Mesh Segmentation

Thomas Funkhouser

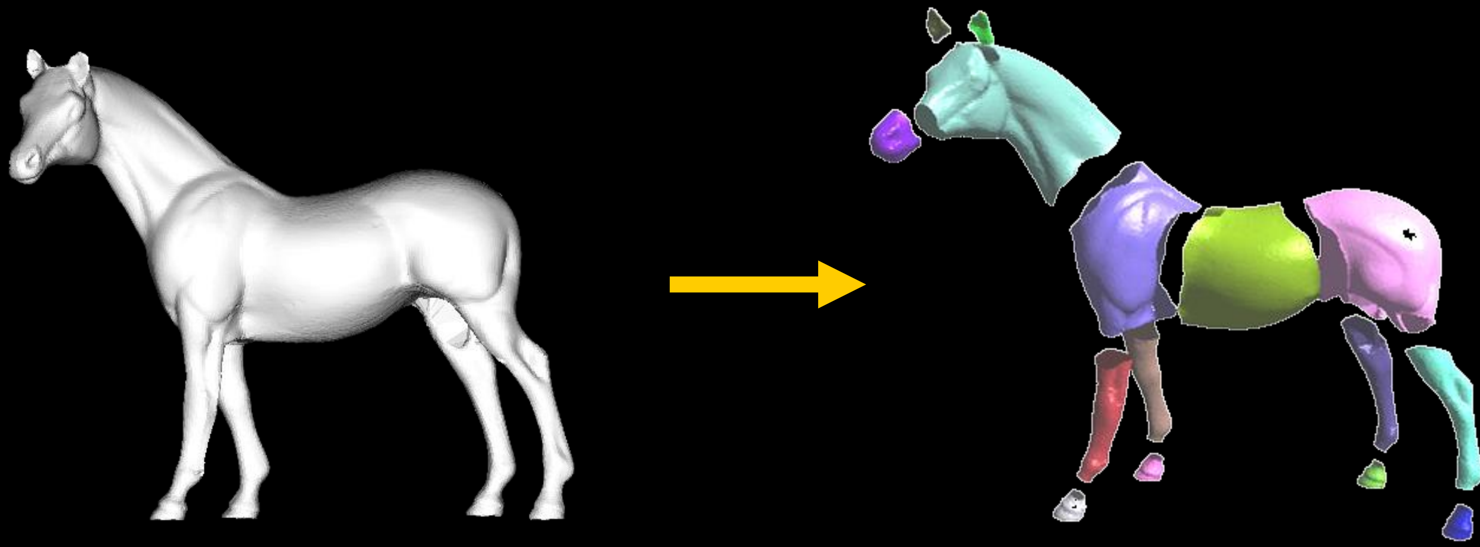
COS 526, Fall 2014

(most slides by Arik Shamir)

Introduction

Goal:

- Given: a mesh M = {V,E,F}
- Create: a set S of submeshes M_i that partition the faces of M into disjoint subsets.



Shamir

Motivation

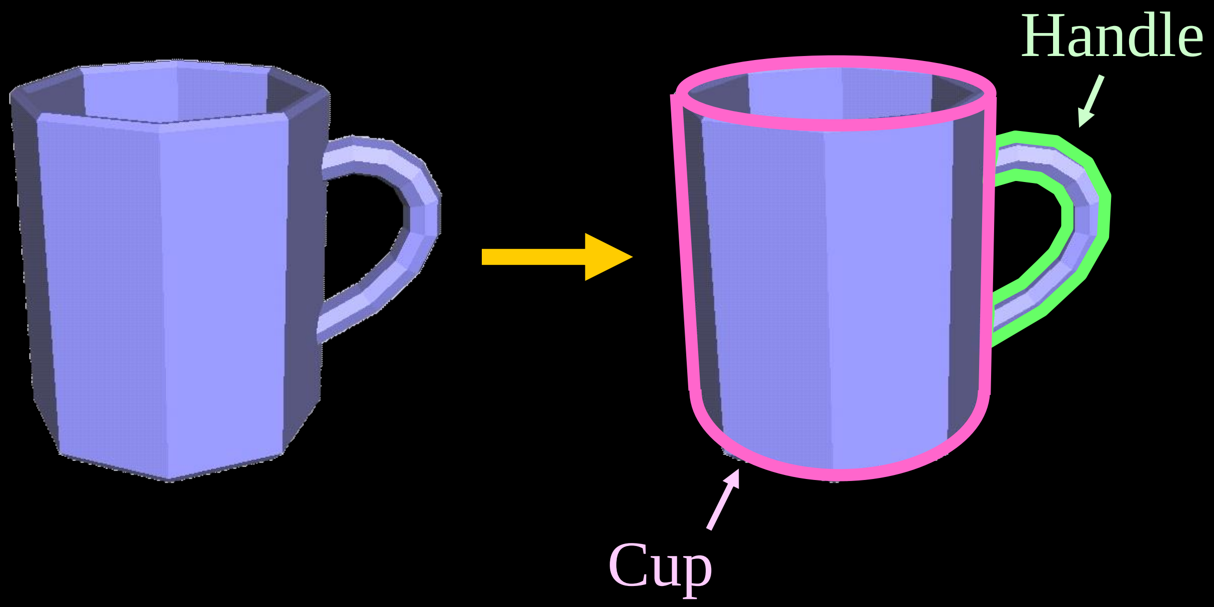
Applications:

- Analysis
- Representation
- Recognition
- Collision detection
- Animation
- Modeling
- etc.

Motivation

Applications:

- ➢ Analysis
- Representation
- Recognition
- Collision detection
- Animation
- Modeling
- etc.

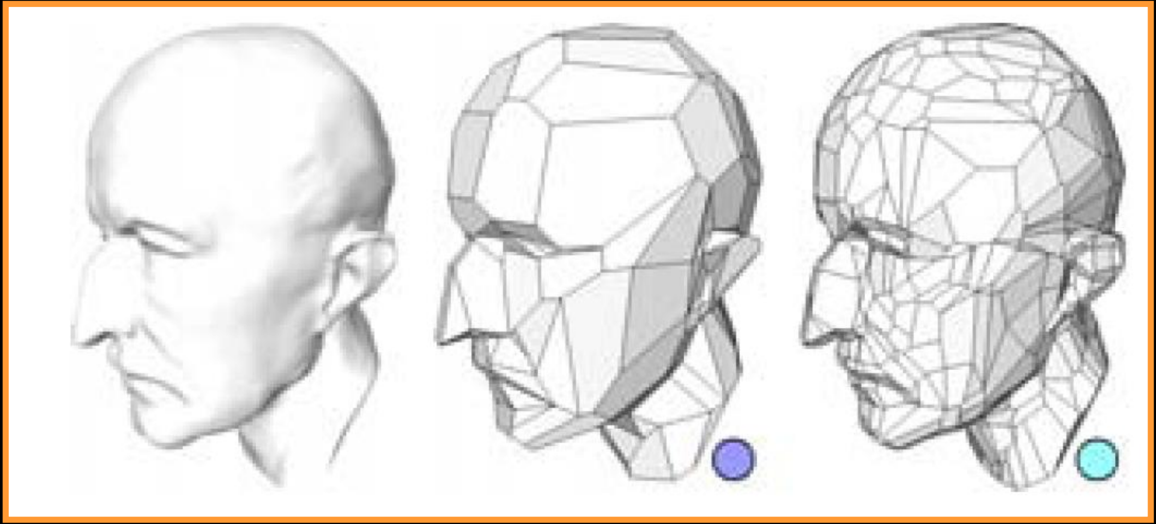


Motivation

Applications:

- Analysis
- ➢ Representation
- Recognition
- Collision detection
- Animation
- Modeling
- etc.

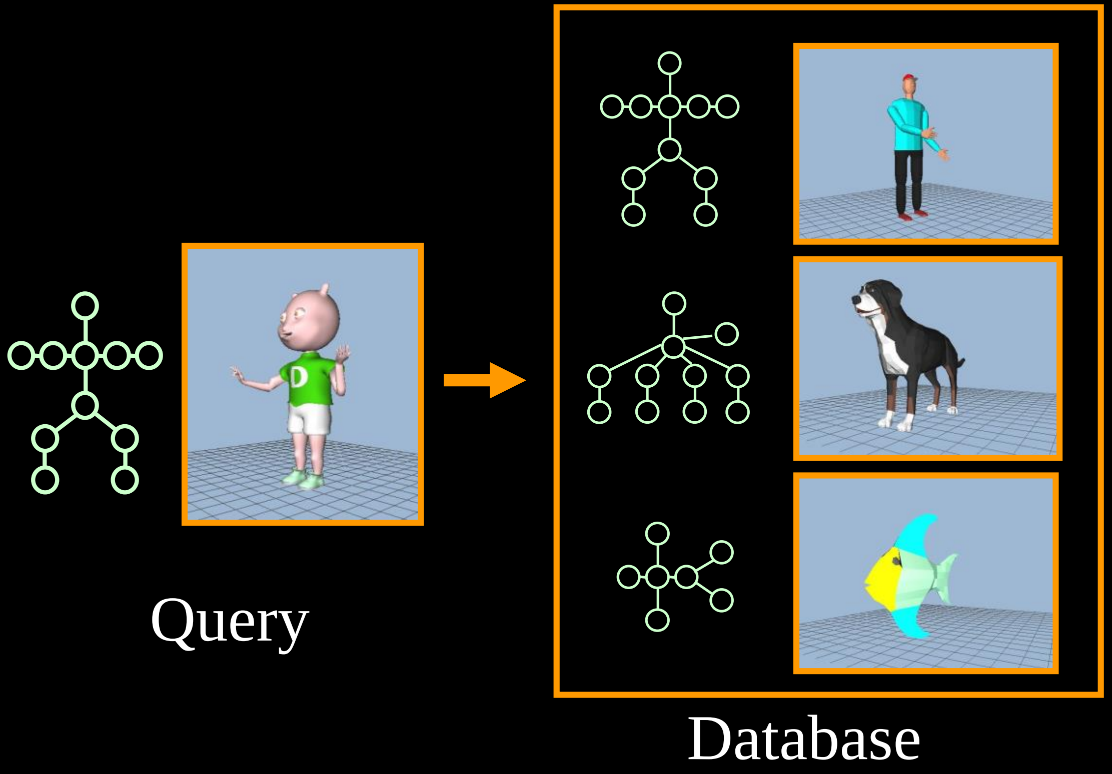
Cohen-Steiner et al.



Motivation

Applications:

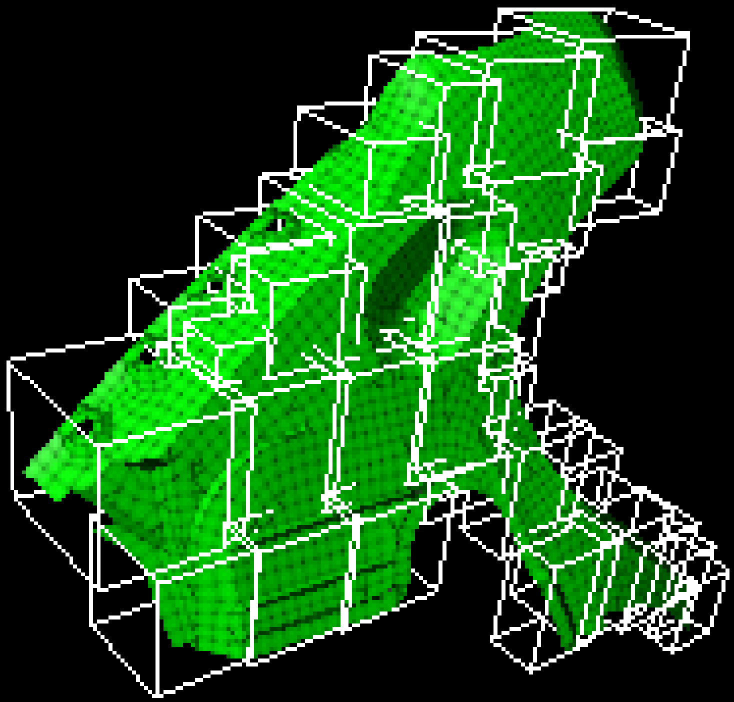
- Analysis
- Representation
- ➢ Recognition
- Collision detection
- Animation
- Modeling
- etc.



Motivation

Applications:

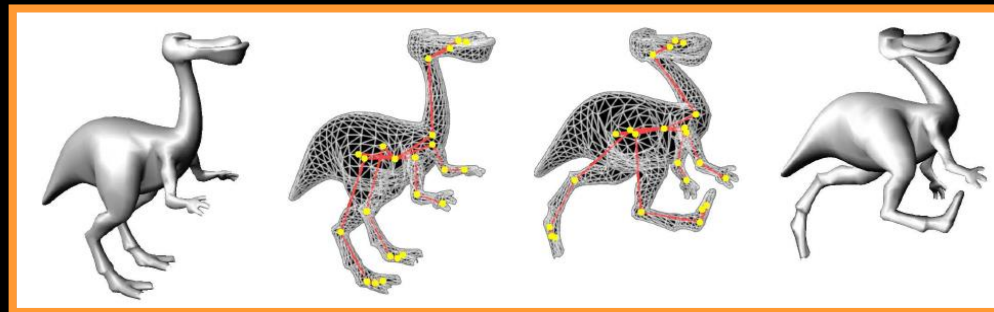
- Analysis
- Representation
- Recognition
- Collision detection
- Animation
- Modeling
- etc.

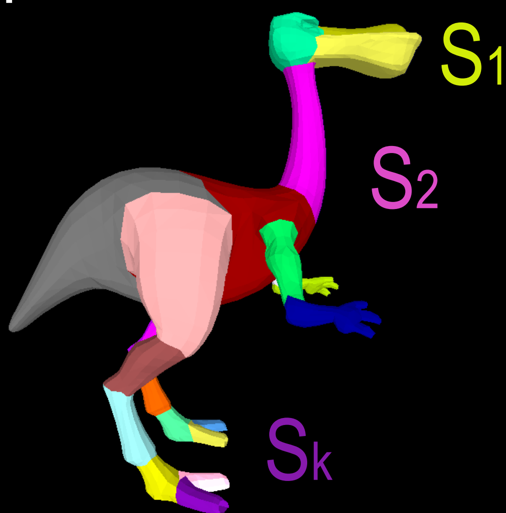


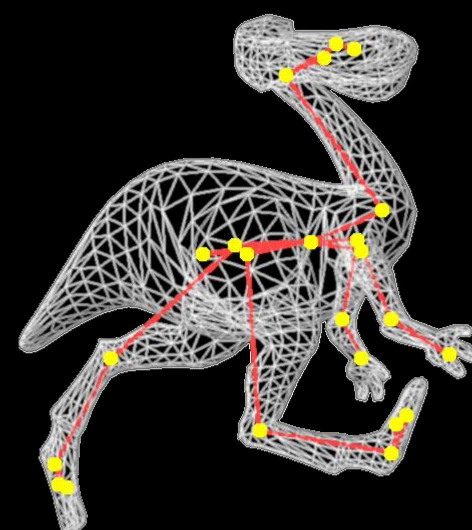
Motivation

Applications:

- Analysis
- Representation
- Recognition
- Collision detection
- ➢ Animation
- Modeling
- etc.







Katz & Tal

Motivation

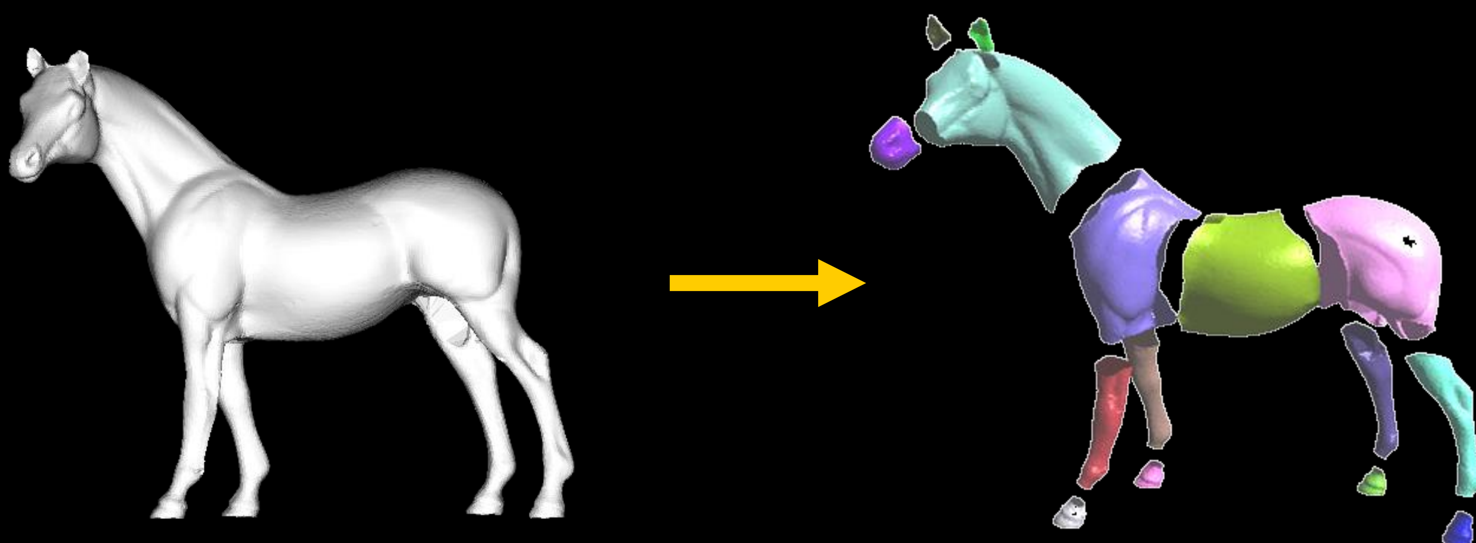
Applications:

- Analysis
- Representation
- Recognition
- Collision detection
- Animation
- ➢ Modeling
- etc.

Problem Statement

Optimization formulation:

- Given: a mesh M = {V,E,F}
- Create: a set S of submeshes M_i that partition the faces of M into disjoint subsets that minimize an objective function J under a set of constraints C



Shamir

Outline

Constraints

Objective function

Algorithmic strategies

Evaluation

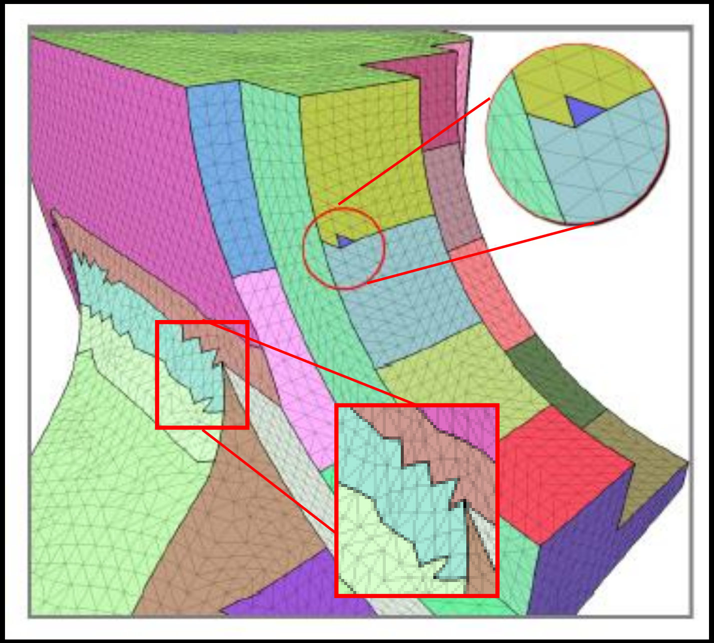
Constraints

Cardinality

- Not too small and not too large or a given number (of segment or elements)
- Overall balanced partition

Geometry

- Size: area, diameter, radius
- Convexity, Roundness
- Boundary smoothness

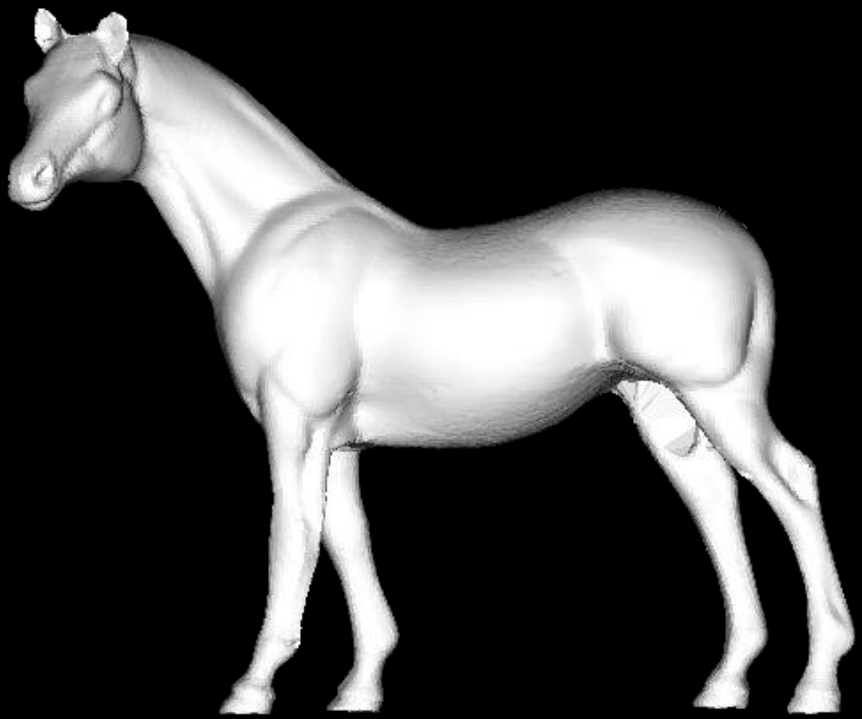


Topology

- Connectivity (single component)
- Disk topology

Objective Function

Object function J says how “good” a segmentation is …

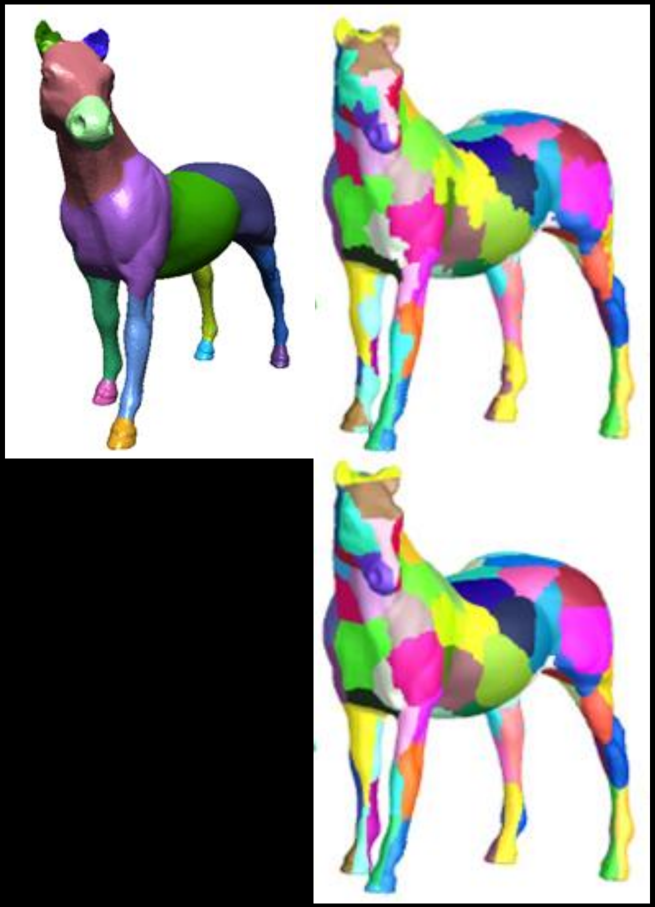


What properties define a good segmentation of this horse?

Objective Function

Object function J says how “good” a segmentation is …

- Number of segments?
- Surface properties?
- Boundary properties?
- Global shape properties?
- Match examples?
- Semantics?
- etc.

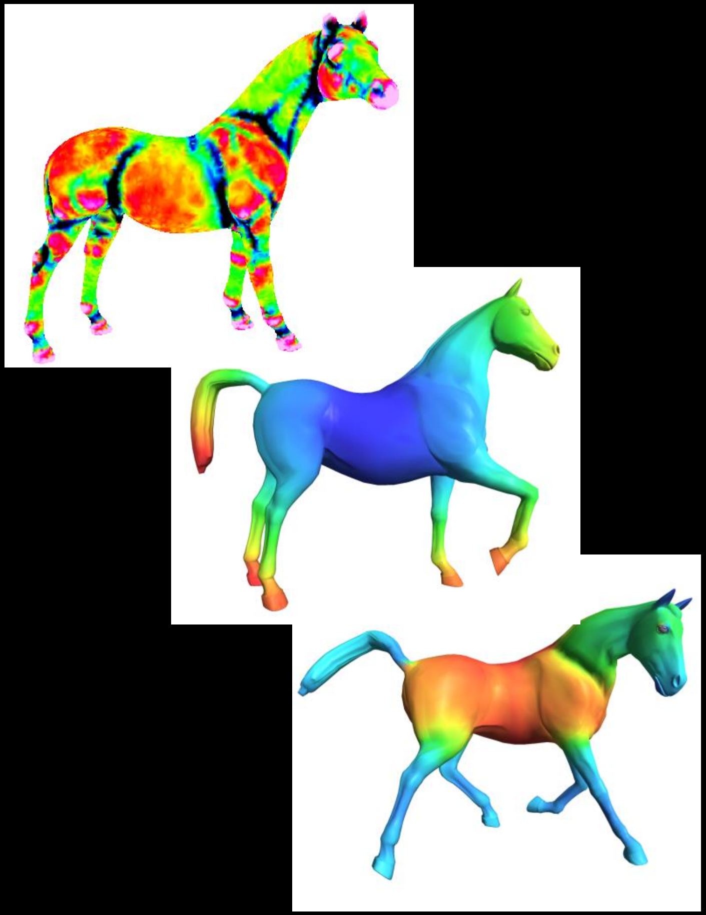


Shamir

Objective Function

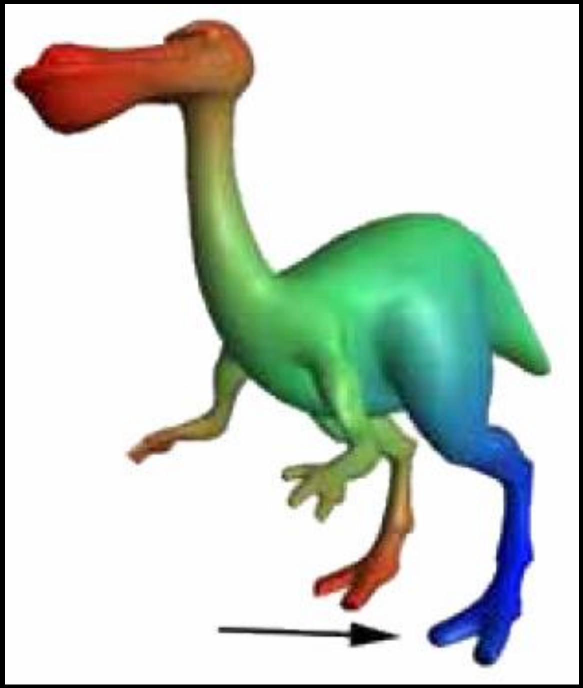
Mesh attributes to consider:

- Distances
- Normal directions
- Smoothness, curvature
- Shape diameter
- Distance to proxies
- Convexity
- Symmetry
- etc.

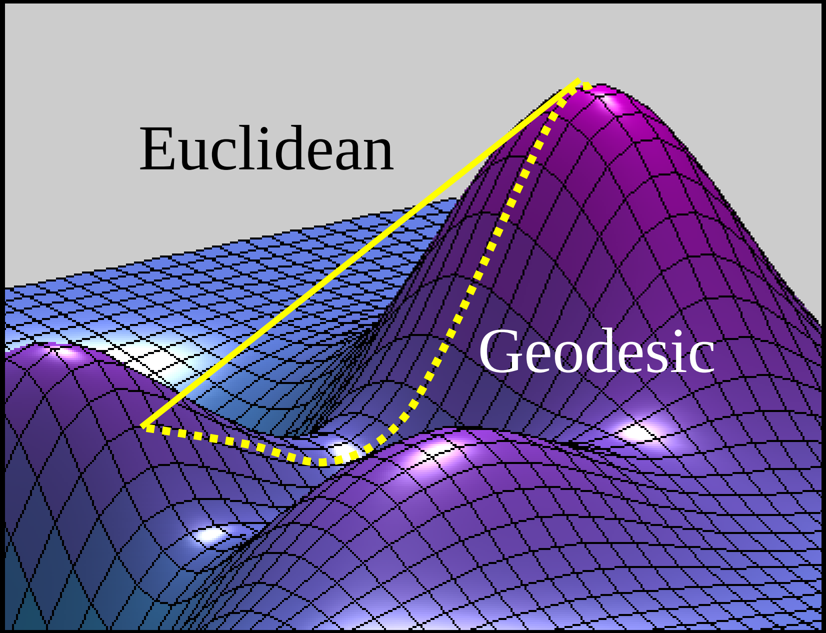


Distances

Triangles in same segment ought to be close



Geodesic distance to point



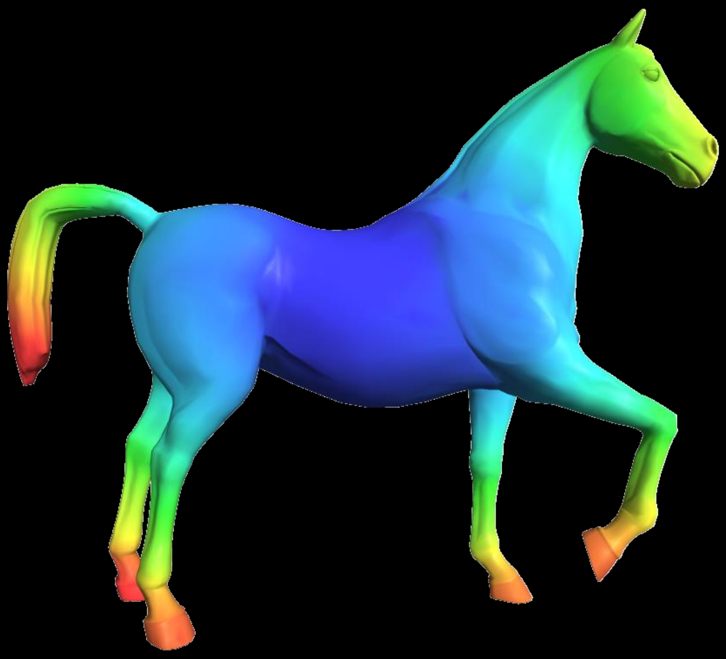
Geodesic vs. Euclidean distance

Shamir

Distances

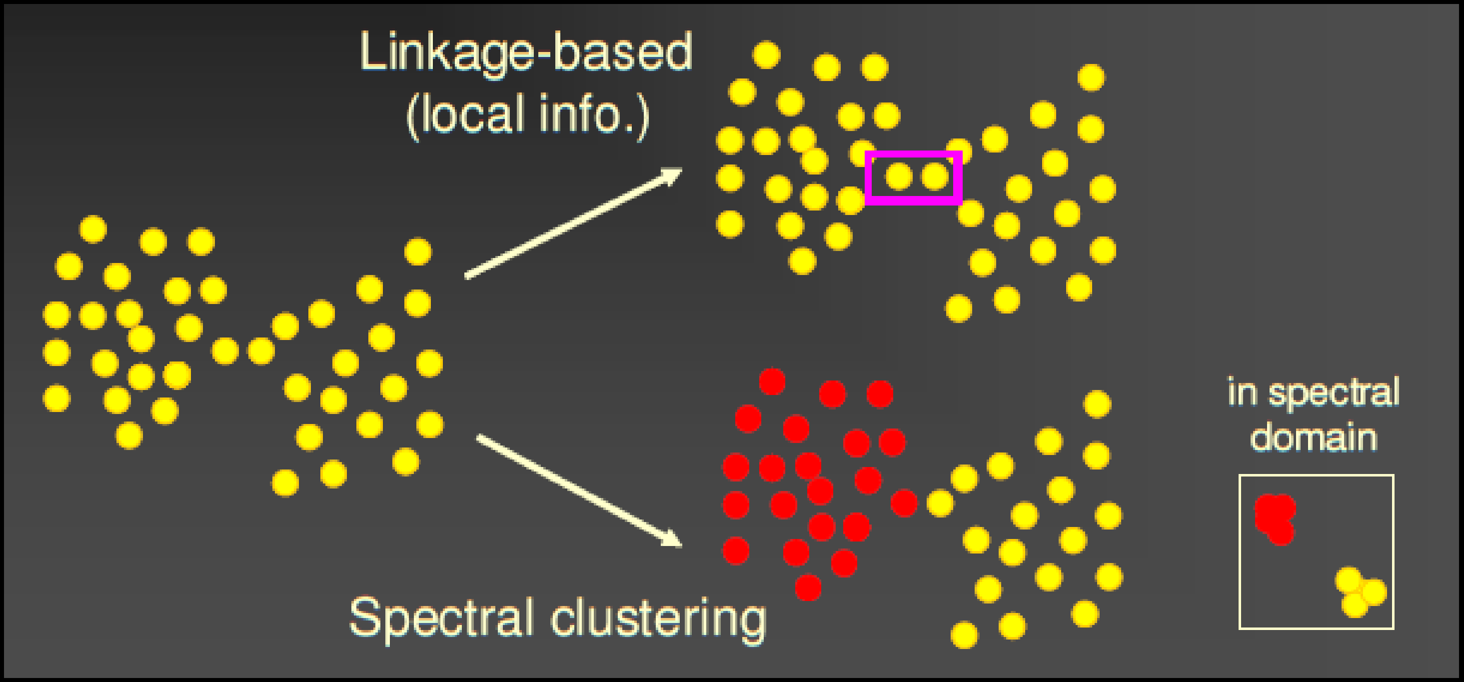
Triangles in same segment ought to be close

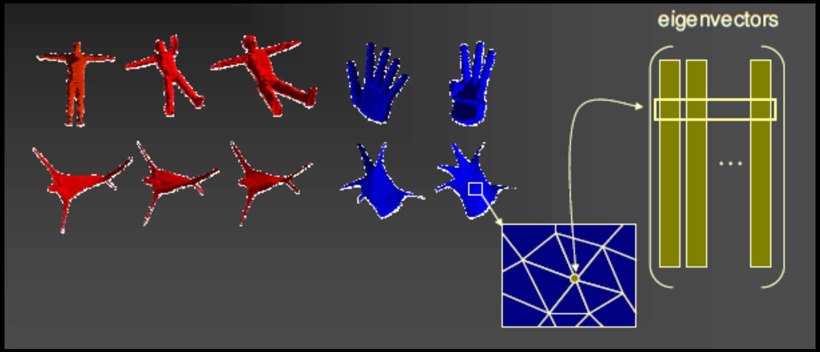
Discontinuities in functions of distance indicate possible boundaries

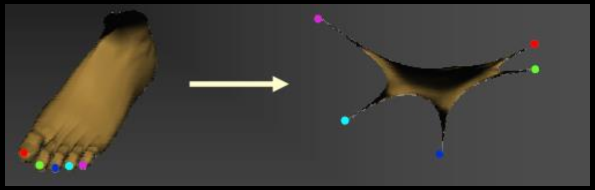


Average geodesic distance to other points

Distances with Spectral Embedding



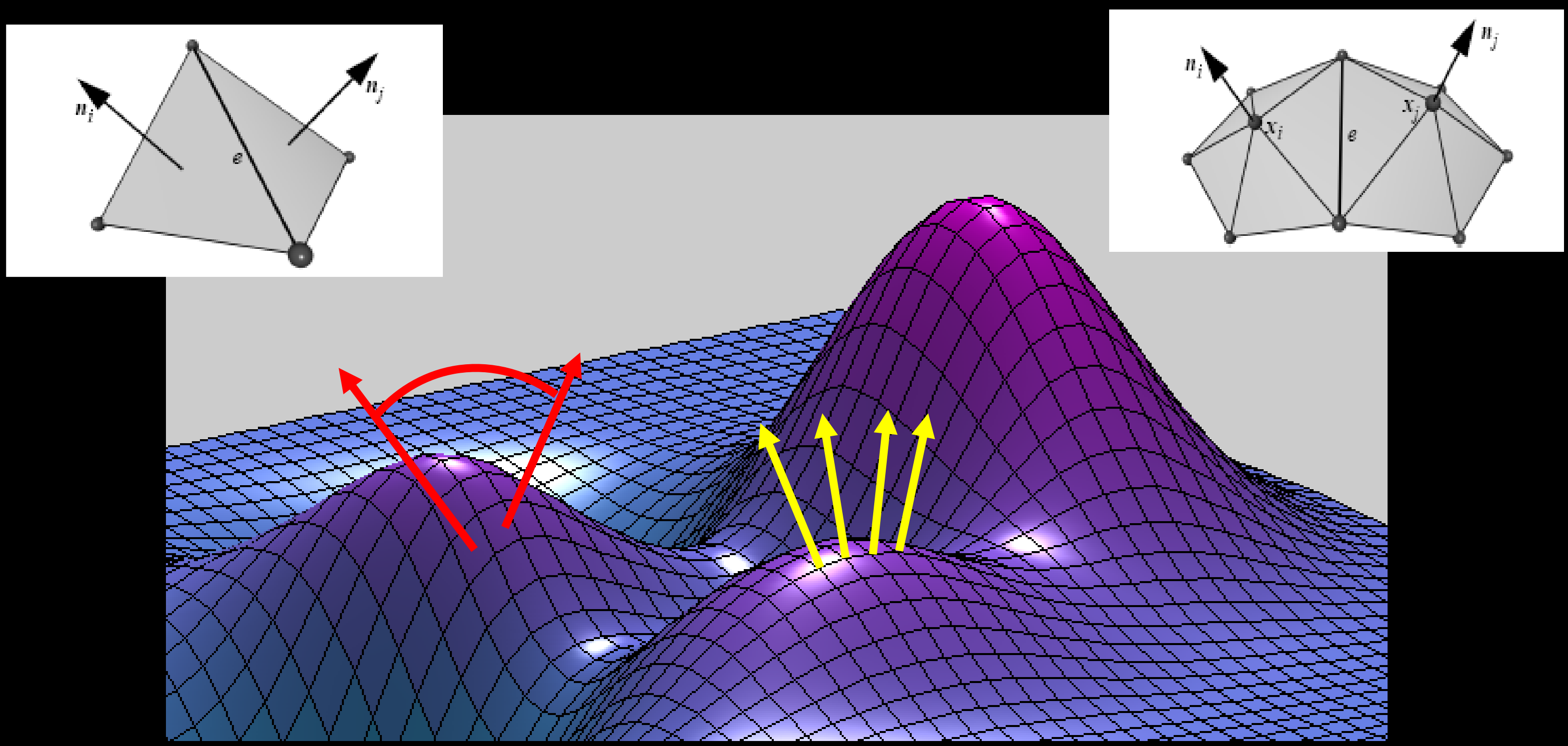




Zhang

Normal direction, Dihedral Angles

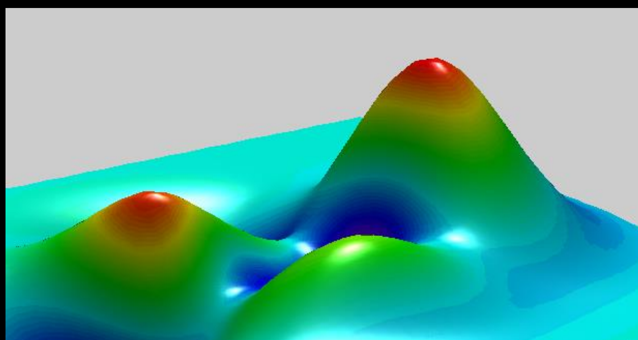
Triangles in same segment ought to have normals that are: similar (planar)?, continuous (no creases)?



Shamir

Smoothness, Curvature

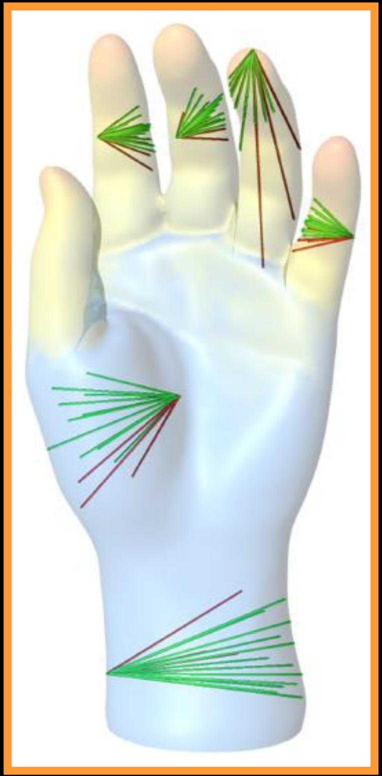
Concave creases indicate good segmentation boundaries

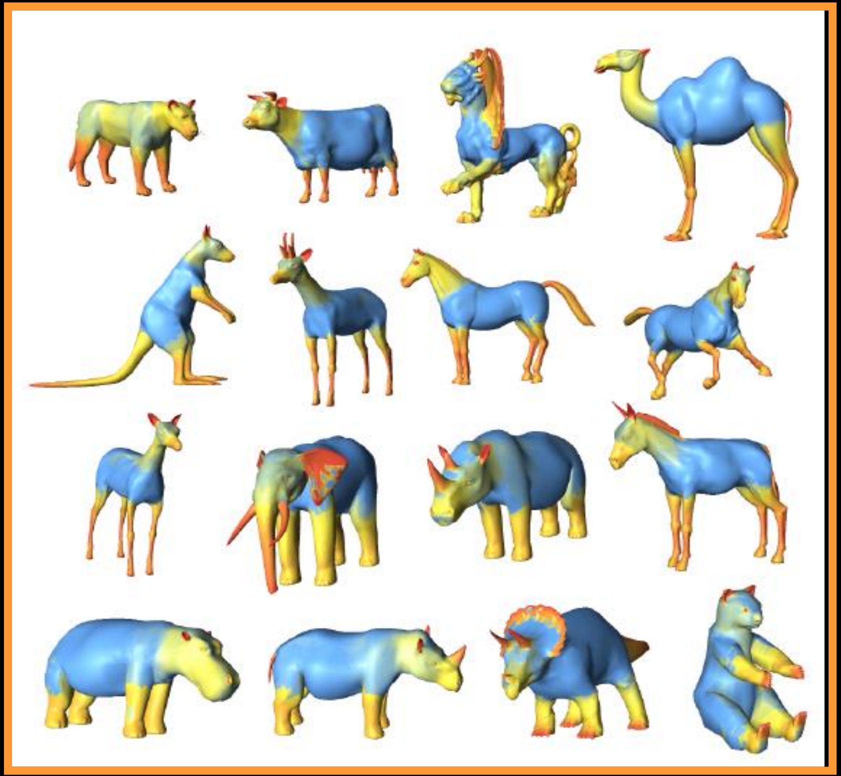


Shamir

Diameter

Distinguish between thin and thick parts in a model

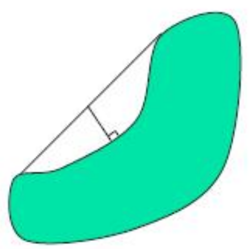




Convexity

Parts generally should be convex and compact

$$\textbf{Convexity} = \frac{\sum_{t \in P} dist(t, C(P)) \cdot area(t)}{\sum_{t \in P} area(t)},$$

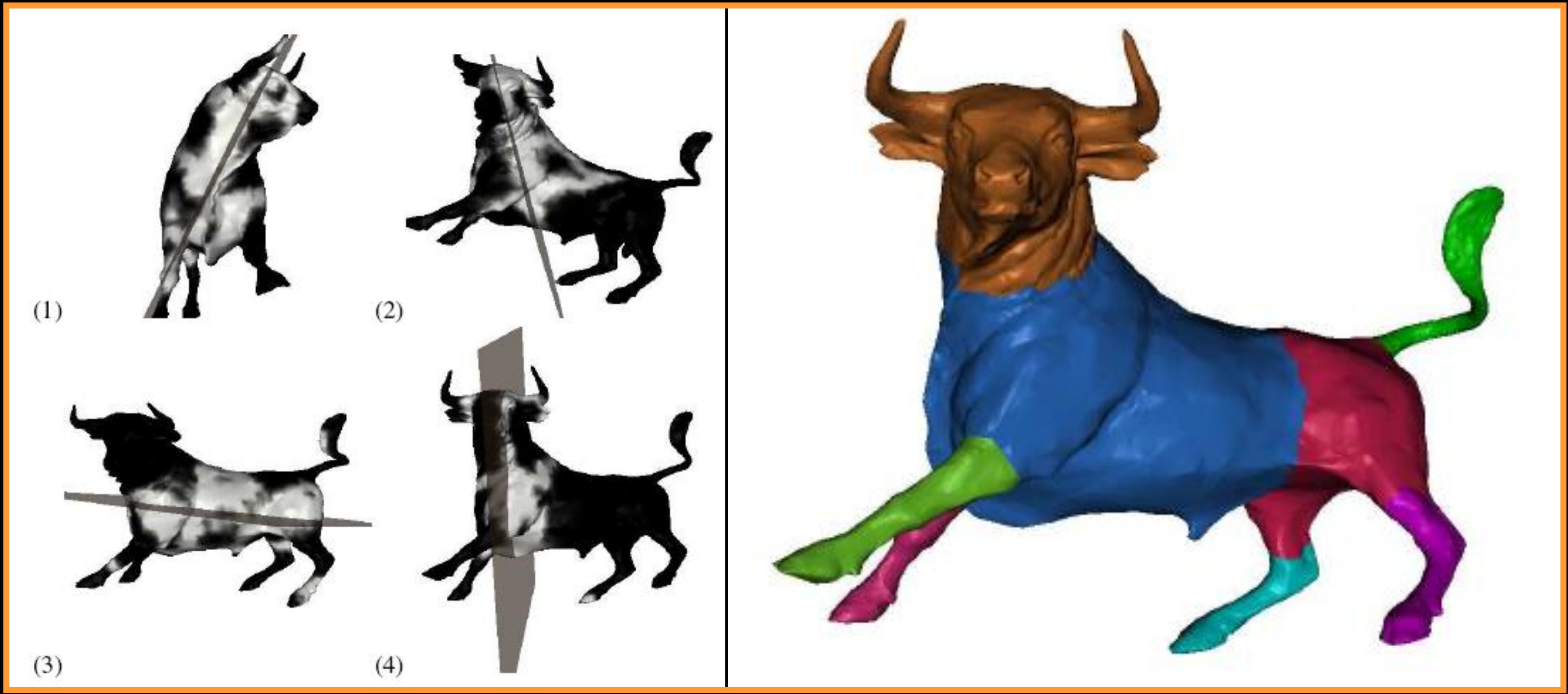


$$\textbf{Compactness} = \frac{area(C)}{volume(C)^{2/3}}$$

Kraevoy

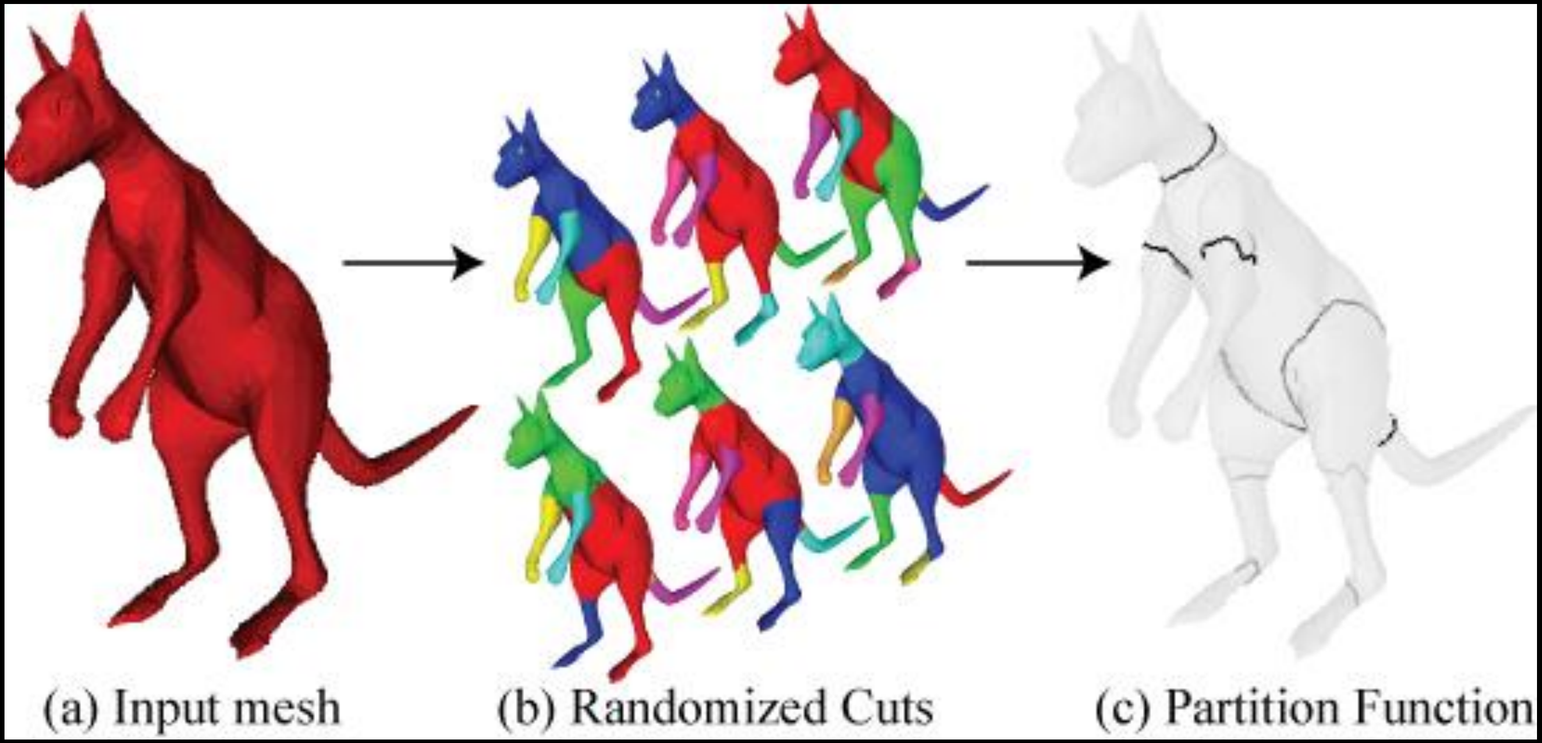
Symmetry

Segments should be locally symmetric



Combining many properties

Randomized cuts

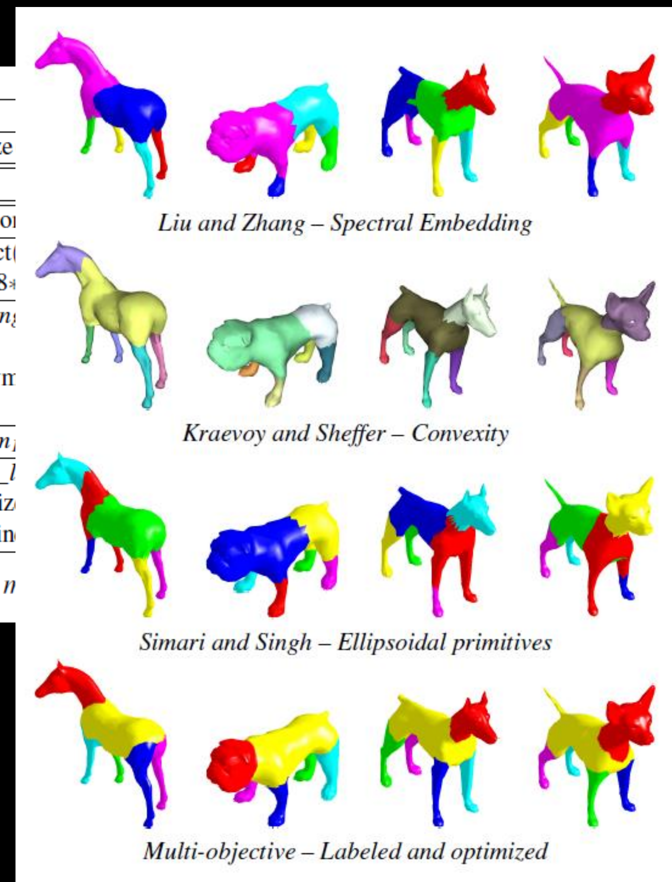


Segmenting and Labeling

Multi-objective mesh segmentation

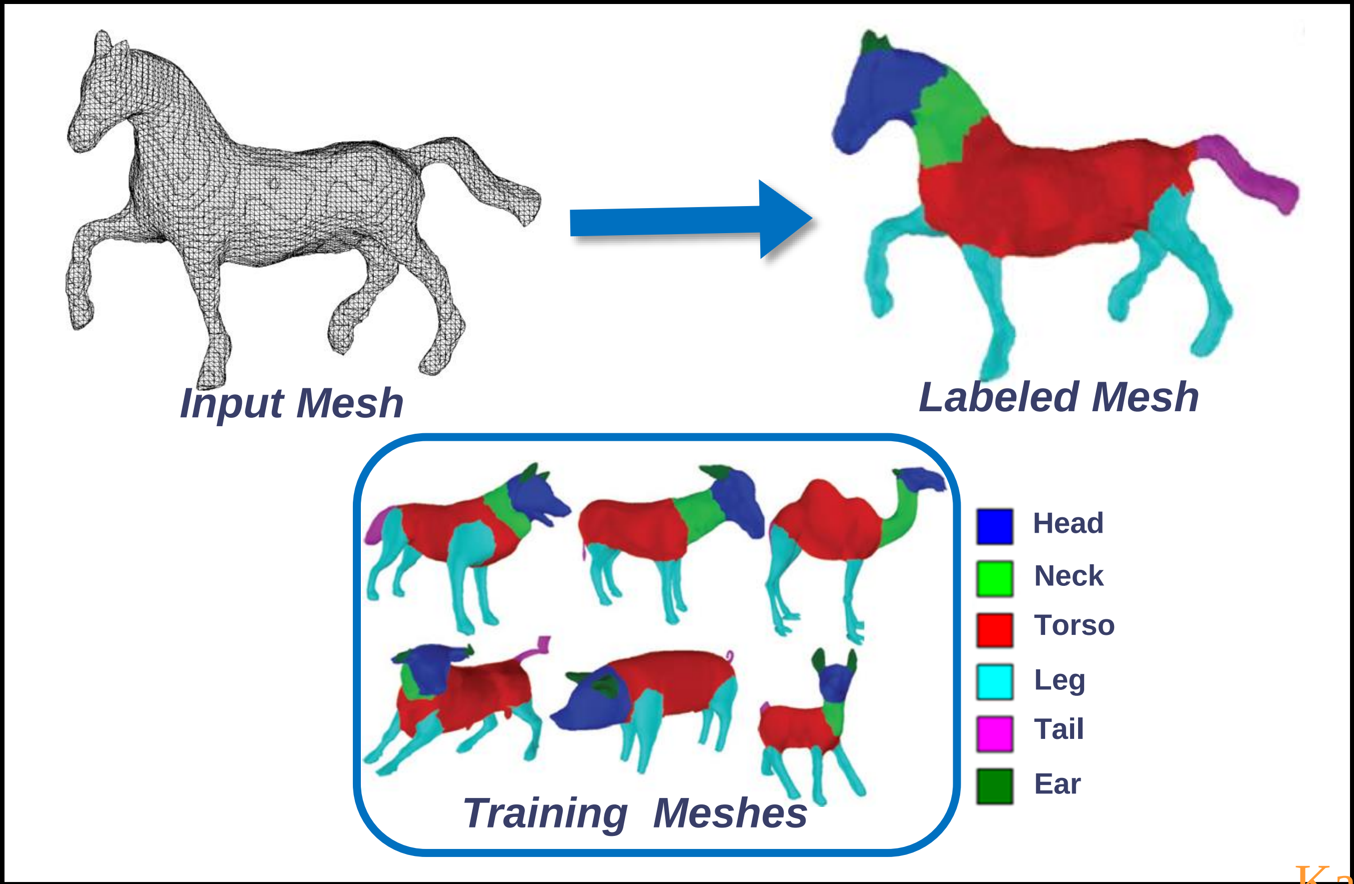
	Summary of objectives used	
	narrow(·), flat(·), planarsymmetric(·), ellipsoidal(·), perpendicular(·, ·), similarsize	
Model	**Labels**	**Segmentation objectives**
Hammer	*handle*, *head*	5∗narrow(*handle*), perpendicular(*handle*, *head*), co
Quadruped	*head*, *body*, *leg*$_1$, …, *leg*$_4$	$\forall_i$narrow(*leg*$_i$), similarsize(*leg*$_1$, …, *leg*$_4$), compact(In dogs, compactness of head is emphasized with 8∗
Bird	*body*, *wing*$_1$, *wing*$_2$, *tail*	narrow(*body*), $\forall_i$flat(*wing*$_i$), similarsize(*wing*$_1$, *win* compact(*tail*), 10∗convexparts(*Seg*) Constraints: body and tail lie on plane of global sym are reflected from *wing*$_1$.
Octopus	*head*, *arm*$_1$, …, *arm*$_8$	ellipsoidal(*head*), $\forall_i$narrow(*arm*$_i$), similarsize(*arm*
Humanoid	*head*, *torso*, *arm_left* *arm_right*, *leg_left*, *leg_right*	narrow(*arm_left*), narrow(*arm_right*), narrow(*leg_l* compact(*head*), similarsize(*arm1*, *arm2*), similarsiz Subparts (upper arm, forearm, hand, etc.) are obtain

Figure 13: *Objectives used to obtain segmentations of each m*



Segmenting and Labeling

Use conditional random field to learn segments and labels based on examples



Kalogerakis

Outline

Constraints

Objective function

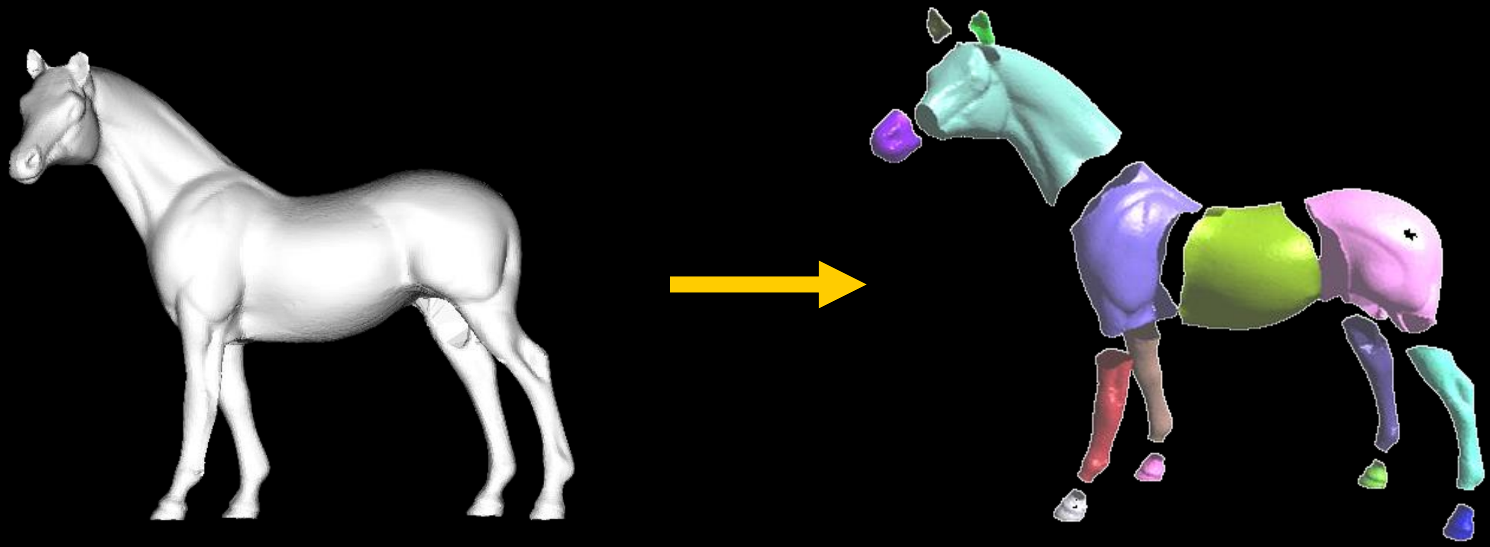
Algorithmic strategies

Evaluation

Algorithmic Strategies

Segmentation problem:

- Given: a mesh M = {V,E,F}
- Create: a set S of submeshes M_i that partition the faces of M into disjoint subsets.



Shamir

Algorithmic Strategies

If $|M| = n$ and $|S| = k$, then the search space of possible mesh decompositions is of order k^n.

- NP-complete
- Must revert to approximation algorithm

Segmentation as Clustering

The basic segmentation problems can viewed as assigning primitive mesh elements to sub meshes

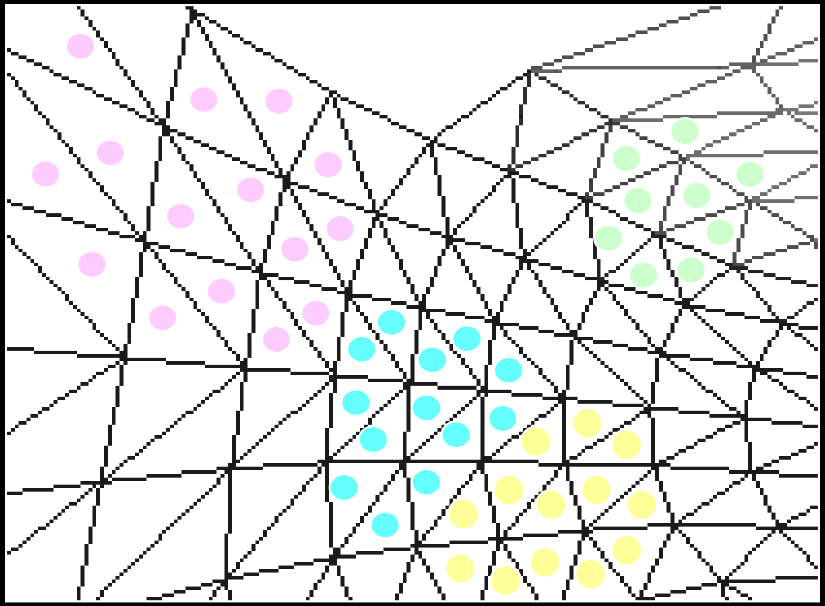
- Clustering problem
- Well-studied in machine learning

Most segmentation strategies have basis in classic clustering algorithms:

- Region growing (local greedy)
- Primitive fitting (model-based)
- Hierarchical clustering (global greedy)
- K-means (iterative)
- Graph Cut

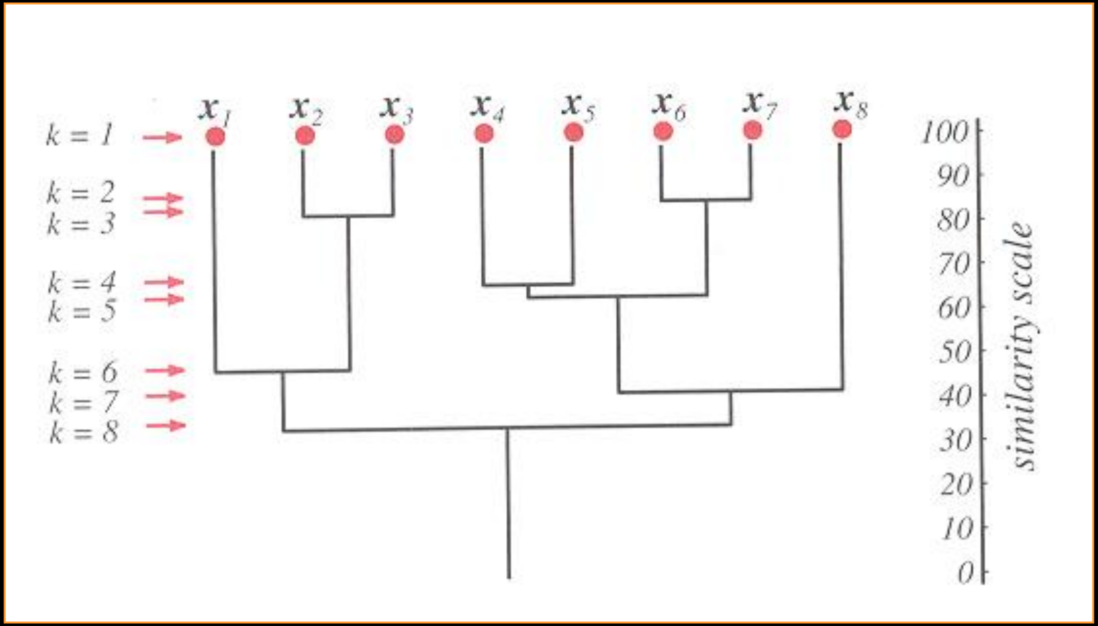
Shamir

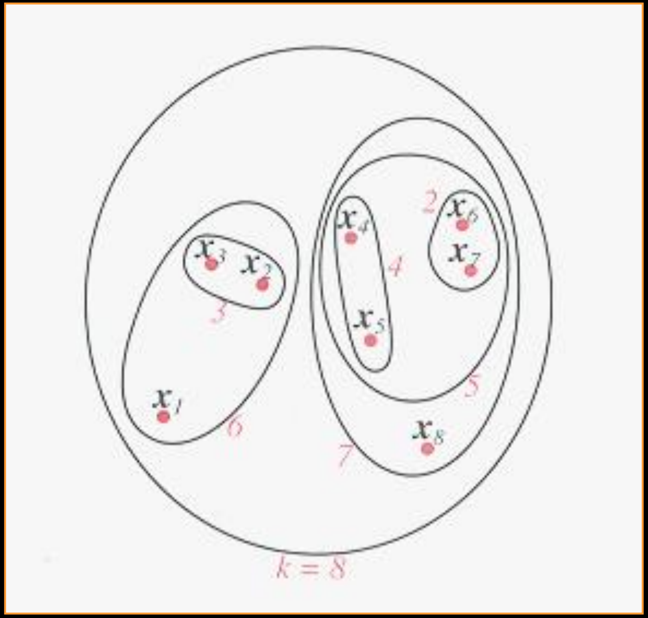
Region Growing



Shamir

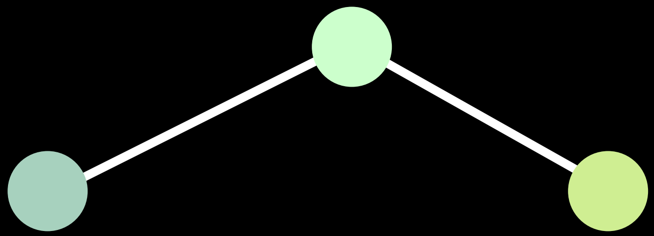
Hierarchical Clustering

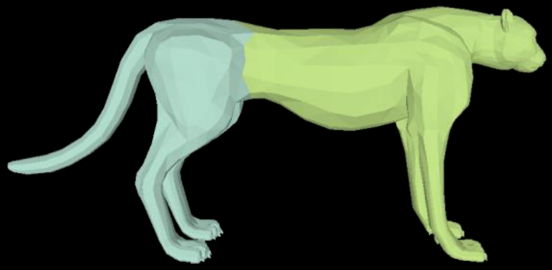




Duda

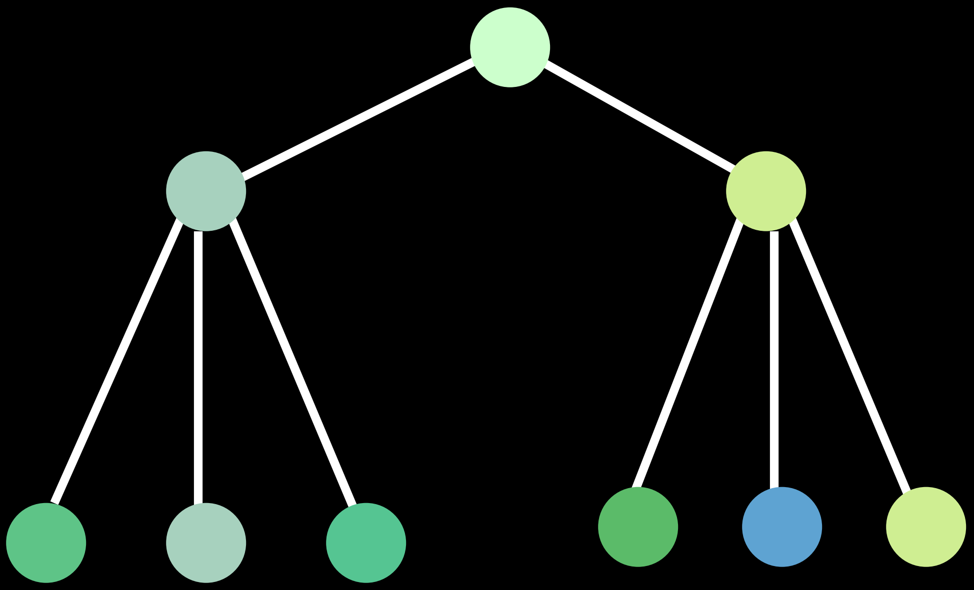
Hierarchical Clustering

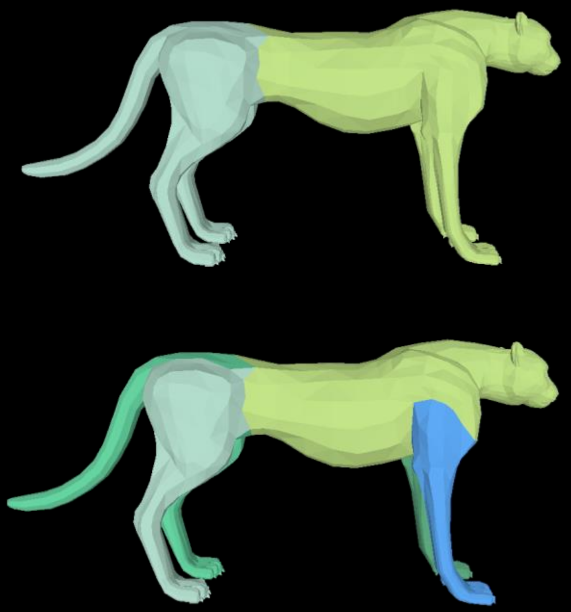




Katz

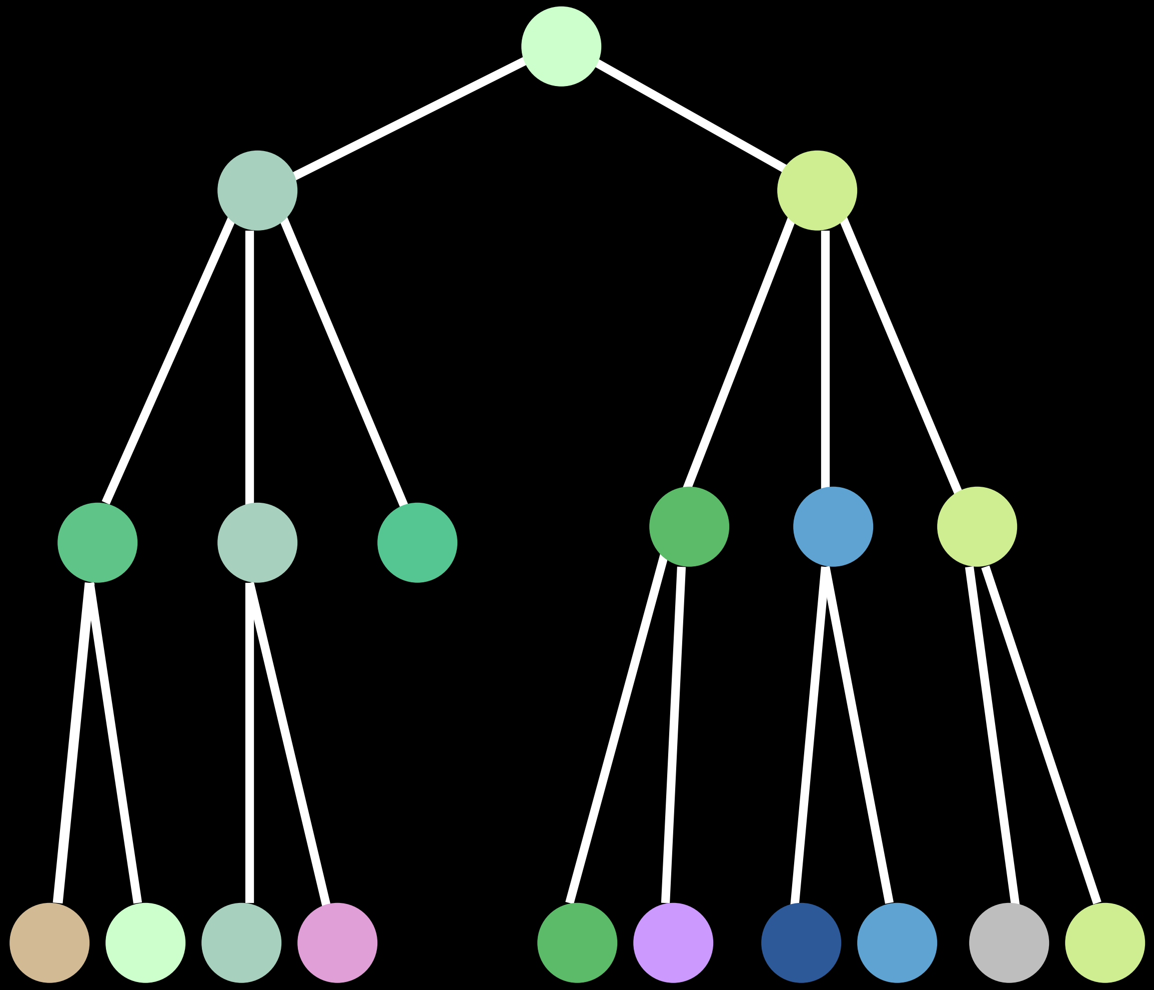
Hierarchical Clustering

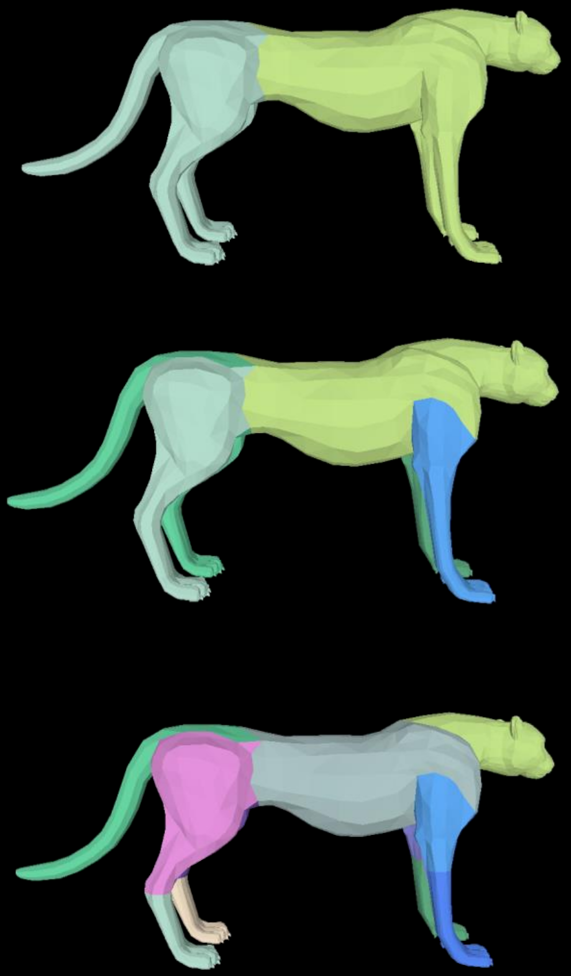




Katz

Hierarchical Clustering





Katz

Lloyd (k-means)

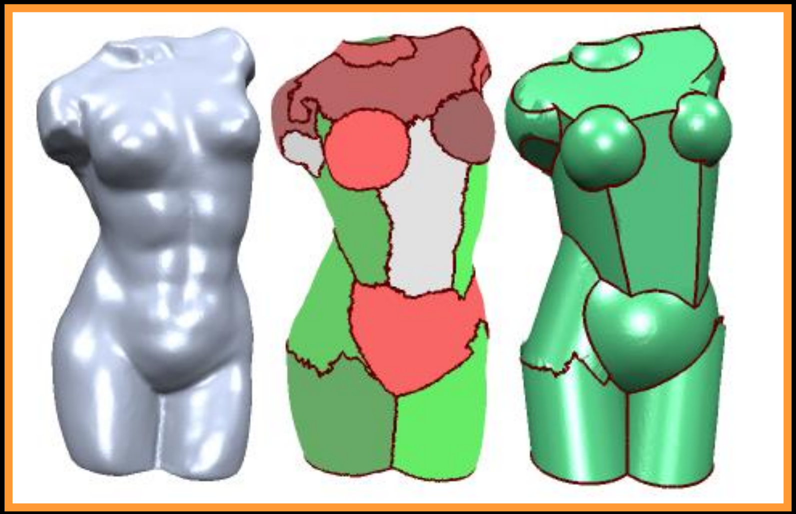
Shalfman

Primitive Fitting

Find set of primitives that best approximates shape and map triangles to primitives

Planes

Cylinders

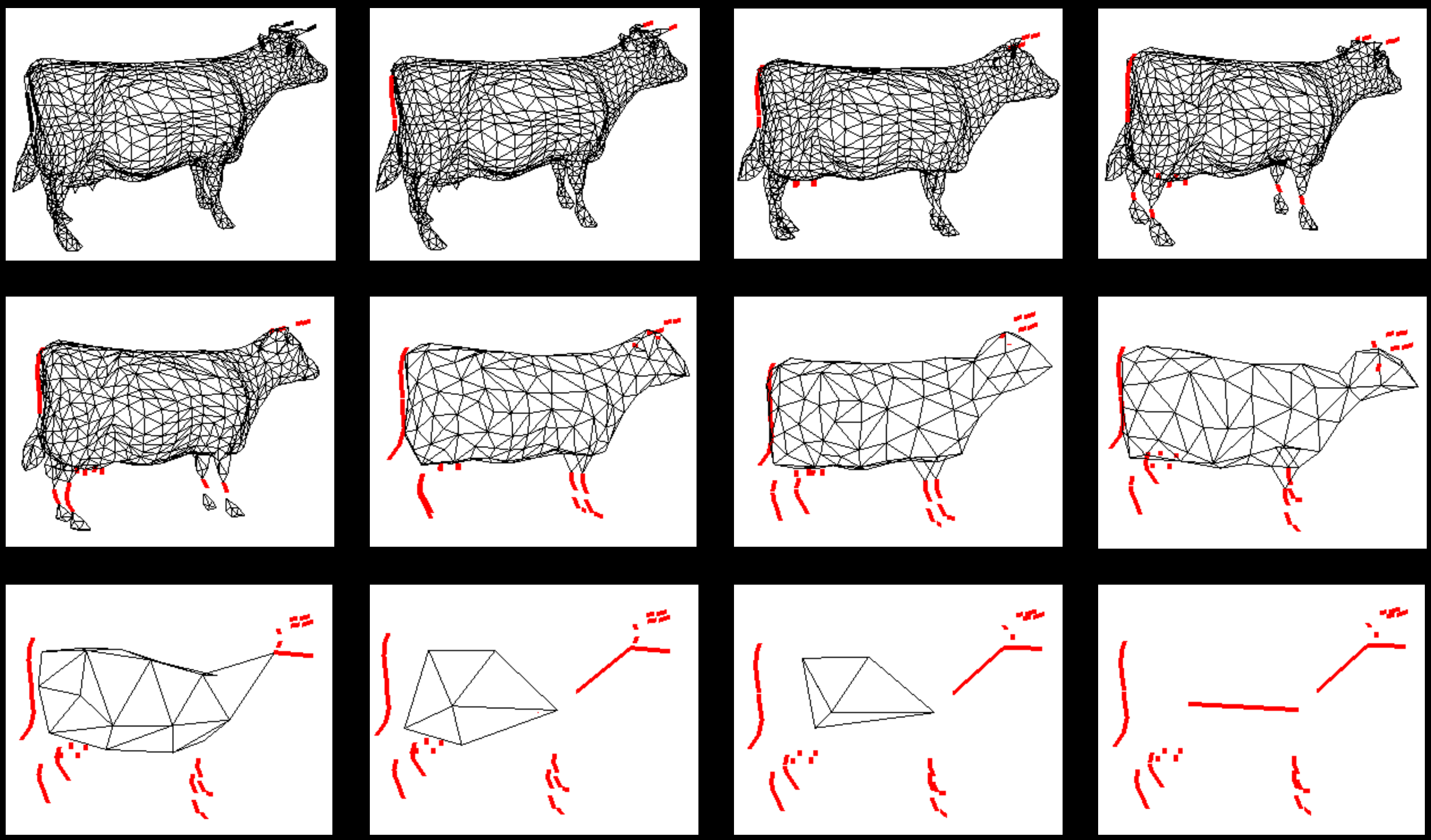


Spheres, cylinders, & rolling ball surfaces

Shamir

Simplification

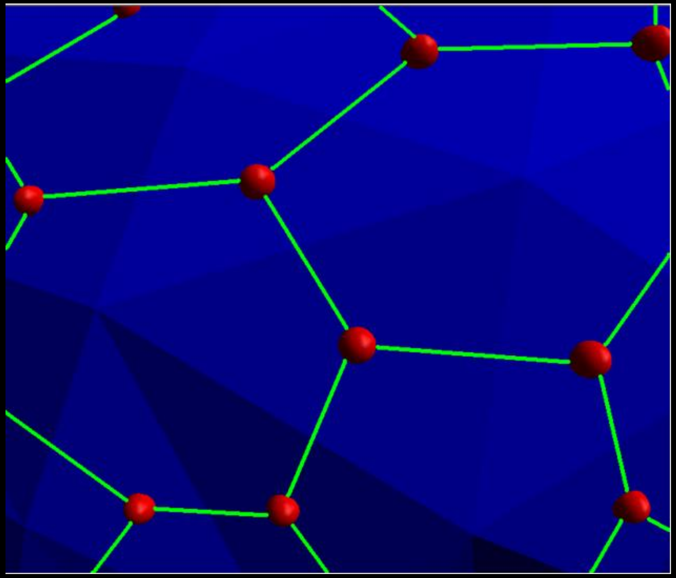
Iterative edge collapses



Graph Cuts

Define a graph where each node is an element and the edges hold weights according to the distances between the elements.

Example: dual graph and the weight is the dihedral angle.

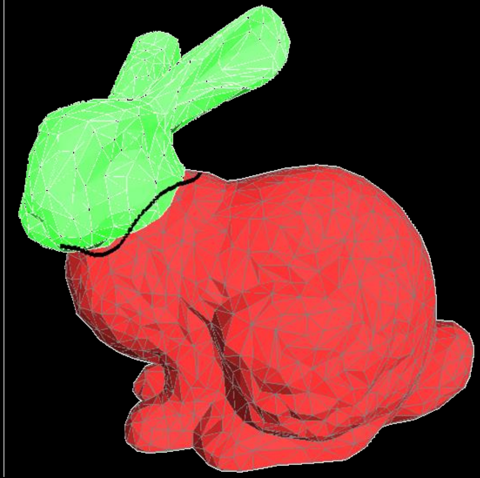


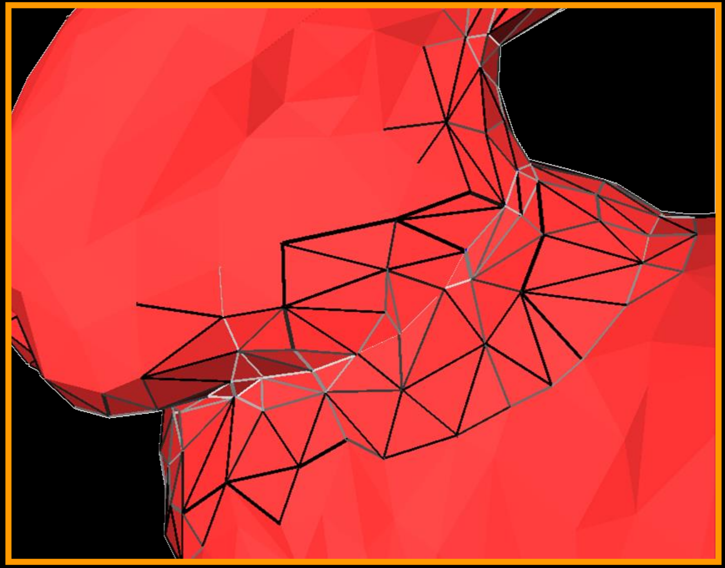
Shamir

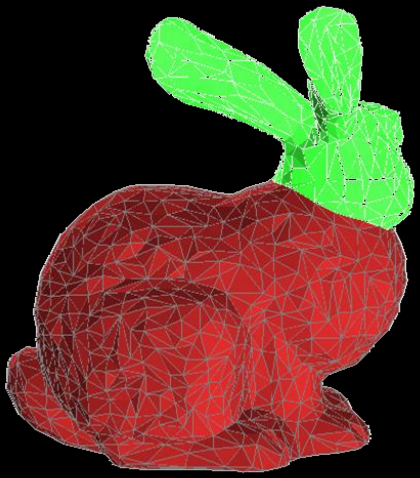
Graph Cuts

Define a graph where each node is an element and the edges hold weights according to the distances between the elements.

Example: dual graph and the weight is the dihedral angle.







Comparison of Strategies

Strategies

- Region growing
- Hierarchical
- Iterative
- Graph cut

greedier ↑

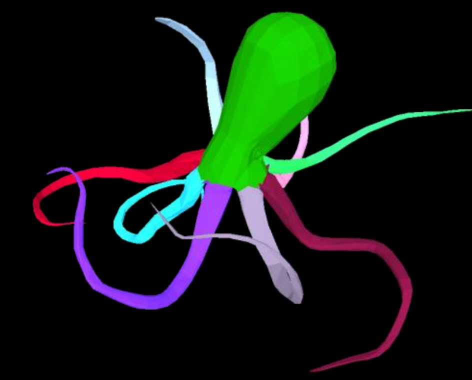
intensive ↓

Other considerations: local control, hierarchy, convergence, parametric vs. non parametric…

Shamir

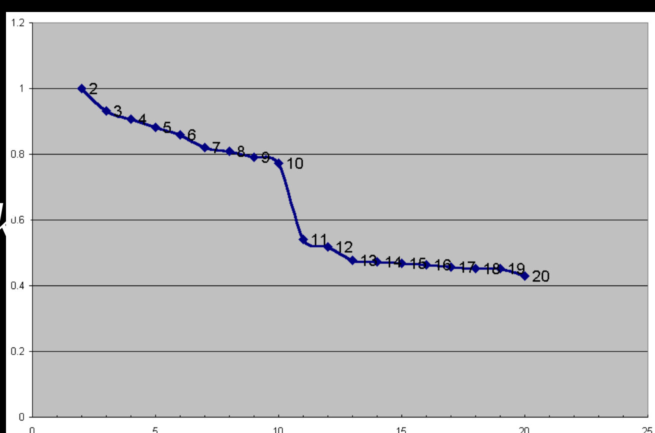
Choosing the Number of Segments

$$G(k) = \min_{i<k}(Dist(REP_k, REP_i))$$



G

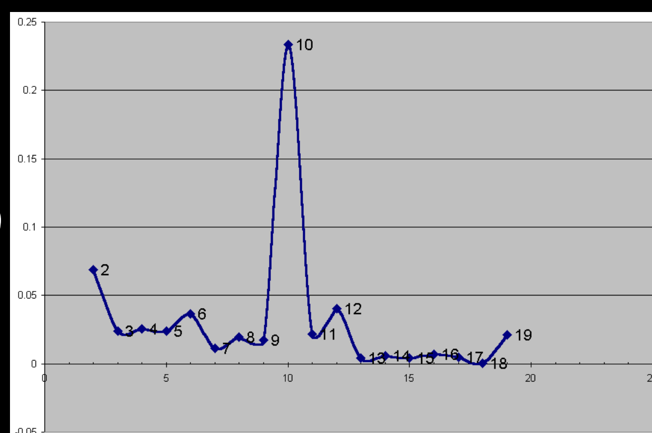
G(k



k

G'

G'(k)



k

Katz

Outline

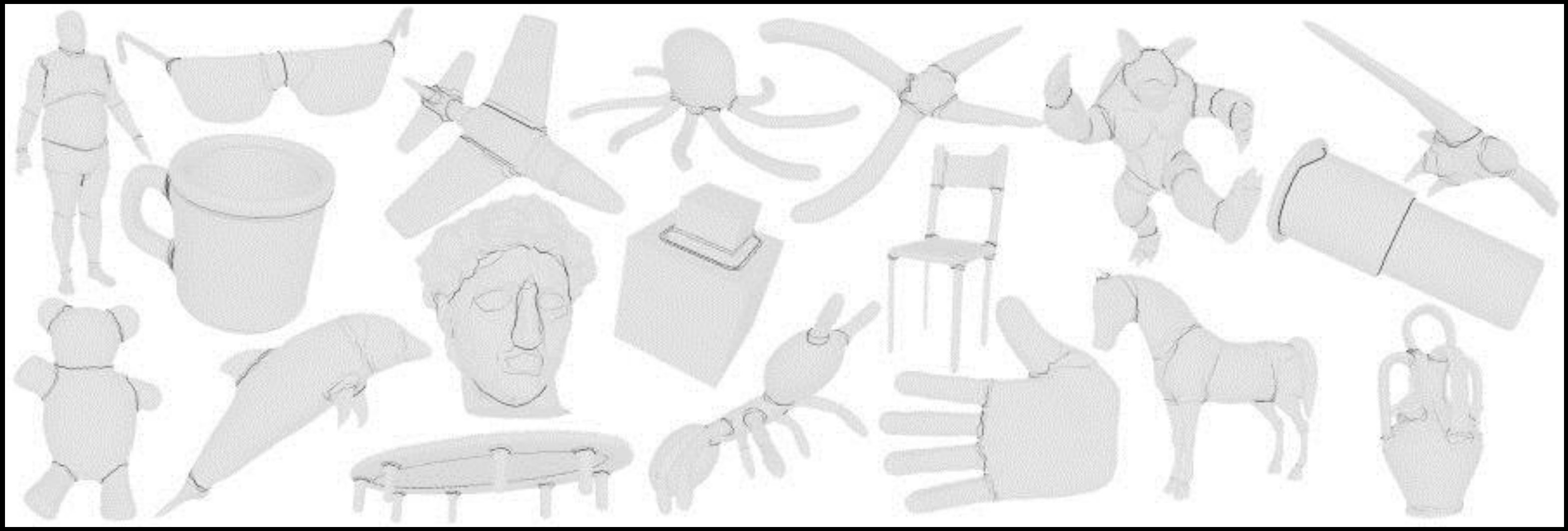
Constraints

Objective function

Algorithmic strategies

Evaluation

Benchmark for Mesh Segmentation



Chen09