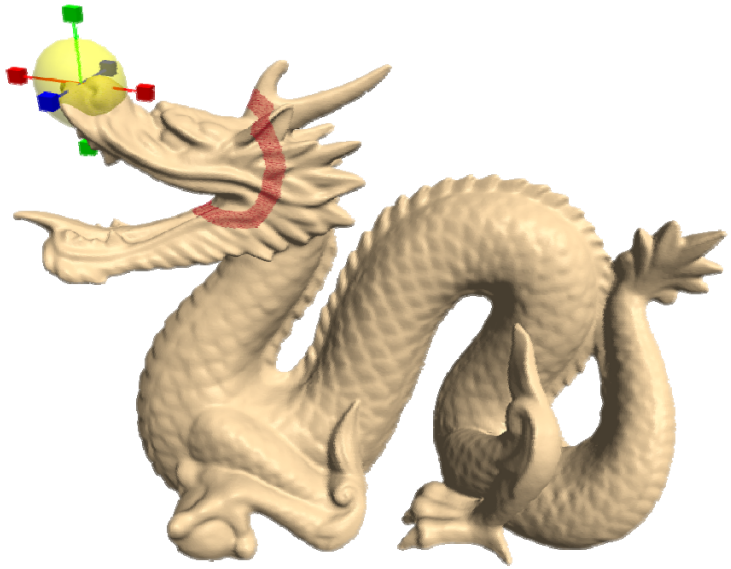
Modeling constraints: $x_j = c_j, \quad j \in \{j_1, j_2, \ldots j_k\}$

Results

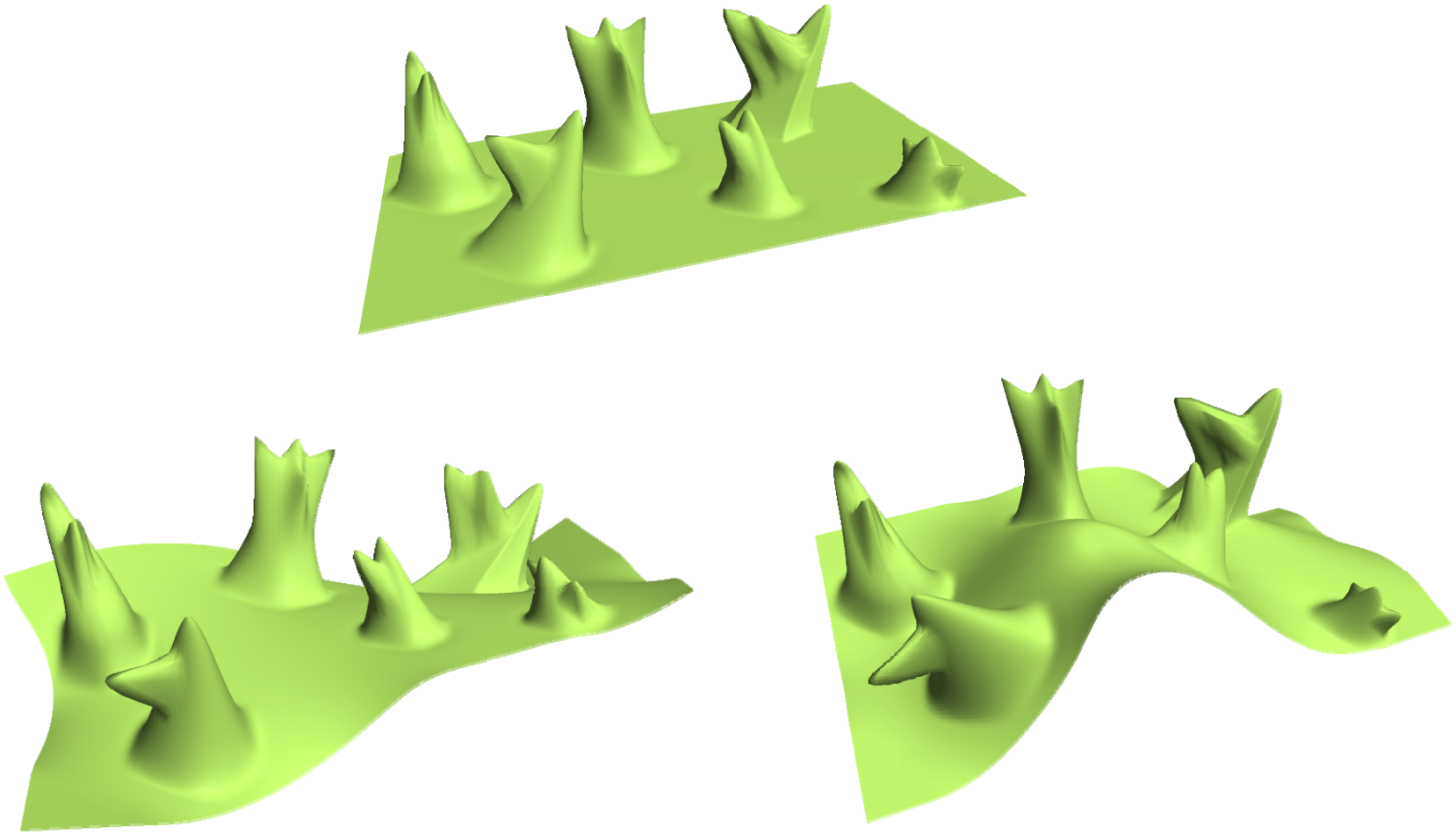






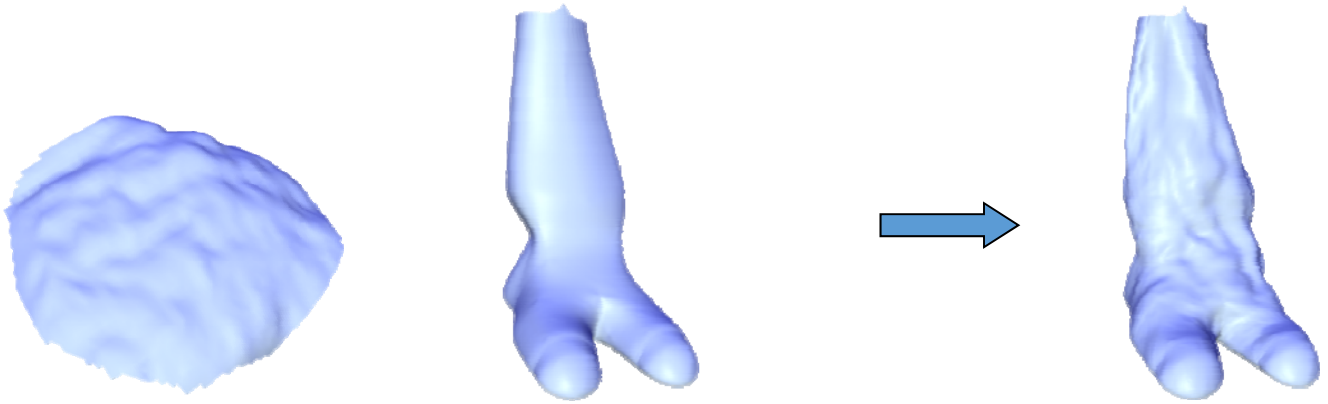


Results

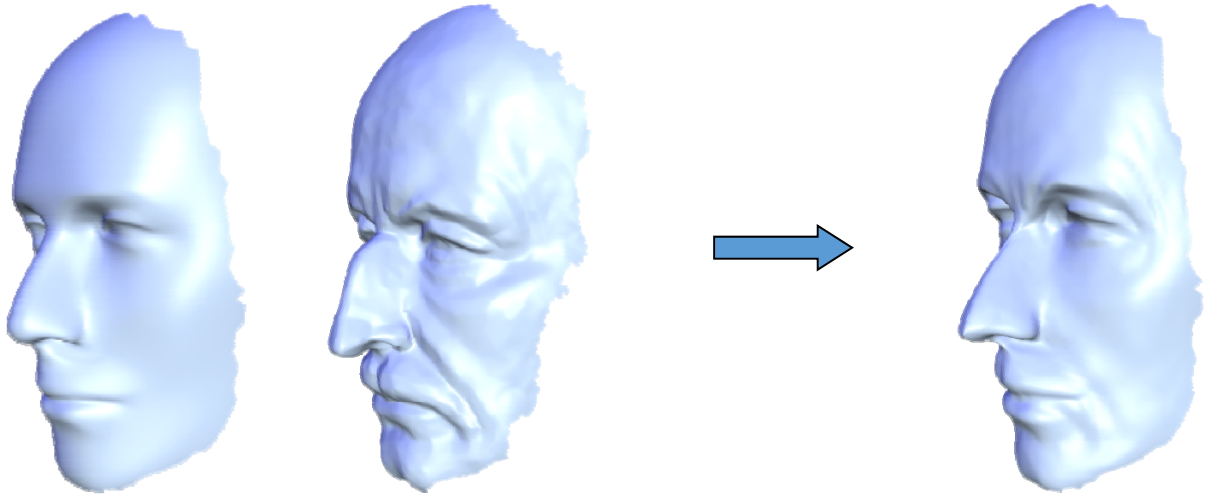


Detail transfer and mixing

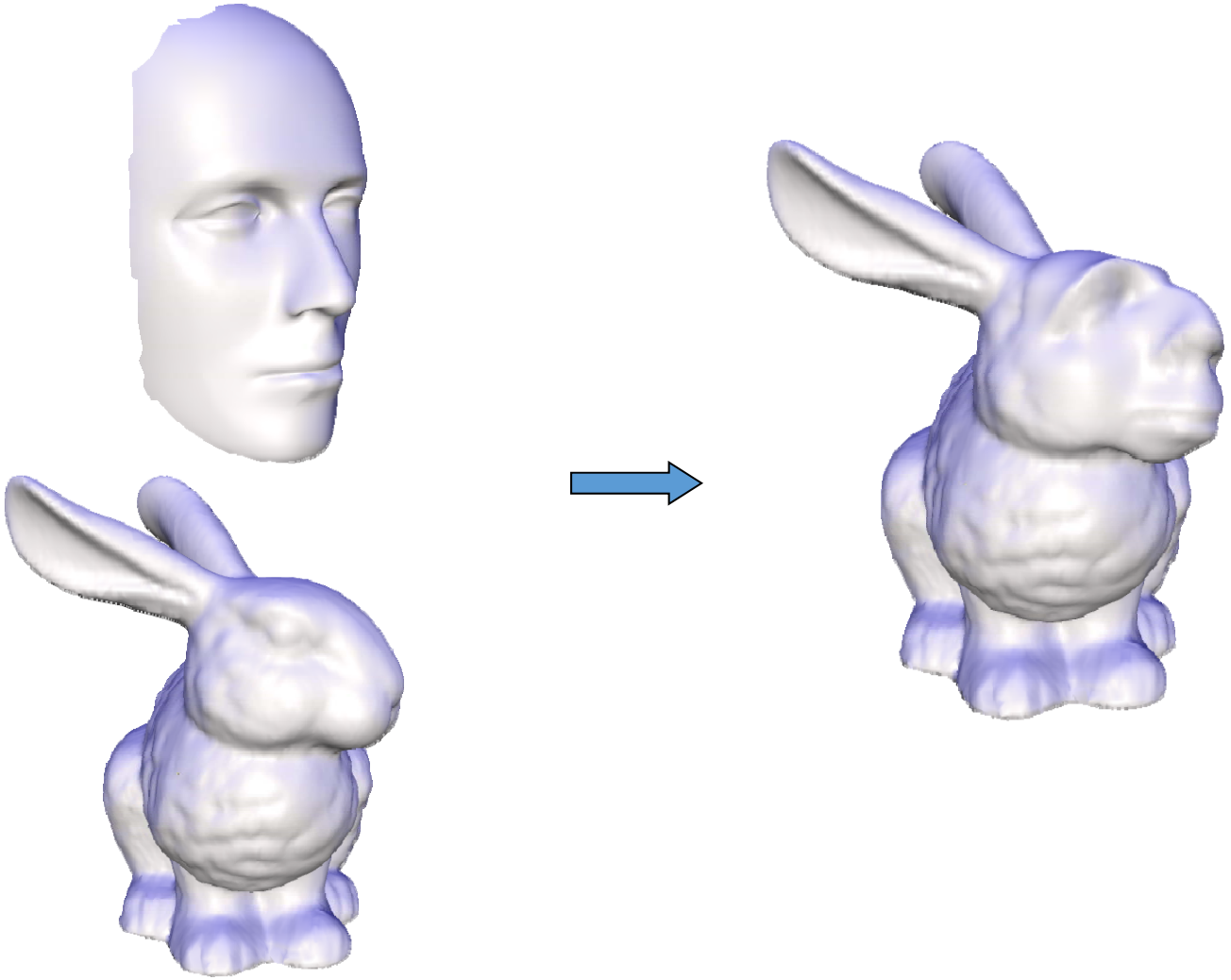
- “Peel“ the coating of one surface and transfer to another



Examples

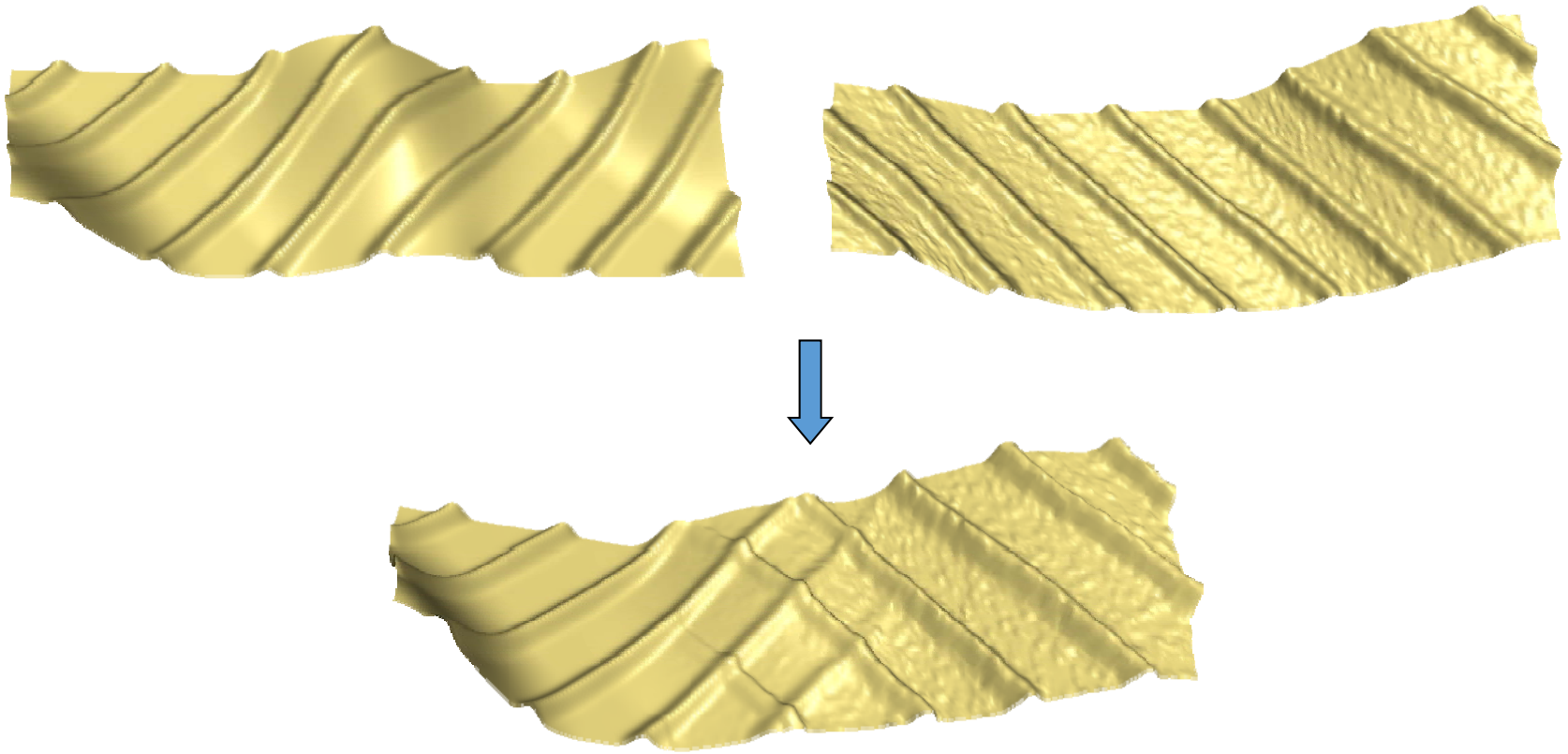


Examples



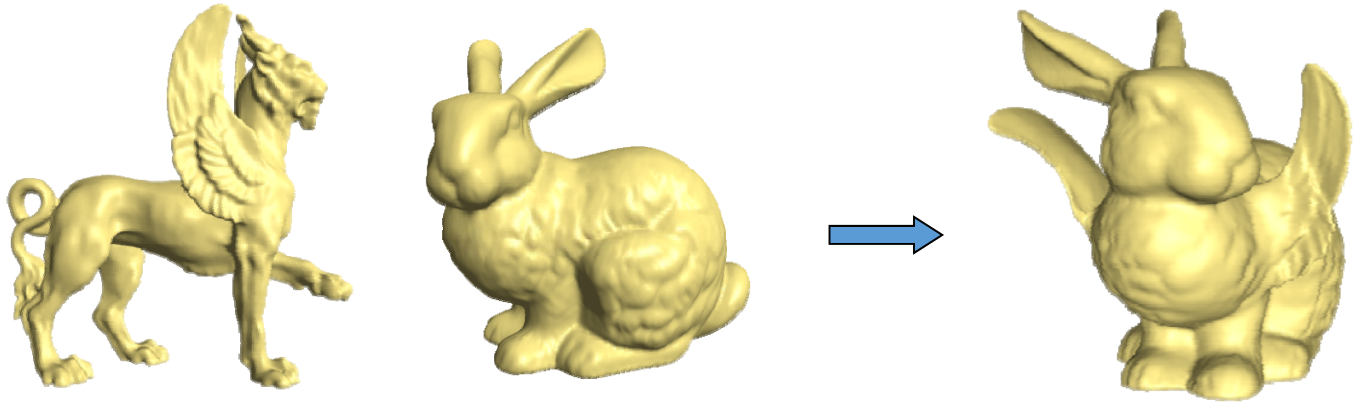
Mixing Laplacians

- Taking weighted average of δ_i and δ'_i



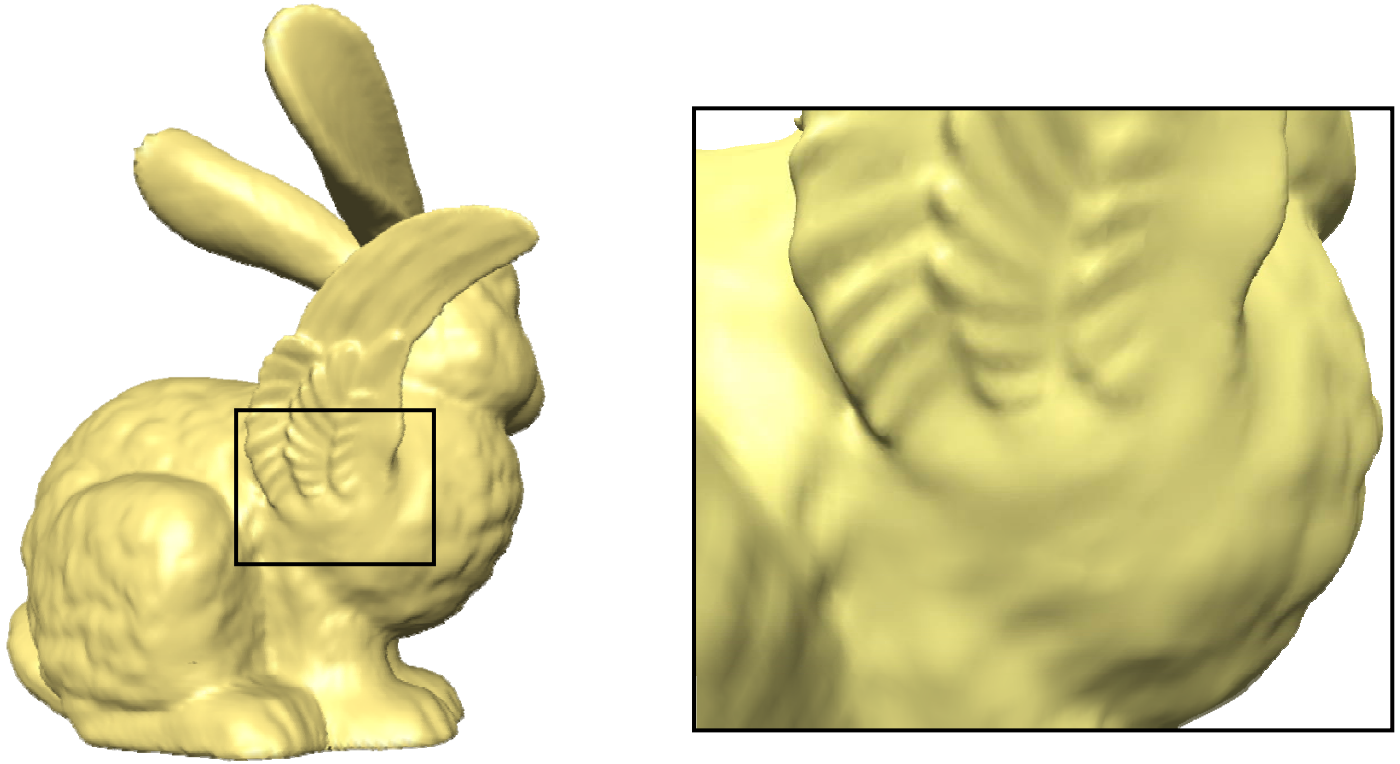
Mesh transplanting

- The user defines
  - Part to transplant
  - Where to transplant
  - Spatial orientation and scale
- Topological stitching
- Geometrical stitching via Laplacian mixing



Mesh transplanting

- Details gradually change in the transition area



Mesh transplanting

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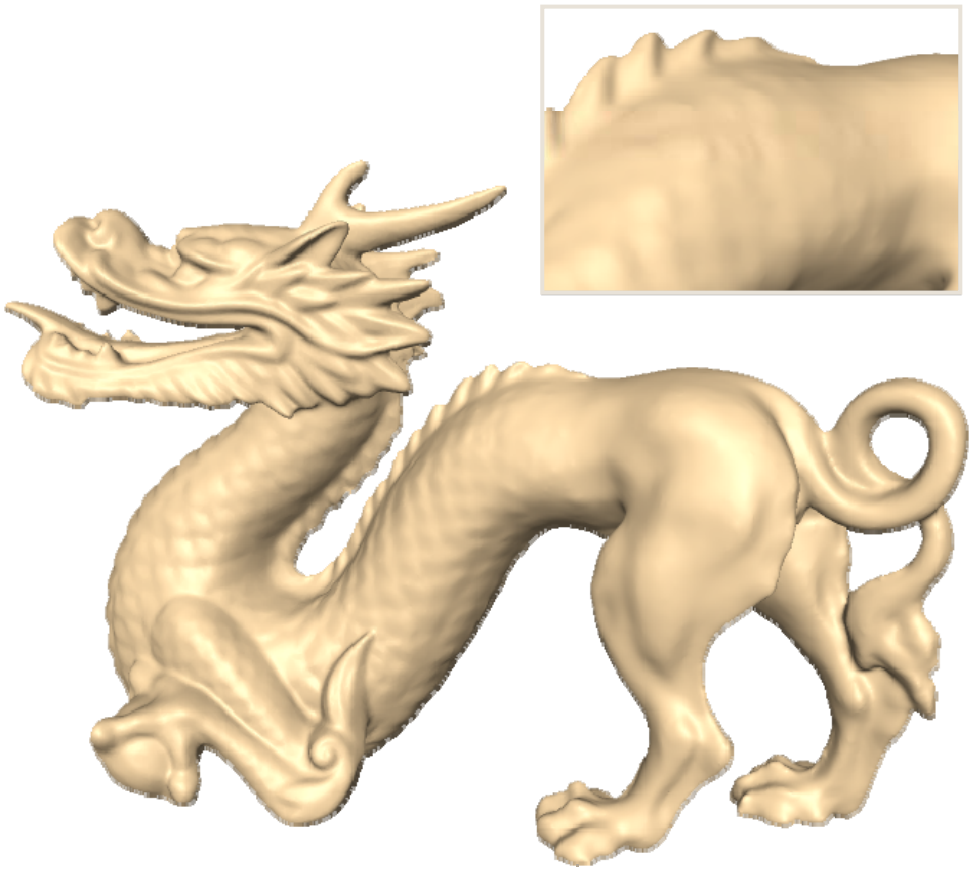


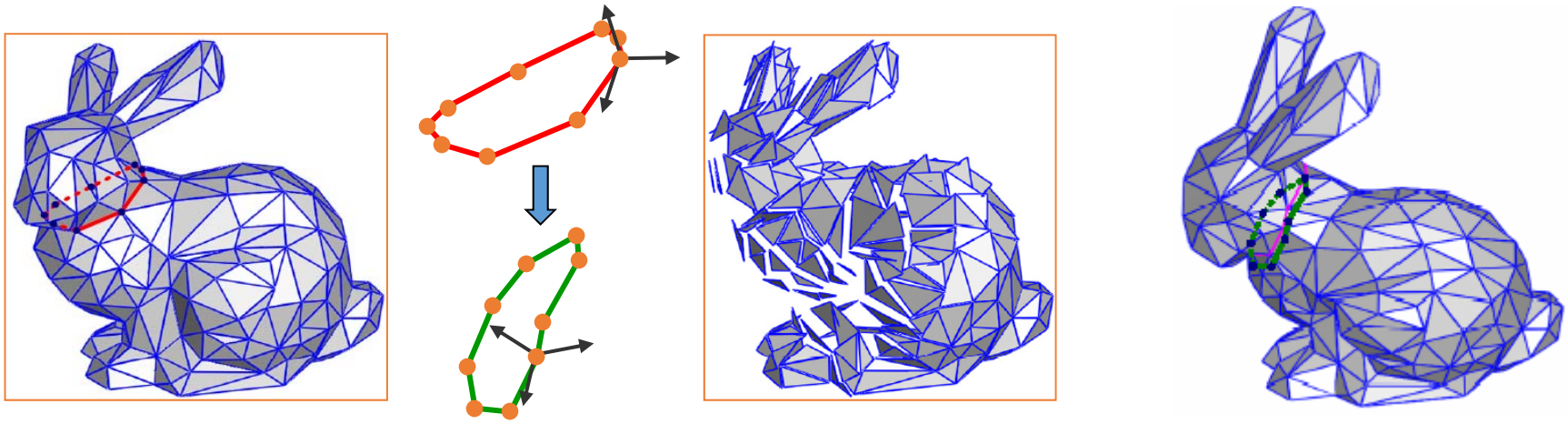
Invariance – solutions

- Explicit transformation of the differential coordinates prior to surface reconstruction
  - Lipman, Sorkine, Cohen-Or, Levin, Rössl and Seidel [SMI 04], “Differential Coordinates for Interactive Mesh Editing“,
    - Estimation of rotations from naive reconstruction
  - Yu, Zhou, Xu, Shi, Bao, Guo and Shum [SIGGRAPH 04], “Mesh Editing With Poisson-Based Gradient Field Manipulation“,
    - Propagation of handle transformation to the rest of the ROI using geodesic distances
  - Zayer, Rössl, Karni and Seidel [EG 05], “Harmonic Guidance for Surface Deformation“,
    - Propagation of handle transformation to the rest of the ROI using harmonic functions

1.5 Poisson Mesh Editing

Yu et al. Mesh Editing With Poisson-Based Gradient Field Manipulation. Siggraph 2004.

- The representation: the gradients of the functions X, Y, Z on each triangle of the mesh
- Deformation: propagate the transformation of the handle onto the ROI using geodesic distances



Poisson editing – images

- Inspiration: Poisson Image Editing [Pérez et al. 03]

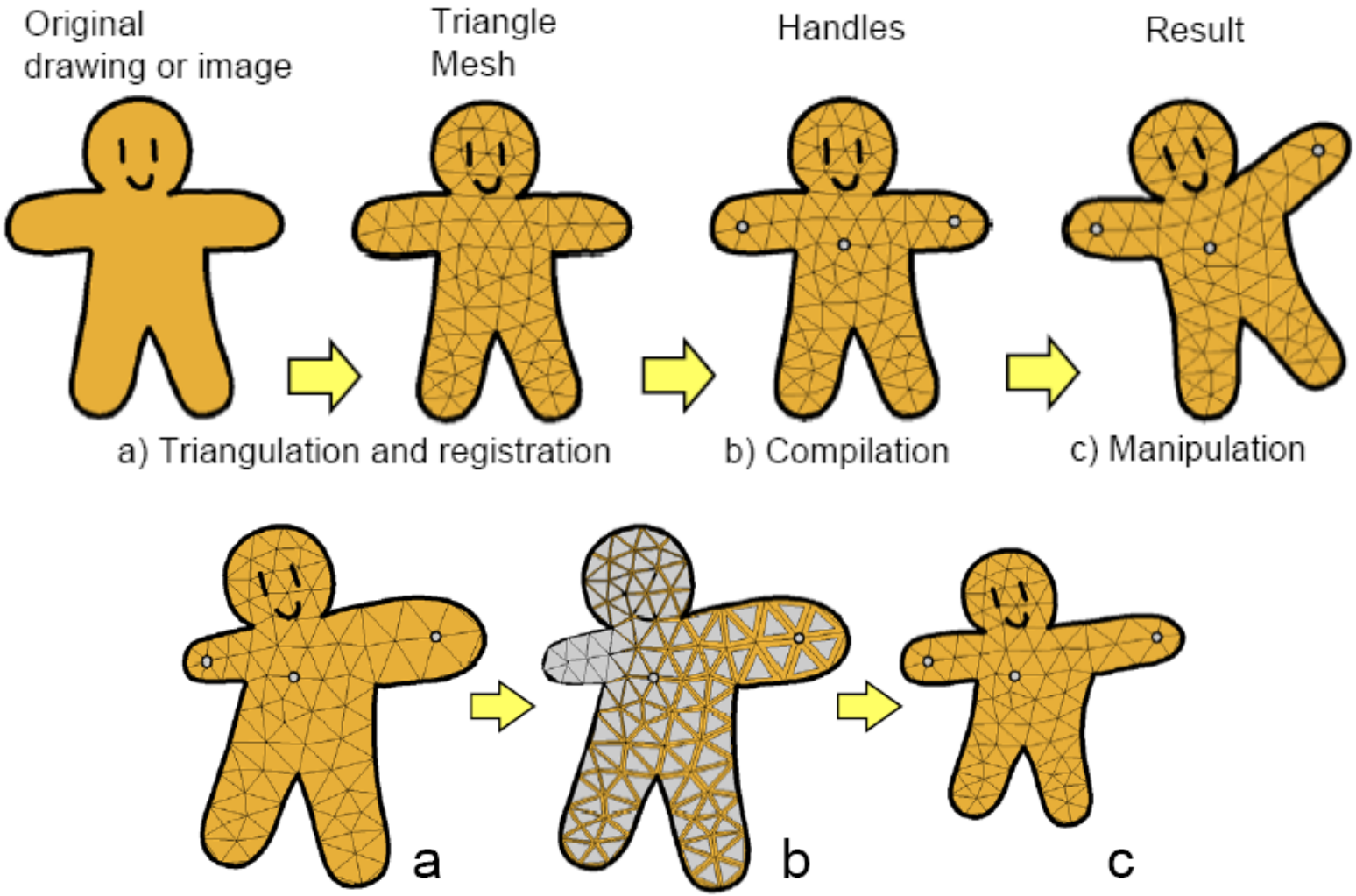
- Reconstruct a function from its gradients via the Poisson equation:

$$\arg\min_{f} \int_{\Omega} \|\nabla f - \mathbf{w}\|^2, \quad \text{s.t.} \quad f\big|_{\partial\Omega} = f^*\big|_{\partial\Omega}$$

$$\Delta f = \operatorname{div} \mathbf{w} \quad \text{with} \quad f\big|_{\partial\Omega} = f^*\big|_{\partial\Omega}$$

1.6 As-rigid-as-possible Deformation

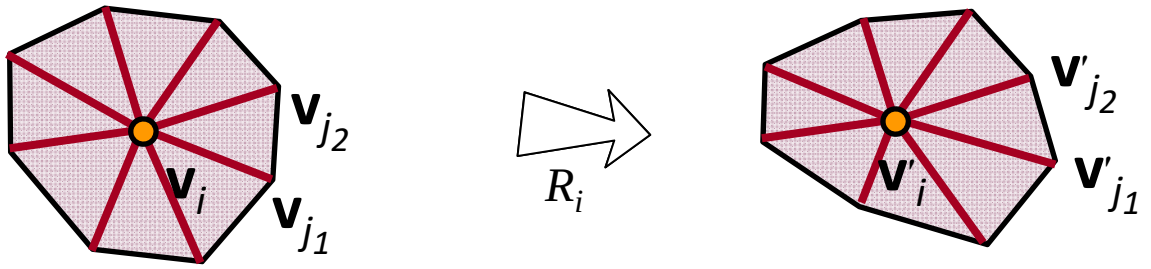
[Siggraph 2003]



1.7 ARAP Modeling

[Sorkine and Alexa, As-Rigid-As-Possible Surface Modeling. SGP 2007]

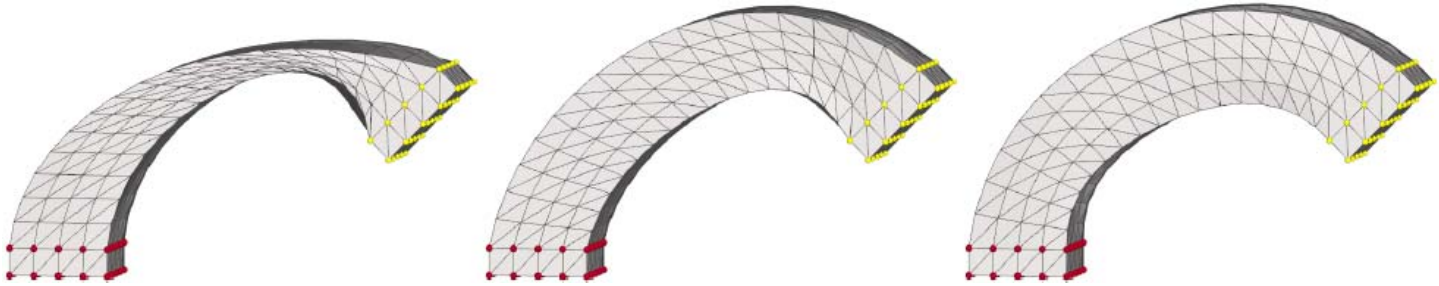
- Ask all star edges to transform rigidly by some rotation R, then the shape of the cell is preserved



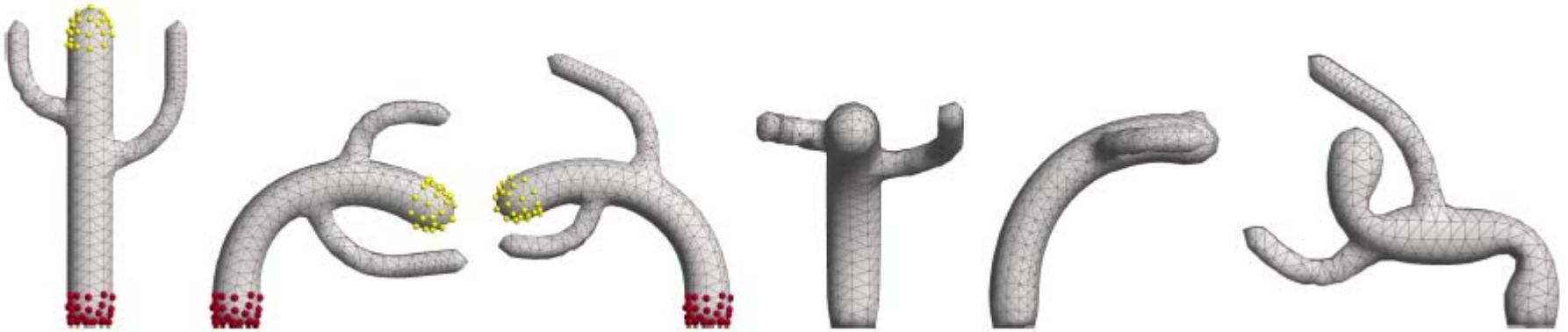
$$\min_{\mathbf{v}'} \sum_{i=1}^{n} \sum_{j \in N(i)} \left\| (\mathbf{v}'_i - \mathbf{v}'_j) - R_i(\mathbf{v}_i - \mathbf{v}_j) \right\|^2$$

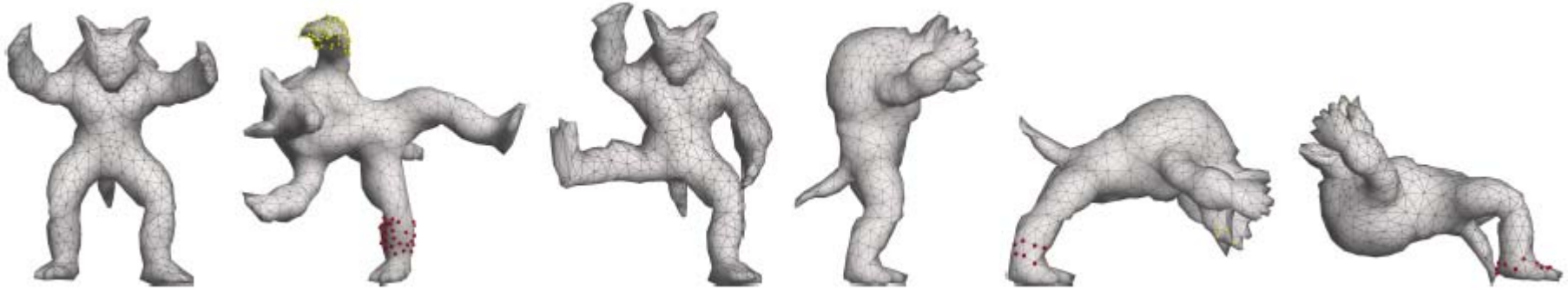
$$s.t.\ \mathbf{v}'_j = \mathbf{c}_j,\ j \in C$$

ARAP Modeling



initial guess 1 iterations 4 iterations

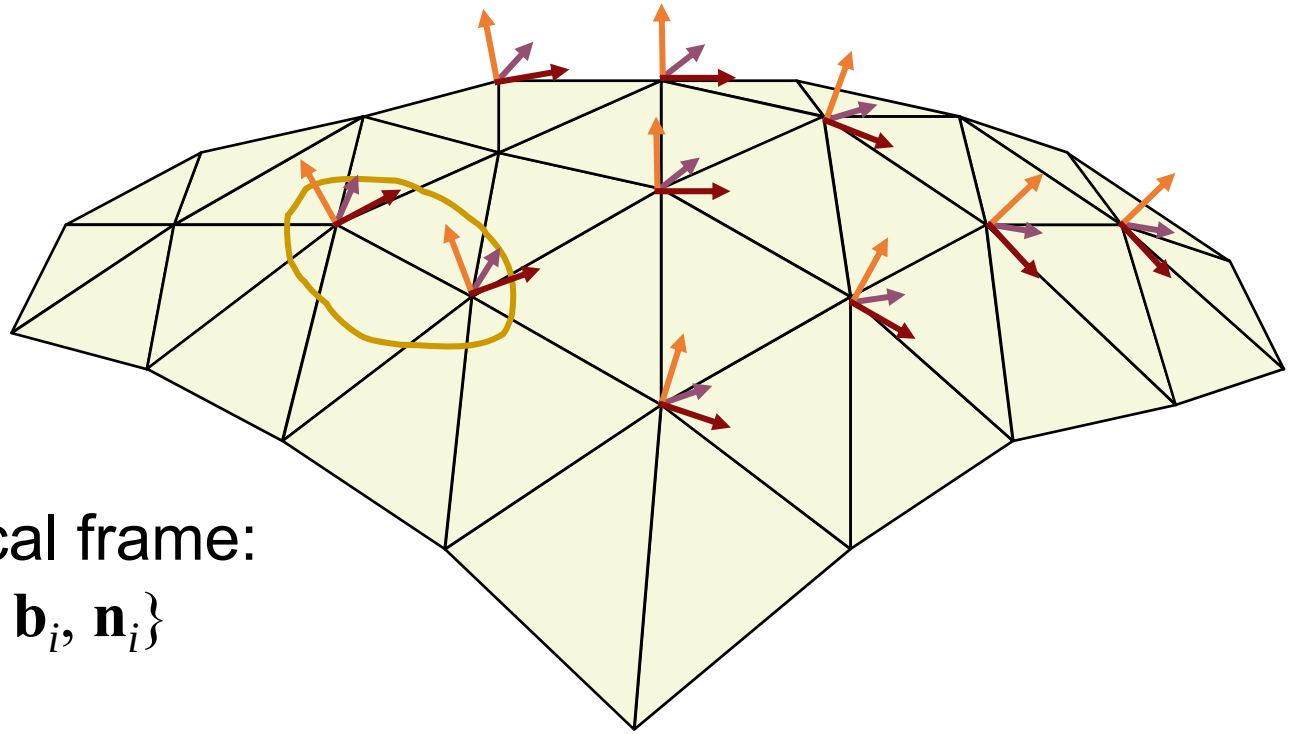




1.8 Linear Rotation-invariant Coordinates

[Lipman et al. Siggraph 05]

- Keep a local frame at each vertex
- Prescribe changes to some selected frames



Local frame:

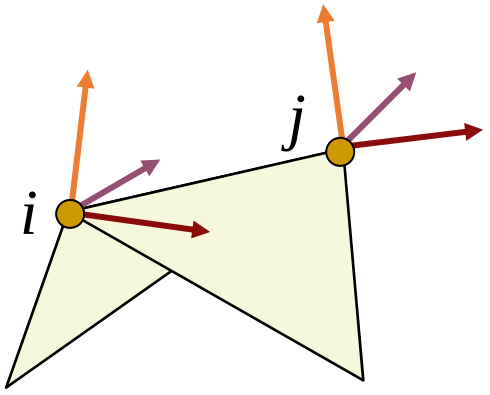
$\{\mathbf{a}_i, \mathbf{b}_i, \mathbf{n}_i\}$

Frame-based deformations

- Encode the differences between adjacent frames
- Solve for the new frames in least-squares sense

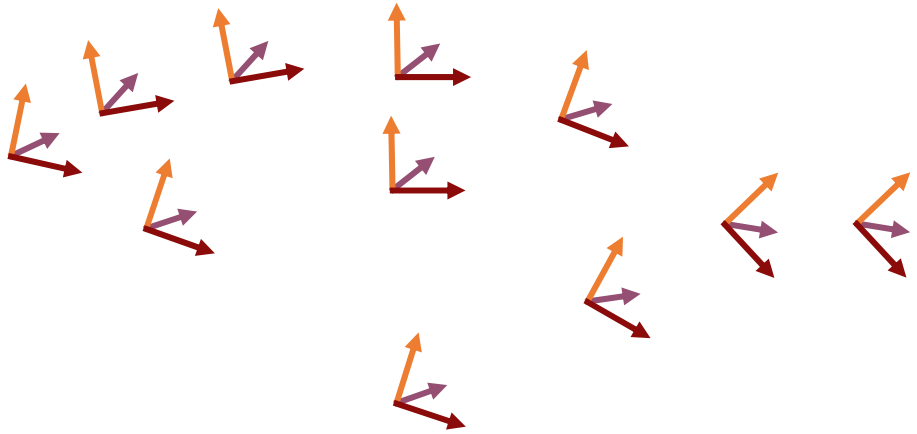
$$\mathbf{a}_i - \mathbf{a}_j = \alpha_1 \mathbf{a}_i + \alpha_2 \mathbf{b}_i + \alpha_3 \mathbf{n}_i$$
$$\mathbf{b}_i - \mathbf{b}_j = \beta_1 \mathbf{a}_i + \beta_2 \mathbf{b}_i + \beta_3 \mathbf{n}_i$$
$$\mathbf{n}_i - \mathbf{n}_j = \gamma_1 \mathbf{a}_i + \gamma_2 \mathbf{b}_i + \gamma_3 \mathbf{n}_i$$
$$\ldots\ldots$$

constraints



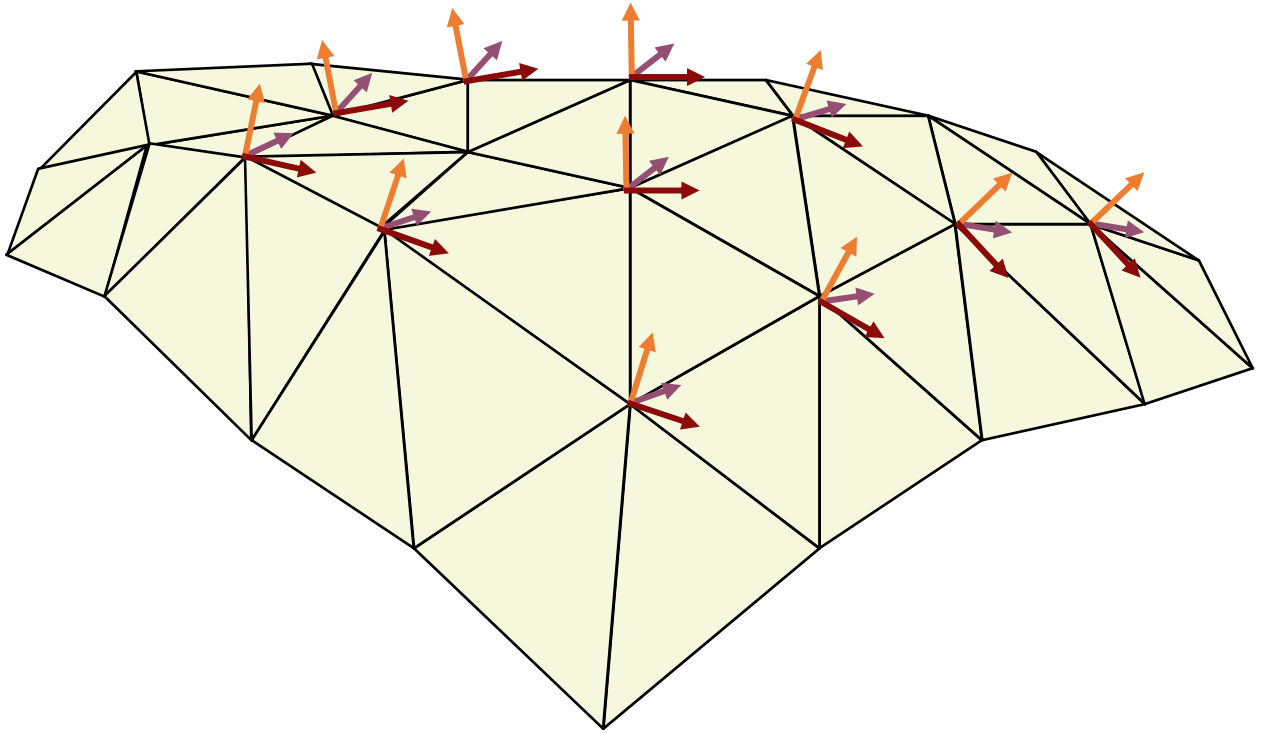
Frame-based deformations

- Reconstruction:
  - After having the frames, solve for positions

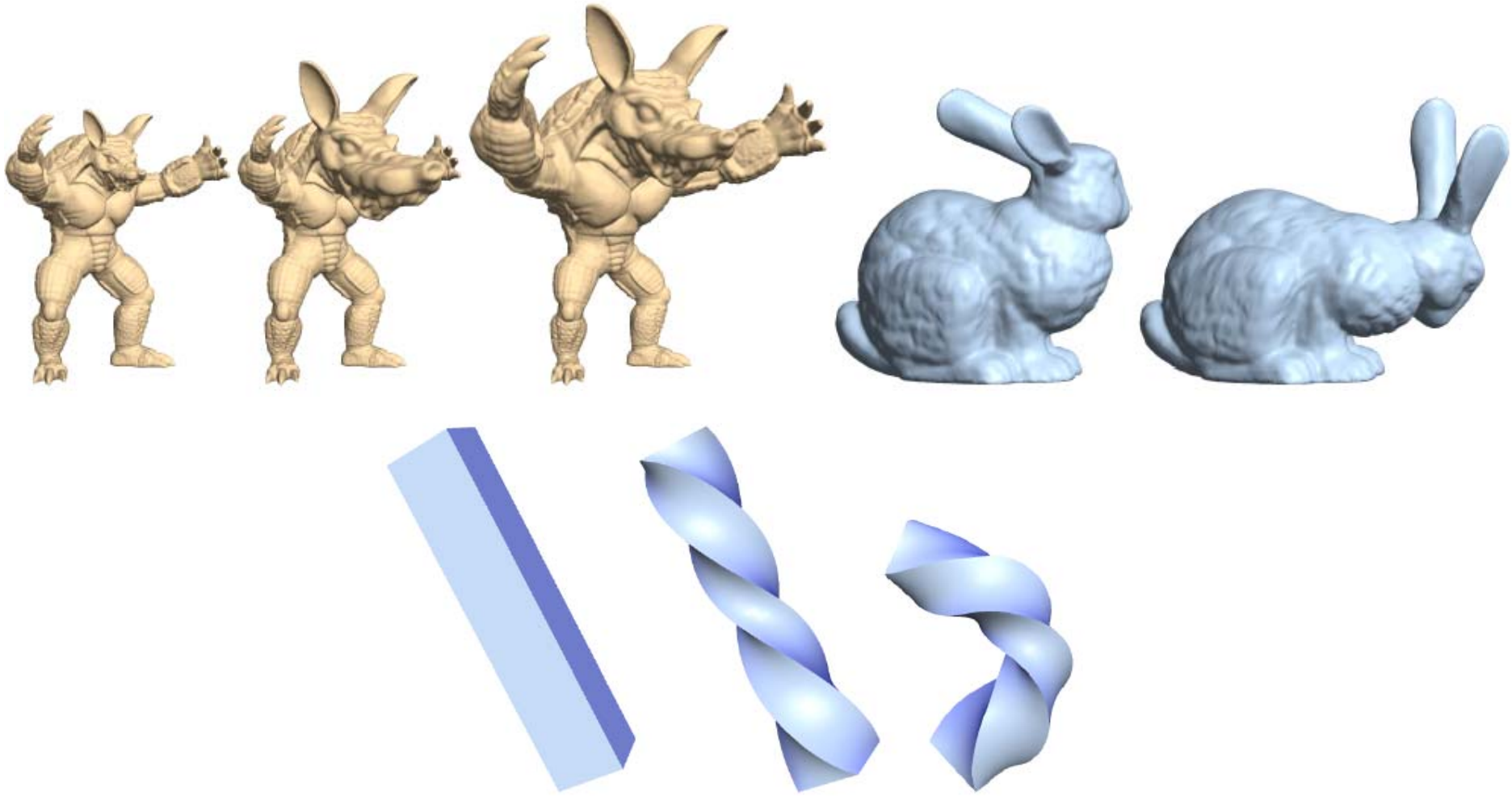


Frame-based deformations

- Reconstruction:
  - After having the frames, solve for positions



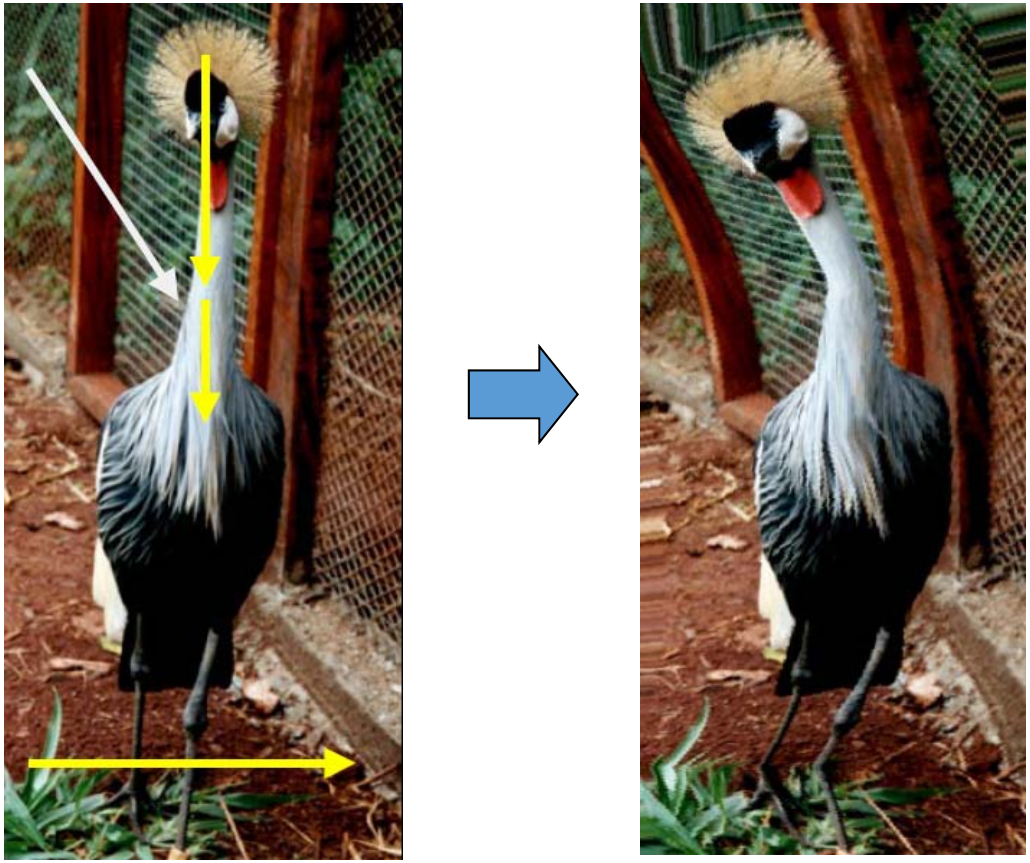
Results



2. Curve Proxy

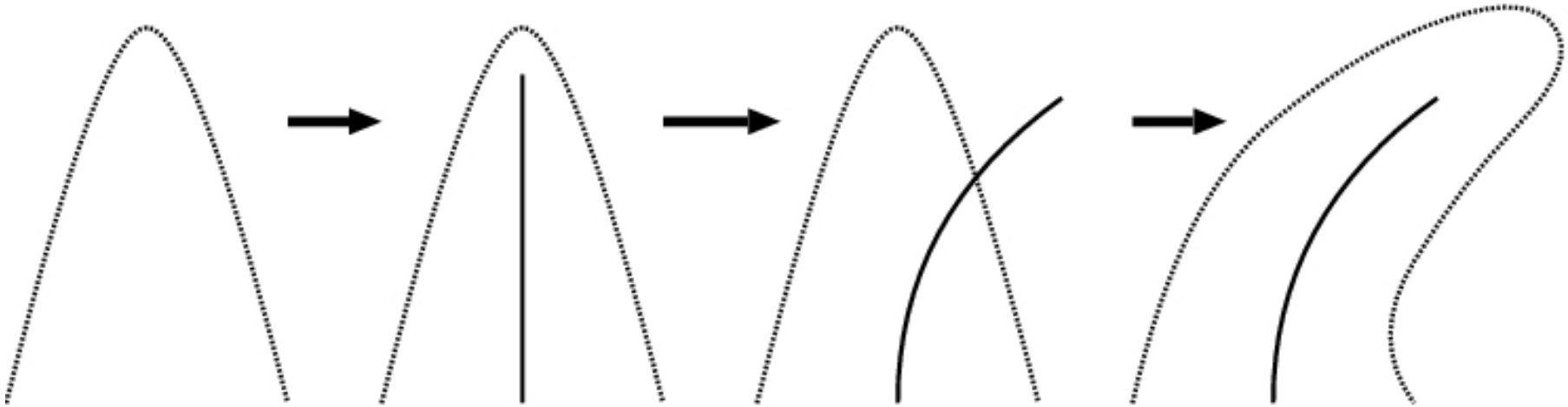
User Specifications

- Line or curve features

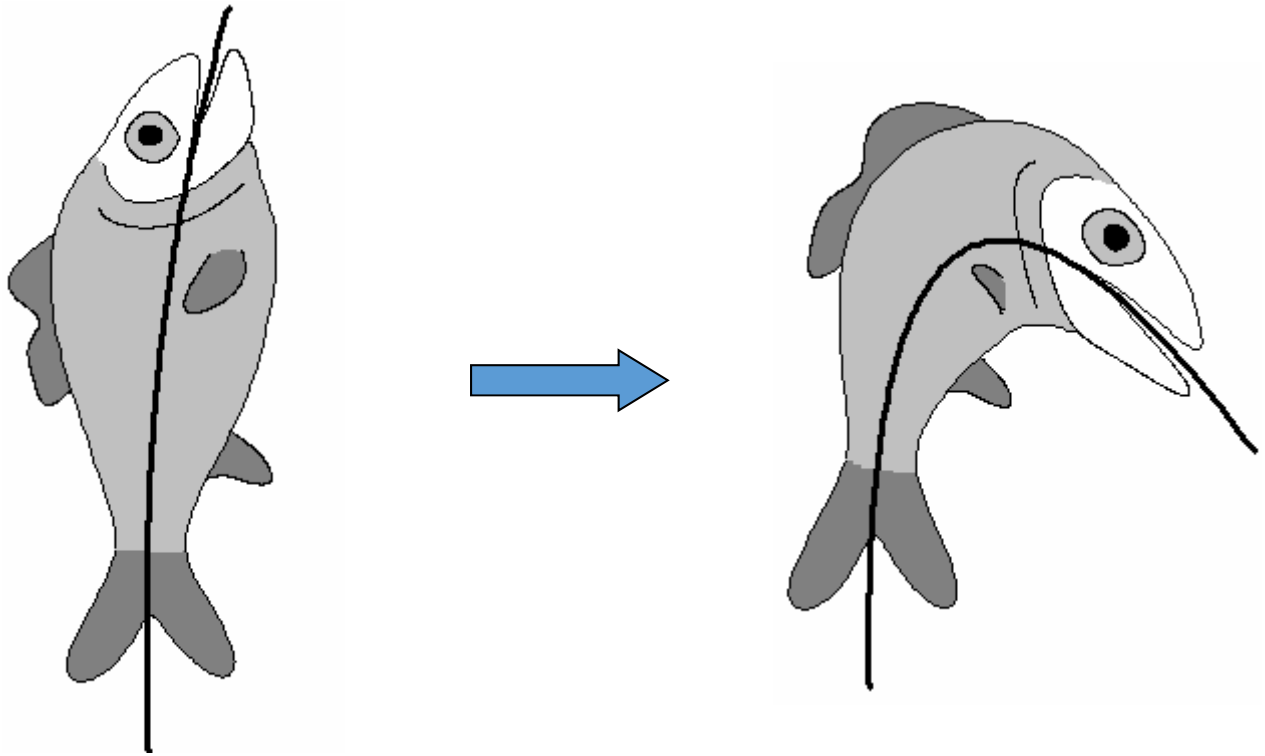


2.1 Skeleton based

- Axial Deformation [1994]

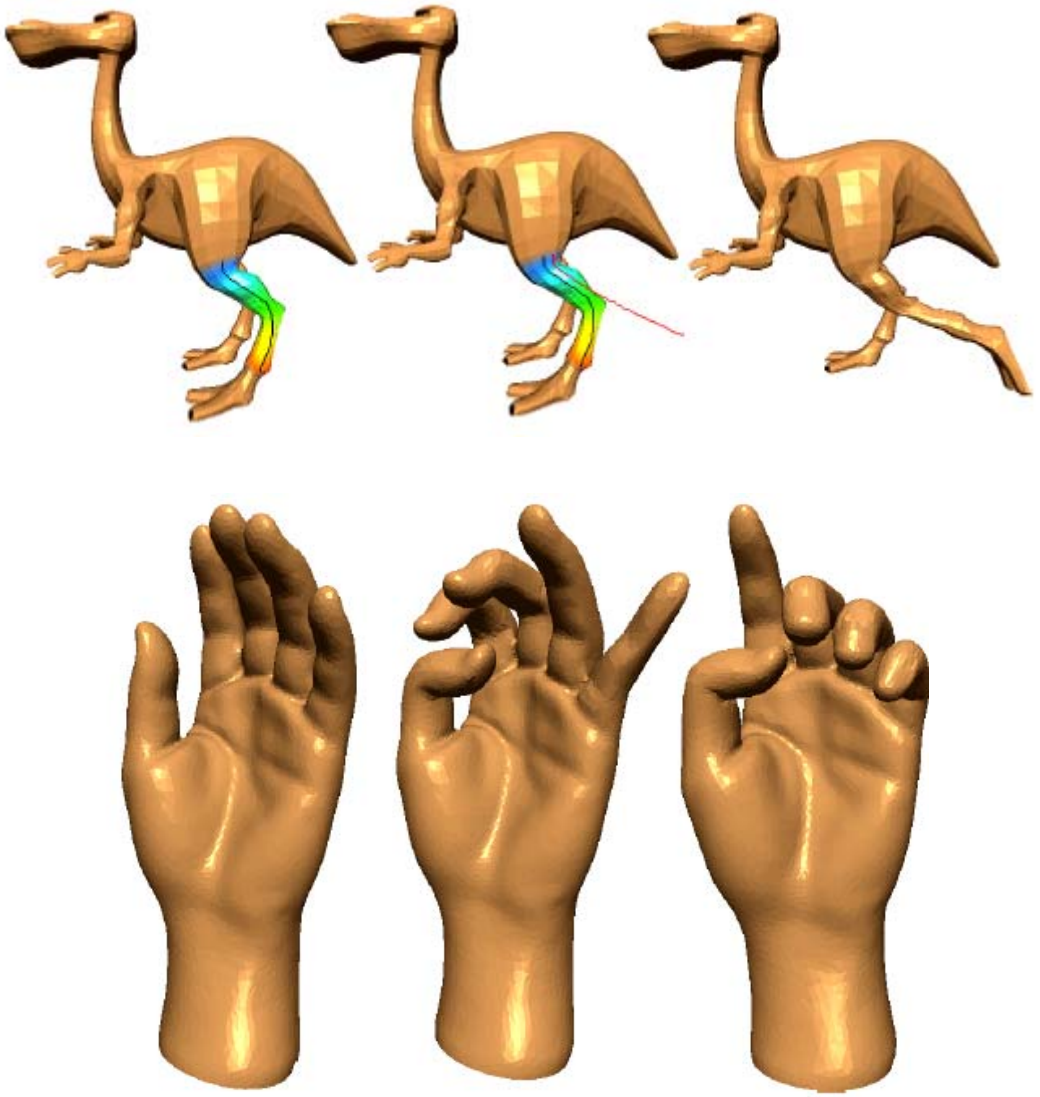


Axial Deformation

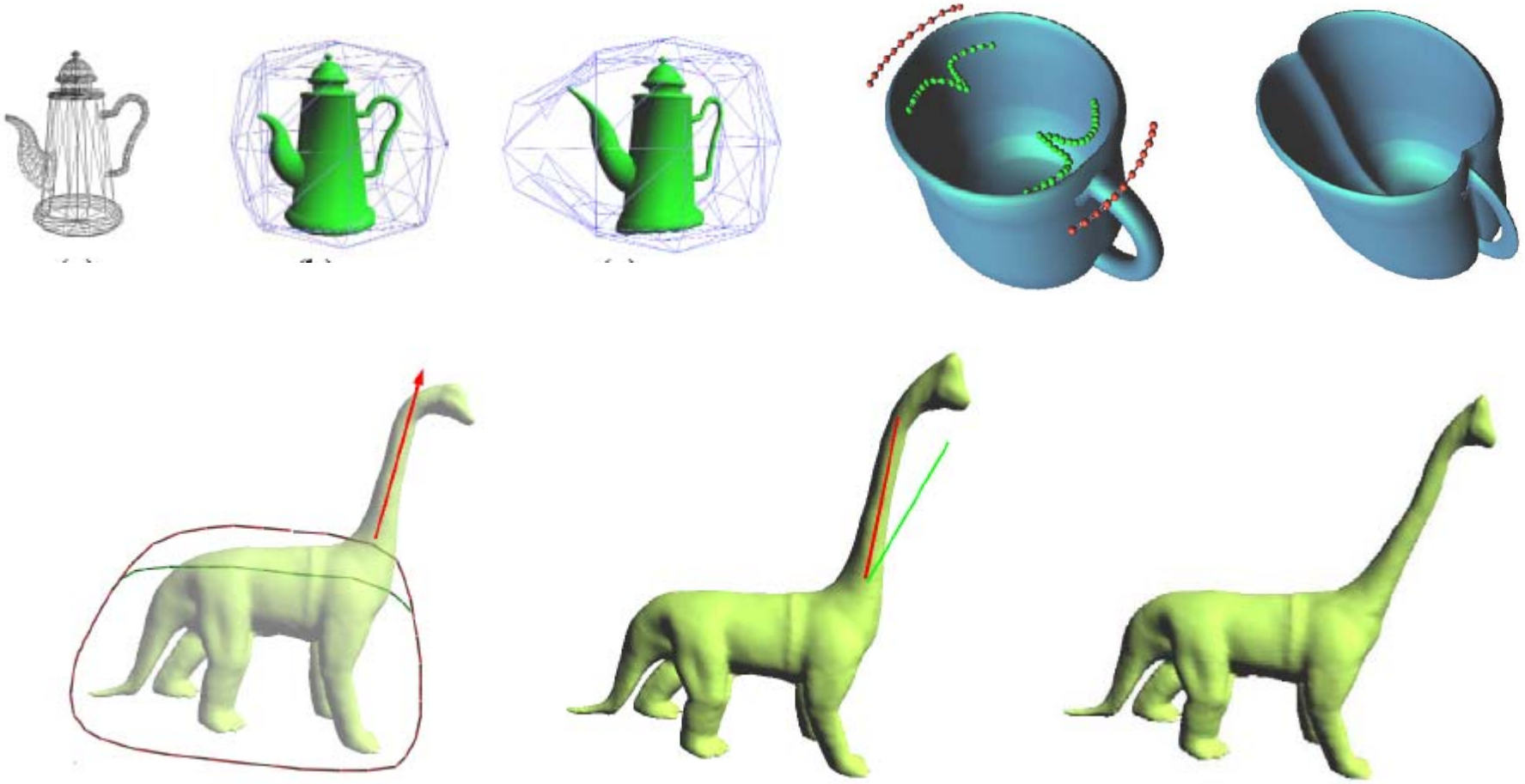


2.2 Sketching Deformations

[2005]

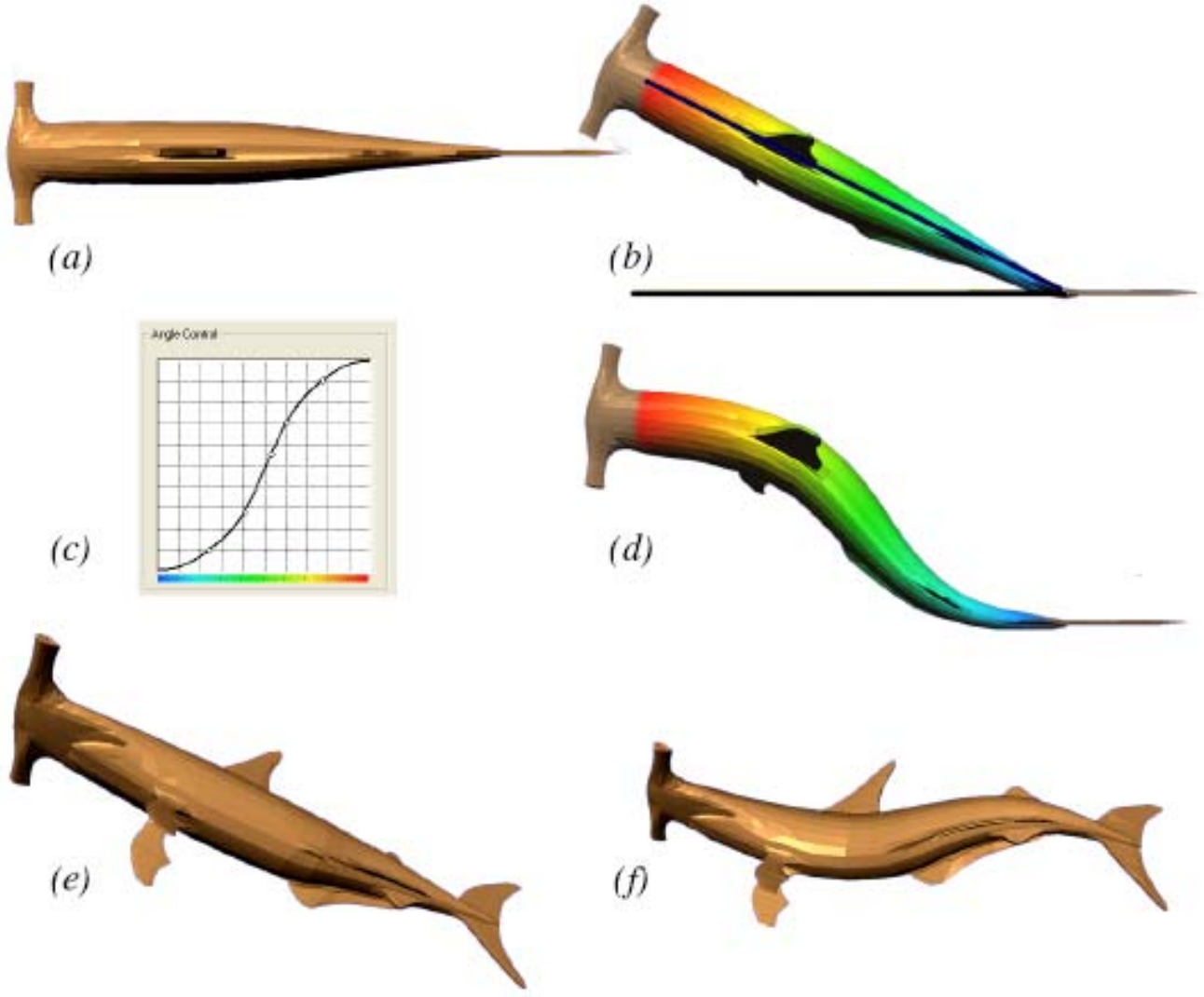


Sketching Deformation



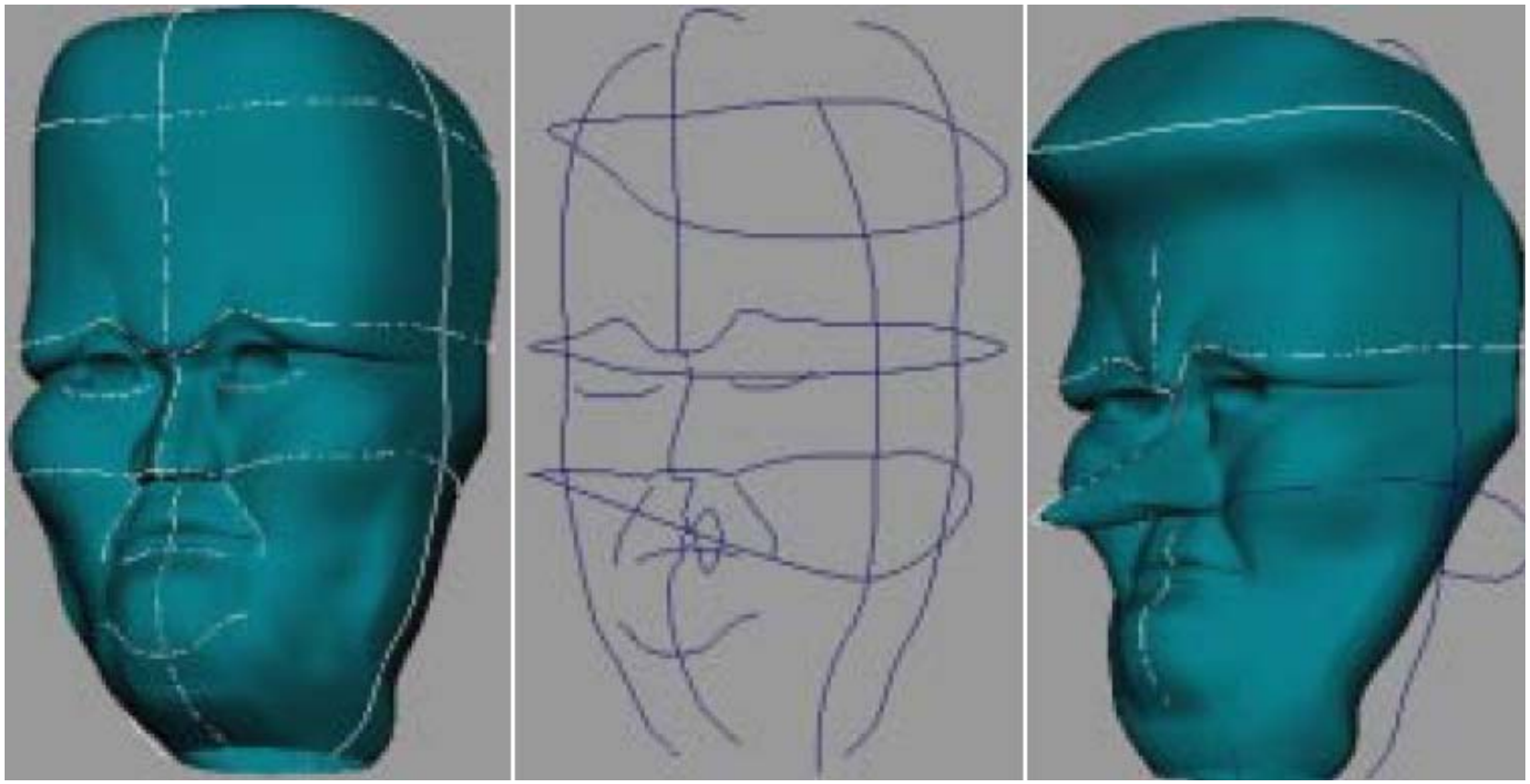
Skeleton-based Deformation

[2002]


(a)
(b)
Angle Control
(c)
(d)
(e)
(f)

2.3 Wires based

[Siggraph 1999]

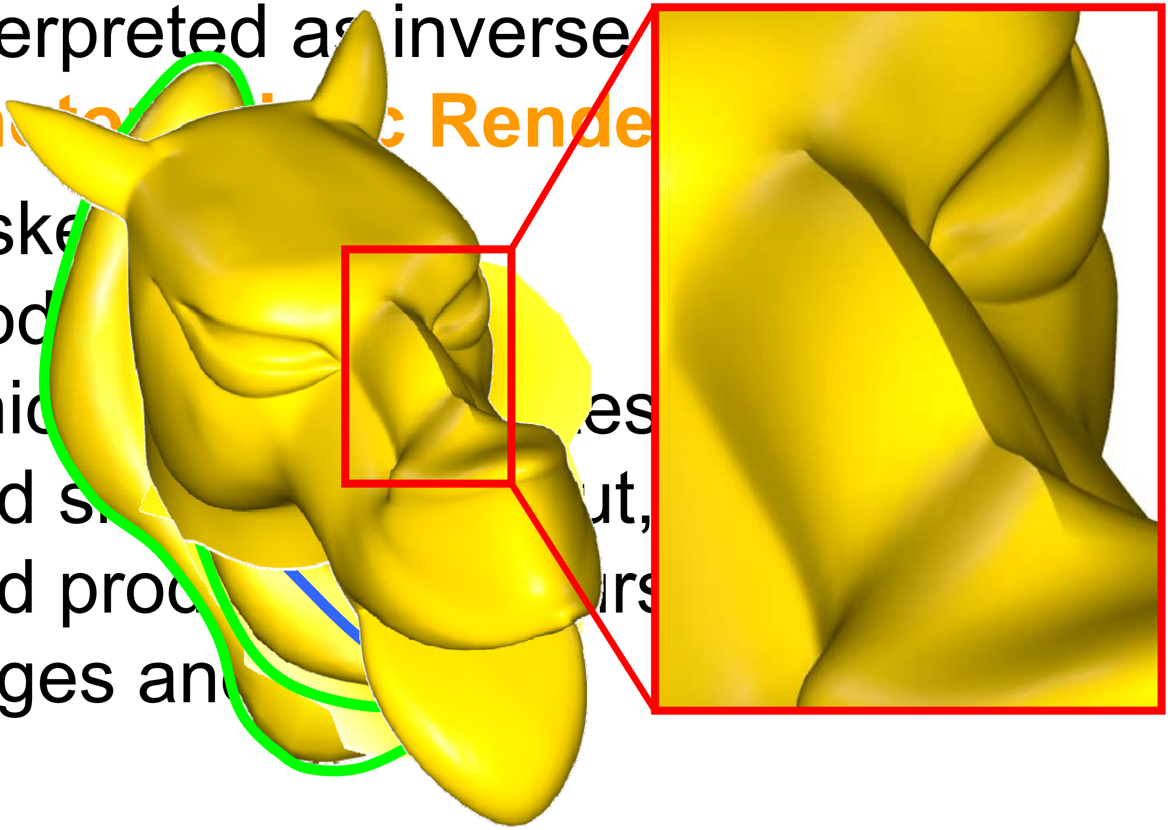


2.4 Silhouette sketching based

[Nealen et al. Siggraph 05]

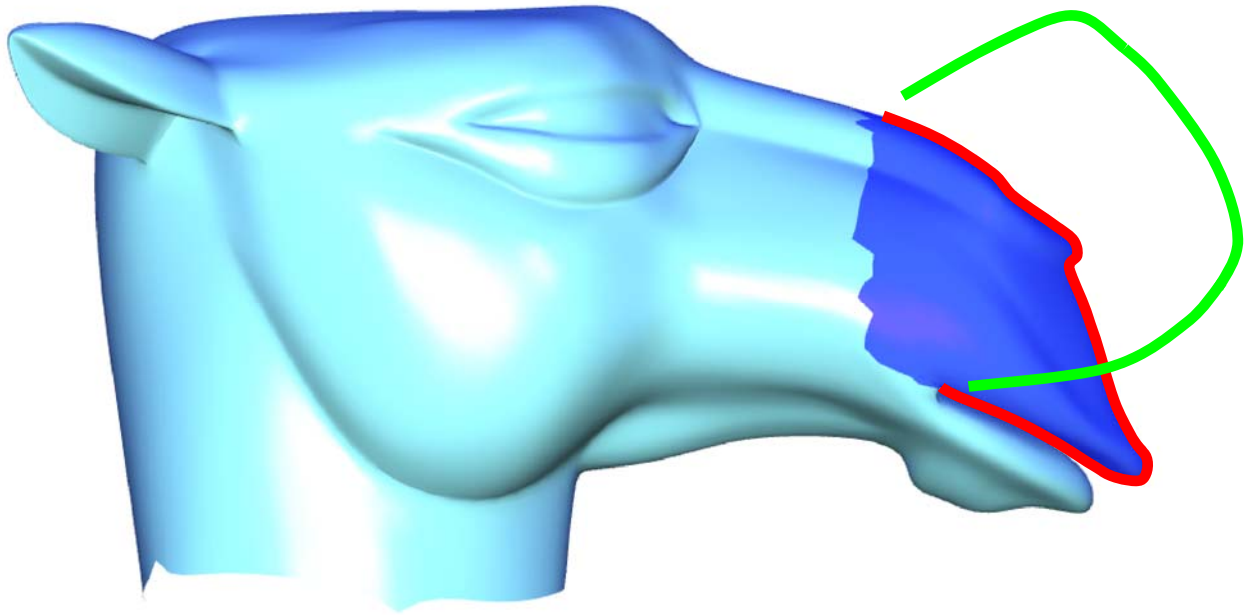
• Silhouette sketching

- ... can be interpreted as inverse ... **Ph... c Rende...**
- A ske... mod... whic... es and s... ut, and proc... rs ridges an...



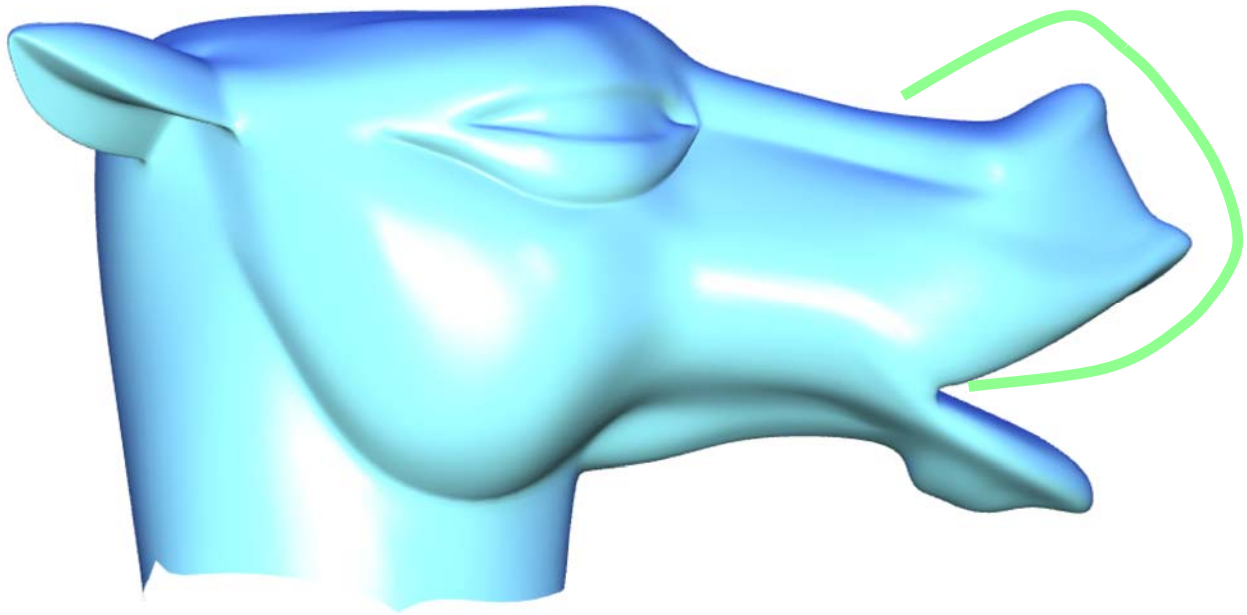
Silhouette Sketching

- Approximate sketching
  - Balance weighting between detail and positional constraints



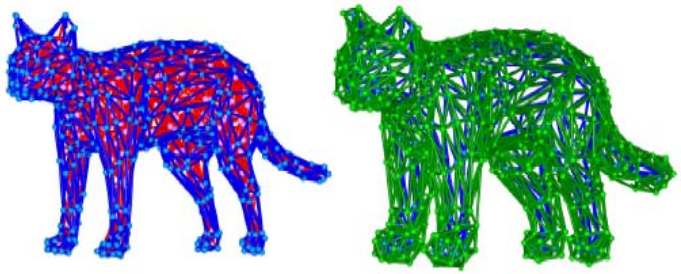
Silhouette Sketching

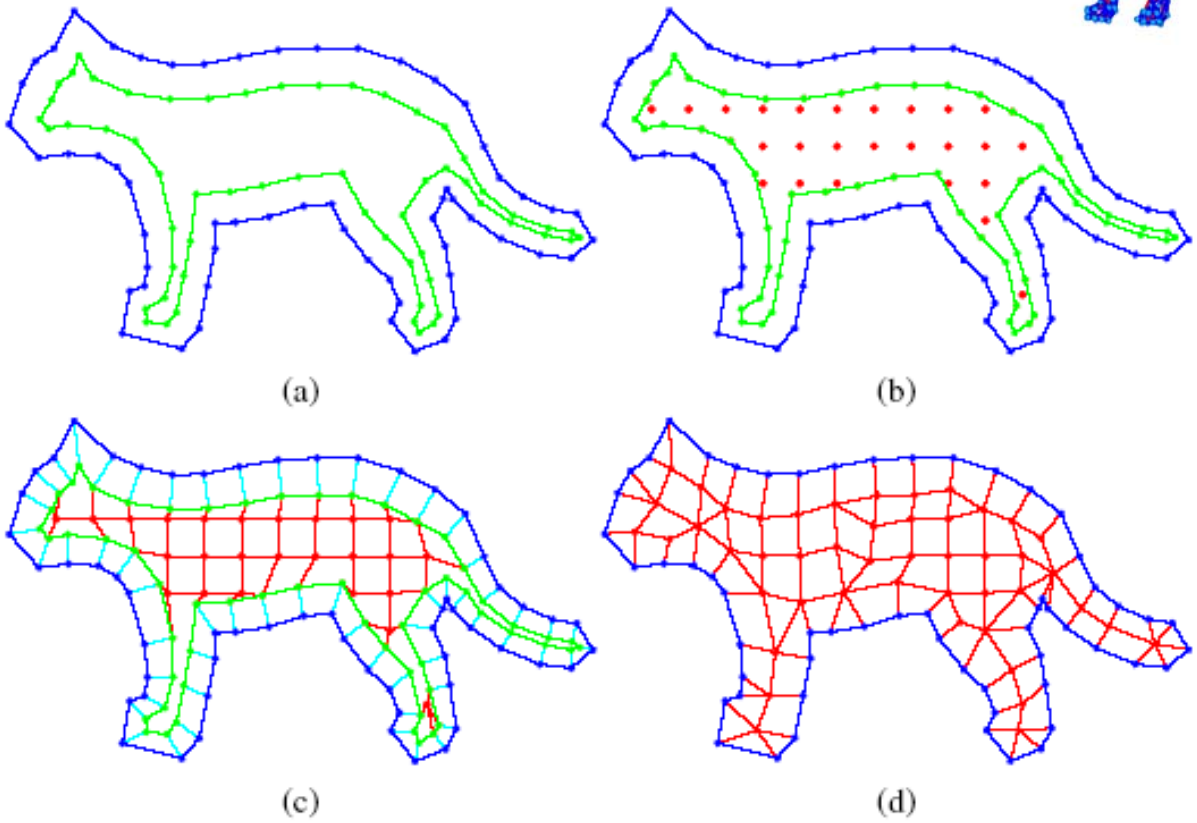
- Approximate sketching
  - Balance weighting between detail and positional constraints

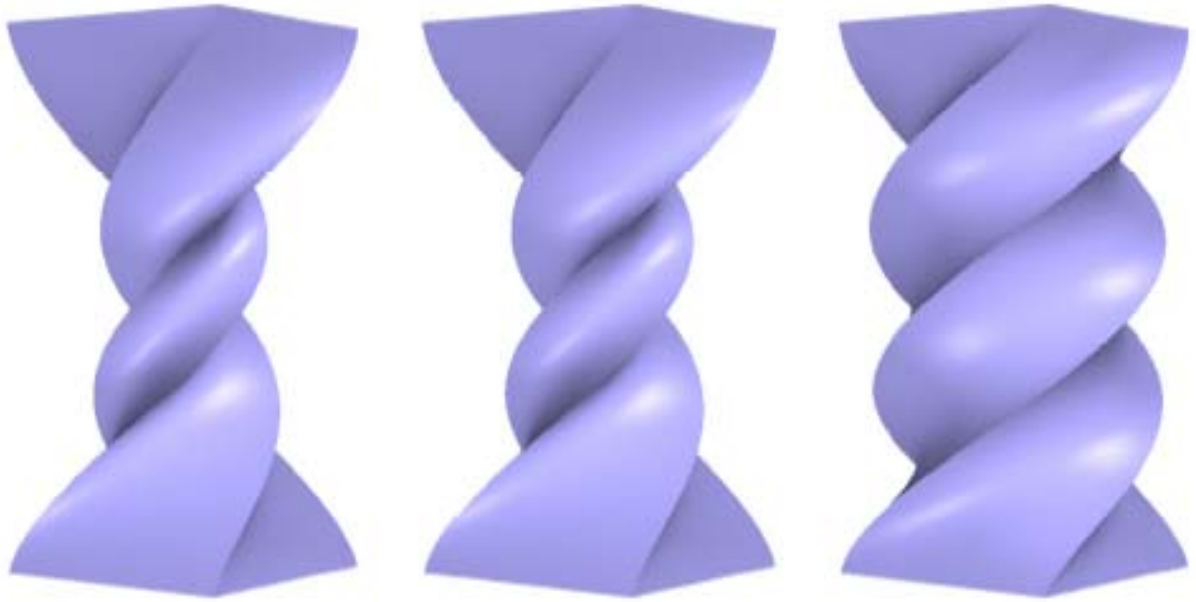


2.5 Volumetric Graph Laplacian

[Zhou et al. Siggraph 2005]



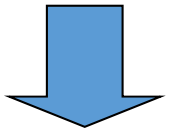


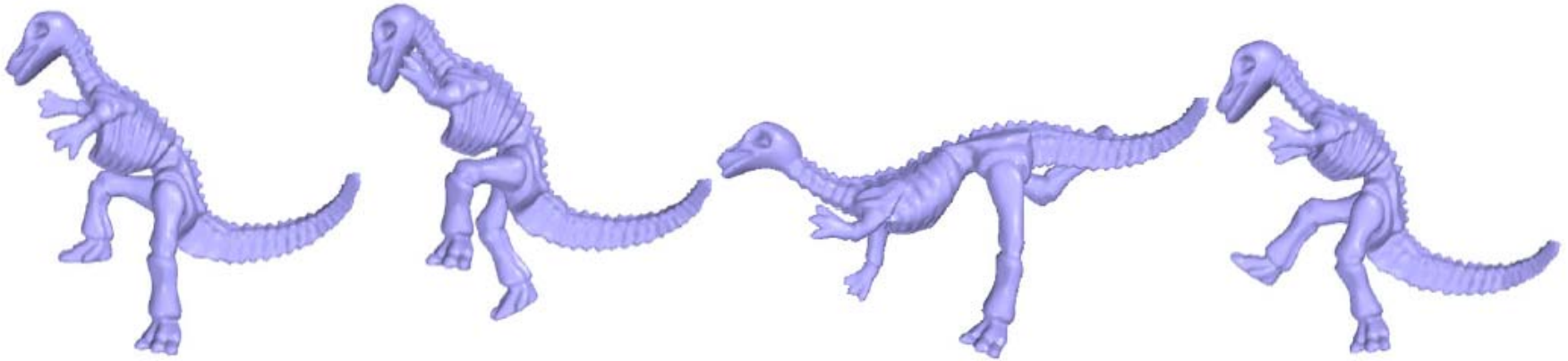


(a) Laplacian surface (b) Poisson mesh (c) VGL

(a) Laplacian surface (b) Poisson mesh (c) VGL

Animation Modeling from 2D Cartoons





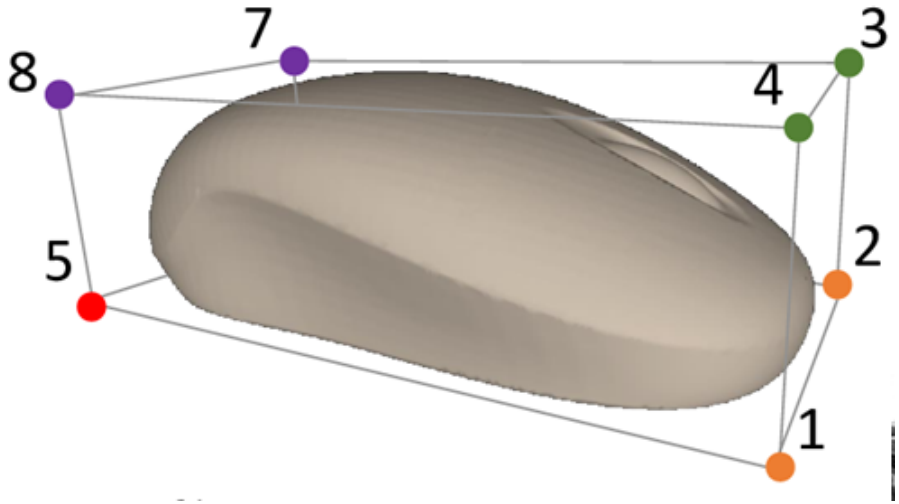
Short Summary: curve proxy

- Curve features
- Skeletons
- Silhouette
- Free-form sketches
- Wires
- 2D image contours
- …

3. Mesh Proxy

User Specifications

- Define a mesh proxy for the shape: generally a simpler, coarse mesh which encloses the shape
  - The shape is embedded into the mesh proxy
- Deform the mesh proxy using point/line base methods
- Advantages:
  - You can deform arbitrary objects
  - Independent of object representation



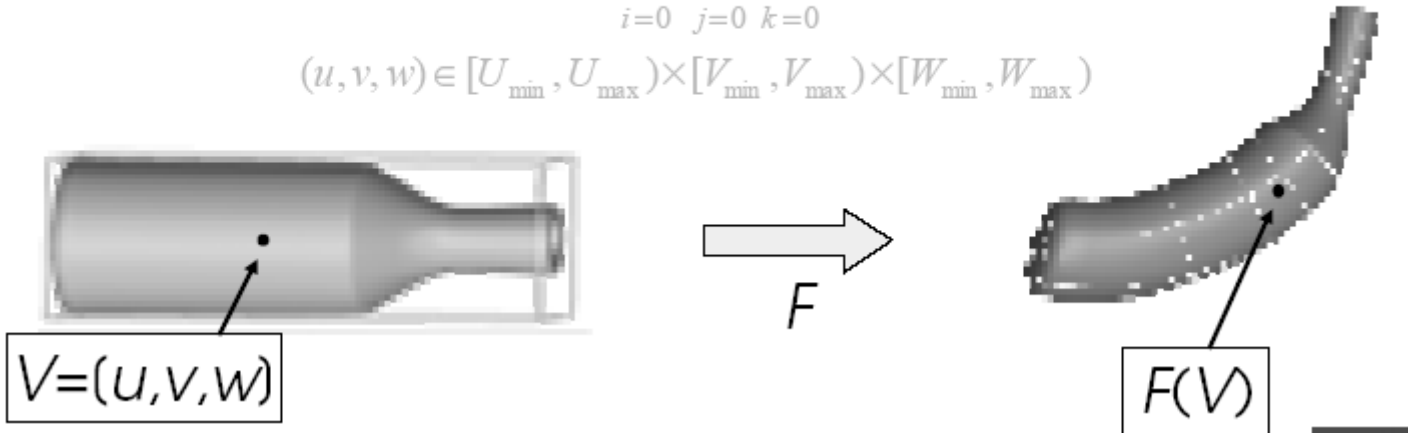
3.1 Free-form Deformation (FFD)

[Sederberg et al. 86]

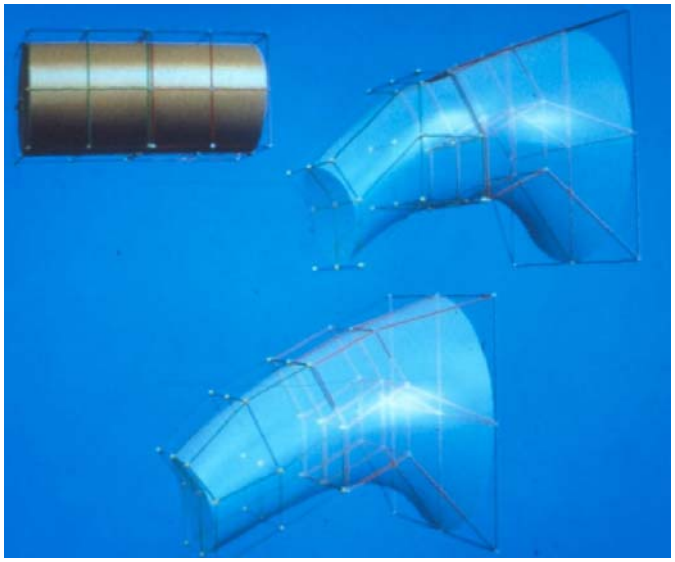
- Proxy: a **lattice** mesh
  - more easily parametrized than the object
  - Deformation defined by the tensor Bezier solid

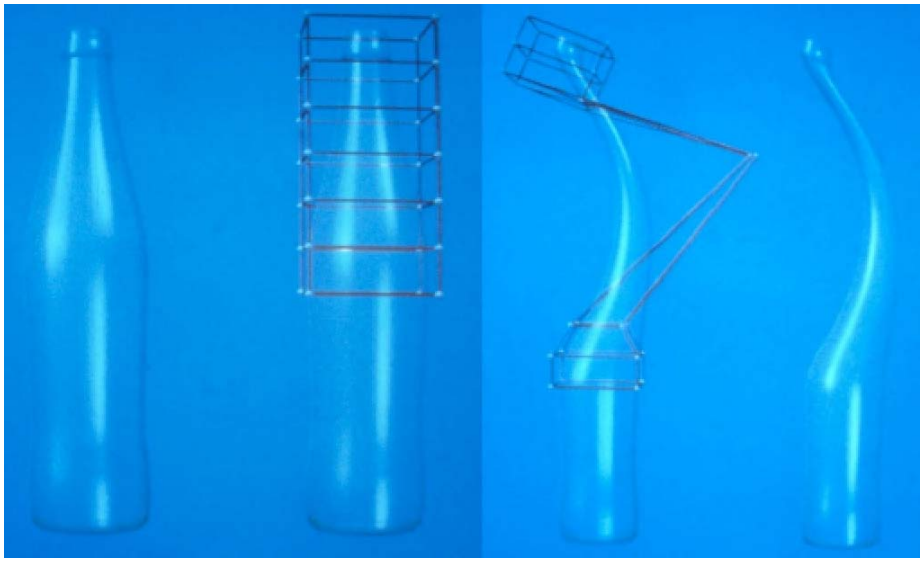
$$X_{new} = F(u,v,w) = \sum_{i=0}^{l}\sum_{j=0}^{m}\sum_{k=0}^{n} P_{ijk} B_i(u) B_j(v) B_k(w)$$

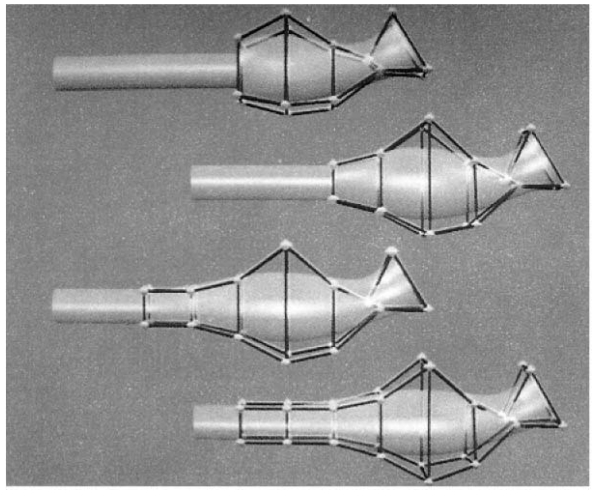
$$(u,v,w) \in [U_{\min}, U_{\max}) \times [V_{\min}, V_{\max}) \times [W_{\min}, W_{\max})$$

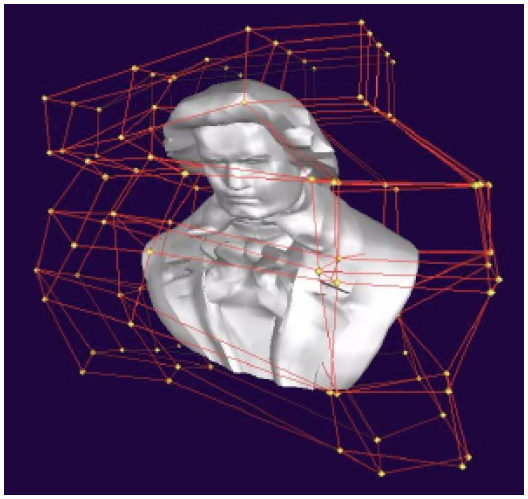


FFD Examples



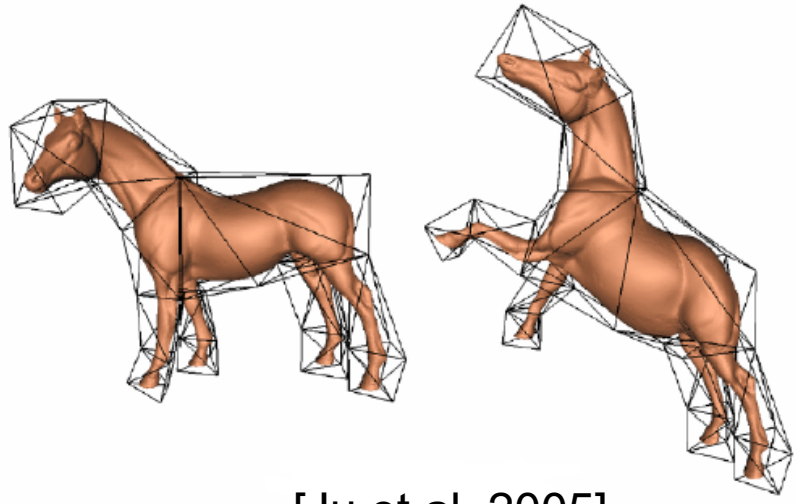




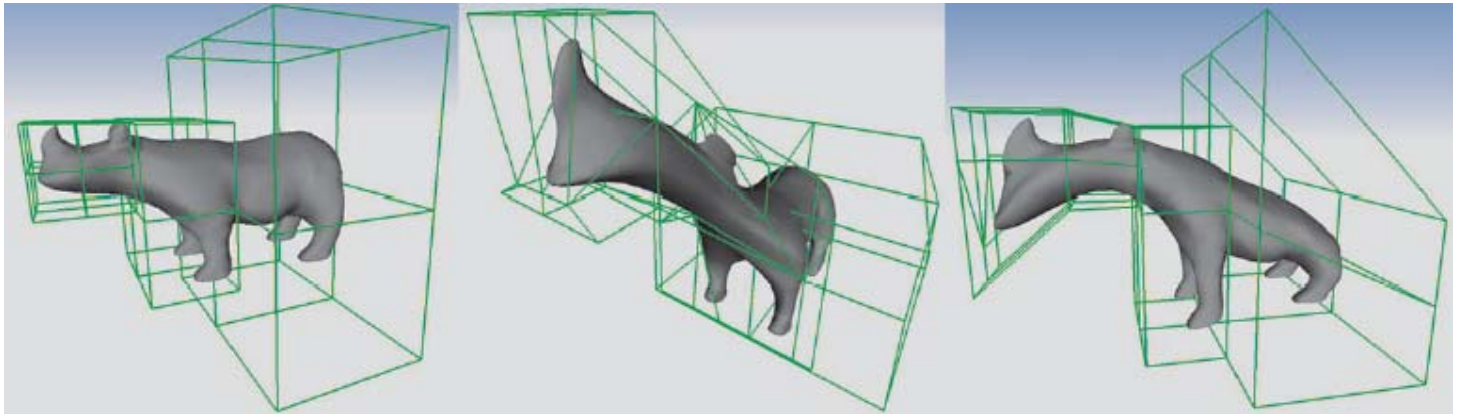


3.2 Cage-based deformation

- Proxy: cage
  - Barycentric coordinates
  - Many works…



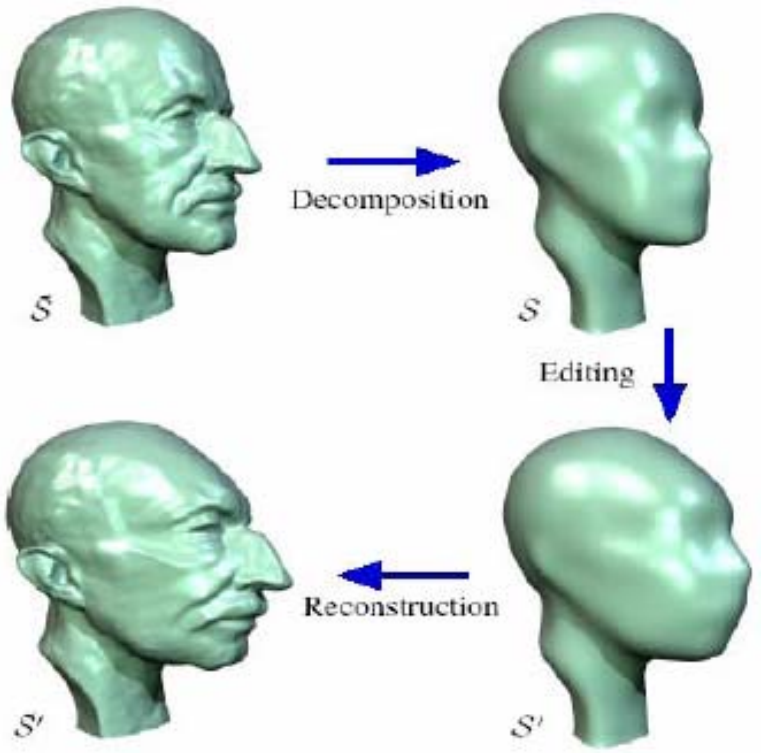
[Ju et al. 2005]



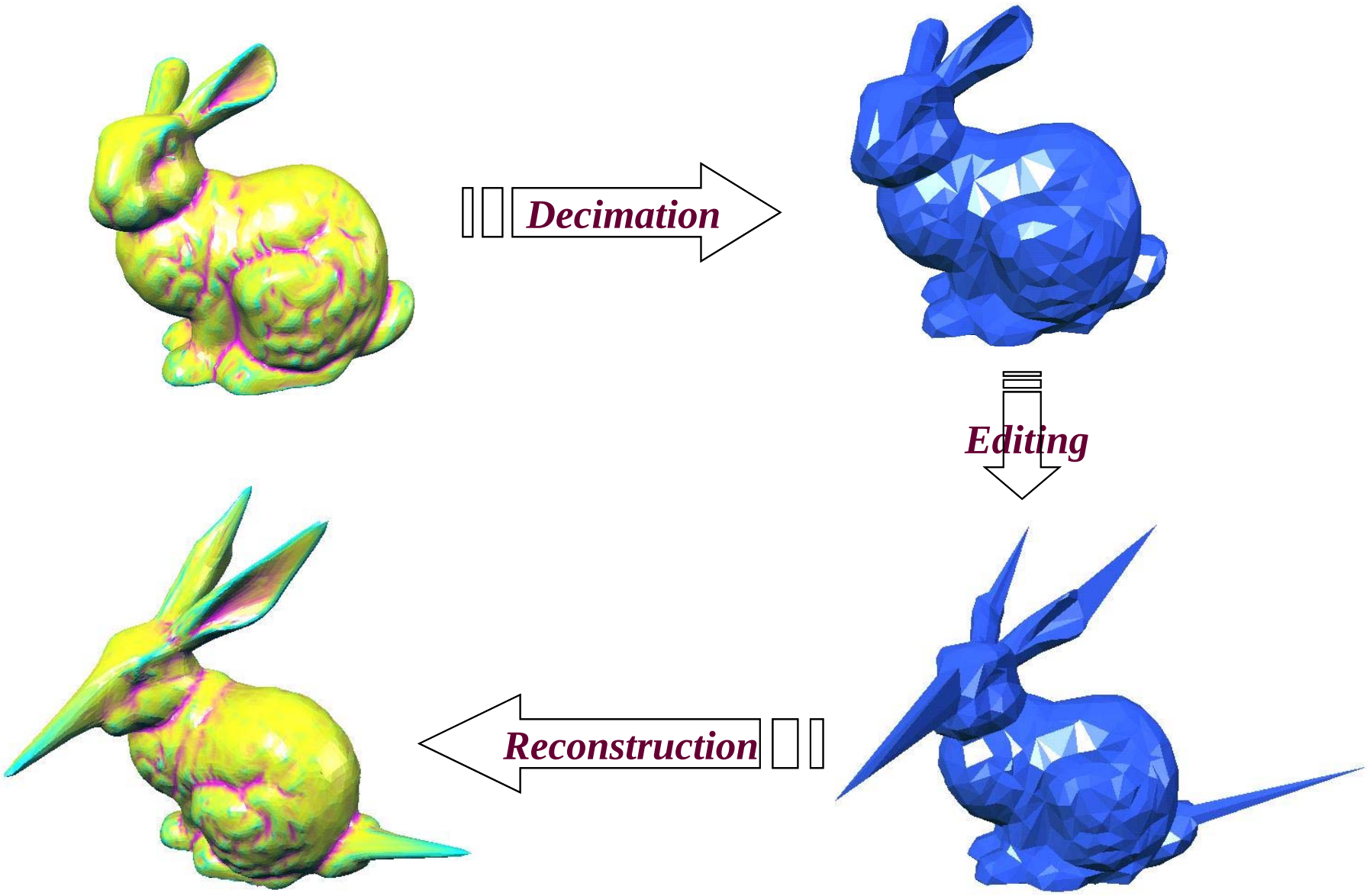
3.3 Multiresolution Editing

- Proxy: simplified shape

- Pros
  - Preserving details, scalable
- Cons
  - Instable reconstruction for large deformation
  - Resampling problem
- Invariant variables
  - Detail information



[Kobbelt et al. 2003]


Decimation
Editing
Reconstruction

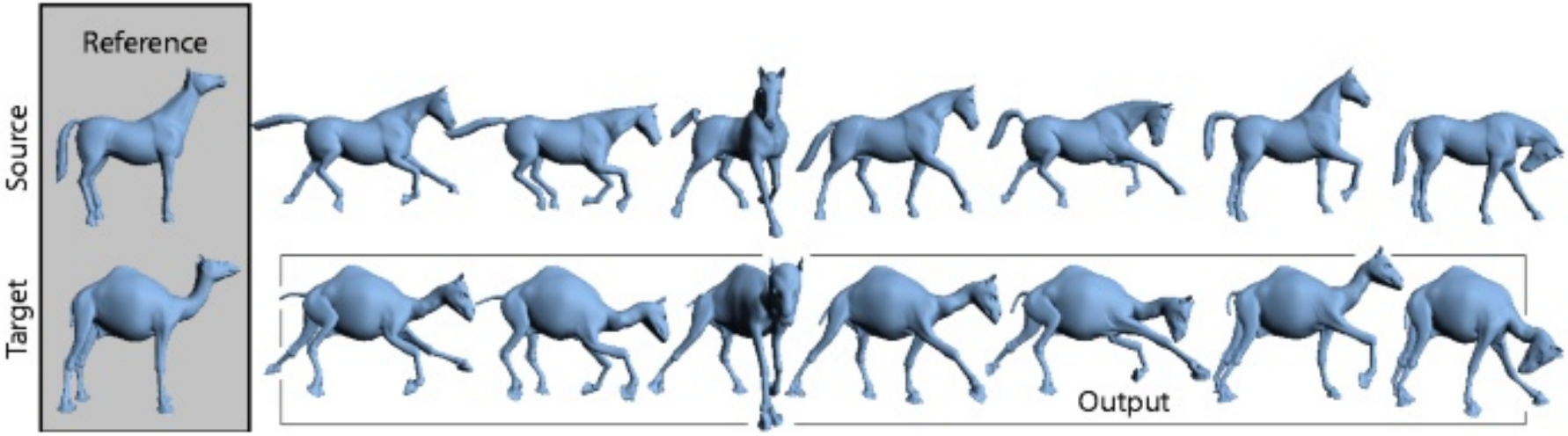
Short Summary: mesh proxy

- Lattice
- Cage
- Simplified shape
- …

4. Deformation Transfer

Deformation Transfer

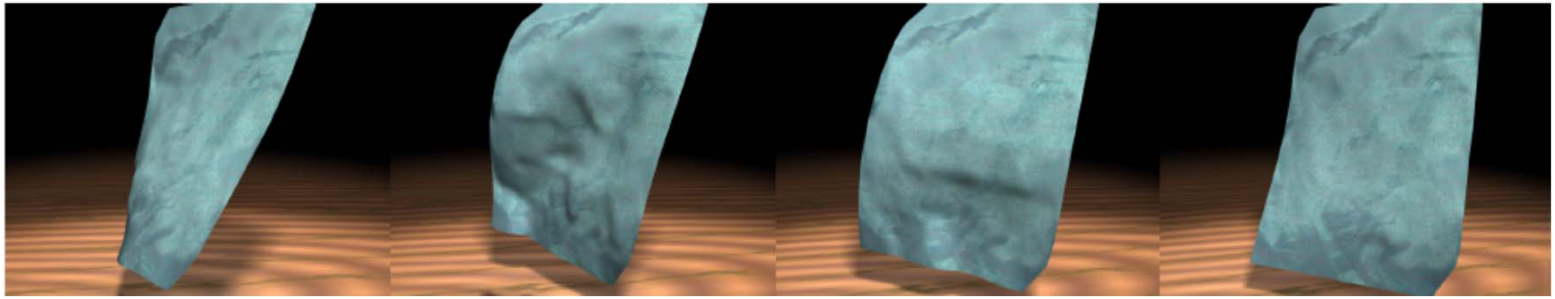
Siggraph 2004



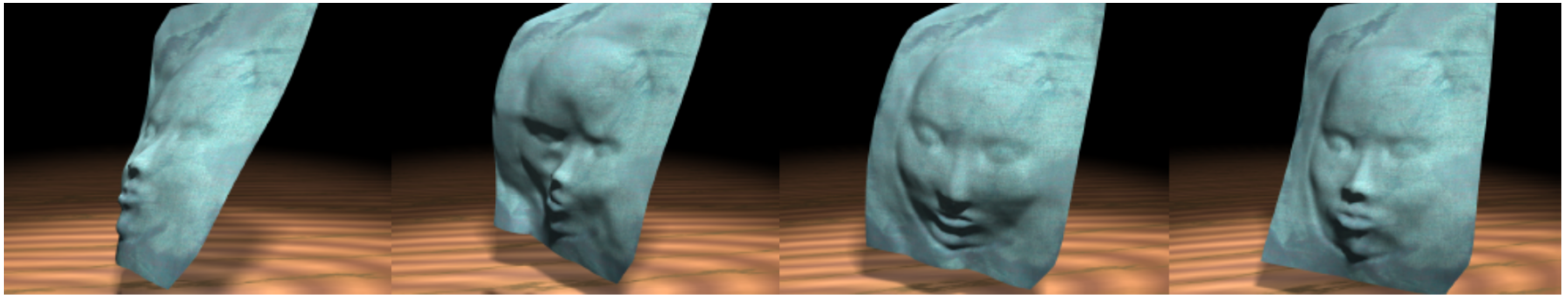
Editing Arbitrary Deforming Surface Animations

Siggraph 2006

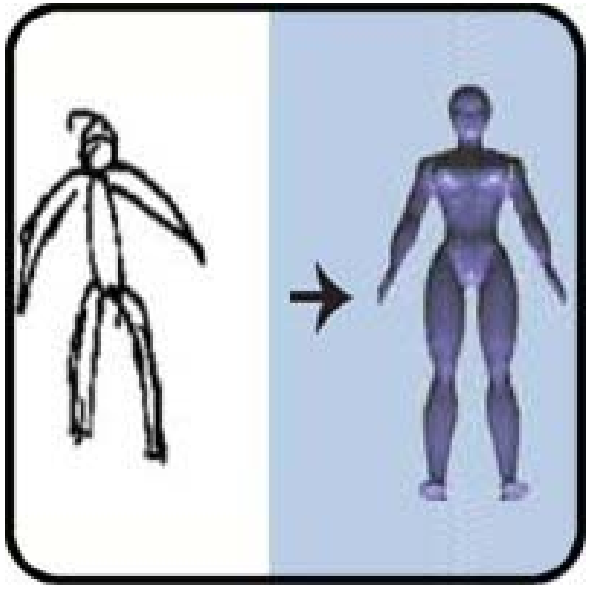
Deforming Surface



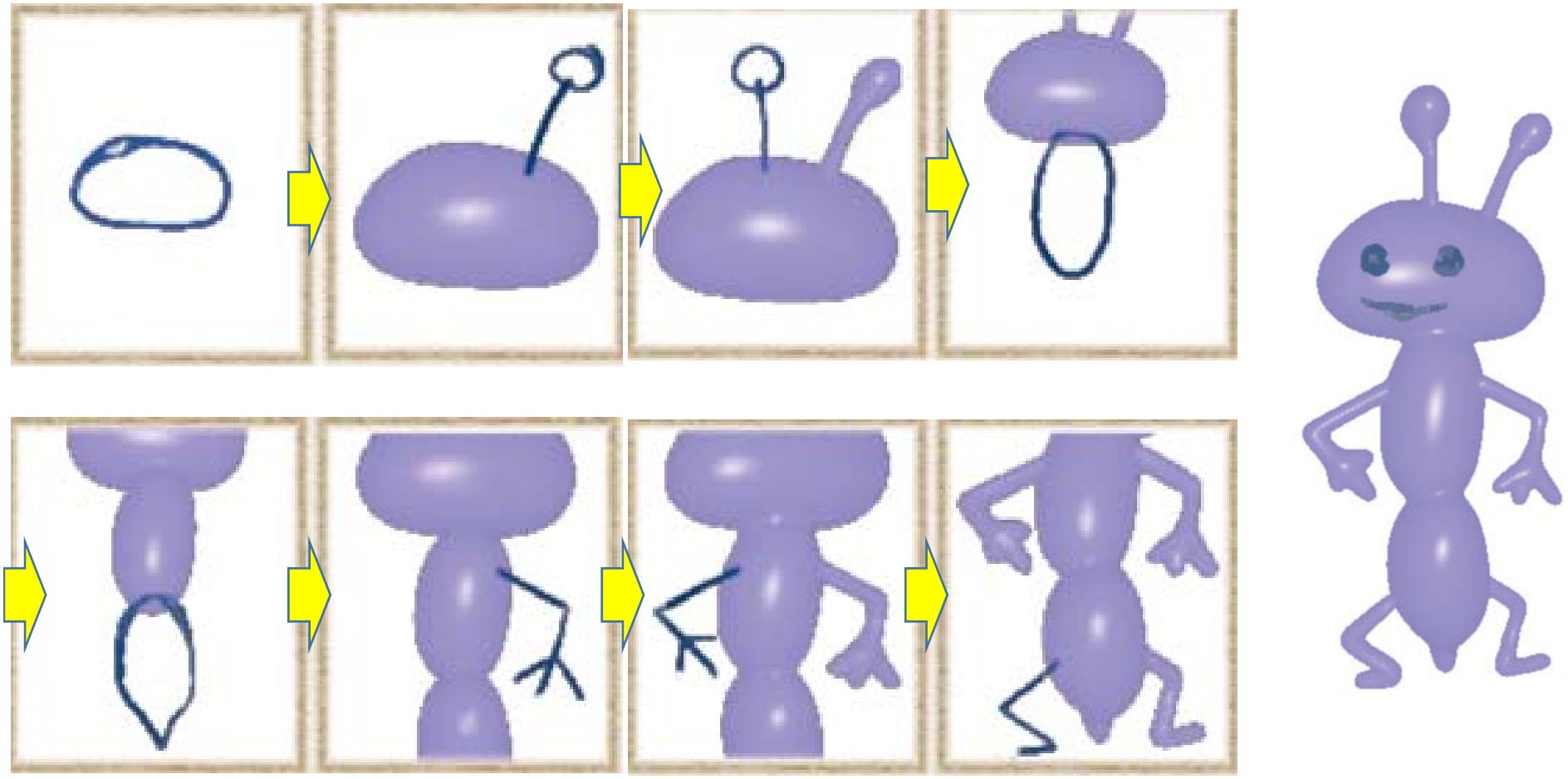
Editing Surface



5. Sketch-based Modeling
(基于草图的建模)

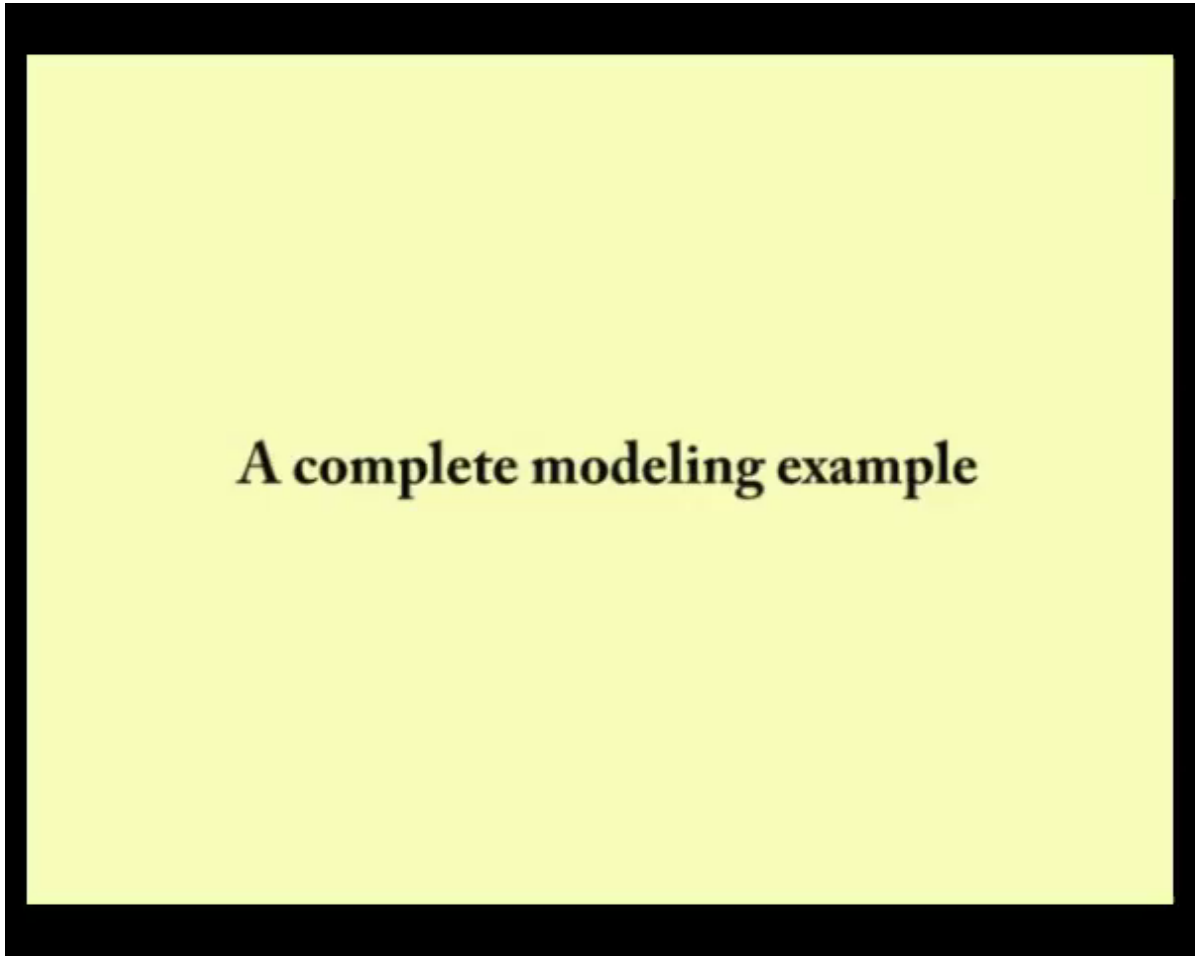


An Example



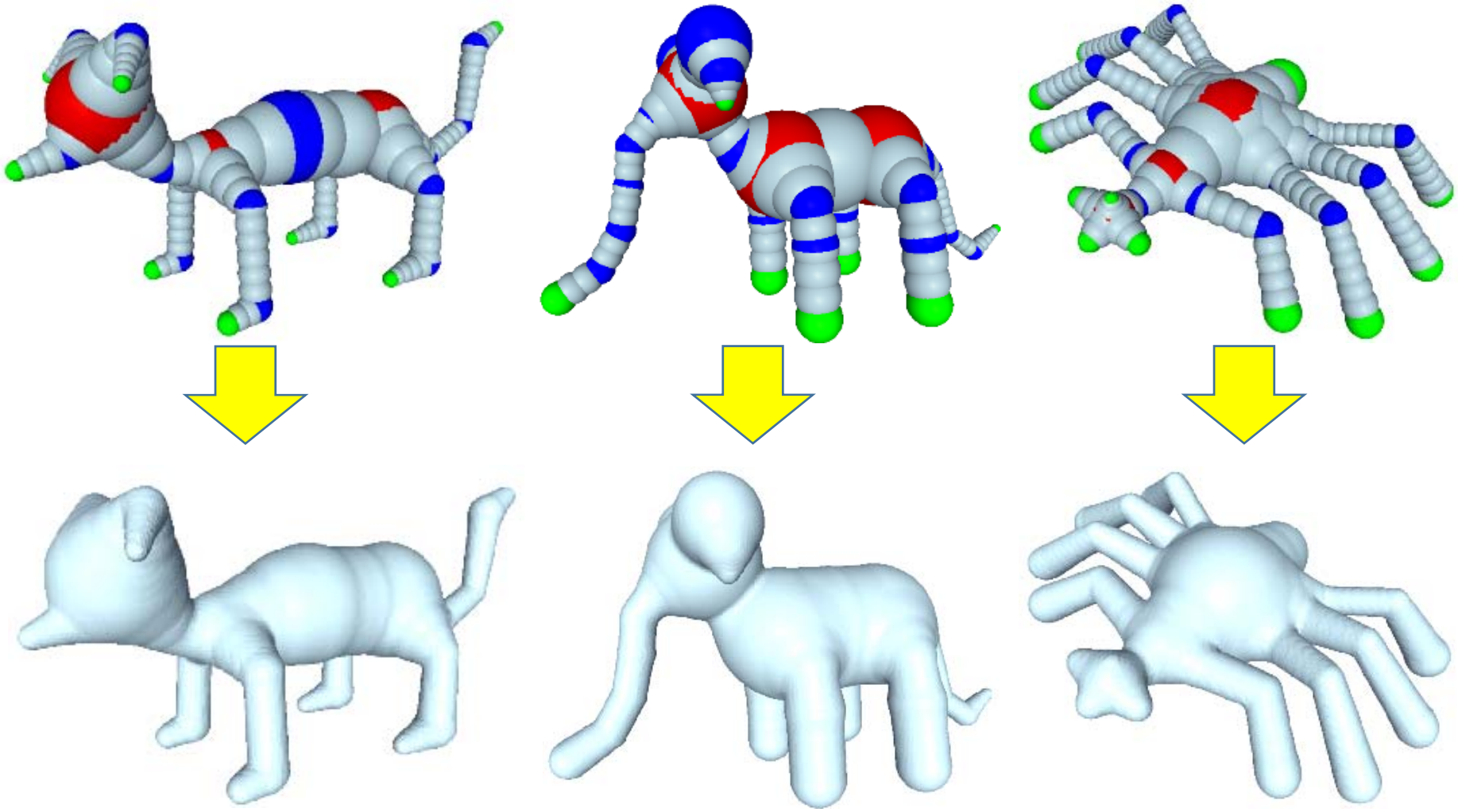
B-Mesh

[Ji et al. 2010]

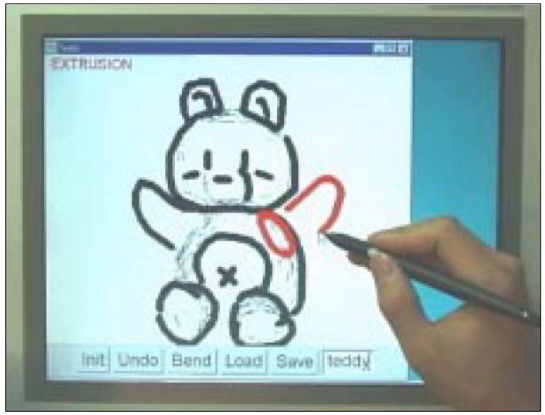


B-Mesh

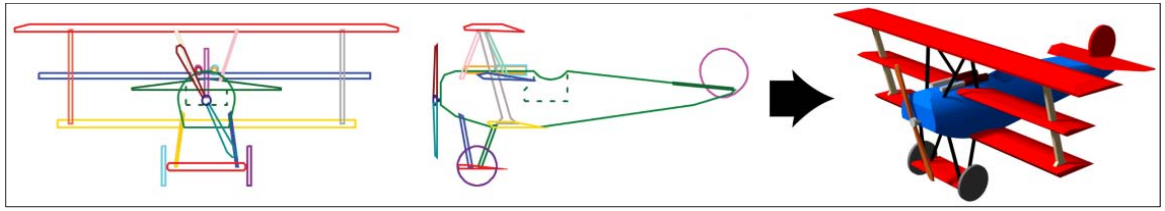
[Ji et al. 2010]



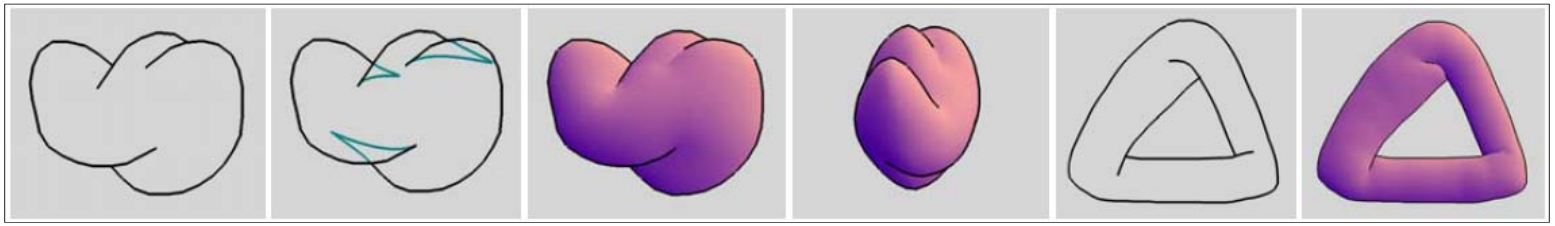
Sketch-based Modeling Systems



[Igarashi et al. 1999]



[Rivers et al. 2010]



[Karpenko et al. 2006]

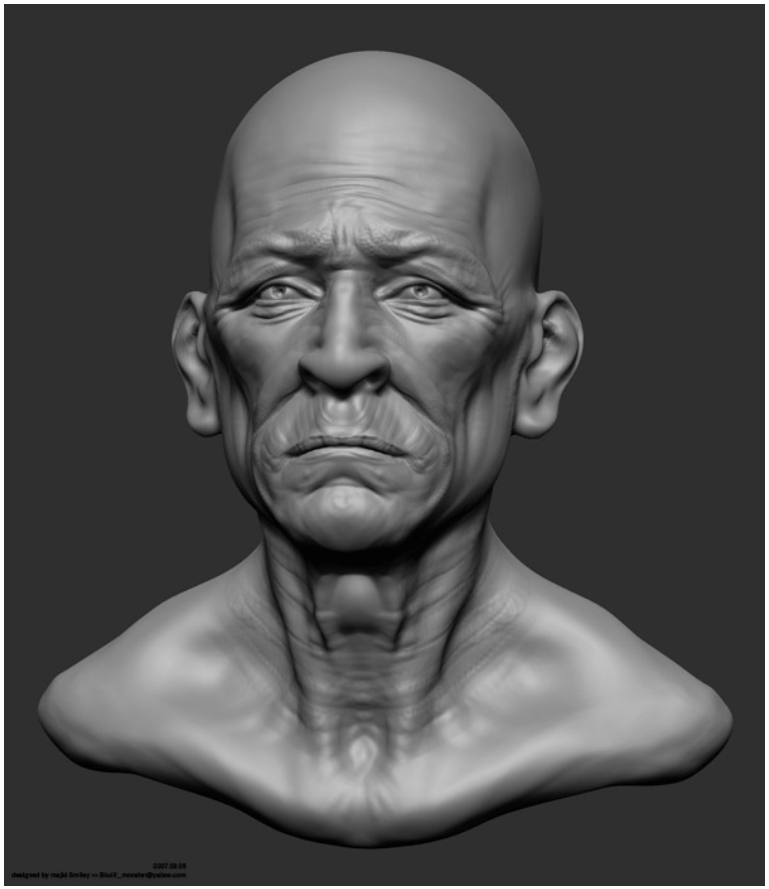
More…

Sketch2Scene [Xu et al. 2013]

Sketch-to-Design [Xie et al. 2013]

6. Sculpturing Modeling

Highly Detailed Meshes



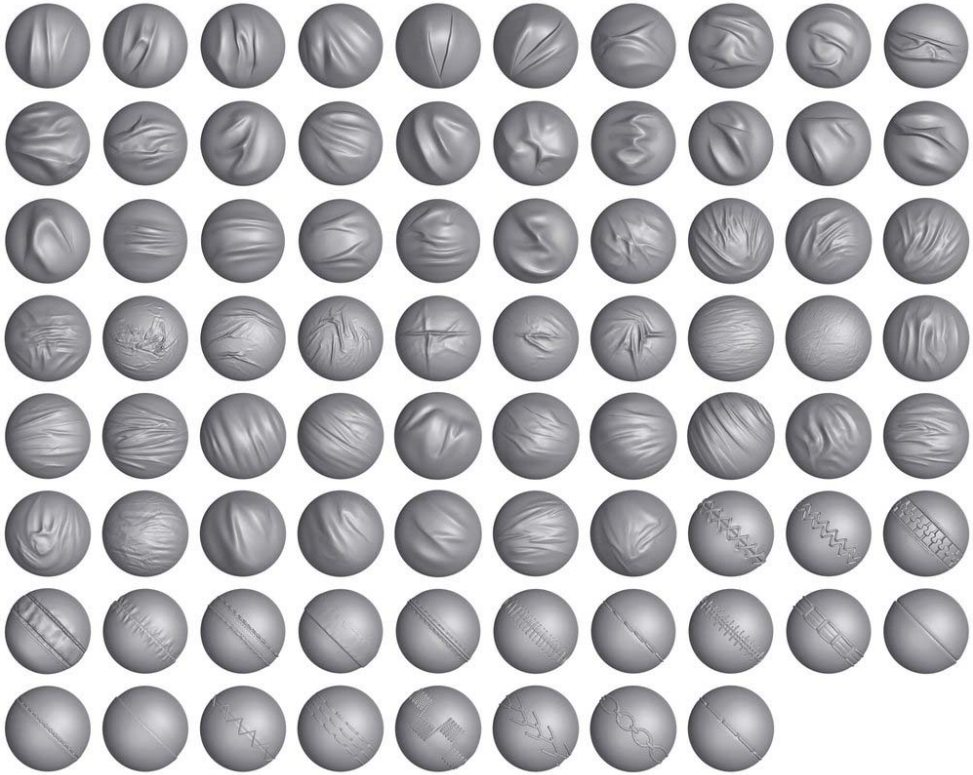
Motivation: Sculpturing

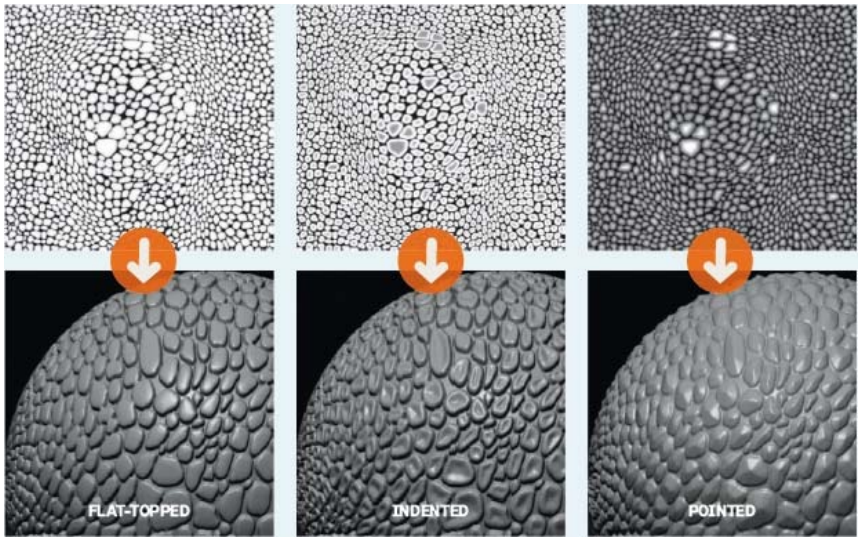
Sculpturing Modeling

- A series of sculpting/brush operators

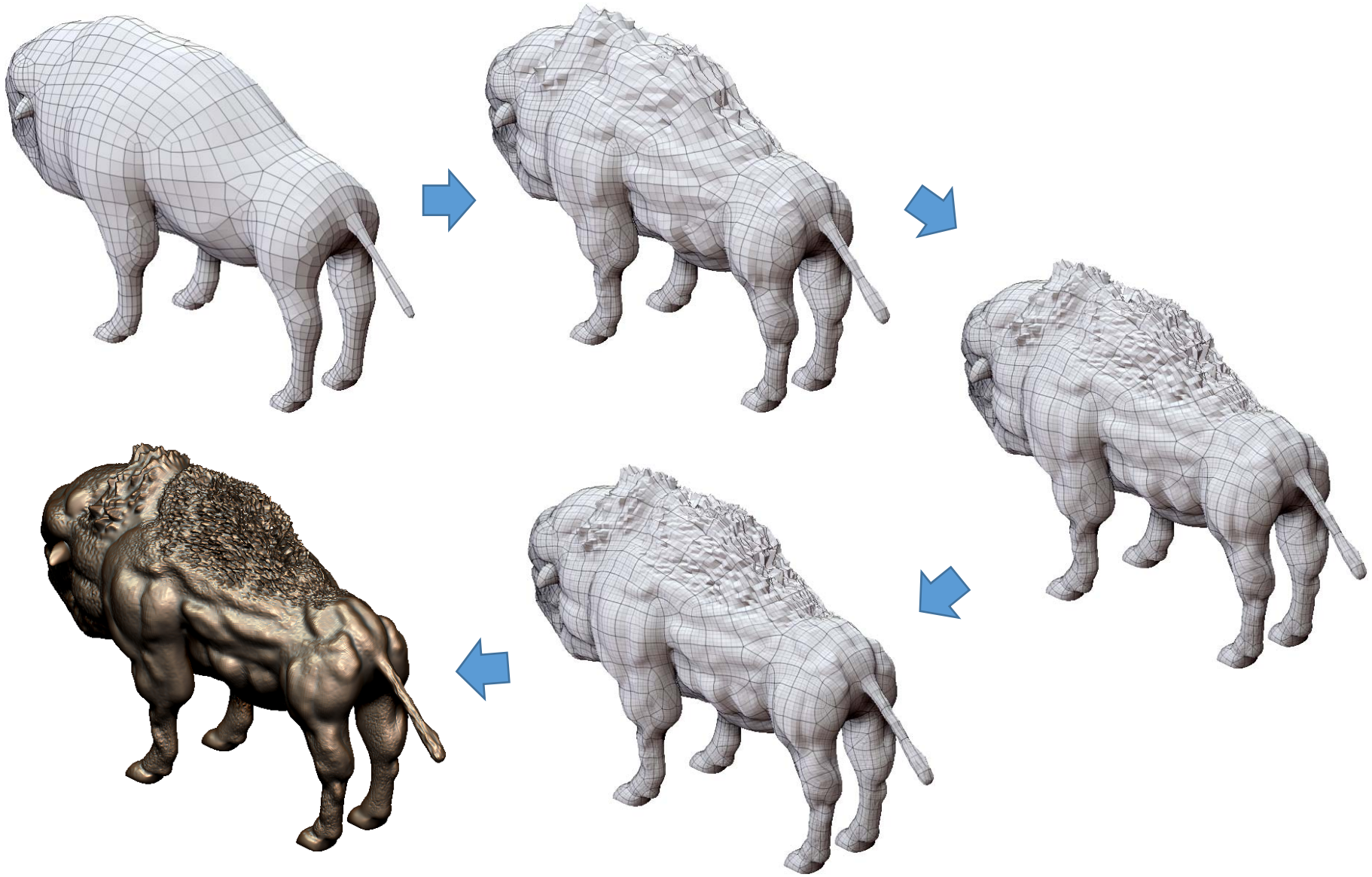
Sculpting Modeling Tools

3D Brushes





Sculpting Modeling



Summary: Shape Editing

- Points
  - Points, vertices, …
- Lines/Curves
  - Sketches, skeletons, silhouettes, wires, …
- Meshes
  - Bezier nets, lattices, cages, …
- Other shapes
  - Deformation transfer: learning deformation from other shapes
- Physically-based shape deformation (*)
  - Material-based, FEM, simulation

中国科学技术大学
University of Science and Technology of China

Data-Driven Modeling

三维几何模型数据库

1. Modeling by Examples

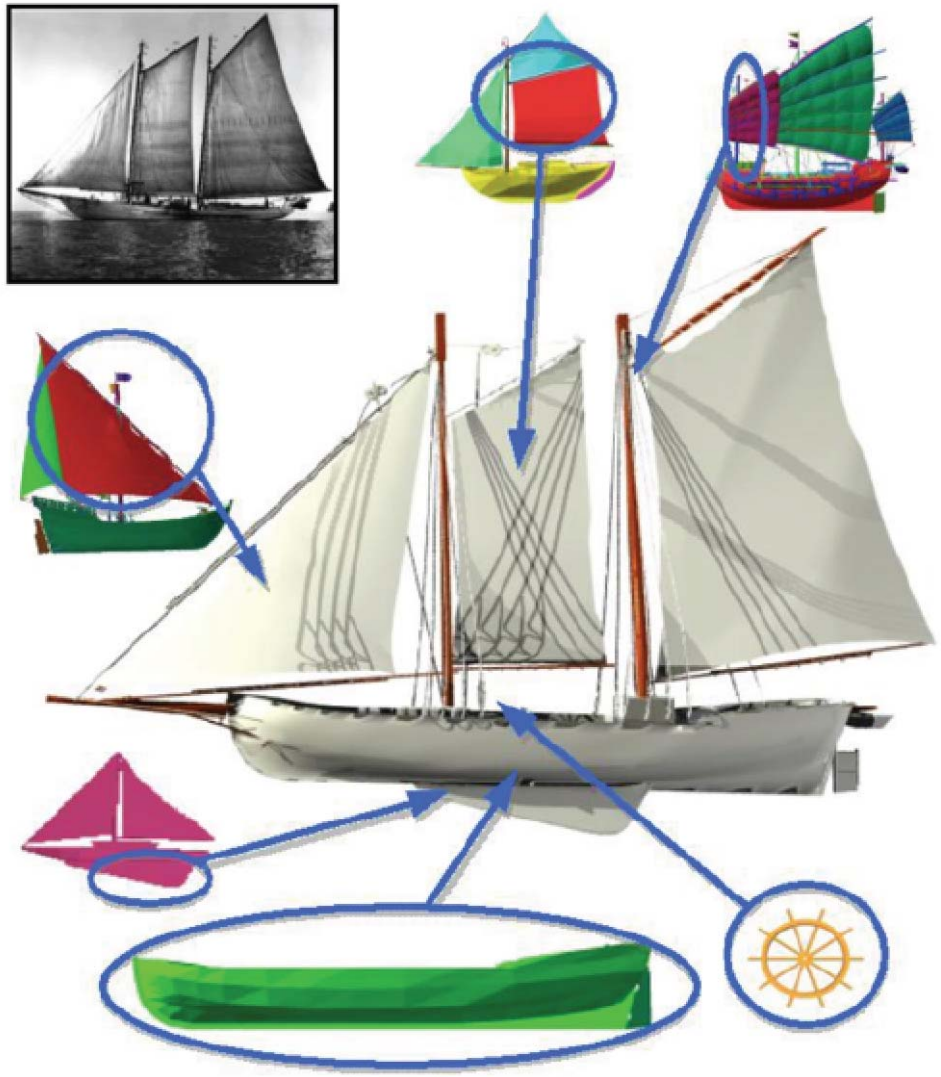
[Funkhouser et al. Siggraph 2004]

1. Segment into parts
2. Search 3D database for parts
3. Compose parts into a model

Modeling by Examples

[Funkhouser et al. Siggraph 2004]

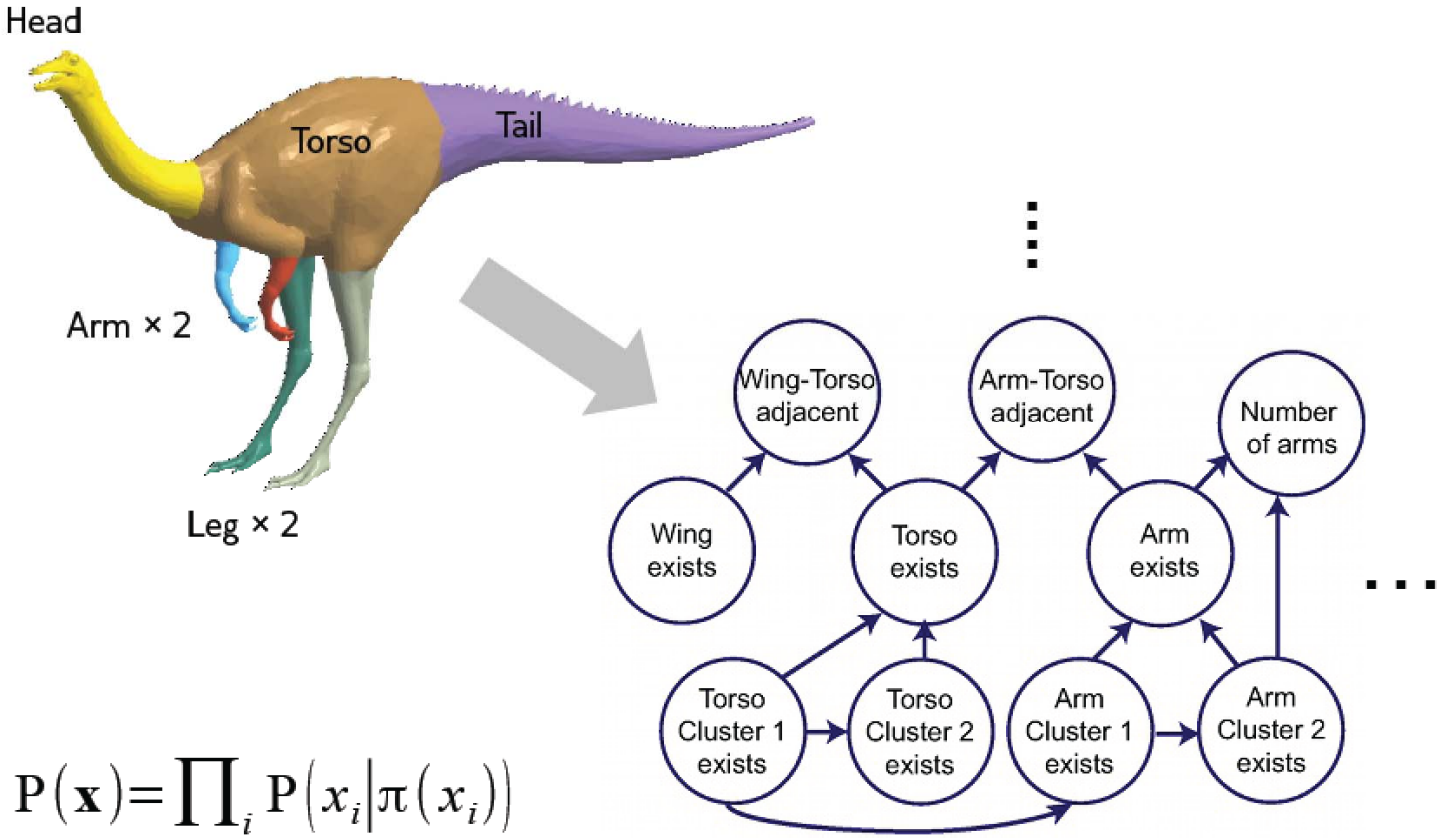
1. Segment into parts
2. Search 3D database for parts
3. Compose parts into a model



2. Probabilistic Reasoning

[Chaudhuri et al. Siggraph 2011]

- Design space

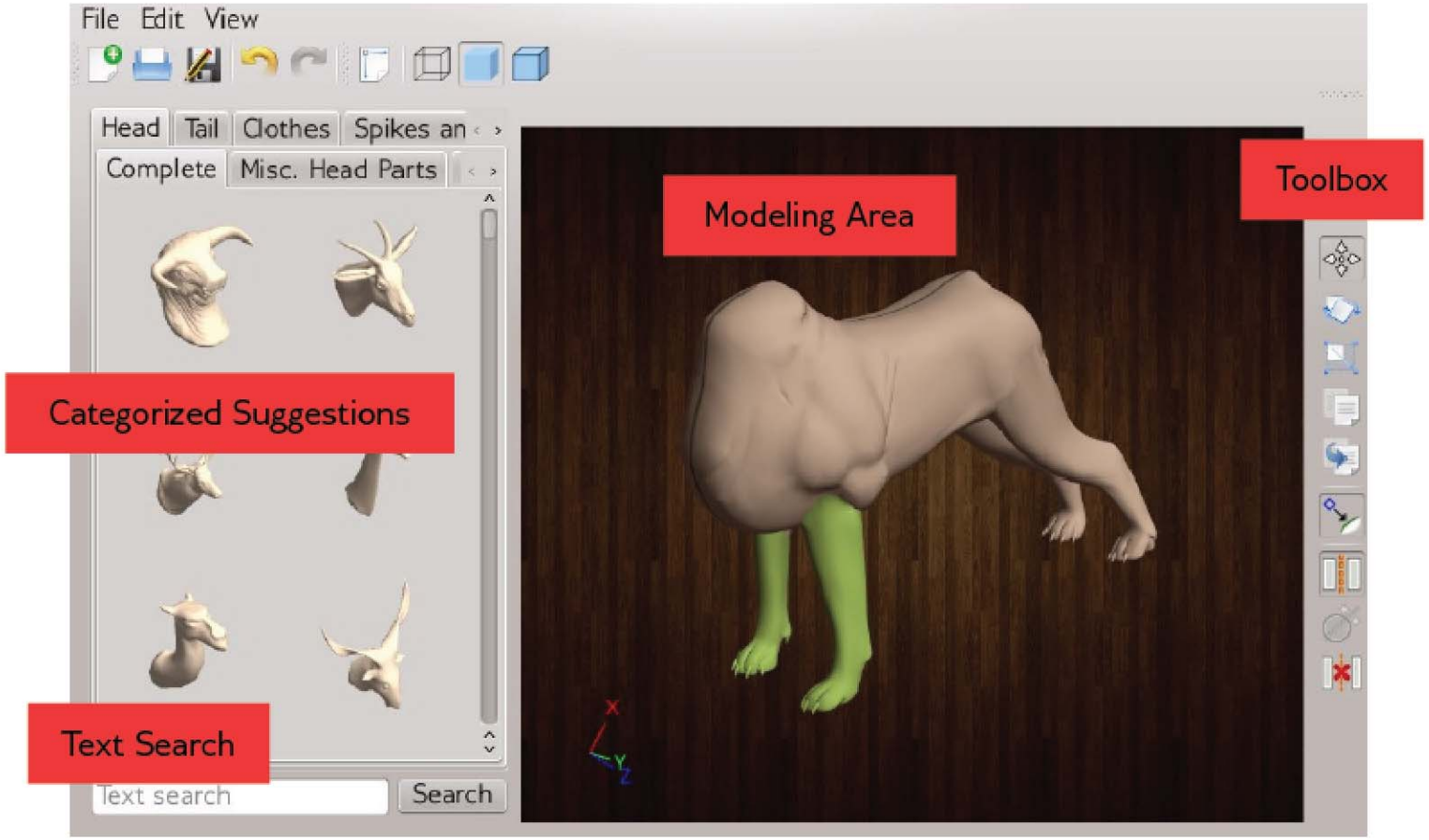


$$\mathrm{P}(\mathbf{x}) = \prod_i \mathrm{P}\left(x_i \middle| \pi(x_i)\right)$$

2. Probabilistic Reasoning

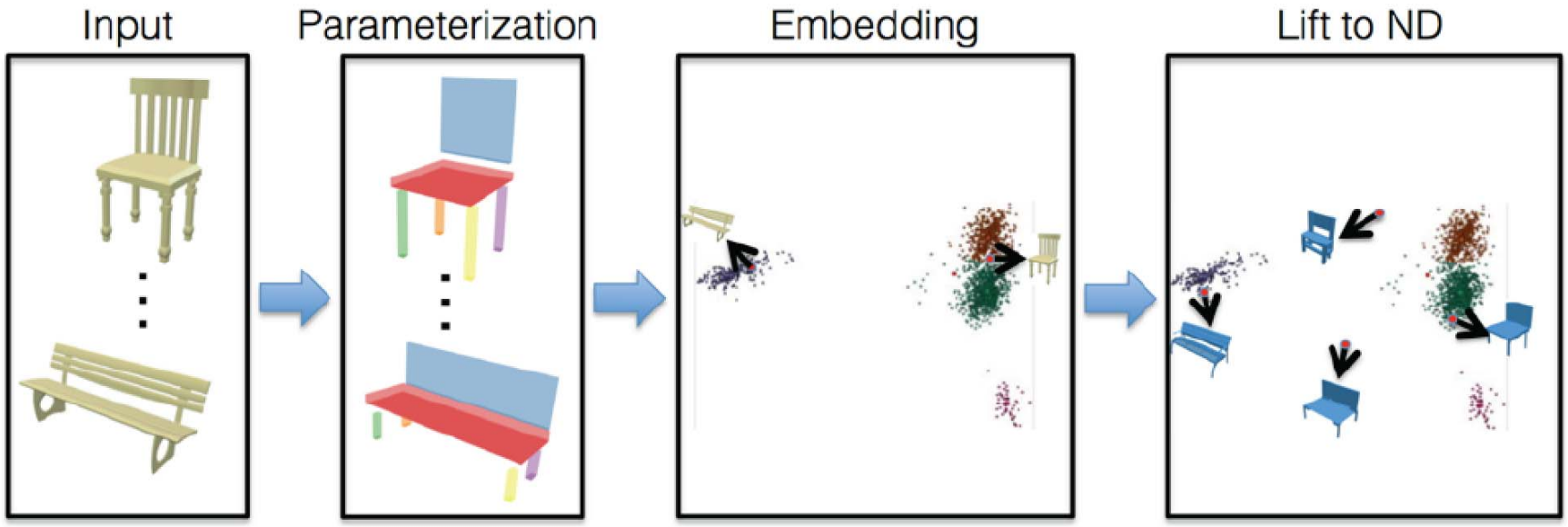
[Chaudhuri et al. Siggraph 2011]

- Exploring the design space



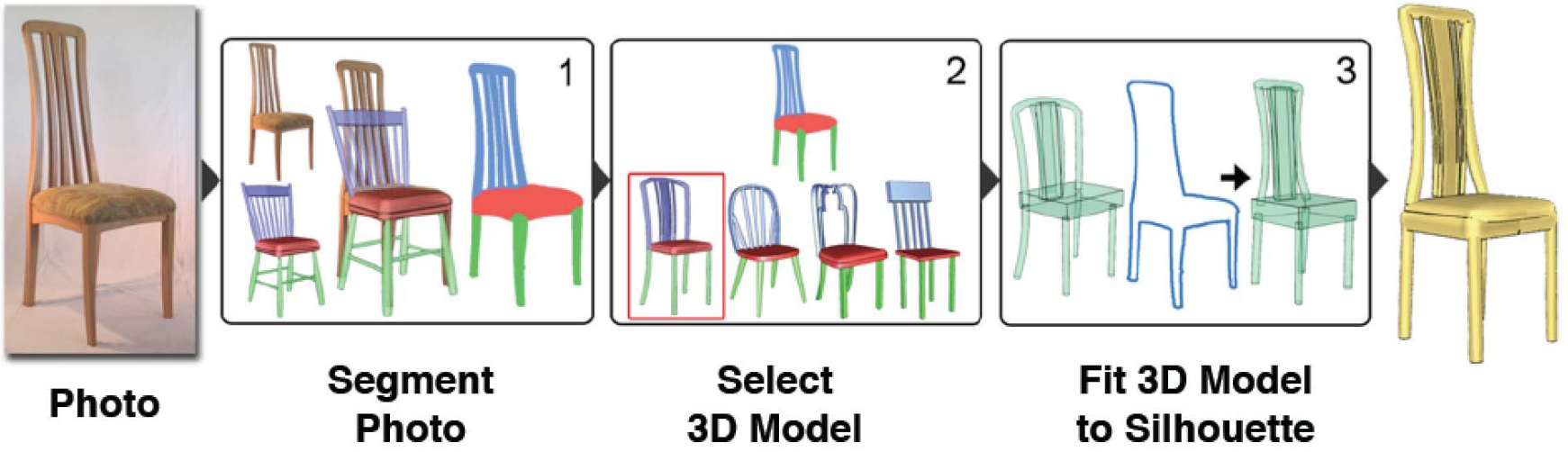
3. ShapeSynth: Exploration as Design Tool

[Averkiou et al. Siggraph 2014]



4. Photo-inspired Modeling

[Xu et al. Siggraph 2012]

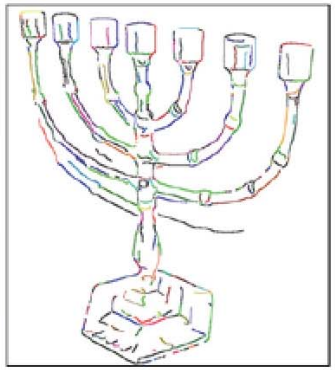


Examples

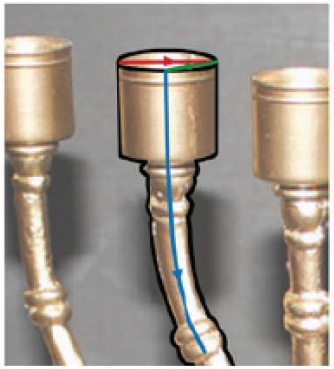
5. Primitive-based Modeling

Chen et al. 2013

Input



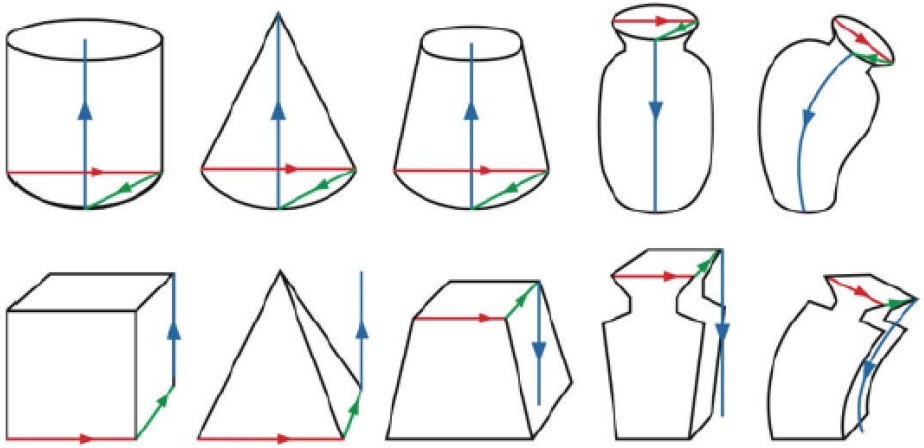
Edges



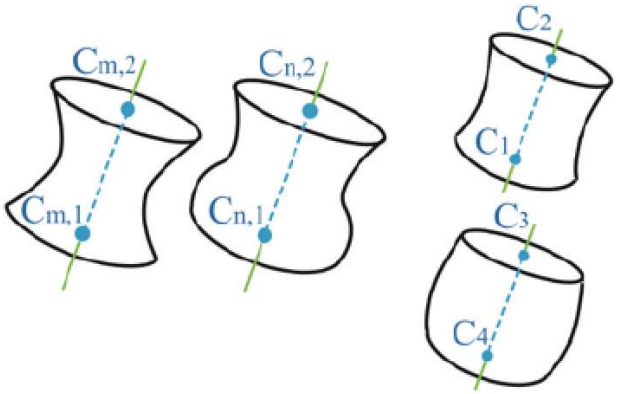
User Input

Reconstruction

Edited Picture



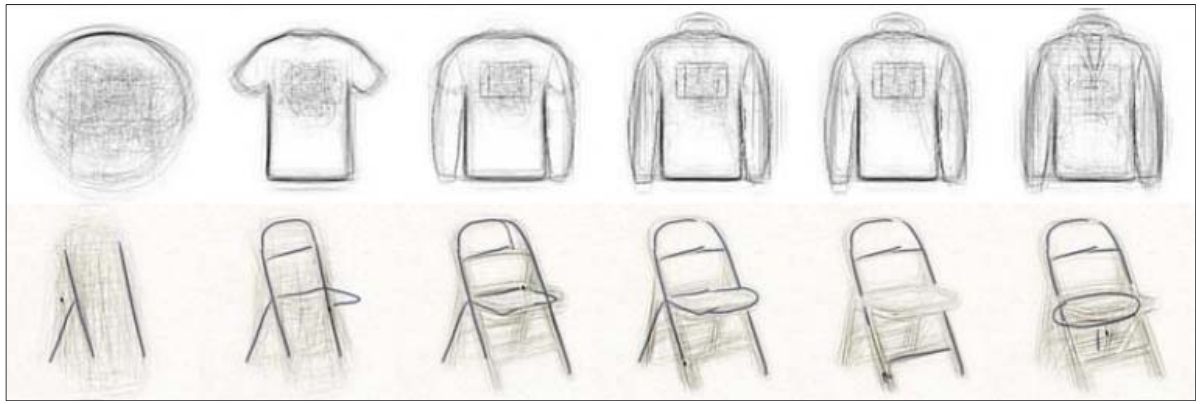
Generalized Cylinders and Cuboids



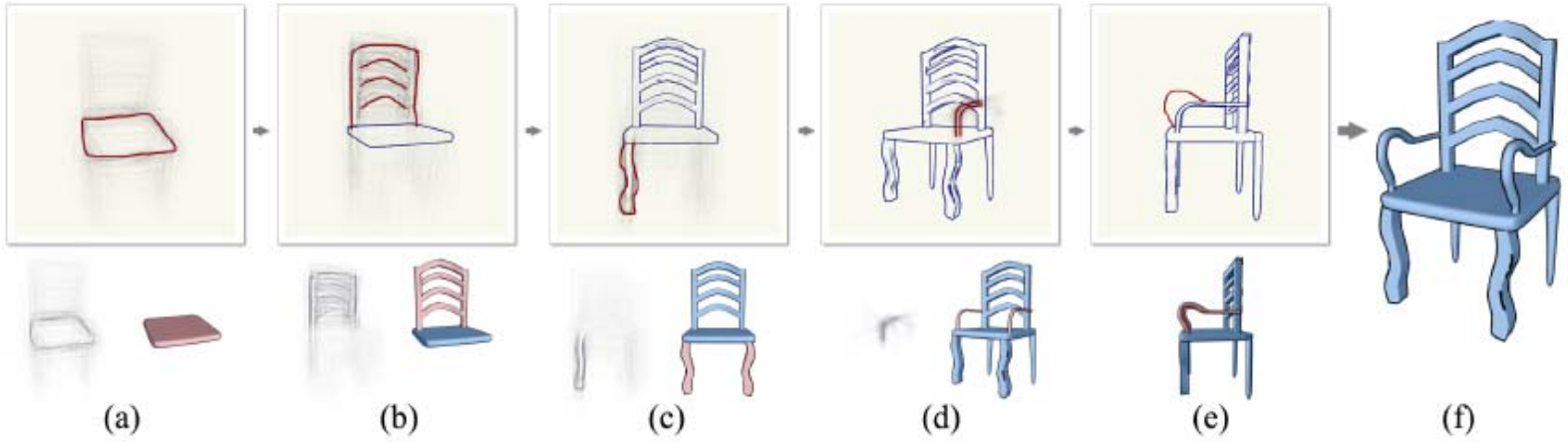
Parallelism Co-planarity

6. Shadow Guidance

Fan et al. 2013

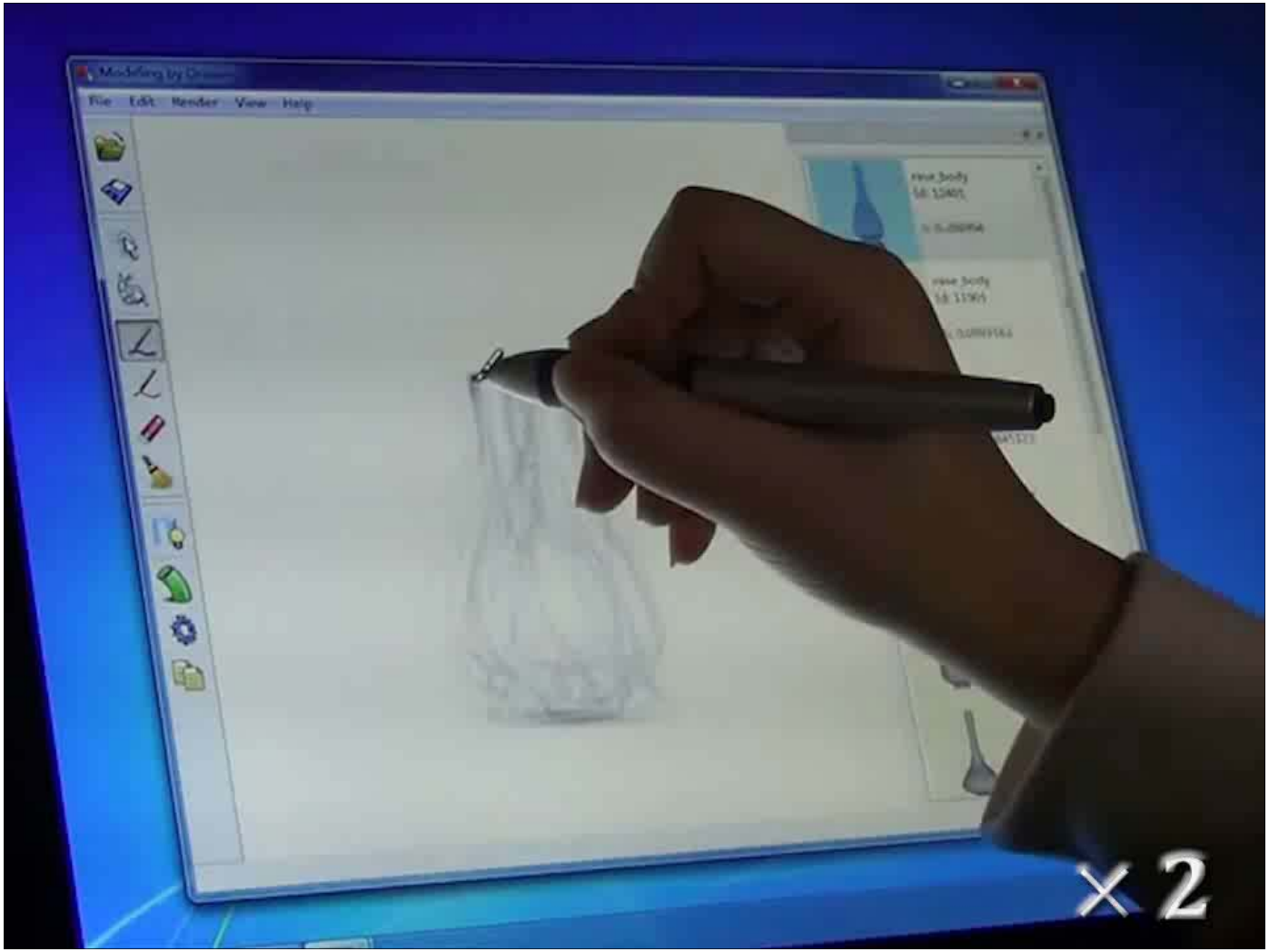


ShadowDraw [Lee et al. 2011]



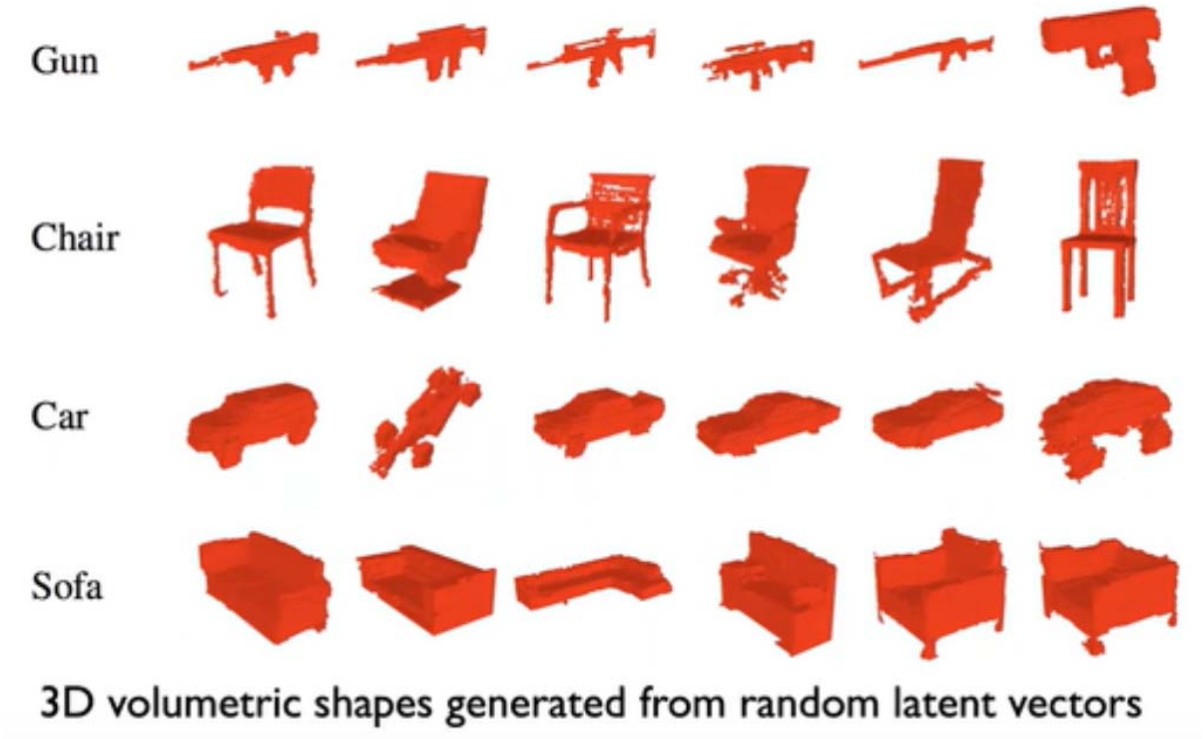
6. Shadow Guidance

Fan et al. 2013



7. Learning Generative Models of 3D Shapes (3D-GAN)

- Emergence of various 3D-GANs for shape generation



3D volumetric shapes generated from random latent vectors

Chinagraph 2020 Key note talk by Hao Zhang:
https://www.bilibili.com/video/BV1Pa4y1x7au?p=3

Chaudhuri, et al. Learning Generative Models of 3D Structures. Computer Graphics Forum (Eurographics STAR), 2020.

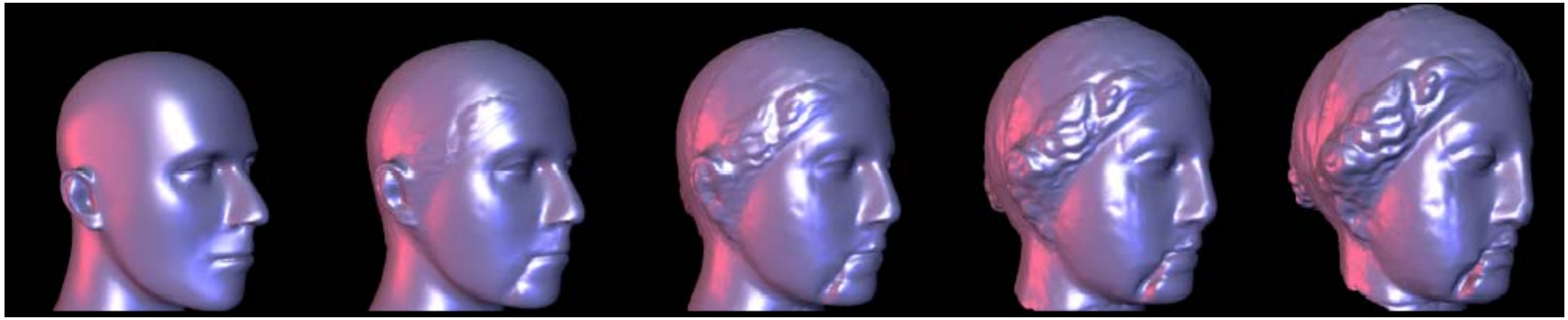
中国科学技术大学

University of Science and Technology of China

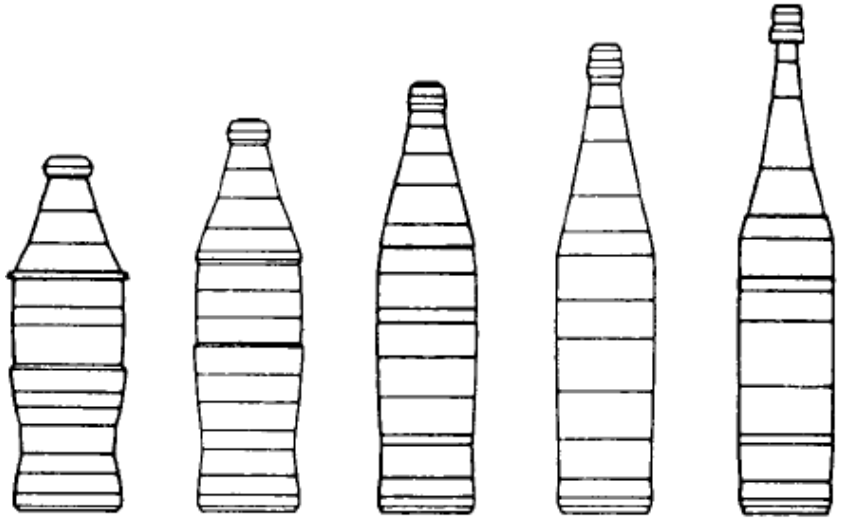
Shape Morphing

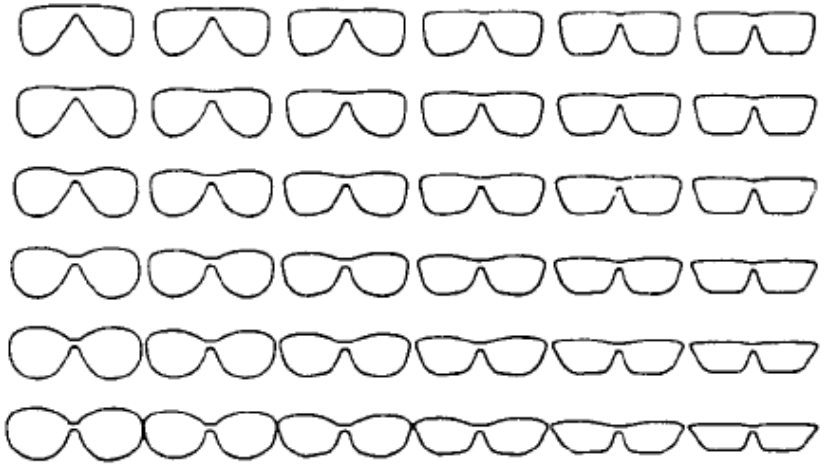
Shape Morphing

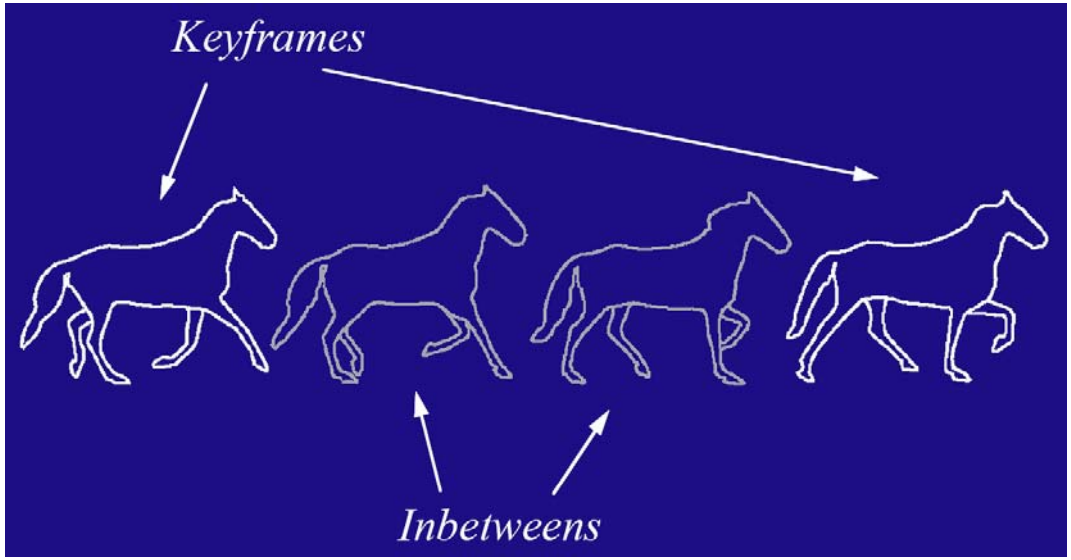
- Given two objects produce sequence of intermediate objects that gradually evolve from one object to the other
  - Interpolate object shapes
  - Interpolate object attributes
    - Color, texture, normal, etc.



Applications

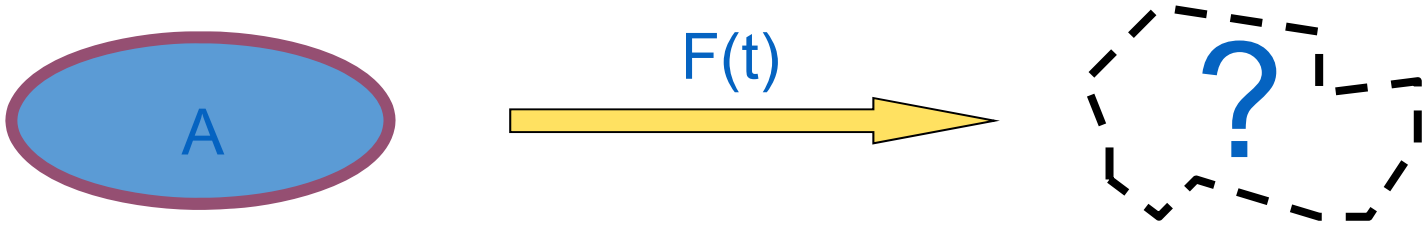




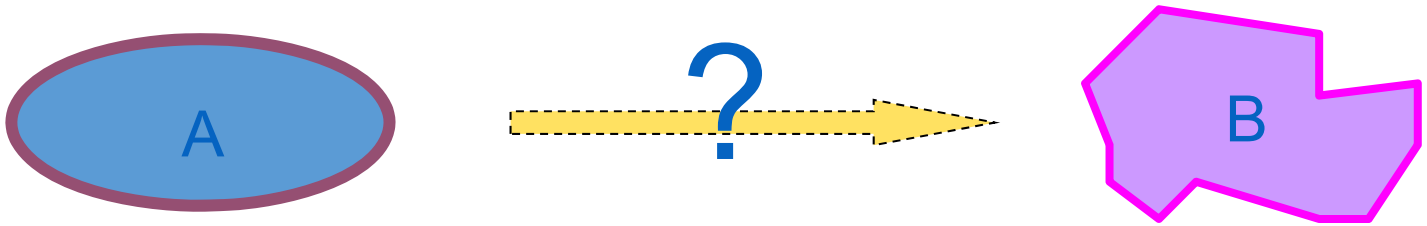


Shape Transformations

- Warping: Unary Op
  - Given Object A and F(t), find Object B



- Morphing: Binary Op
  - Given Object A and Object B, find F(t)



Terminologies

- Morphing
- Metamorphosis
- Shape blending
- Shape averaging
- Shape interpolation
- Shape transition

Rules for Good Morphing

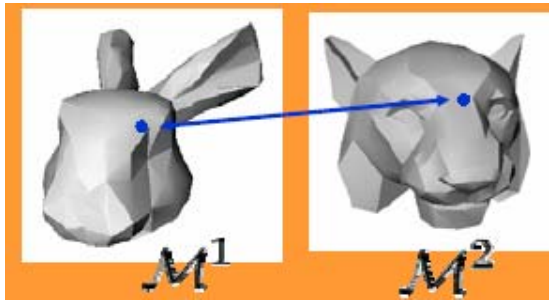
- Natural
  - Keep as much as possible of the two shapes during the transformation
    - Volume, curvature, area, etc...
  - Subjective aesthetic criteria
- User control
  - intuitive
  - not too heavy
  - can be adapted to user's knowledge

Morphing

- Input: two meshes source & target
  - Frames at t_0 and t_n
- Output: sequence of intermediate meshes
  - Frames t_1 to t_{n-1}
- Intermediate mesh:
  - For each point on source/target model specify location at time t_i consistent with source & target

Morphing: Two Sub-Problems

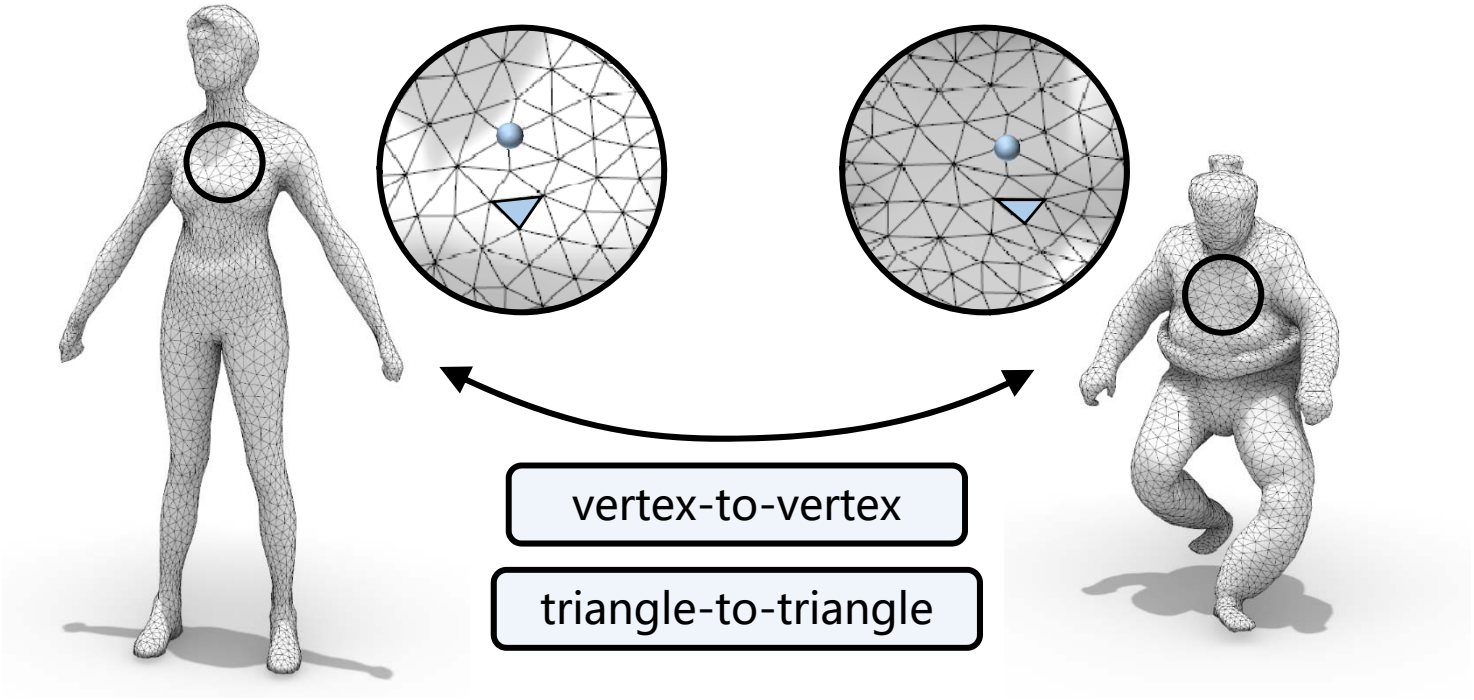
- Correspondence problem
  - Compatible meshes
  - For each point on source/target meshes find corresponding point on second mesh = Parameterization



- Path problem
  - Inbetween shapes
  - Specify trajectory in time for each point
    - For mesh – specify vertex trajectory

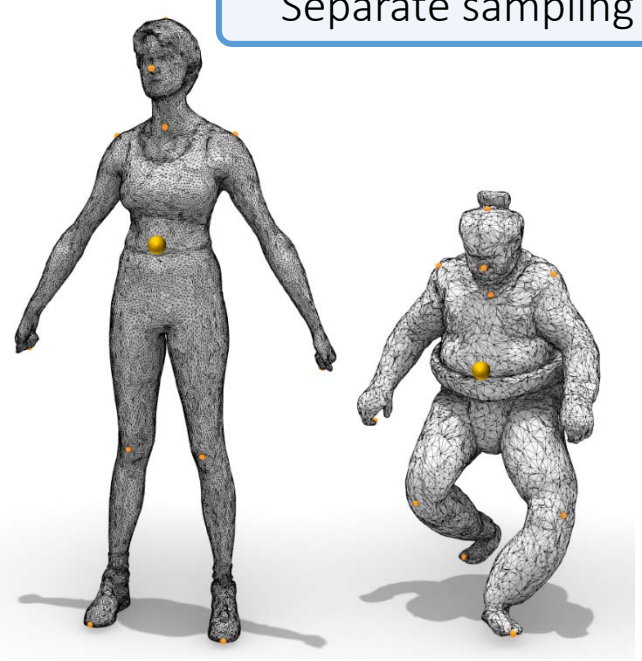
1. Vertex Correspondence

- Compatible meshes (consistent meshes, inter-map)
  - Each vertex on source mesh mapped to vertex on target (and vice versa)
  - Have common connectivity



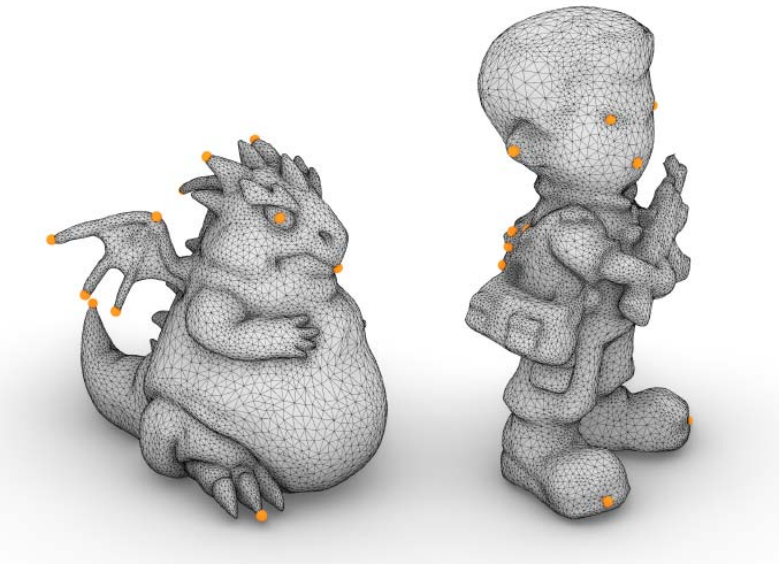
Challenges

Separate sampling



Homogeneous models

Different geometries



Heterogeneous models

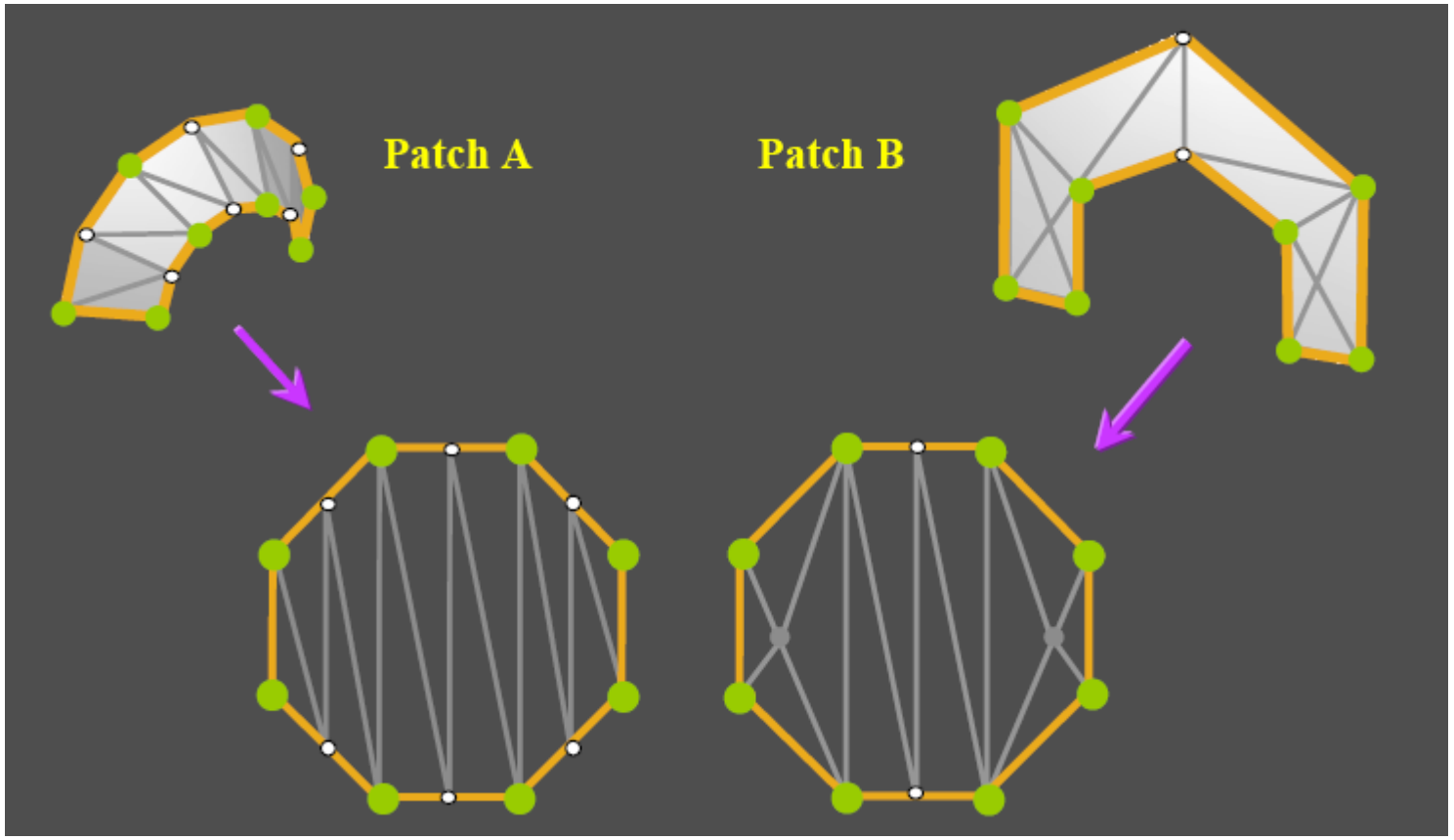
Correspondence: Parameterization

- To compute map between source mesh S and target mesh T parameterize both on common domain D:

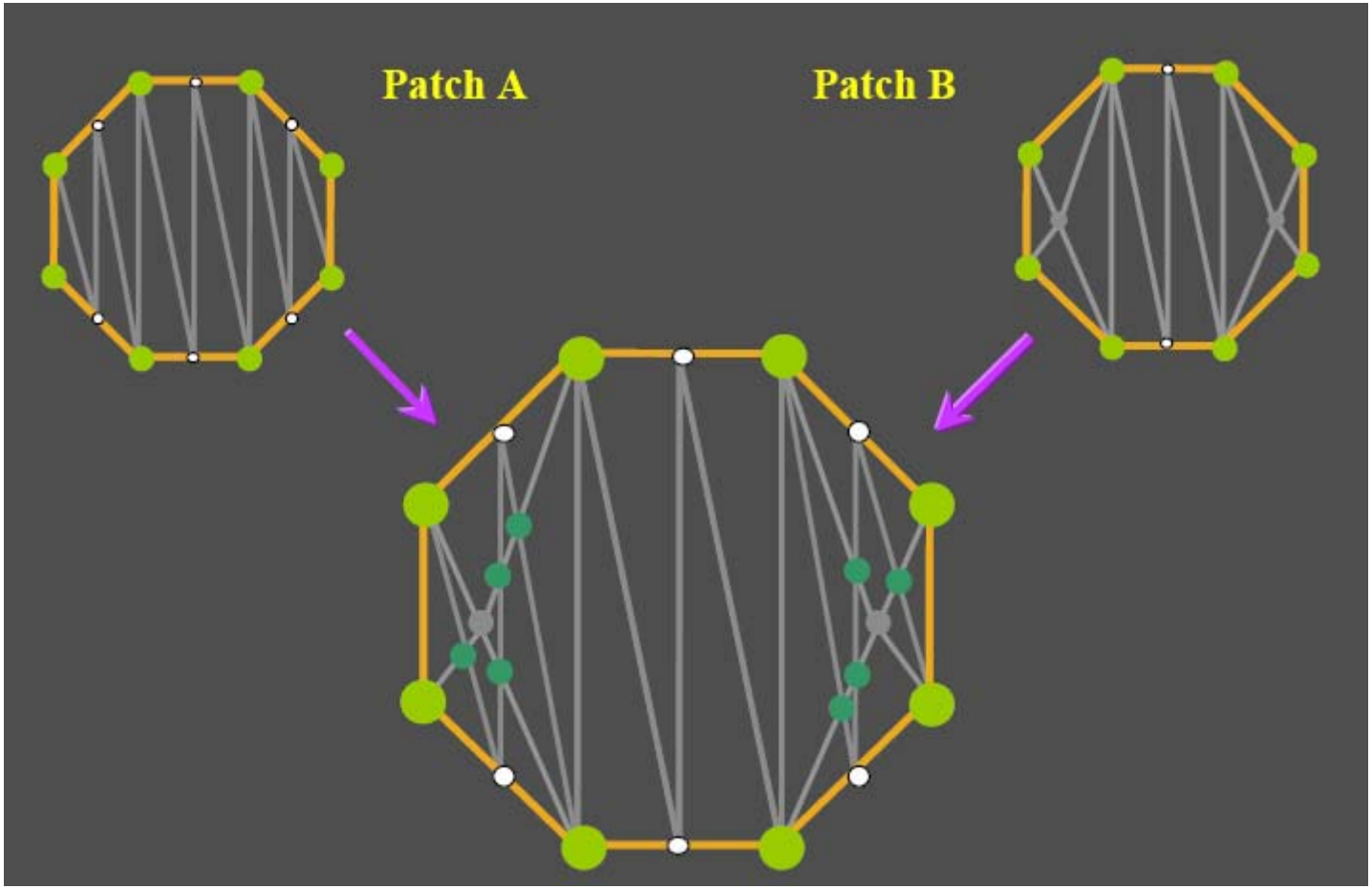
$$F_s : S \rightarrow D$$
$$F_t : S \rightarrow D$$
$$F_{st} = F_t^{-1} F_s$$

- Common domain options
  - 2D patch(es) – works for genus 0 + boundary
    - Use convex boundary (why?)
  - Sphere
  - Base mesh

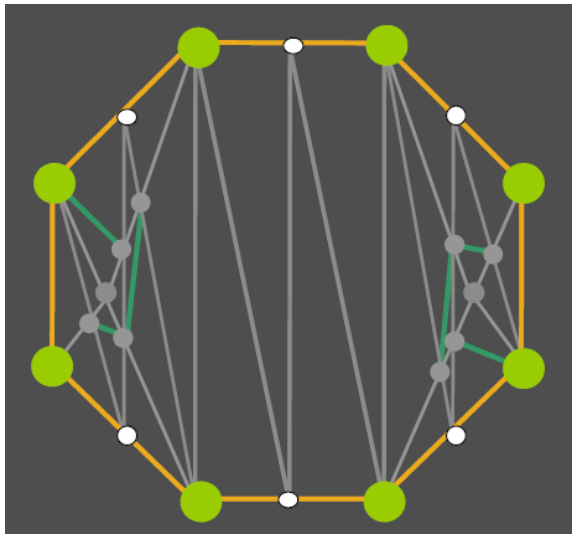
1.1 Parameterization: Planar domain

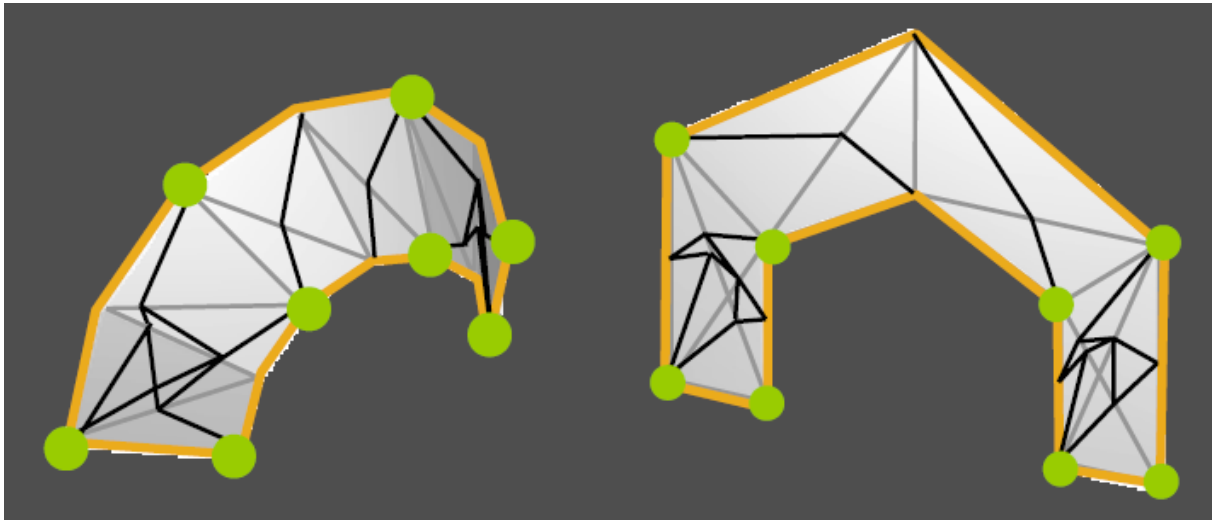


1.1 Parameterization: Planar domain

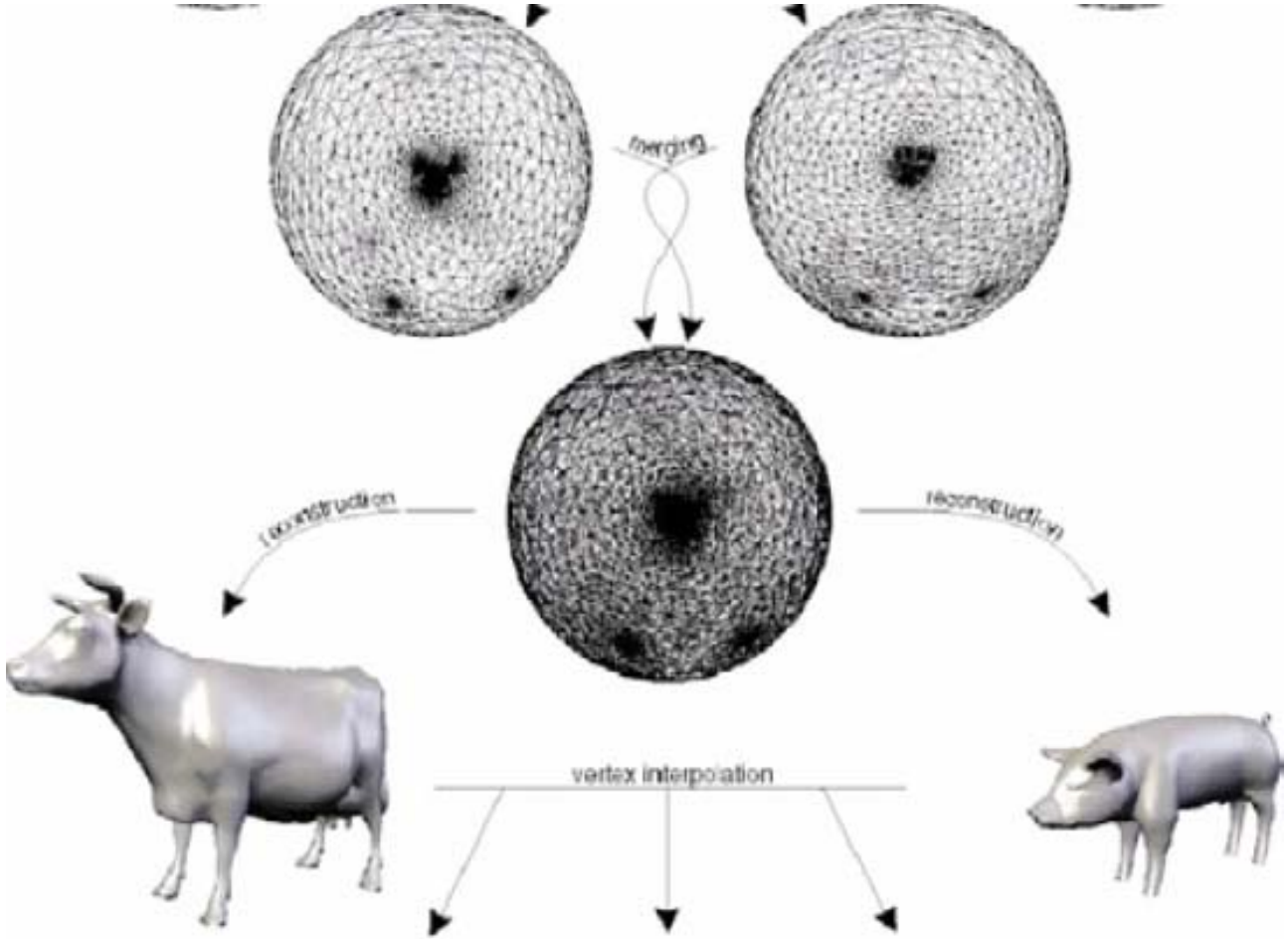


1.1 Parameterization: Planar domain





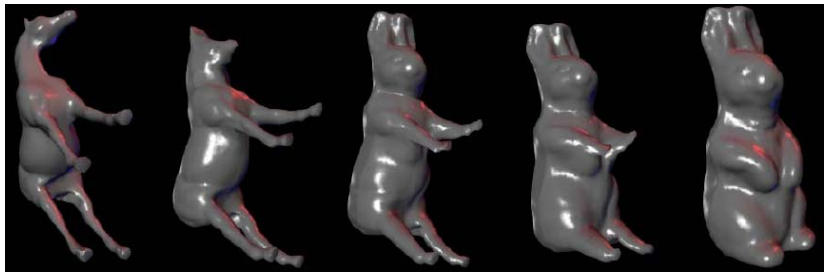
1.2 Parameterization: Sphere domain

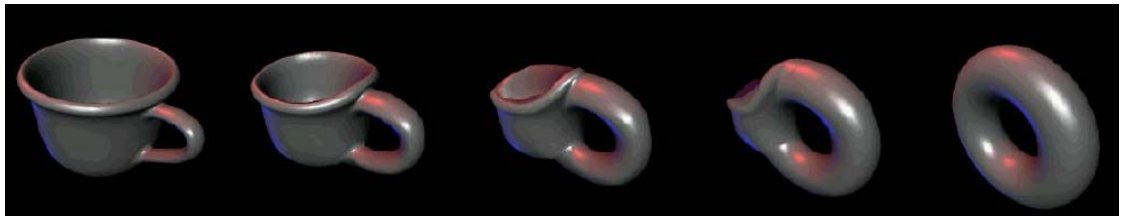


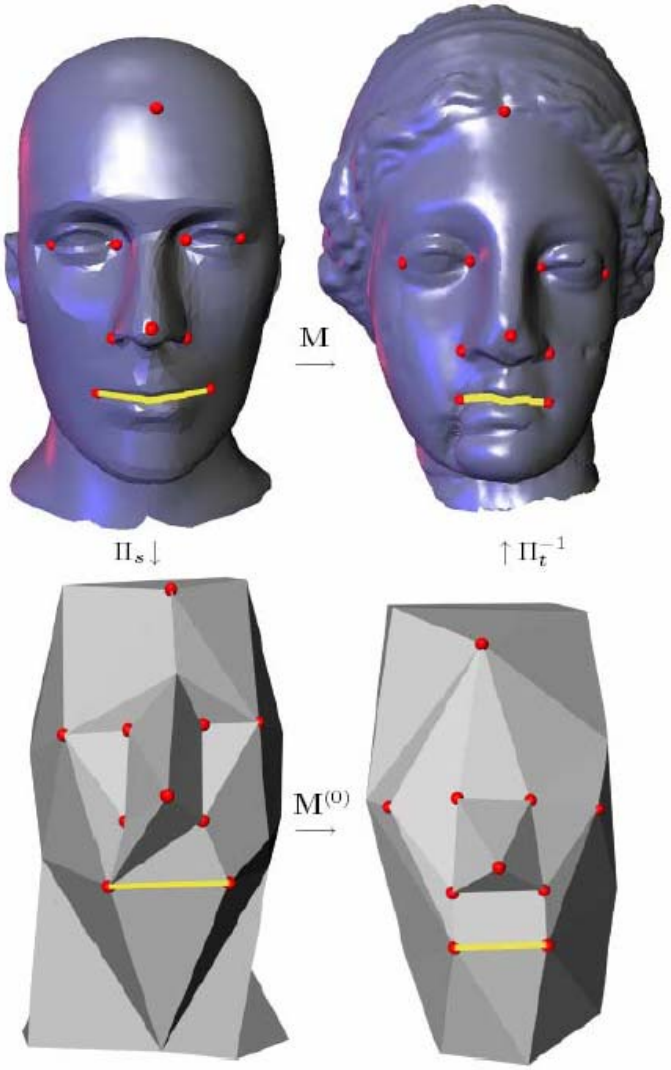
1.3 Parameterization: Base mesh

Lee et al. 1999

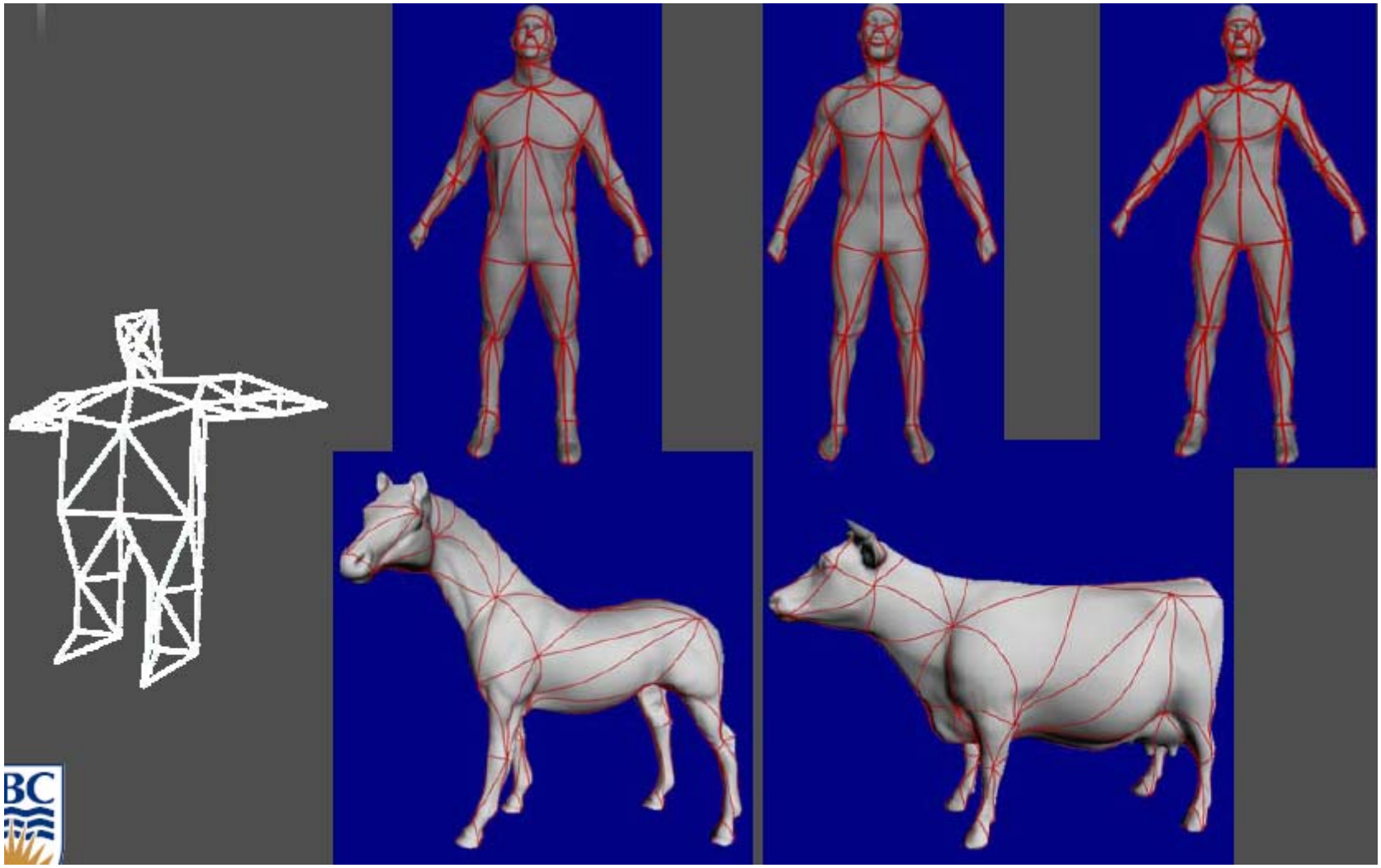
- MAPS



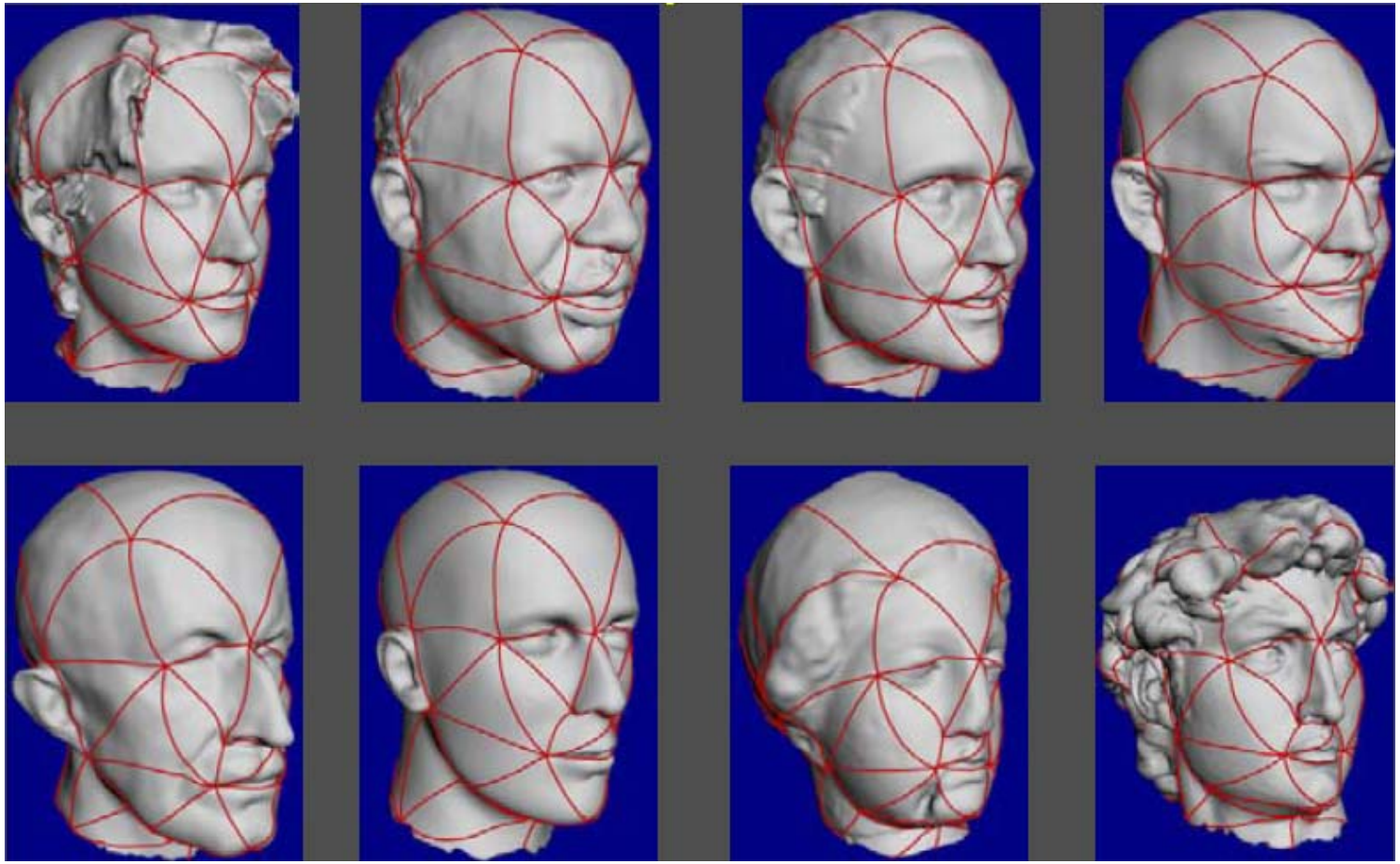




1.3 Parameterization: Base mesh

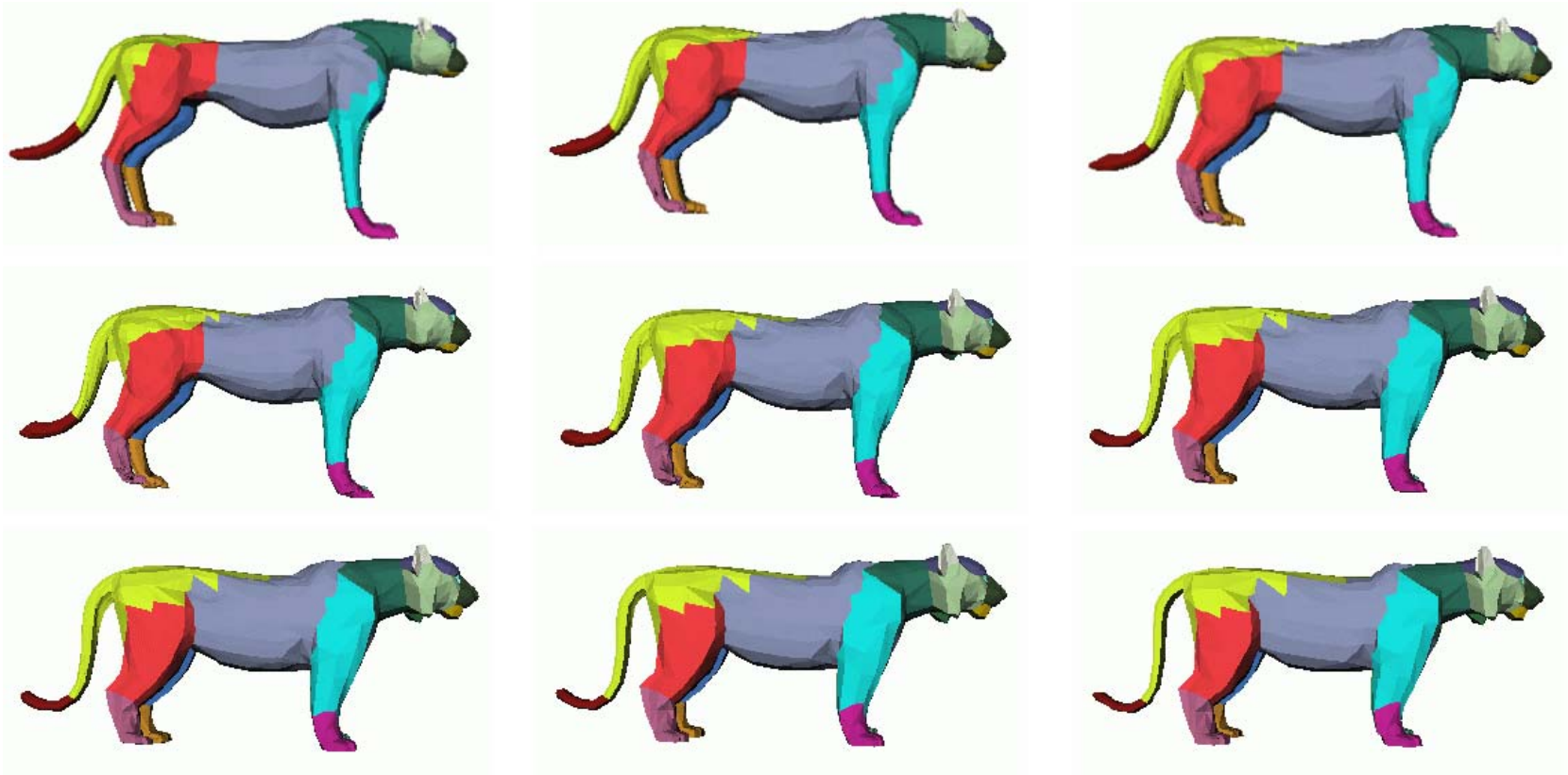


1.3 Parameterization: Base mesh



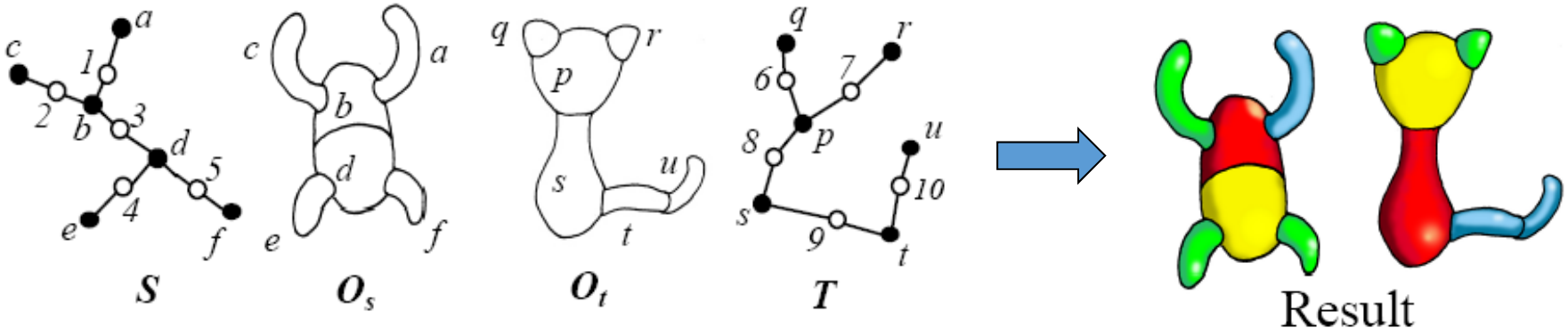
1.4 Decomposition Based

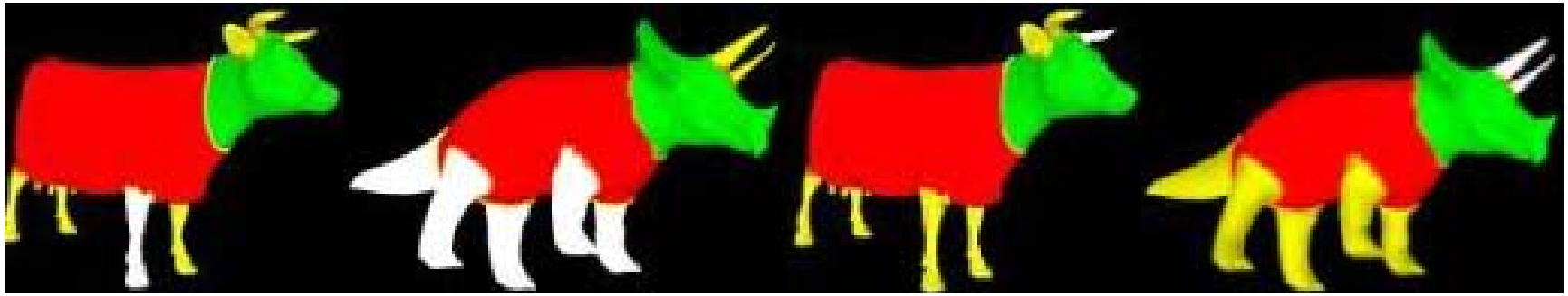
[Shlafman et al. 2002]



1.5 Component Based

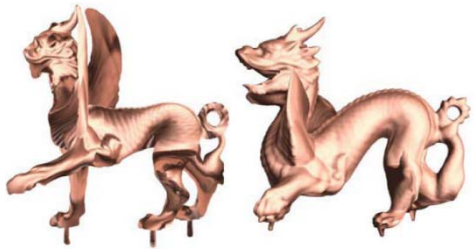
[Zhao et al. 2003]





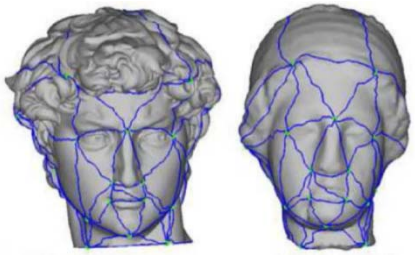
1.6 Many Recent Works

Overlaying-based

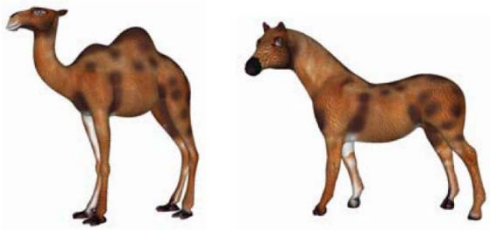


[Schreiner et al. 2004]

Subdivision-based

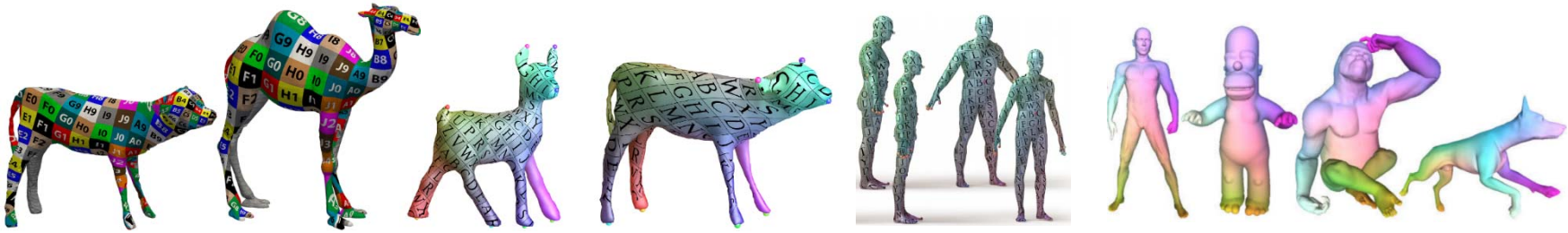


[Kwok et al. 2012]



[Kraevoy et al. 2004]

Common domain-based

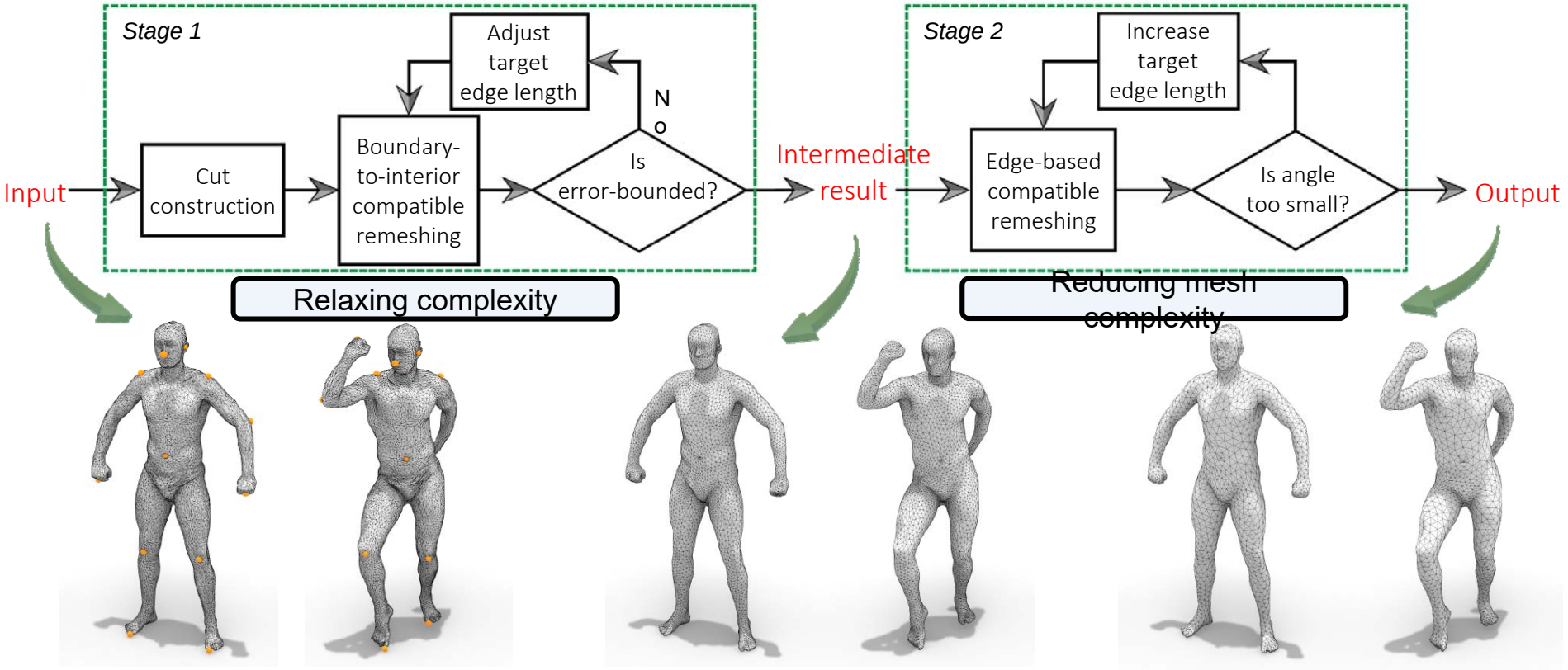


[Aigerman et al. 2014] [Aigerman et al. 2015] [Aigerman et al. 2016] [Mandad et al. 2016]

1.7 Error-Bounded Compatible Remeshing

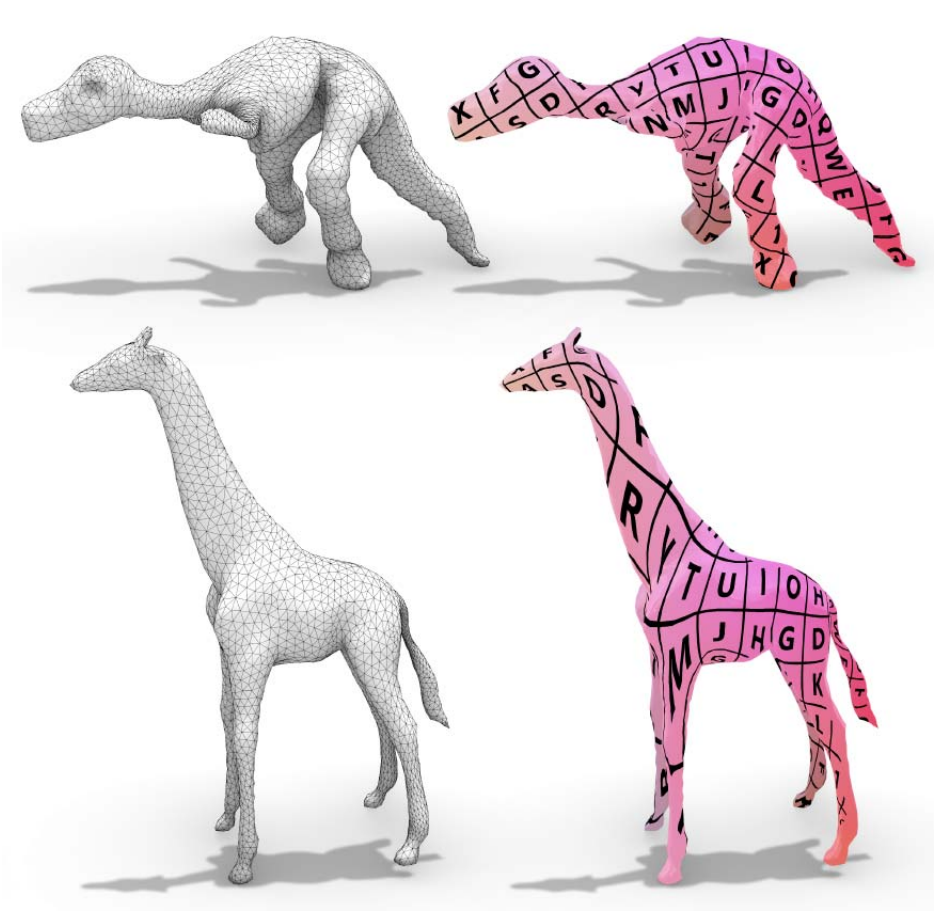
Yang et al. Error-Bounded Compatible Remeshing. Siggraph 2020.

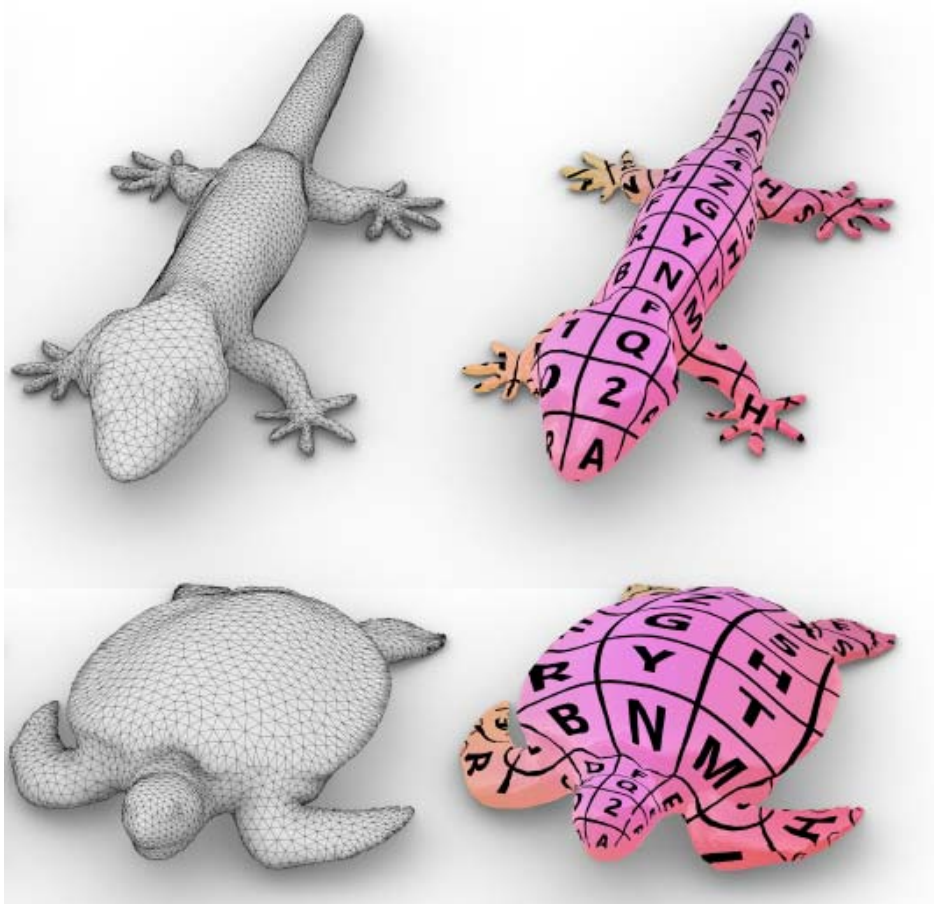
- Optimization based method



1.7 Error-Bounded Compatible Remeshing

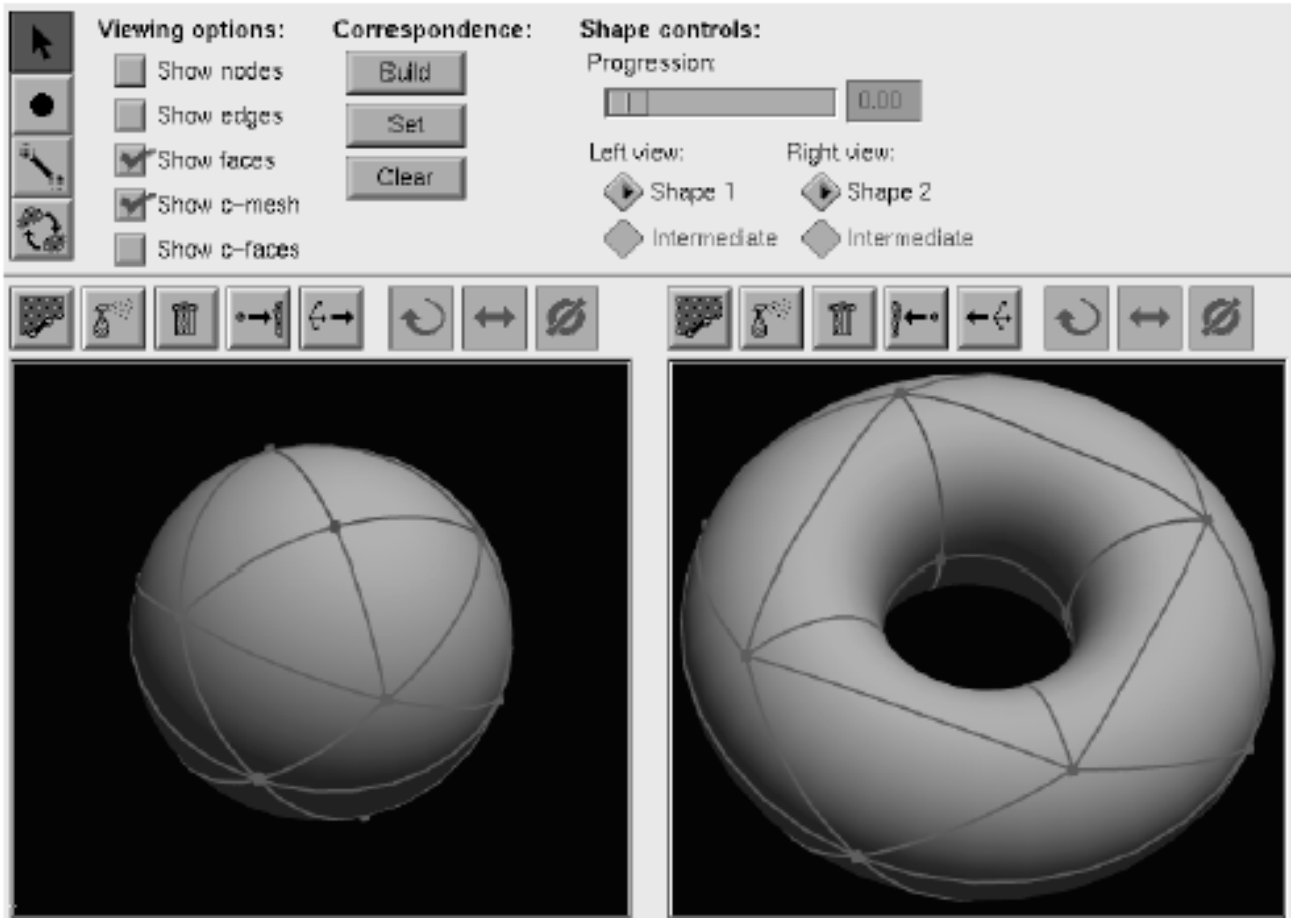
Yang et al. Error-Bounded Compatible Remeshing. Siggraph 2020.





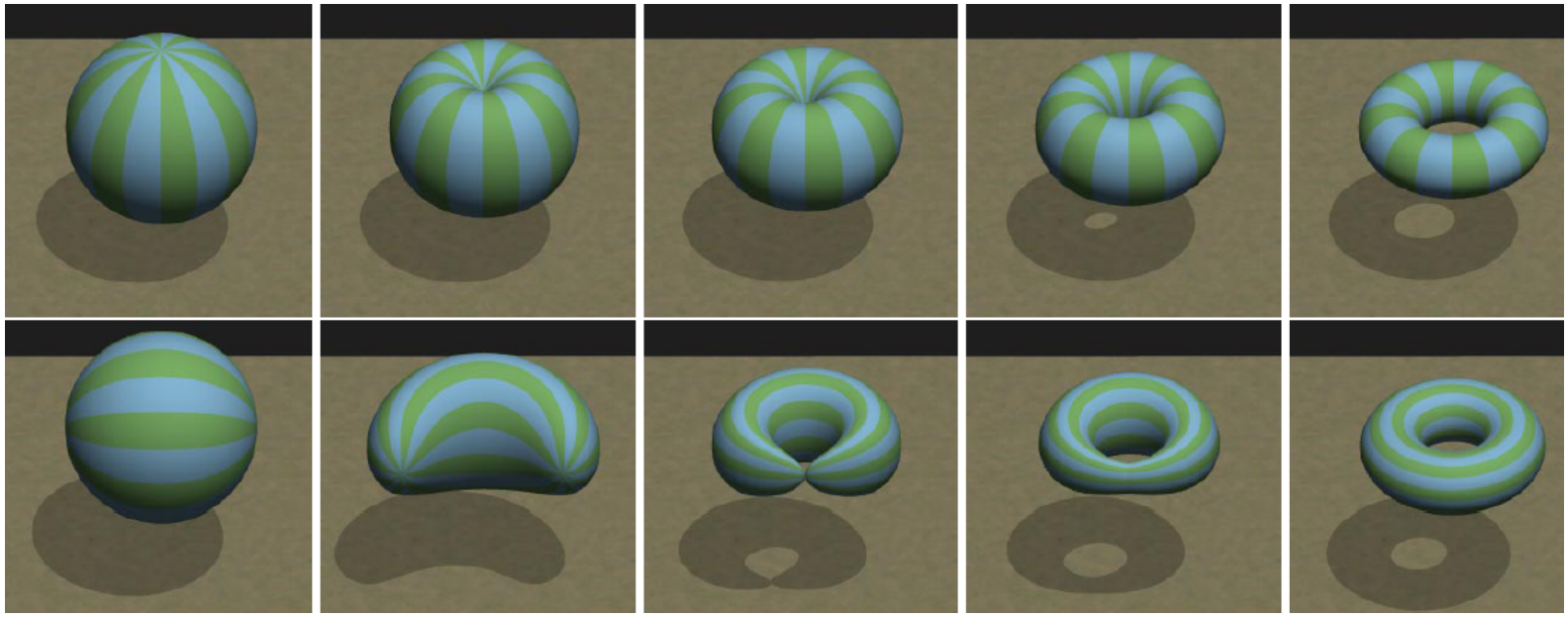
1.8 Different Topologies

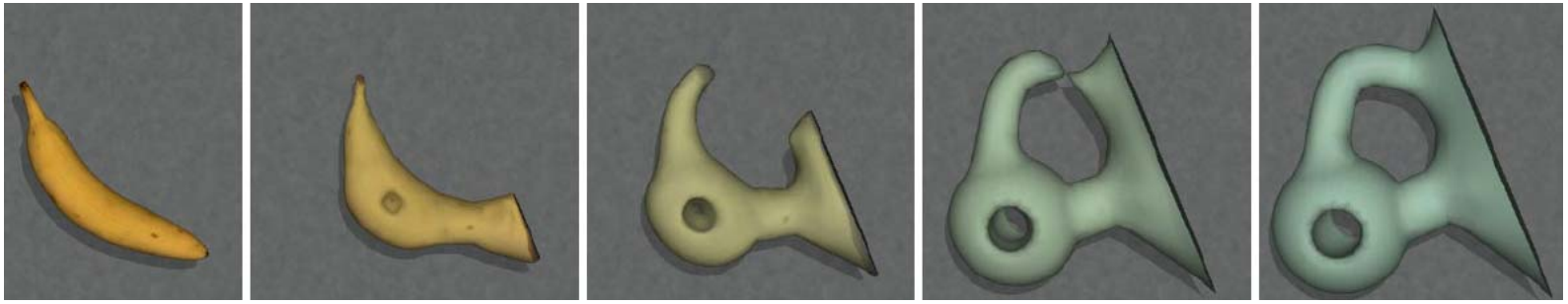
[DeCarlo et al. 1996]



1.8 Different Topologies

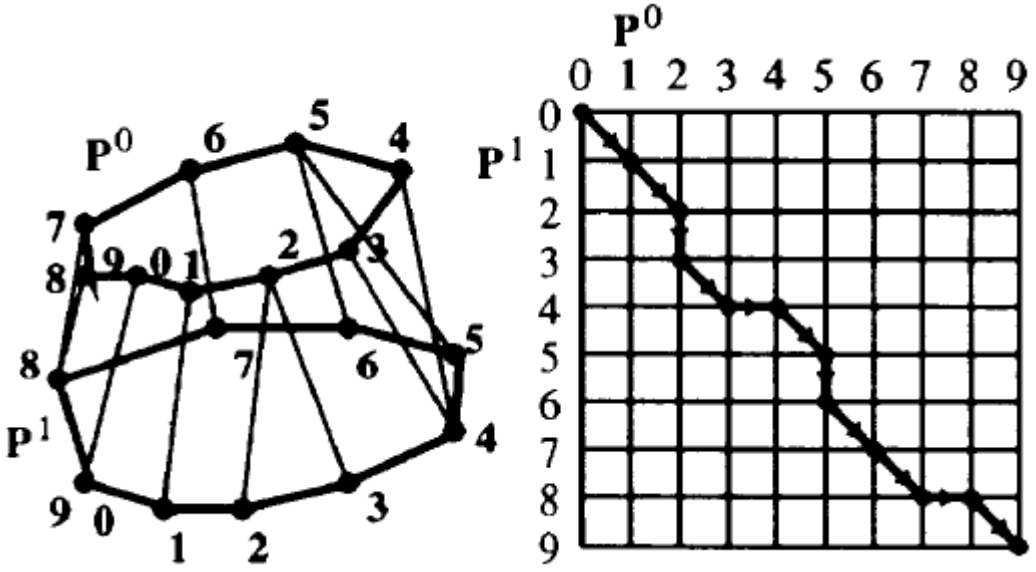
[DeCarlo et al. 1996]

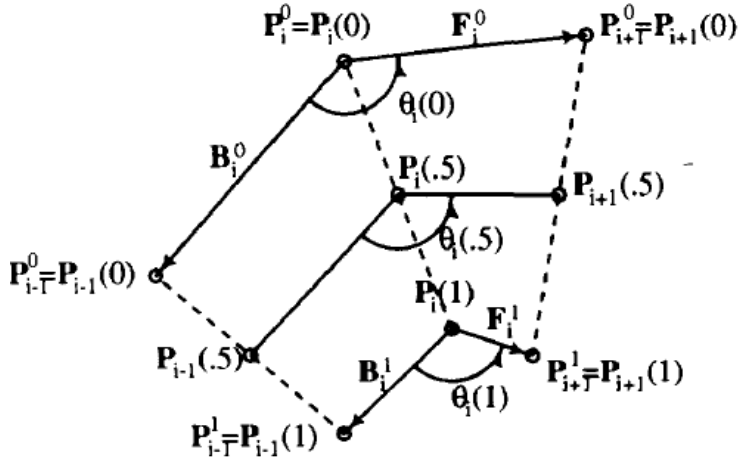




More: Correspondences between planar shapes – Matching

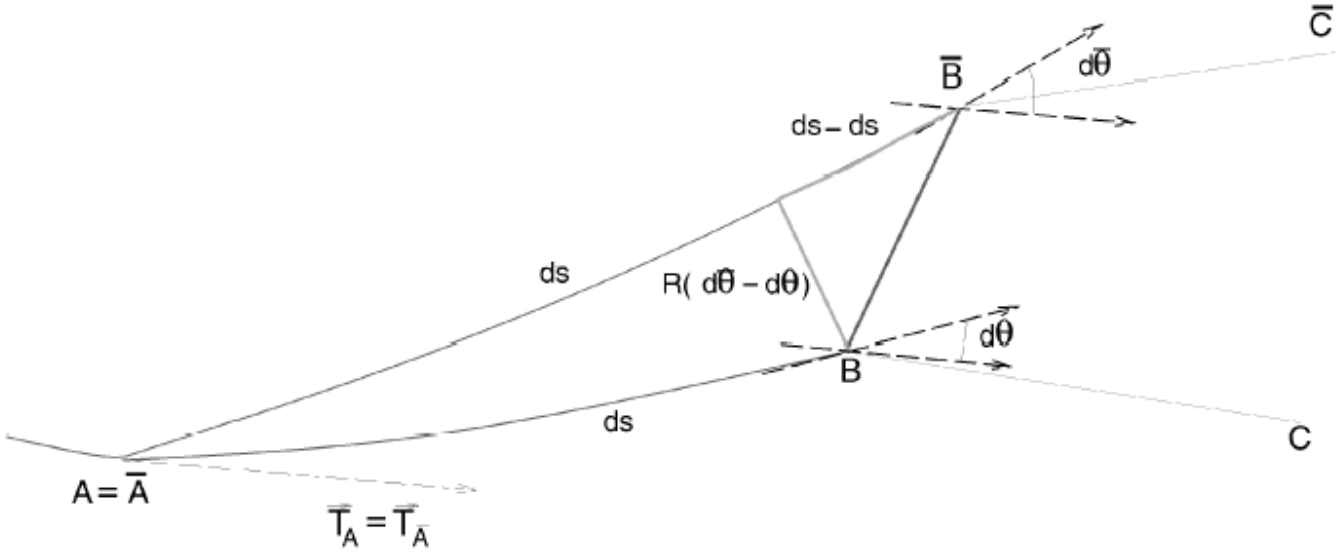
- Physically Based Method [Sederberg et al. 1992]

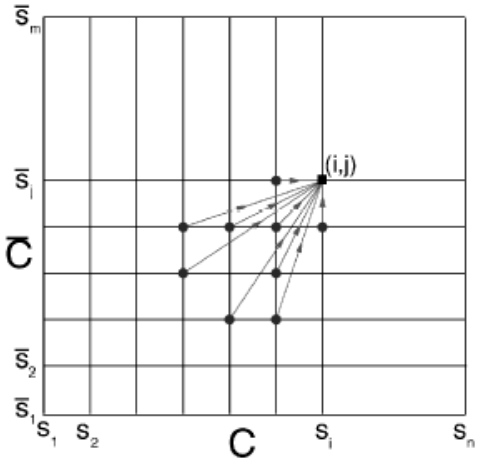




More: Correspondences between planar shapes – Matching

- Curve Aligning [Sebastian et al. 2003]

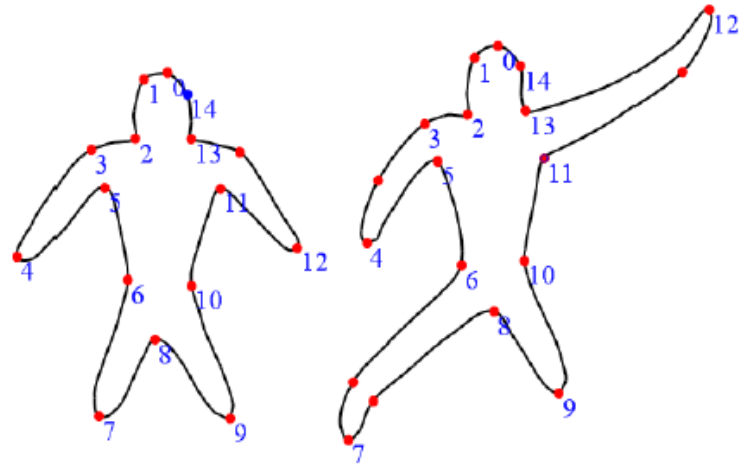


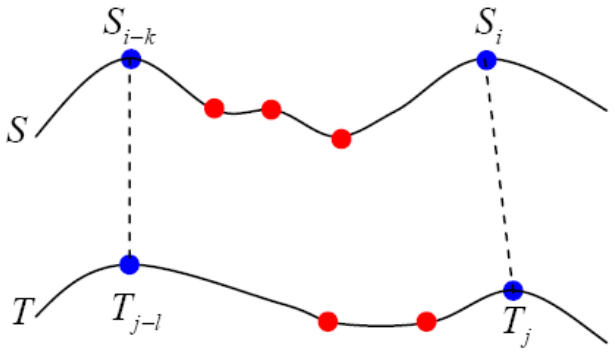


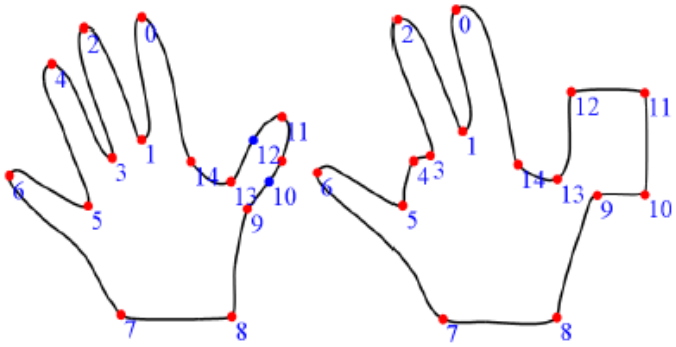
$$\mu[g] = \int_C \left| \frac{\partial}{\partial s} \left(\overline{C}(\overline{s}) - C(s) \right) \right|^2 ds + R \int_C \left(\kappa(s) - \overline{\kappa}(\overline{s}) \right)^2 ds,$$

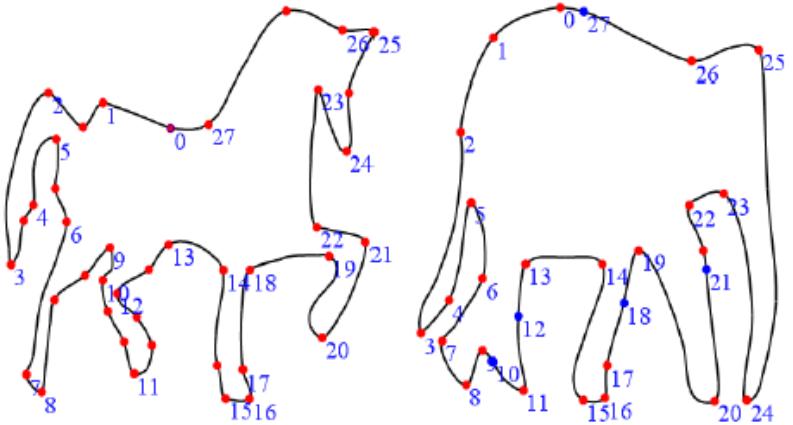
More: Correspondences between planar shapes – Matching

- Perceptually Based Method [Liu et al. 2004]



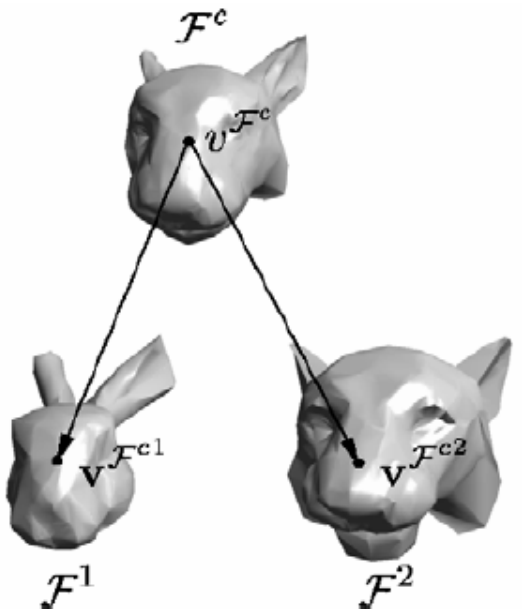






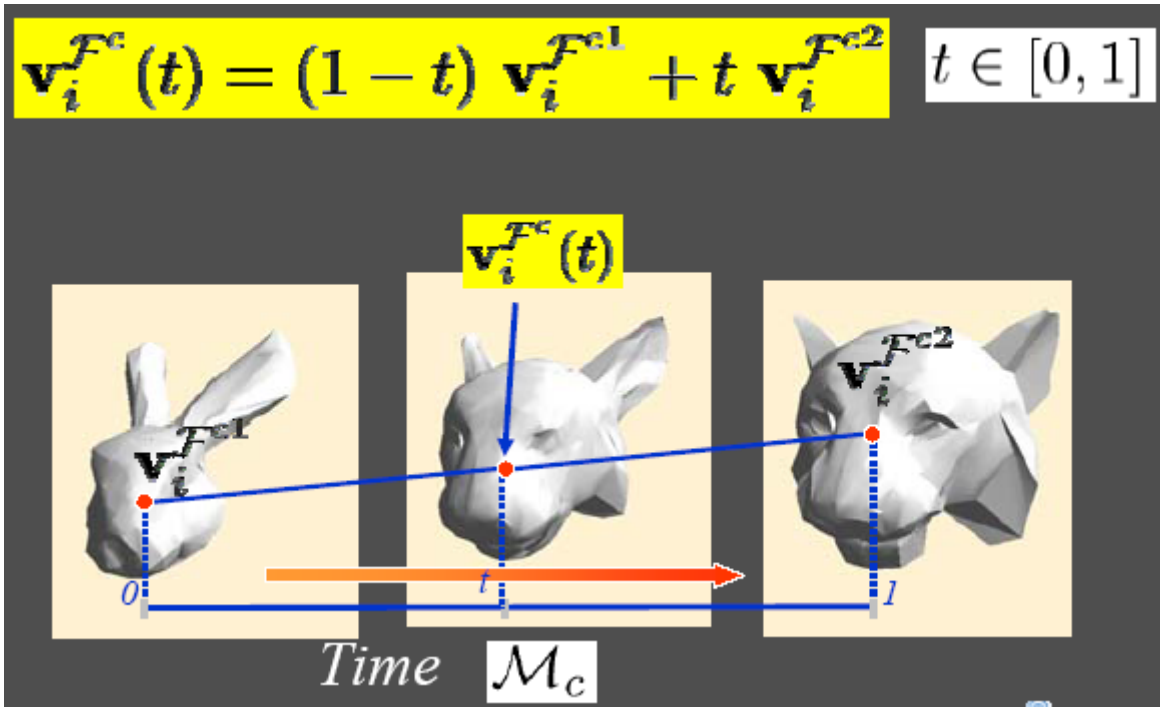
2. Vertex Path (Trajectory)

- Input:
  - All vertices on source & target have one-to-one correspondence with each other
  - Each vertex has two 3D coords v^{Fc1} (source) and v^{Fc2} (target)
- Output: generate the intermediate shapes from two shapes



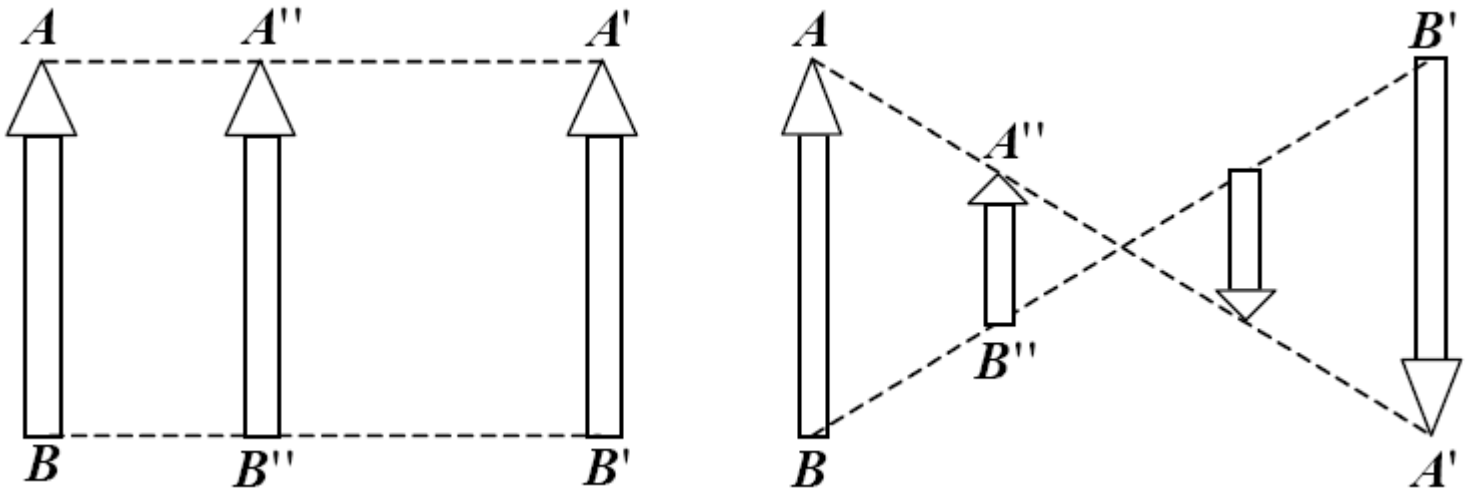
Simplest Method: Linear Interpolation

- Linear interpolation between corresponding points
- Work well for many cases
  - many drawbacks

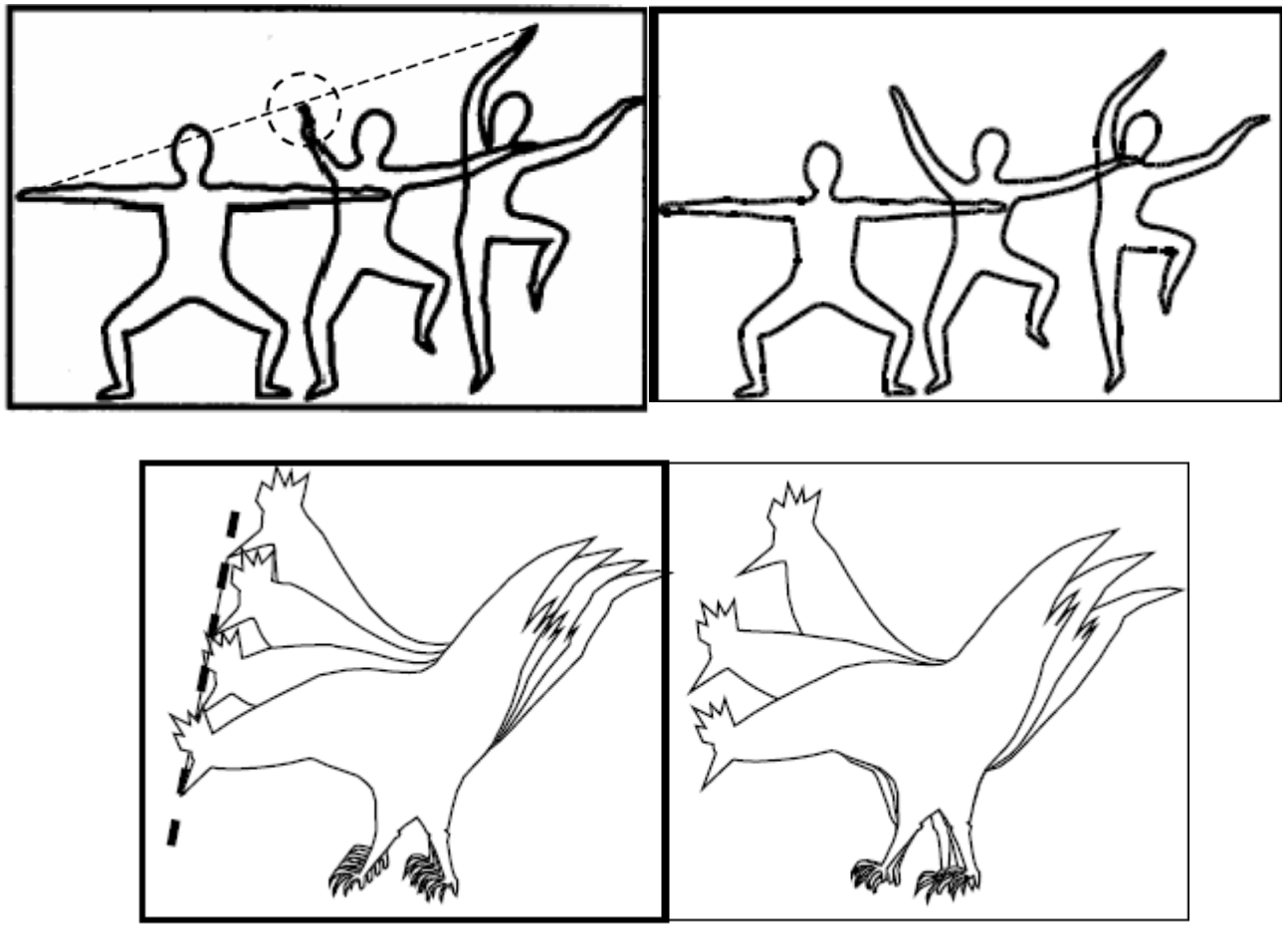


Linear Interpolation

- Simple and easy
- Drawbacks
  - Shrinkage



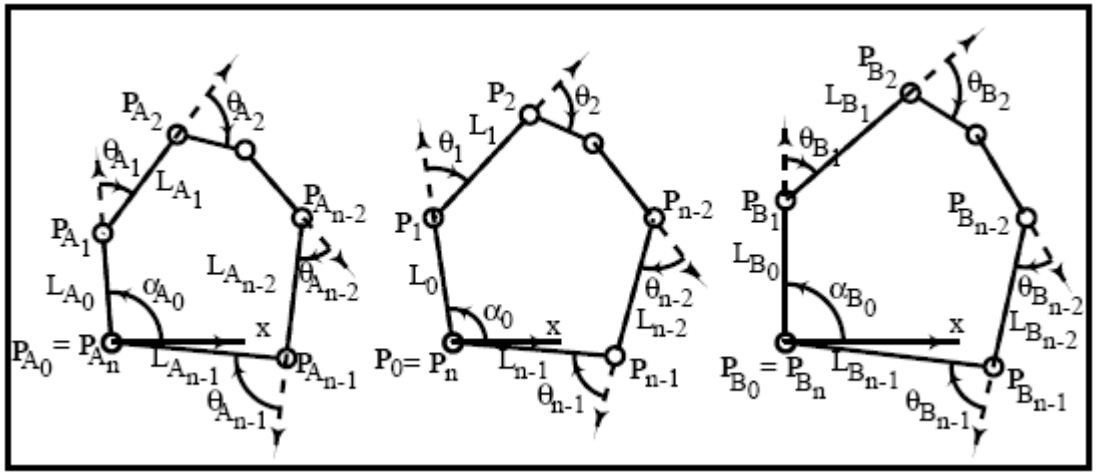
Unnatural Results in Linear Interpolation



Intrinsic Approach

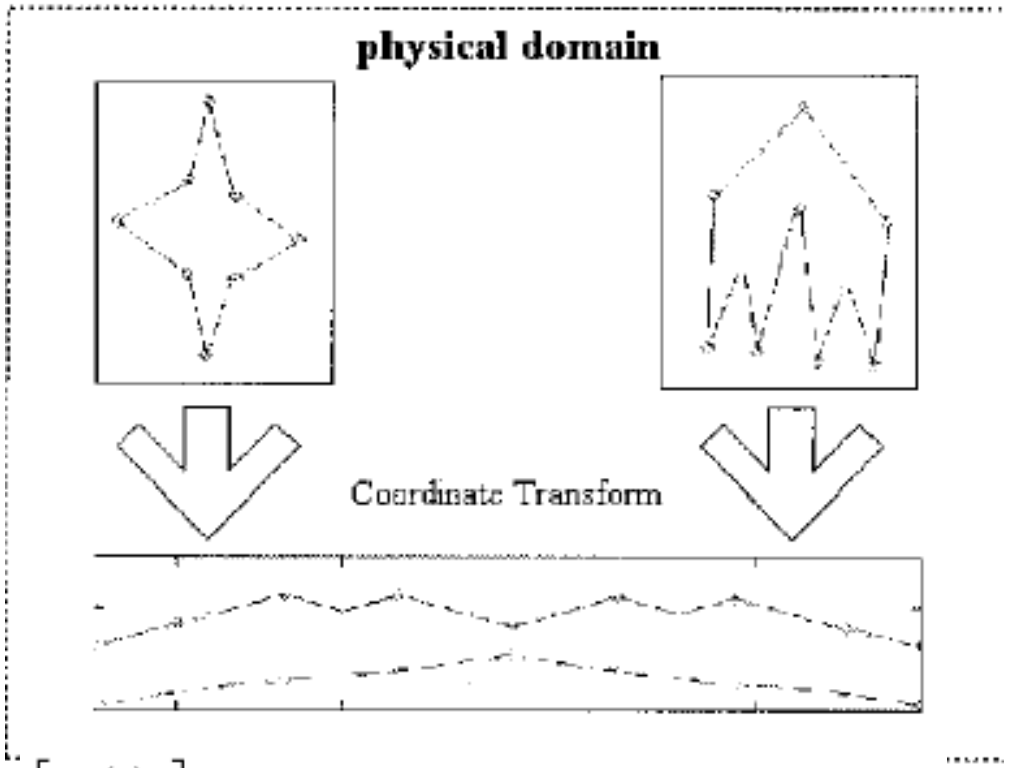
Sederberg et al. 1993

- Intrinsic variables
  - edge lengths
  - turning angles



Fourier Approach

Chen et al. 2001



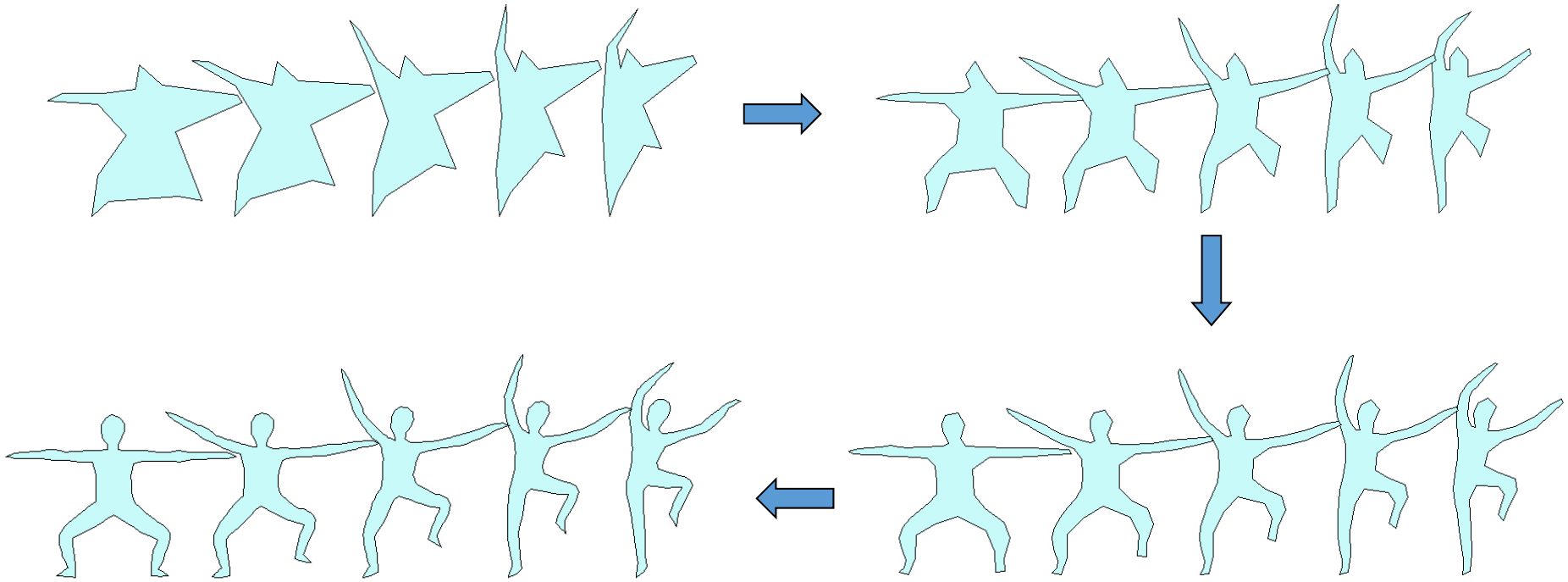
$$\begin{bmatrix} x(t) \\ y(t) \end{bmatrix}$$

$$= \begin{bmatrix} a_0 \\ c_0 \end{bmatrix} + \sum_{k=1}^{\infty} \begin{bmatrix} a_k & b_k \\ c_k & d_k \end{bmatrix} \begin{bmatrix} \cos(2\pi kt) \\ \sin(2\pi kt) \end{bmatrix}$$

Wavelet Approach

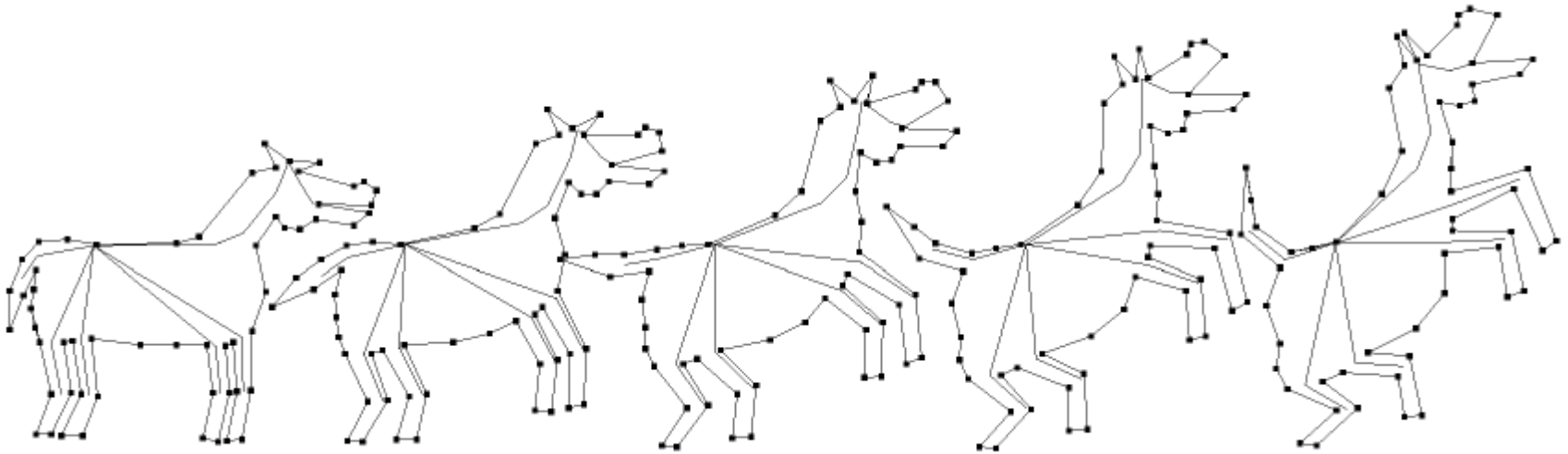
- Wavelet decomposition

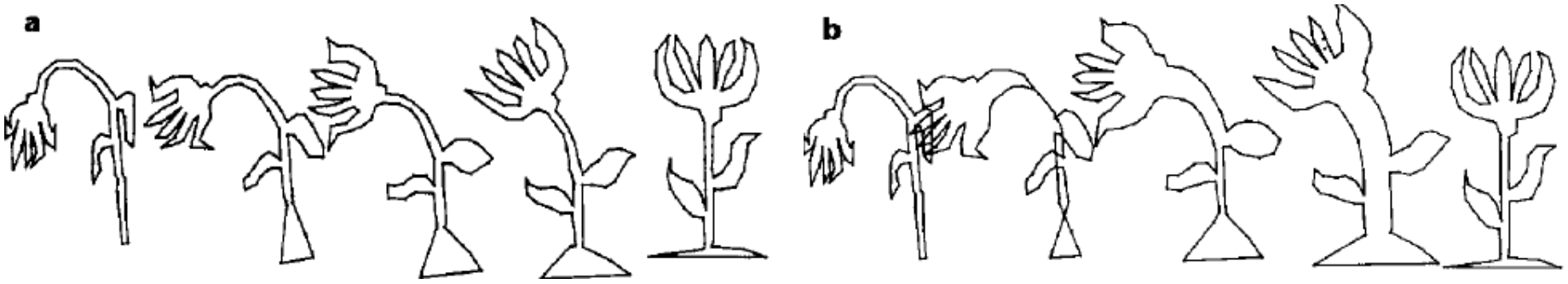
Zhang et al. 2000



Star Skeleton Representation

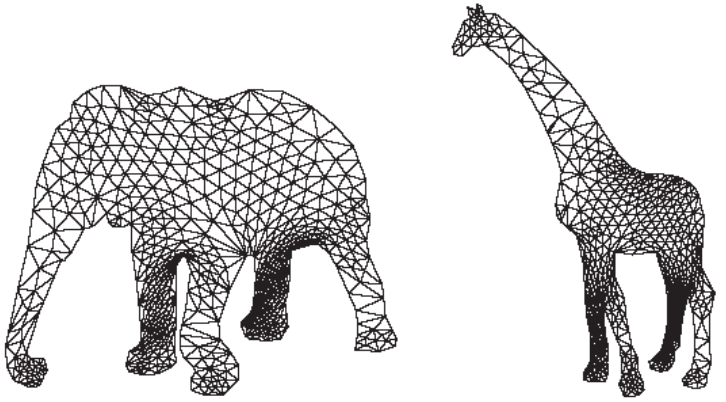
[Shapira et al. 1995]





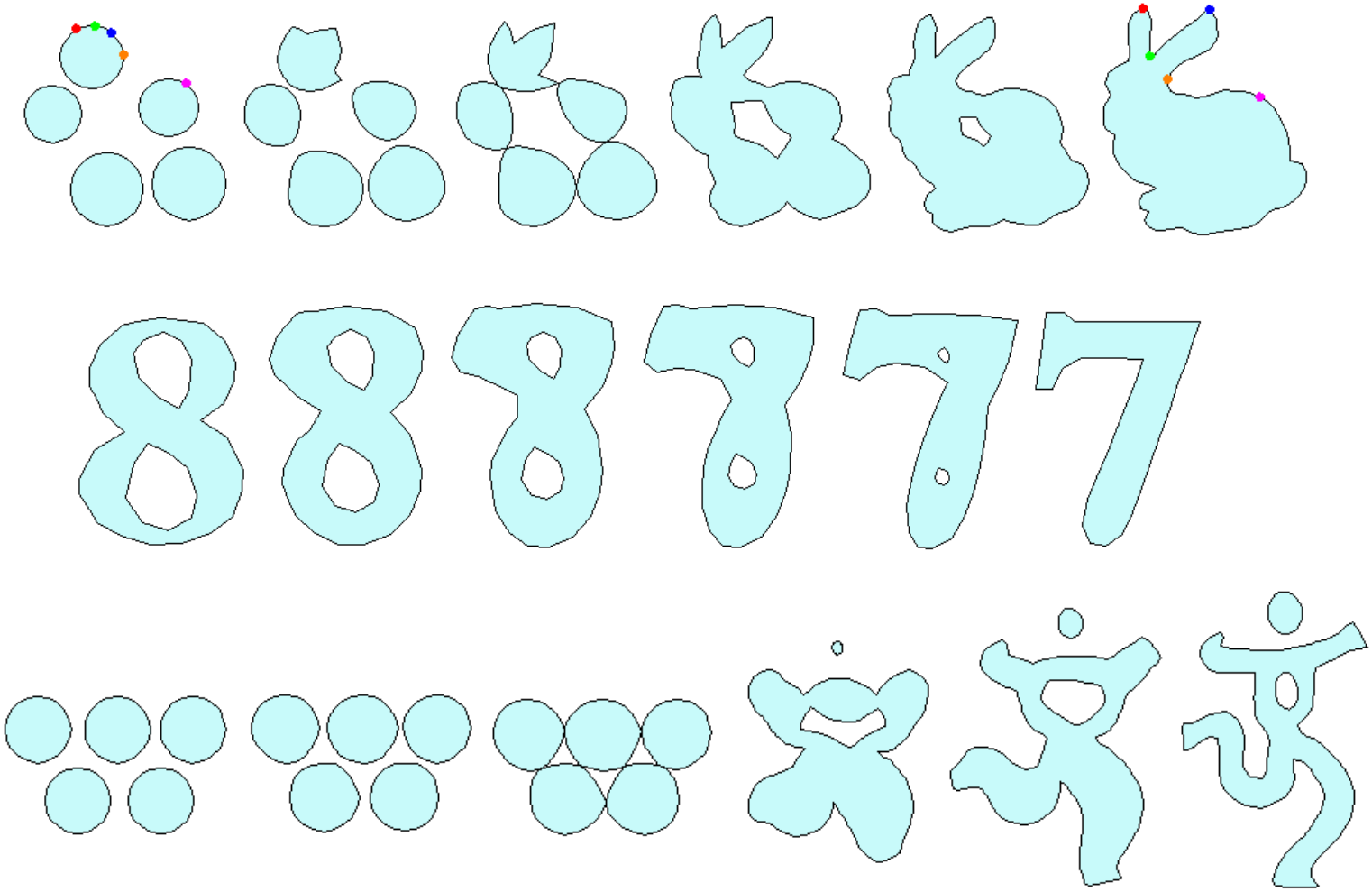
Interior Based Approach

- Based on compatible triangulation
  - [Gotsman and Surazhsky, 1999-2001]
  - As-rigid-as-possible [Alexa et al. 2000]



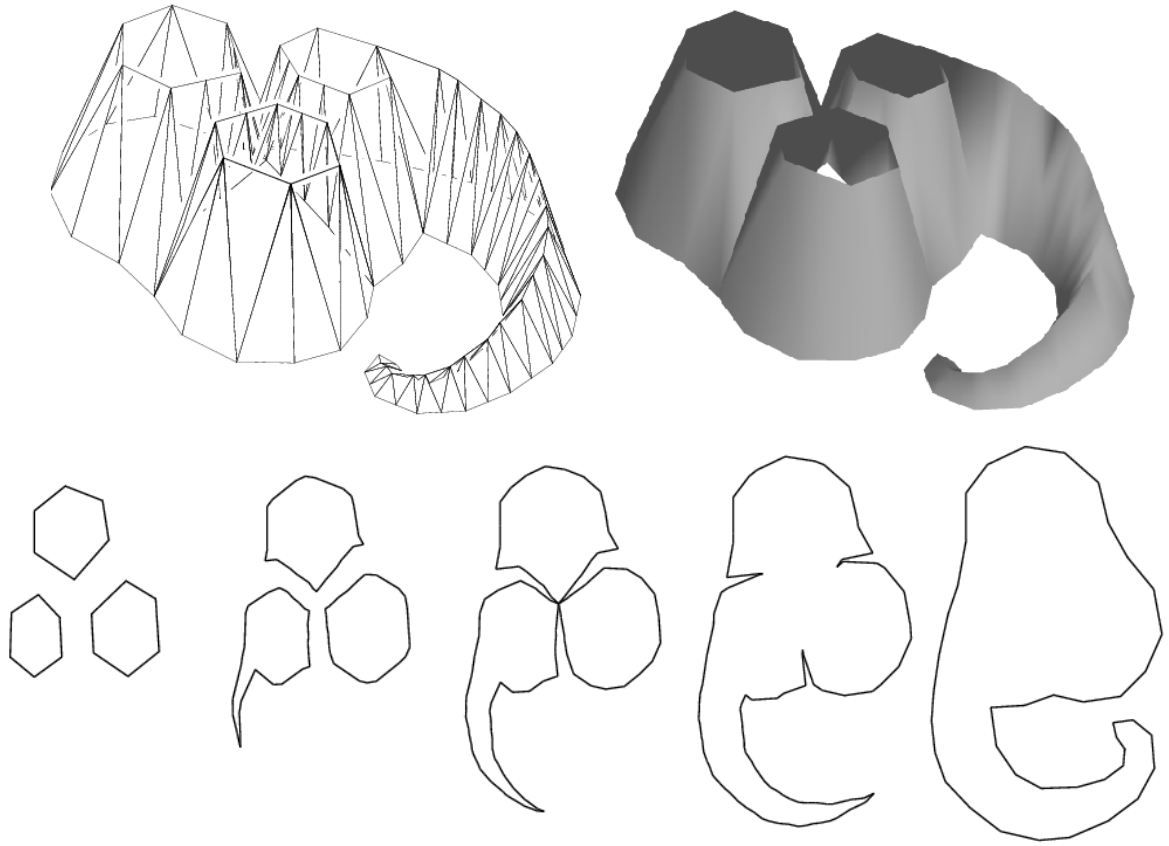
Morphing between Different Topologies

Liu et al. 2005



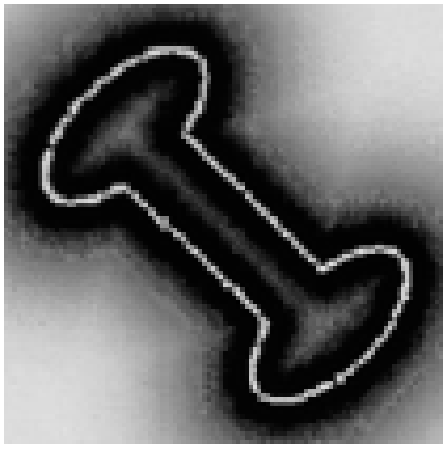
Implicit Approaches

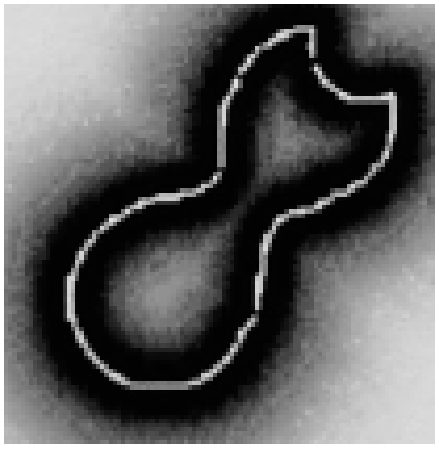
- Construct a 4D function which interpolates two shapes (with iso-value 0 and 1 respectively)



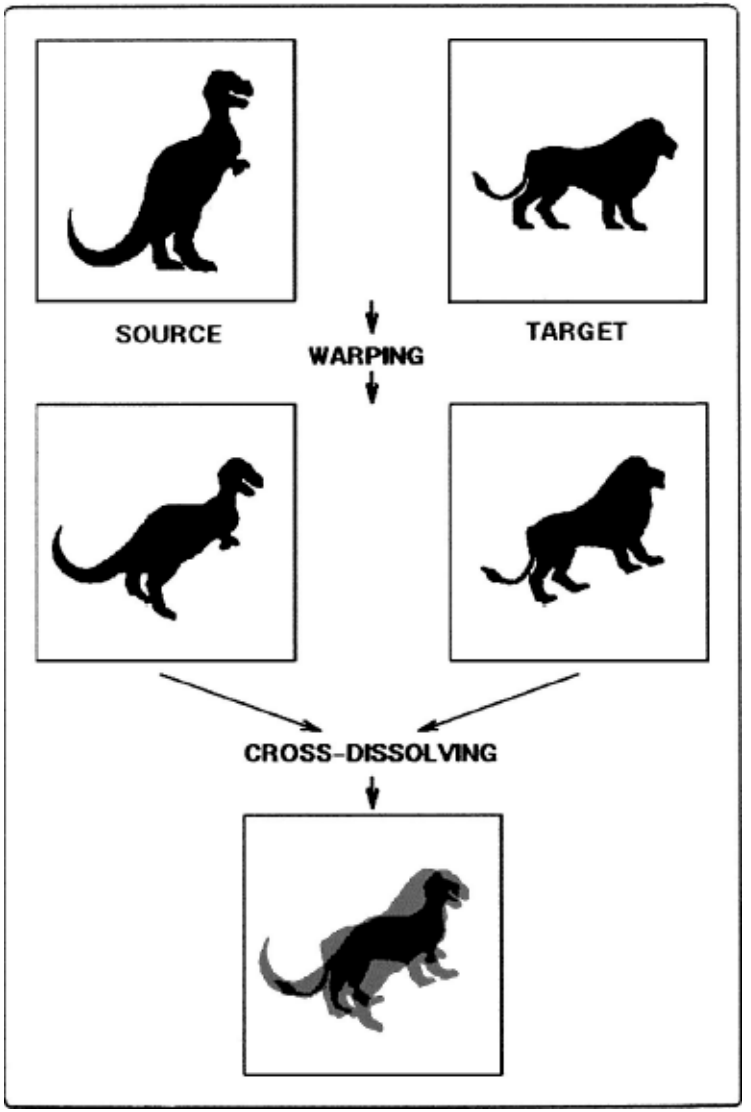
Distance Field

- Distance field of a shape

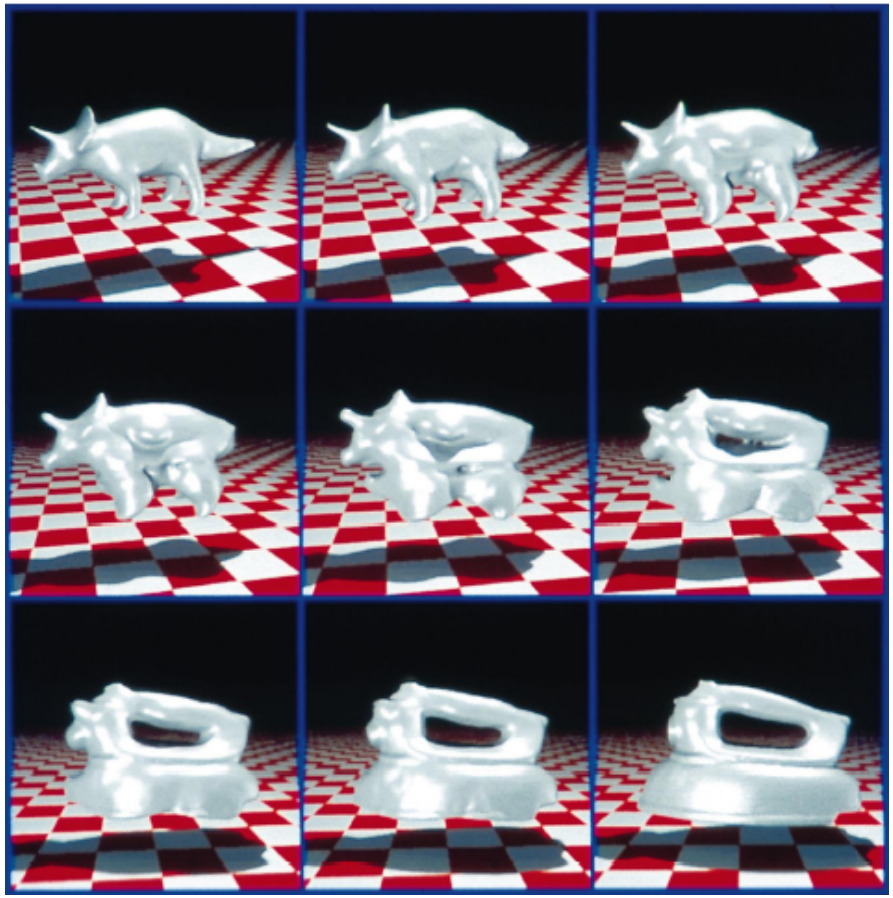


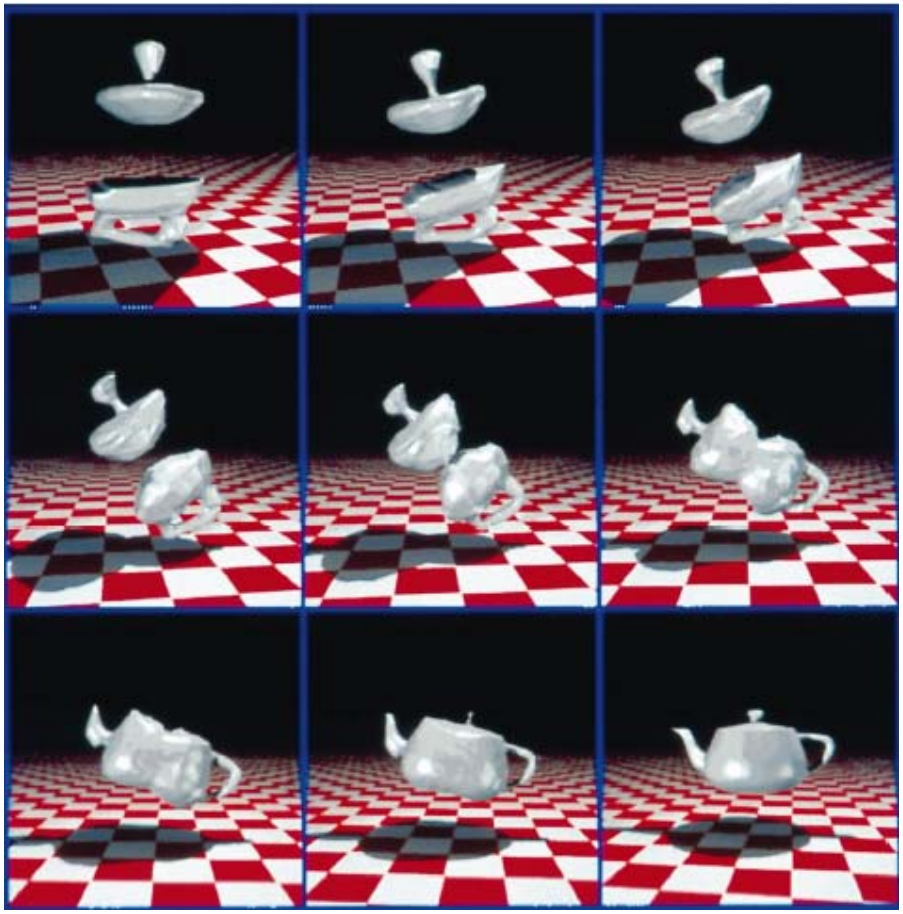


[Cohen-Or et al. 1998]



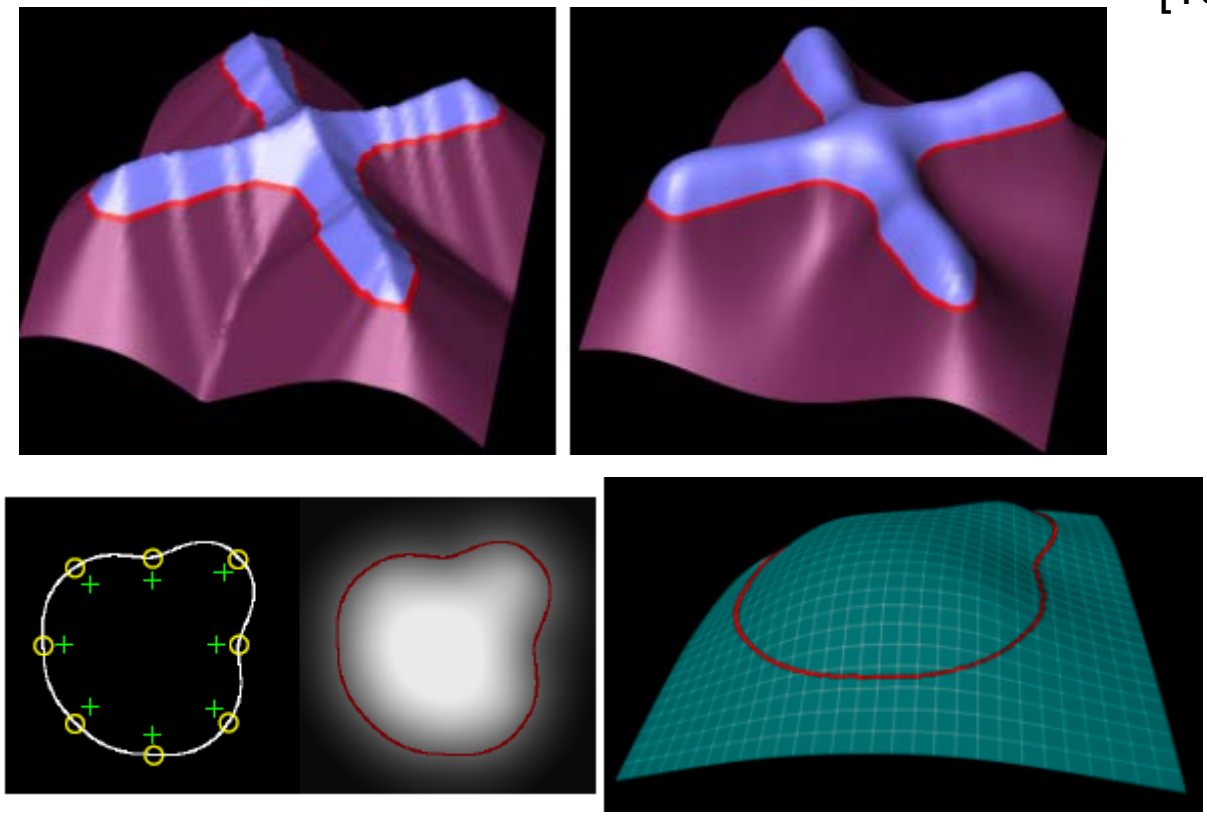
Distance Field





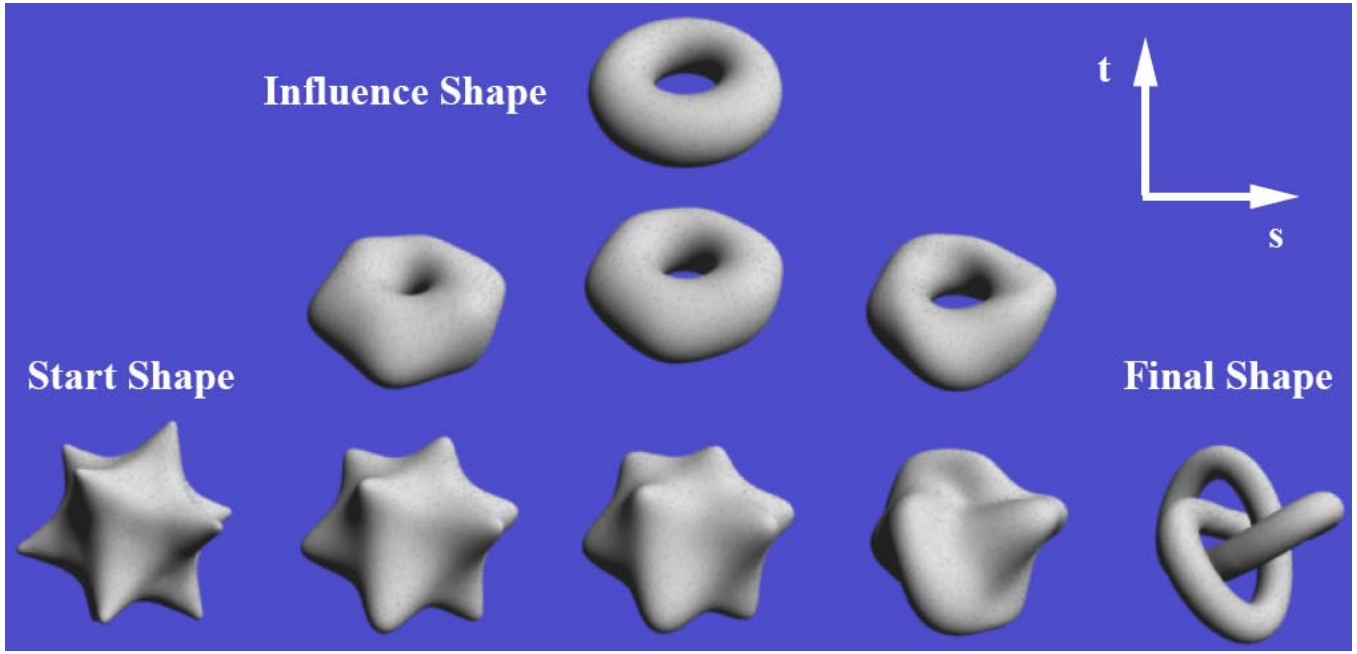
Variational Implicit Function

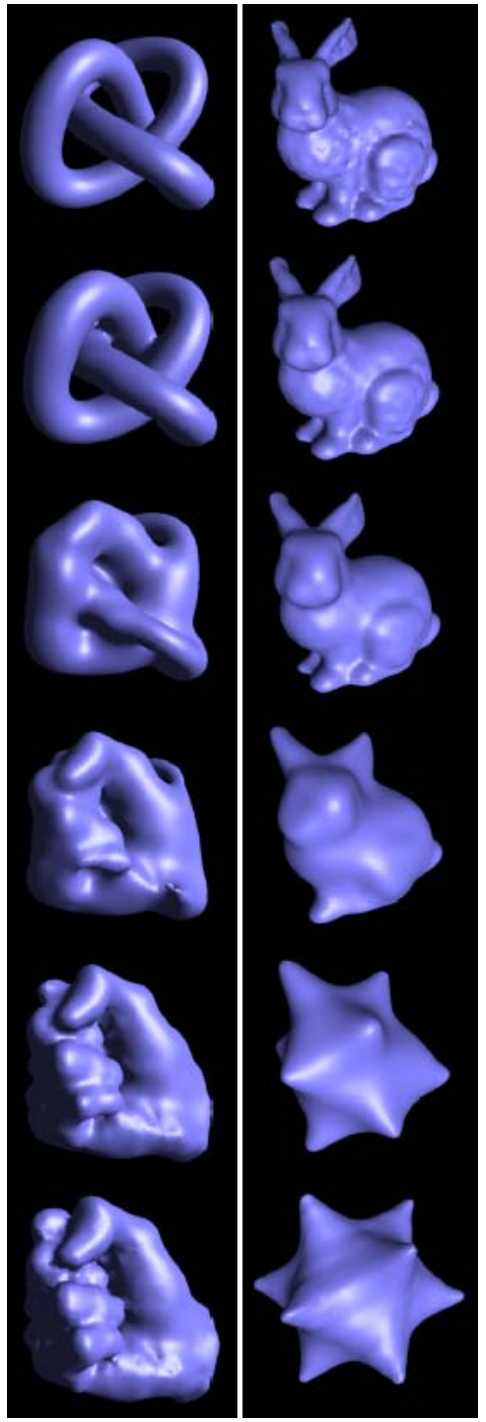
[Turk et al. 1999]



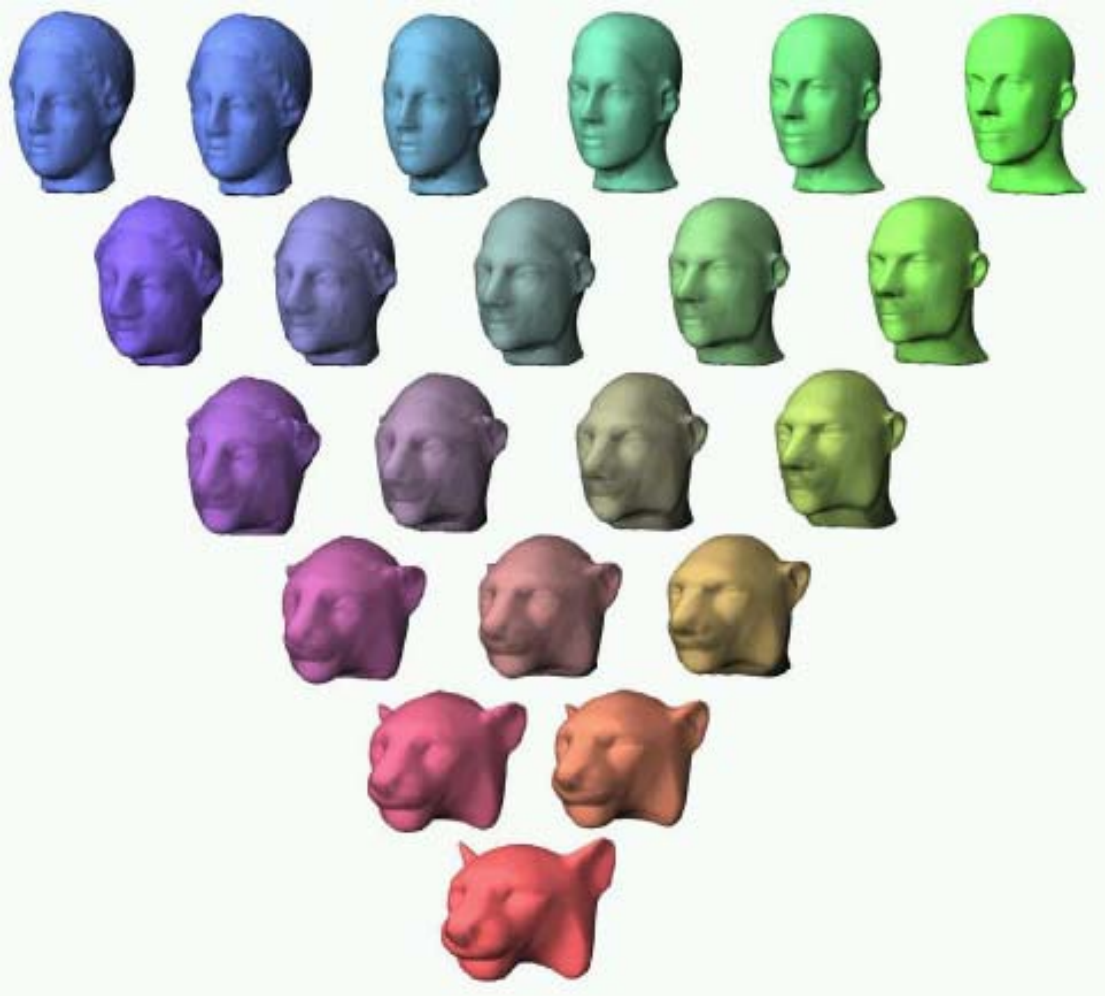
$$f(\mathbf{x}) = \sum_{j=1}^{n} d_j \phi(\mathbf{x} - \mathbf{c}_j) + P(\mathbf{x})$$

Examples



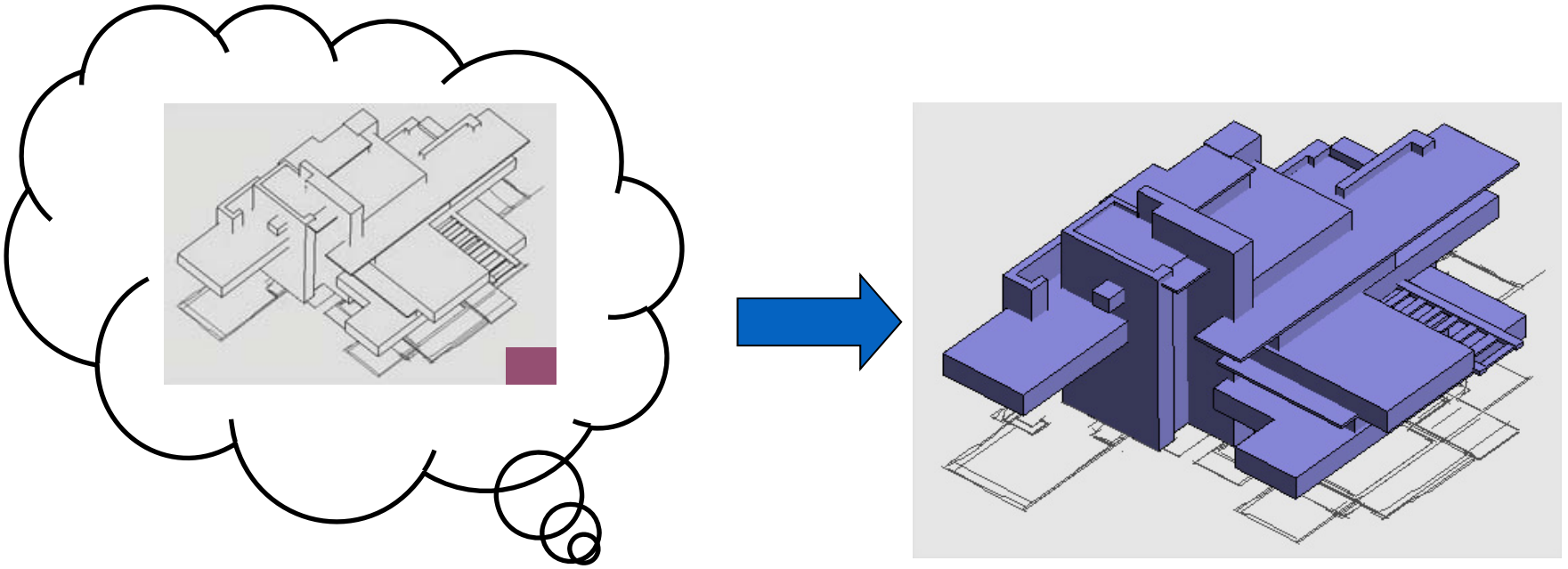


Polymorph:
Morphing between multiple shapes



Summary

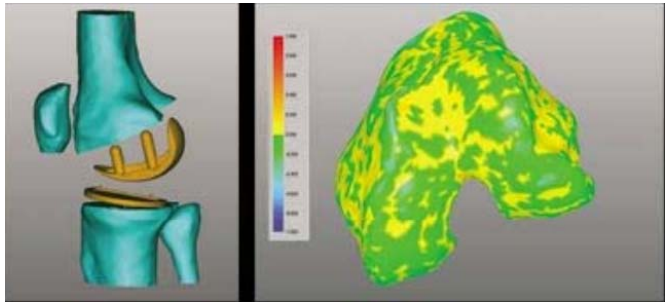
3D content creation is still hard

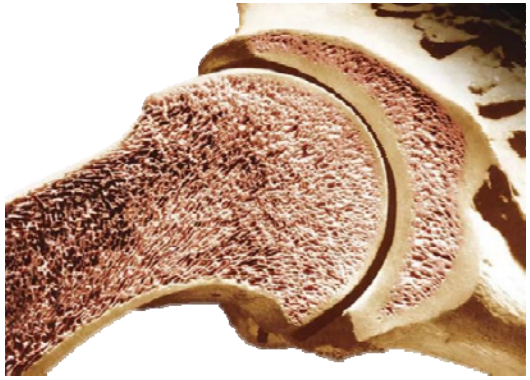


- One of the most central and challenging problems in graphics
  - (Comparing to simulation and rendering)

Challenges to Geometric Modeling

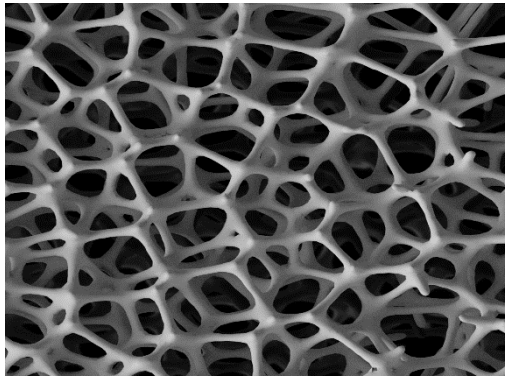
- Modeling porous structure
- Modeling non-homogeneous materials
  - varying density
  - changing composition
  - multiple phases (solid, liquid)
  - …





生物多孔组织

多孔泡沫



微胞腔结构

中国科学技术大学

University of Science and Technology of China

谢　谢　！