Capturing the Essence of Shape in Polygonal Meshes

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Outline

1. Introduction
2. Degree of Interest Functions
3. Essential Shape Representations in 3D
4. Essential Shape Representations in 2D
5. Conclusion & Future Work

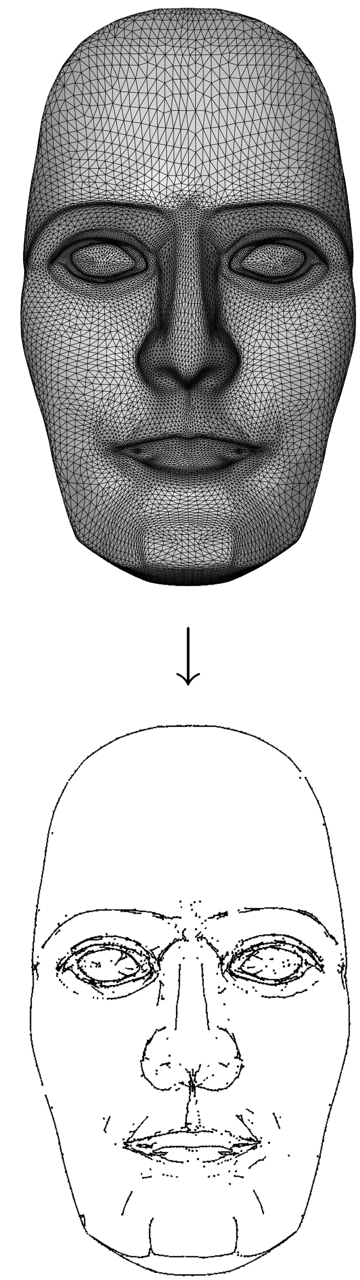
Motivation & Goals

- mesh evaluation, recognition, comparison, search, simplification, etc.

⇒ *essence of shape* important

- many different approaches
  (e. g., Raab (1998), Rössl et al. (2000), Hisada et al. (2002))
  → many different concepts of what is important
  ⇒ general concept necessary

- **two goals**:
  - extraction of essential features of meshes in form of curves on the surface
  - criterion exchangable



Essential Shape Representation

- *shape*: form of surface or silhouette
  $\longrightarrow$ geometric properties
  $\longrightarrow$ non-geometric properties irrelevant

- definition *essential shape representation* (ESR):
  essential features of a shape according to a certain *ESR criterion*

- specific algorithm: *ESR scheme*

- important goals:
  - coding and decoding
  - (lossy) compression
  - multiscale representation
  - resampling

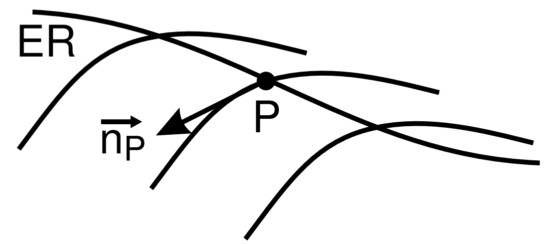
Overview

1. Introduction
2. Degree of Interest Functions
   - Modified Shape Index
   - Fold Index
3. Essential Shape Representations in 3D
4. Essential Shape Representations in 2D
5. Conclusion & Future Work

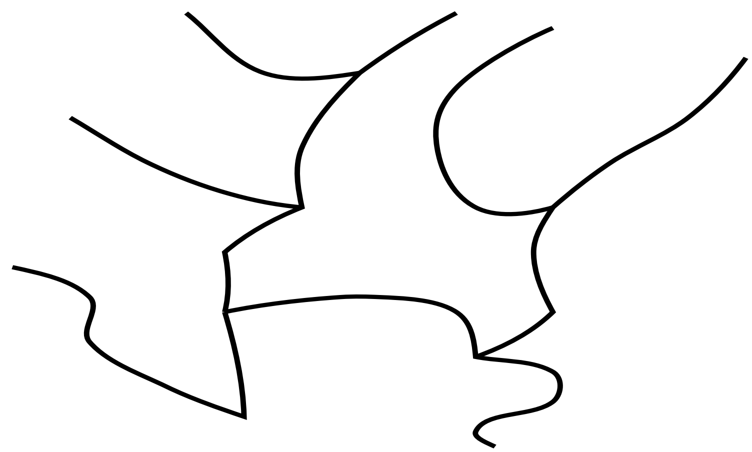
Degree of Interest Functions

- definition *degree of interest* (DoI) function:
  ESR criterion that captures the importance of surface points as scalar values

- DoI function defines *extreme ridges*:
  1D path on the surface S where DoI value
  is (restricted) locally maximal:
  $ER : \{\forall P \in S : \mathrm{DoI}(P) > \mathrm{DoI}(P \pm \varepsilon\, \overrightarrow{n_P})\}$

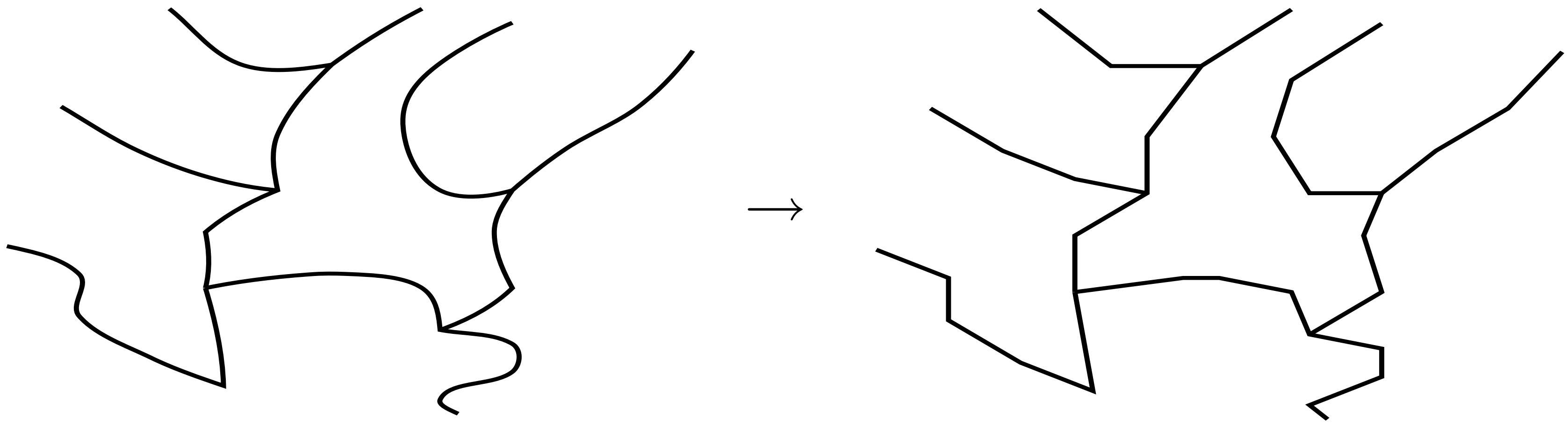


→ network of extreme ridges



Degree of Interest Functions

- discrete DoI functions → computation per vertex



- desired properties of a DoI function
  - ideally: favoring of features based on a given scale

  → not possible using a local DoI function

  - emphasize prominent geometric features of the surface

  → ridges and ruts
  - account for intensity of the feature

Shape Index

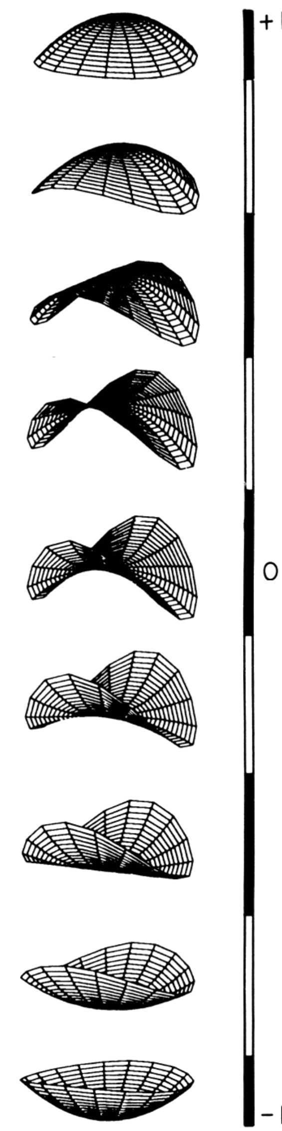
- DoI function based on local geometric shape

- *shape index* (Koenderink, 1990)

$$\mathrm{DoI}(V) := s = \frac{2}{\pi}\arctan\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right) \quad (\kappa_1 \geq \kappa_2)$$

- extreme values not at geometrically interesting points

$\Rightarrow$ shape index not well suited as a DoI function

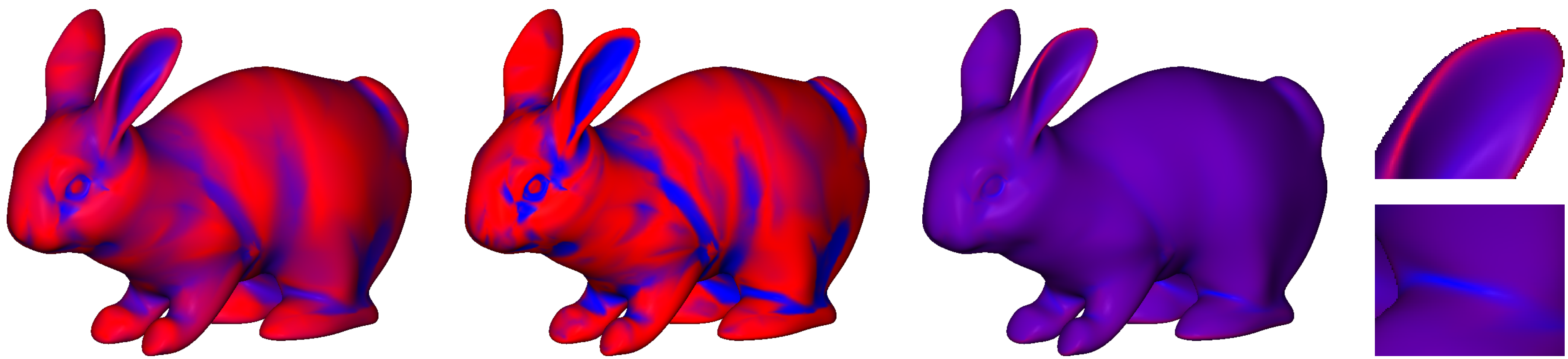


Modified Shape Index

- sine function for emphasizing ridges and ruts

$$
\begin{aligned}
\mathrm{DoI}(V) &:= \sin(\pi s) \\
&= \sin\left(2\arctan\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)\right) \qquad (\kappa_1 \geq \kappa_2) \\
&= \frac{2\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)}{1+\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)^2} \qquad (\kappa_1 \geq \kappa_2)
\end{aligned}
$$

- scaling by $(\kappa_1 - \kappa_2)$ to account for significance of features



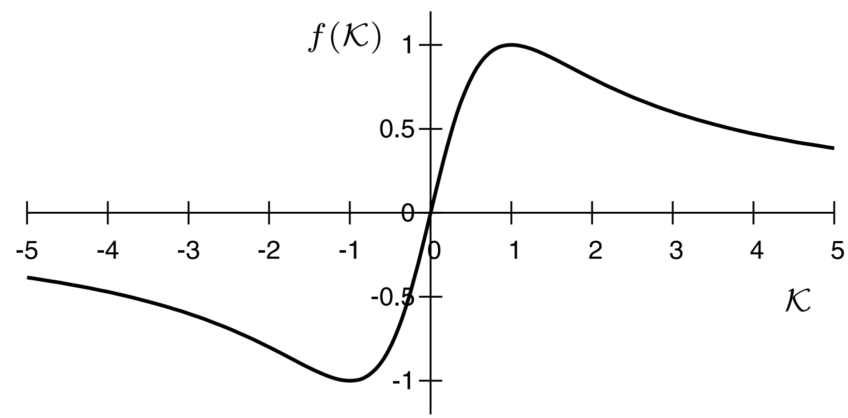
shape index modified shape index scaled modified shape index

Fold Index

- local classification of shape on a surface: $\mathcal{K} = \left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right) \quad (\kappa_1 \geq \kappa_2)$
  - classifies local environment of a point: 1 for ideal ridges and -1 for ideal ruts
  - grows with shrinking κ_i and vice versa (for constant Δ_κ)

- assuming continuous function $f(\mathcal{K})$
  - maximum at $\mathcal{K} = 1$ and minimum at $\mathcal{K} = -1$
  - monotone between $\mathcal{K} = -1$ and $\mathcal{K} = 1$
  - asymptotic to $\mathcal{K}$-axis above $\mathcal{K} = 1$ and below $\mathcal{K} = -1$

$\Rightarrow$ well suited as DoI function



- scaling to account for significance

$$\mathrm{DoI}(V) := (\kappa_1 - \kappa_2)\, f(\mathcal{K})$$

Fold Index

- scaled modified shape index

$$\mathrm{DoI}(V) := (\kappa_1 - \kappa_2)\frac{2\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)}{1+\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)^2}$$

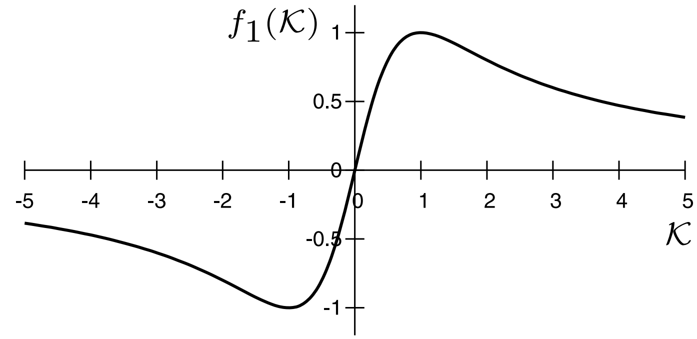
$$\rightarrow f_1(\mathcal{K}) = \frac{2\mathcal{K}}{1+\mathcal{K}^2}$$

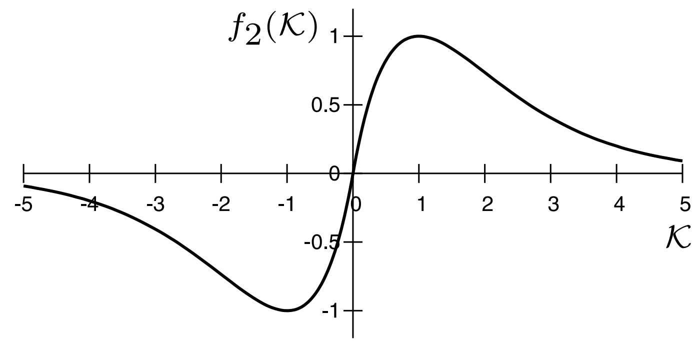
- function f easily exchangable
- e. g., new function f_2

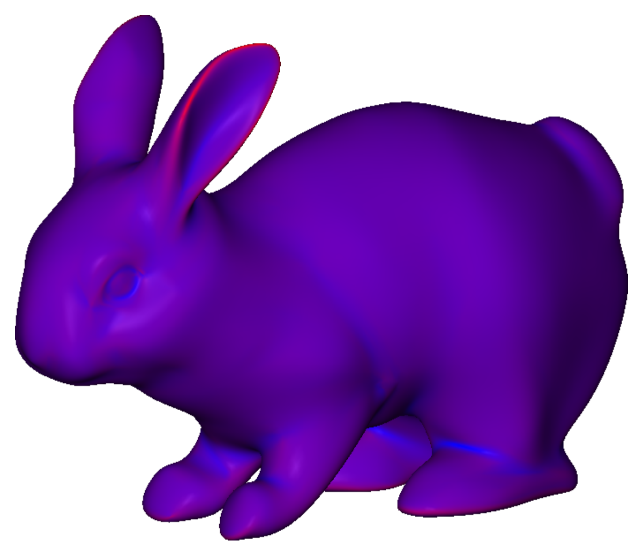
$$f_2(\mathcal{K}) = \mathcal{K}\, e^{(1-|\mathcal{K}|)}$$

$$\Rightarrow \mathrm{DoI}(V) := -(\kappa_1 + \kappa_2)\, e^{\left(1-\left|\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right|\right)}$$

- advantages
  - generalized concept
  - emphasizes ridges and ruts
  - takes feature significance into account



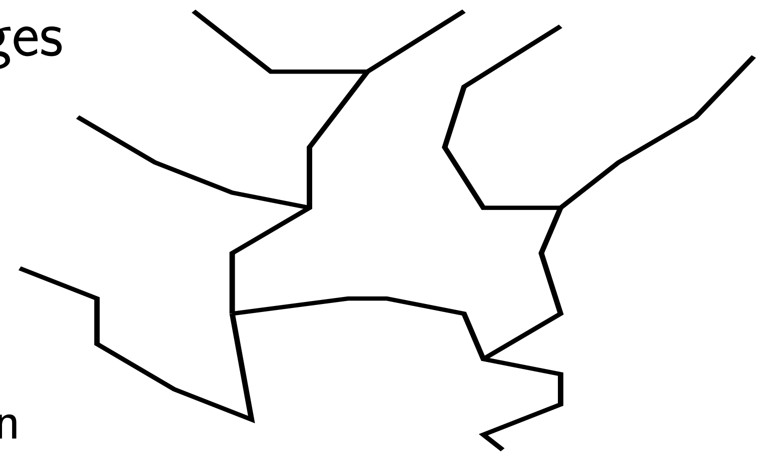




Overview

1. Introduction
2. Degree of Interest Functions
3. Essential Shape Representations in 3D
    - External Skeleton
    - Wave Propagation Algorithm
    - Applications
4. Essential Shape Representations in 2D
5. Conclusion & Future Work

ESR Scheme

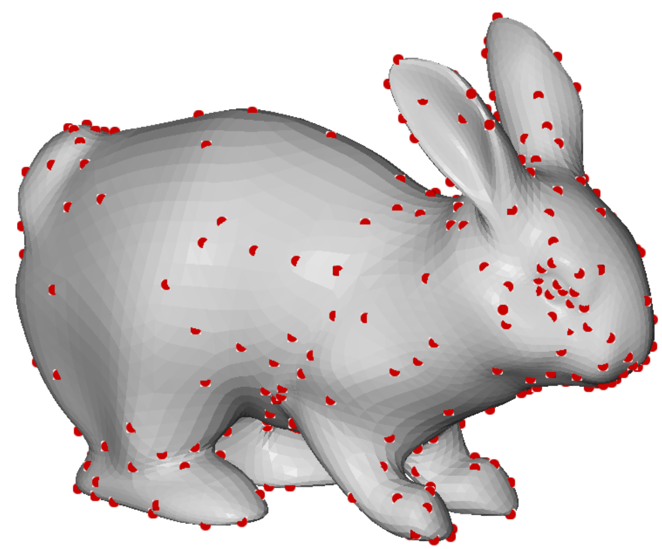


- goal: extraction of network of extreme ridges
  - starting points for extreme ridges
  - stepwise tracing of extreme ridges

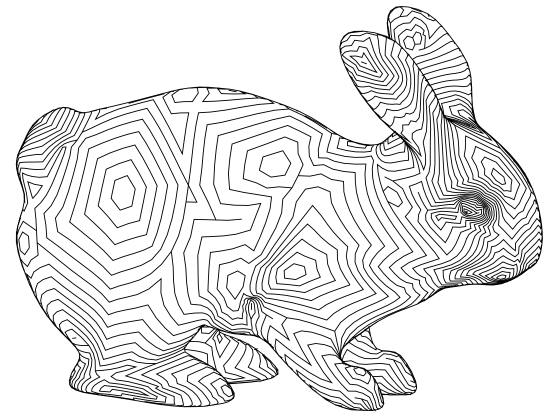
- steps of the algorithm
  1. locate unrestricted local maxima of DoI function
  2. wavefront propagation on mesh's surface
  3. trace extreme ridges along local maxima

- unrestricted local maxima of DoI function
  - compare vertex' DoI value
    to all its direct neighbors

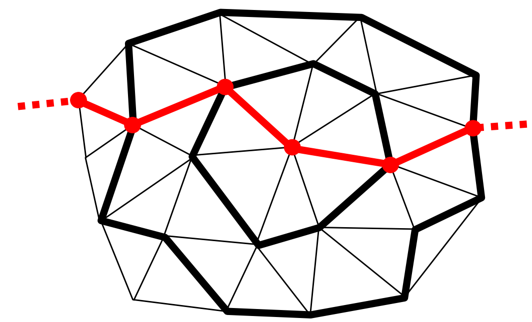
  $\longrightarrow$ wavefront initiators



Wave Propagation



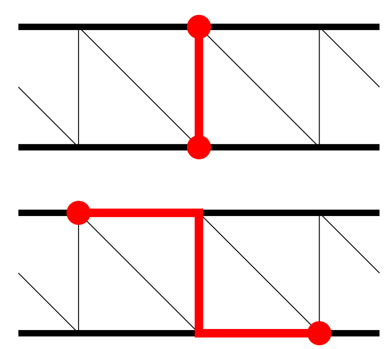
- rationale
  - wave propagation as means for mesh traversal
  - wavefronts as direction $\pm\varepsilon\,\overrightarrow{n_P}$



- extreme ridge identification
  - comparison of DoI values on wavefronts

  ⇒ restricted local maxima

- connect restricted maxima across wavefronts

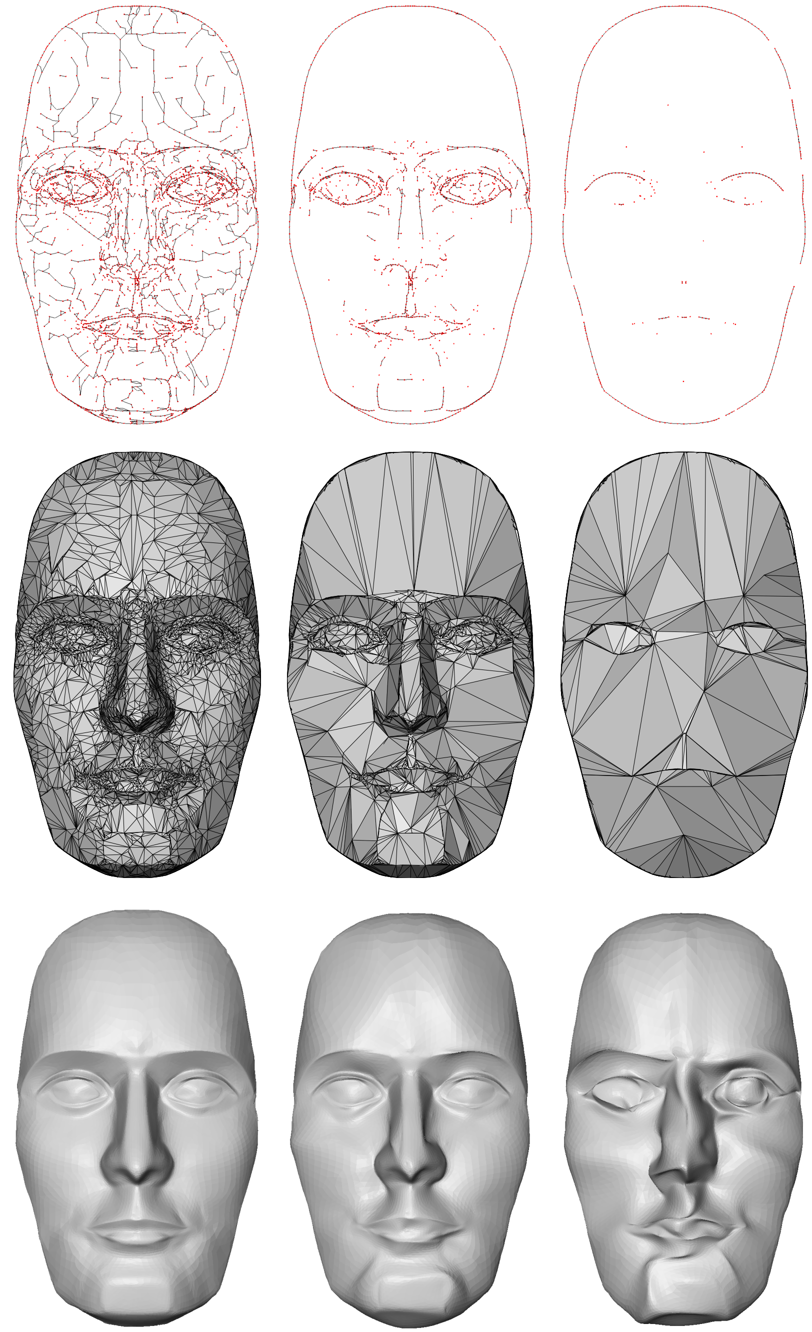


⇒ network of extreme ridges

⇒ external skeleton

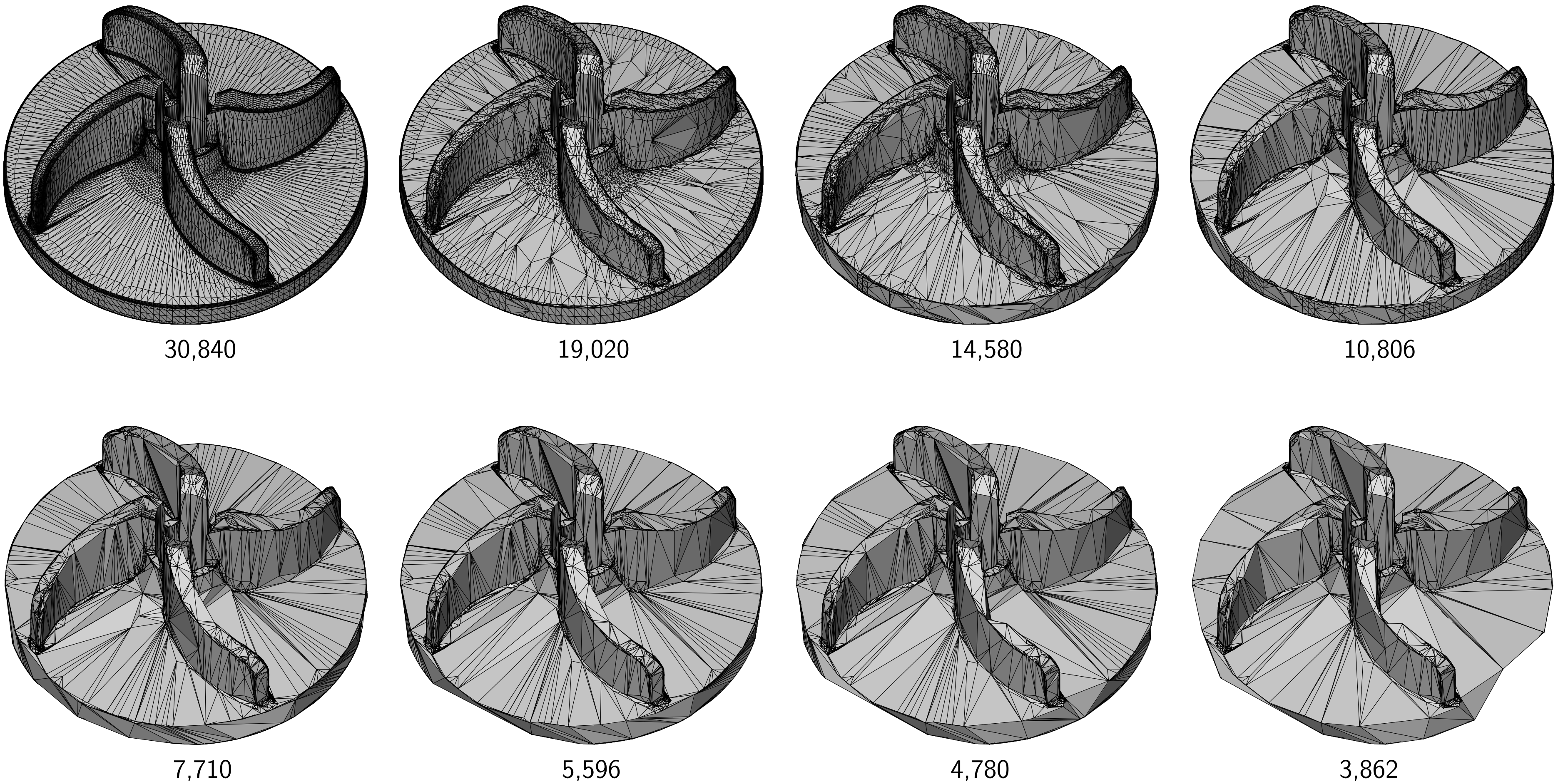
External Skeleton

- multi-scale
  - pruning external skeleton
  - pruning unrestricted local maxima
  - low-pass filtering of mesh
- resampling
  - edge collapse operation
  - vertex split operation
- reconstruction
  - topology preservation
  - establishing location by relaxation



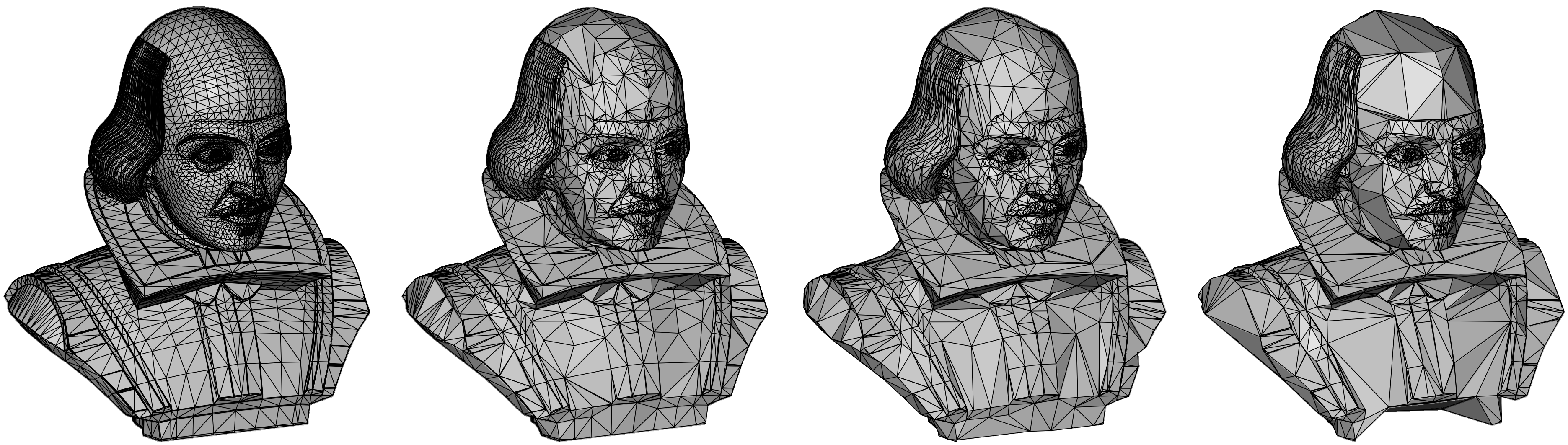
External Skeleton: Applications

- mesh decimation & progressive meshes



External Skeleton: Applications

- network transfer



20,247 7,867 6,325 5,355

Overview

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    - Silhouettes
    - Hybrid Hidden Line Removal
    - Applications
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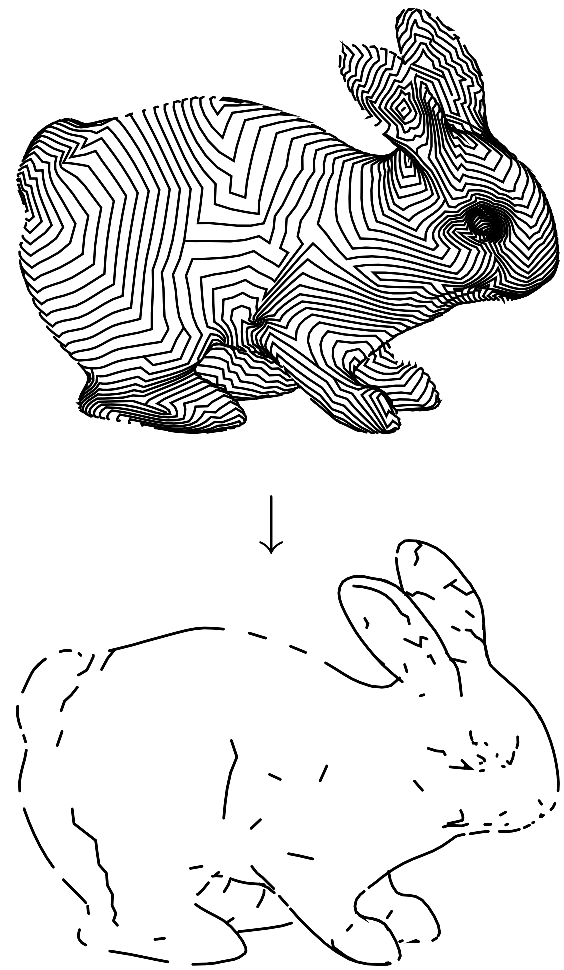
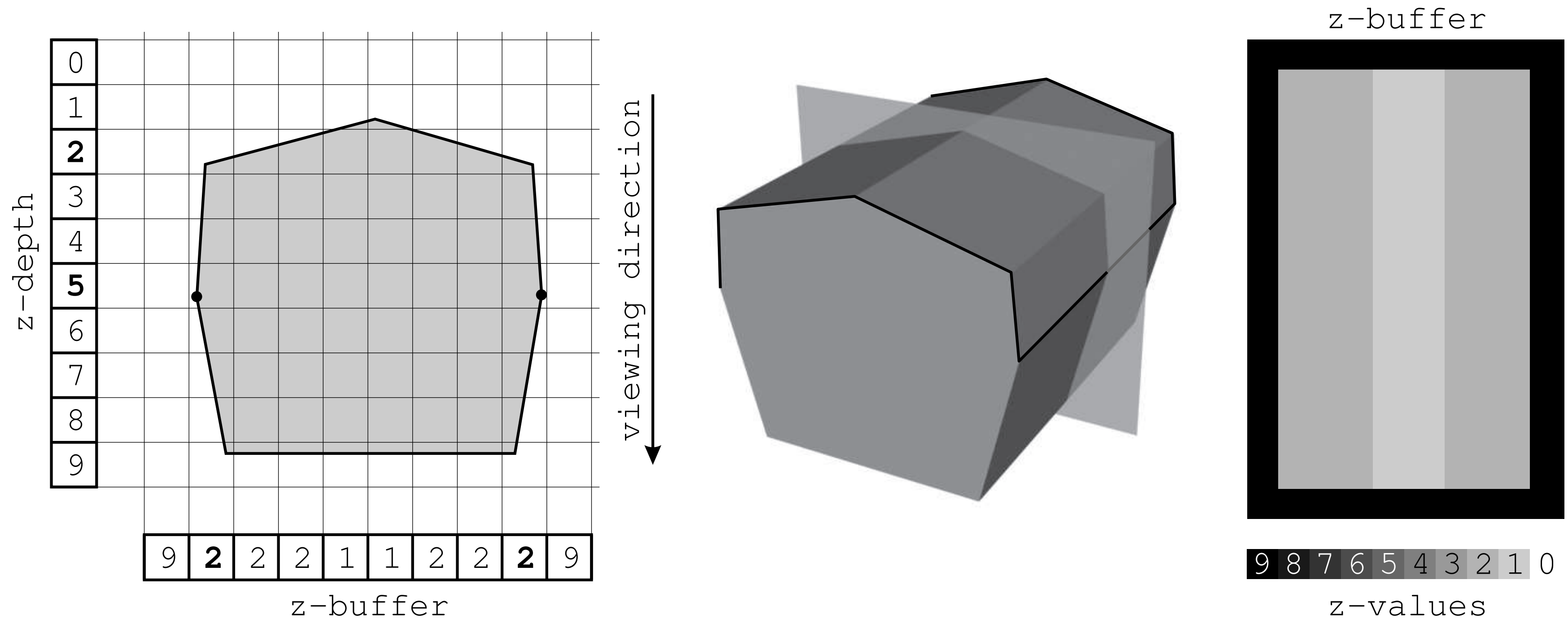
Silhouettes as Essential Shape Representations

- silhouettes very important for shape recognition
- silhouettes as ESRs according to definition
  $DoI(V) := \overrightarrow{n} \cdot \overrightarrow{v}$
- not suitable for silhouette rendering
- two main tasks for
  - silhouette detection
  - hidden line removal

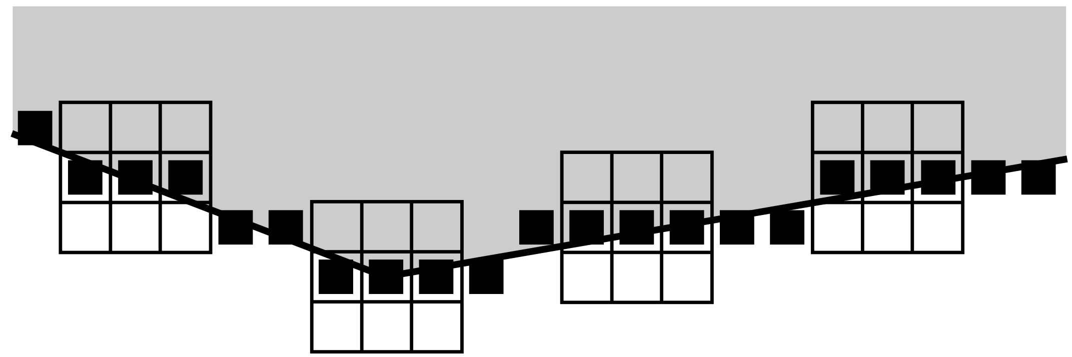


A New Hybrid Approach for HLR

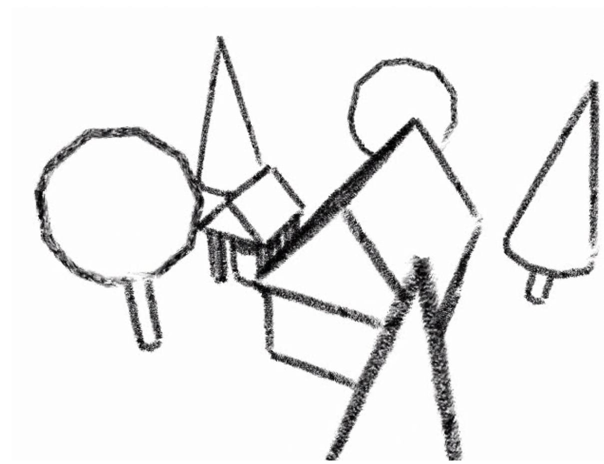
- using occlusion information available in z-buffer
- observations
  - silhouette edges always at discontinuities of z-buffer
  - numerical problem:
    z-buffer value at silhouette pixel often closer to viewer than silhouette



A New Hybrid Approach for HLR



- 8-neighborhood search
  - also z-buffer lookup of 8 neighboring pixels
  - silhouette visible if any pixel farther than silhouette

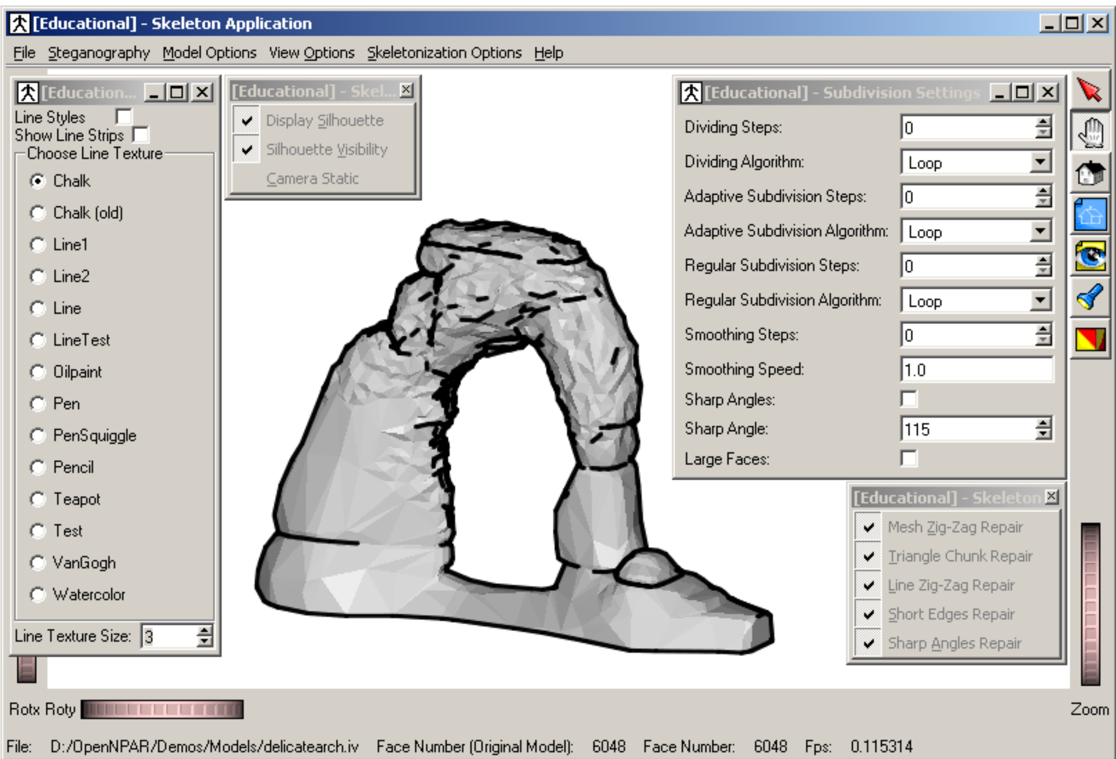


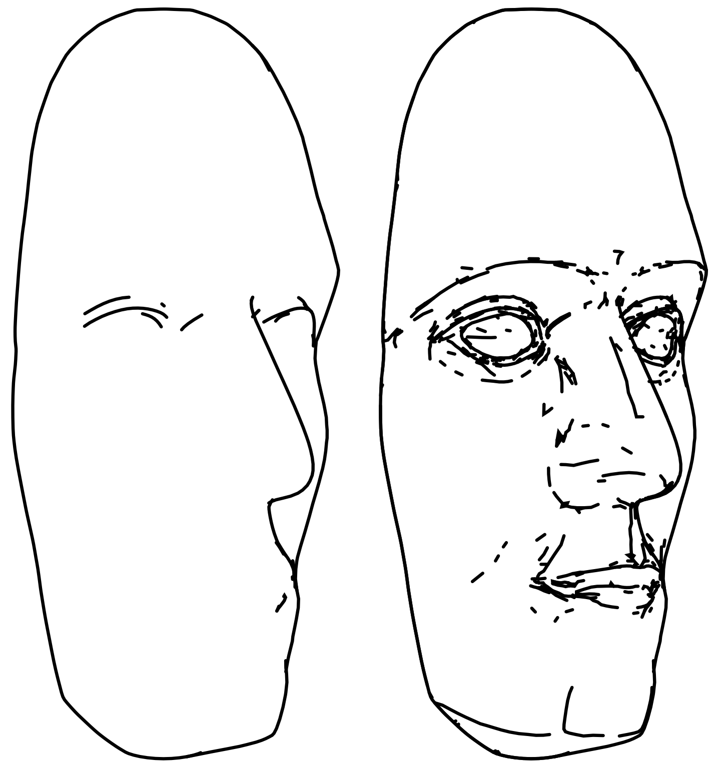
- properties
  - rendering of additional buffers not necessary
  - at most pixel accuracy
  - artifacts neglectable

$\longrightarrow$ preferring speed over accuracy

Application: OpenNPAR

- framework for integration of 3D and 2D ESRs



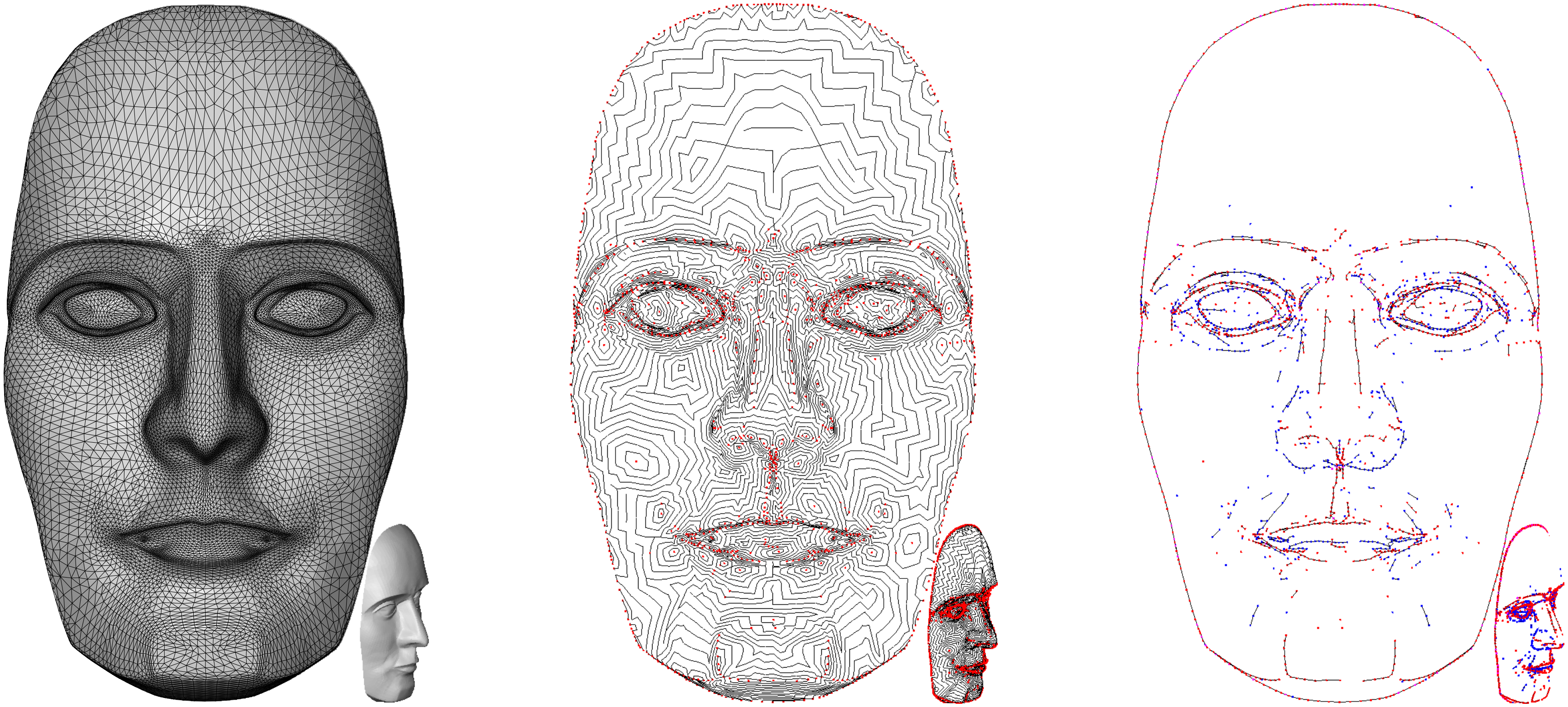


Conclusion

- concept of *essential shape representations*
- specific algorithm based on wave propagation
  to extract *external skeleton*
- flexible notion of importance: *degree of interest functions*
- *silhouettes* as essential shape representation in 2D
- application scenarios

Future Work

- study to evaluate DoI functions
- restriction of balanced tesselation
- combining global and local notions of ESRs
- shape matching based on external skeletons
- hybrid hidden line removal for feature edges



Thank You for Your Attention

Essential Shape Representations

- *essential shape representation* (ESR):

  essential features of a shape according to a certain *ESR criterion*
- specific algorithm: *ESR scheme*
- important requirements
  1. coding and decoding
  2. (lossy and/or lossless) compression
  3. database search by extracted features
  4. multiscale representation
  5. resampling
  6. assessment of geometric properties
  7. editing shape on feature level
  8. animation at feature level
- polygonal model: internal vs. external ESR schemes
- ESR criteria: abstraction of form vs. surface details

Related Work Overview

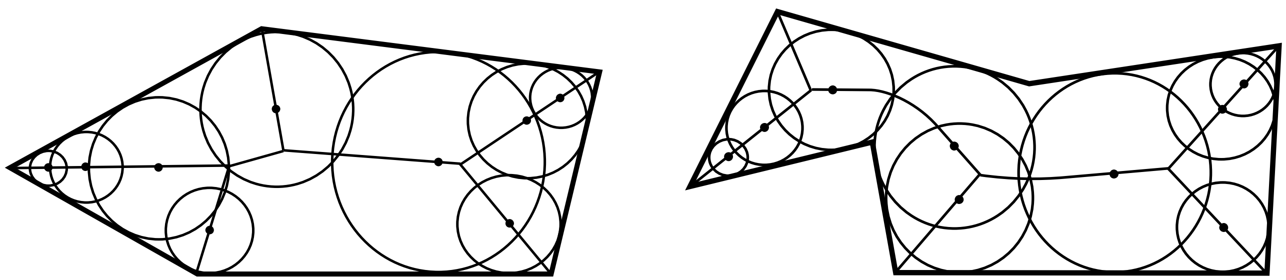
algorithm	applied to 2D/3D	type of shape representation applied to	extracted features	extracted primitives
Voronoi diagram	2D	mathematical concept	internal	curves
	3D			surfaces
medial axis	2D	mathematical concept	internal	curves
	3D			surfaces
Reeb graph	2D/3D	mathematical concept	internal	graph
discrete skeleton extraction	2D	discrete data	internal	pixel
	3D		internal (and external)	voxel or graph
boundary representation feature extraction	3D	boundary representation	internal	graph or surface
			surface	graph or faces

Related Work Overview: B-Reps

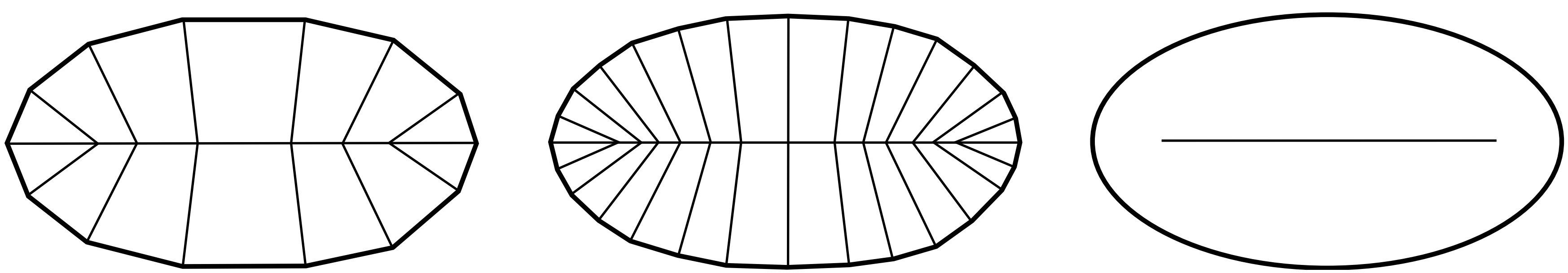
algorithm	internal/ external	result	interaction required	main features captured
Teichmann & Teller (1998)	internal	graph	yes	global
Bloomenthal & Lim (1999)	internal	graph	no	global
Wade & Parent (2000) etc.	internal	graph	no	global
Amenta et al. (1998) etc.	internal	surface	no	global
Raab (1998) etc.	internal	graph	no	global
Ma et al. (2003)	internal	graph	no	global
Verroust & Lazarus (1997)	internal	graph	yes	global
Roessl & Kobbelt (2000)	external	graph	no	local
Watanabe & Belyaev (2001)	external	faces	no	local
Belyaev & Ohtake (2000)	external	faces	no	local
Hisada et al. (2001) etc.	external	graph	no	local
Lee & Lee (2002)	external	graph	yes	local

Medial Axis as ESR

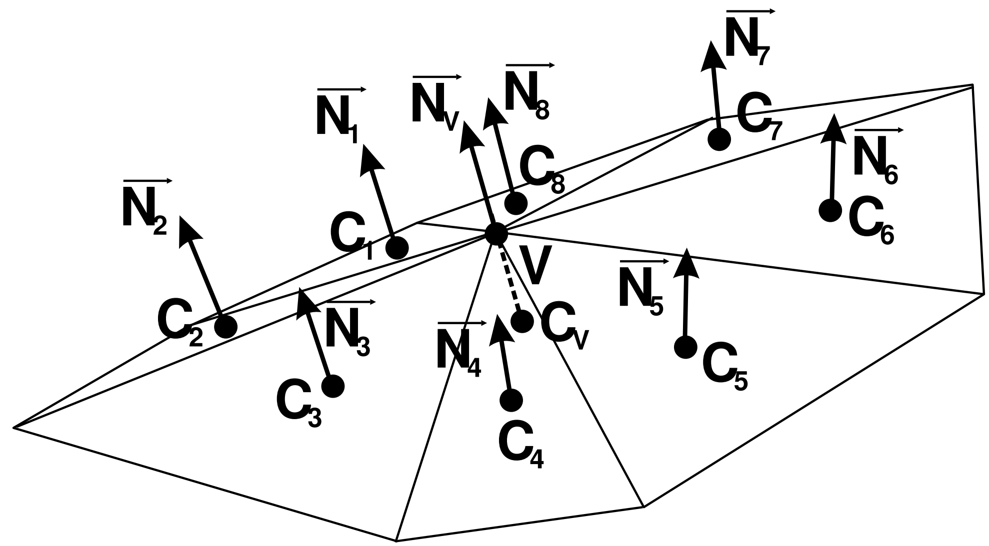
- medial axis of polygons
  - polygonal graph when shape convex
  - contains parabolic curves when shape concave



- observation
  - artifacts in medial axis due to sampling
  - artifacts grow when sampling gets better



Heuristic DoI Function



- centroids

  $C_j = \sum_{i=1}^{n} \frac{V_{ji}}{n} \qquad j \in [1, k]$

- average centroid

  $C_V = \sum_{j=1}^{k} \frac{C_j}{k}$

- normal approximation

  $$\overrightarrow{N_V} = \frac{\sum\limits_{j=1}^{k} \overrightarrow{N_j}}{\left\| \sum\limits_{j=1}^{k} \overrightarrow{N_j} \right\|}$$

- projection of C_V onto this normal

  $\overrightarrow{P} = \overrightarrow{N_V} \left(\overrightarrow{(V, C_V)} \cdot \overrightarrow{N_V} \right)$

- length and direction of $\overrightarrow{P}$ as heuristic DoI function

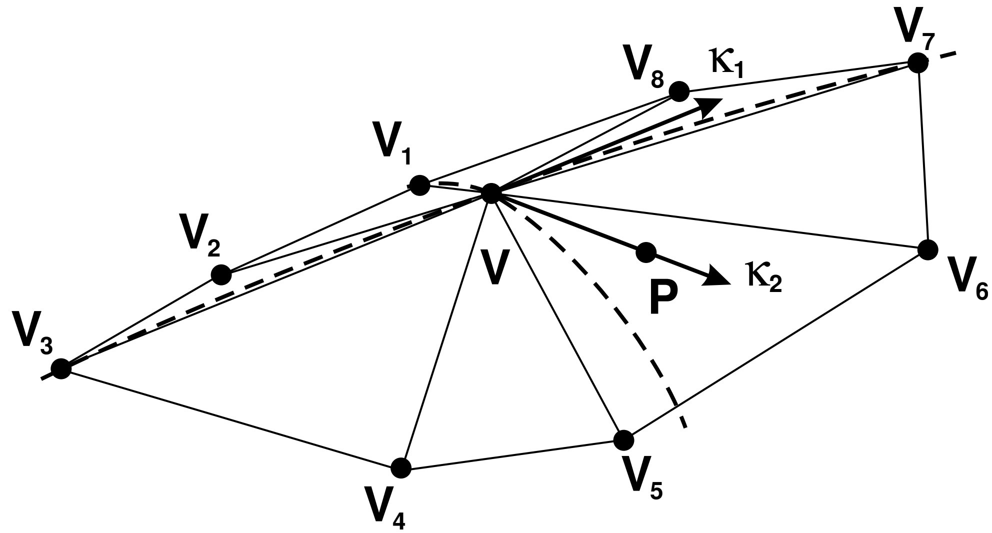
  $\mathrm{DoI}(V) = -(\overrightarrow{N_V} \cdot \overrightarrow{P})$

- weighted approximation

  $$C_V = \frac{\sum\limits_{j=1}^{k} C_j A_{C_j}}{\sum\limits_{j=1}^{k} A_{C_j}}$$

  $$\overrightarrow{N_V} = \frac{\sum\limits_{j=1}^{k} \overrightarrow{N_j} A_{C_j}}{\left\| \sum\limits_{j=1}^{k} \overrightarrow{N_j} A_{C_j} \right\|}$$

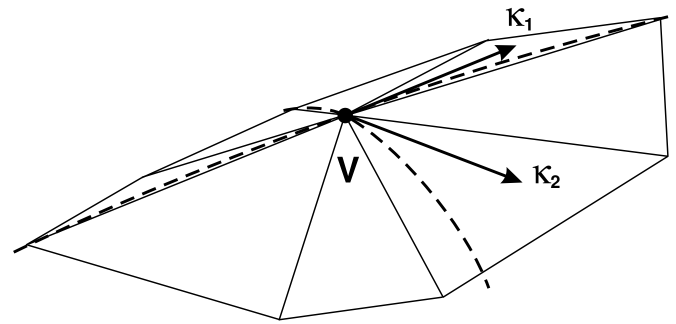
Curvature Computation



- approximation of the principal curvatures κ_1 and κ_2 and their principal directions (Rössl, 1999),
  local approximation trough biquadratic Taylor polynomial
- interpolation of κ_1 and κ_2 at point P with position p using the k neighbor vertices (Shephard, 1968):

$$\kappa_i = \frac{\sum_j \frac{\kappa_{ij}}{\left|p-p_j\right|^2}}{\sum_j \frac{1}{\left|p-p_j\right|^2}} \qquad i \in \{1;2\}$$

Curvature Approximation I



- according to Rössl (1999)
- local parameterization
  $\rightarrow u_i$ and v_i for V's n direct neighbors:

  $F(u_i, v_i) = Q_i \quad (1 \leq i \leq n)$
- biquadratic Taylor polynomial using first and second partial derivatives:

  $F(u, v) = uF_u + vF_v + \frac{u^2}{2}F_{uu} + uvF_{uv} + \frac{v^2}{2}F_{vv}$
- linear system $\mathbf{VF} = \mathbf{Q}$:

  $\mathbf{V} = (u_i, v_i, \frac{u_i^2}{2}, u_i v_i, \frac{v_i^2}{2})_i$, $\mathbf{F} = (F_u, F_v, F_{uu}, F_{uv}, F_{vv})^\top$, and $\mathbf{Q} = (Q_i)_i^\top$
- solving:

$$\mathbf{F} = \begin{cases} \mathbf{V}^\top(\mathbf{V}\mathbf{V}^\top)^{-1}\mathbf{Q} & : \quad n < 5 \\ \mathbf{V}^{-1}\mathbf{Q} & : \quad n = 5 \\ (\mathbf{V}^\top\mathbf{V})^{-1}\mathbf{V}^\top\mathbf{Q} & : \quad n > 5 \end{cases}$$

Curvature Approximation II

- κ as a function of a direction λ with $\lambda = \frac{dv}{du} = \tan\alpha$:

  $\kappa(\lambda) = \frac{F_{uu}N + 2F_{uv}N\lambda + F_{vv}N\lambda^2}{F_uF_u + 2F_uF_v\lambda + F_vF_v\lambda^2}$

- principal curvatures as real solutions of:

$$det \begin{vmatrix} \lambda^2 & -\lambda & 1 \\ F_uF_u & F_uF_v & F_vF_v \\ F_{uu}N & F_{uv}N & F_{vv}N \end{vmatrix} = 0$$

- two solutions $\lambda_{1,2} \in \mathbb{R}$ of the equation

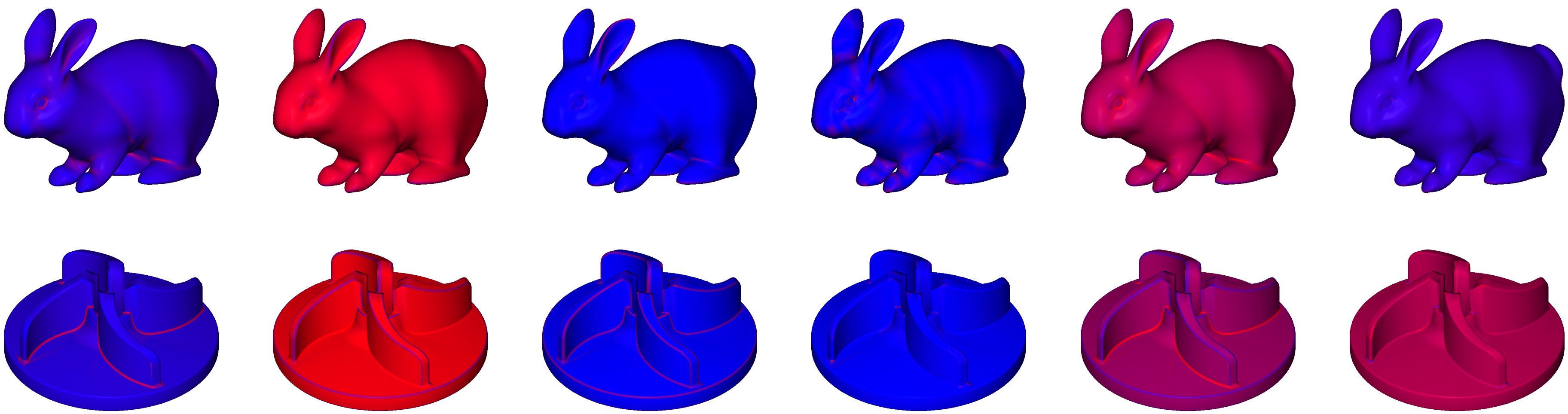
$$\begin{aligned} 0 = \; & \lambda^2 \quad (F_uF_v\, F_{vv}N - F_vF_v\, F_{uv}N) + \\ & \lambda \quad (F_uF_u\, F_{vv}N - F_vF_v\, F_{uu}N) + \\ & 1 \quad (F_uF_u\, F_{uv}N - F_uF_v\, F_{uu}N) \end{aligned}$$

- principal directions:

$$\begin{aligned} \overrightarrow{v(\alpha)} &= \frac{\cos\alpha\, F_u + \sin\alpha\, F_v}{\|\cos\alpha\, F_u + \sin\alpha\, F_v\|} \\ &= \frac{F_u + \tan\alpha\, F_v}{\|F_u + \tan\alpha\, F_v\|} \\ \overrightarrow{v_{1,2}} &= \frac{F_u + \lambda_{1,2}F_v}{\|F_u + \lambda_{1,2}F_v\|} \end{aligned}$$

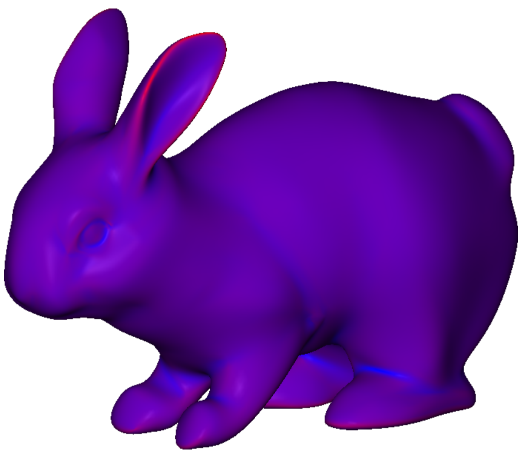
Simple Curvature-Based DoI Functions

$$\mathrm{DoI}(V) =$$

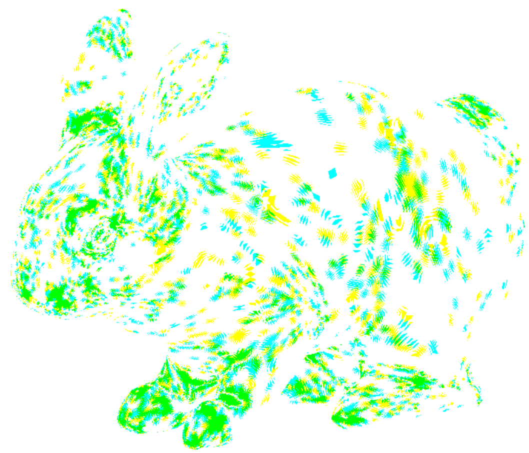


Comparison Fold Indices

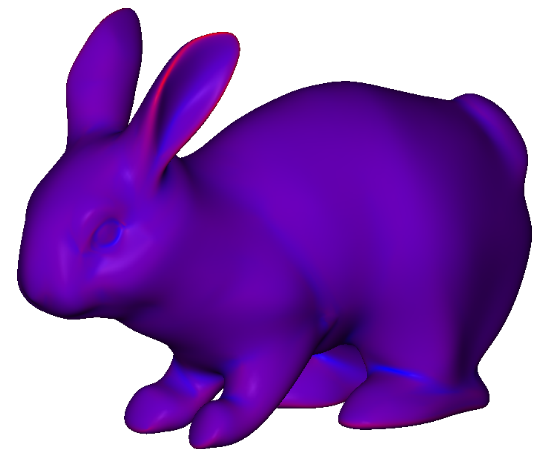
scaled modified shape index fold index (f_1)

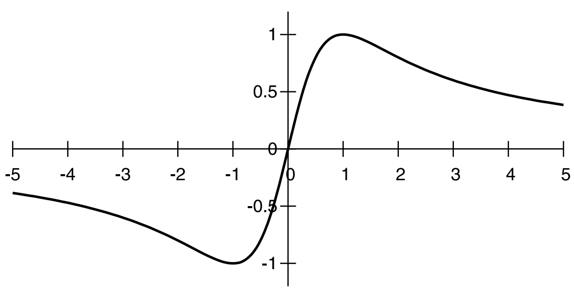


scaled difference image

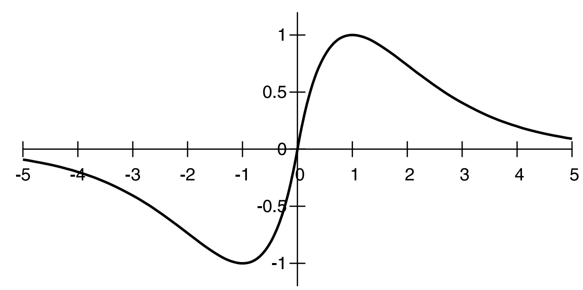


fold index (f_2)





$$\mathrm{DoI}(V) = (\kappa_1 - \kappa_2)\, f\,(\mathcal{K})$$



$$f_1(\mathcal{K}) = \frac{2\mathcal{K}}{1+\mathcal{K}^2}$$

$$\mathcal{K} = \left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)$$

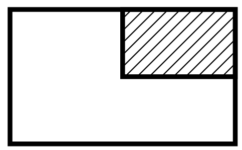
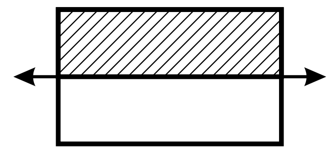
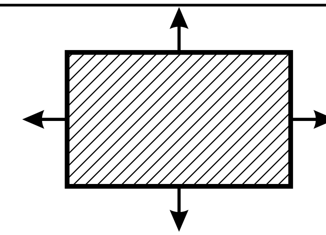
$$f_2(\mathcal{K}) = \mathcal{K}\, e^{(1-|\mathcal{K}|)}$$

$$\mathrm{DoI}(V) = (\kappa_1 - \kappa_2)\frac{2\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)}{1+\left(\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right)^2}$$

$$(\kappa_1 \geq \kappa_2)$$

$$\mathrm{DoI}(V) = -(\kappa_1 + \kappa_2)\, e^{\left(1-\left|\frac{\kappa_2+\kappa_1}{\kappa_2-\kappa_1}\right|\right)}$$

Singularity Index

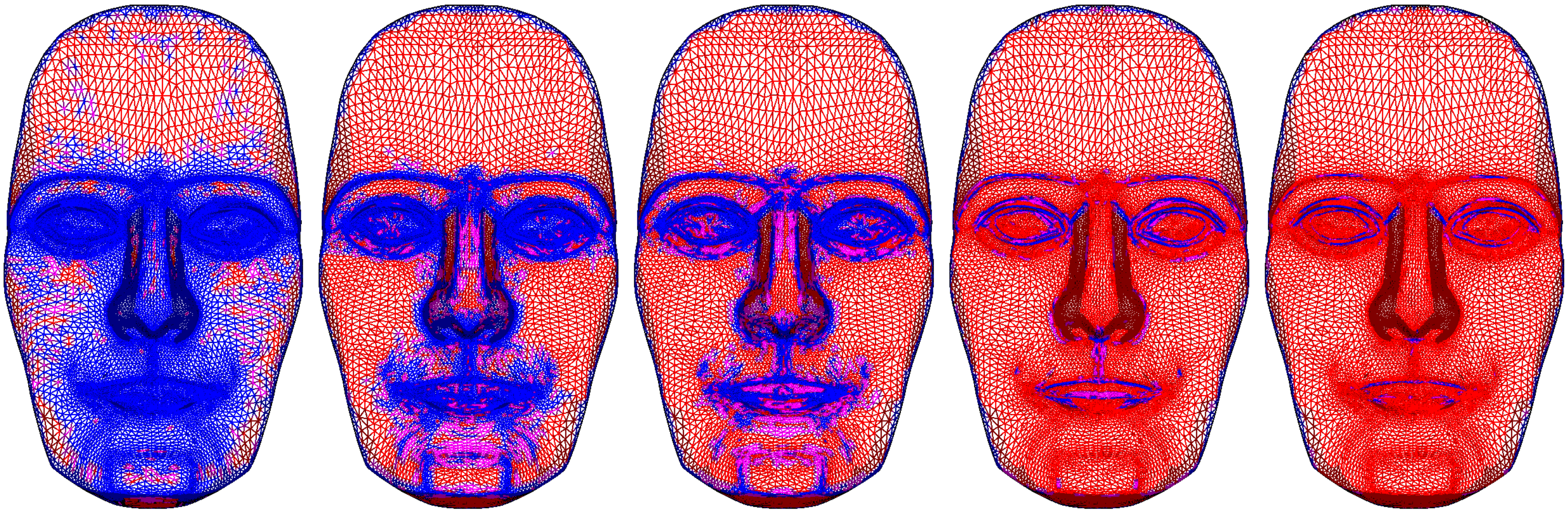
window metaphor			
singularity	0	1	2
$\Delta\kappa_{1,2}(V)$	$\Delta\kappa_{1,2} \geq t$	$\Delta\kappa_i \geq t$; $\Delta\kappa_j < t$	$\Delta\kappa_{1,2} < t$
primitive	point	line	surface

- postulation: singularity degrees of 0 and 1 are interesting

$\Rightarrow$ $\mathrm{DoI}(V) = t_{\mathrm{S2}\rightarrow\mathrm{S1}}$: t where singularity degree changes from 2 to 1

$\Rightarrow$ $\mathrm{DoI}(V) = \max(\Delta\kappa_1(V), \Delta\kappa_2(V))$

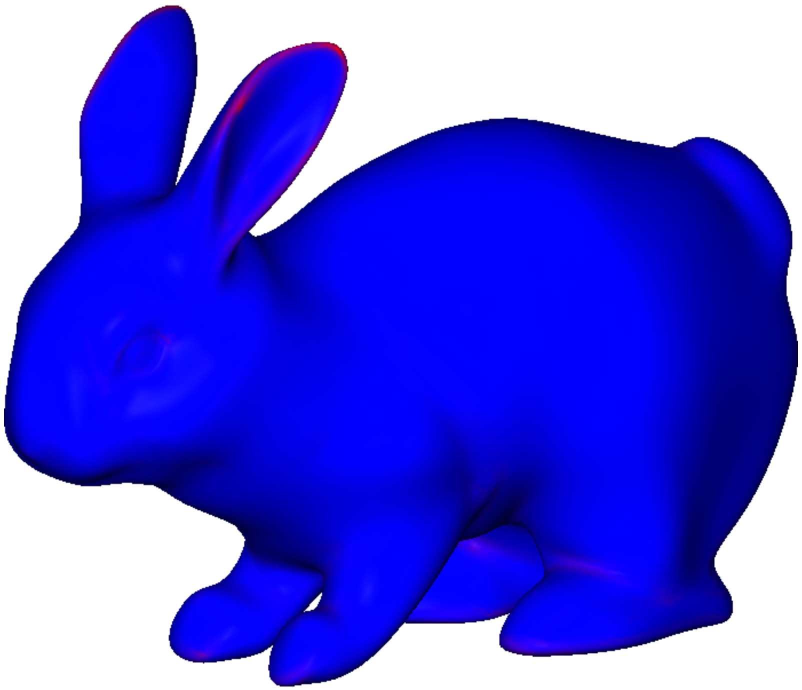
Singularity Index: Singularity Regions

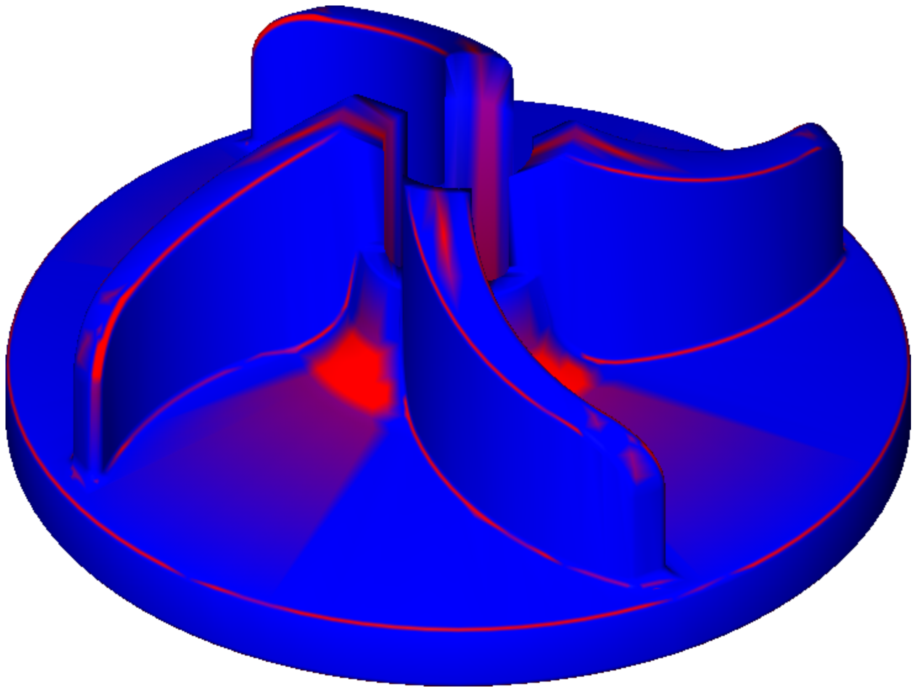


$t = 0.1$ $t = 0.5$ $t = 1.0$ $t = 5.0$ $t = 10.0$

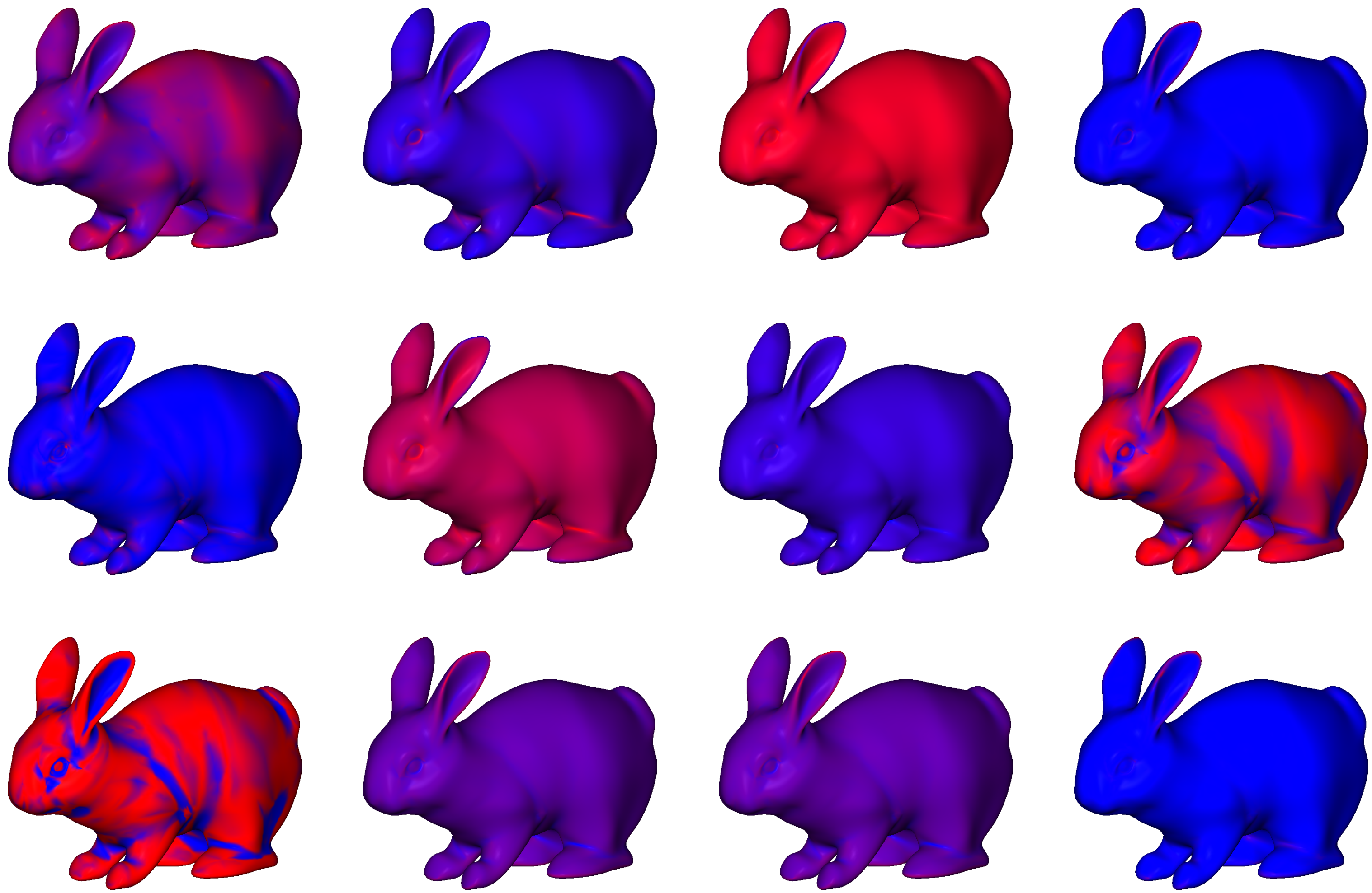
singularity 0 singularity 1 singularity 2

Singularity Index: Examples





Comparison DoI Functions I



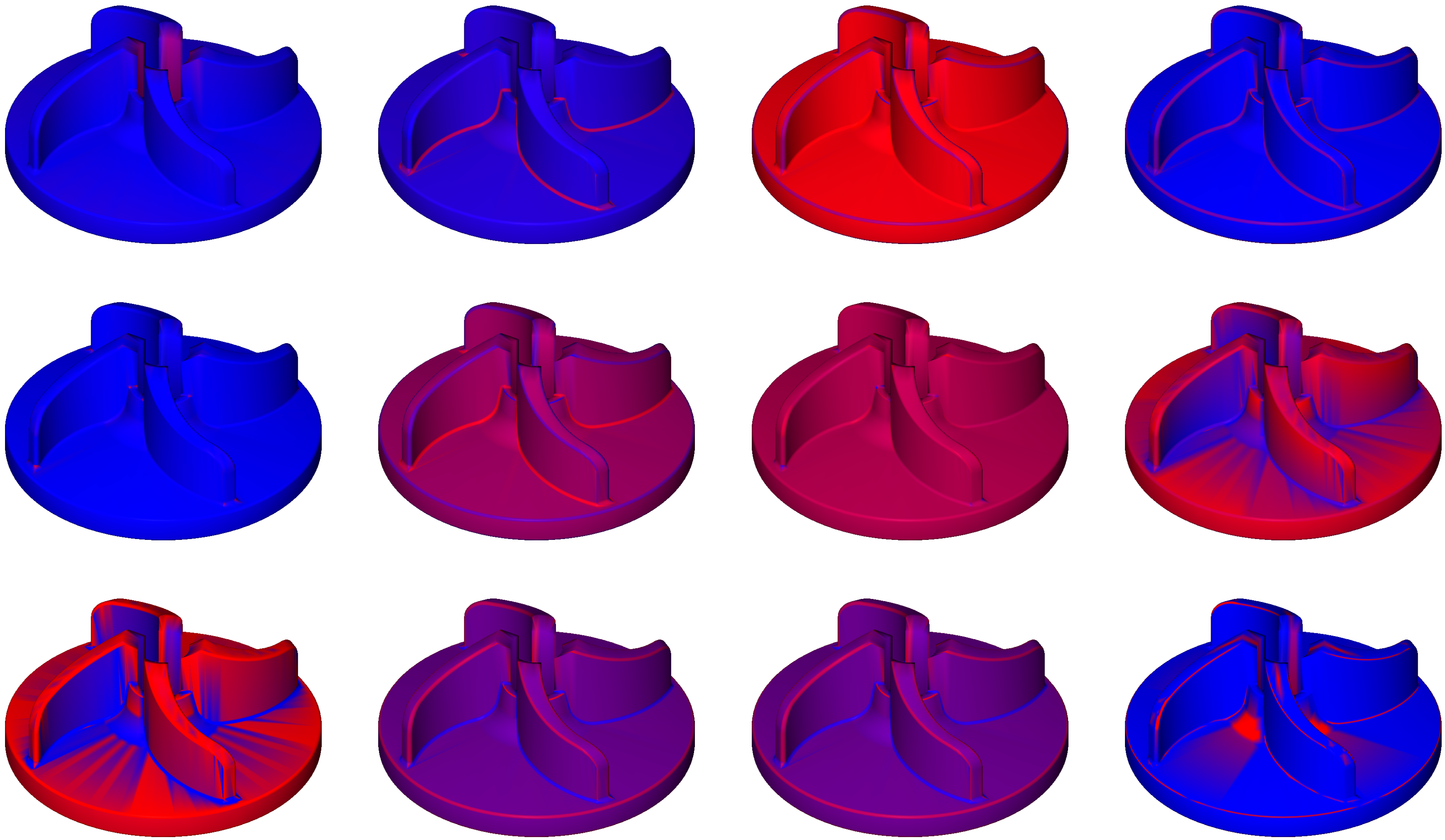
heuristic
minimal absolute curvature
modified shape index

κ_1
average curvature
fold index, f_1

κ_2
Gaussian curvature
fold index, f_2

maximal absolute curvature
shape index
singularity index

Comparison DoI Functions II



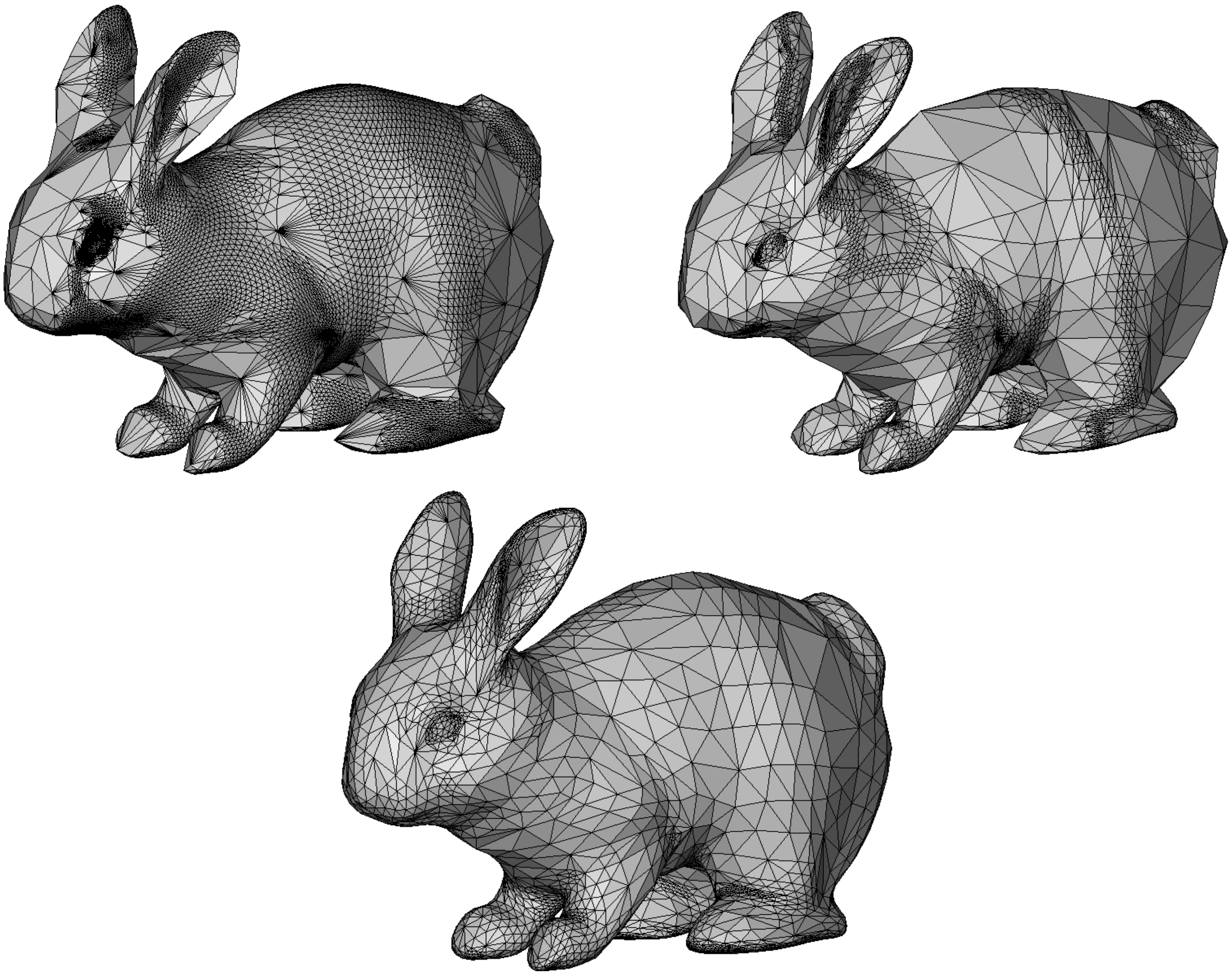
heuristic
minimal absolute curvature
modified shape index

κ_1
average curvature
fold index, f_1

κ_2
Gaussian curvature
fold index, f_2

maximal absolute curvature
shape index
singularity index

DoI Functions for Adaptive Subdivision



Requirements for Wave Propagation

- approximately circular waves so that
  wavefronts are perpendicular to extreme ridges

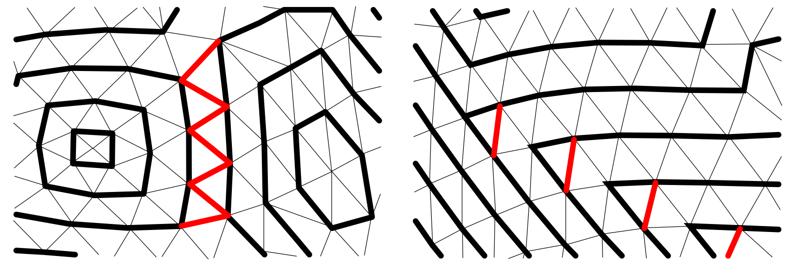
⇒ approximately constant wave propagation velocity

⇒ balanced tessellation necessary

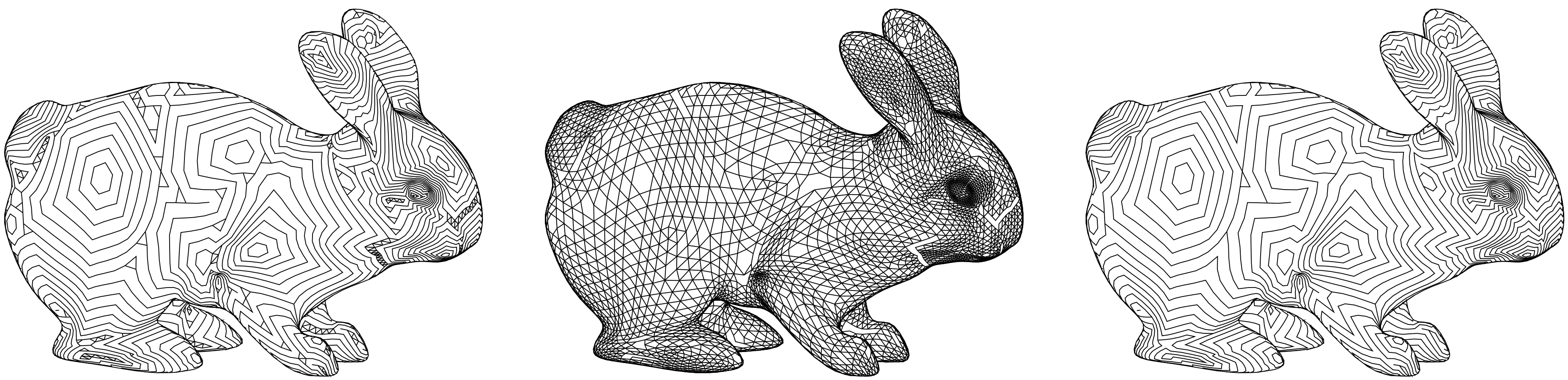
- potentially growing error with age of wavefront

⇒ many wavefront initiators

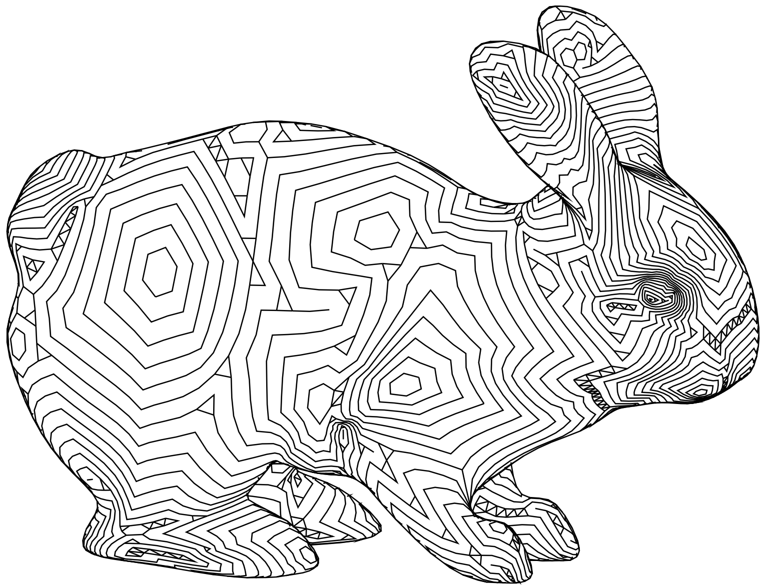
Wavefront Regularization

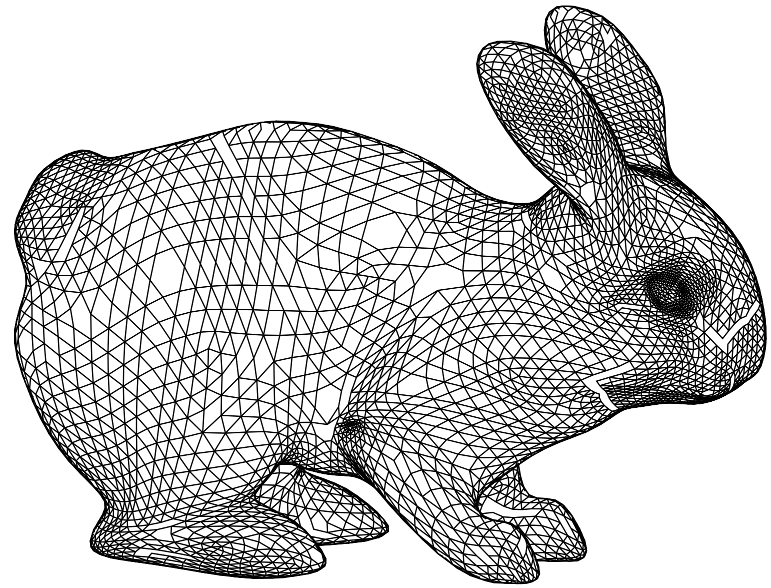


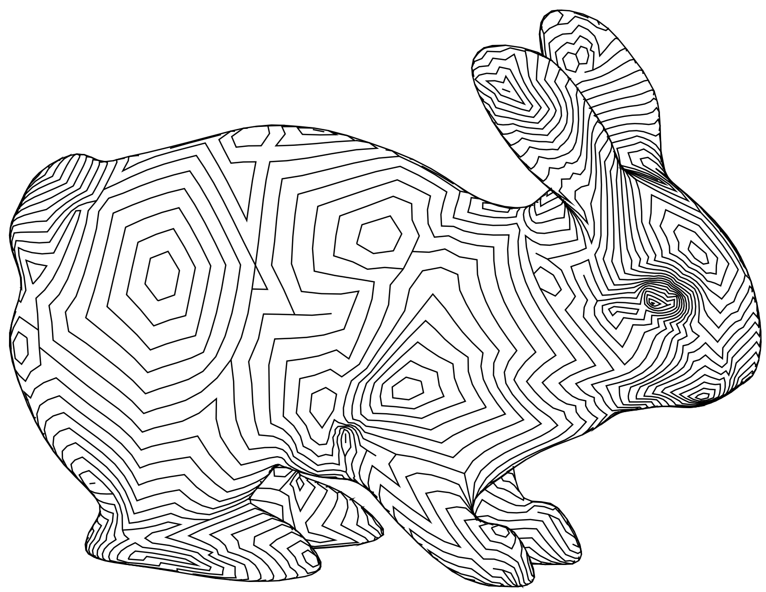
- erroneously marked edges
  → meeting wavefronts
  → merged wavefronts
- correction with regularization edges
  → theoretically possible wavefront edges:
  → direct neighbors of inter-wavefront edges



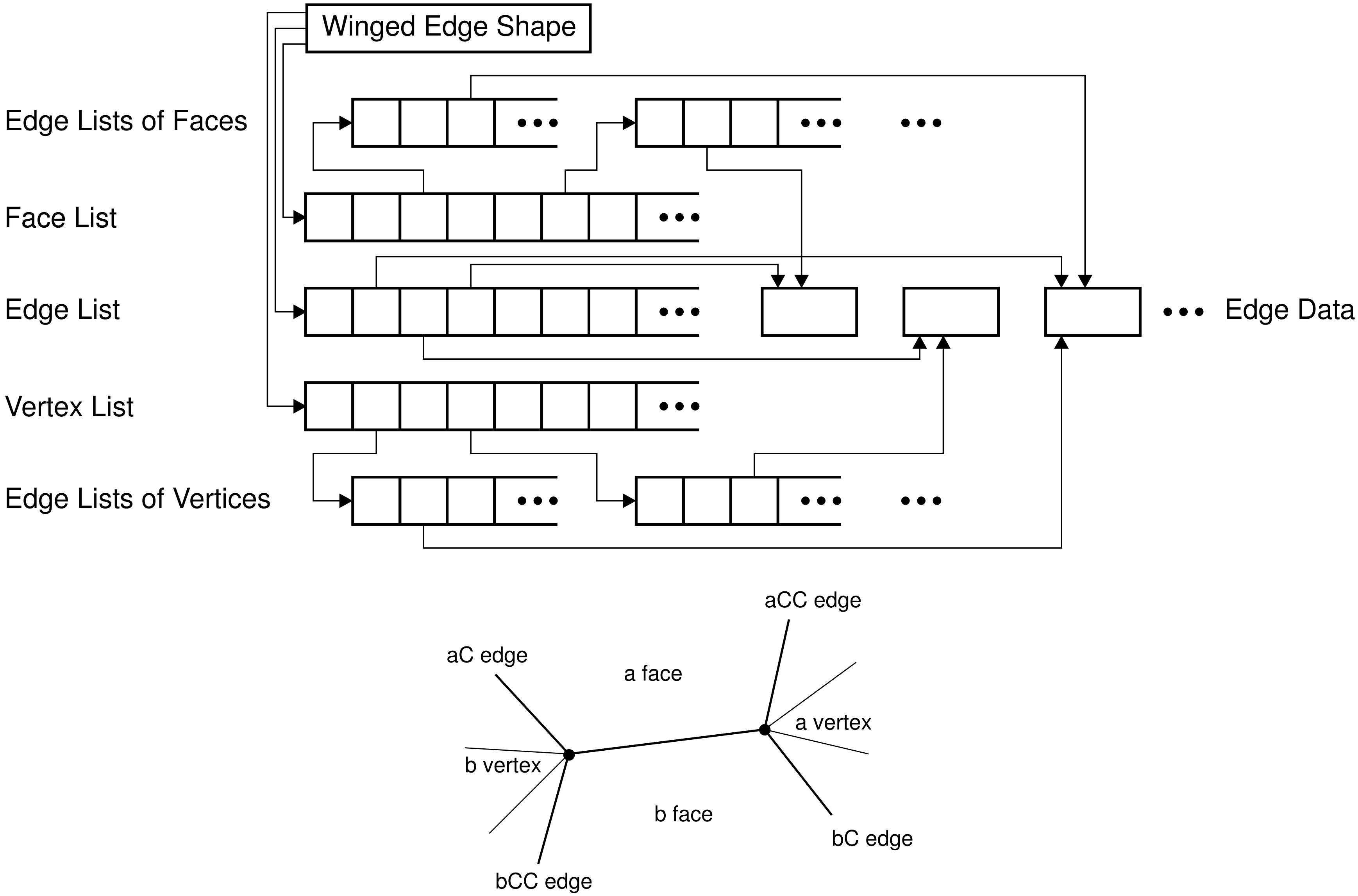
Wavefront Regularization



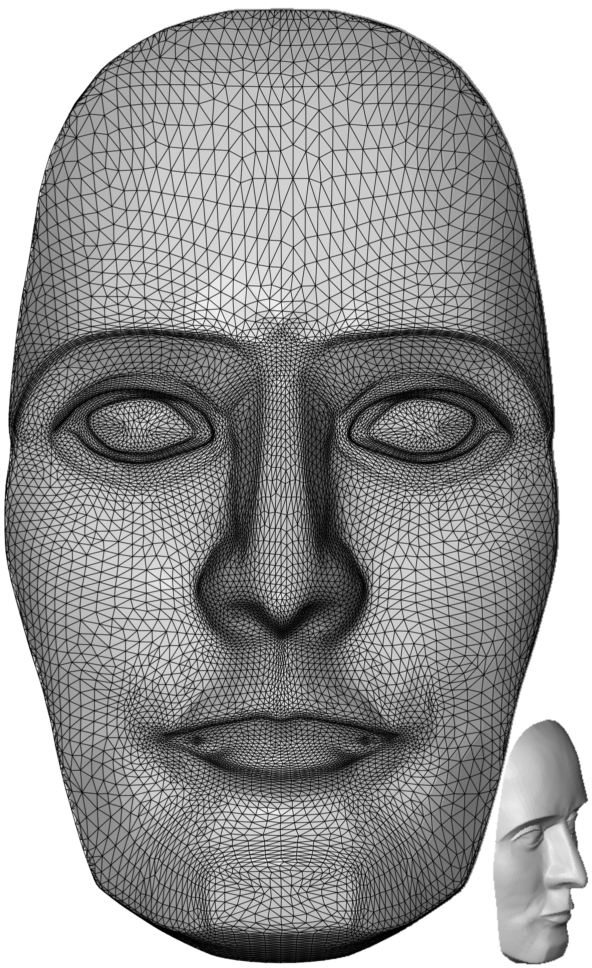




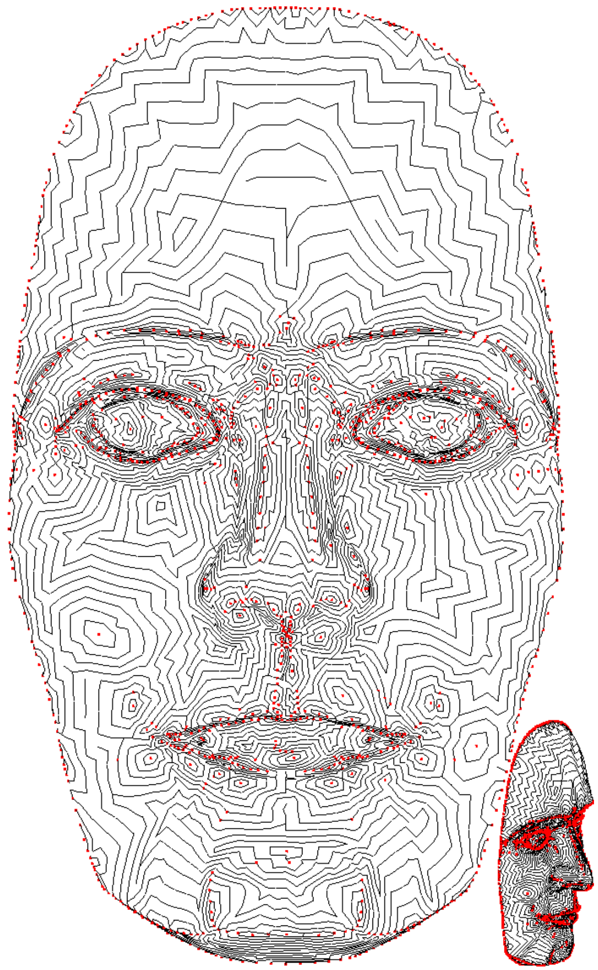
Winged Edge Data Structure



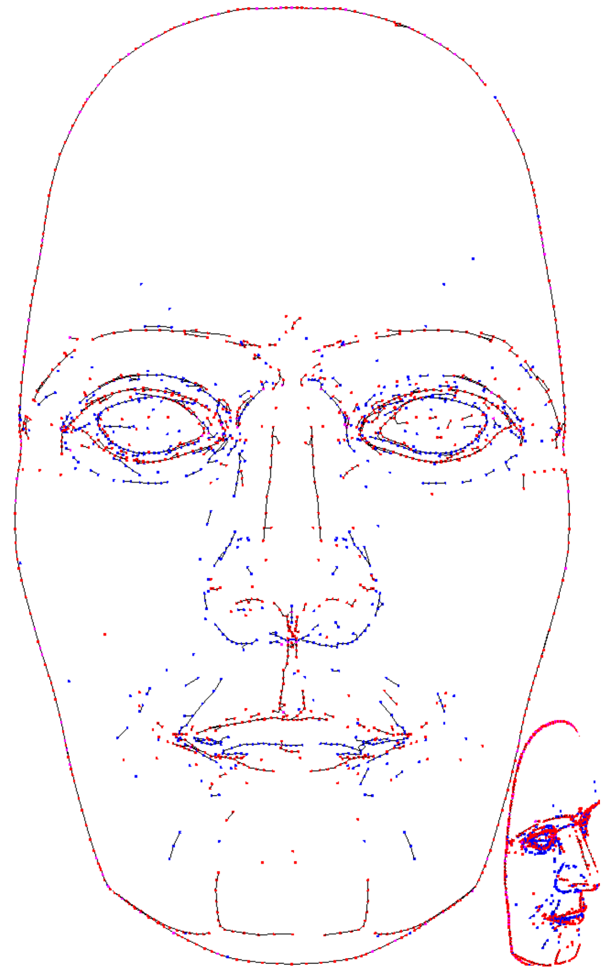
External Skeleton: Multiple Wave Propagation Runs



orginal model



wavefronts, minima of κ_2



external skeleton,
maxima of κ_1 and minima of κ_2

External Skeleton: Scale I

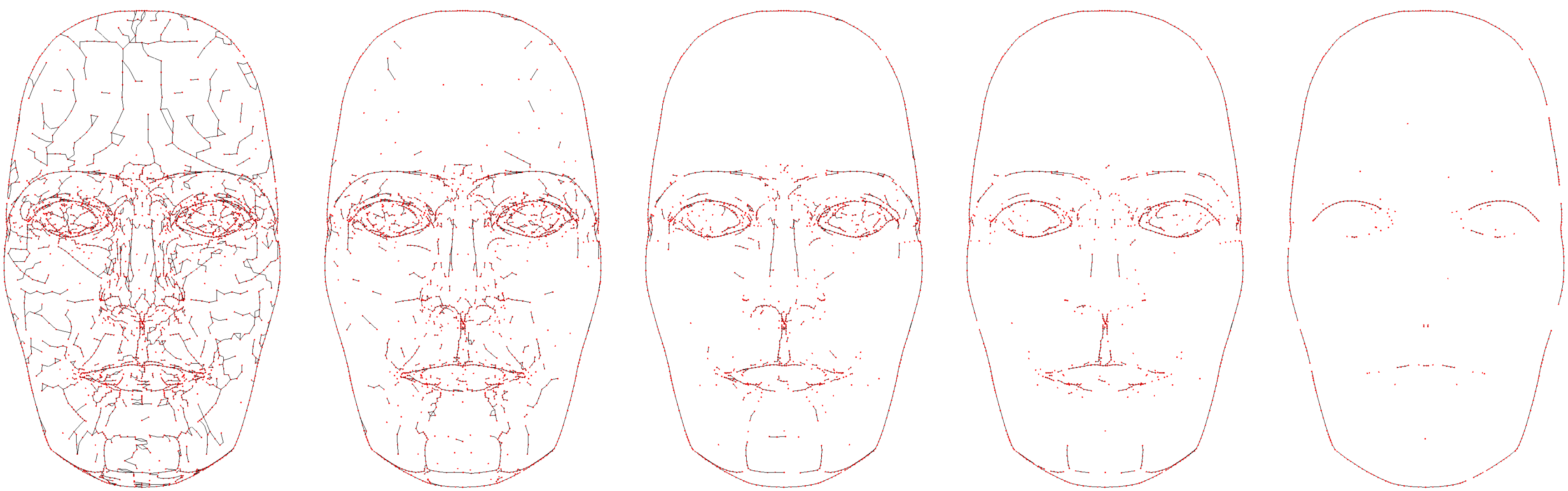
$MS_0 \xrightarrow{\textit{low-pass filter}} MS_1$

$MS_0 \downarrow$ *exhaustive search* LM_0; $MS_1 \downarrow$ *exhaustive search* LM_2

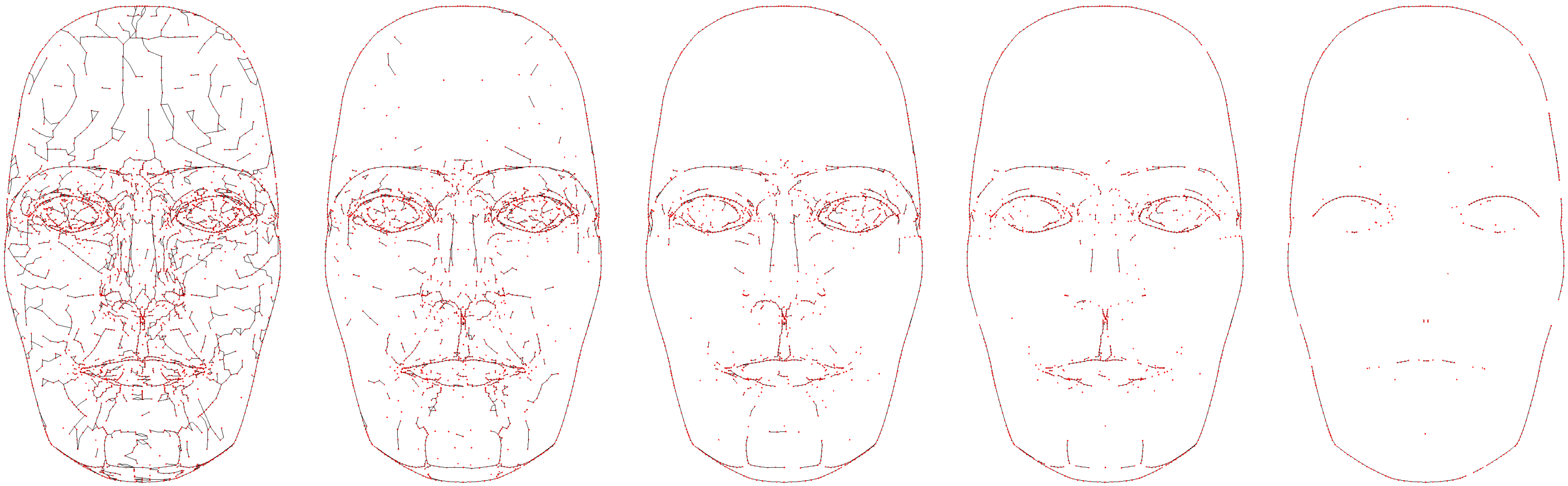
$LM_0 \xrightarrow{\textit{prune}} LM_1$ $\quad LM_2 \xrightarrow{\textit{prune}} LM_3$

$LM_0 \downarrow$ *graph construction* ES_0; $LM_1 \downarrow$ *graph construction* ES_2; $LM_2 \downarrow$ *graph construction* ES_4; $LM_3 \downarrow$ *graph construction* ES_6

$\mathrm{ES}_0 \xrightarrow{\textit{prune}} \mathrm{ES}_1$ $\quad \mathrm{ES}_2 \xrightarrow{\textit{prune}} \mathrm{ES}_3$ $\quad \mathrm{ES}_4 \xrightarrow{\textit{prune}} \mathrm{ES}_5$ $\quad \mathrm{ES}_6 \xrightarrow{\textit{prune}} \mathrm{ES}_7$



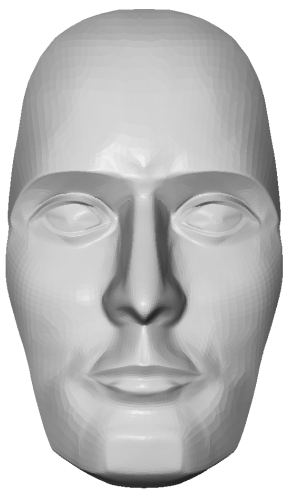
External Skeleton: Scale II

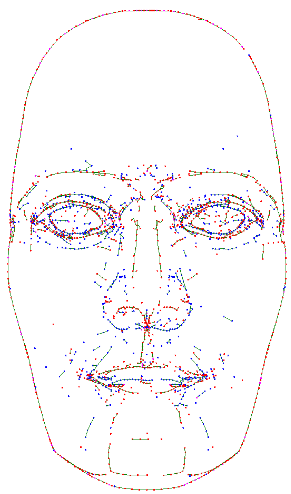


(a) (b) (c) (d) (e)

Model	Original	External Skeletons				
Figure		(a)	(b)	(c)	(d)	(e)
vertices (#)	11,710	2,955	1,967	1,274	938	389
vertices (%)	100	25.2	16.8	10.9	8.0	3.3
edges (#)	35,124	3,402	1,943	1,161	774	339
edges (%)	100	9.7	5.5	3.3	2.2	1.0

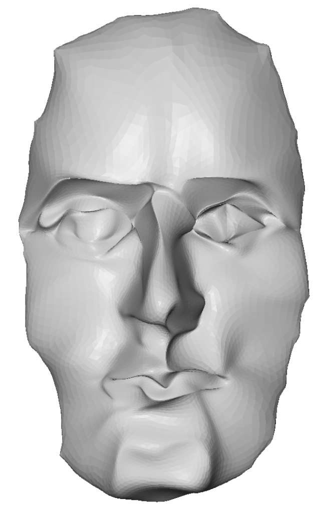
External Skeleton: Reconstruction—Location


original shape

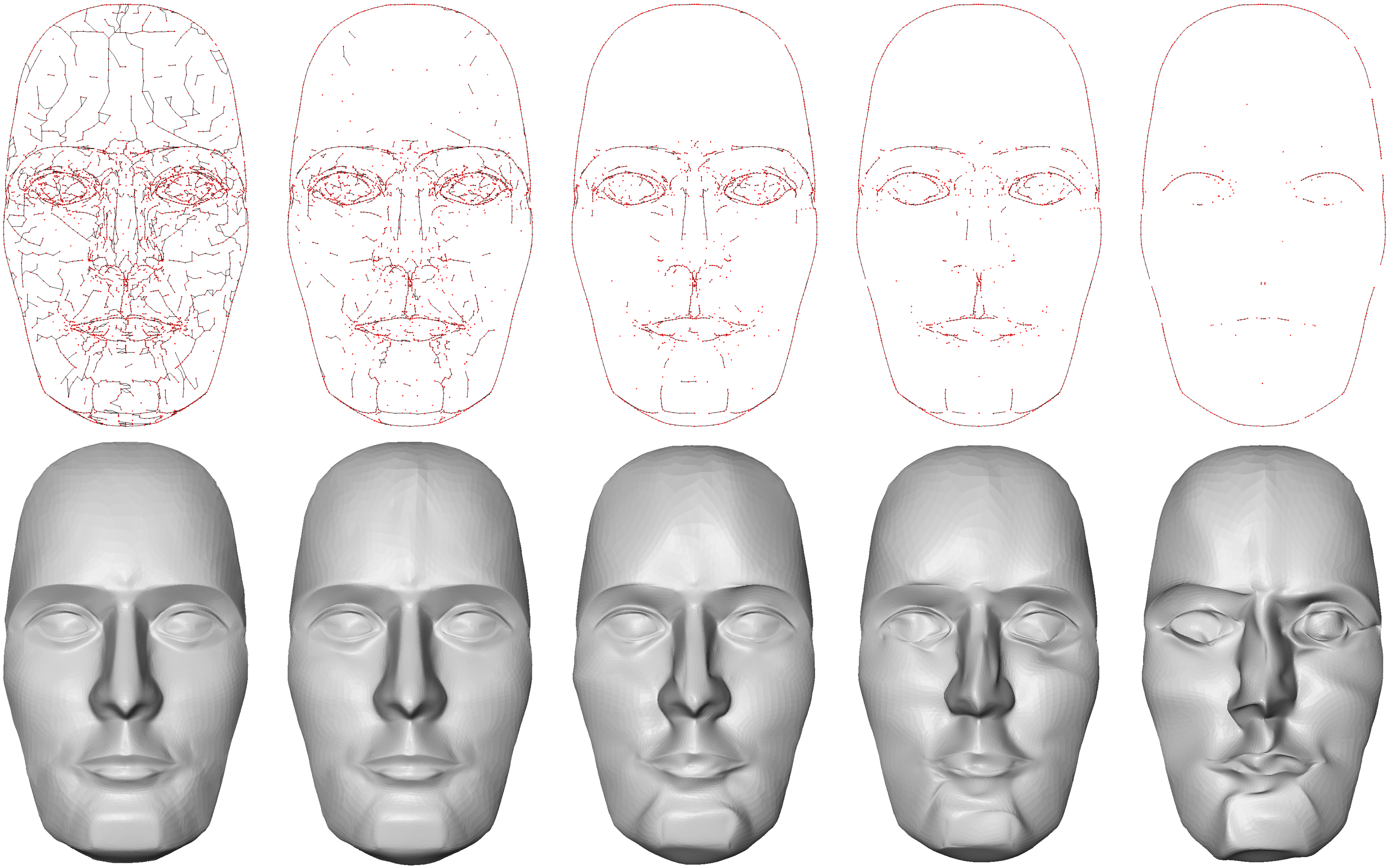

external skeleton


original mesh with noise

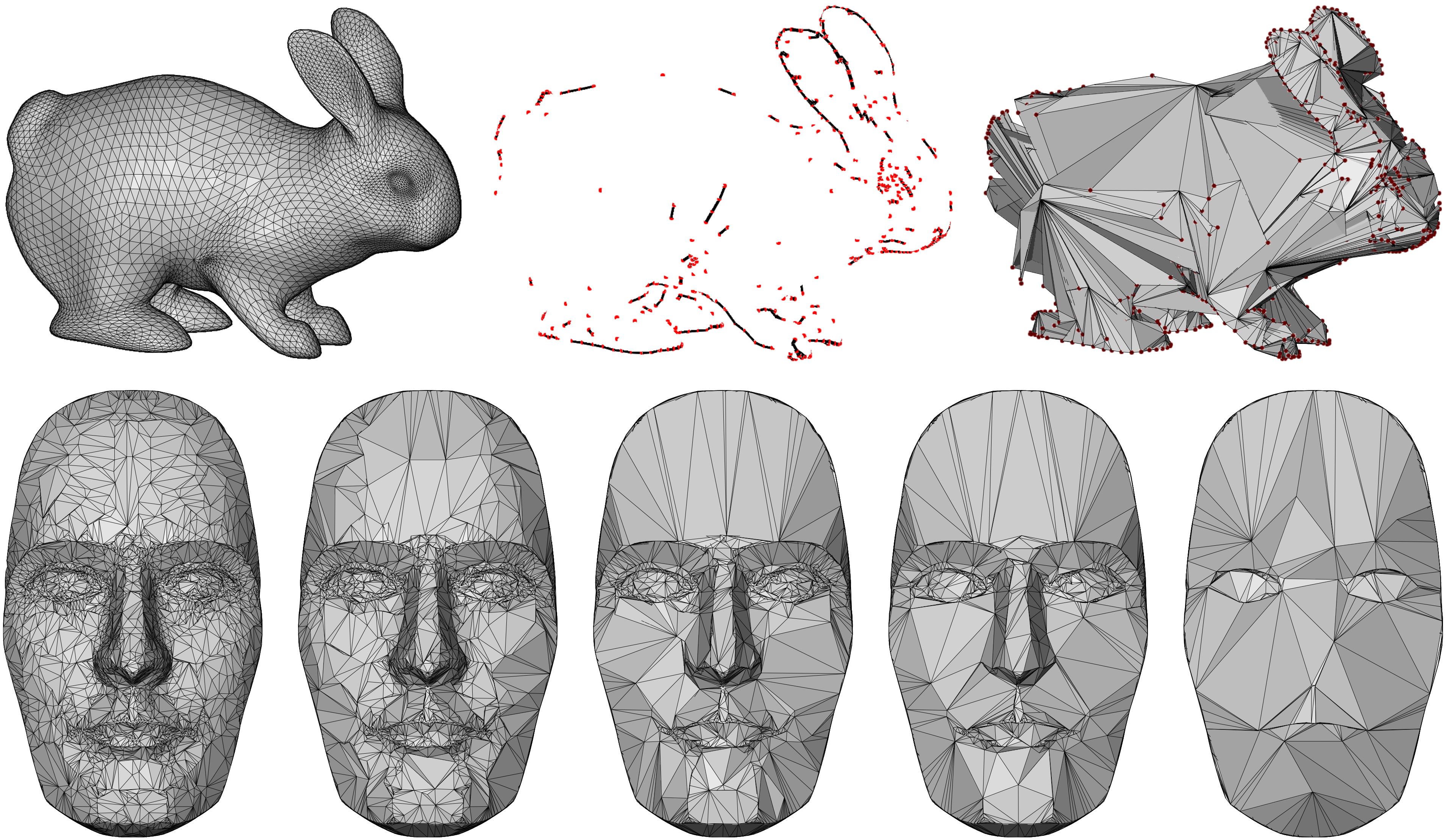

relaxation applied


relaxation without freezing

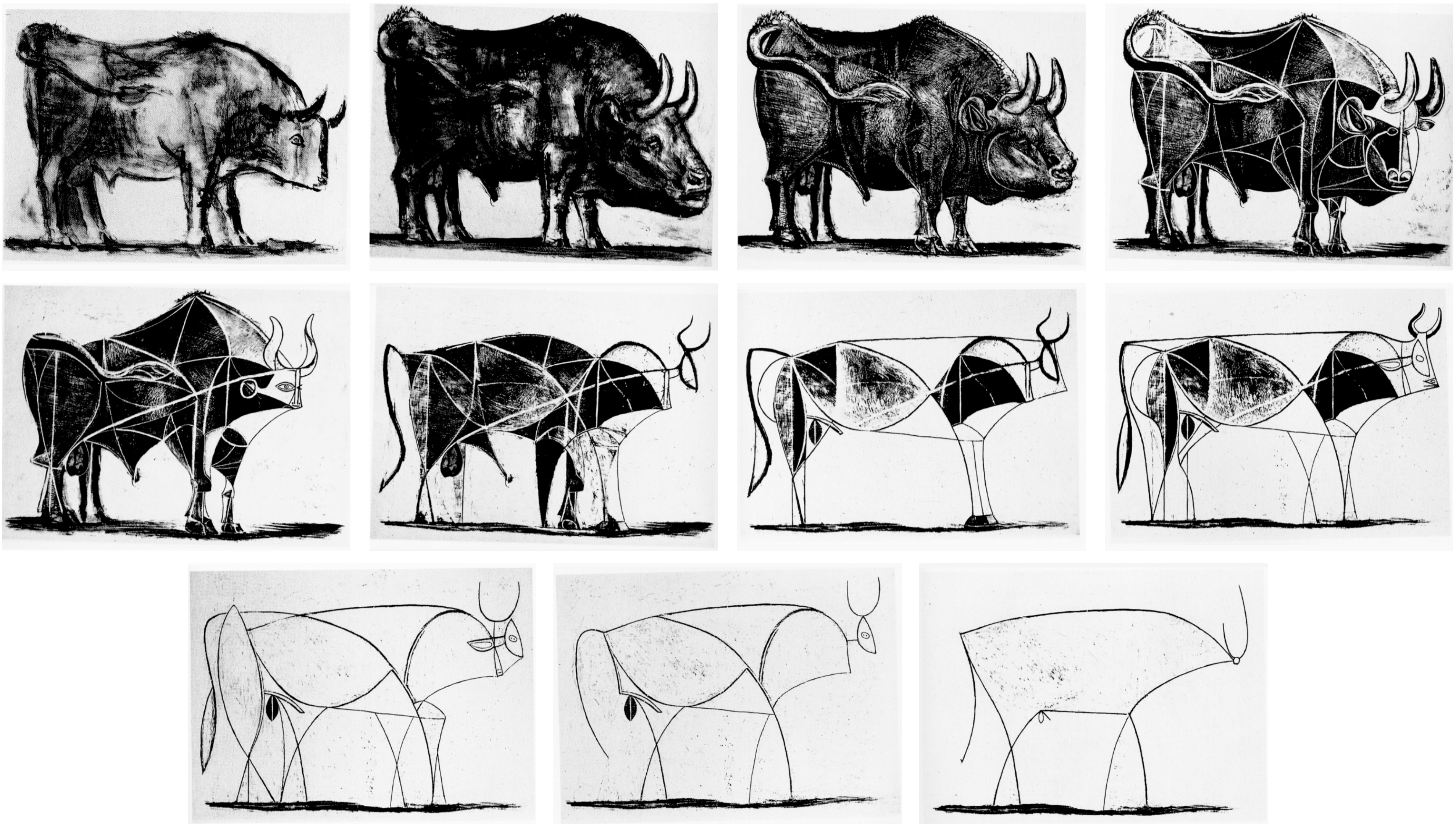
External Skeleton: Reconstruction & Scale



External Skeleton: Reconstruction—Topology

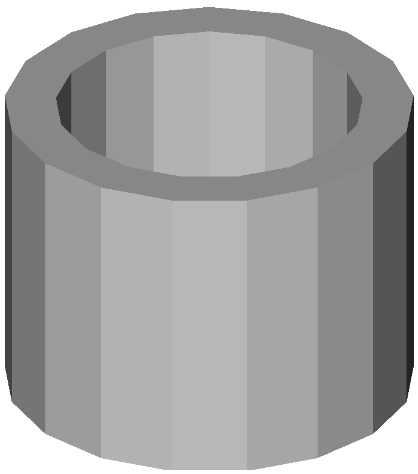


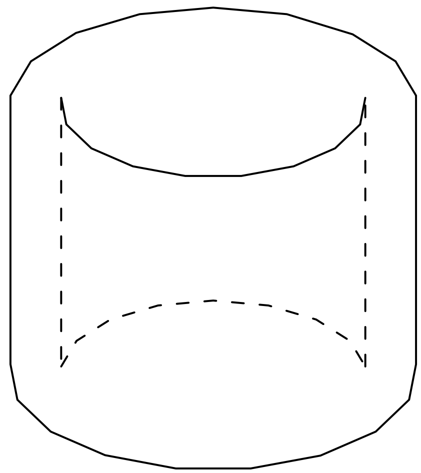
Artistic Example

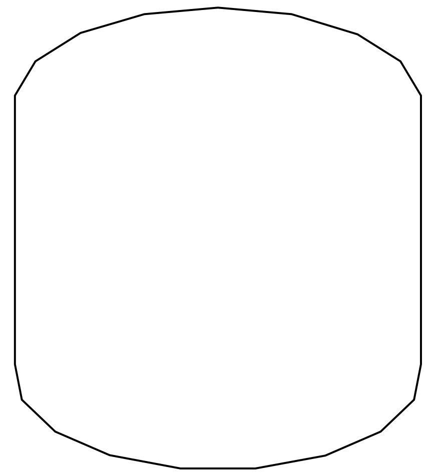


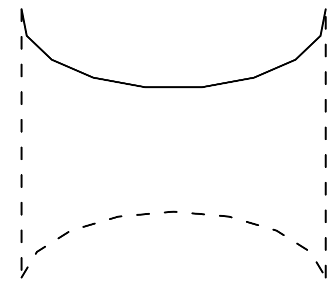
“The Bull,” 1945/46. Lithography series by Picasso. From Lévy (1991).

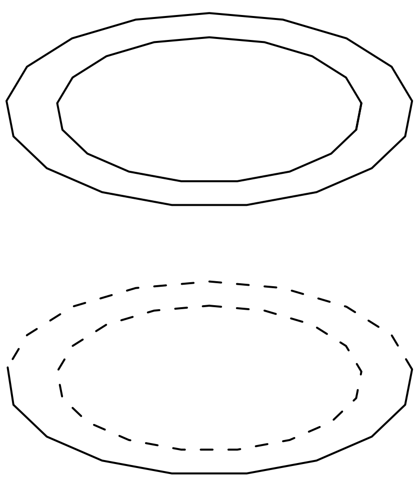
Line Drawings: Terms

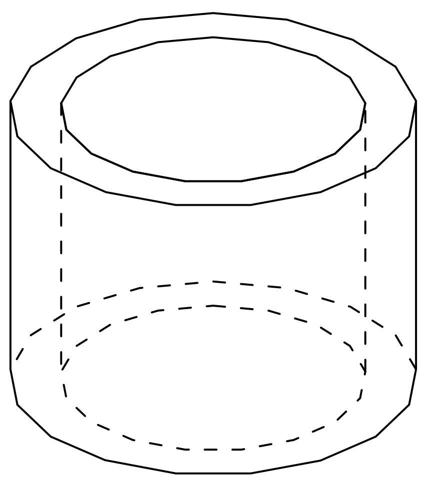

object

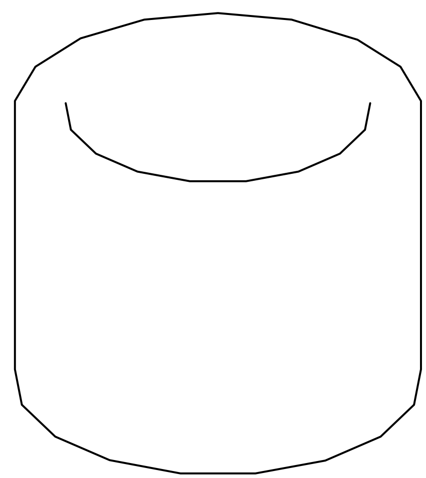

silhouette

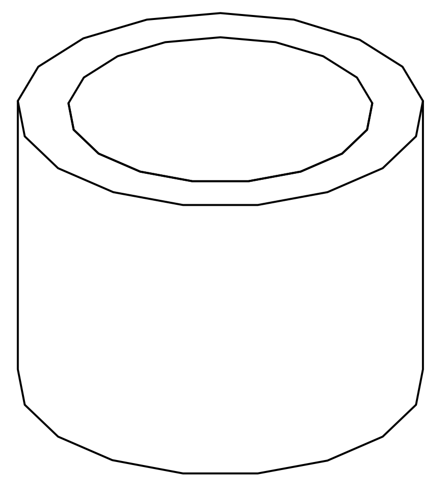

contour/outline


inner silhouette


feature lines

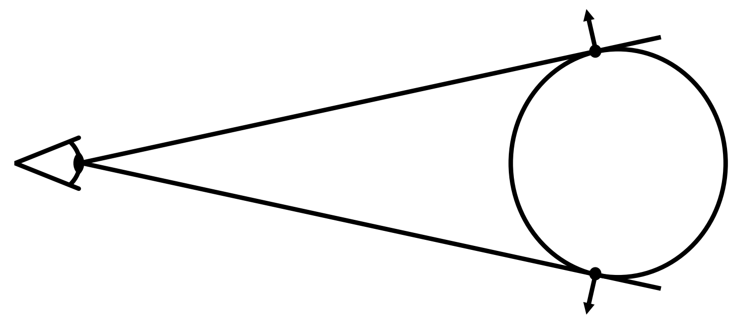

all lines


visible silhouette

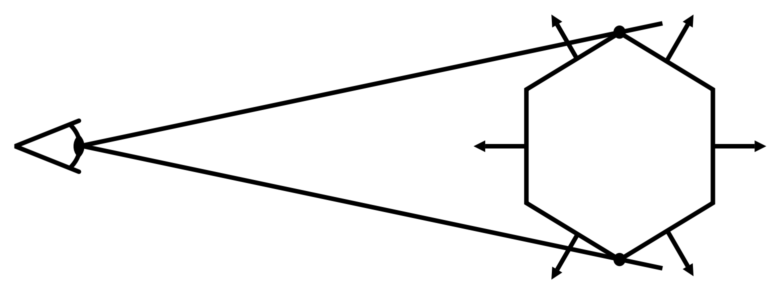

visible lines

Silhouette: Definitions

- *silhouette* (in general)
  set S of all points that are
  tangential as seen by a viewer:
  $S = \{P : 0 = \overrightarrow{n_i} \cdot \overrightarrow{v}\}$ (orth. proj.)
  $S = \{P : 0 = \overrightarrow{n_i} \cdot \overrightarrow{(p_i - c)}\}$ (persp. proj.)



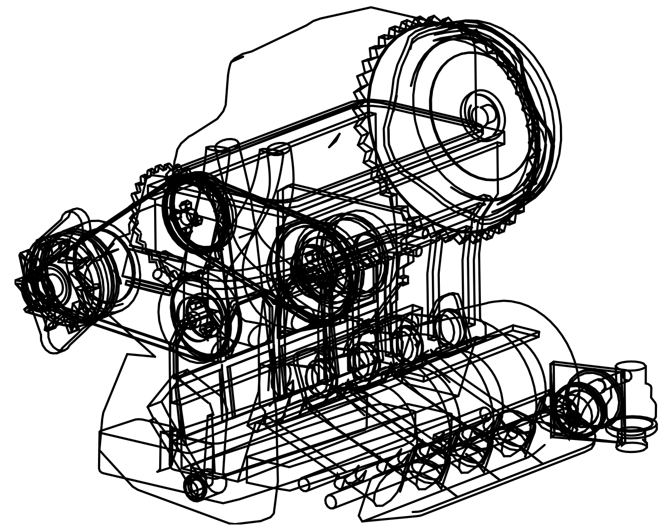
- *polygonal shapes* and
  discontinuities (on smooth surfaces)
  edges/curves attached to
  - one front-facing polygon/surface and
  - one back-facing polygon/surface

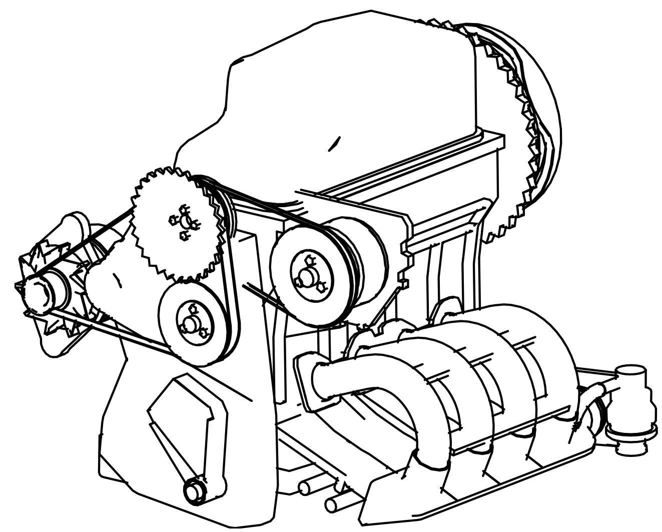


- *silhouette or feature line stroke*
  set of a number of connected silhouette or feature line edges

Silhouette Algorithm

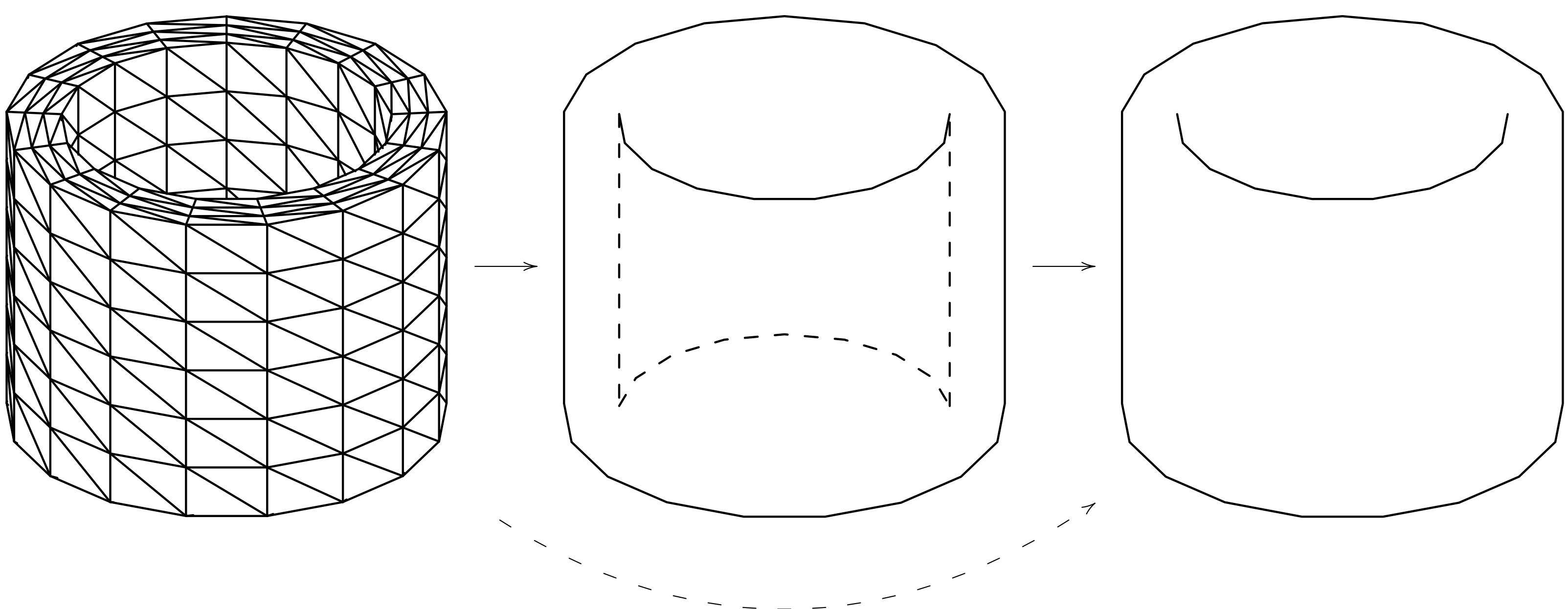
- **2 main tasks**:
  - detection of potential silhouette edges
  - hidden line removal (visibility culling)
- some algorithms perform both tasks in one step
- computation per frame necessary (both tasks)
  $\Rightarrow$ often high run-time complexity
- need for algorithms for speeding up the process
  - allow small inaccuracies
  - pre-processing $\rightarrow$ smart data structures





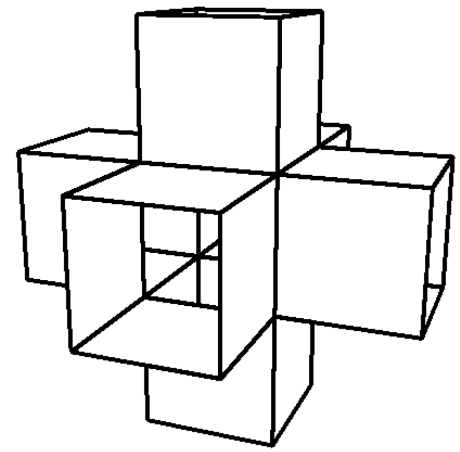
Process of Silhouette Detection

- input: polygonal mesh
- output: (visible) silhouette edges
  - as a pixel image
  - as a set of edges
- intermediate step of hidden line removal not always necessary
  → some algorithms perform HLR and silhouette detection in one step

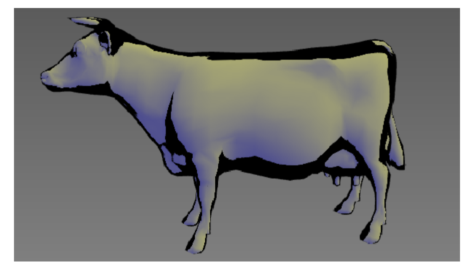


Classification of Silhouette Algorithms

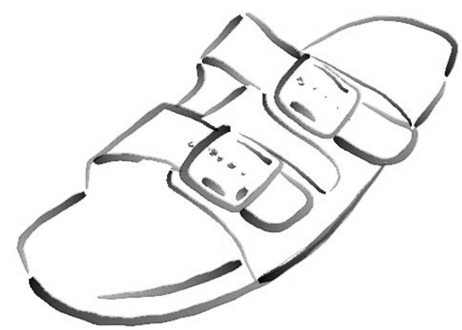
- algorithms in image-space
  - work with rendered pixel buffers
  - silhouette detection and visibility culling simultaneously
- hybrid algorithms
  - manipulations in object-space
  - normal rendering to get silhouettes in image-space
  - silhouette detection and visibility culling simultaneously
- algorithms in object-space
  - silhouette detection without rendering
  - silhouette detection and visibility culling separately
- visibility culling for object-space silhouettes
  - in image-space
  - in object-space
  - hybrid algorithms



Hertzmann (1999)



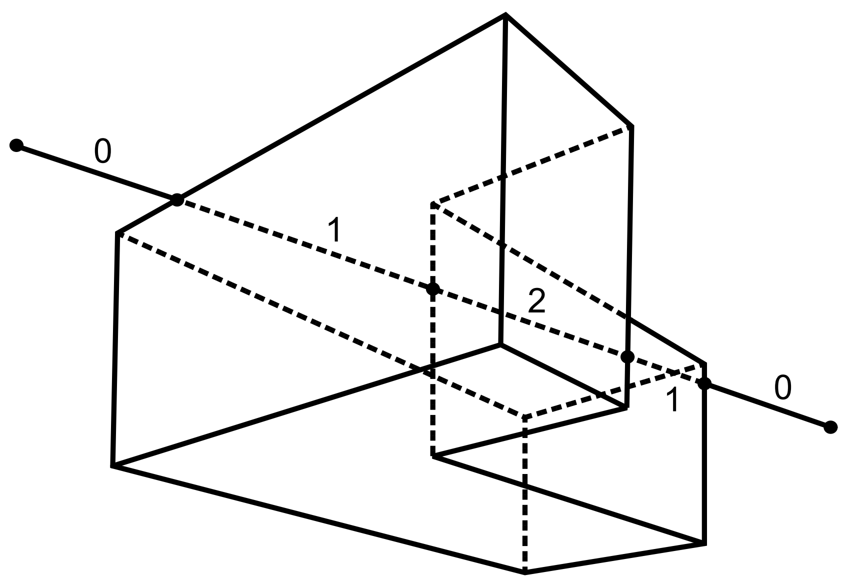
Gooch et al. (1999)



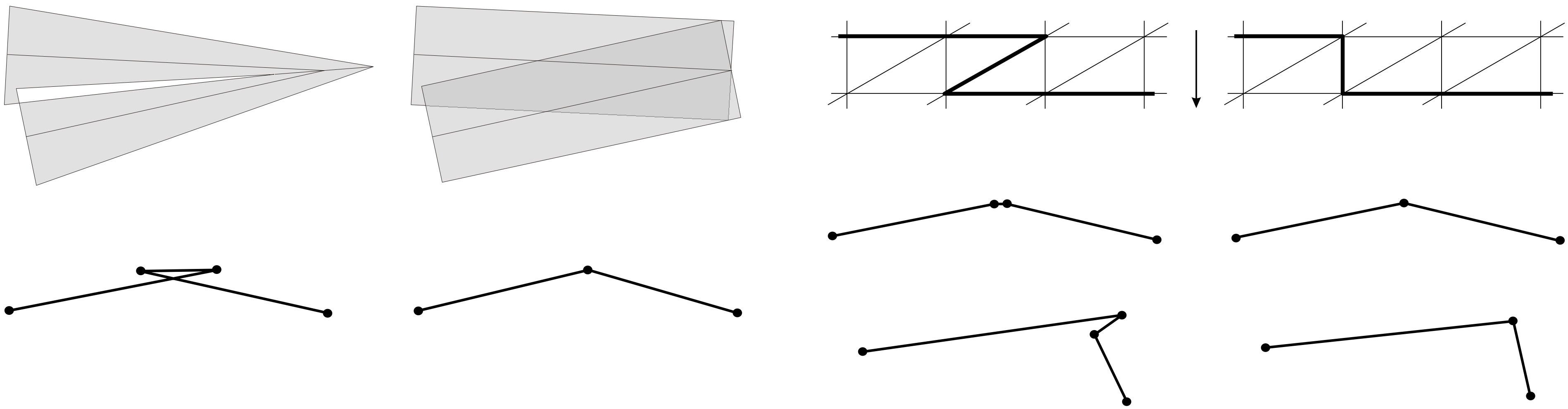
Northrup & Markosian (2000)

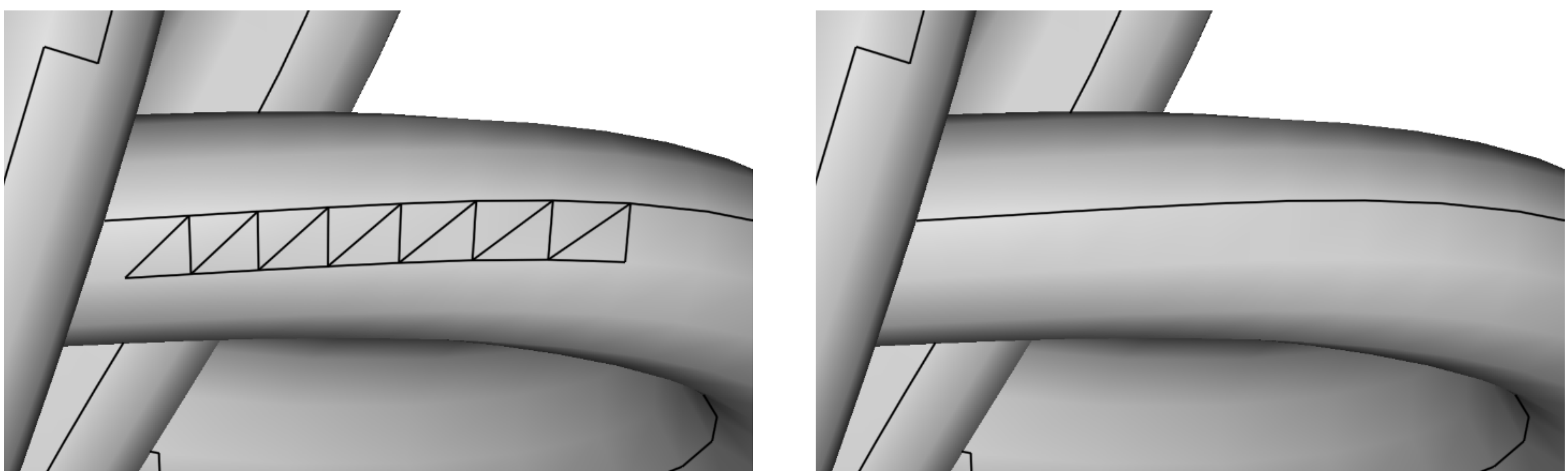
Appel's Algorithm

- visibility culling of lines using **quantitative invisibility** QI (Appel, 1967)
- QI changes only at silhouette edges
- visible: line segments with $\text{QI} = 0$
  invisible: line segments with $\text{QI} \geq 1$

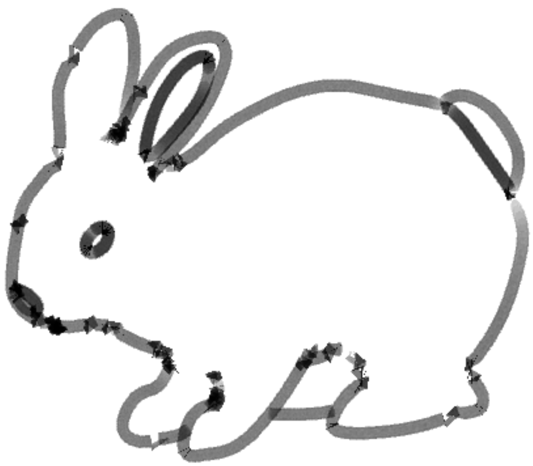


Artifact Removal: Cases

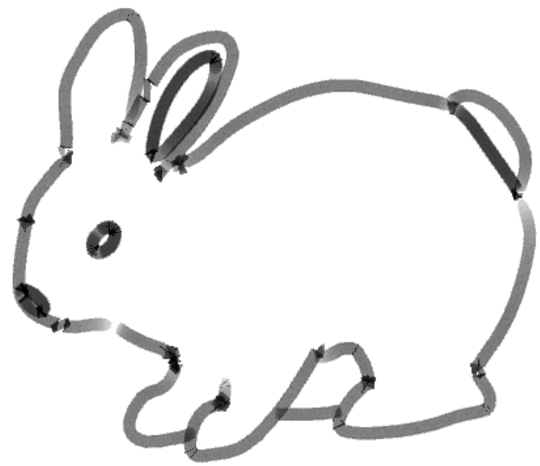




Artifact Removal: Example



none



object-space

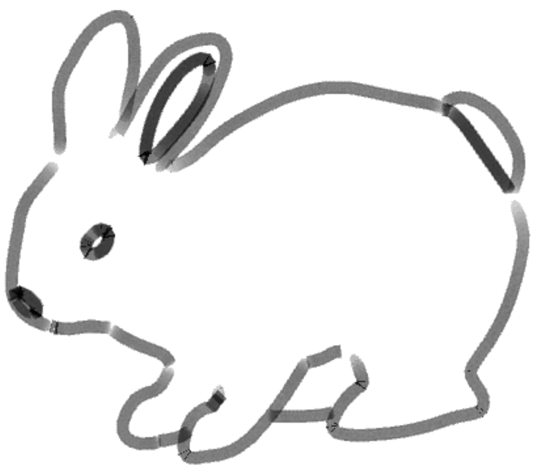
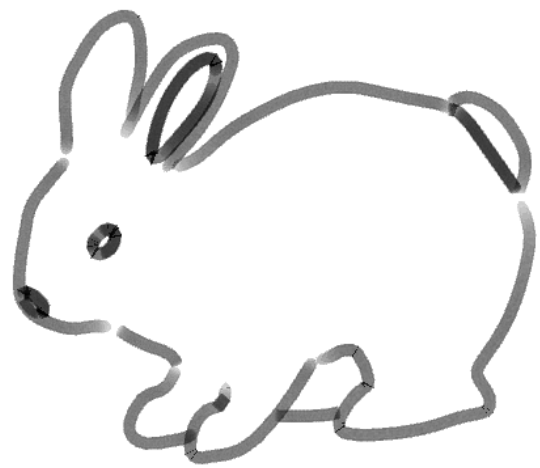
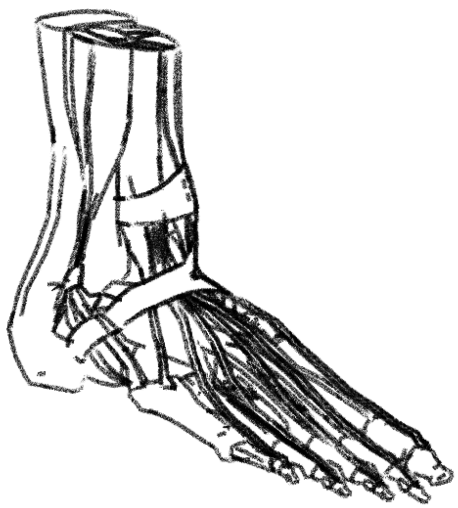
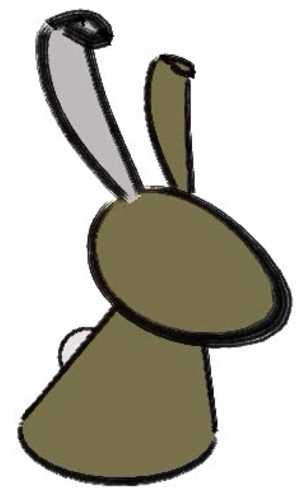
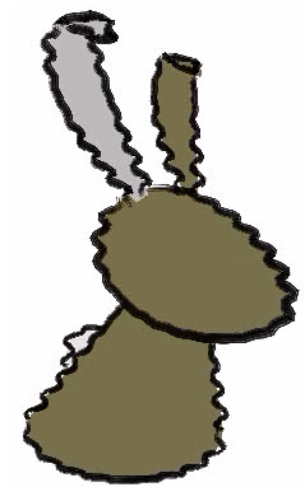


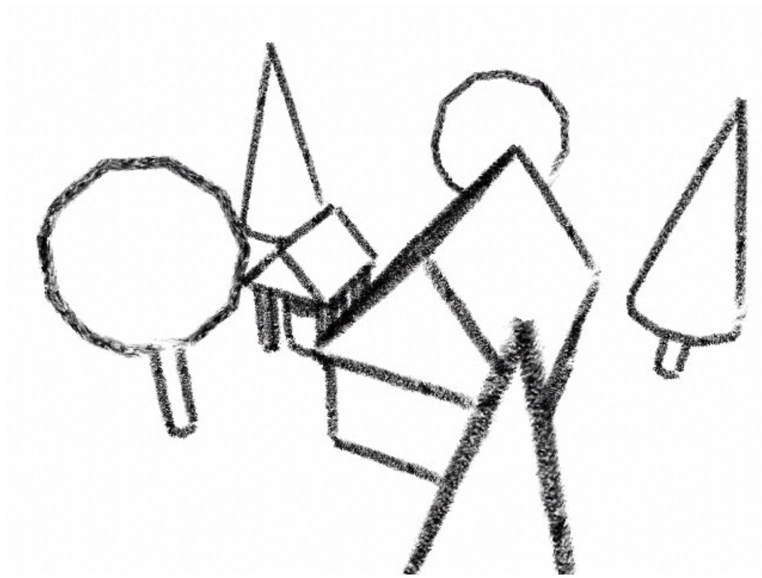
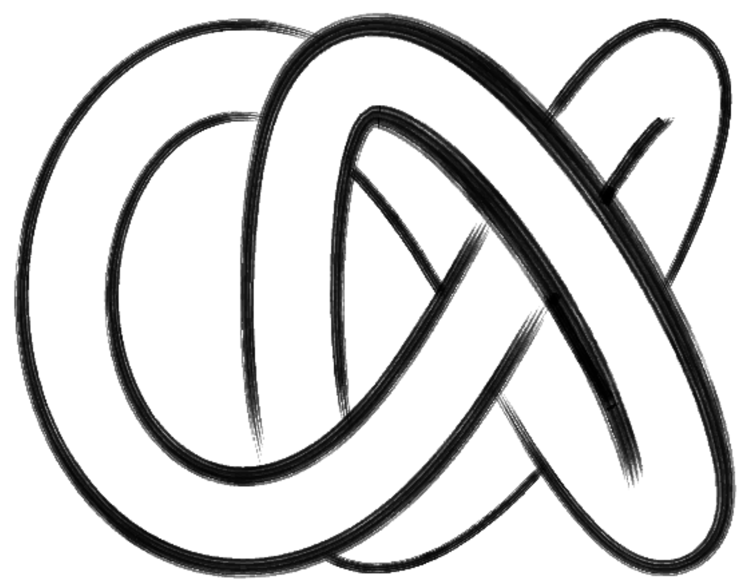
image-space



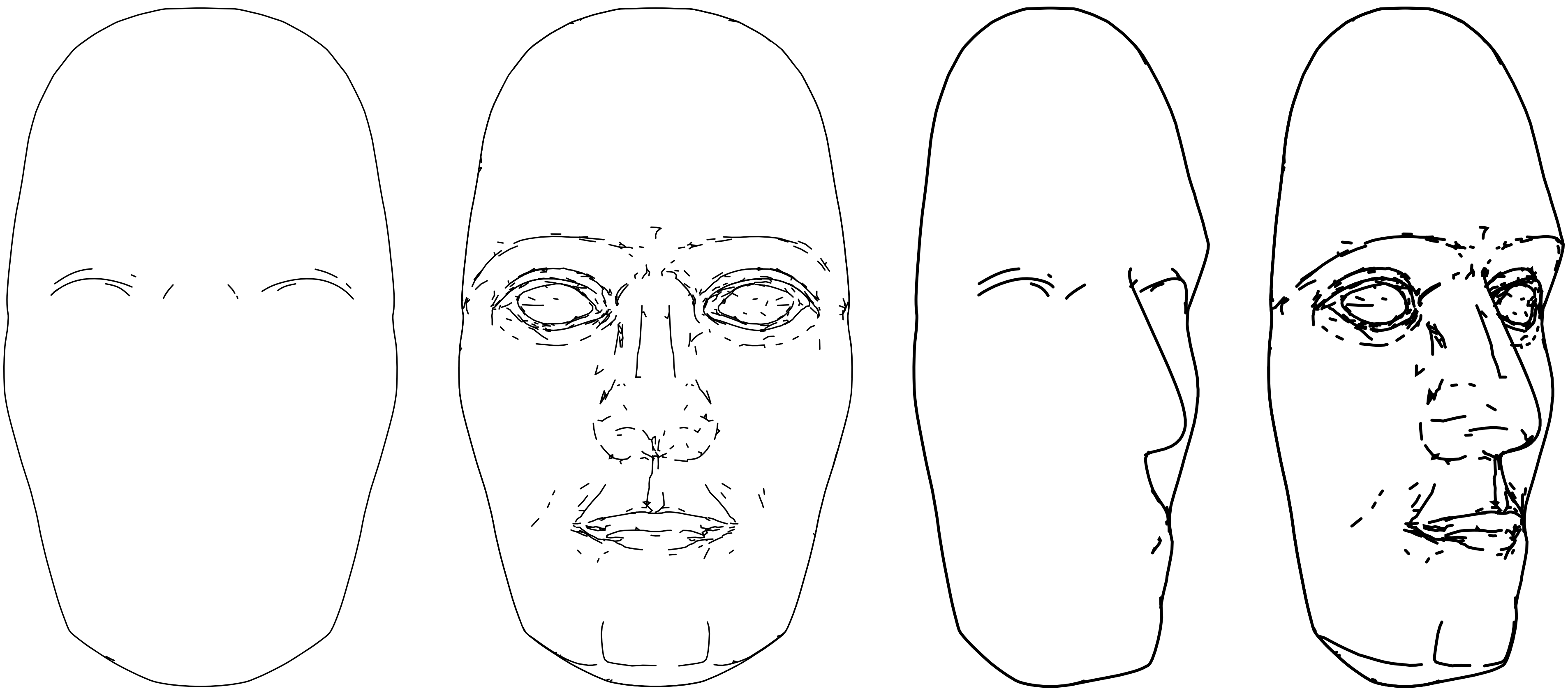
all

Example Renditions

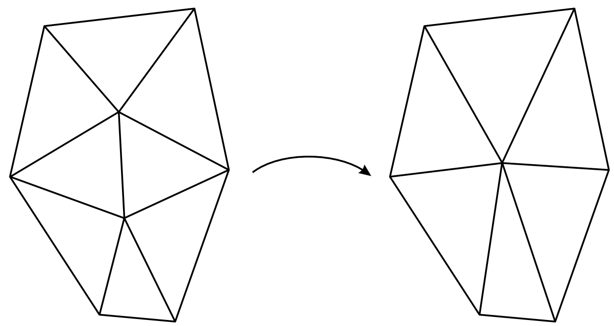



Applications & Case Study

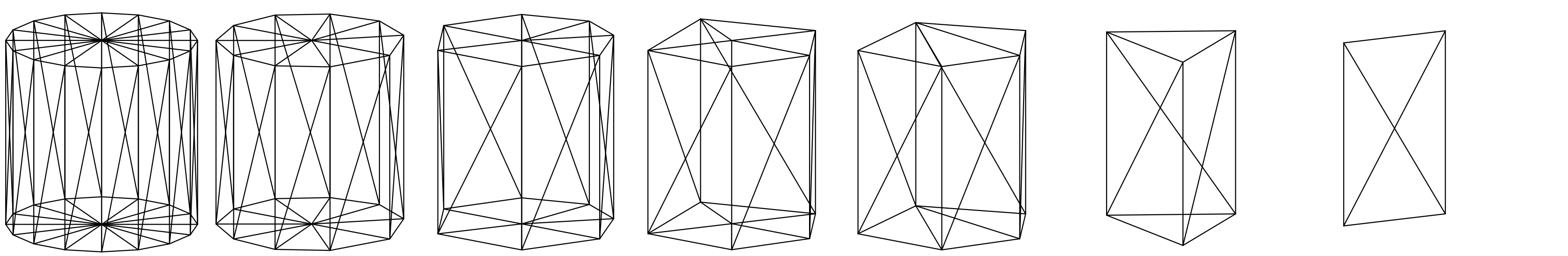


Internal Skeletons

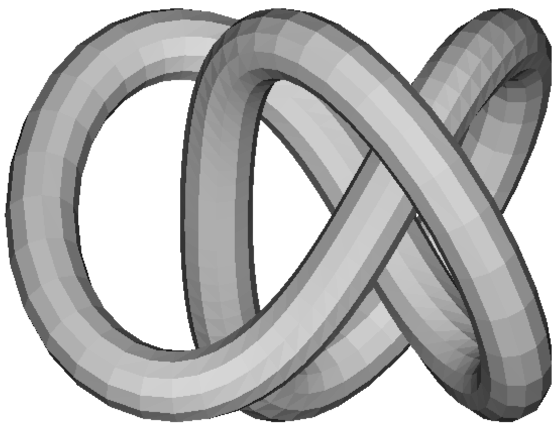
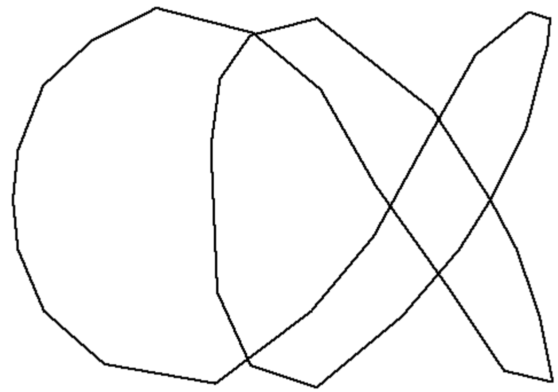
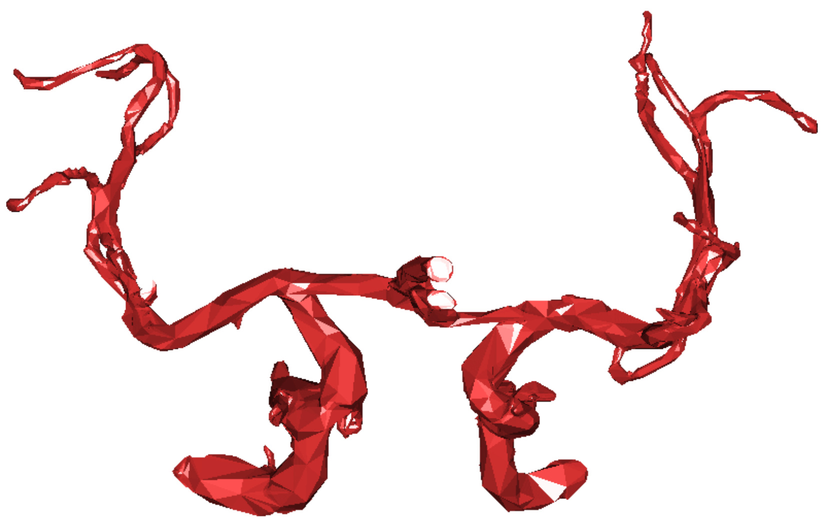
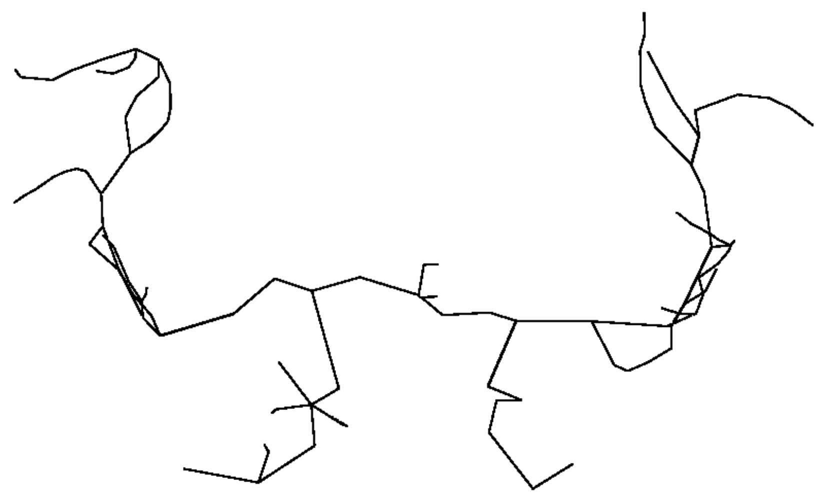
- edge collapse process
  - derived from *progressive meshes* (Hoppe et al. (1993), Hoppe (1996))
  - iteration while valid polygons exist (Raab, 1998)
- strategies for selection of next edge to collapse
  - shortest edge, minimal error, etc.
- well suited for elongated structures, not well suited for compact shapes



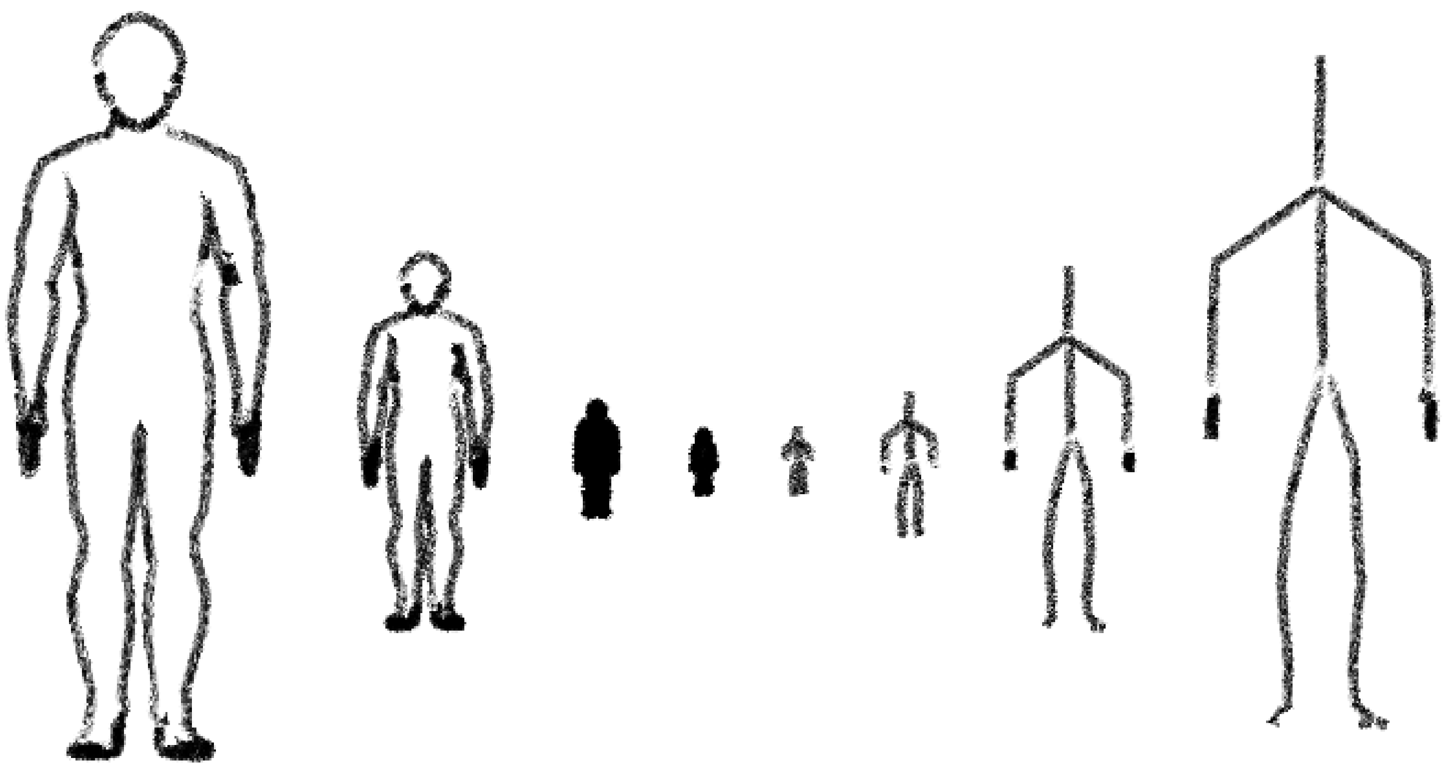
- extensions
  - initial welding of model
  - re-positioning of skeleton vertices



Internal Skeletons: Examples

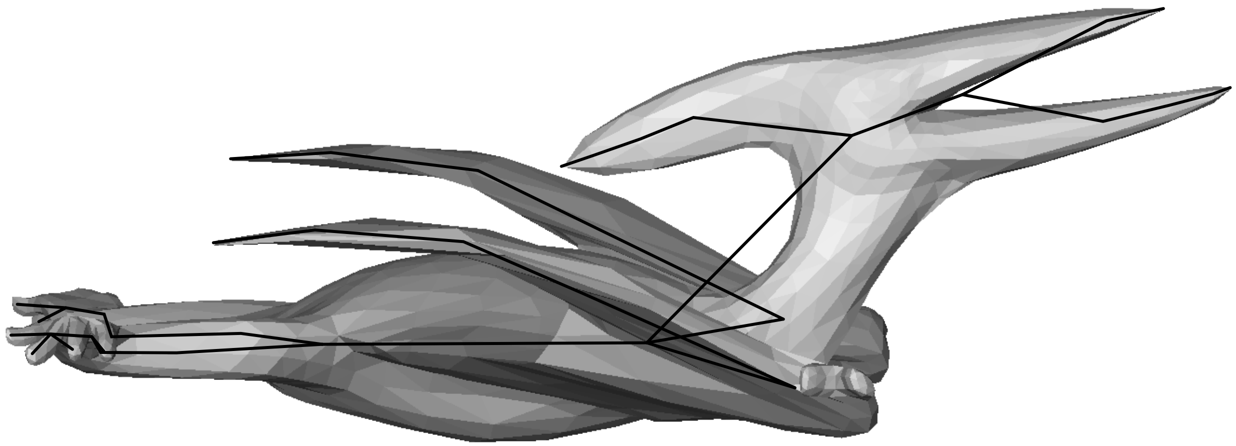





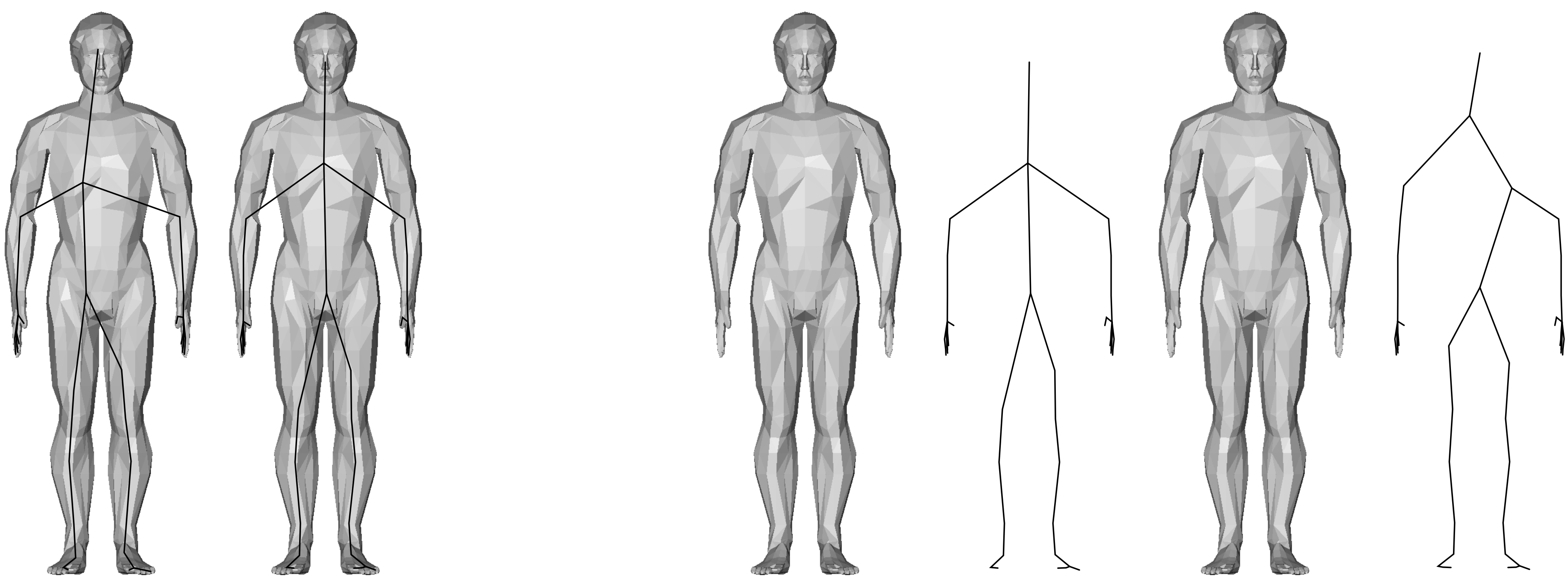
Internal Skeletons: Application Example



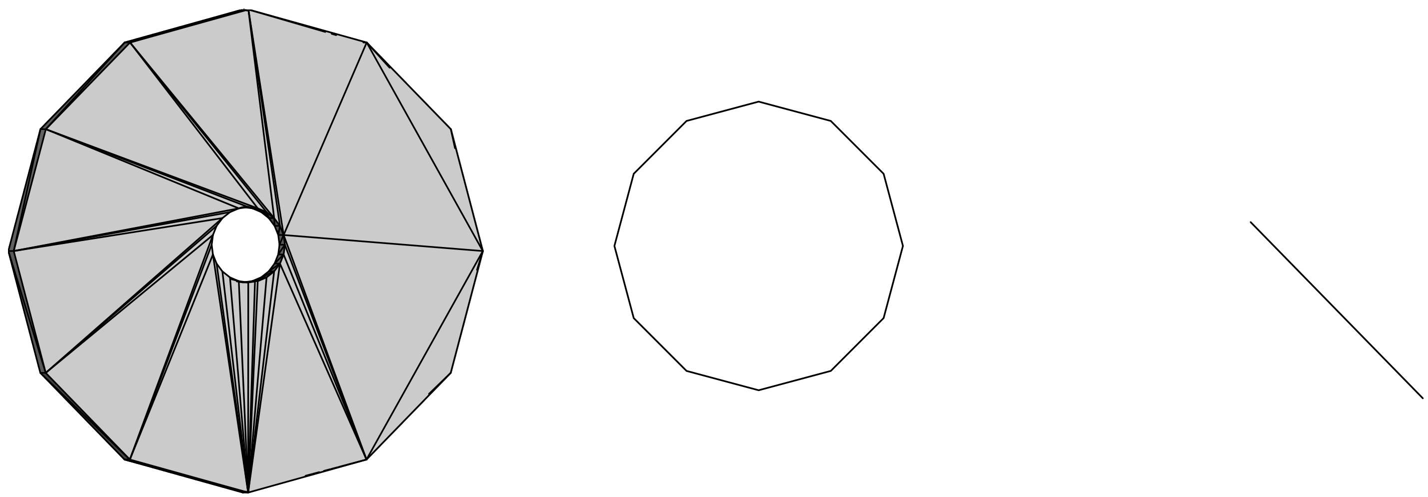
- depiction of distant objects using their internal skeletons
  - better recognition of the essential form
  - less run-time computation necessary

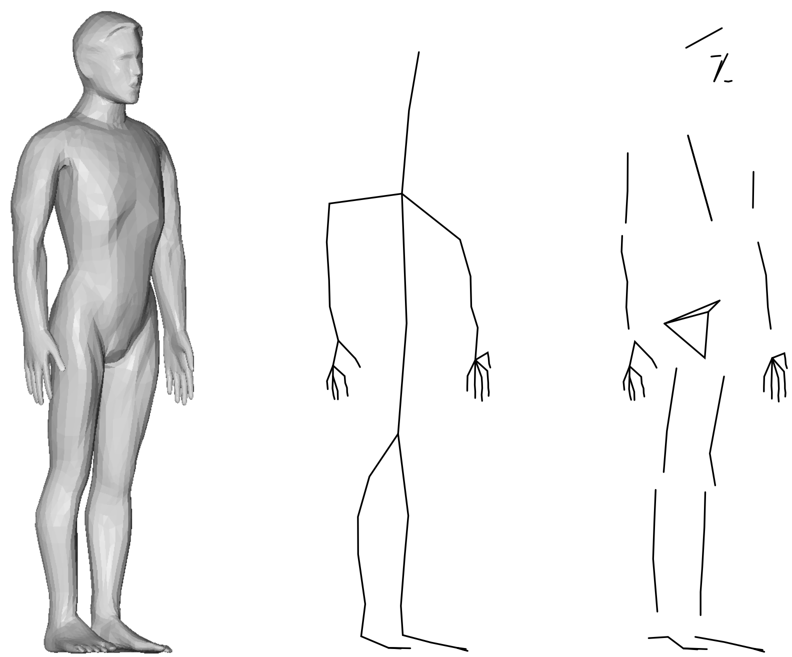
Problems With Internal Skeletons I



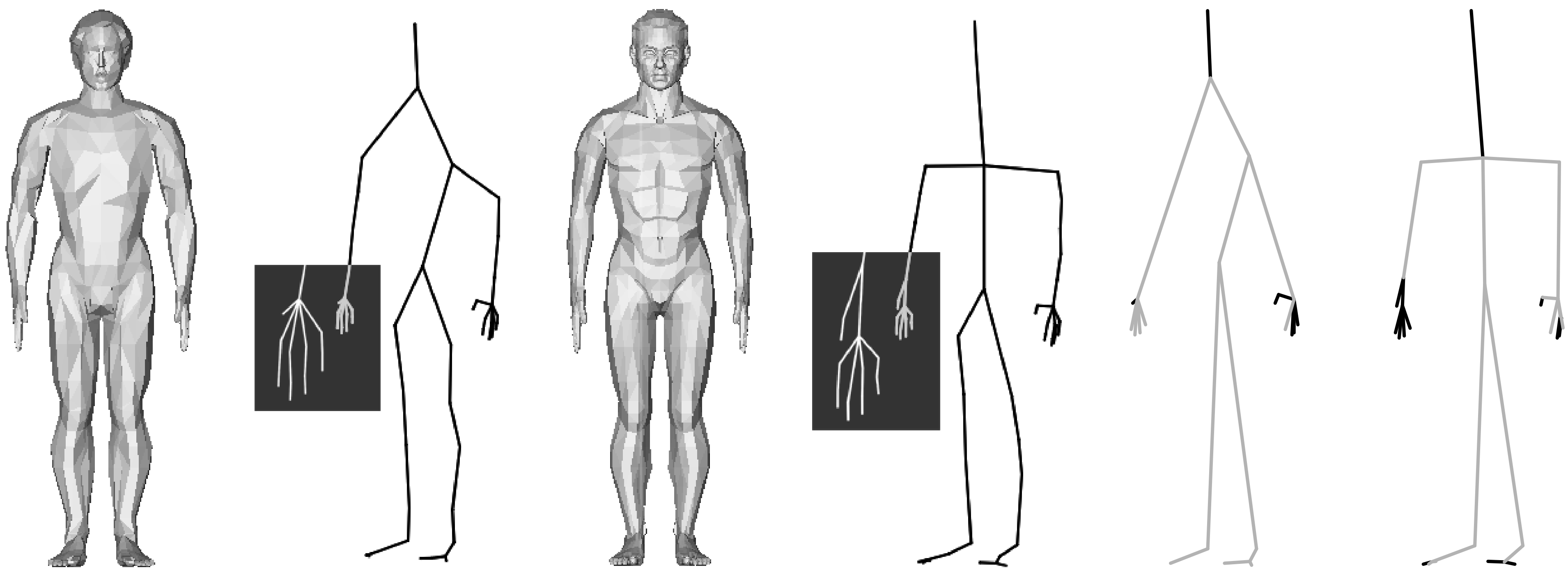


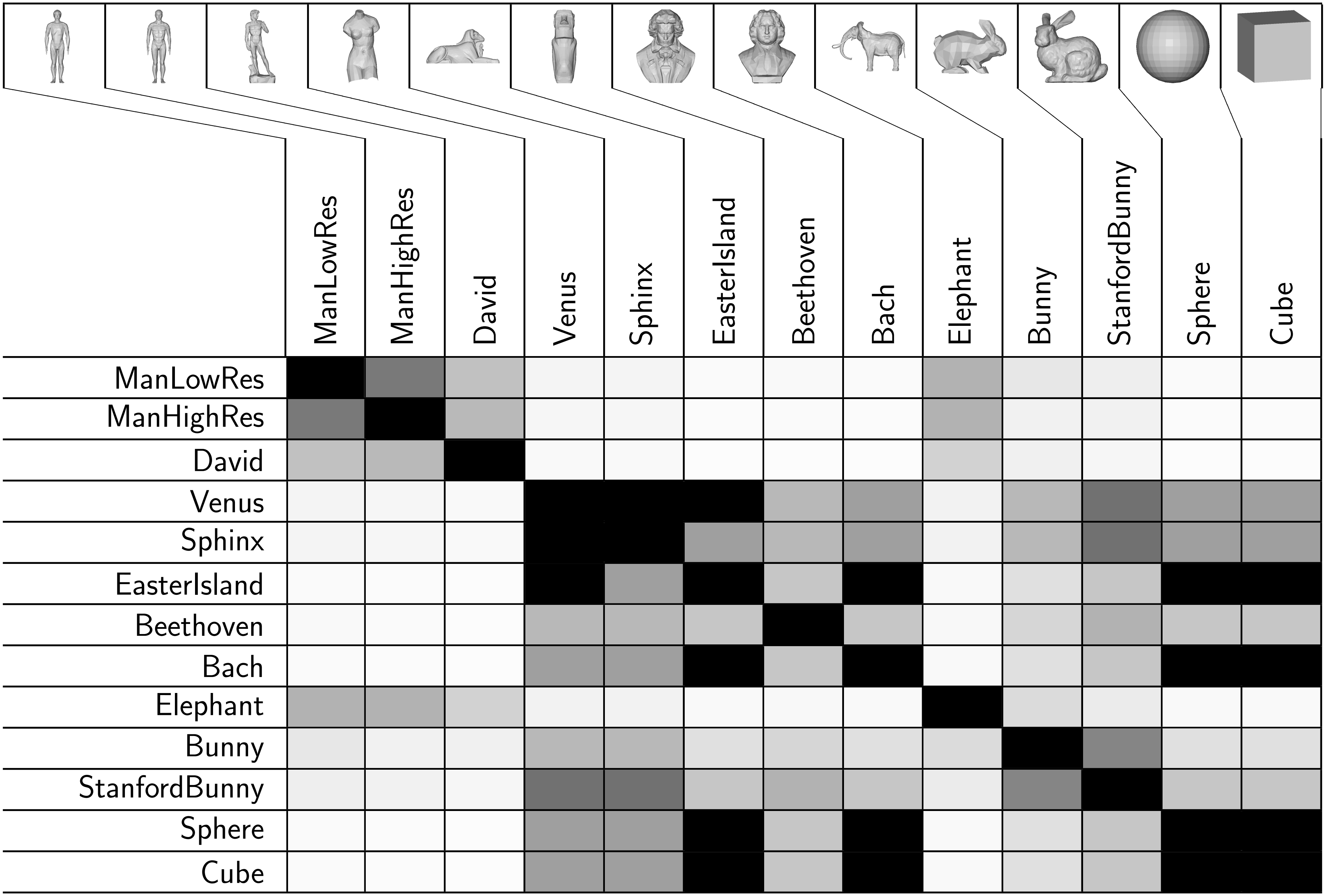
Problems With Internal Skeletons II



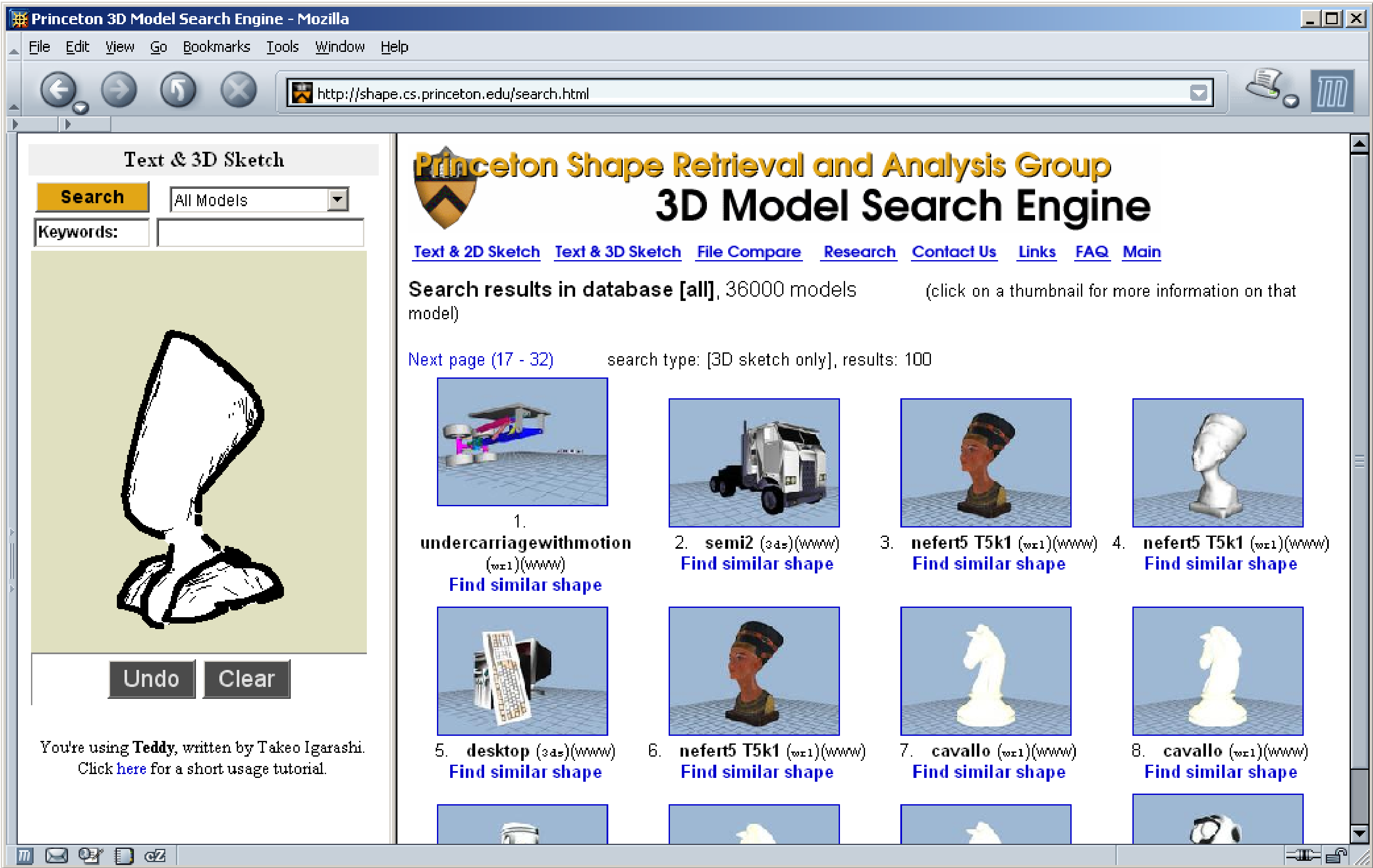


Shape Matching Using Internal Skeletons

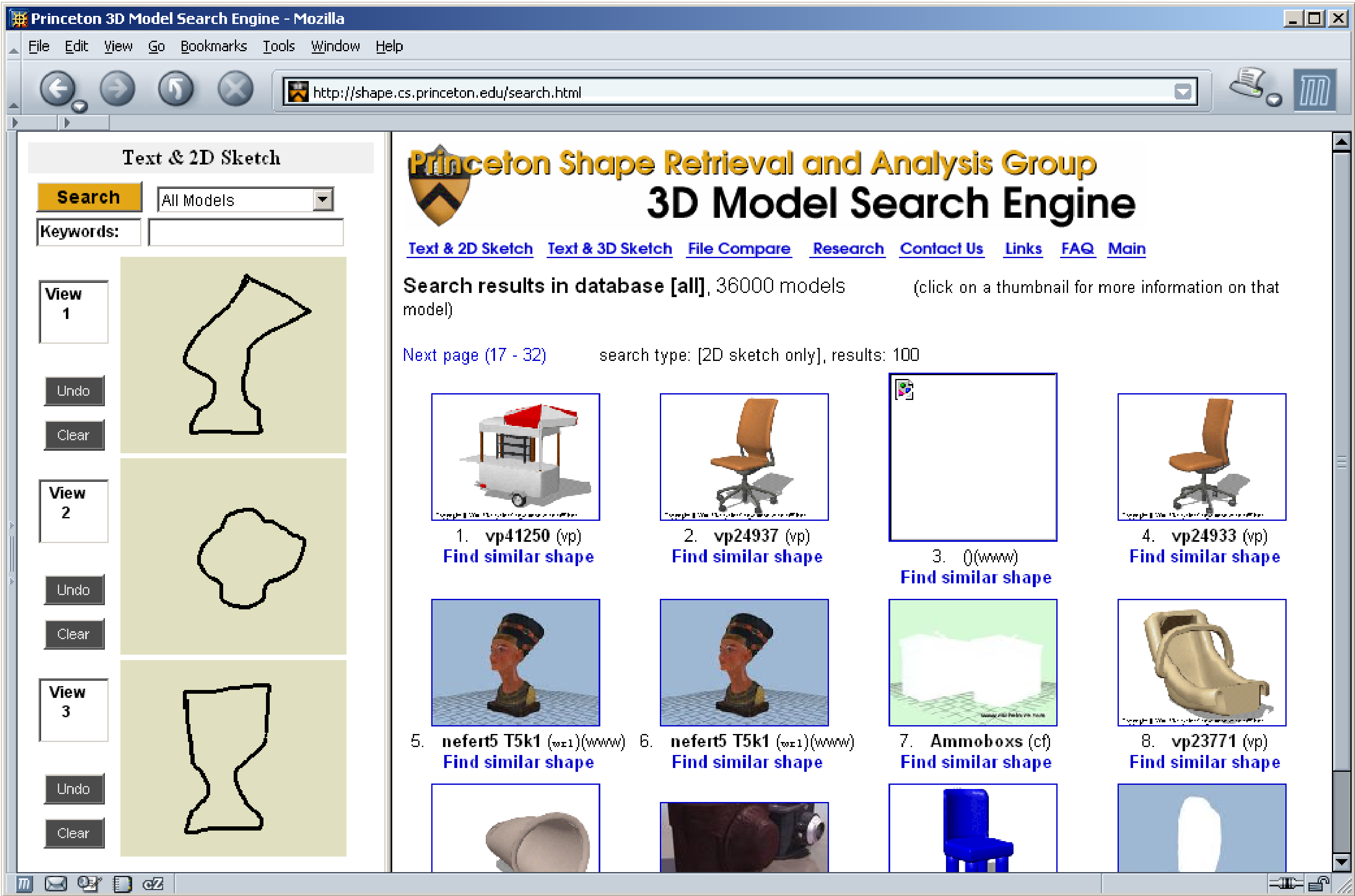



ManLowRes
ManHighRes
David
Venus
Sphinx
EasterIsland
Beethoven
Bach
Elephant
Bunny
StanfordBunny
Sphere
Cube

Model Search: Skeleton



Model Search: Silhouettes



Line Distortion Examples

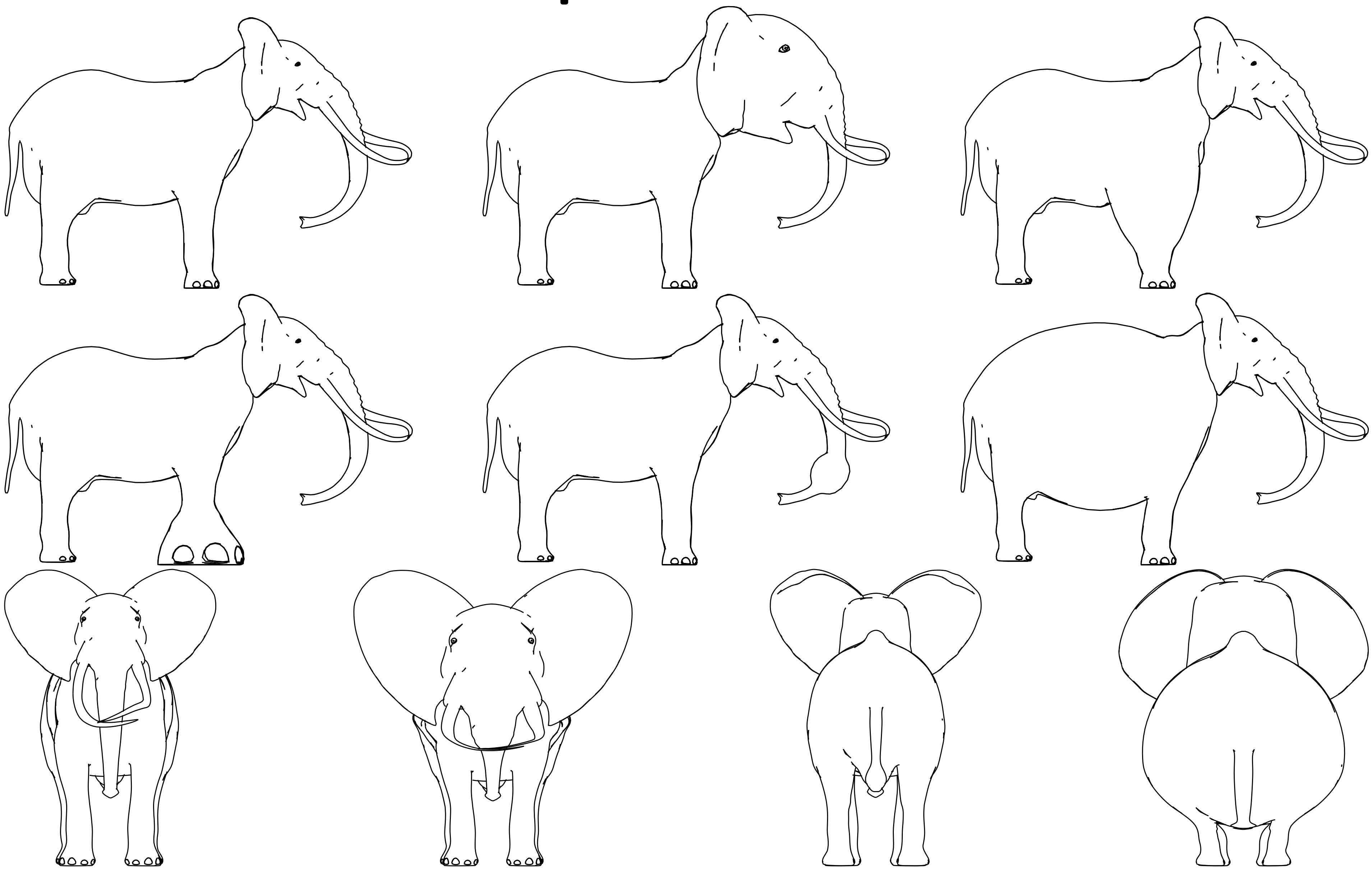


Illustration Watermarks

- classification according to the degree of visually perceivable modification

Illustration Watermarks for Vector Graphics

- without visually perceivable modifications
  - path subdivisions
  - path splitting
- with visually perceivable modifications
  - slight changes of line attributes
  - stylistic modifications

Illustration Watermarks

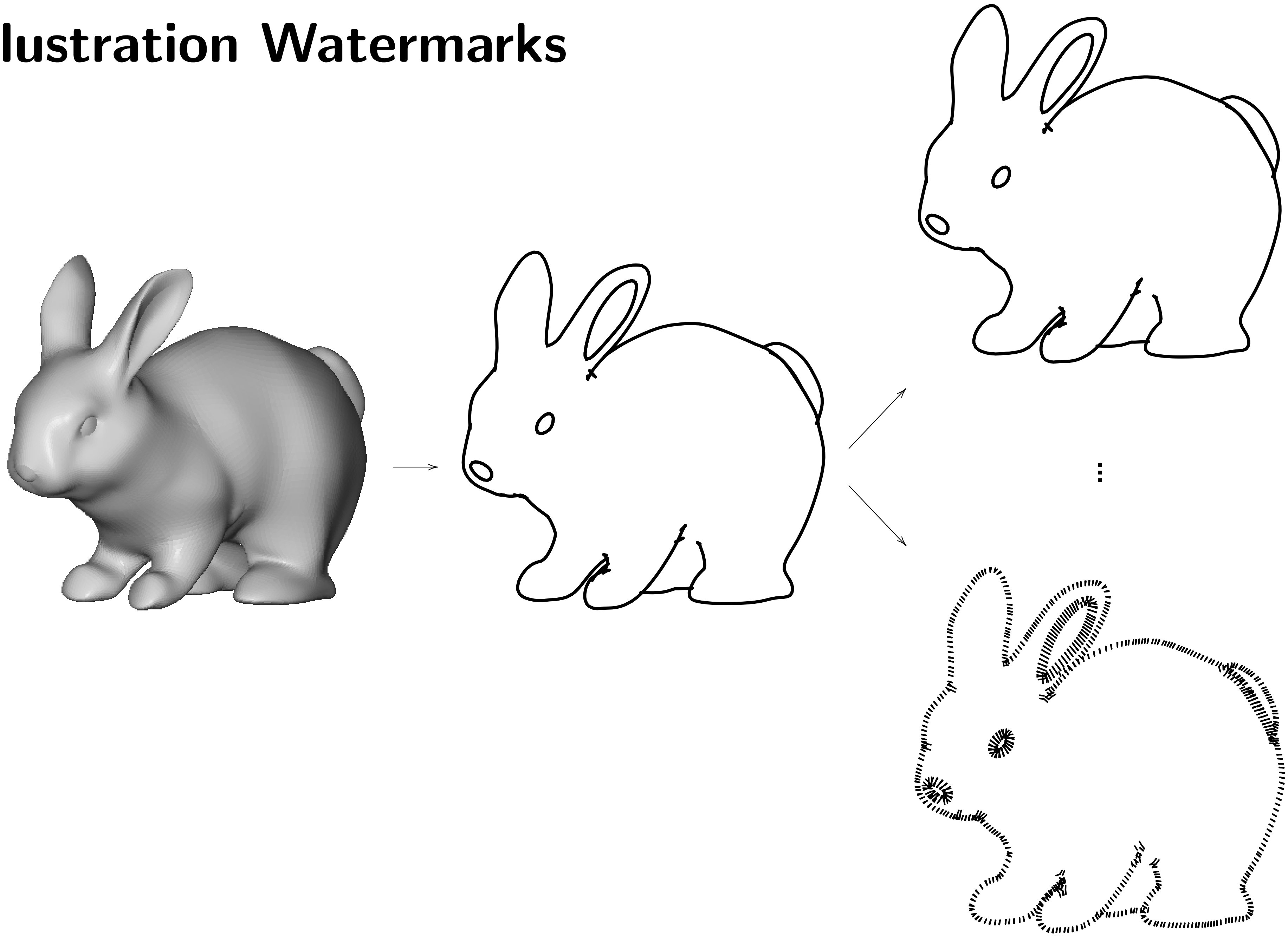


Illustration Watermarks

- three methods
  - path subdivision
  - line attributes
  - angled lines

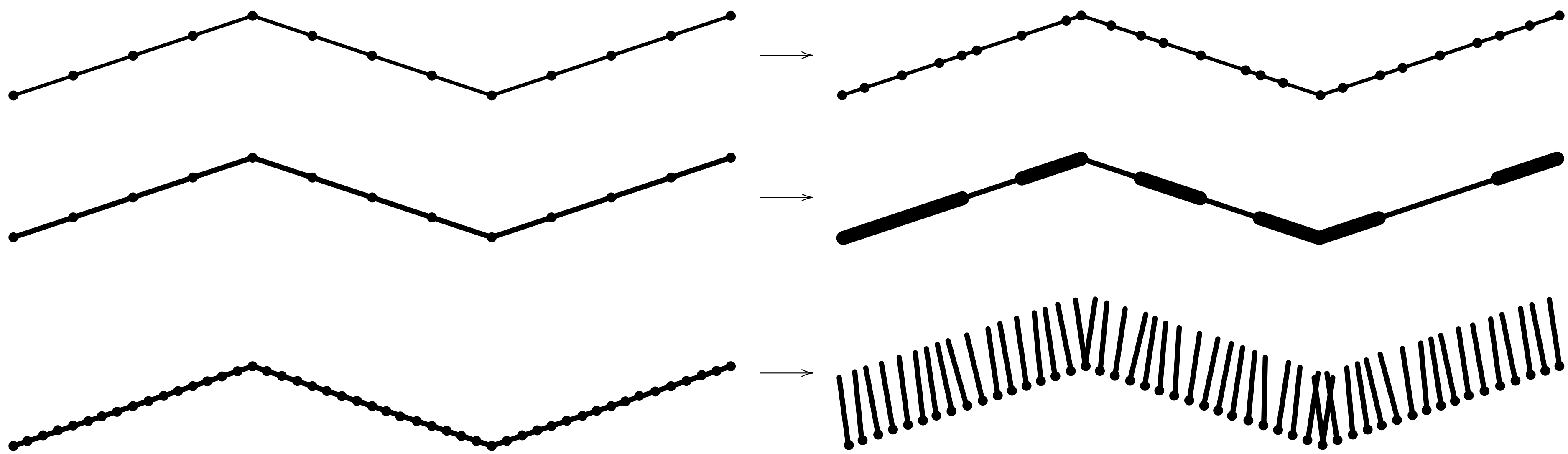
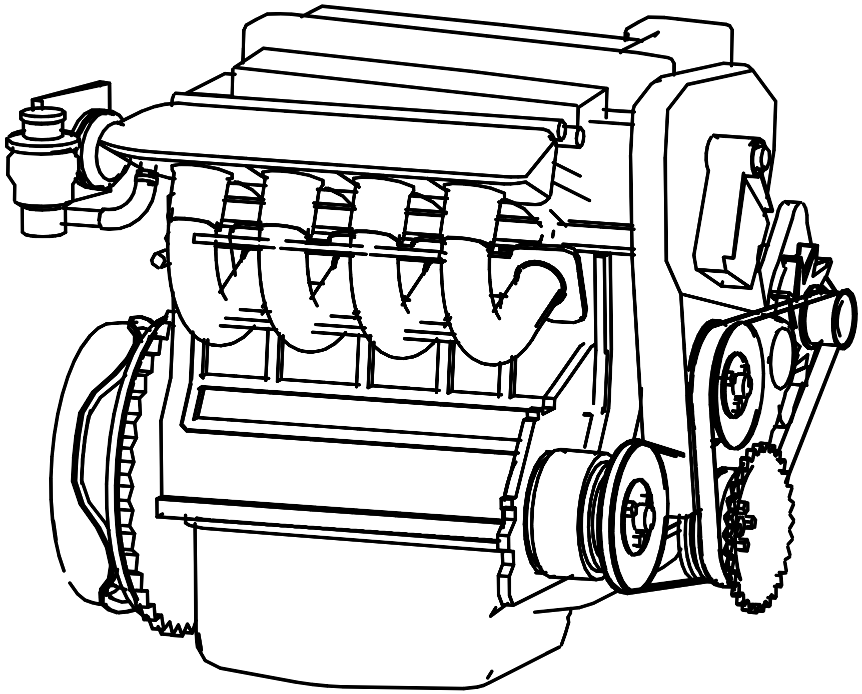


Illustration Watermarks: Example 1



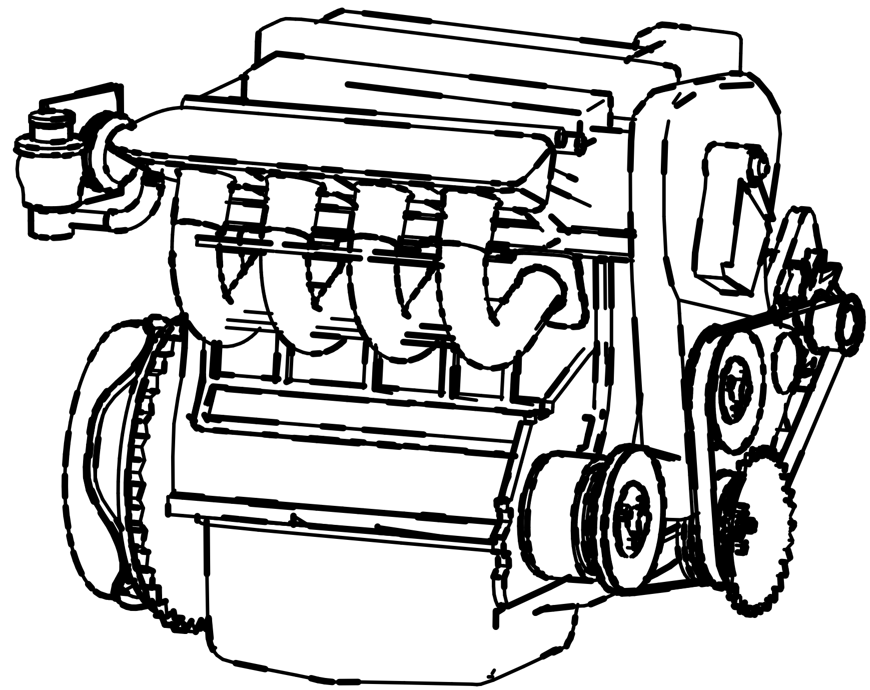
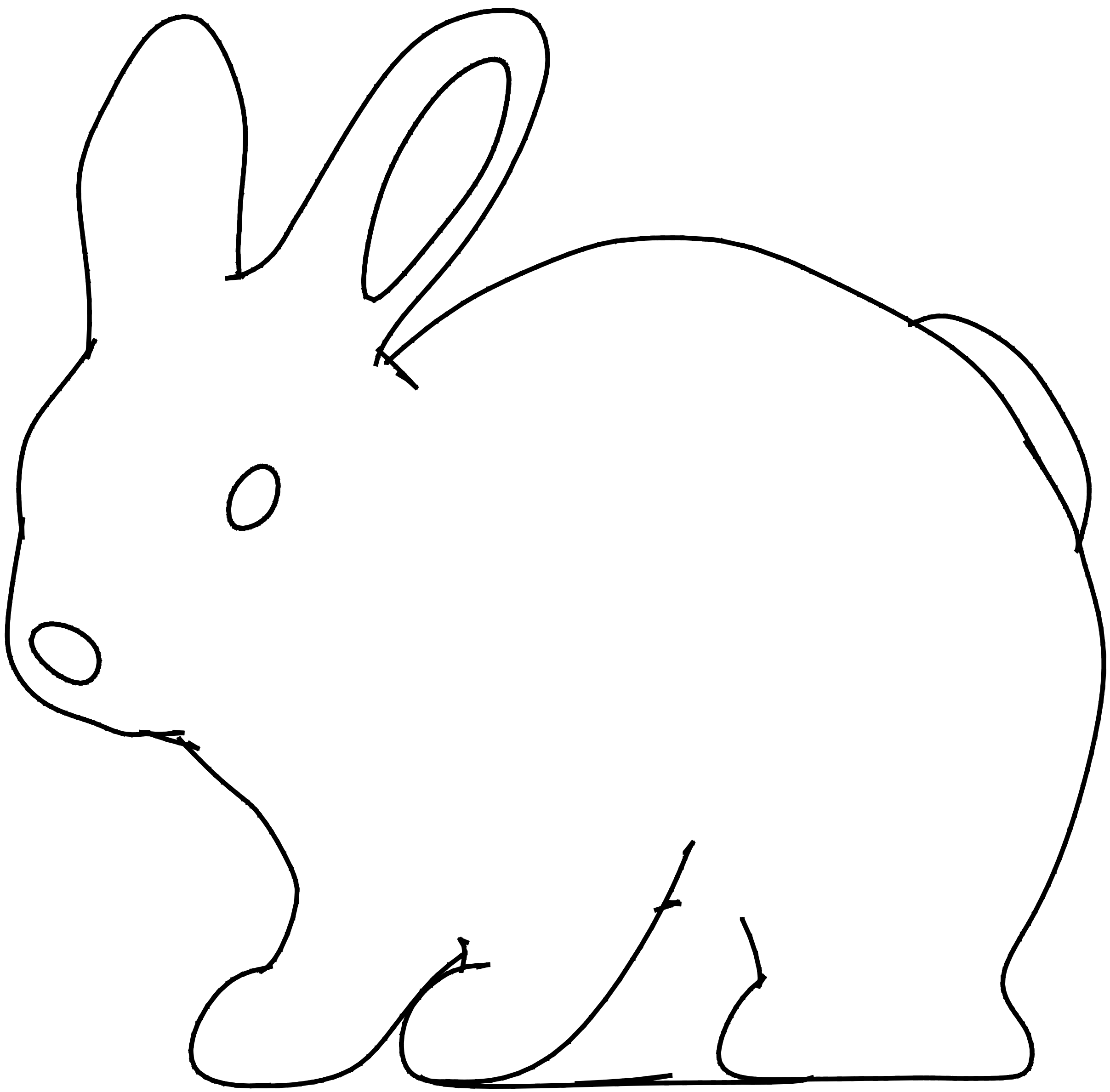
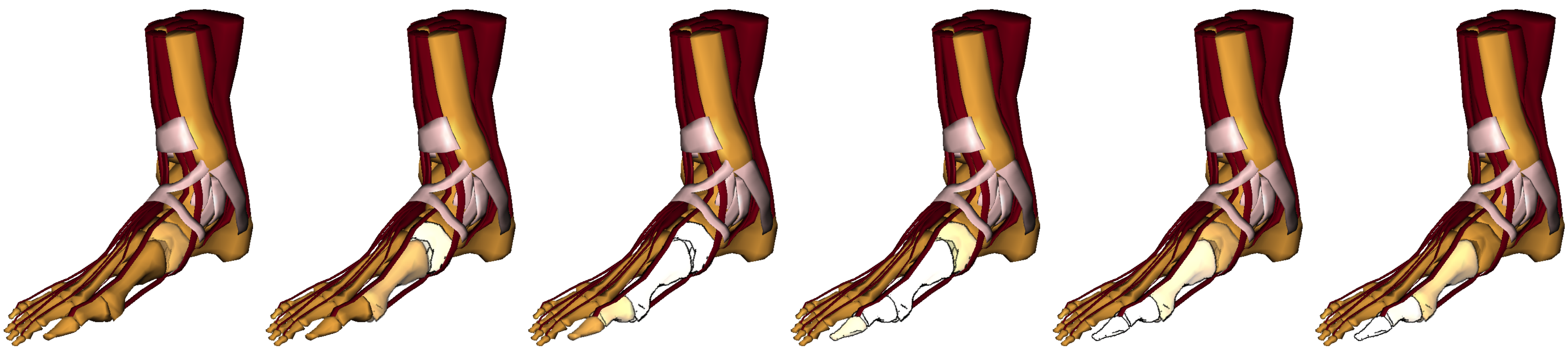


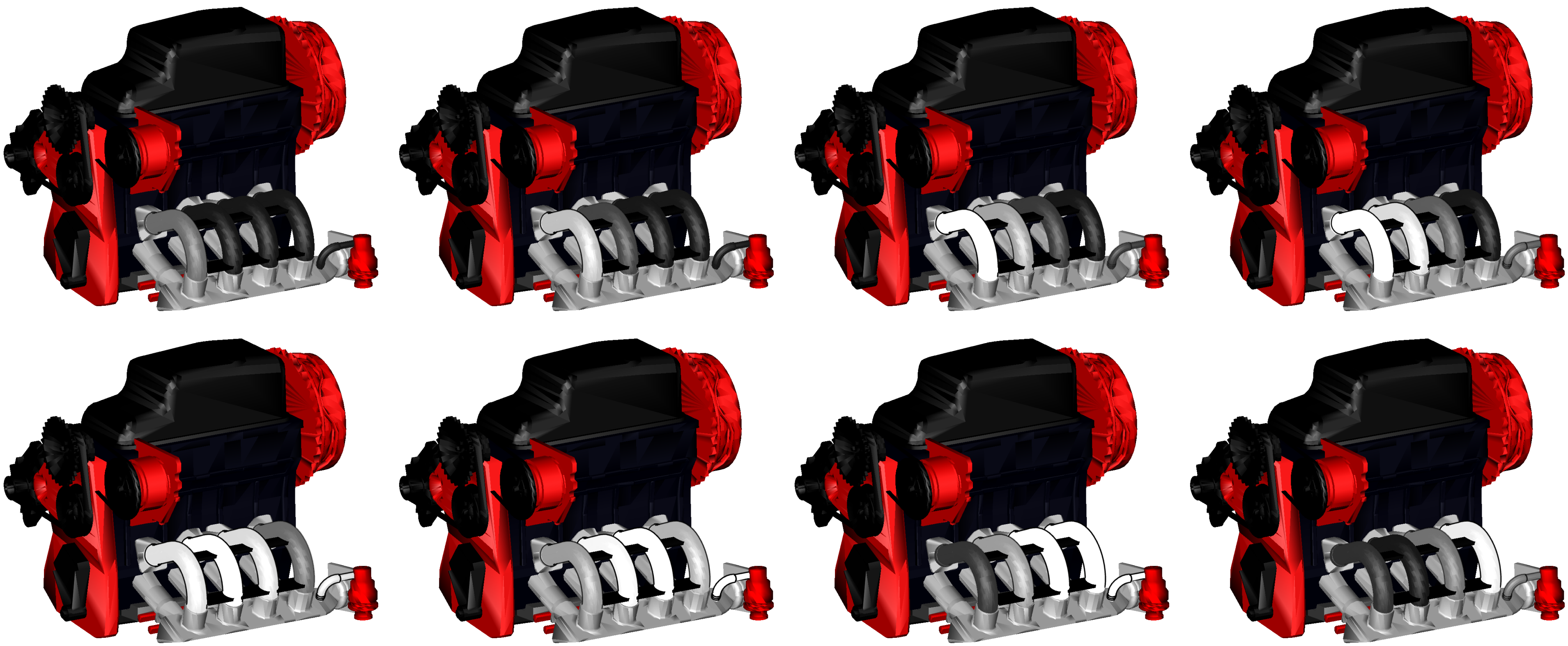
Illustration Watermarks: Example 2



Hybrid Rendering I



Hybrid Rendering II



Silhouettes vs. External Skeletons

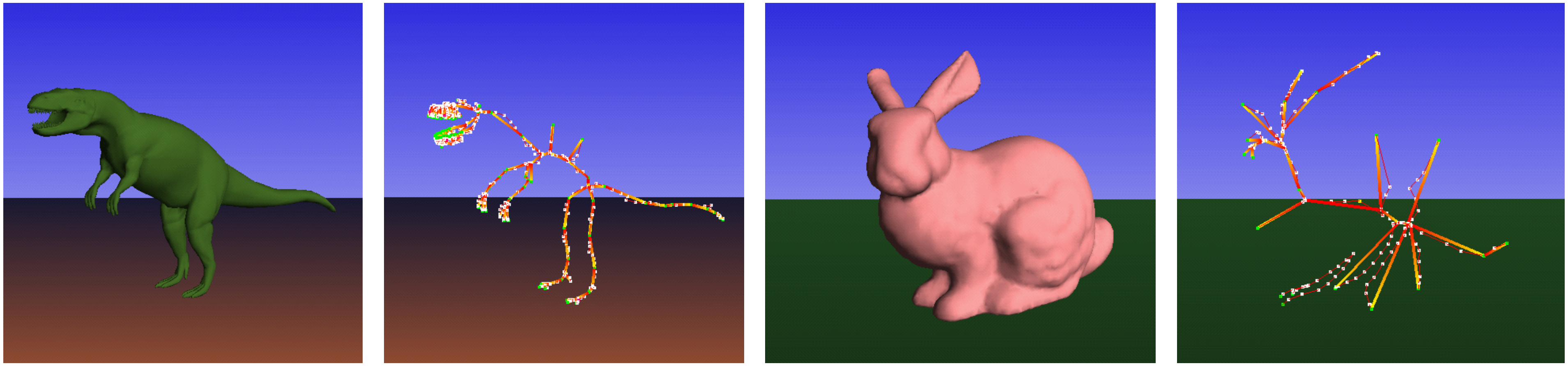
	silhouettes	**external skeletons**
extracted primitive	curves on surface	curves on surface
discrete representation	edges/strokes	edges/strokes
computation with DoI & wave propagation	(yes)	yes
abstraction from	projected shape	DoI property
view-dependent	yes dynamic	usually no usually static

- both can be used for model search (e. g., Princeton Search Engine)
- Koenderink (1984): local shape from "occluding contour"
- silhouettes almost as efficient for shape recognition as shading (Browse & Rodger, 1994)
- silhouettes one of the main cues for figure-ground segregation (Goldstein, 2002)
- silhouettes combined with shading significantly improve figure-ground segregation and shape recognition (Halper et al., 2003)

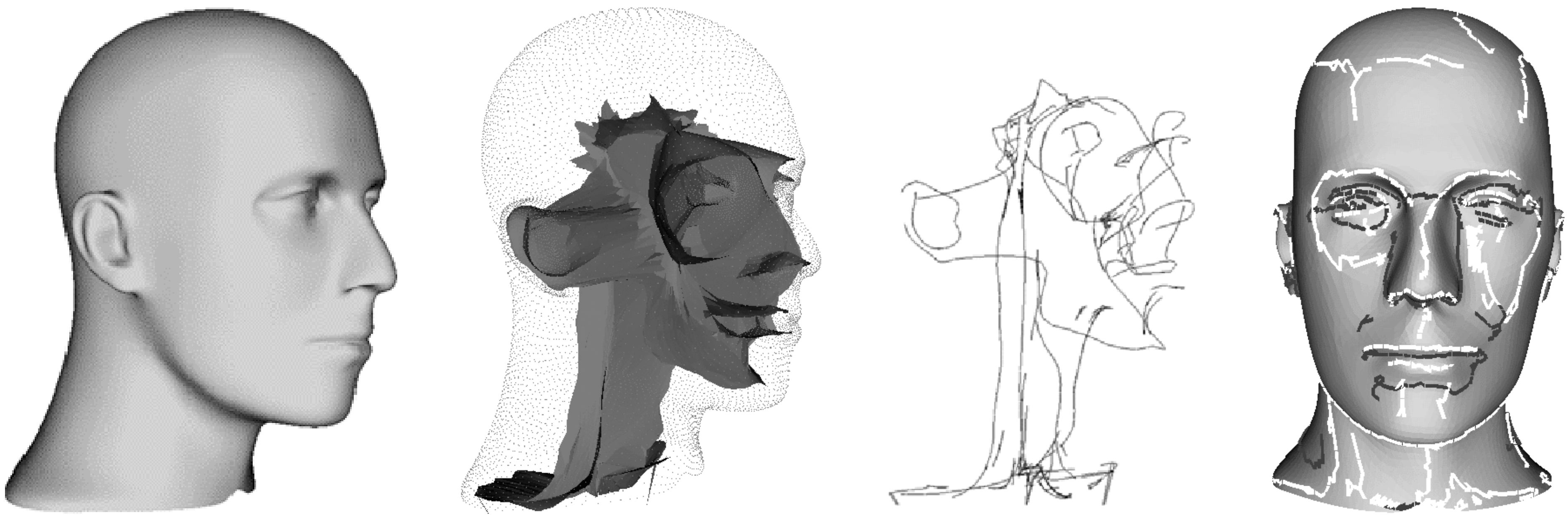
Requirements for ESRs

1. coding and decoding
2. (lossy and lossless) compression
3. database search by extracted features
4. multiscale representation
5. resampling
6. assessment of geometric properties
7. editing shape on feature level
8. animation at feature level

Internal and External ESR Schemes

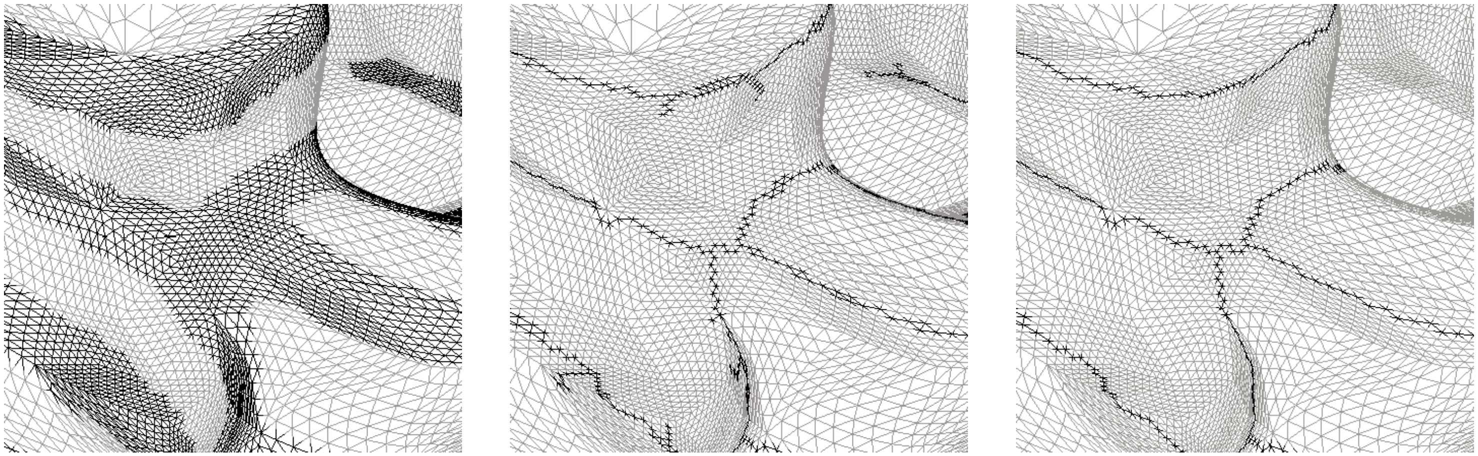


Teichmann & Teller (1998)



Hisada et al. (2002)

External ESR Schemes



Rössl et al. (2000)

Watanabe & Belyaev (2001)