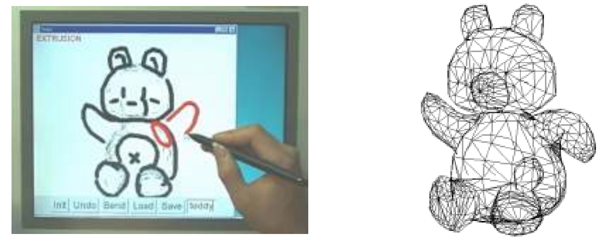
CS 523: Computer Graphics, Spring 2011

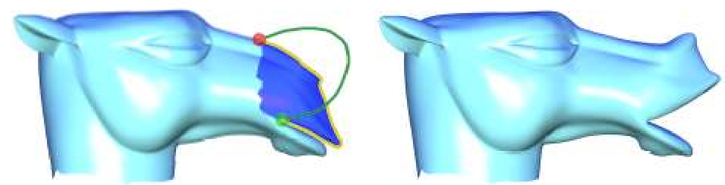
Shape Modeling

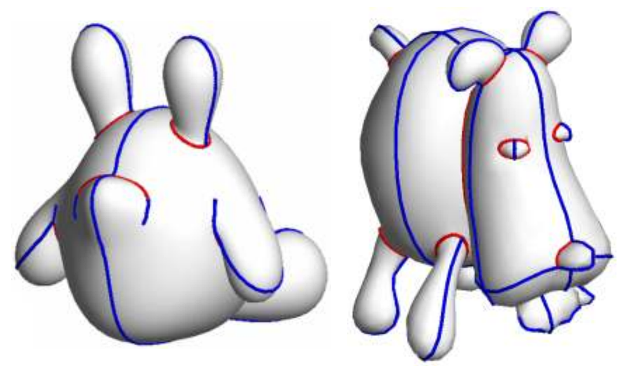
Sketch-based Interfaces and Algorithms for shape creation and editing

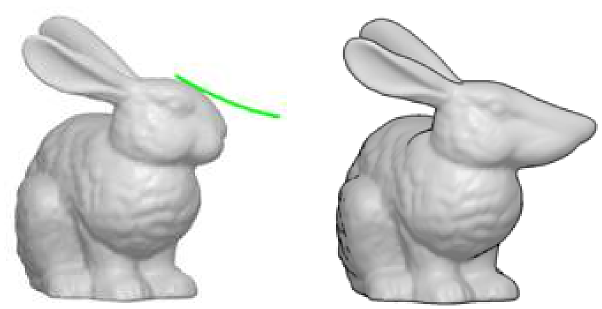
Overview

- **Teddy**
  [Igarashi et al. 1999]
- **Sketch based mesh editing** [Nealen et al 2005]
- **FiberMesh**
  [Nealen et al. 2007]
- **SilSketch**
  [Zimmermann et al. 2008]



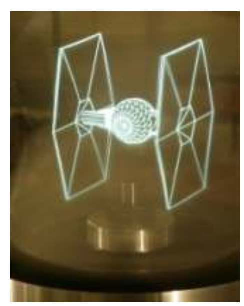






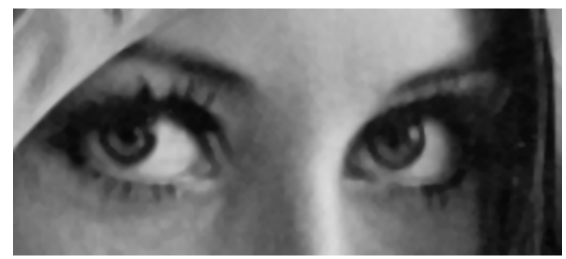
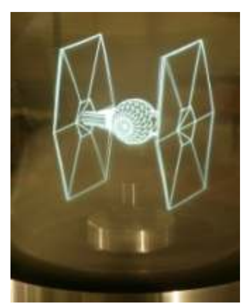
Primary Goal

- Find a possible solution to the human "video out" problem

	Machine	Human
Video in		
Video out	 	 ? 

The Main Question

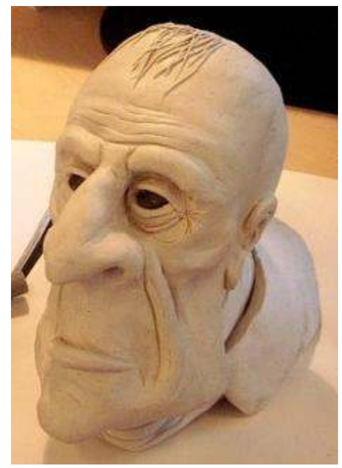
- How can we convey a mental model of shape to a digital computer ?

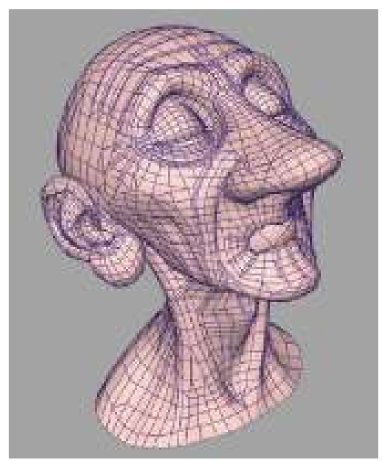
	Machine	Human
Video in		
Video out	 	 ? 

Motivation

Model Creation

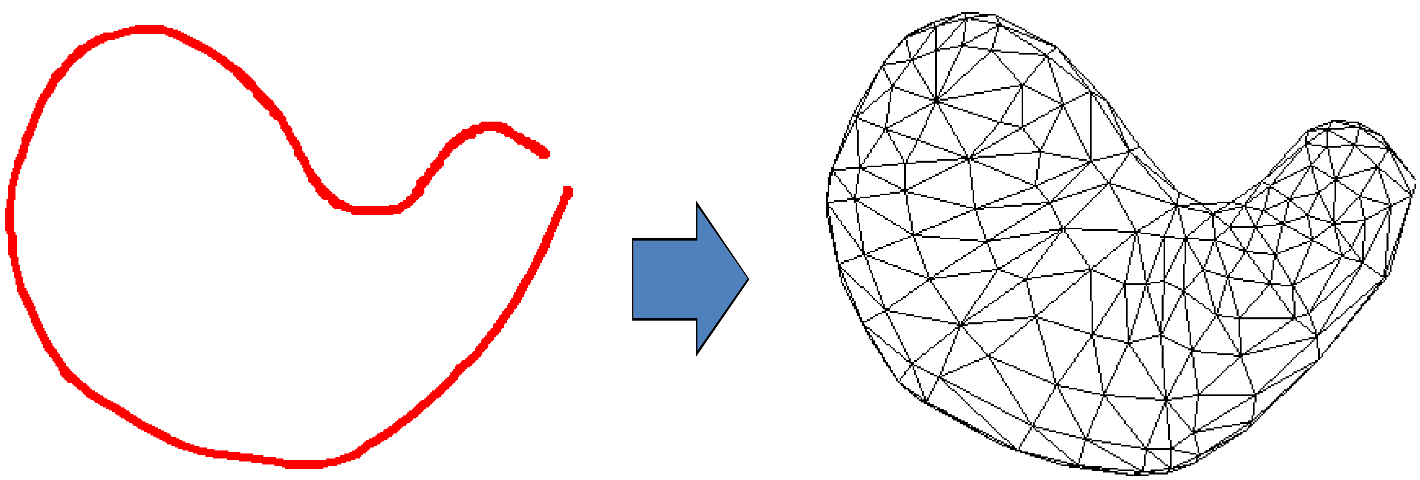
- Digital 3D model creation from scratch is hard
- Common workflow(s)
  - Create clay model + scan
    - Laser scanner
    - Position tracking
  - Create coarse 3D model + refine
    - Subdivision surfaces
    - Parametric patches
    - Detail maps





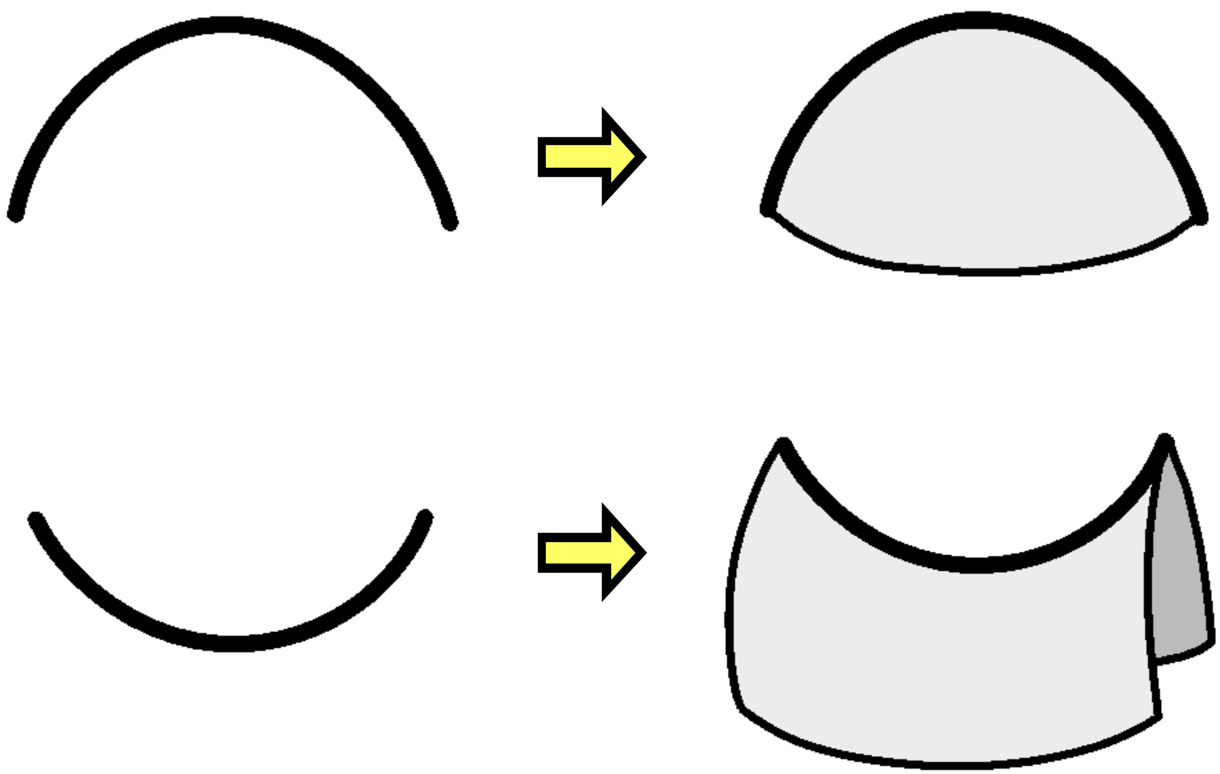
Problem

- How to construct 3D surface from 2D sketch?
  - Infer the missing depth information
  - Construct a discrete surface
  - What rule(s) to use?



Background

- Study on Human perception of 3D shape from 2D drawings [Hoffman 2004]



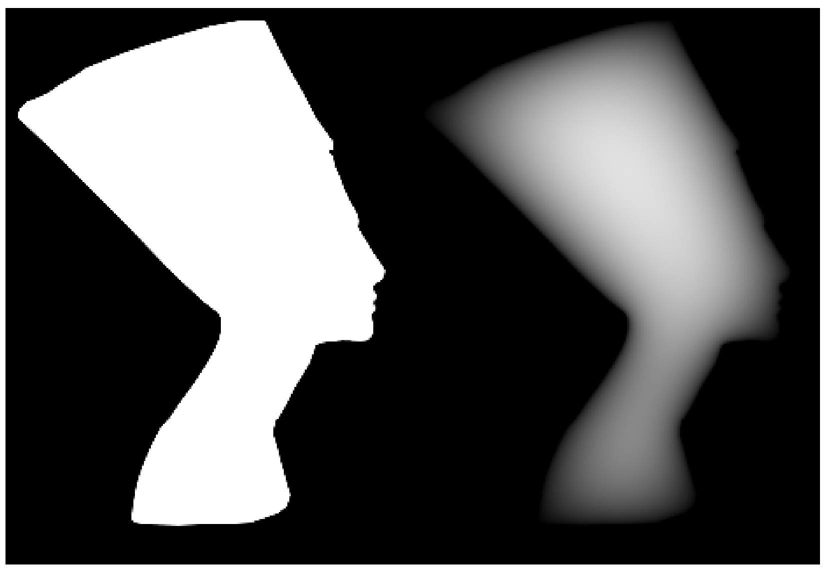
Specific Algorithms

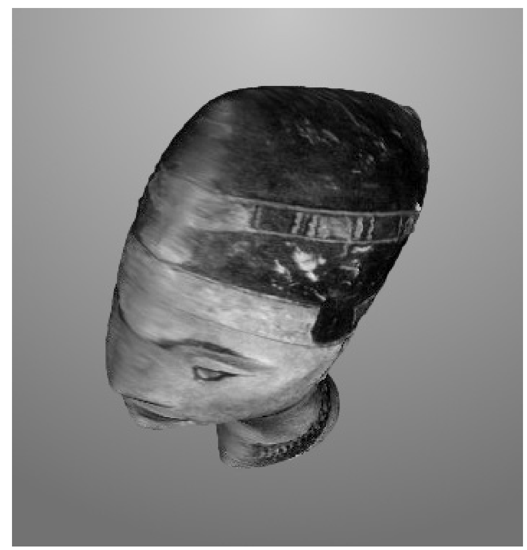
- Level-set method [Williams 91]
- Heuristic mesh construction [Igarashi 99]
- Volumetric construction [Owada 03]
- Convolution surface [Alexe 05]
- Blob tree (Implicit surface) [Schmidt 05]
- Mass-spring system [Karpenko 06]
- Optimization [Nealen 07]

Level-set Method

[Williams 91]

- Compute implicit representation of the contour

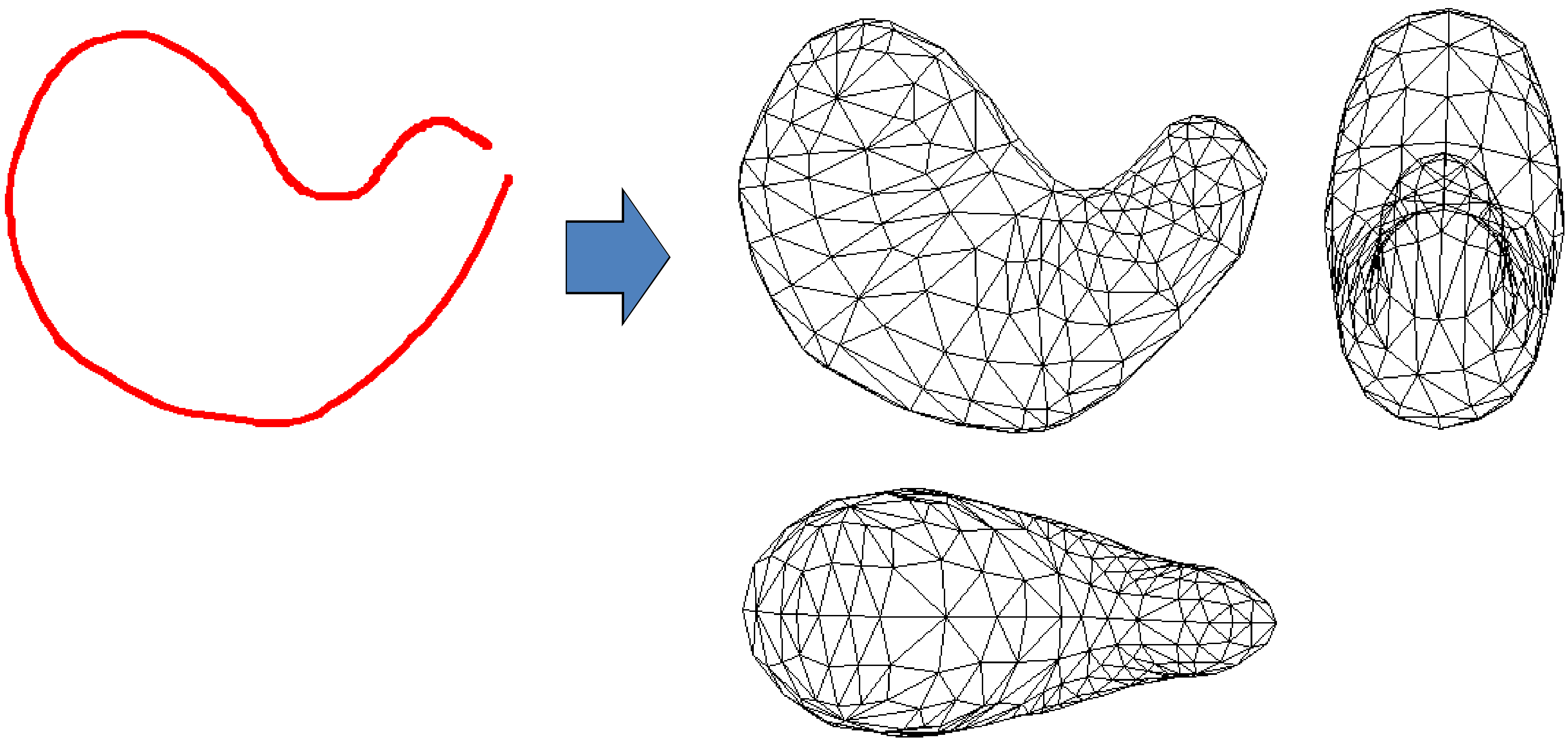




Teddy

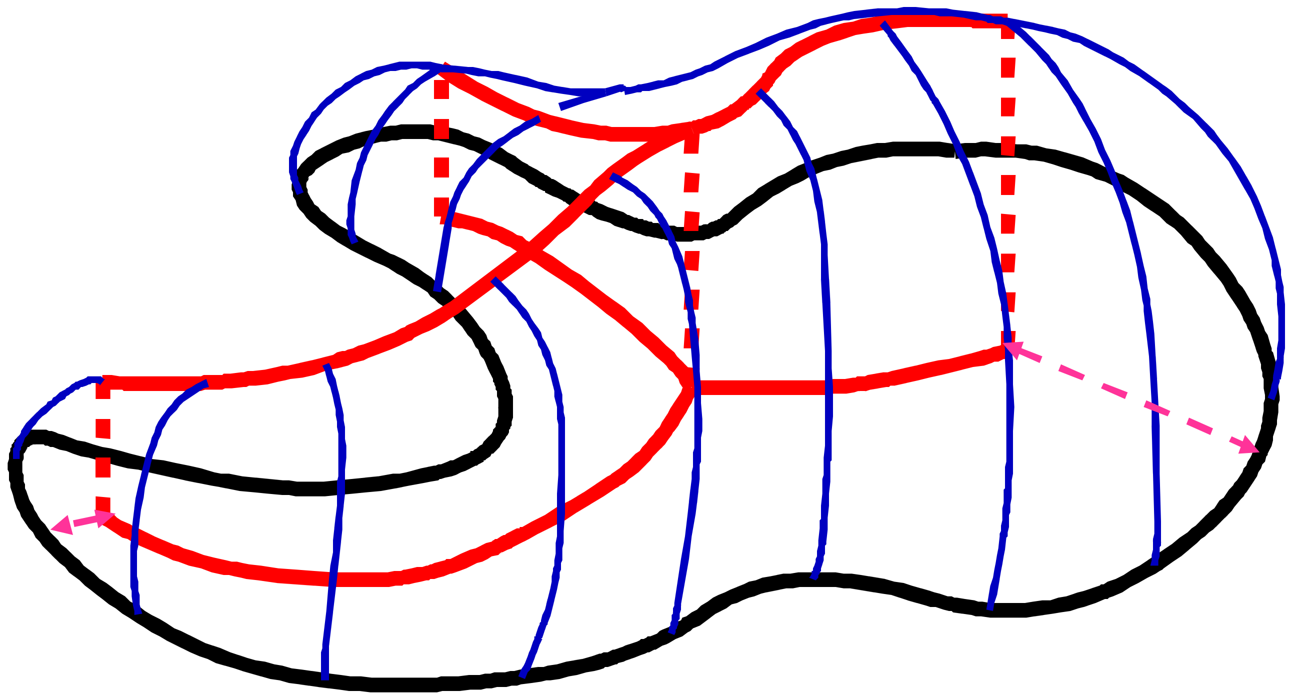
Heuristic Mesh Construction

Teddy



Heuristic Mesh Construction

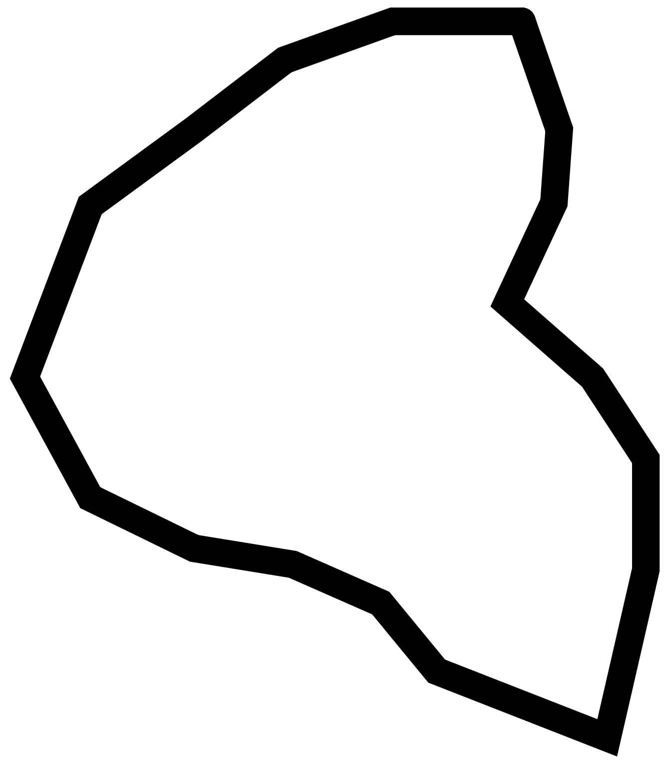
Teddy



1. Find axes
2. Elevate axes
3. Wrap polygon and axes

Heuristic Mesh Construction

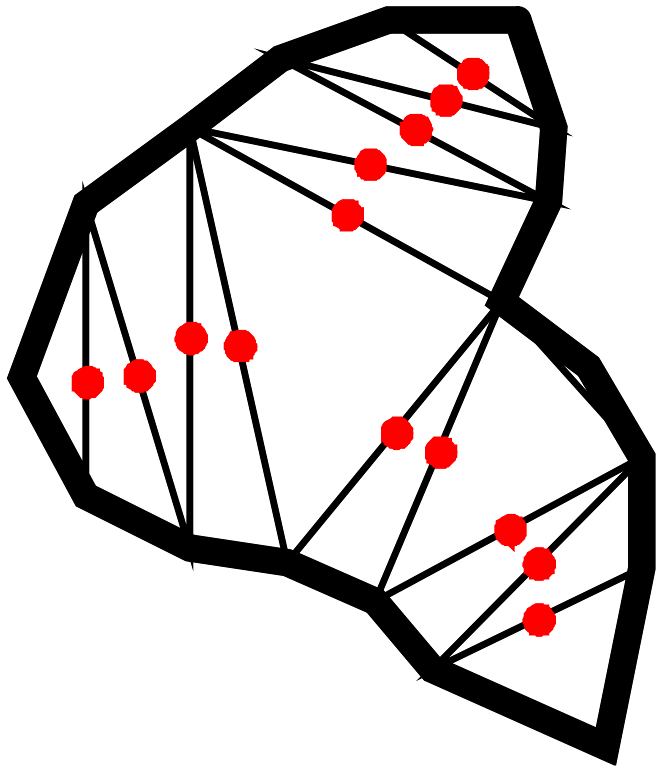
Teddy



Input 2D polygon

Heuristic Mesh Construction

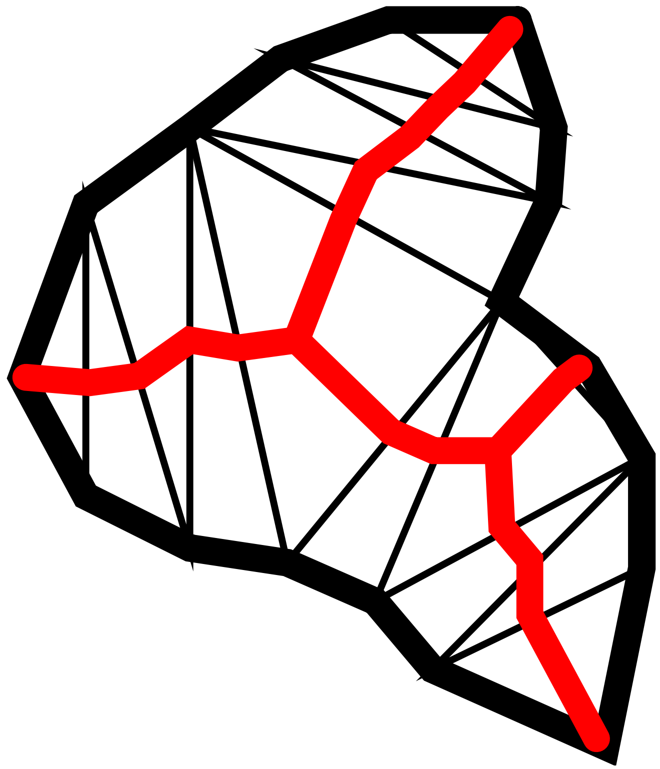
Teddy



Constrained Delaunay Triangulation

Heuristic Mesh Construction

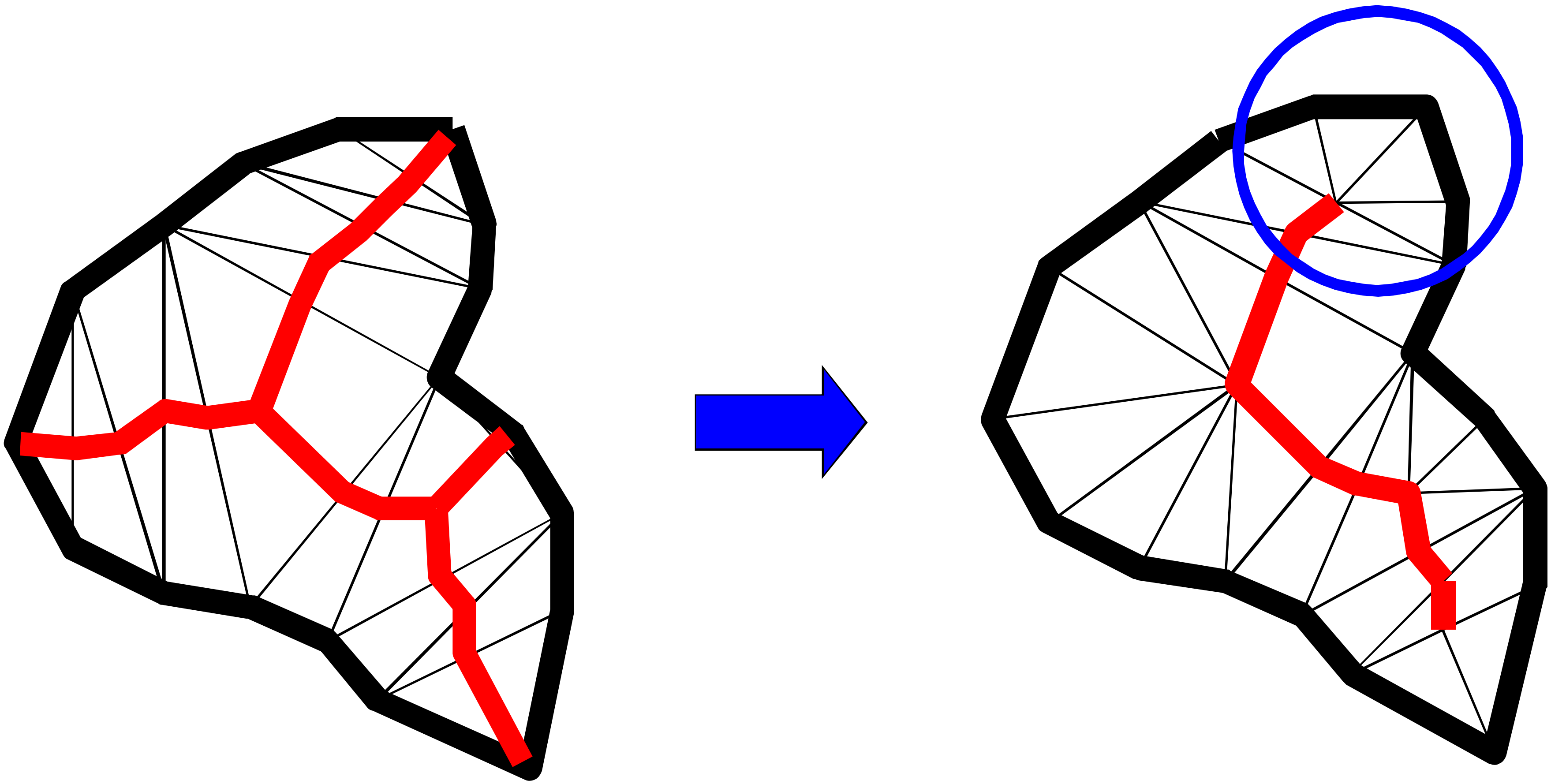
Teddy



Discrete chordal axis [Prasad 97]

Heuristic Mesh Construction

Teddy

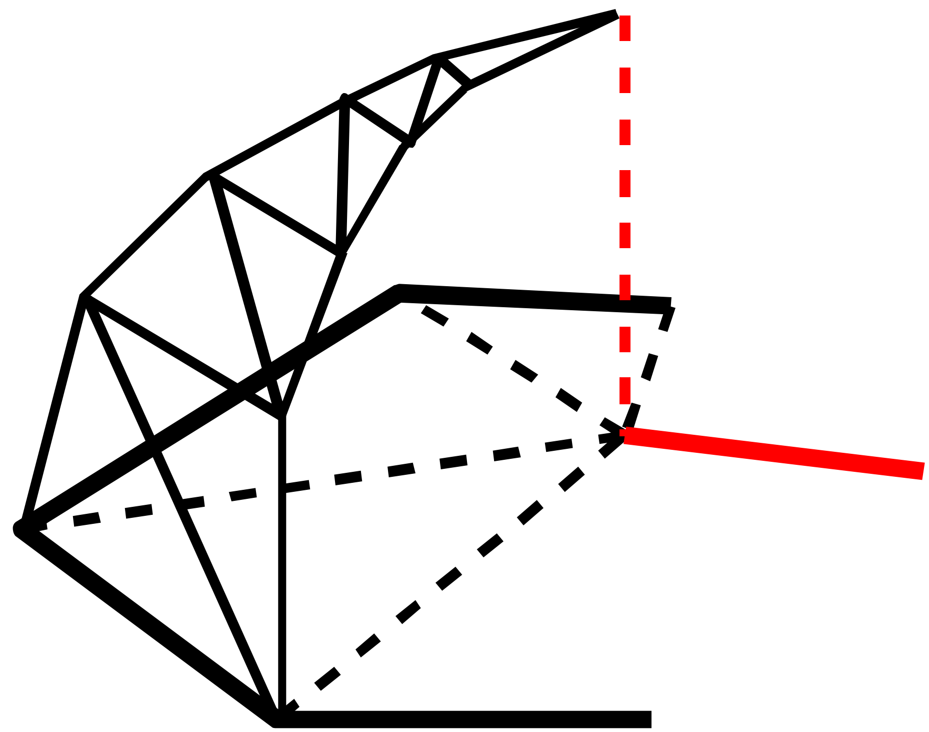


Before trimming

After trimming

Heuristic Mesh Construction

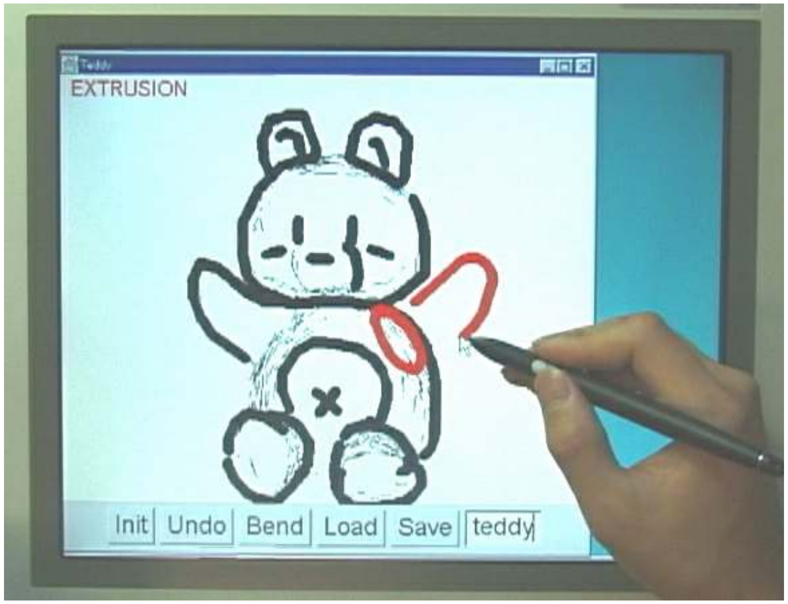
Teddy



Lift the axes, put quarter ovals on the internal edges, and generate mesh.

Teddy

- Results



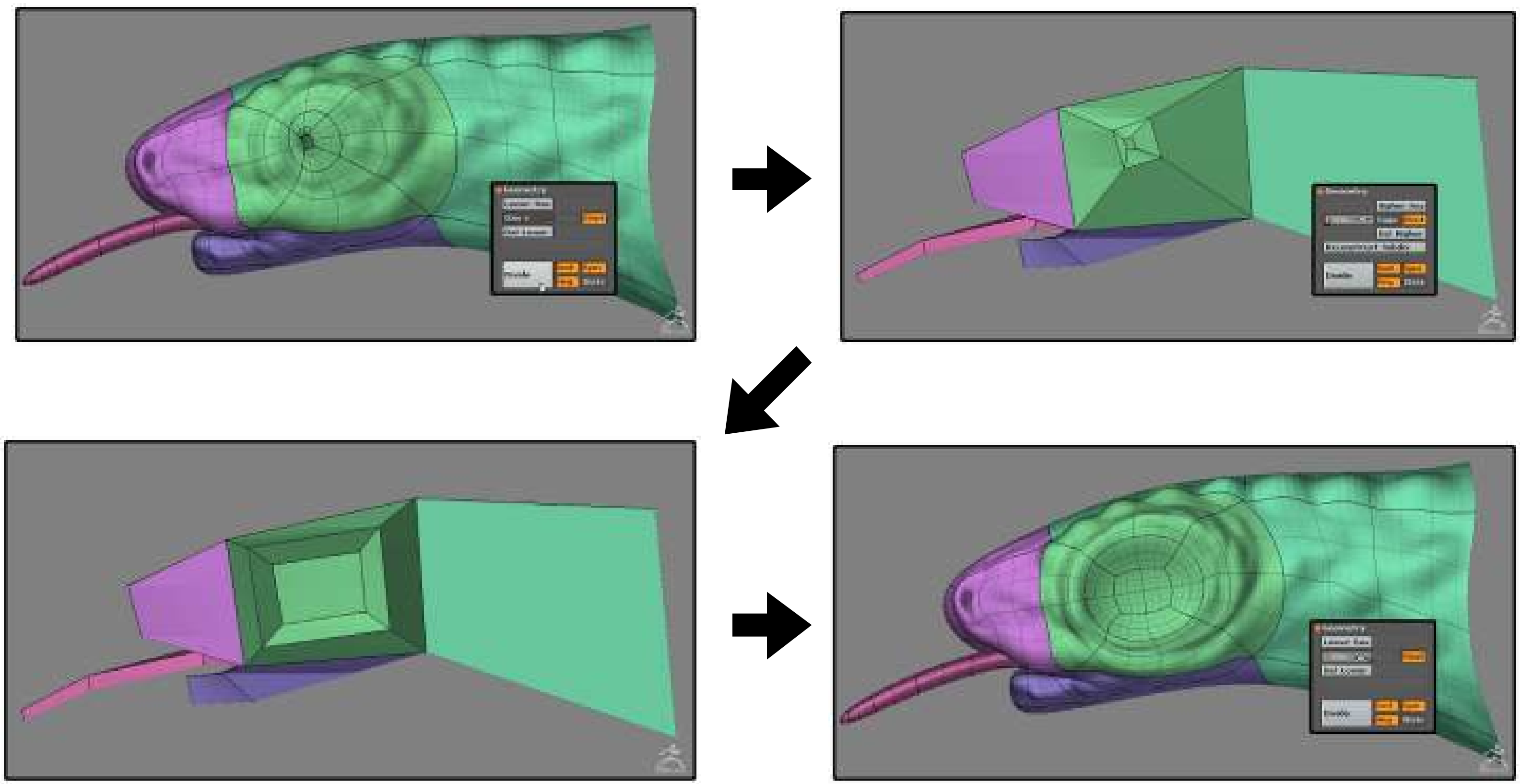
- Fast and first of its kind
- Meshes are of low quality

Sketch-based mesh editing

Motivation

Model Modification

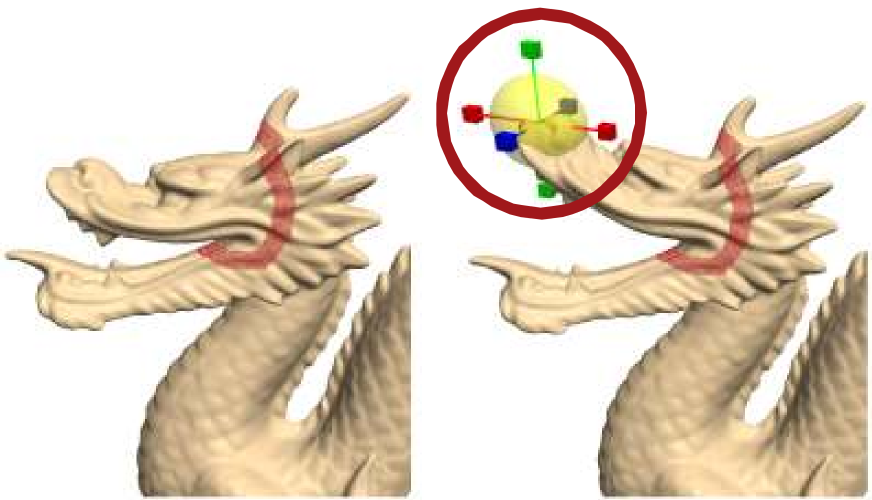
- Digital 3D model modification is nontrivial
- Multiresolution mesh editing /w subdivision



Motivation

Model Modification

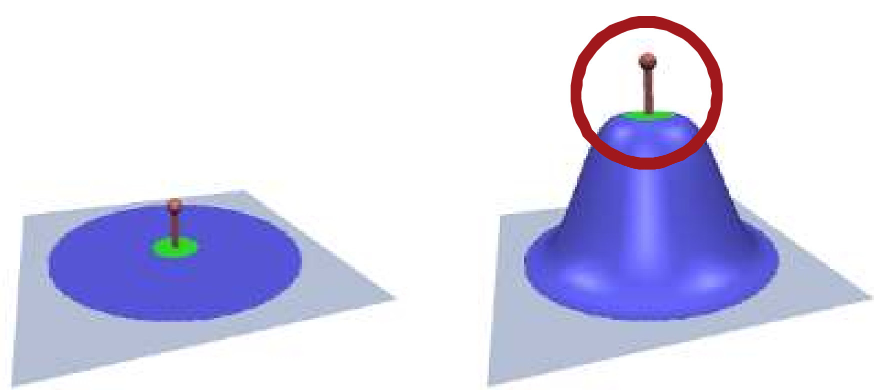
- Digital 3D model modification is nontrivial
- Laplacian / Poisson mesh editing /w handle



[Sorkine et al. 2004]

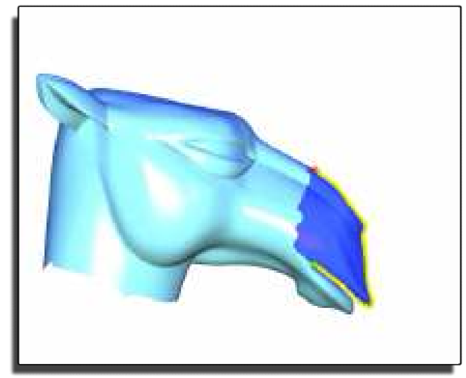
Affine Handle

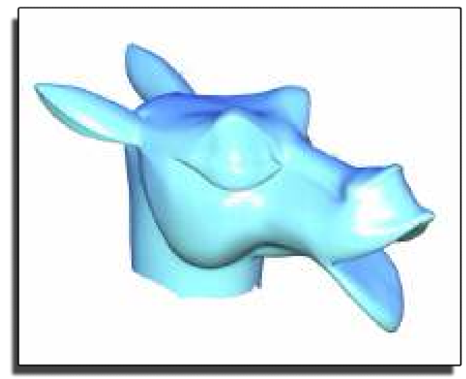
[Botsch and Kobbelt 2004]



Ideas and Contributions

- **A sketch-based interface...**
  - Feature modification (object-space silhouettes)
  - Feature creation (sharp features, ridges, ravines)





- **... For detail-preserving mesh editing**
  - Adjust remaining geometry around the modified/created feature such that shape characteristics are preserved

Ideas and Contributions

- Silhouette sketching

- Feature sketching
- Sketching a shape can be interpreted as inverse **Non-Photorealisti**
- A ske
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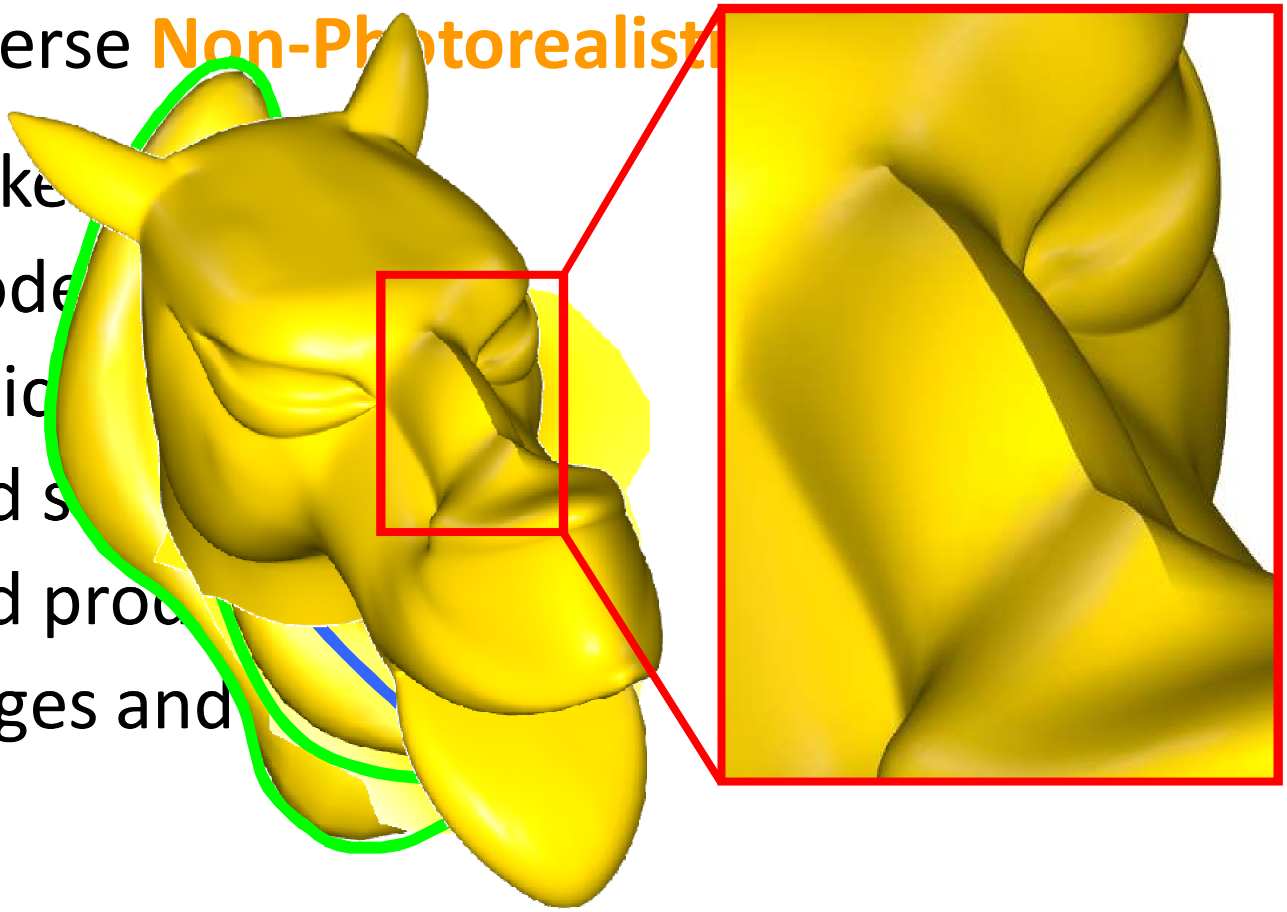
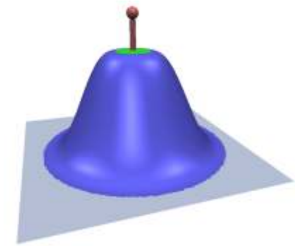
  ridges and

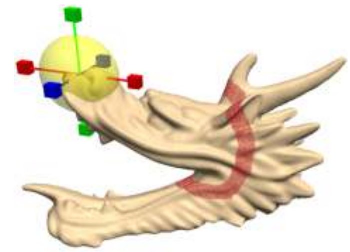


Inspiration and Motivation

- The (affine) handle metaphor
  - Used in (almost) every editing tool
  - Nice, but can be unintuitive for specific editing tasks

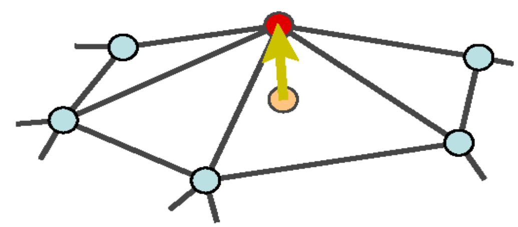


[Botsch and Kobbelt 04]



[Sorkine et al. 04]

- Laplacian Mesh Editing
  - Preserve local detail **after** imposing editing constraints

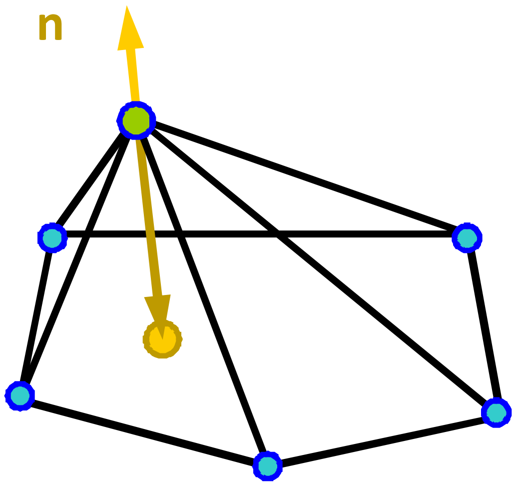


$$\delta_i = \frac{1}{d_i} \sum_{j \in N(i)} (\mathbf{v}_i - \mathbf{v}_j)$$

[Sorkine et al. 04] [Zhou et al. 05]

Mesh Modeling Framework

- Discrete Laplacians



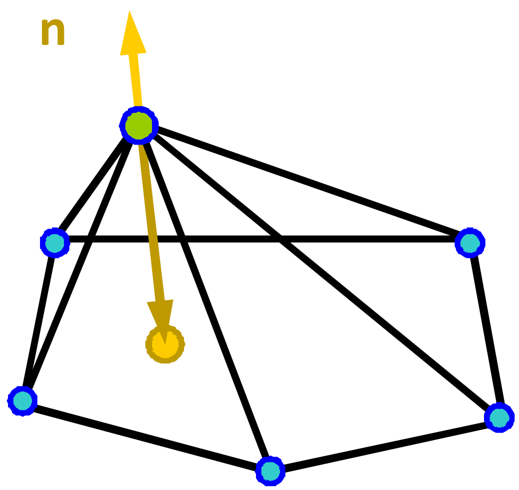
$$\mathbf{L}\,\mathbf{x} = \delta$$

$$\boldsymbol{\delta}_i = \mathbf{x}_i - \frac{1}{\sum_{(i,j)\in E} w_{ij}} \sum_{(i,j)\in E} w_{ij}\mathbf{x}_j$$

$\delta_{\text{cotangent}}$: $w_{ij} = \cot \alpha_{ij} + \cot \beta_{ij}$

Mesh Modeling Framework

- Surface reconstruction



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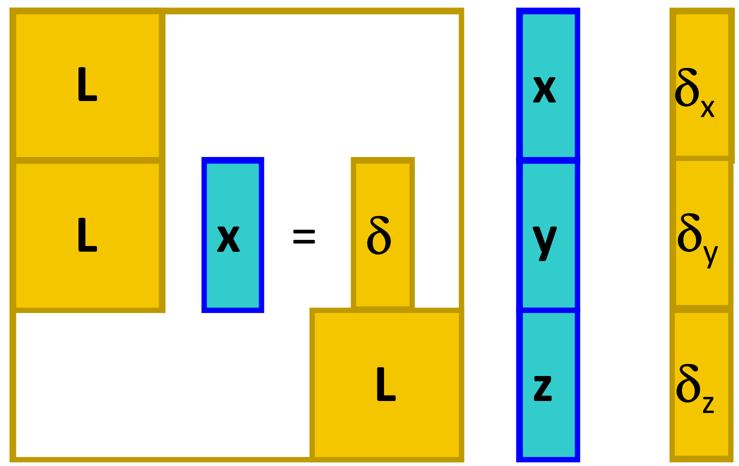
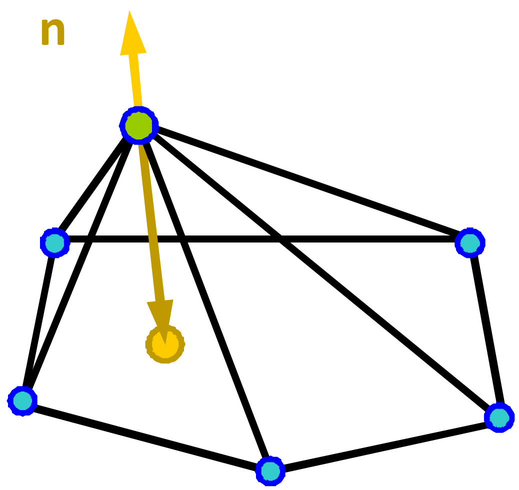
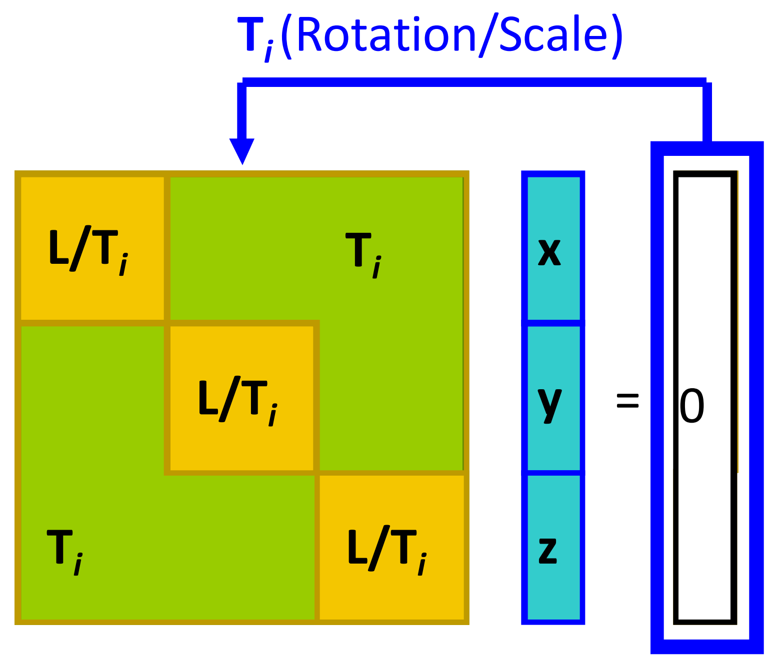


$\delta_{\mathbf{cotangent}}$: $w_{ij} = \cot \alpha_{ij} + \cot \beta_{ij}$

Mesh Modeling Framework

- Implicit transformations



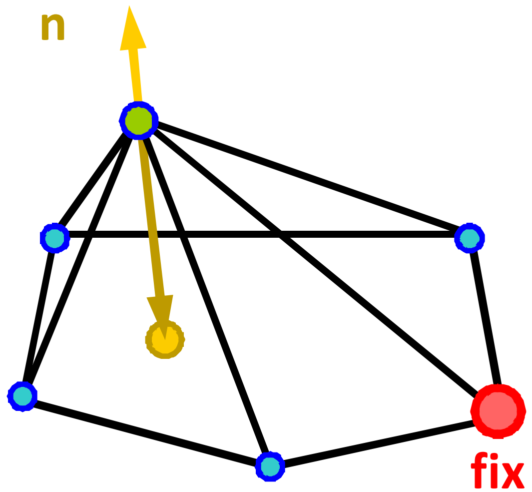


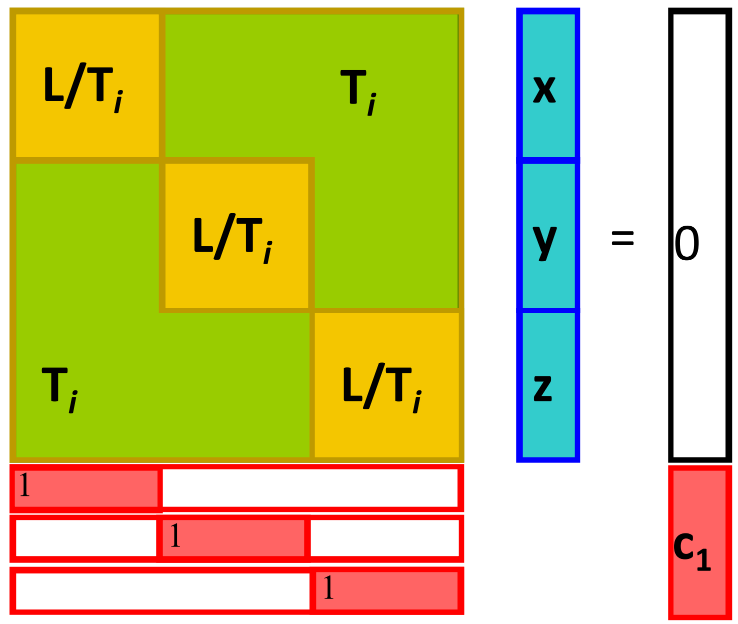
Implicitly compute T_i
transformations by comparing 1-rings of the deformed and non-deformed mesh

For the details see:
Laplacian Mesh Editing
[Sorkine et al. 04]

Mesh Modeling Framework

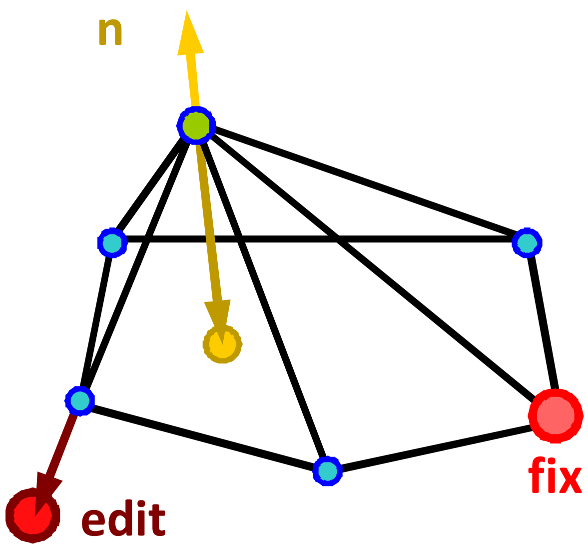
- Surface reconstruction

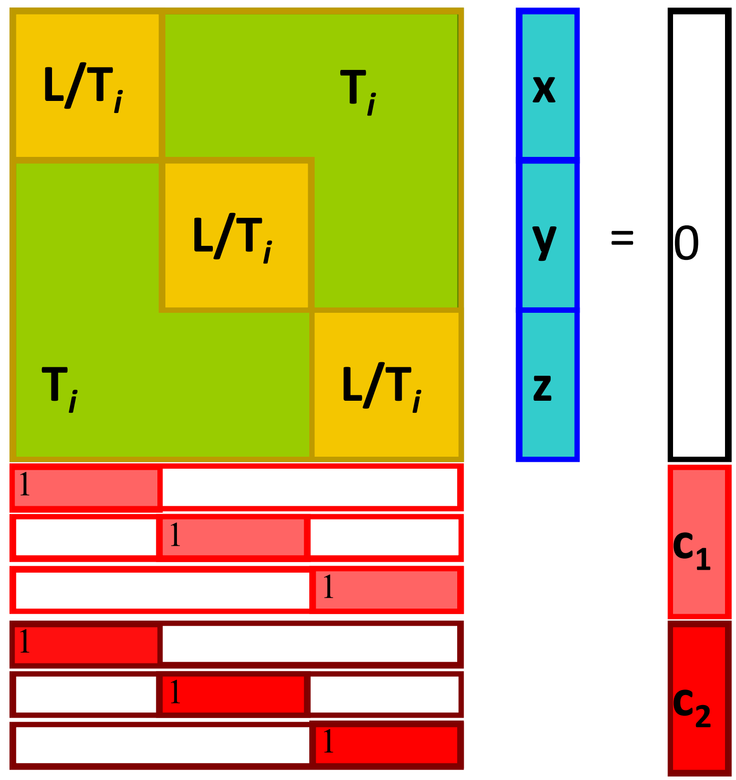




Mesh Modeling Framework

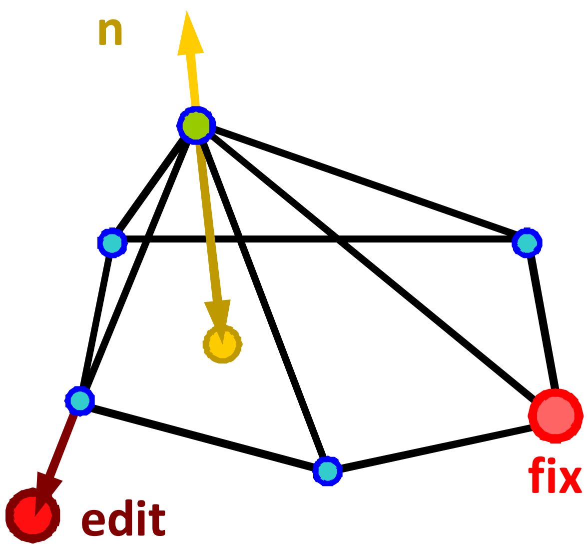
- Editing operations





Mesh Modeling Framework

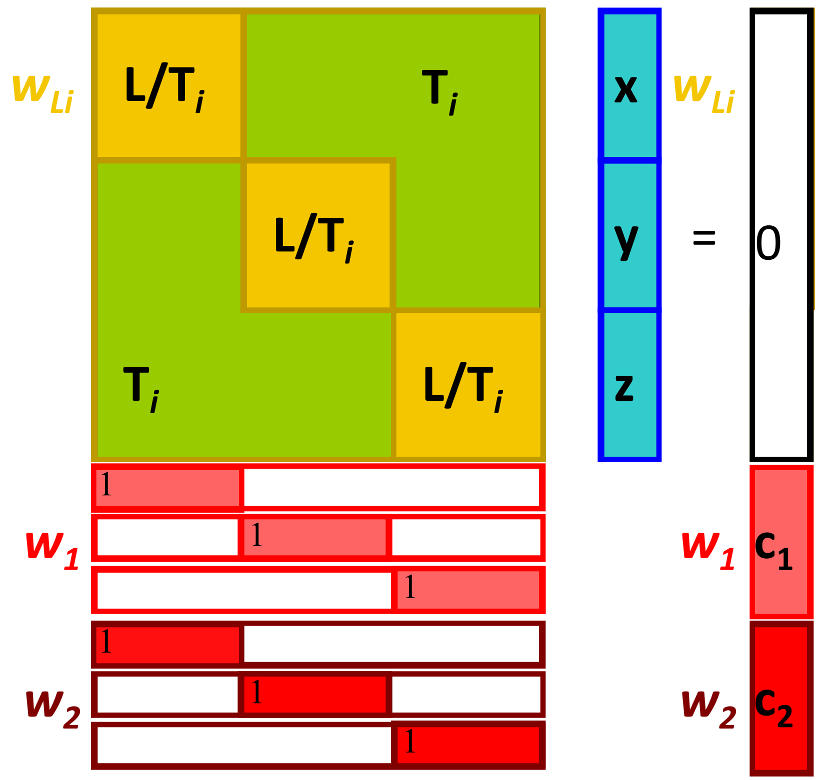
- Least-Squares solution



Normal Equations

$$A^TA \; x = A^T \; b$$

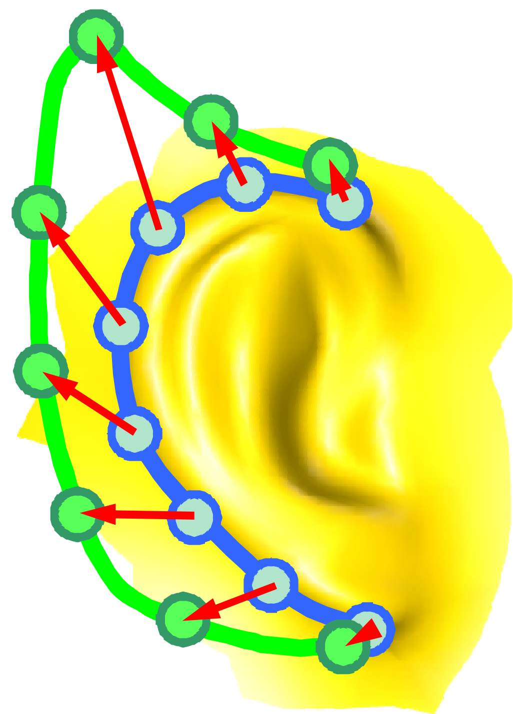
$$x = (A^TA)^{-1} \; A^T \; b$$



$$A \quad x \quad = \quad b$$

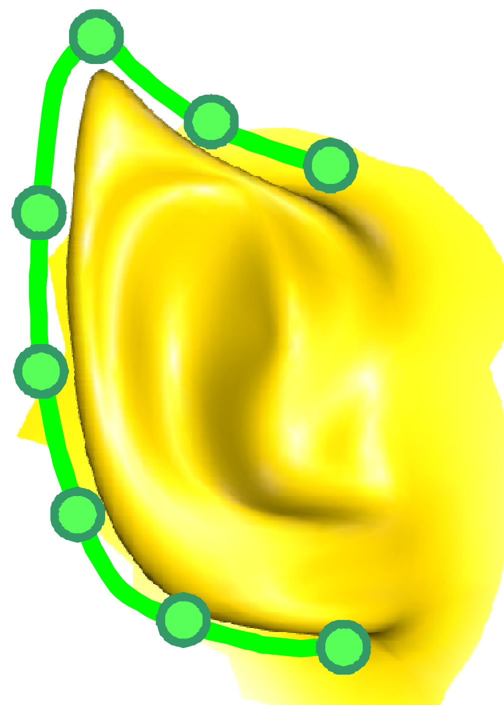
Silhouette Sketching

- Using silhouettes as handles
  - Detect object space silhouette
  - Project to screen space and parametrize [0,1]
  - Parametrize sketch [0,1]
  - Find correspondences



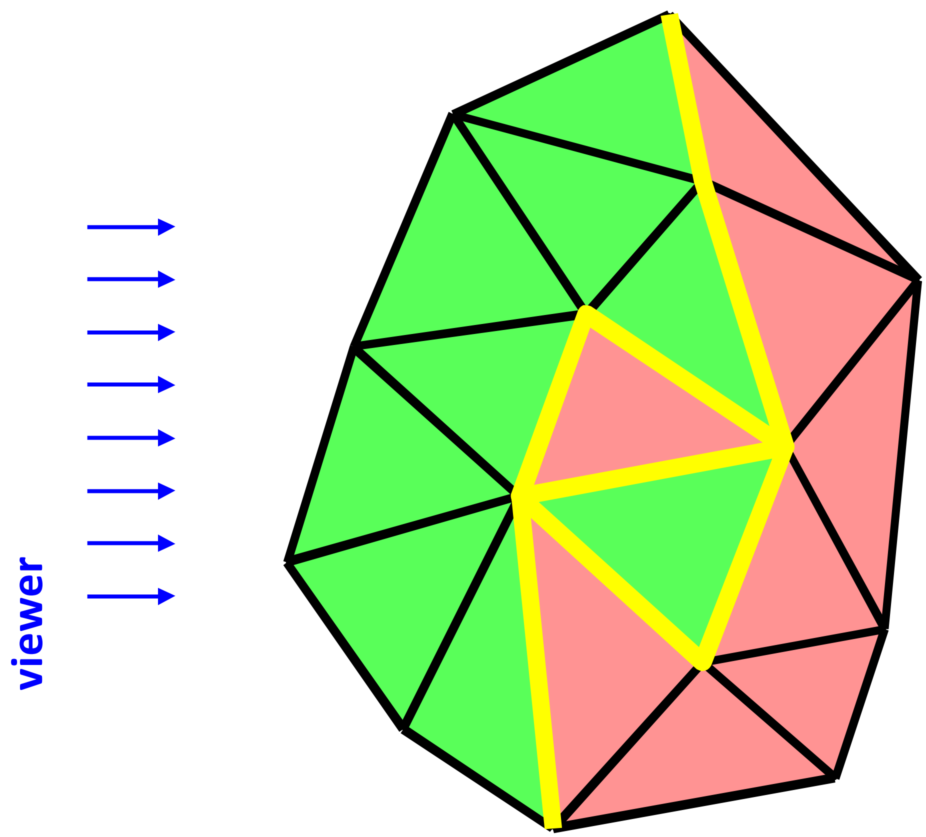
Silhouette Sketching

- Using silhouettes as handles
  - Detect object space silhouette
  - Project to screen space and parametrize [0,1]
  - Parametrize sketch [0,1]
  - Find correspondences
  - Use as positional constraints while retaining depth value



Silhouette Sketching

- What is a good silhouette?



Silhouette Sketching

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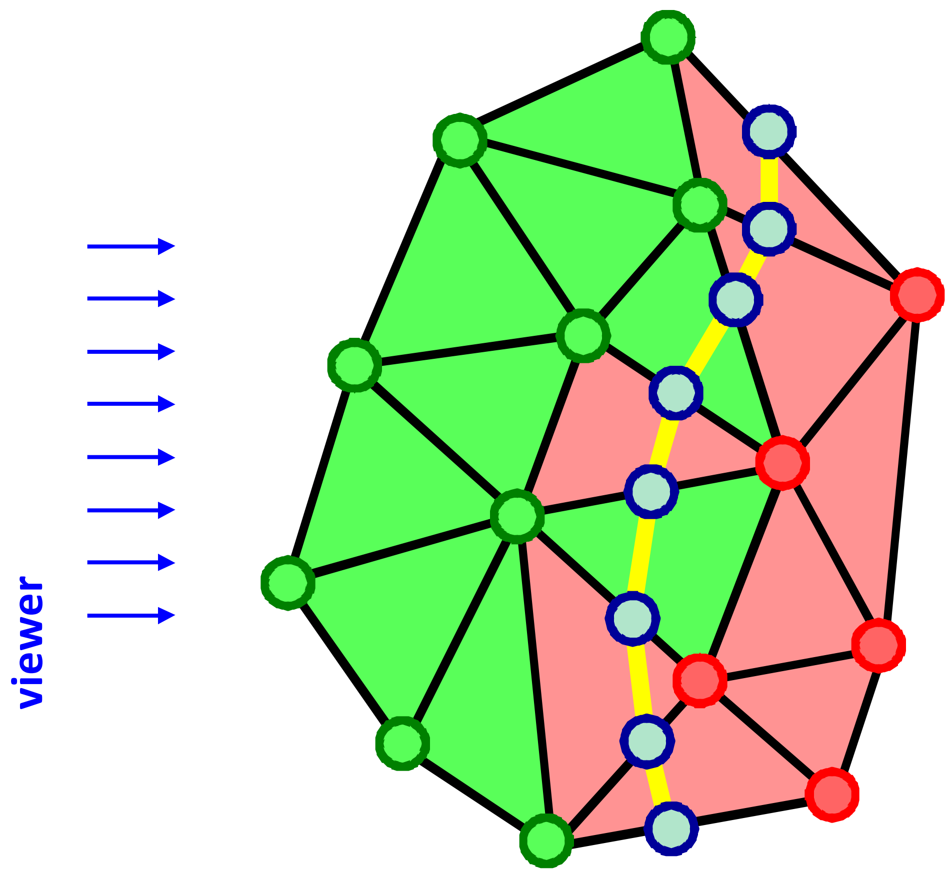
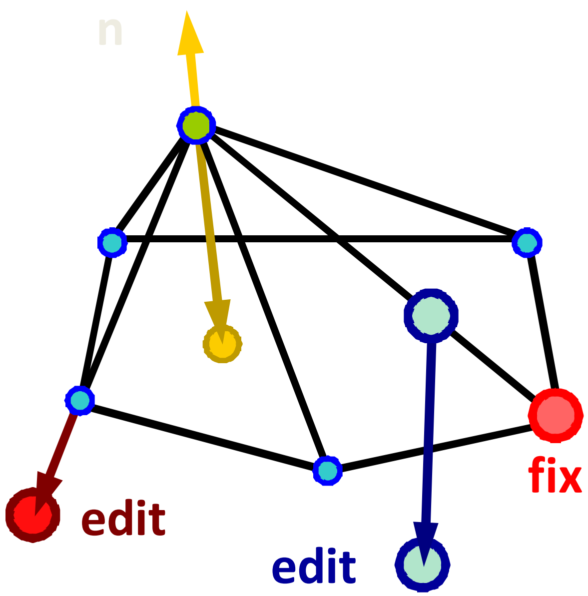


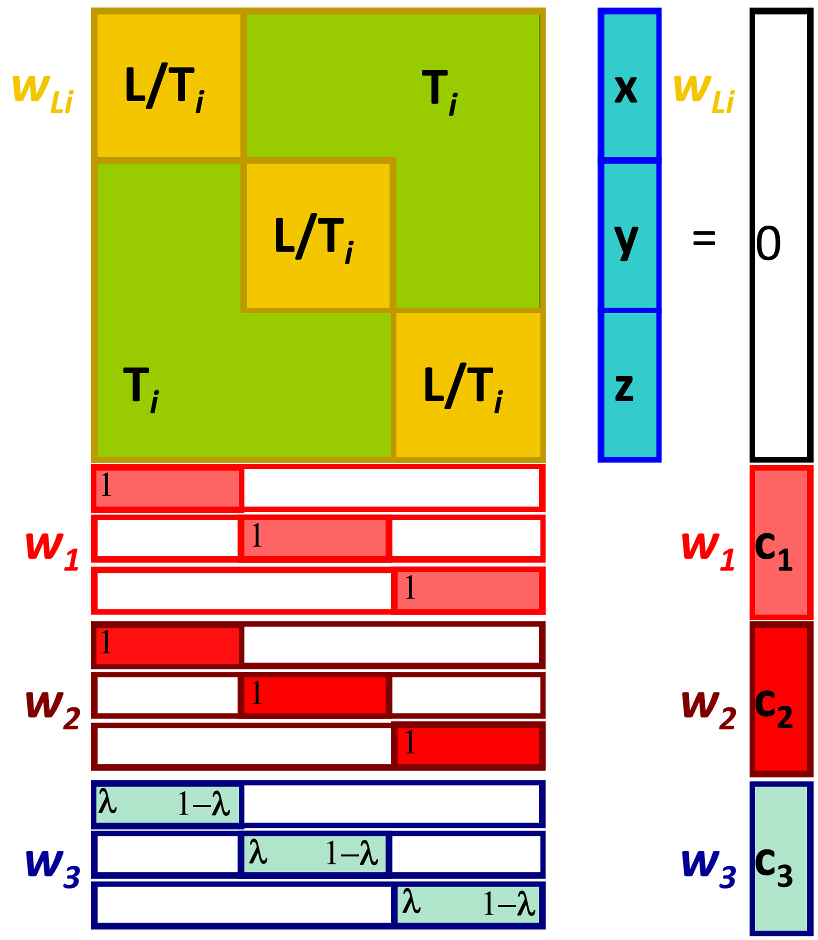
Illustrating Smooth Surfaces
[Hertzmann and Zorin 00]

Silhouette Sketching

- On edge constraints

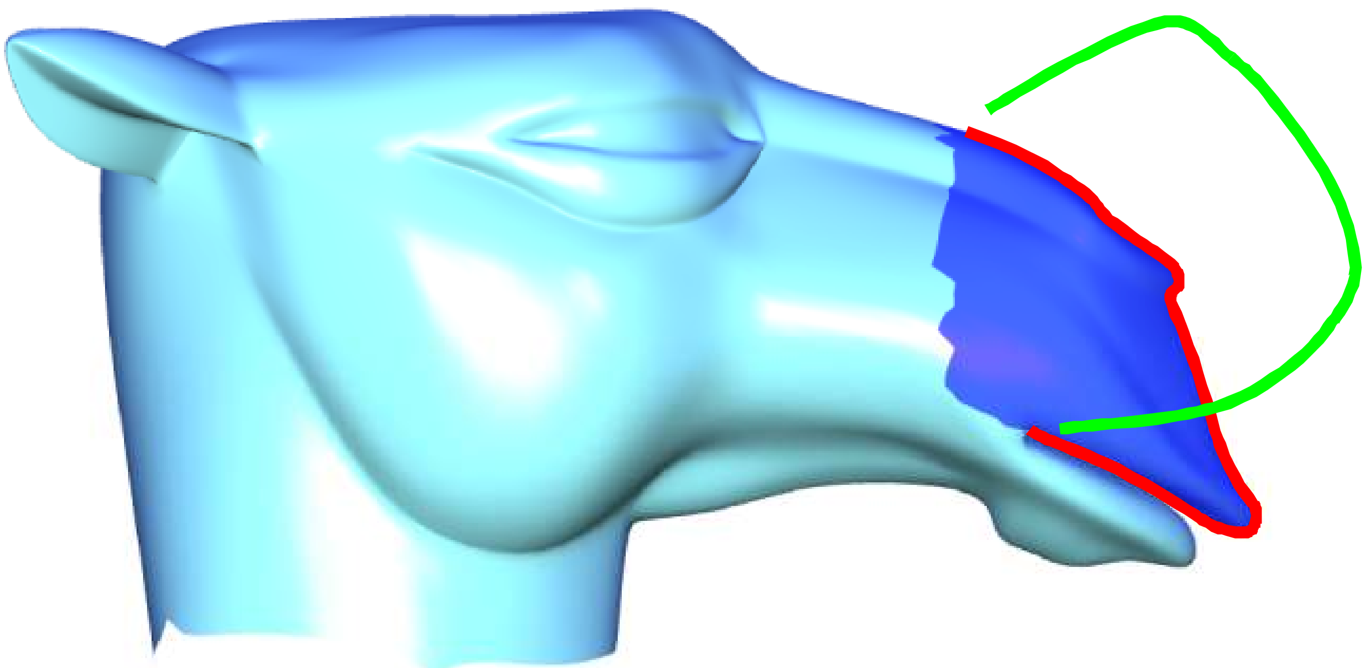


$\lambda\, \mathbf{x}_i + (1\text{-}\lambda)\, \mathbf{x}_j$



Silhouette Sketching

- Approximate sketching
  - Balance weighting between detail and positional constraints



Silhouette Sketching

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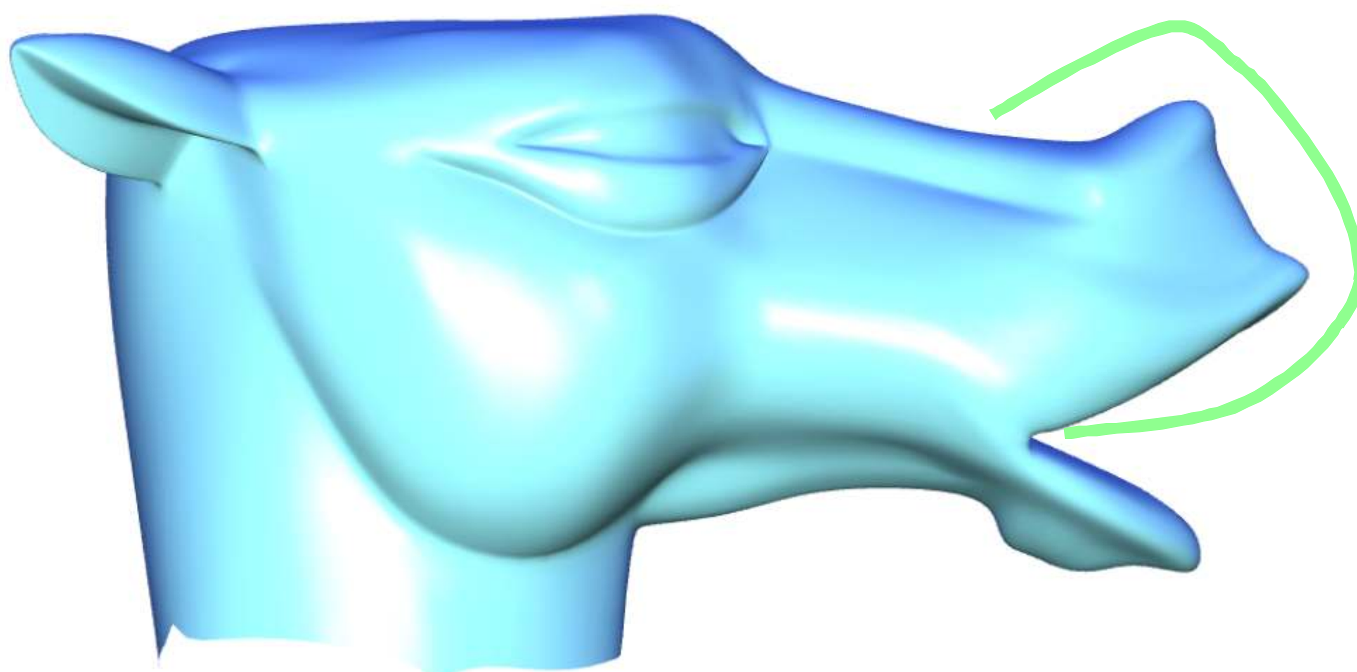
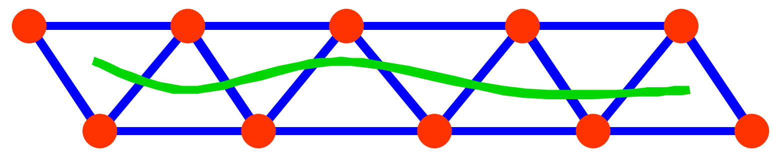
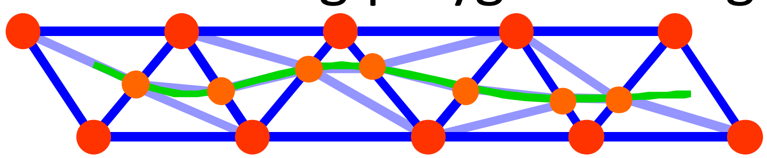


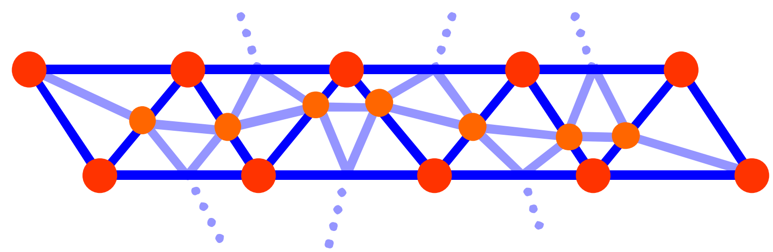
Feature Sketching

- We wish to influence (discrete) differential properties of the mesh for **arbitrary** sketches



- Possible solution
  - Cut existing polygons along the sketch and add new edges

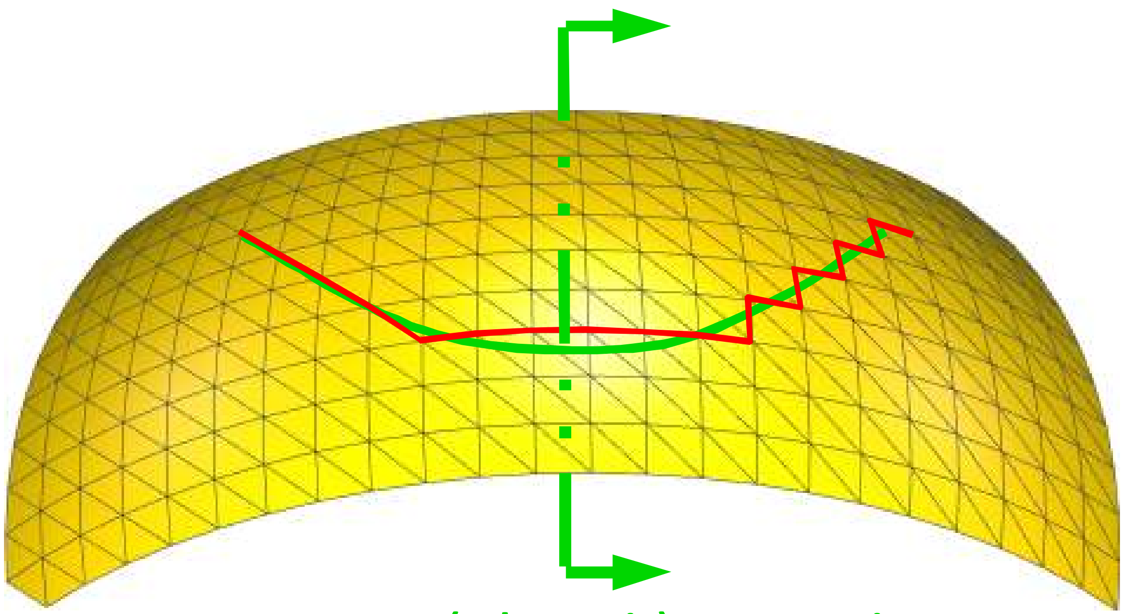




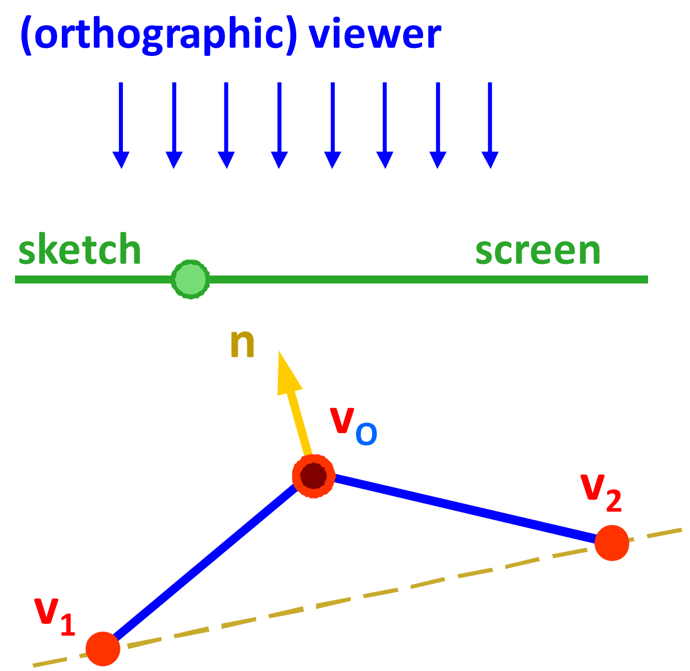
- Our solution
  - Adjust mesh **geometry** to lie under the sketch (as seen from the camera), while preserving mesh **topology** and ensuring well shaped triangles

Geometry Adjustment

- First: **min cost edge path (close to sketch)**
  - Potentially *jaggy* appearance

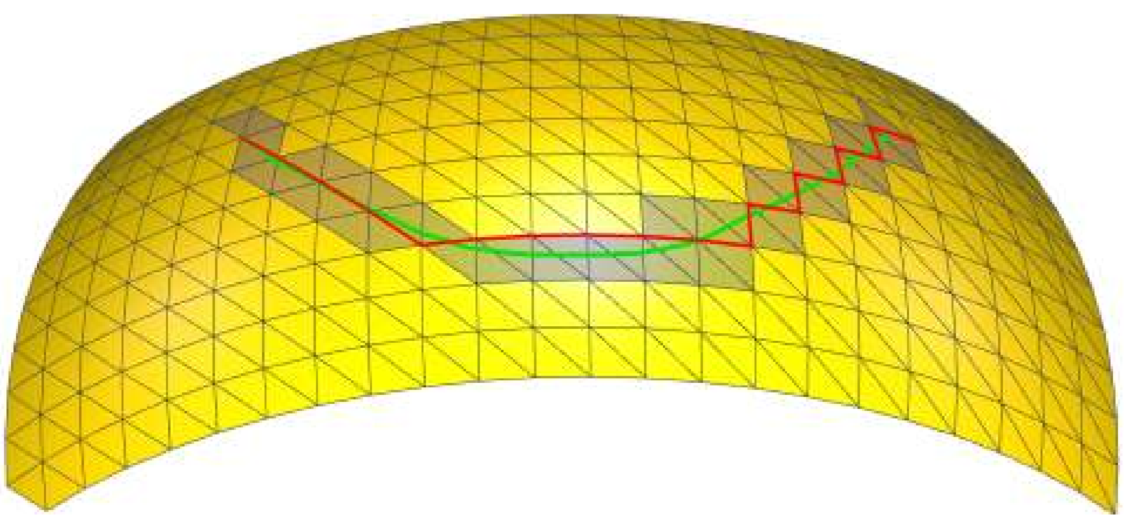


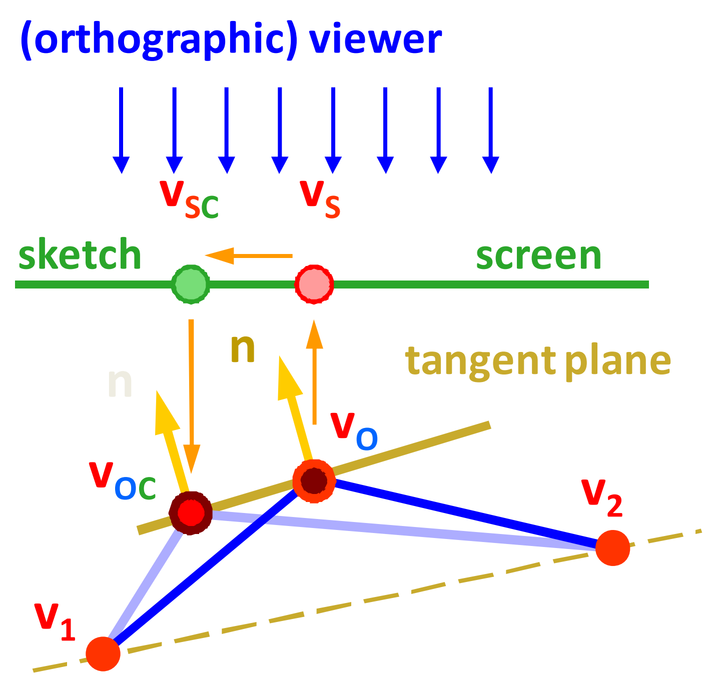
(schematic) cross-section



Geometry Adjustment

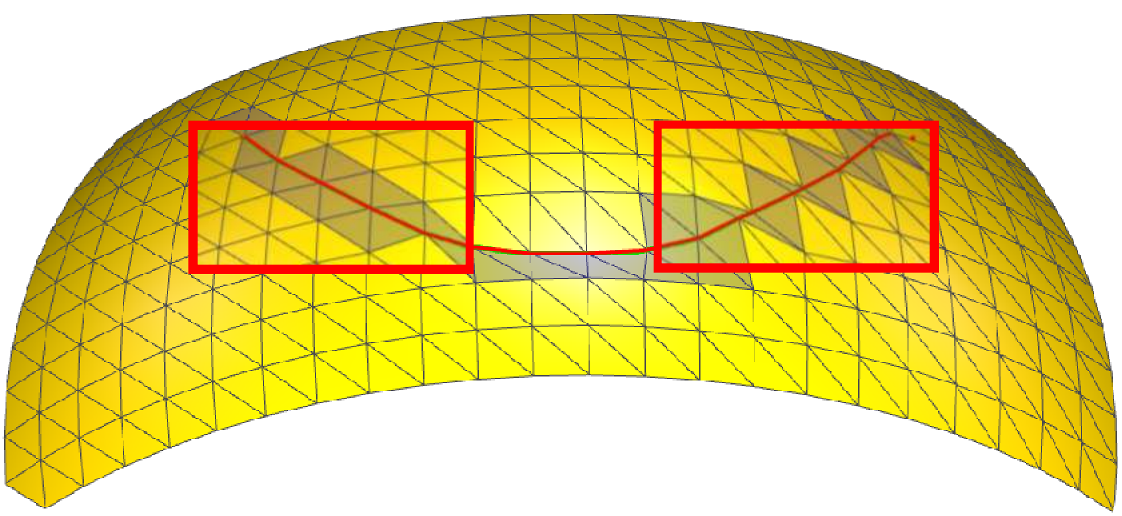
- Second: **projection onto sketch**

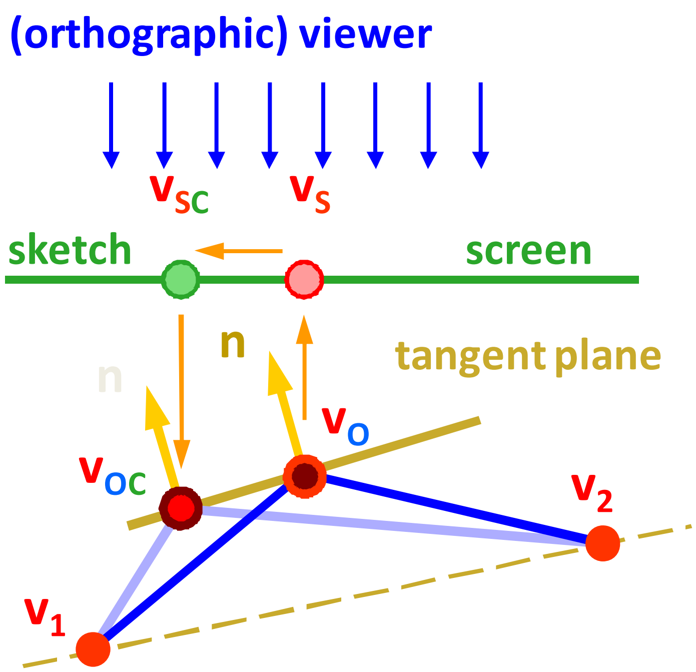




Geometry Adjustment

- Second: **projection onto sketch**
  - Approximates the sketch very well
  - Can introduce badly shaped tri's



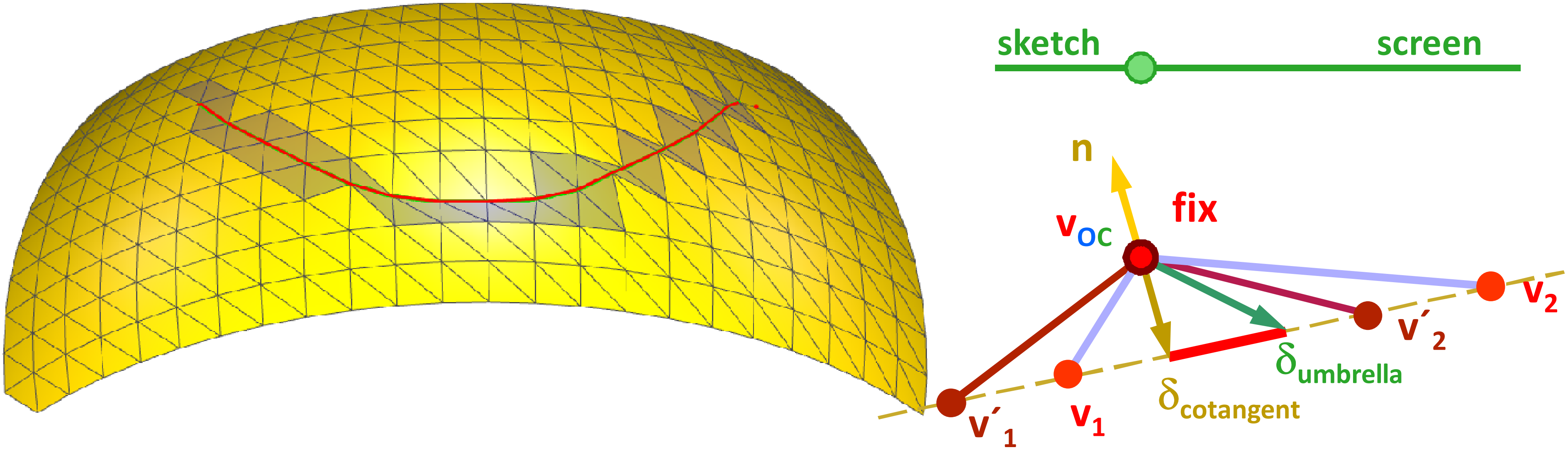


Geometry Adjustment

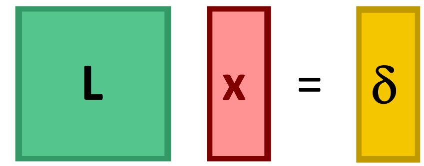
- Third: **local mesh regularization**
  - Ask uniformly weighted Laplacian to become cotangent weighted Laplacian, while fixing path vertices

$$\mathbf{L}\;\mathbf{x} = \delta$$

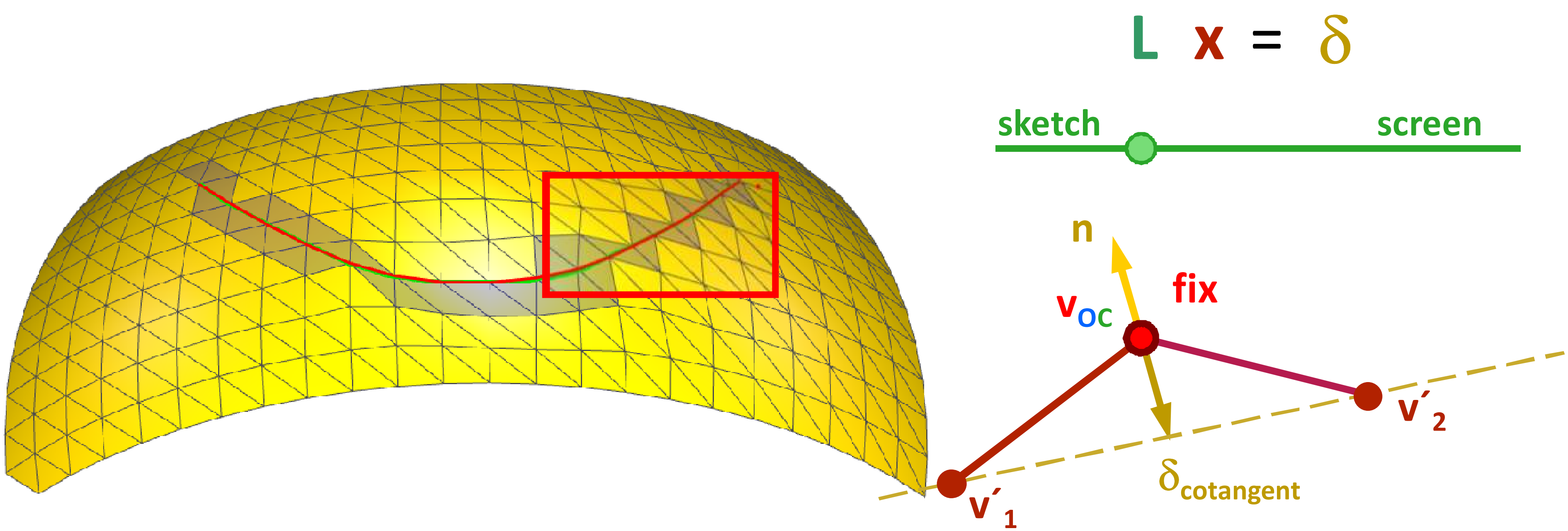
$$\mathbf{L}\;\mathbf{x} = \delta$$



Geometry Adjustment

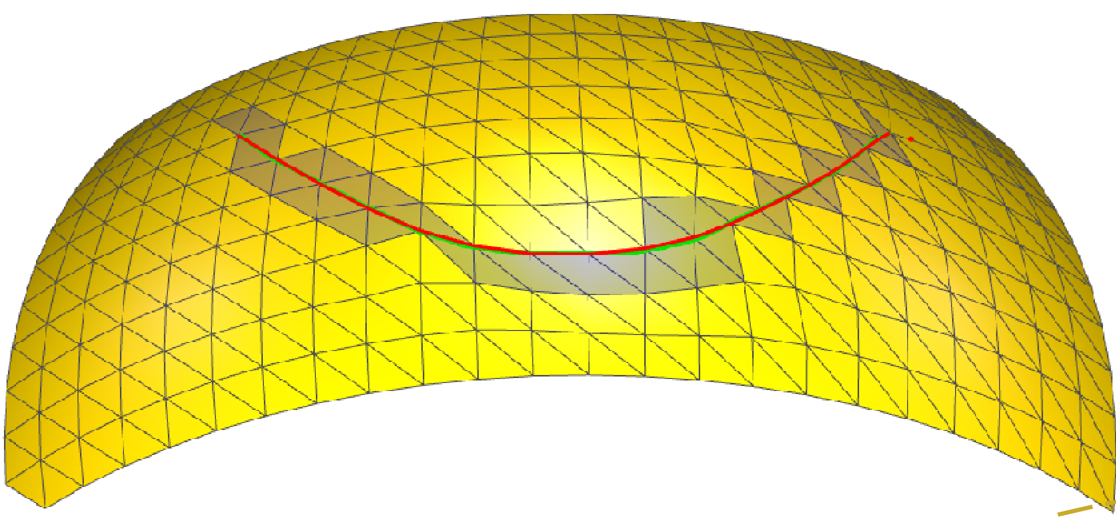


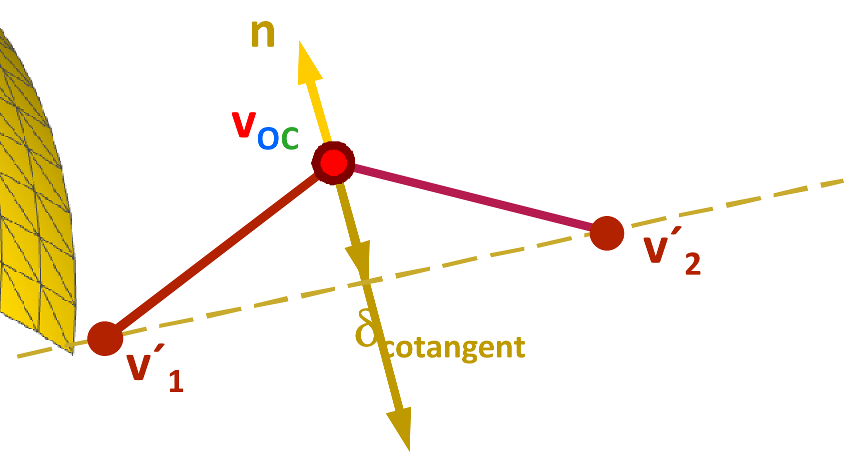
- Third: **local mesh regularization**
  - Well shaped triangles and nice piecewise linear approximation of the users sketch



Feature Edit

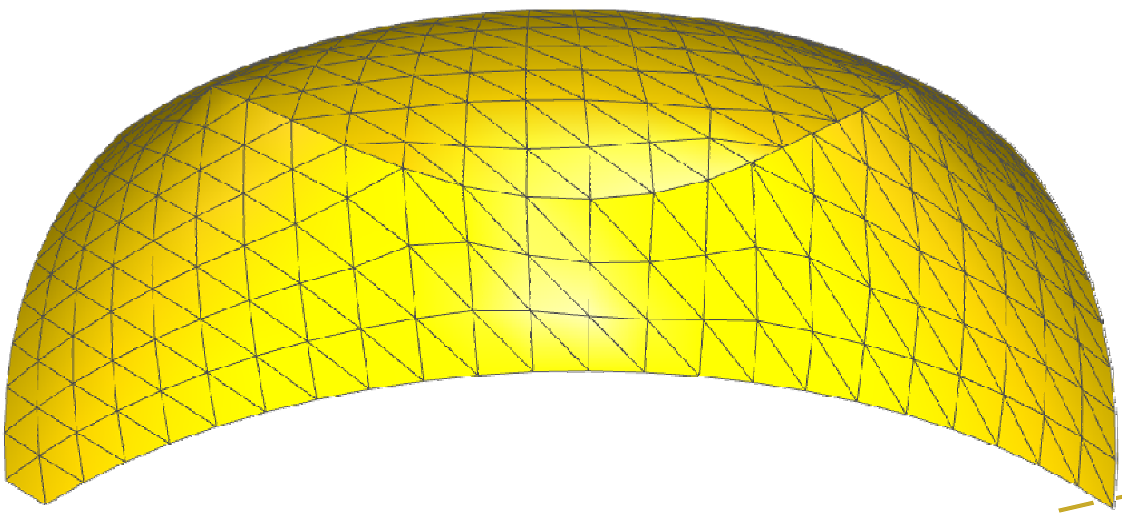
- Edit: **scale (or add to) Laplacians**

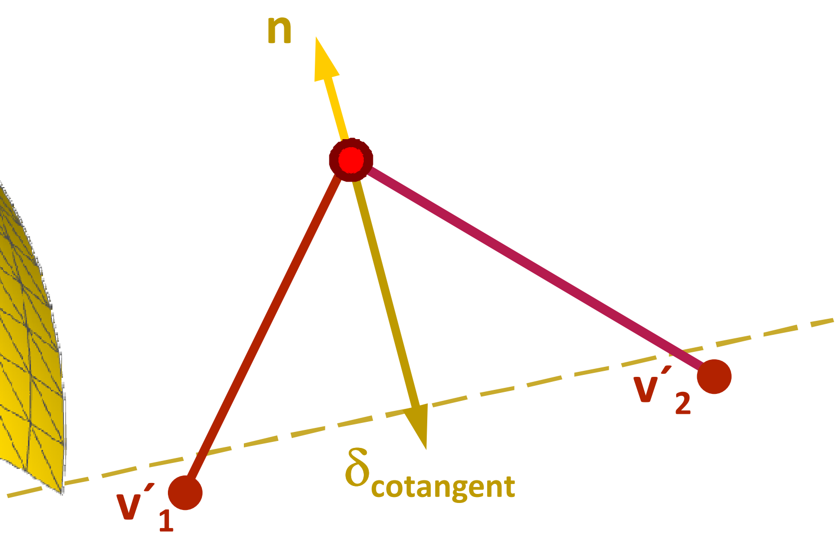




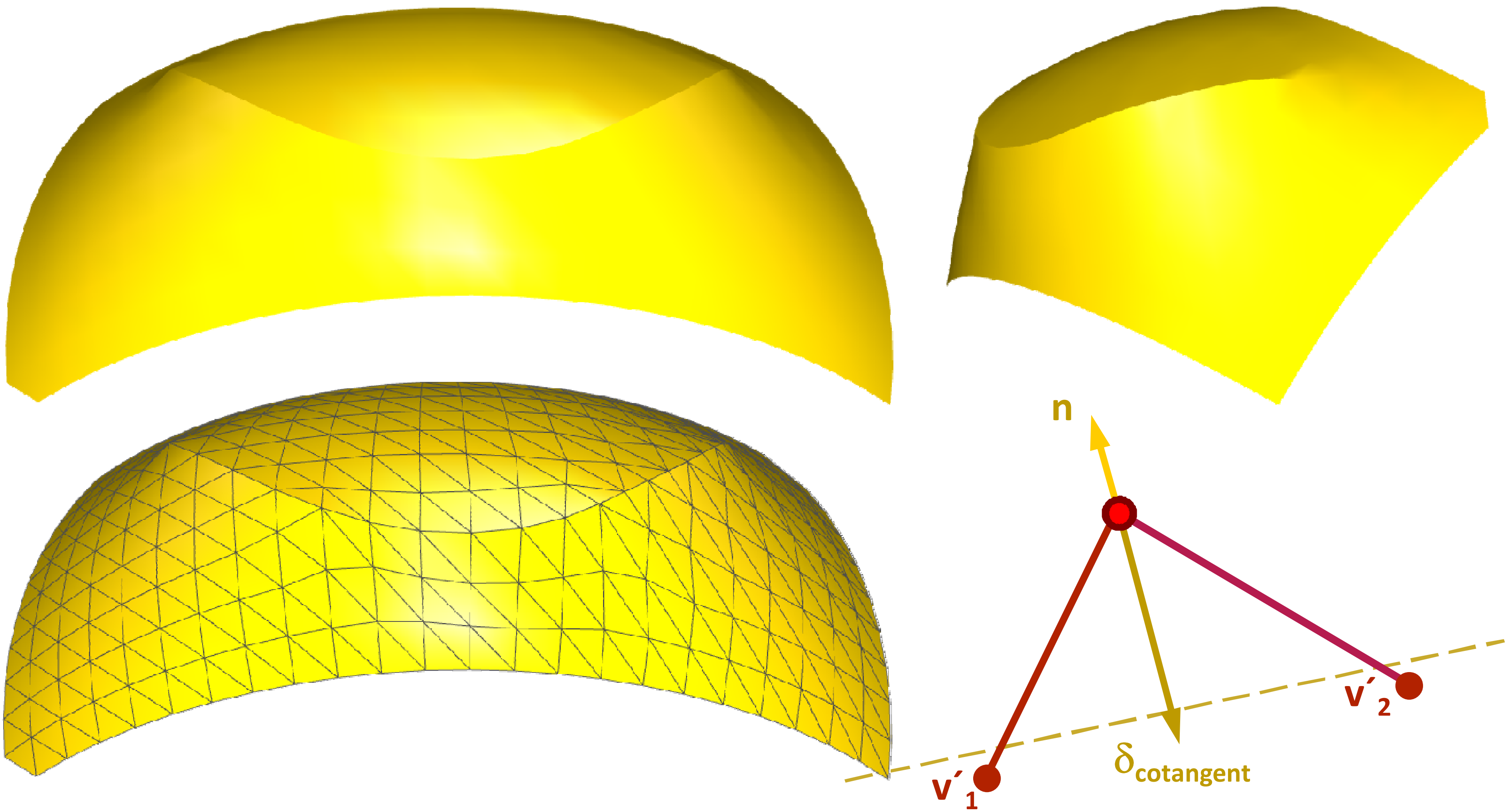
Feature Edit

- Edit: **scale (or add to) Laplacians**



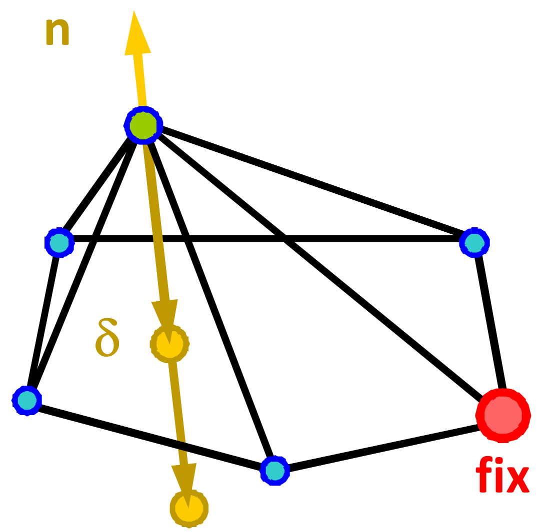


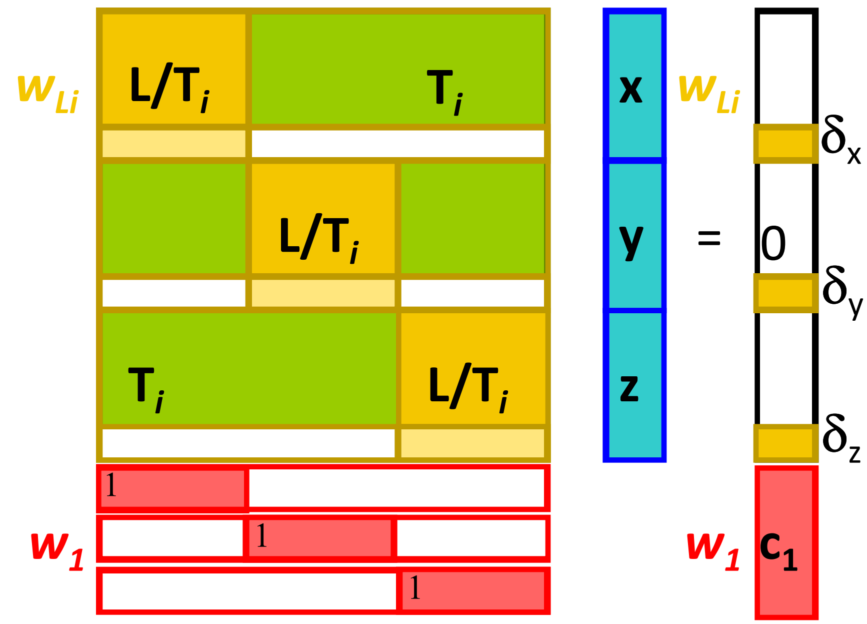
Feature Edit



Laplacian Constraints

- Scale (or add to) Laplacians



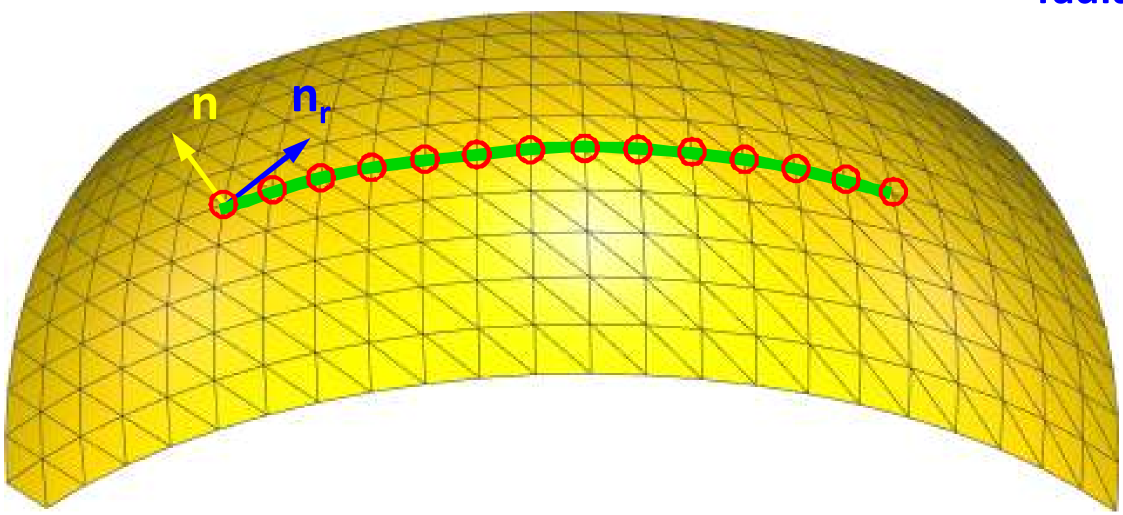


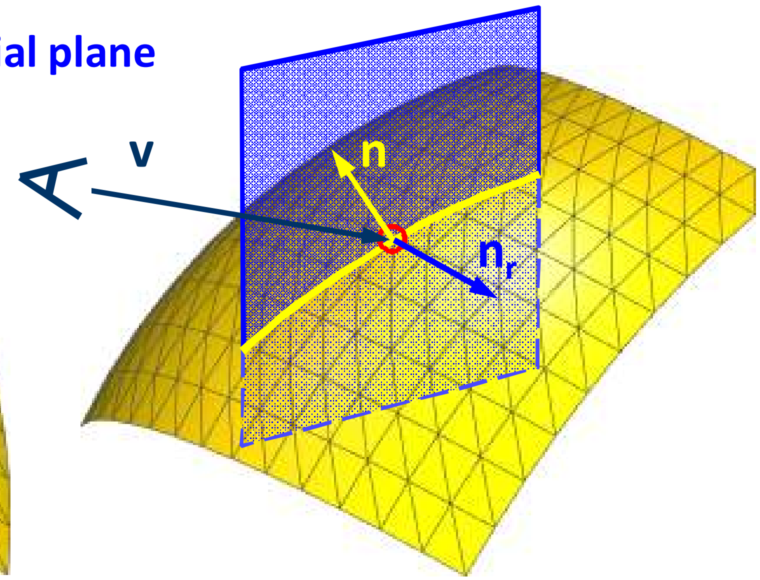
Normal Equations

$$A^TA\ x = A^T\ b$$

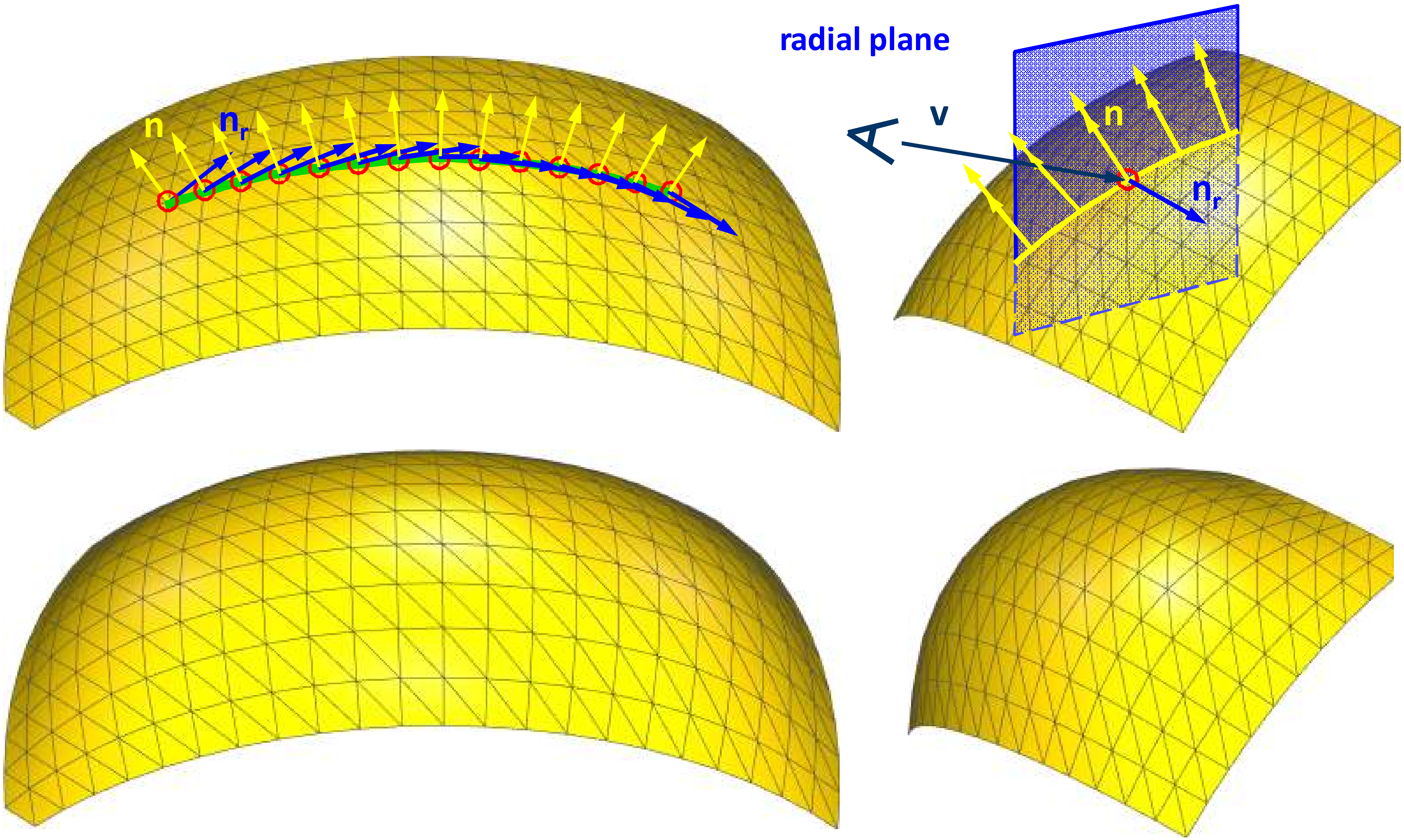
$$x = (A^TA)^{-1}\ A^T\ b$$

Contour Edit

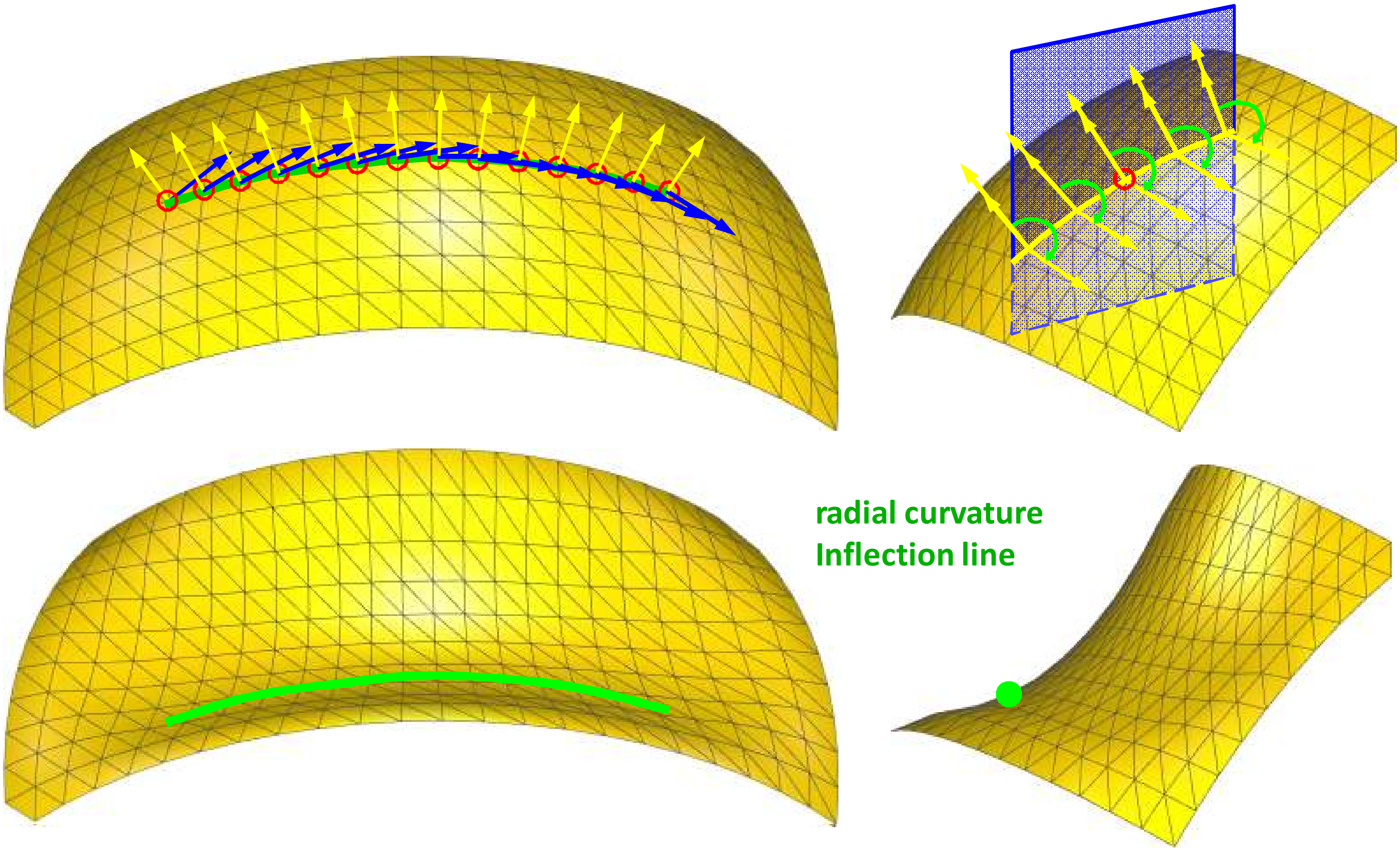




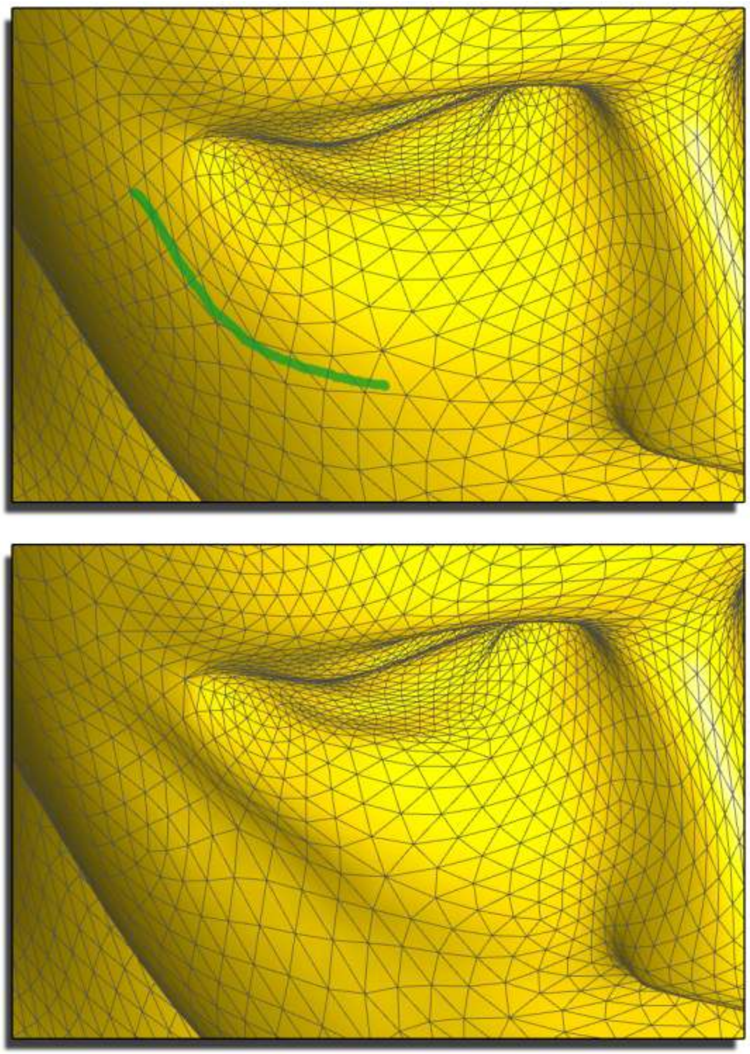
Contour Edit

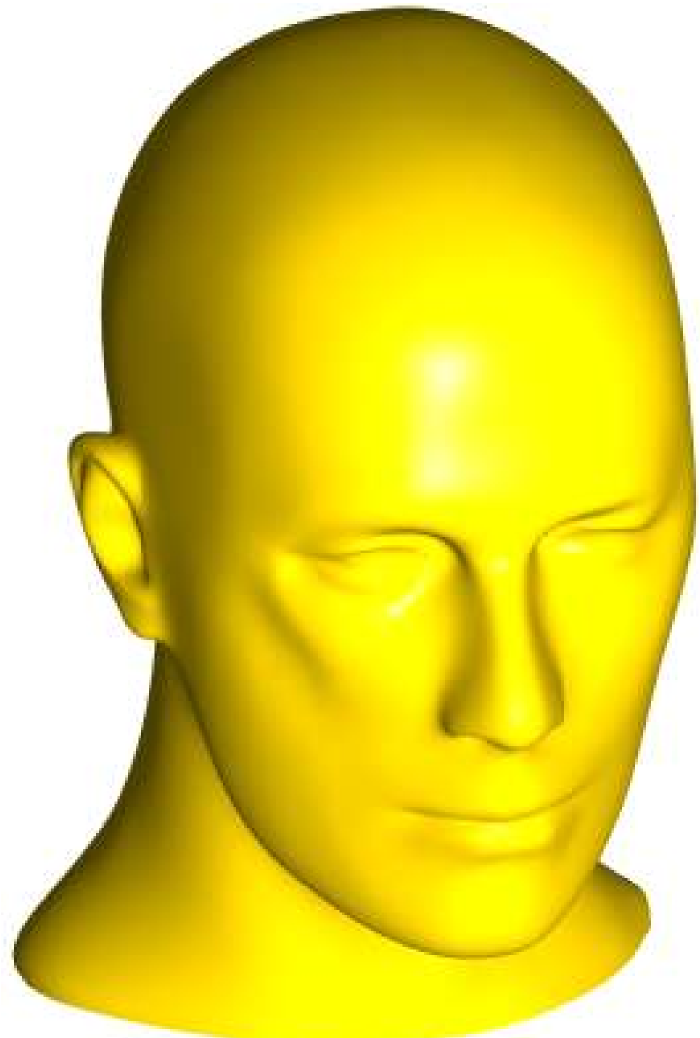


Contour Edit

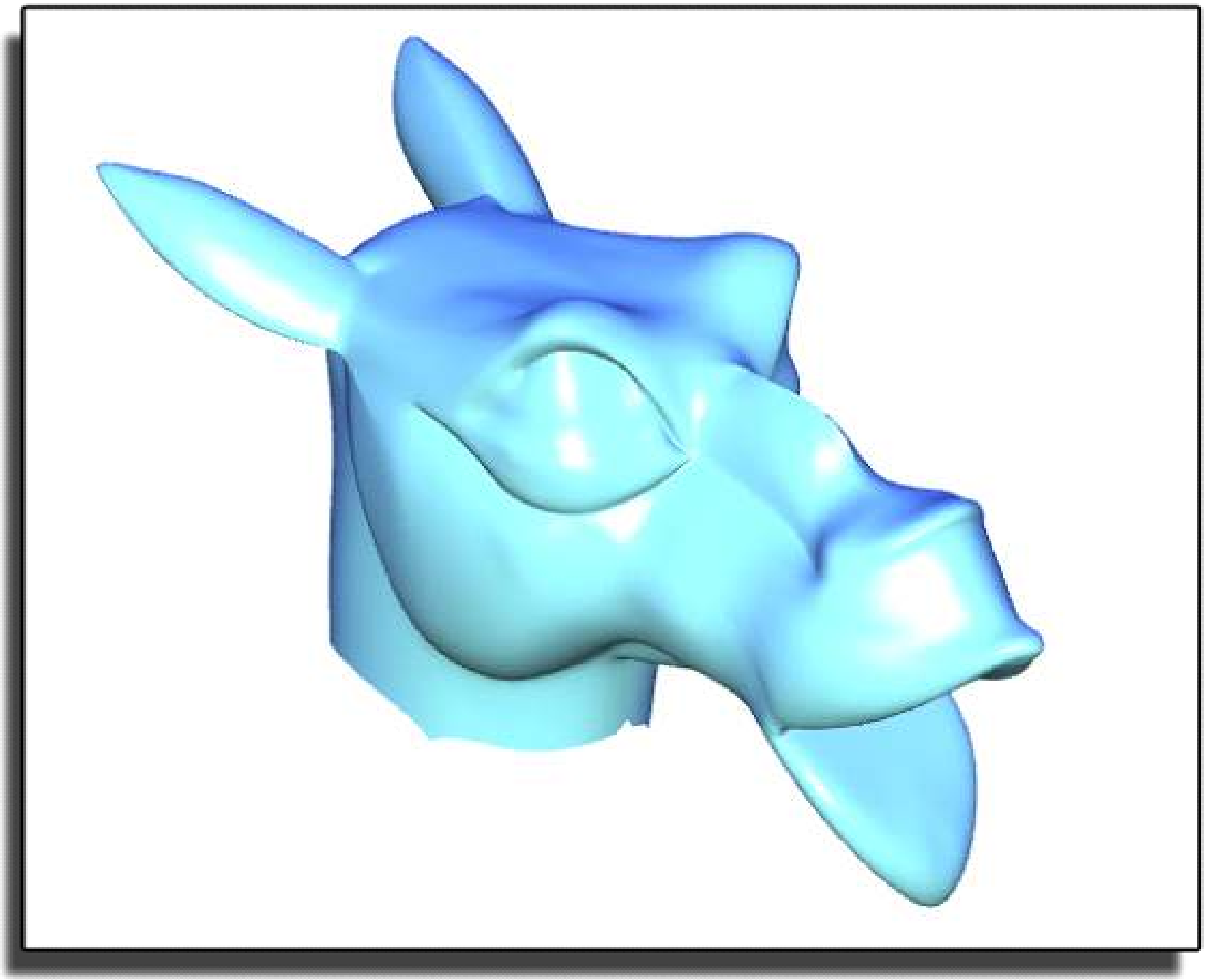


Contour Edit

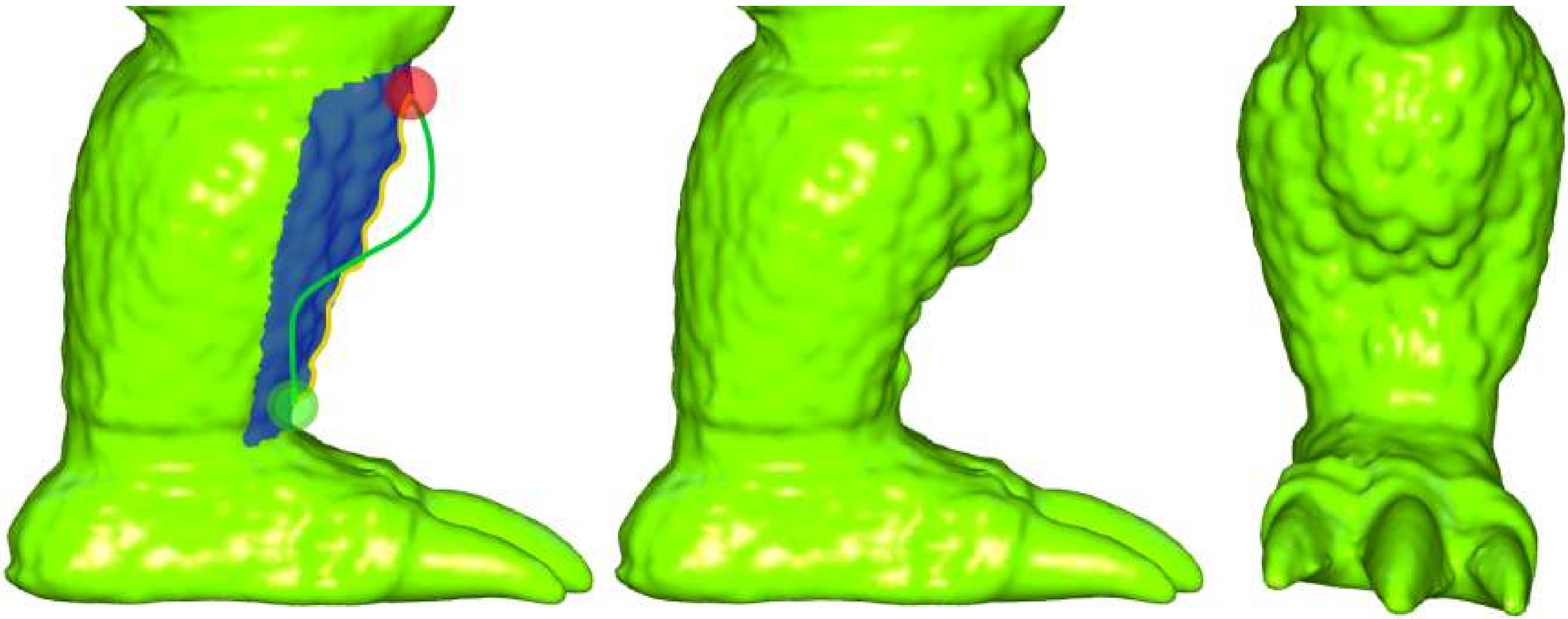




Editing Session Result



Problem: noisy Surface Silhouette



Discussion…

- The good...
  - Intuitive, sketch-based User Interface for silhouette deformation and feature creation/modification
  - Fast model updates after sketch (Iterative Modeling)
  - Preserves surface detail as much as possible
- ... and the *not so good*
  - Object-Space sil‘s useless in the presence of heavy noise
  - Editing differential properties can take time to learn

FiberMesh

Problem Statement

- 3D modeling from scratch is **difficult**

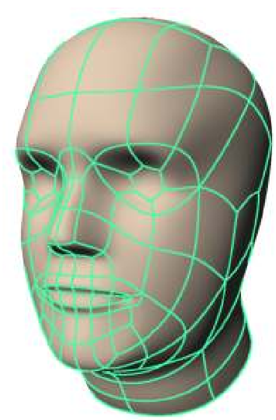
Parametric patches

Subdivision surfaces

Initial patch layout can be tedious

Sketching

Produces simple, rough models

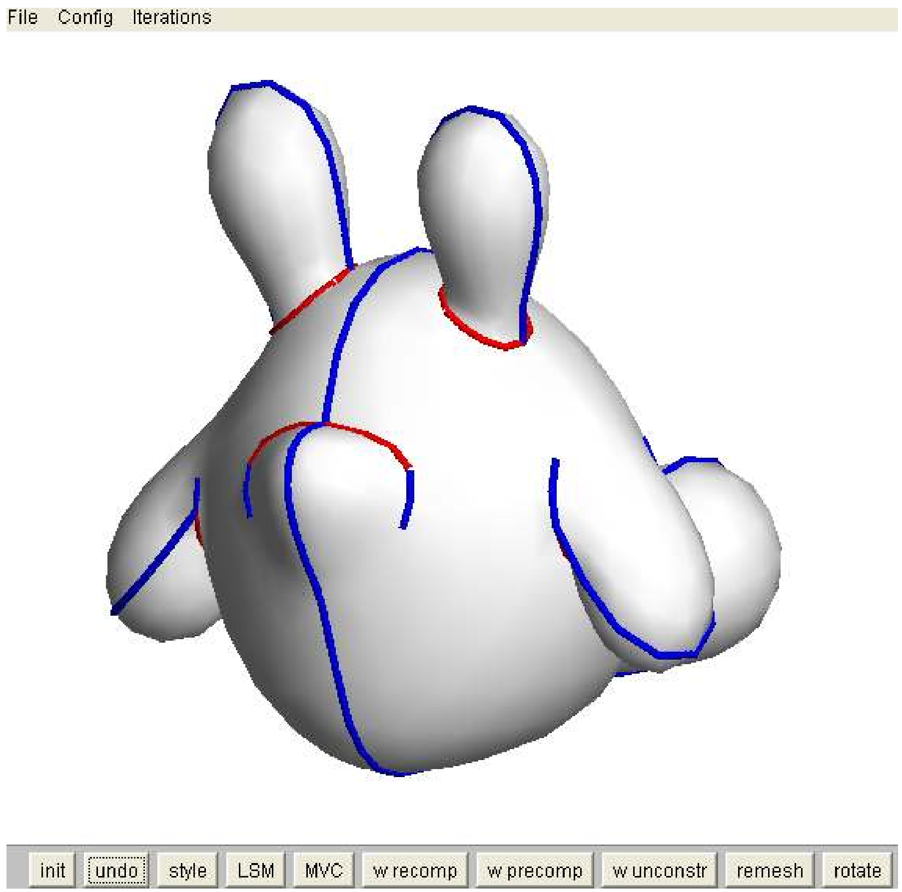


FiberMesh

Overview and Contributions

- **Curves as the user interface**
  - The user's sketches are persistent, and used as a modeling handles
  - Topologically flexible = add / remove anywhere
- **Fast surface construction by (nonlinear) functional optimization**
  - Incorporates curve constraints
  - Runs at interactive rates

FiberMesh Demo



Algorithm Overview

- **3D curve deformation**

Please see paper for details...

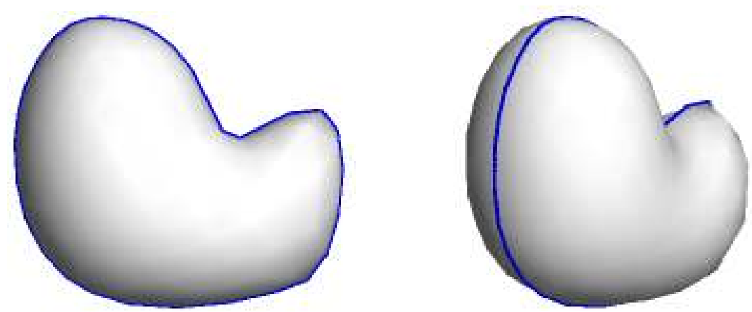
Handle position → Curve geometry

- **Surface optimization**

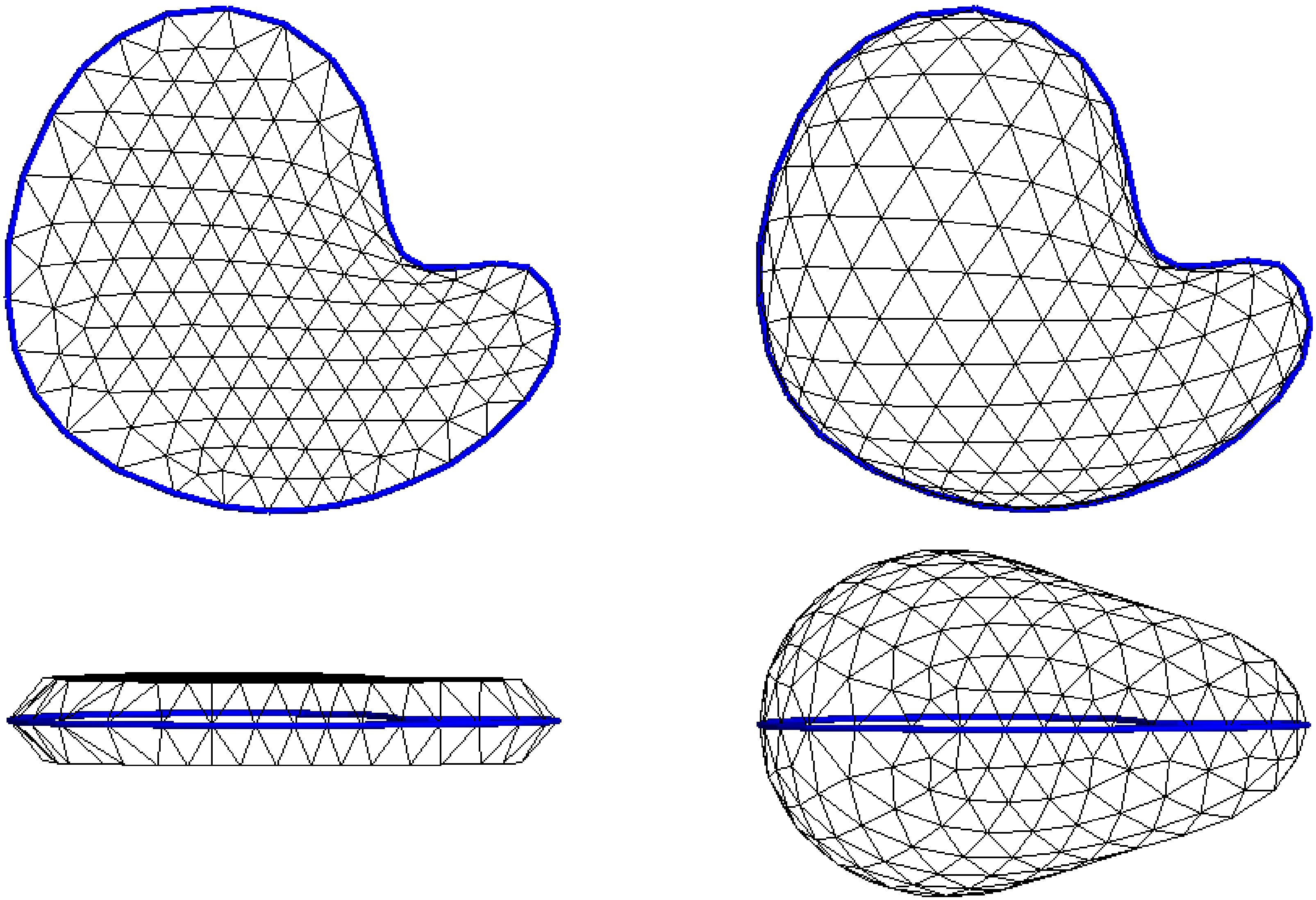
Curve geometry

↓

Surface geometry



Surface Optimization ?

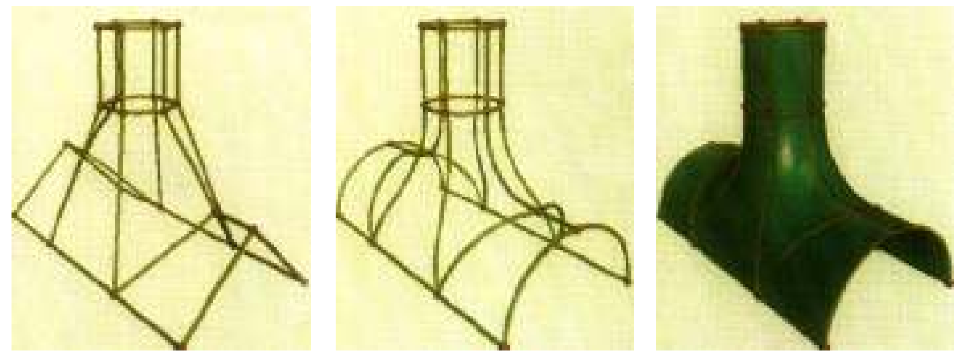


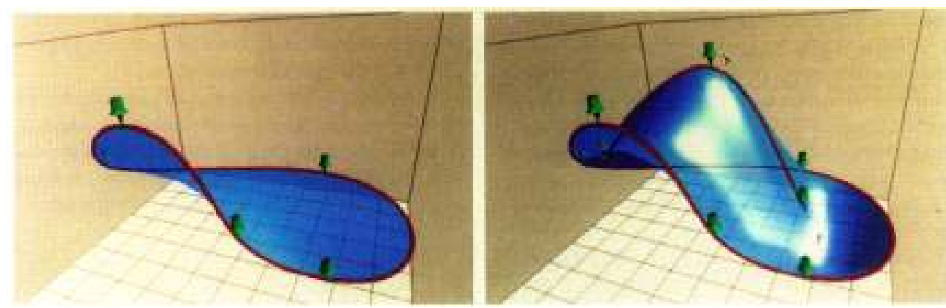
Inspirations

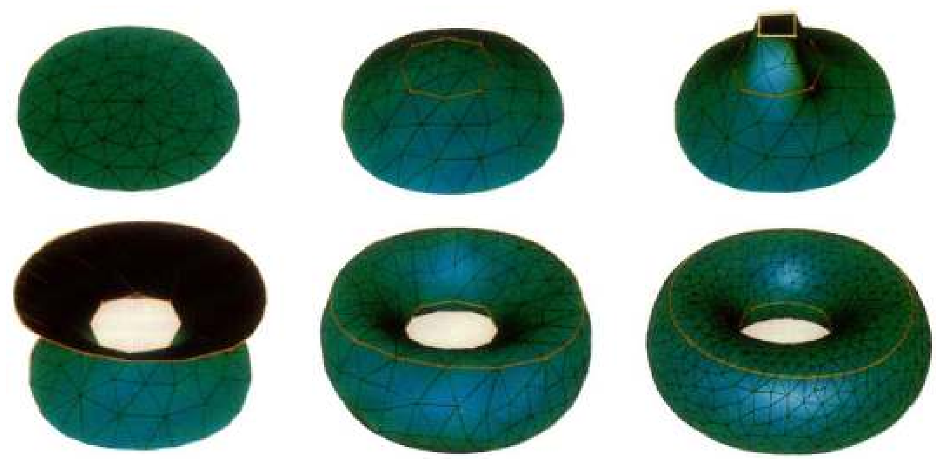
Curve and Surface Optimization

- Minimal energy networks [Moreton and Sequin1991]
- Functional optimization [Moreton and Sequin 1992]
- Variational surface modeling [Welch and Witkin 1992]
- Shape design with triangulated surfaces [Welch and Witkin 1994]
- **What defines „smooth“ ?**

$$\mathbf{L}^k(x) = 0$$

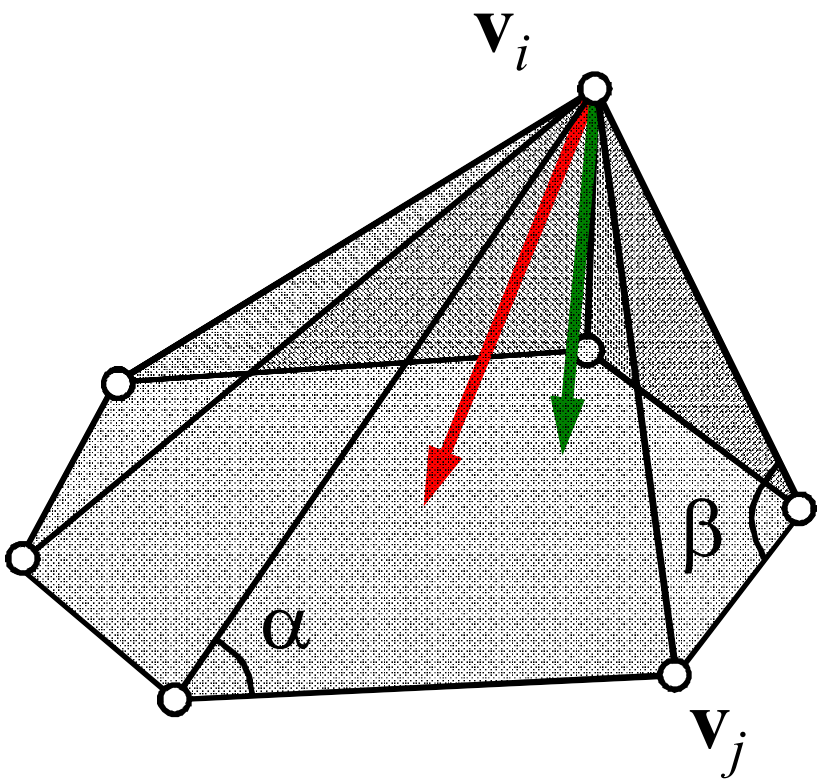






Surface Optimization

Discrete Differential Geometry

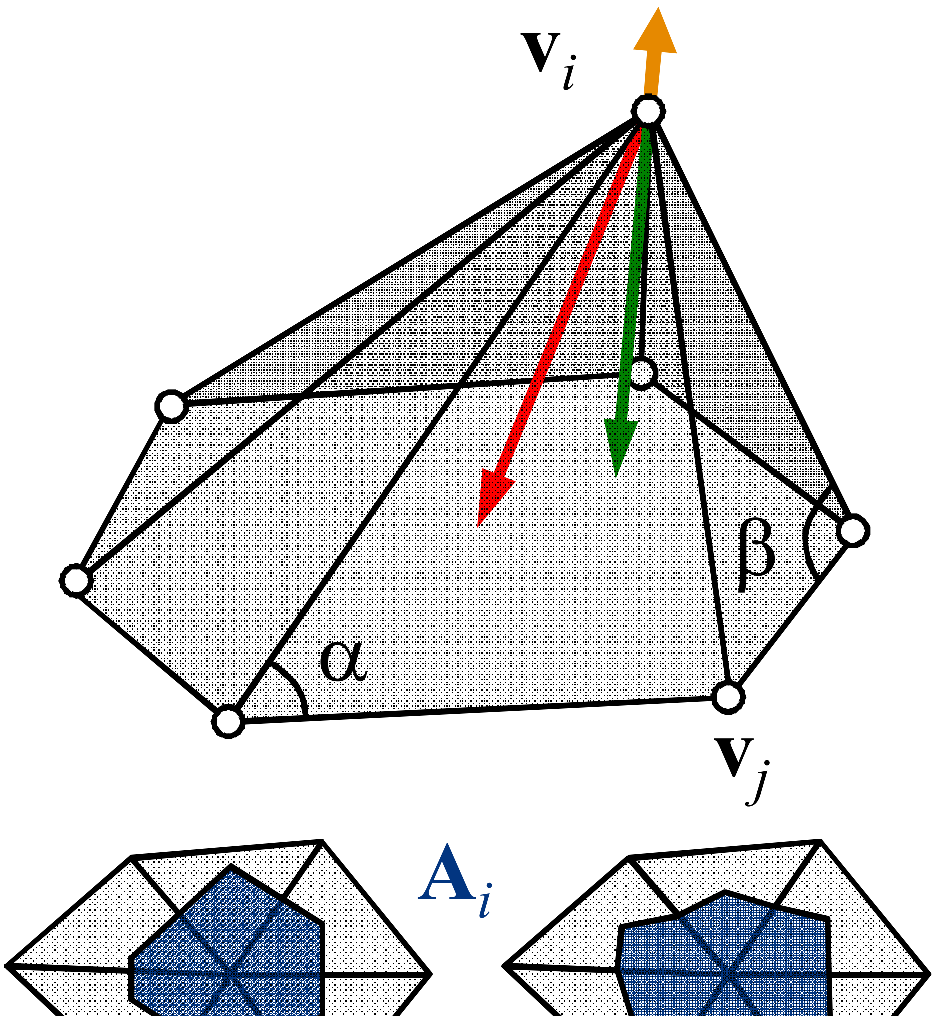


See work from

Polthier, Desbrun, Meyer, Alliez, Grinspun, Schröder, etc.

Surface Optimization

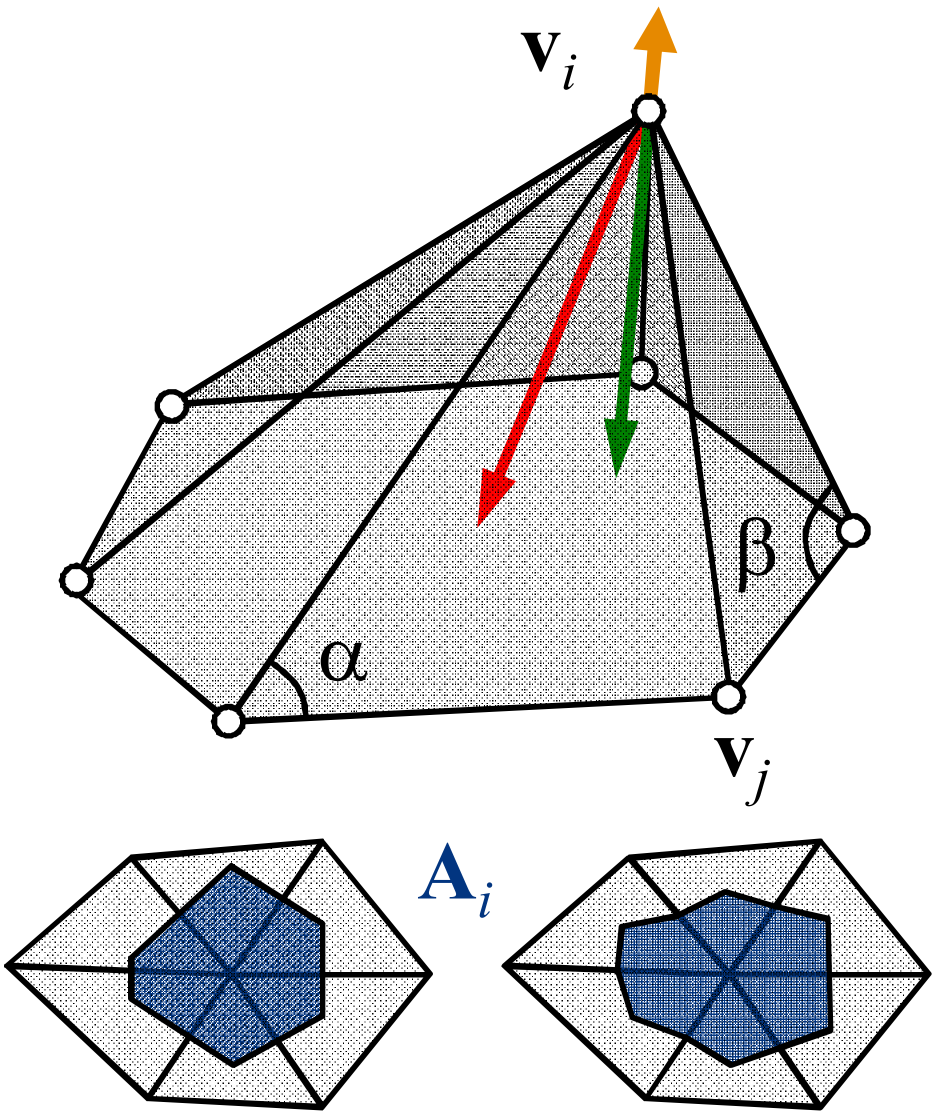
Discrete Differential Geometry



- Laplacian operators
  - **Uniform Laplacian** $\mathbf{L}_u(\mathbf{v}_i)$
  - **Cotangent Laplacian** $\mathbf{L}_c(\mathbf{v}_i)$
  - **Mean curvature normal**

Surface Optimization

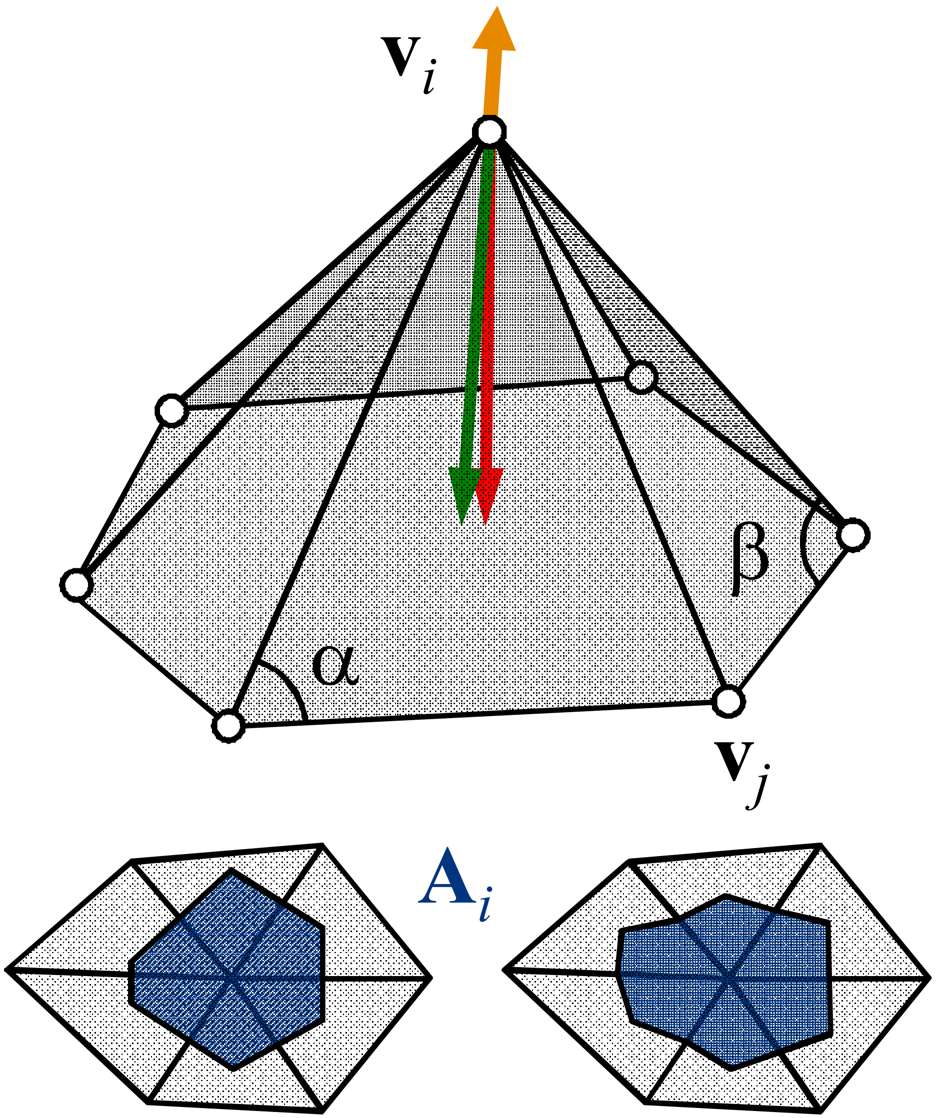
Two Important Observations !



- Laplacian operators
  - **Uniform Laplacian $\mathbf{L}_u(\mathbf{v}_i)$**
  - **Cotangent Laplacian $\mathbf{L}_c(\mathbf{v}_i)$**
  - **Mean curvature normal**
- **Cotangent Laplacian** = **mean curvature normal** x **vertex area ($\mathbf{A}_i$)**
- **For nearly equal edge lengths**
  Uniform ≈ Cotangent

Surface Optimization

Two Important Observations !

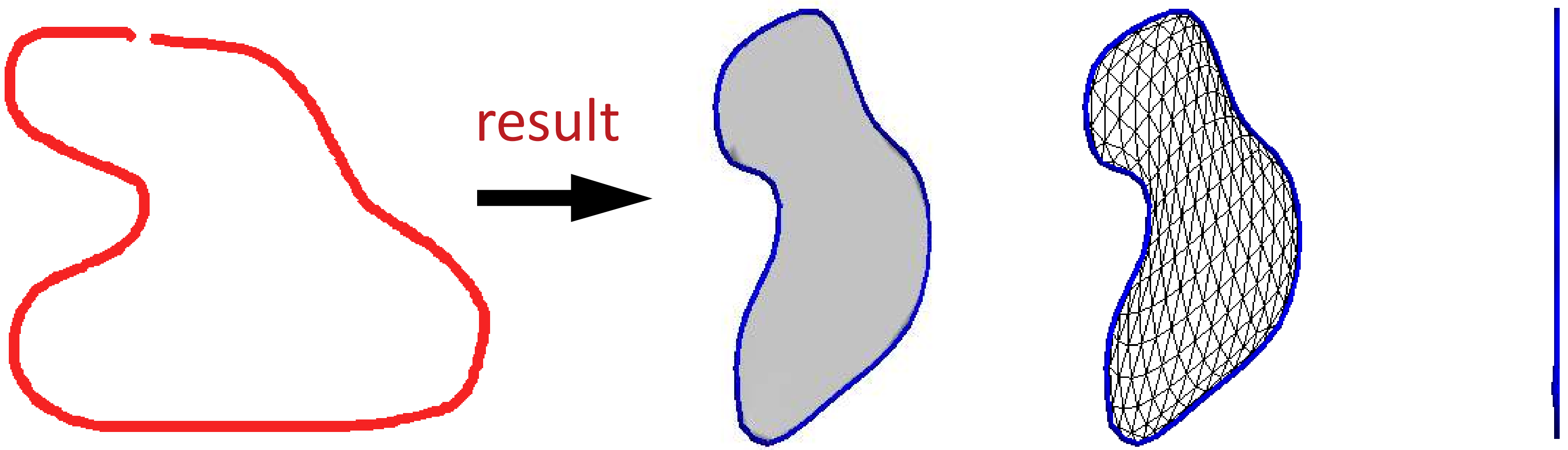


- Laplacian operators
  - **Uniform Laplacian** $\mathbf{L}_u(\mathbf{v}_i)$
  - **Cotangent Laplacian** $\mathbf{L}_c(\mathbf{v}_i)$
  - **Mean curvature normal**
- **Cotangent Laplacian** = **mean curvature normal** x **vertex area** **($\mathbf{A}_i$)**
- **For nearly equal edge lengths**
  Uniform ≈ **Cotangent**

Surface Optimization

Linear- or Nonlinear Optimization ?

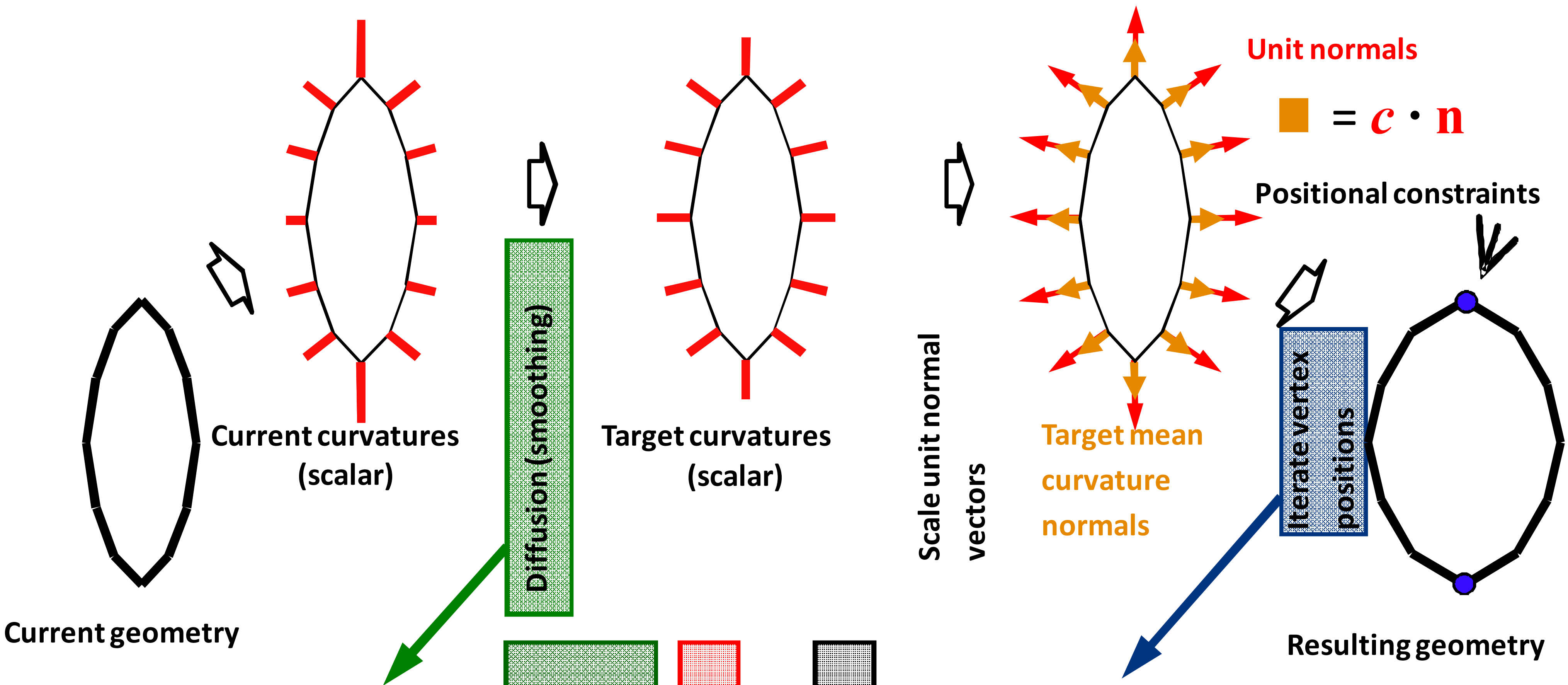
- Linear variational methods **[Botsch and Sorkine 2007]**



- Instead: nonlinear optimization
- Inspired by a discrete fairing algorithm
  - Geometric fairing of irregular meshes for free-form surface design [Schneider and Kobbelt 2002]

Surface Optimization

Overview of a Single Step



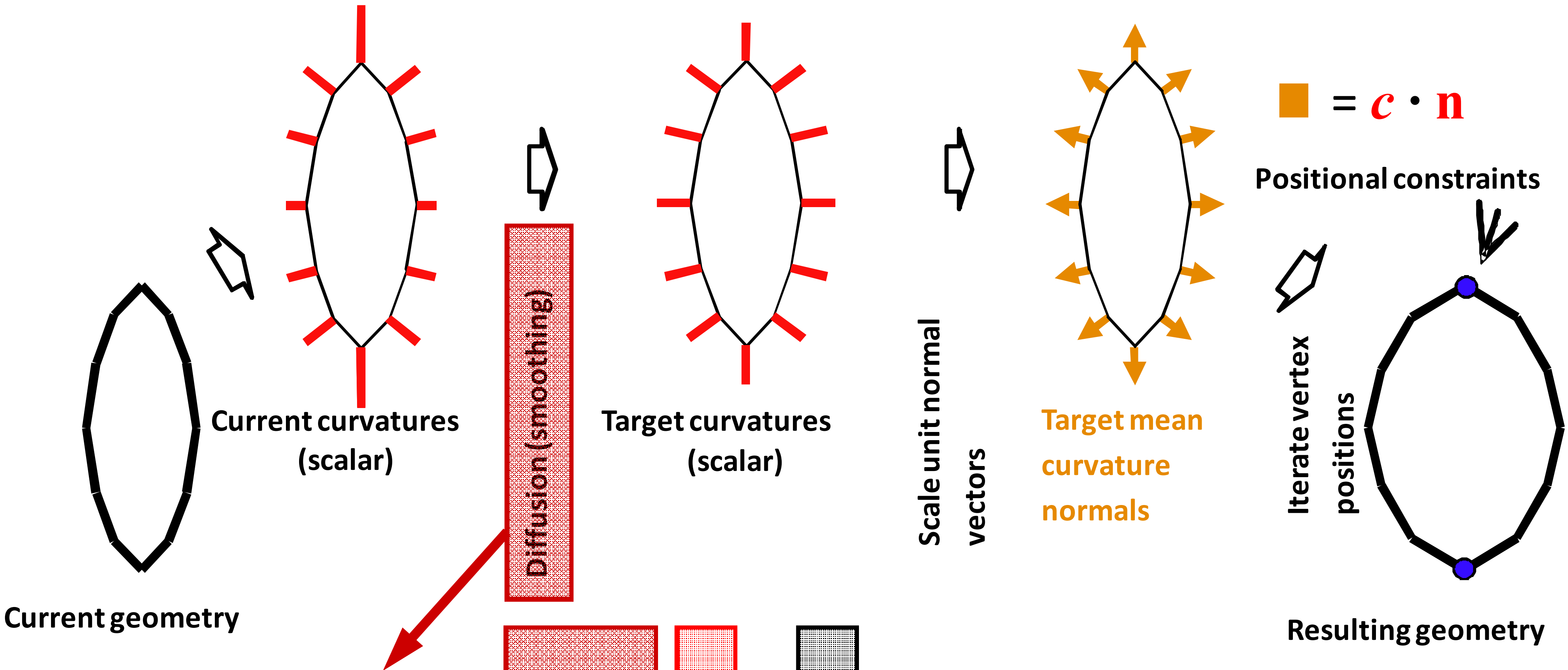
Linear system $\mathbf{L}_c \, c = 0$

But: matrix recomputation

Iterative procedure not designed for interactive response

Surface Optimization

Our Optimizations and Approximations

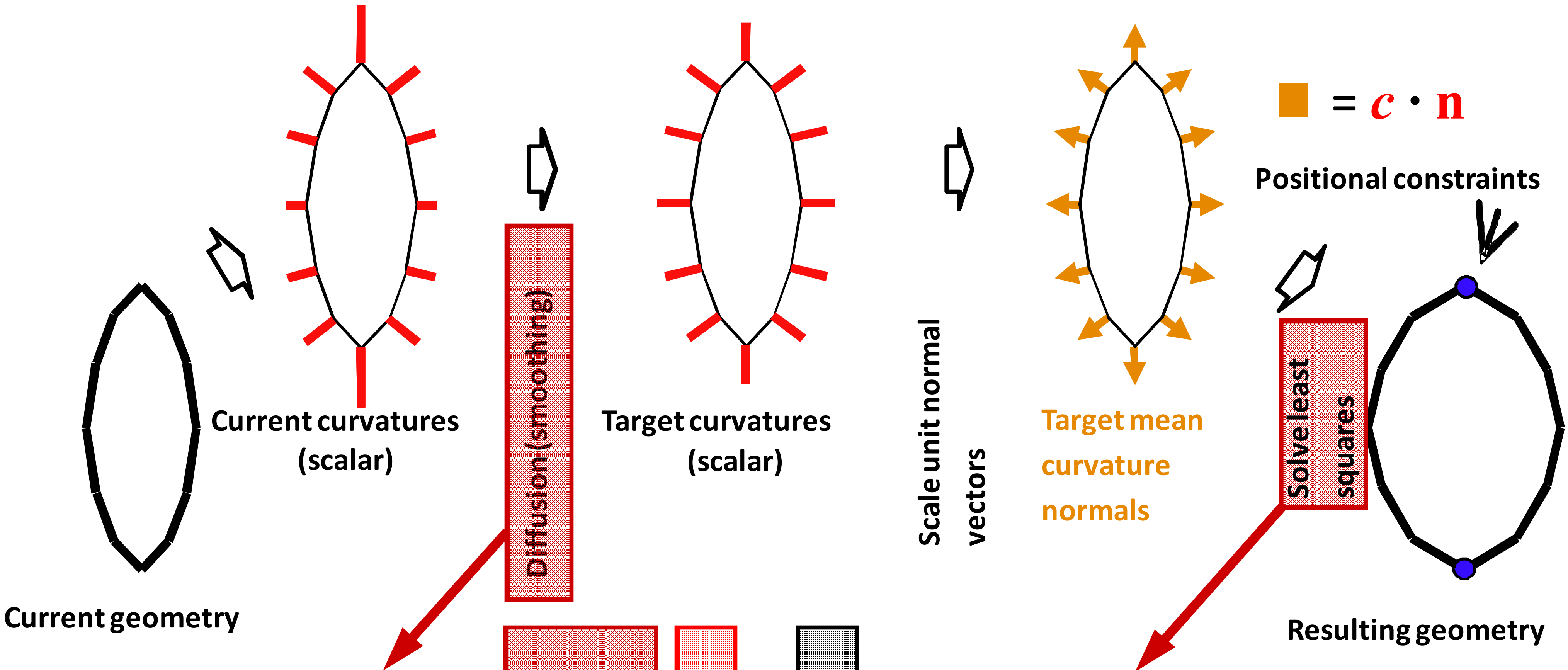


Linear system $\mathbf{L}_u \, c = 0$

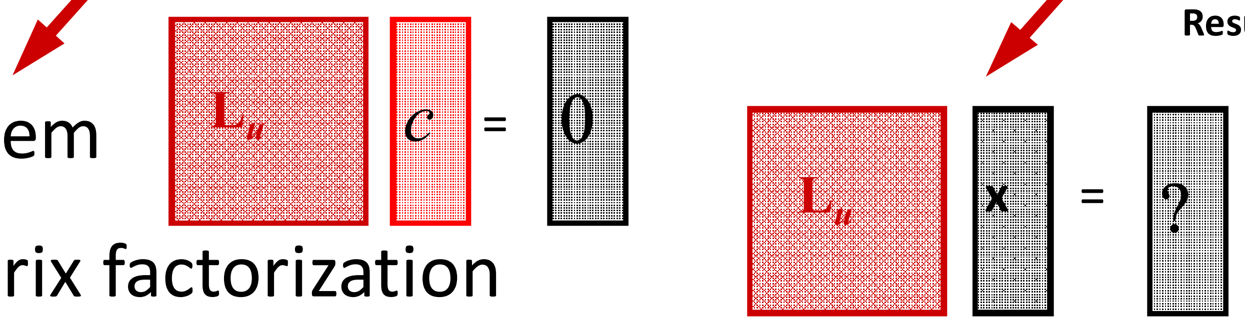
Reuse matrix factorization

Surface Optimization

Our Optimizations and Approximations



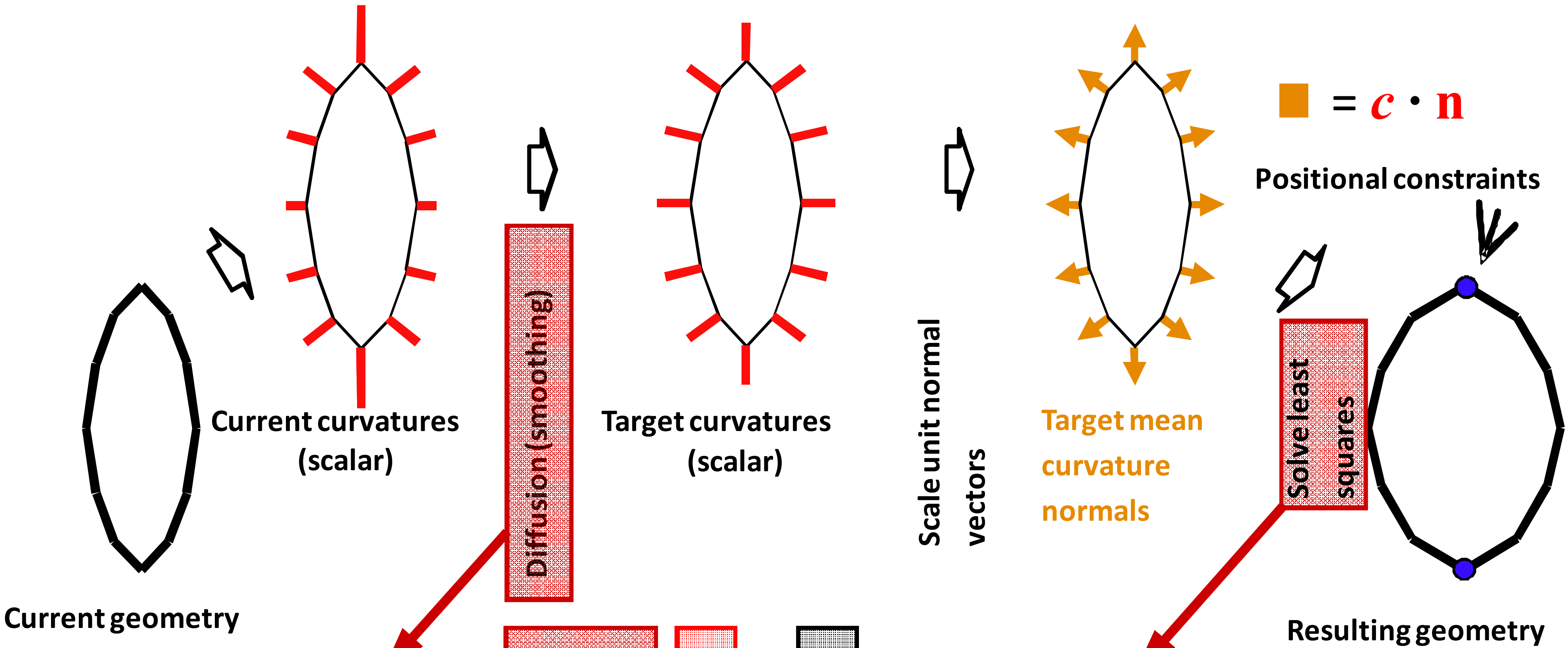
Linear system



Reuse matrix factorization

Surface Optimization

Our Optimizations and Approximations

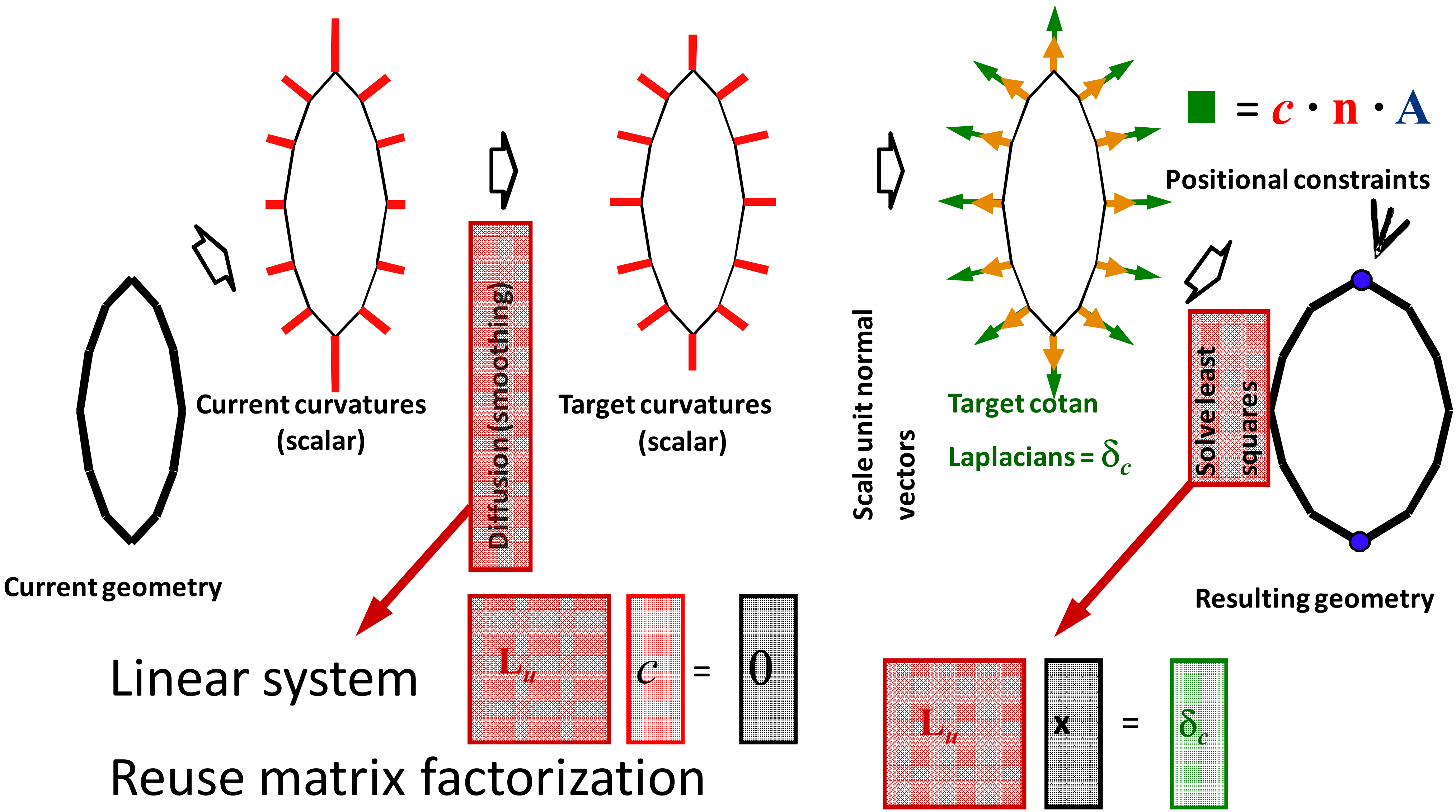


Linear system $\mathbf{L}_u \, c = 0$

Reuse matrix factorization $\mathbf{L}_u \, \mathbf{x} = \delta_c$

Surface Optimization

Our Optimizations and Approximations



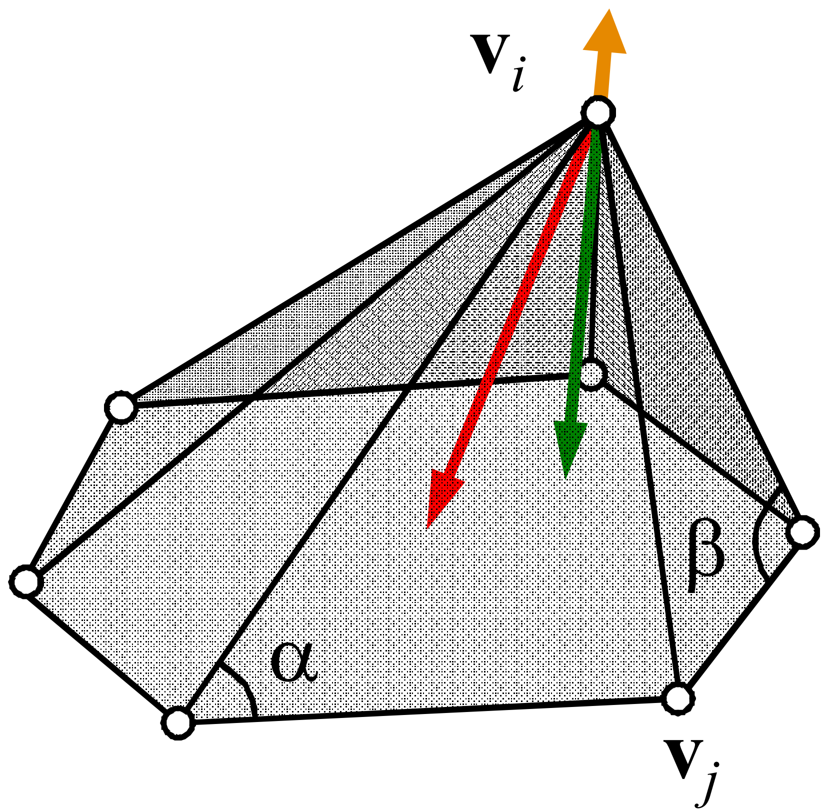
Linear system

Reuse matrix factorization

Surface Optimization

Requirements for our Approximations

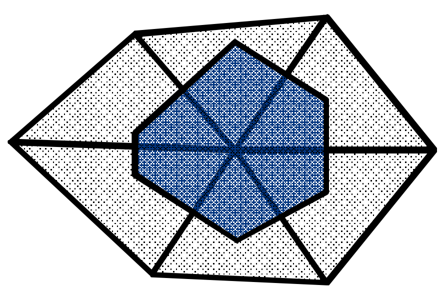
- We replace $\mathbf{L}_c$ with $\mathbf{L}_u$ in both steps
- This a viable approximation for:

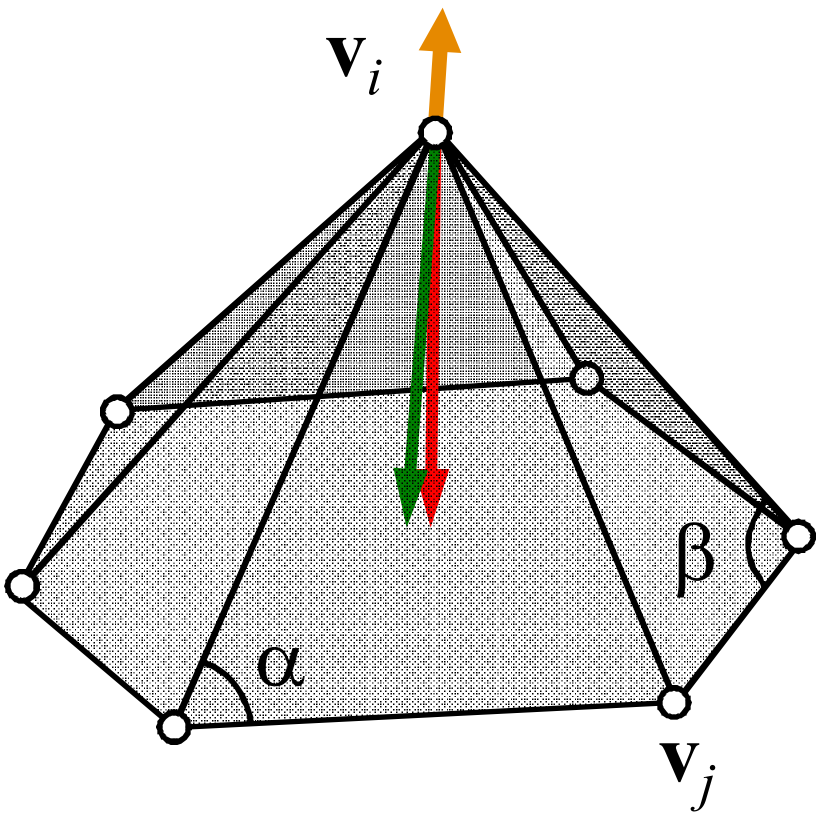


Surface Optimization

Requirements for our Approximations

- We replace $\mathbf{L}_c$ with $\mathbf{L}_u$ in both steps
- This a viable approximation for:
  - **(A)** nearly equal edge lengths (smooth metric)
  - **(B)** nearly equal vertex areas

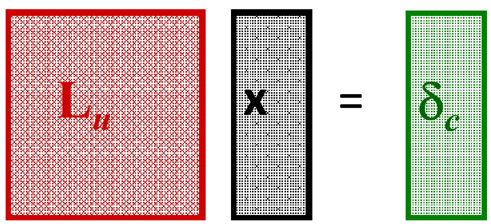




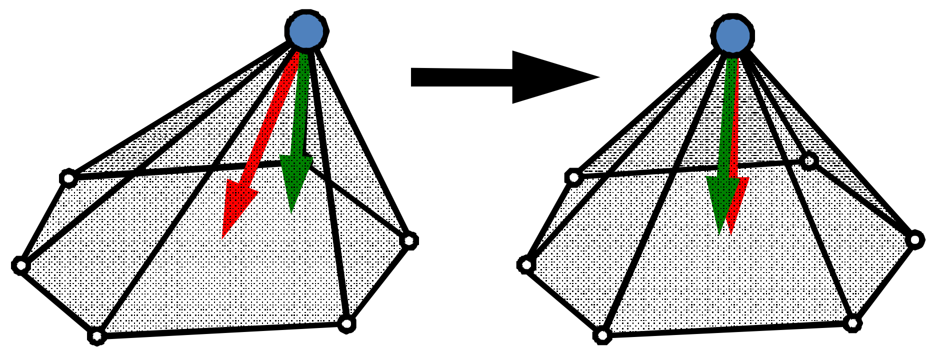
Surface Optimization

How to Enforce (A) and (B)

Setting $\mathbf{L}_u(\mathrm{x})$ equal to δ_c improves inner fairness



[Nealen et al. 2006]

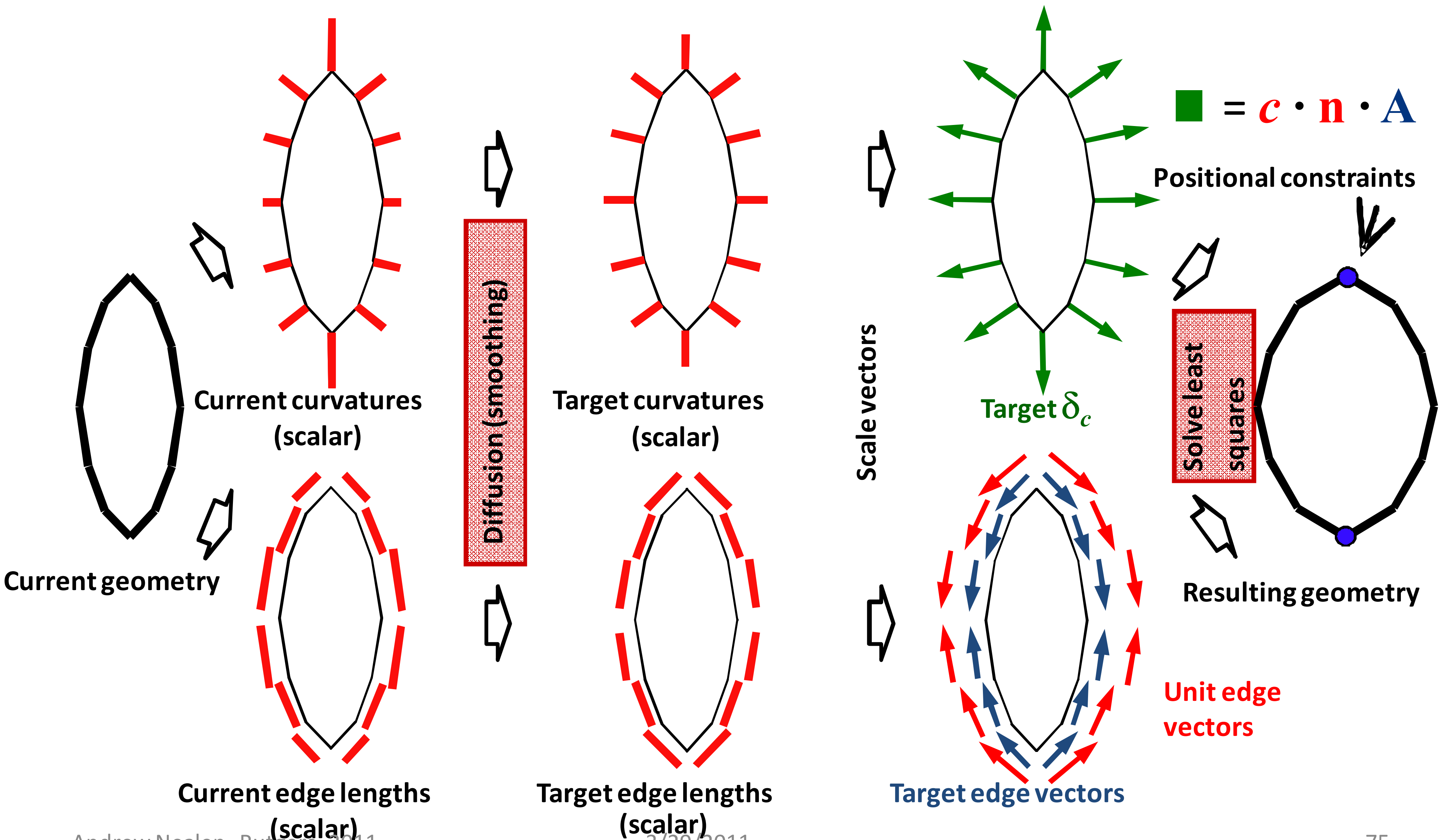


Smooth the edge lengths

Constrain edge vectors

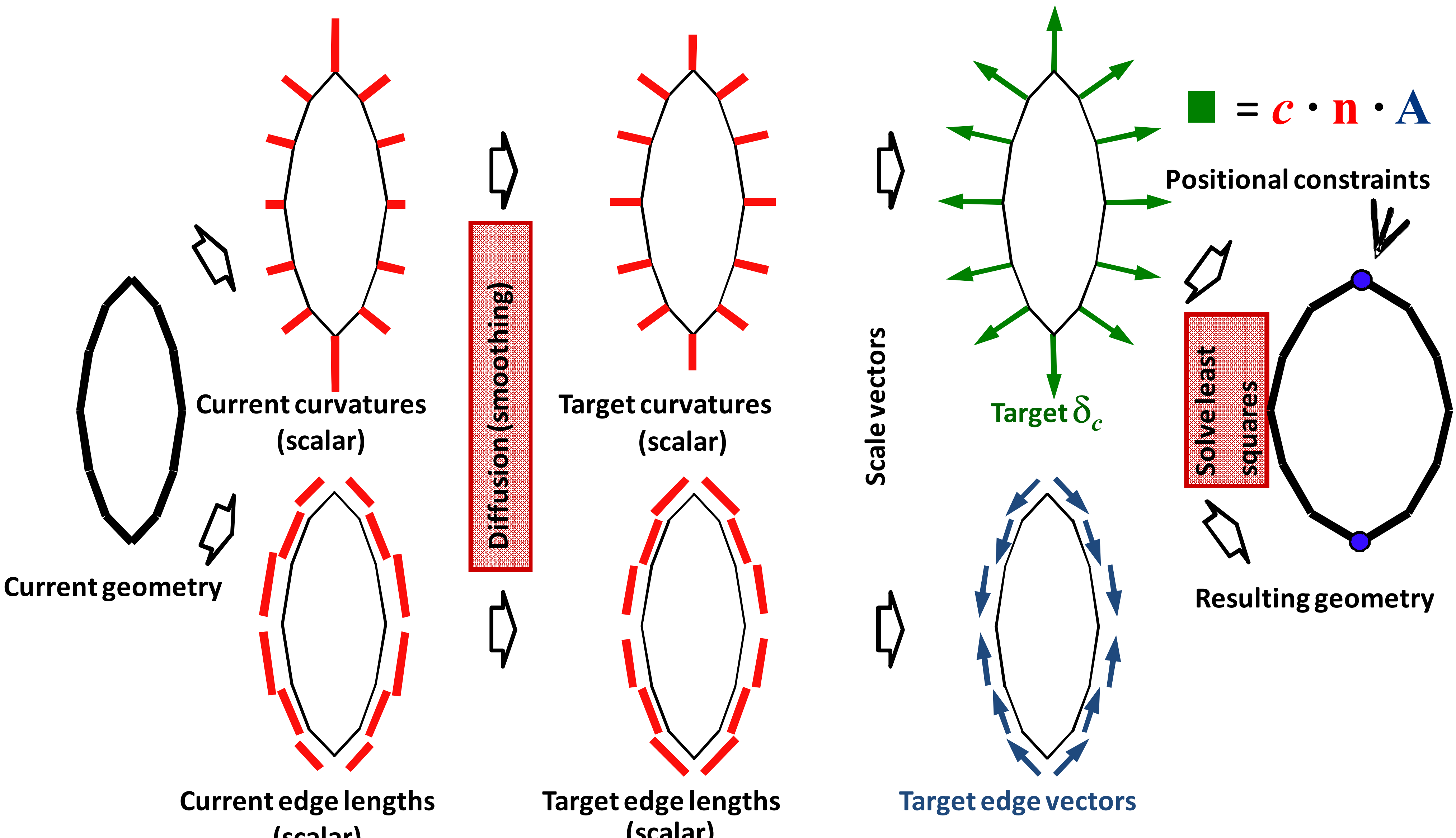
Surface Optimization

Adding Edge Vector Constraints to LS

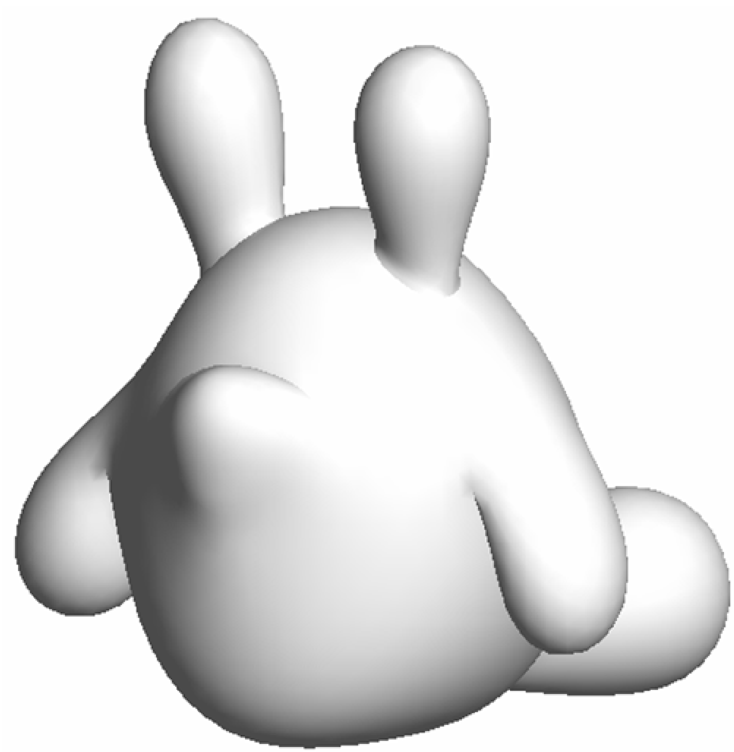


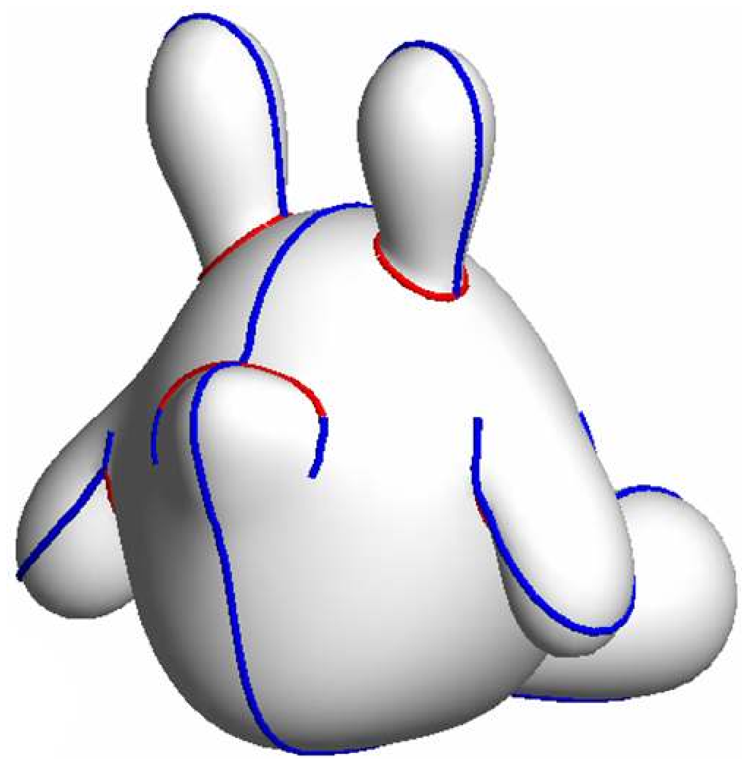
Surface Optimization

A Single Step of the Optimization



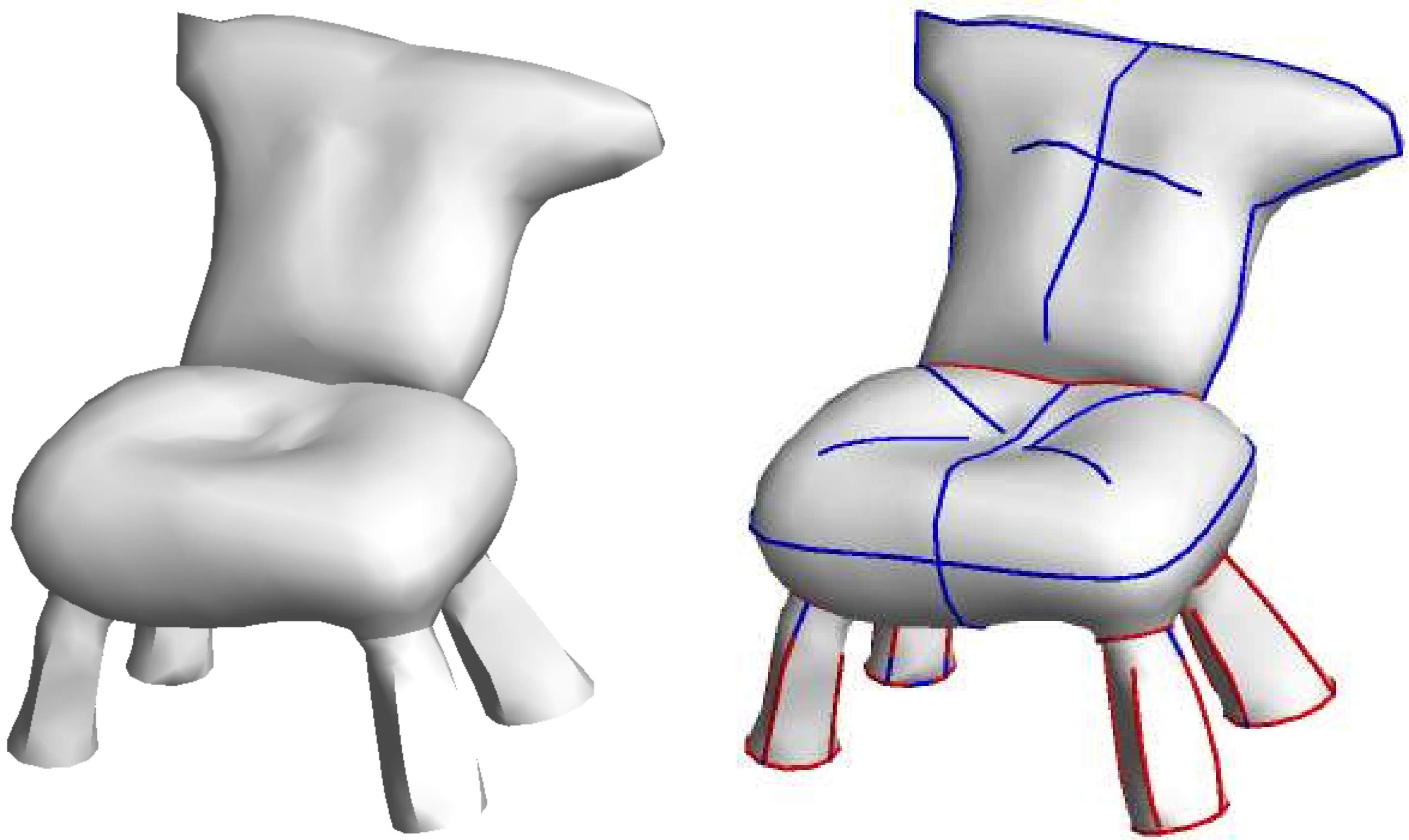
Results





Results

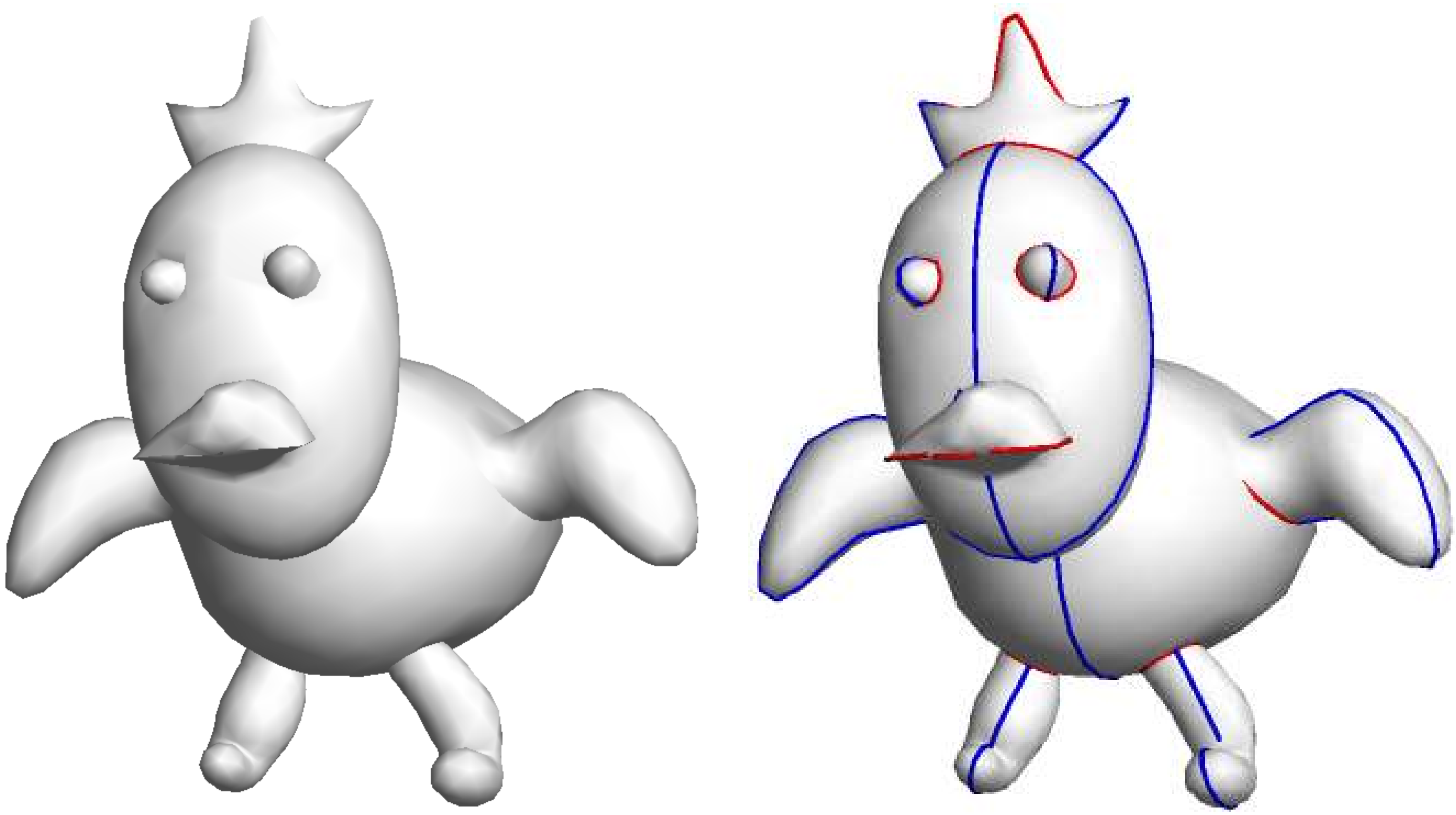
Novice User



15 min intructions + 20 minutes tryout

Results

2D Artist



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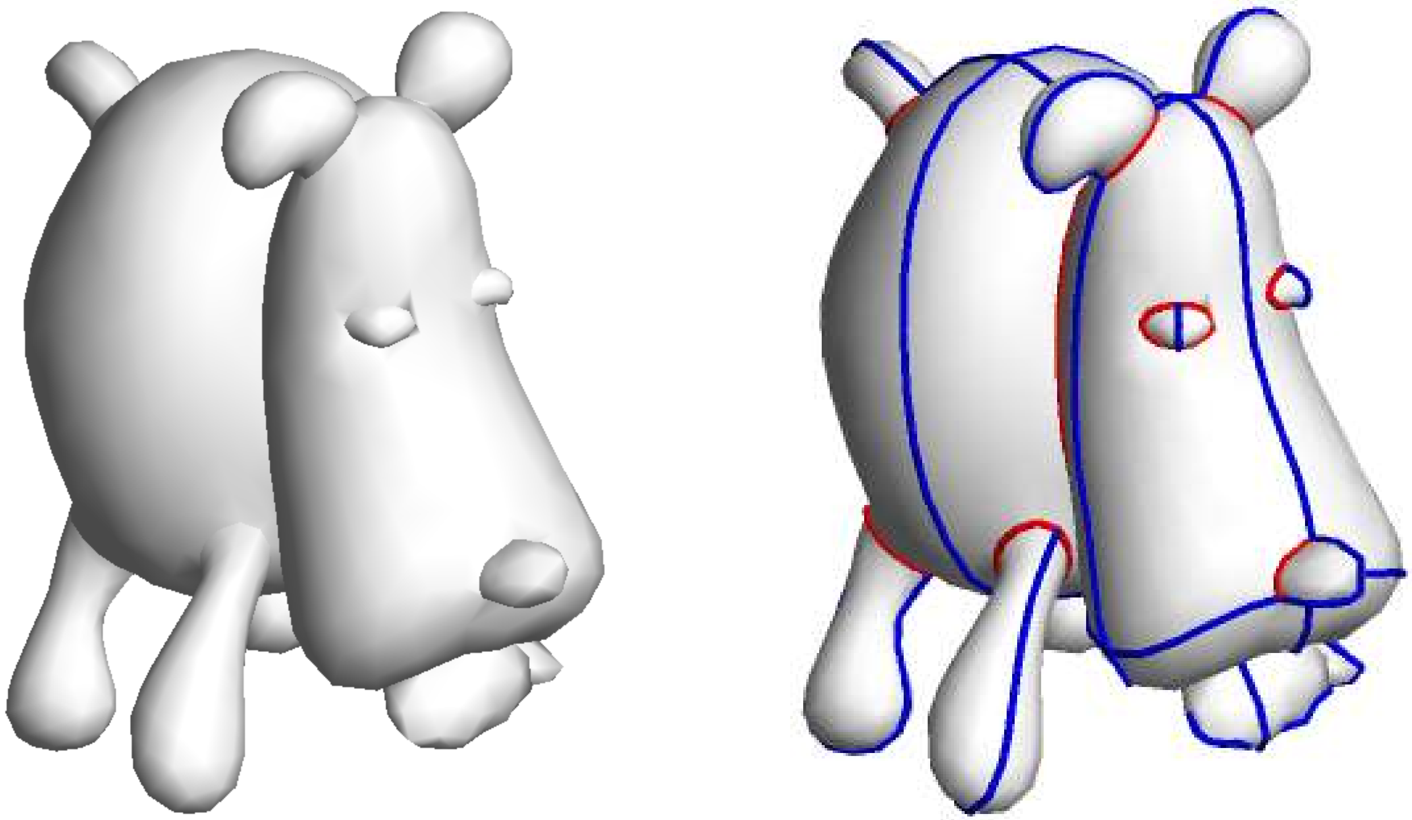
Results

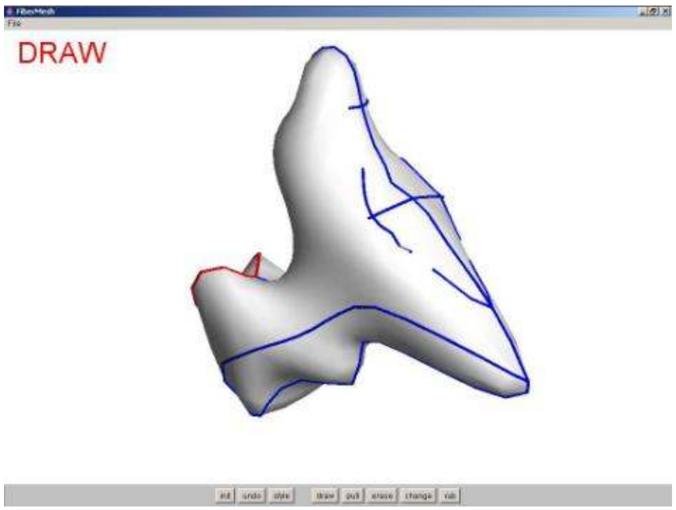
2D Artist

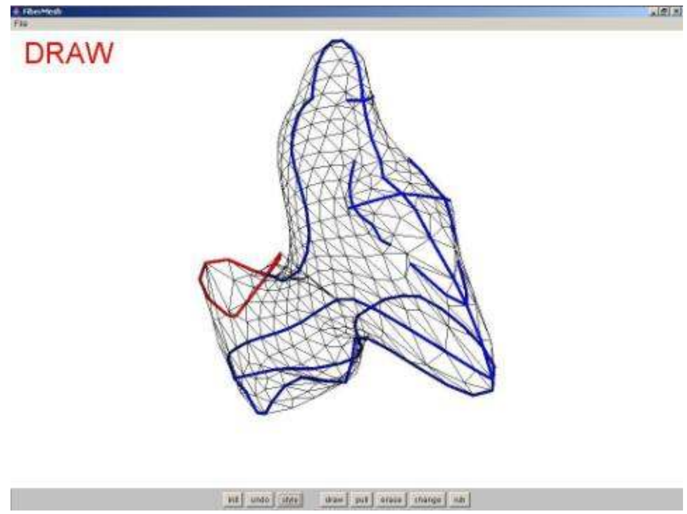


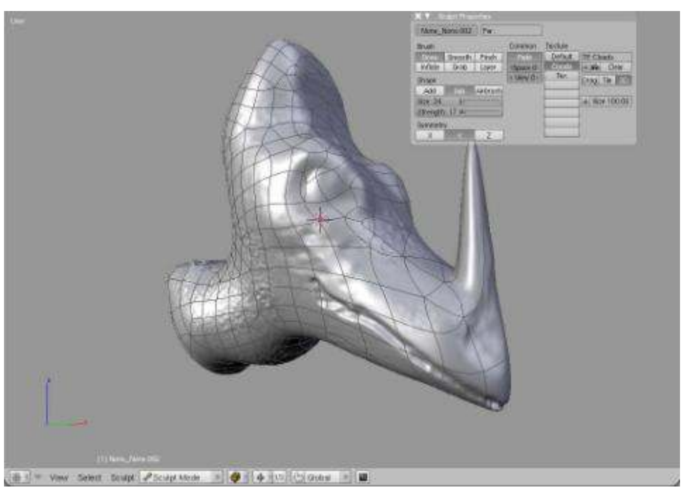
... + 20 minutes tryout

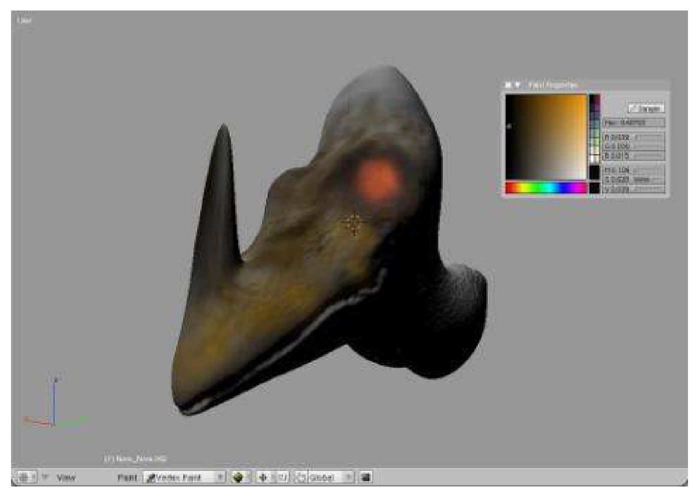
Results

Base Model Creation









Discussion

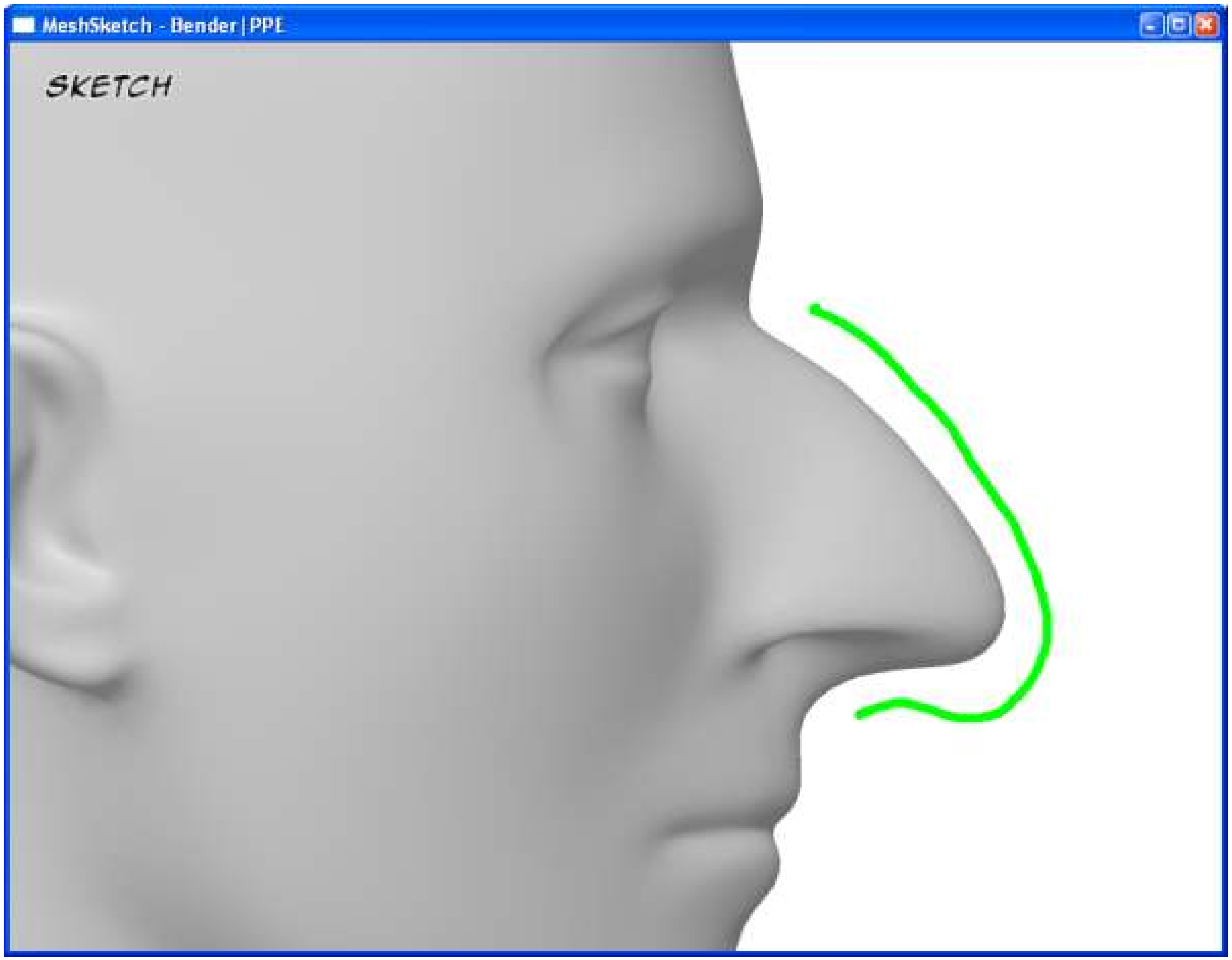
To be Improved...

- Takes a bit to learn the interface operations and their combinations
- Larger meshes would be nice
  - Perhaps „freeze“ part of the mesh
    In general: entire mesh is optimized
  - Multigrid / Multiresolution acceleration techniques
- Add more intuitive modeling operations: symmetry, vertex snapping, merging, etc.

SilSketch

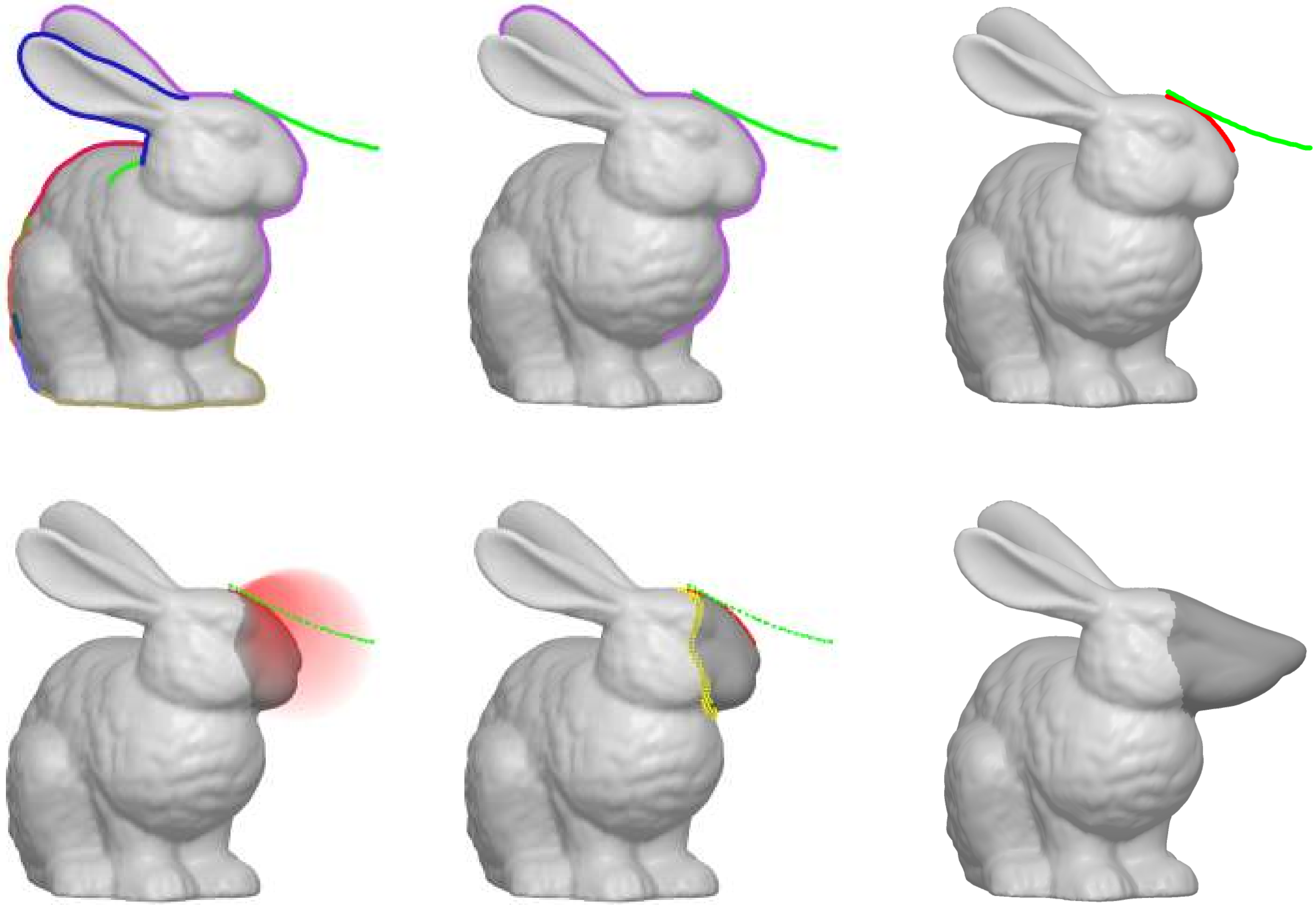
SilSketch

Demo



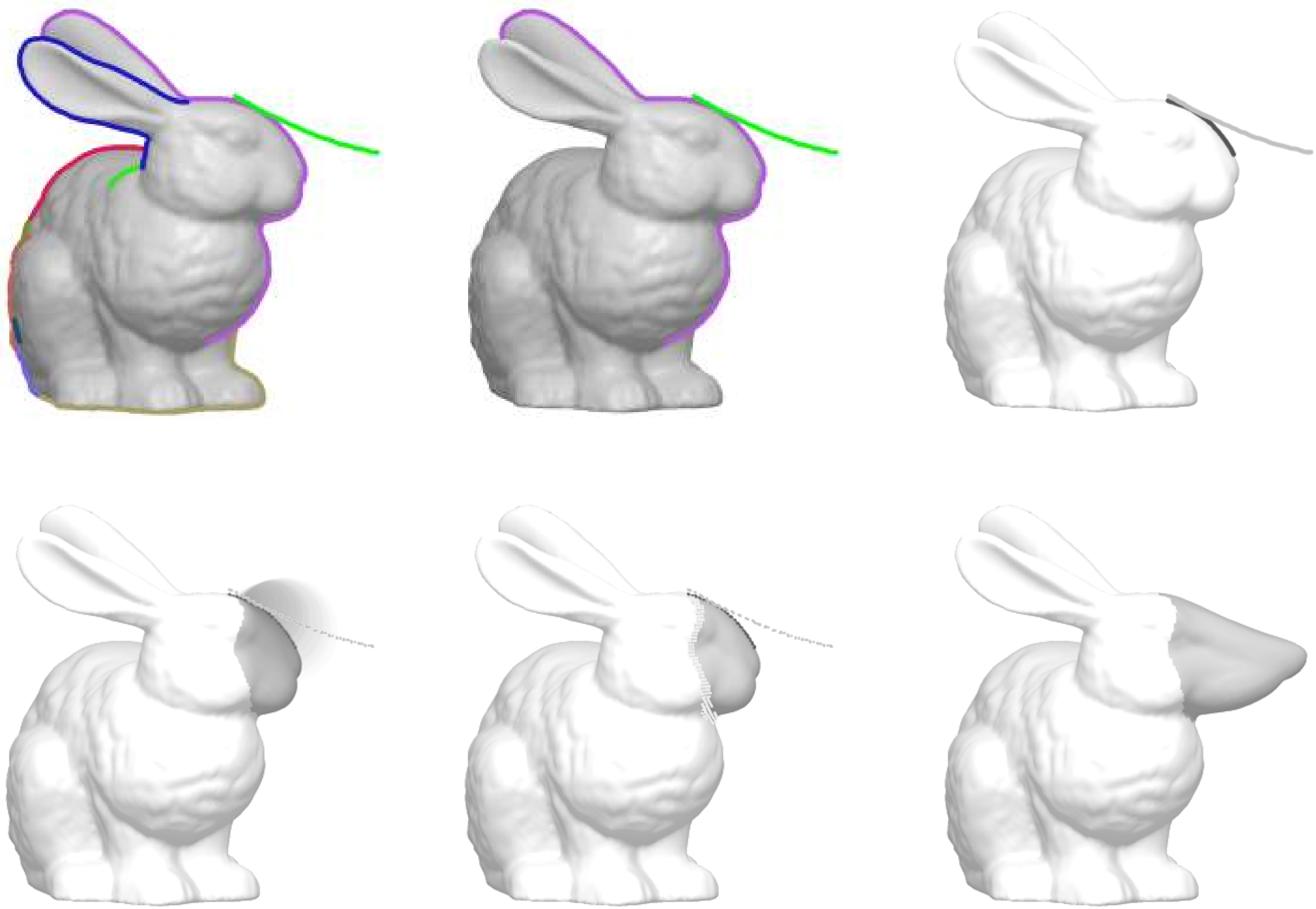
SilSketch

Algorithm Overview

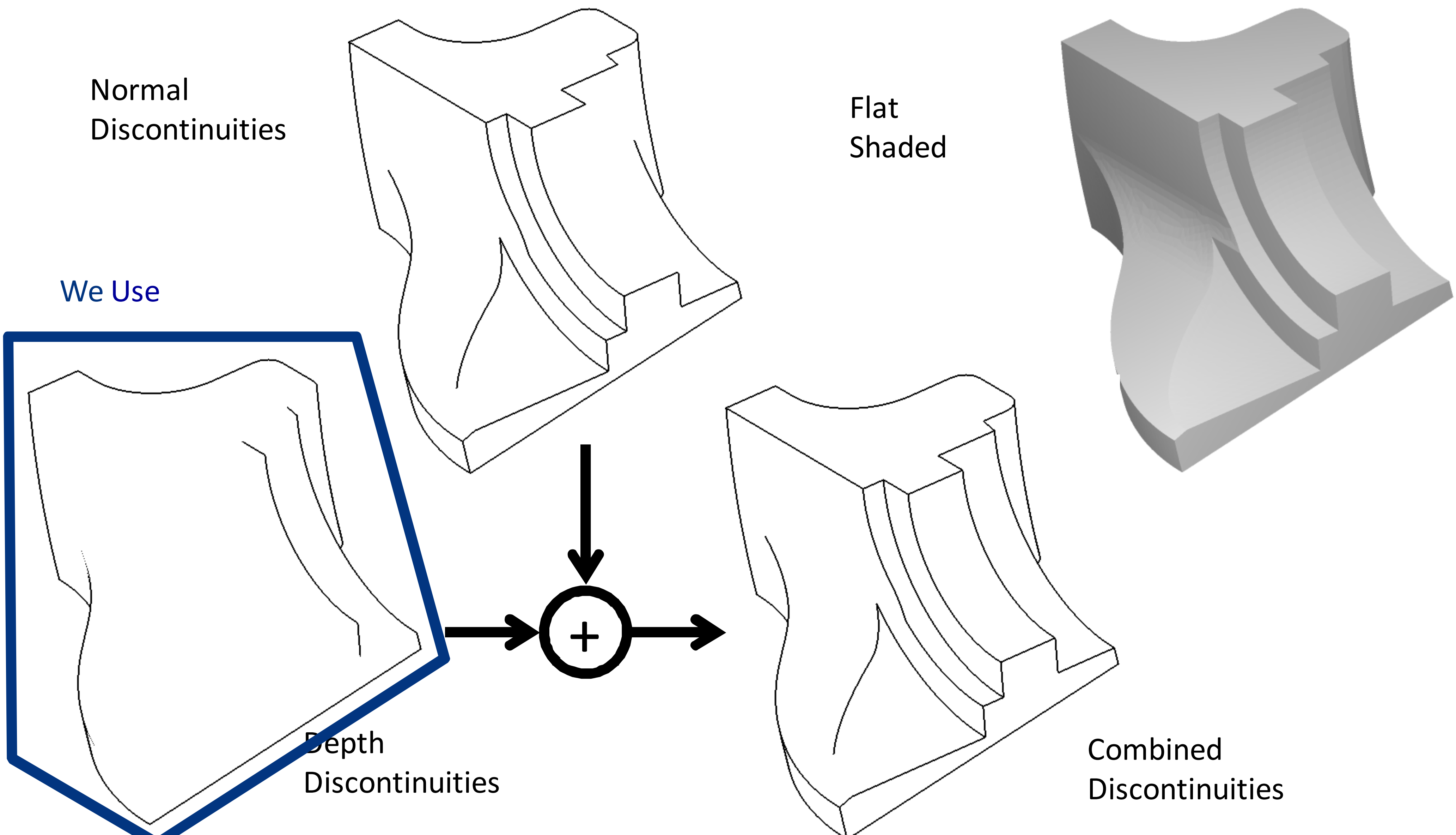


Sil Detection and Segmentation

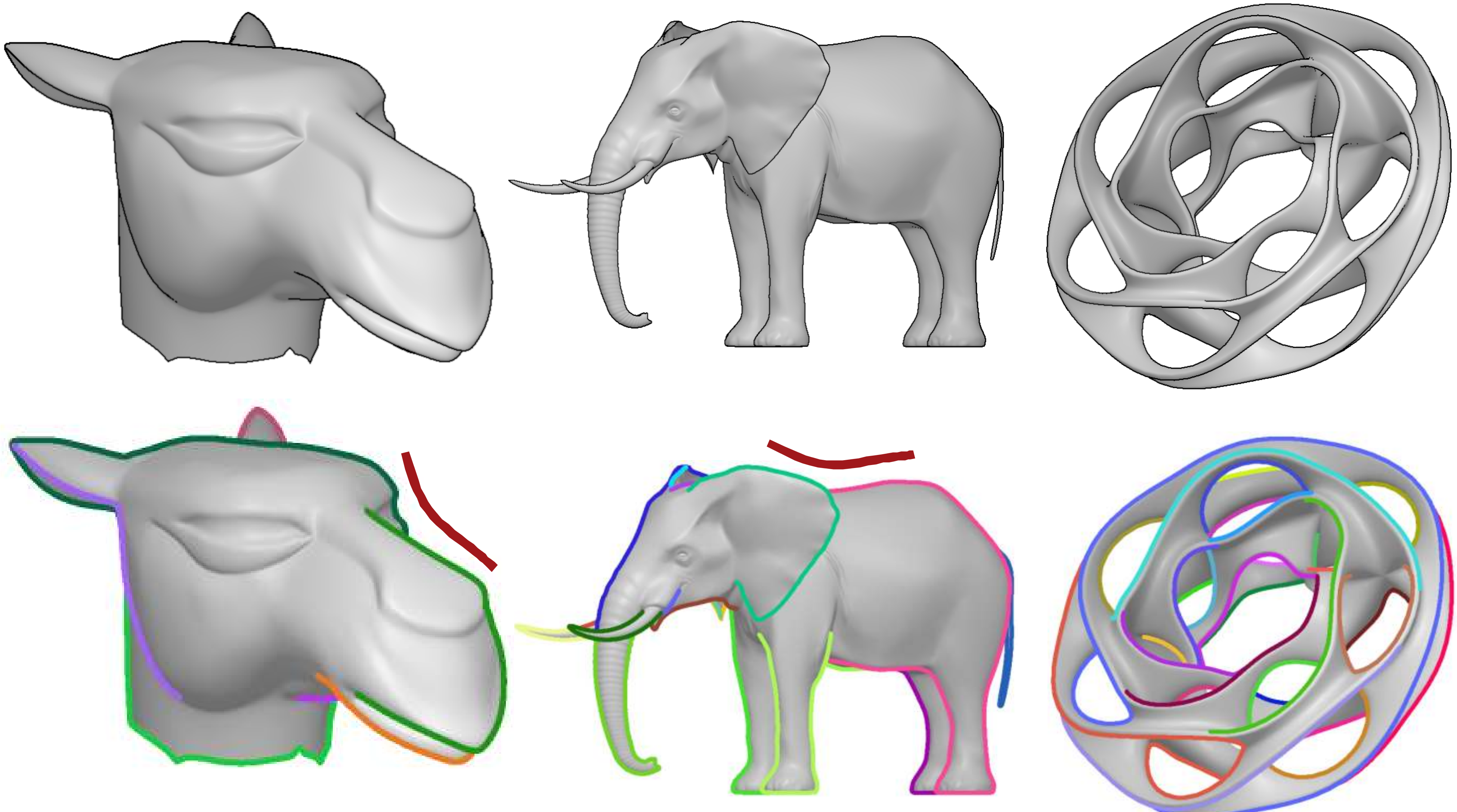
Image Space



Which Lines to Match Against ?



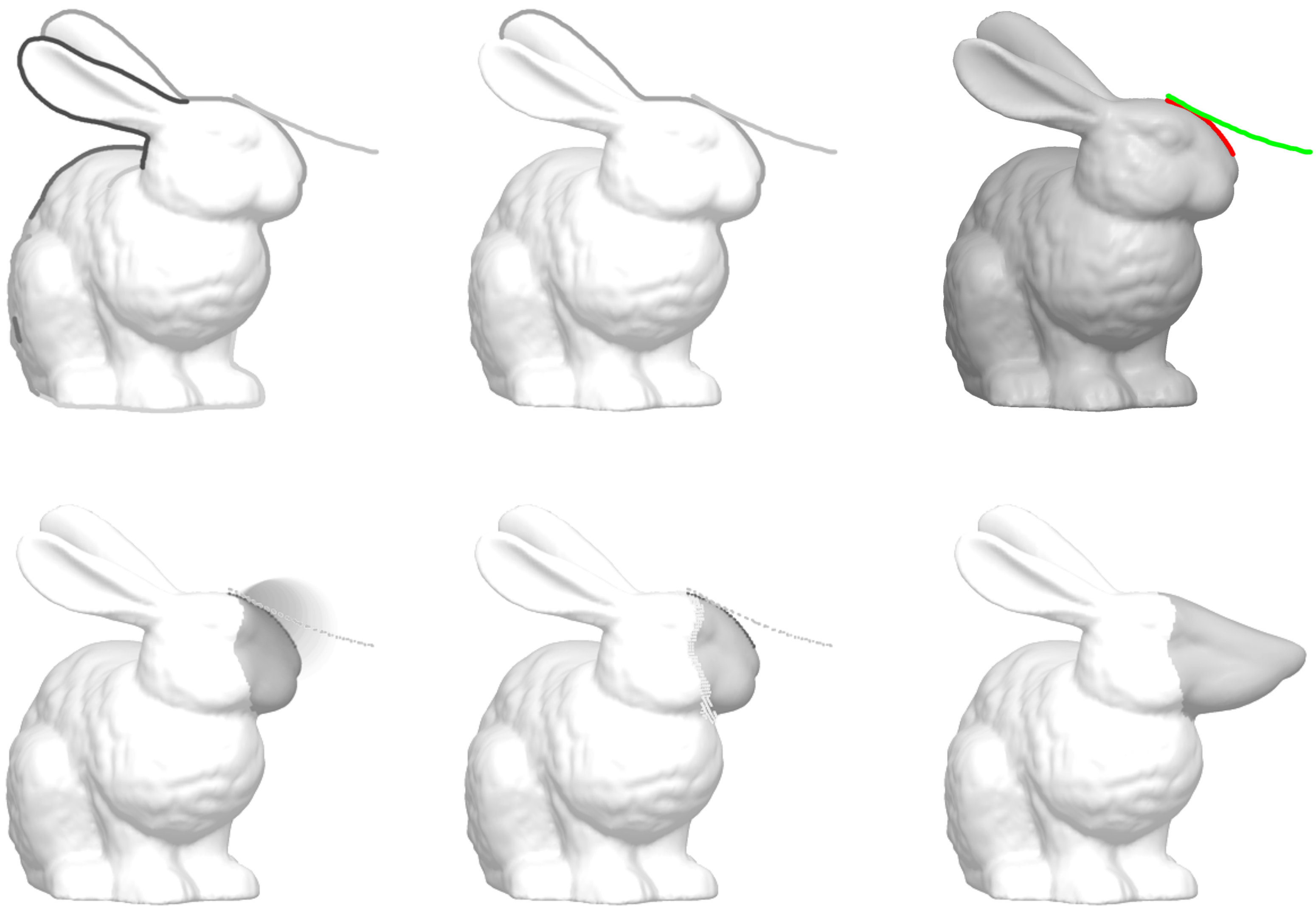
Some Segmentation Results



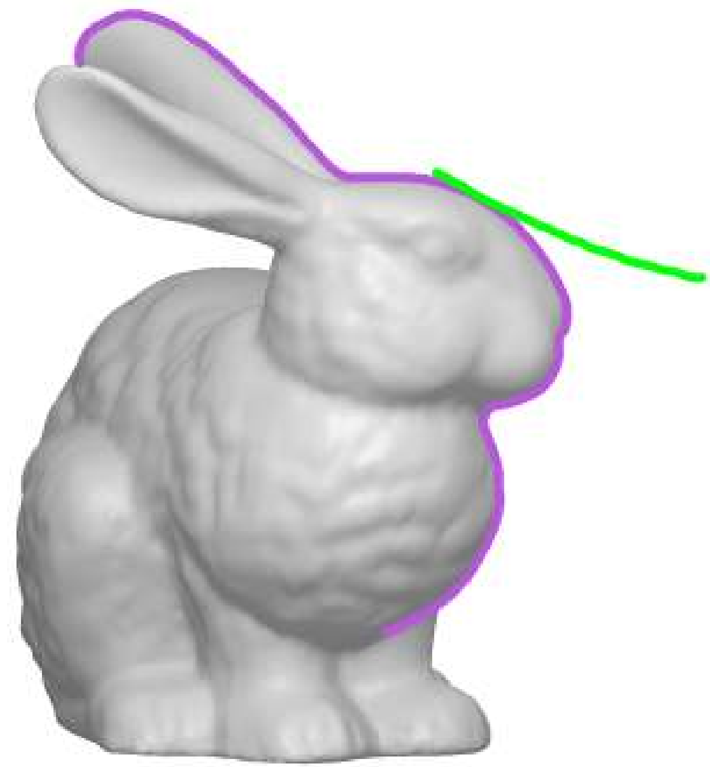
Resolve depth ambiguity

Partial Matching

Image Space



Partial Matching



Input

- Silhouette polyline(s)
- User stroke (polyline as well)

Criterions

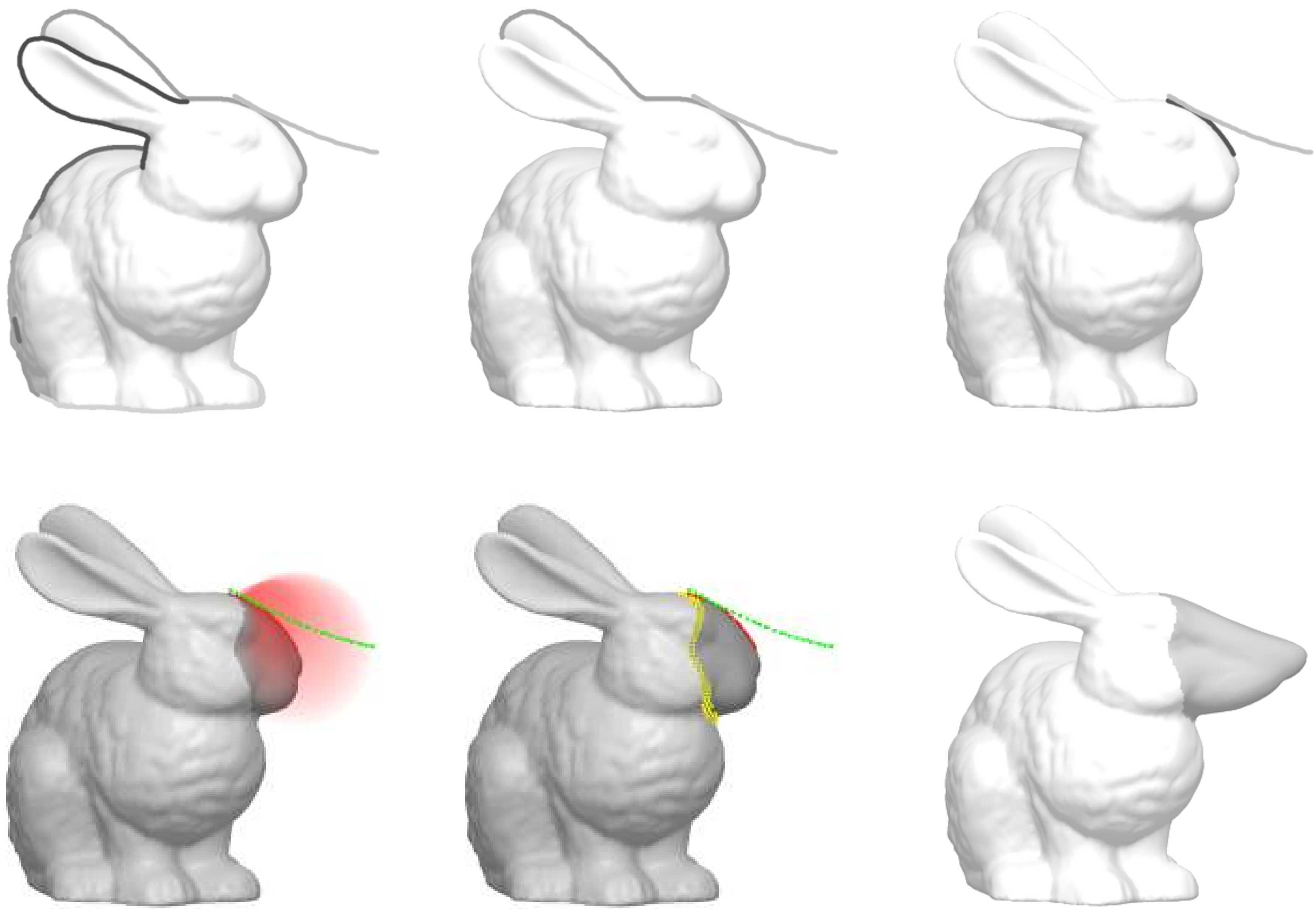
- Proximity
- Shape similarity

Shape Matching

- Partial Matching of Polylines under Similarity Transformations Cohen and Guibas [1997]

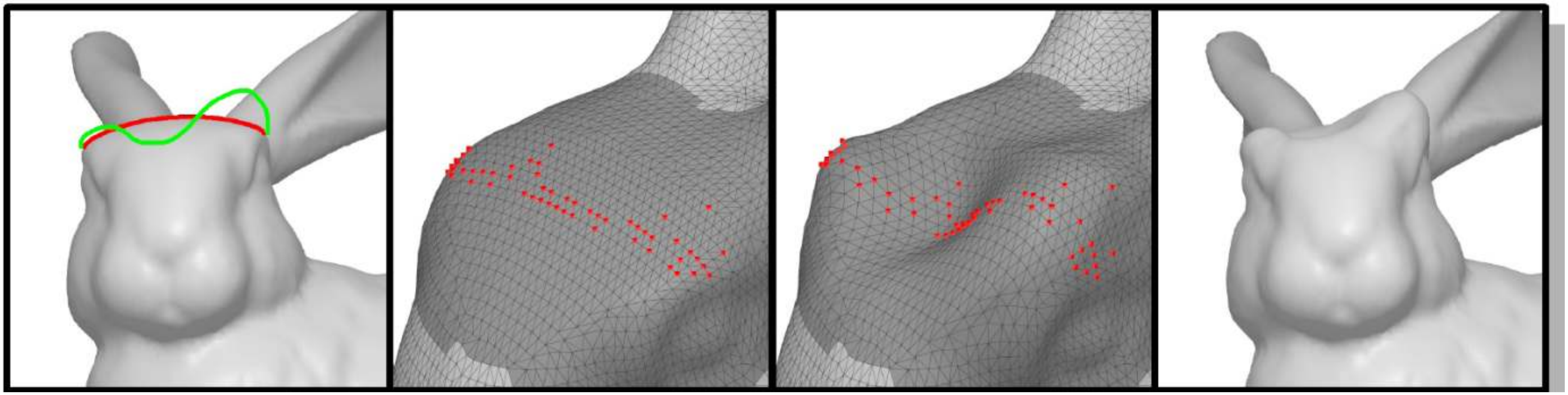
Handle deformation and ROI

Object Space

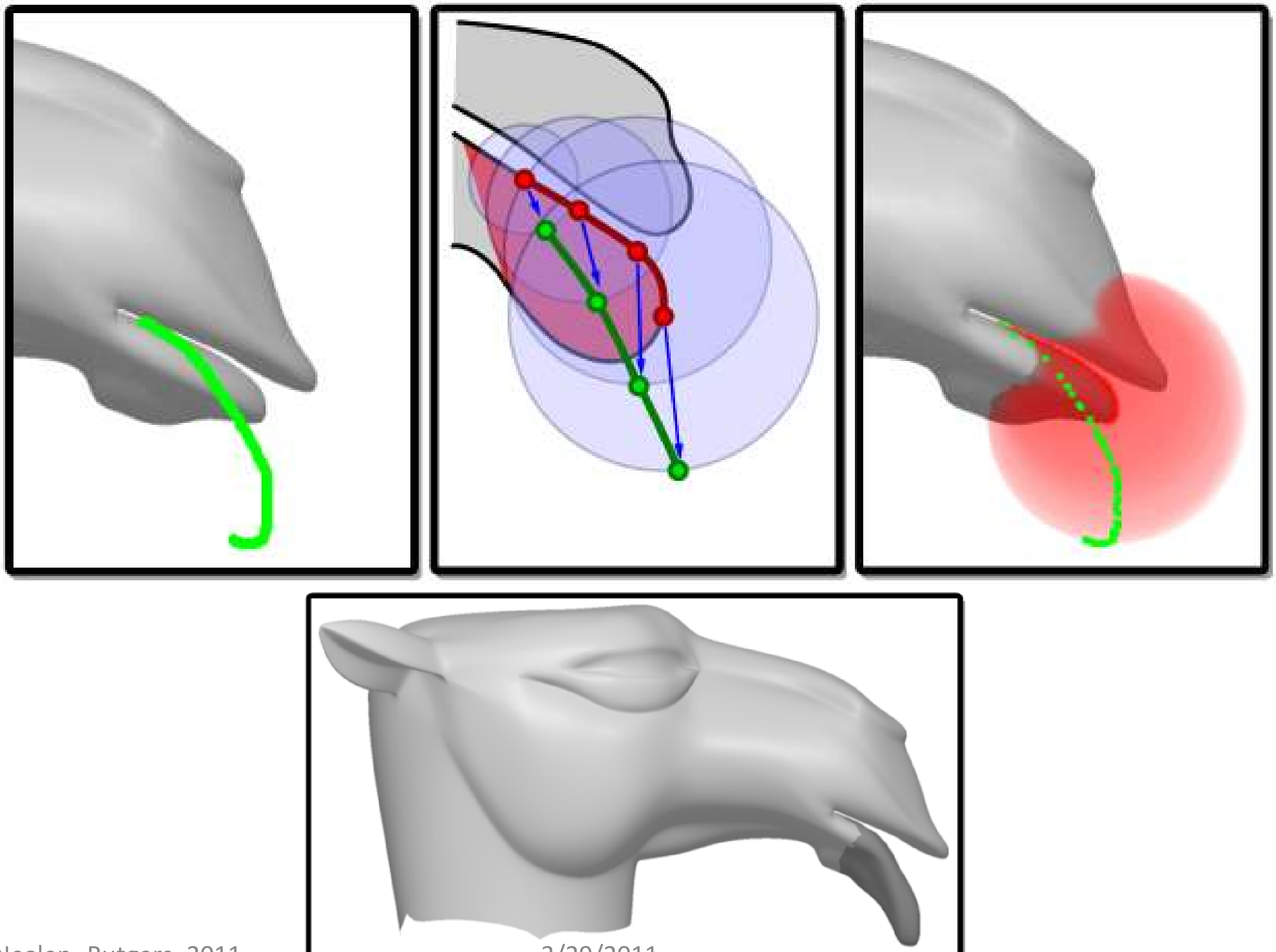


Handle Vertices

Moving from 2D to 3D

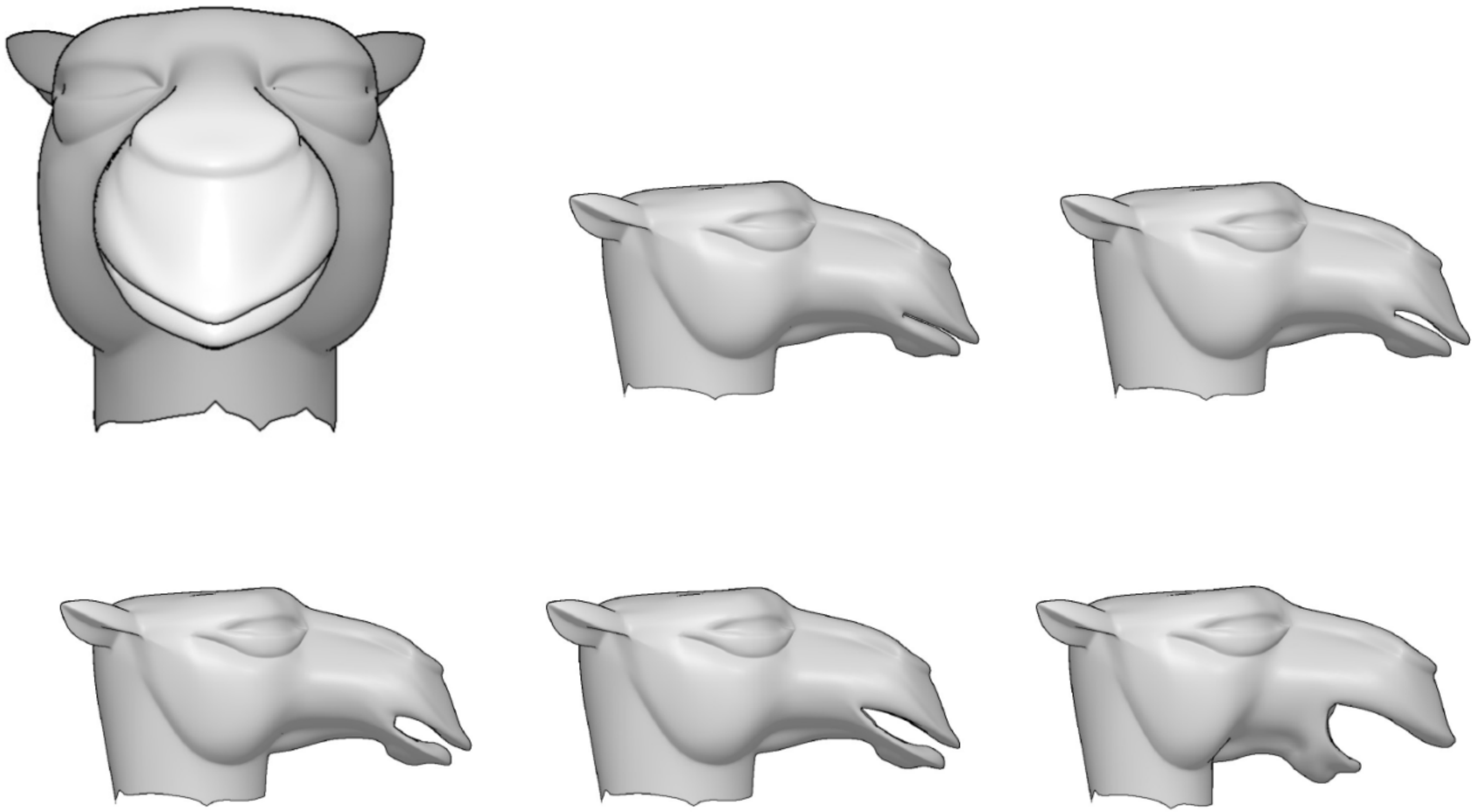


Region of Interest

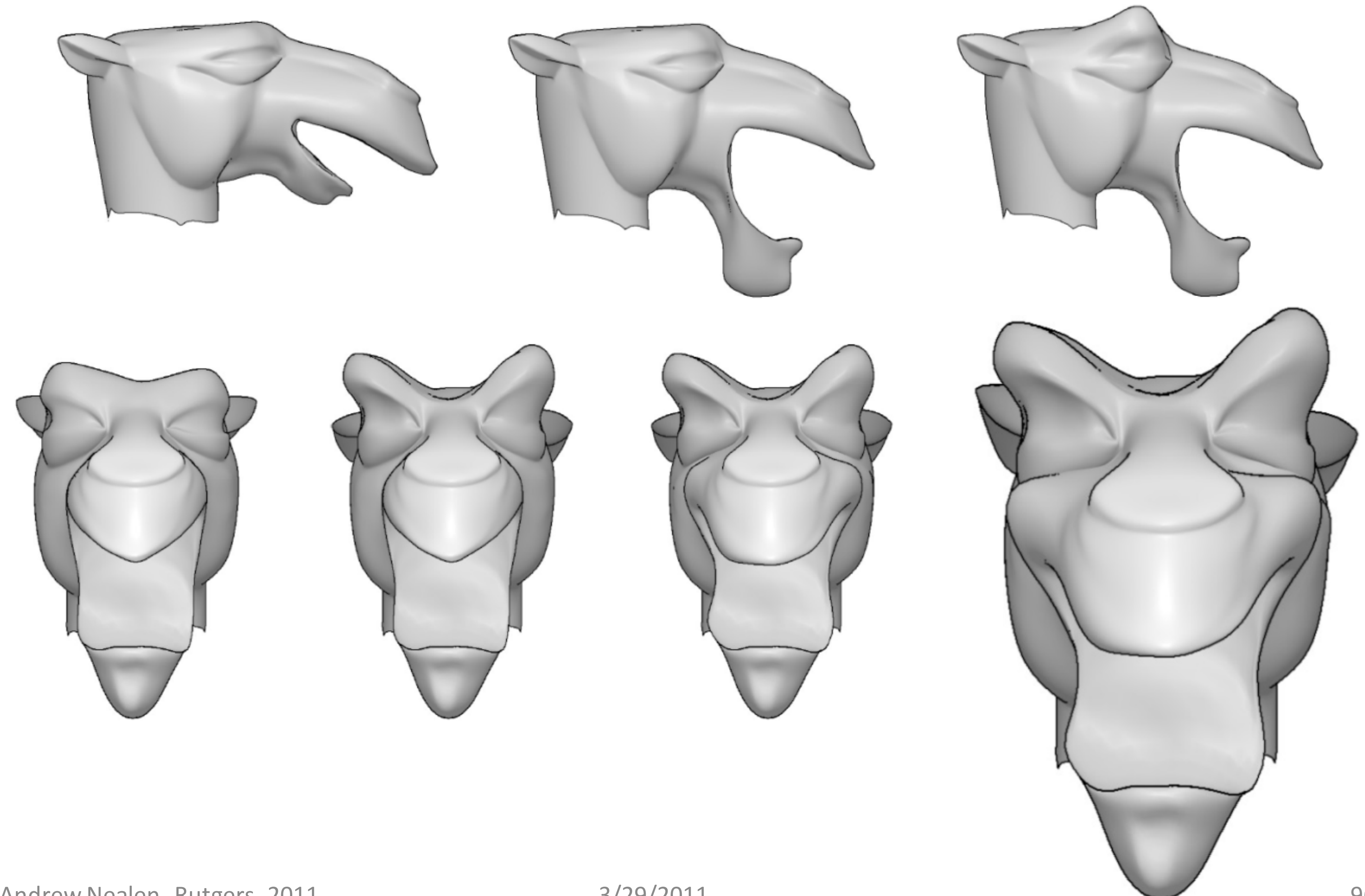


Results

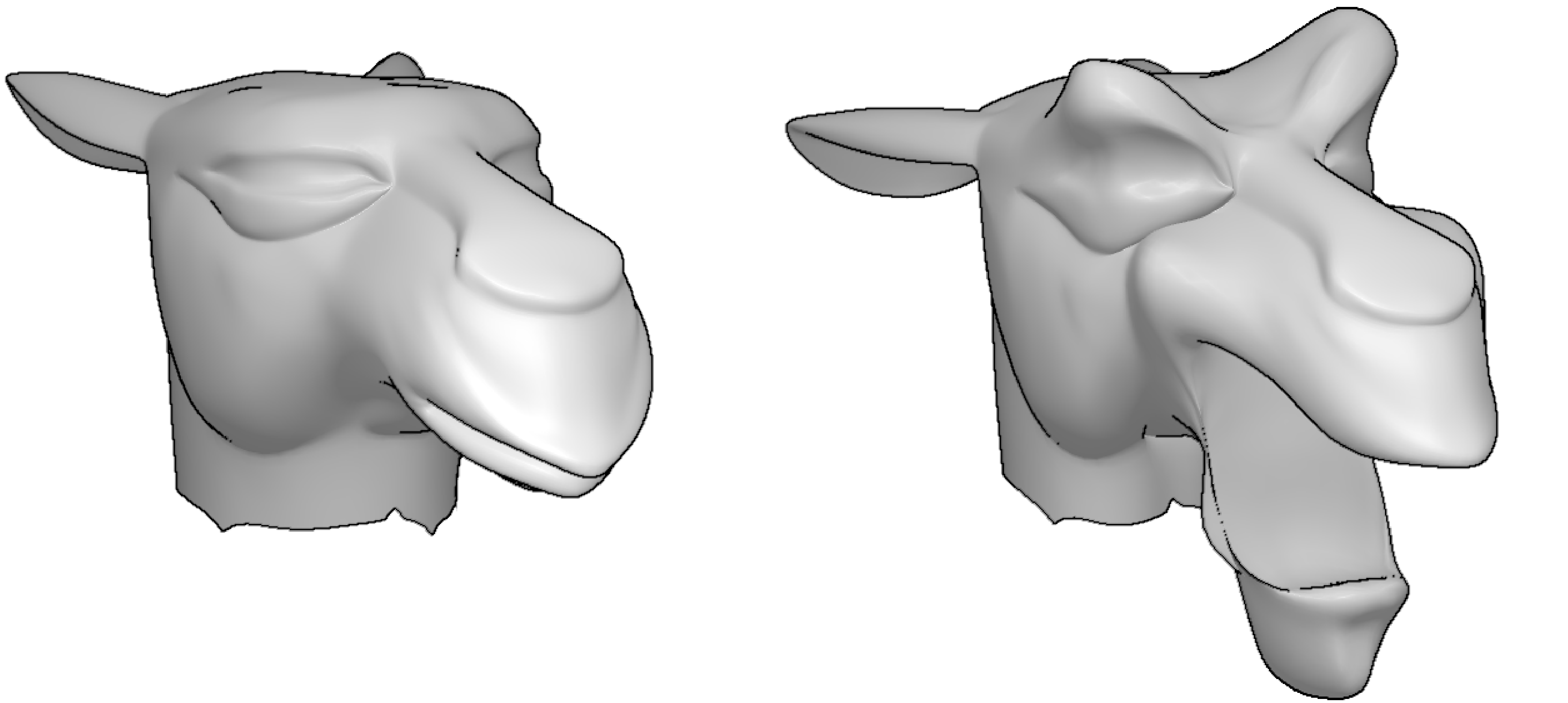
Editing Sequence (1)



Editing Sequence (2)



Editing Sequence Result



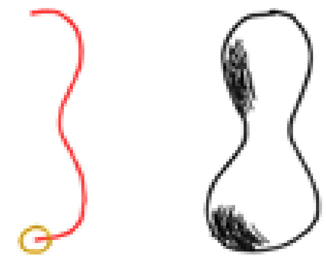
SilSketch

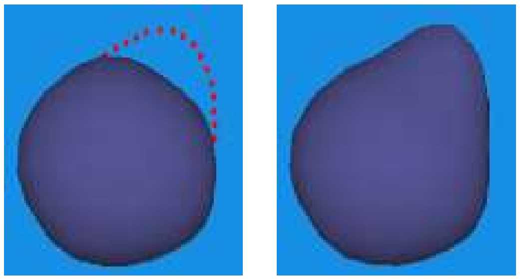
Summary

- The human visual system uses silhouettes as the first index into its memory of shapes
  - SilSketch leverages this human “shape database“
  - This enables the creation of diverse shapes for non professionals
- Extends affine handle transformations to general handle warps
- Was added to the content creation pipeline at Disney Animation Studios

Many other works out there...

- Some research
  - SKETCH
    [Zeleznik et al. 1996]
  - Variational implicits
    [Karpenko et al. 2002]
  - ShapeShop
    [Schmidt et al. 2005]





Conclusions

- Further step(s) towards a human “video out“