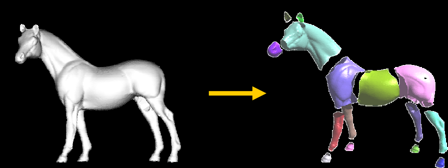
Mesh Segmentation

Thomas Funkhouser

(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.

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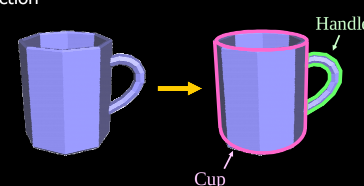

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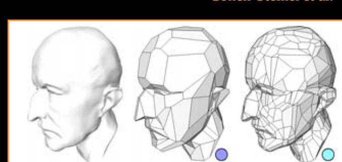
Cohen-Steiner et al.



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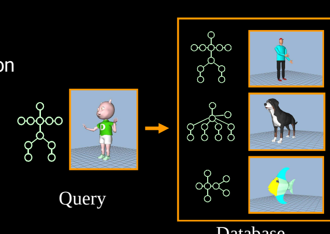

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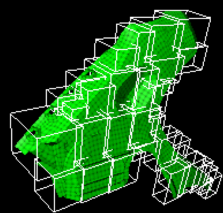

Tal & Frisch

Motivation

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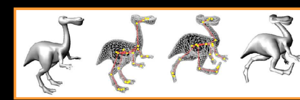

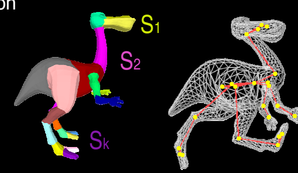

Katz & Tal

Motivation

Applications:
- Analysis
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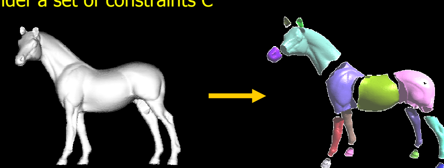
- etc.

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



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Outline

Constraints

Objective function

Algorithmic strategies

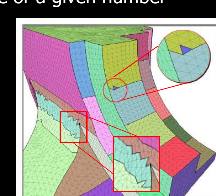
Evaluation

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



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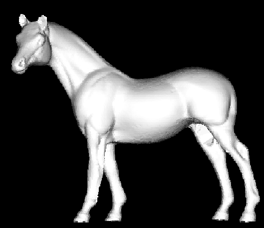
Objective Function

Object function J says how "good" a segmentation is …

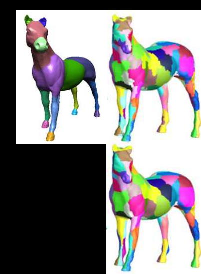


What properties define a good segmentation of this horse?

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.



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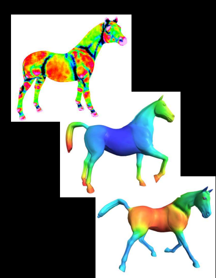
Objective Function

Mesh attributes to consider:

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



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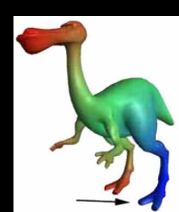
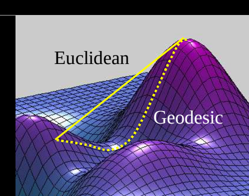
Distances

Triangles in same segment ought to be close



Geodesic distance to point



Geodesic vs. Euclidean distance

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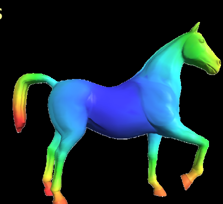
Distances

Triangles in same segment ought to be close

Discontinuities in functions of distance indicate possible boundaries



Average geodesic distance to other points

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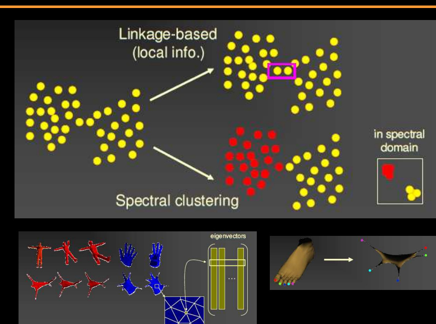
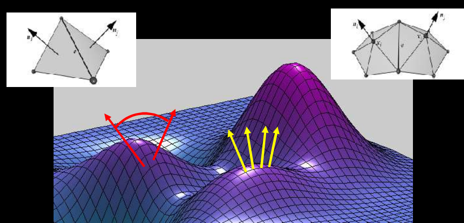
Distances with Spectral Embedding



Zhang

Normal direction, Dihedral Angles

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



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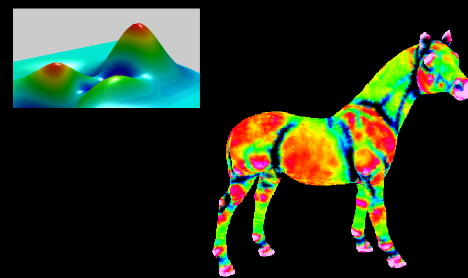
Smoothness, Curvature

Concave creases indicate good segmentation boundaries



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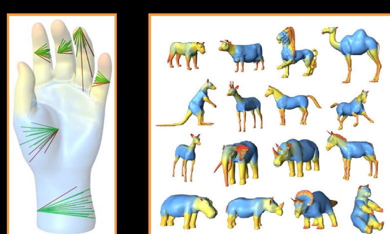
Diameter

Distinguish between thin and thick parts in a model



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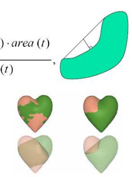
Convexity

Parts generally should be convex and compact

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

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



Kraevoy

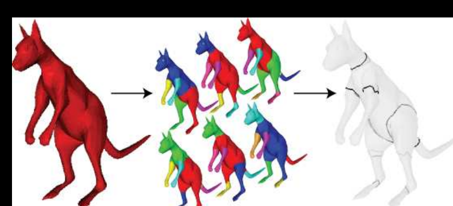
Symmetry

Segments should be locally symmetric

Podolak

Combining many properties

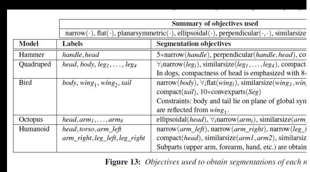
Randomized cuts



(a) Input mesh (b) Randomized Cuts (c) Partition Function

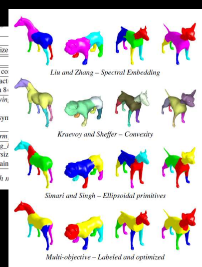
Segmenting and Labeling

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, $leg_1, \ldots, leg_4$*	$\forall_i$narrow(leg_i), similarsize($leg_1, \ldots, leg_4$), 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, $arm_1, \ldots, arm_8$*	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

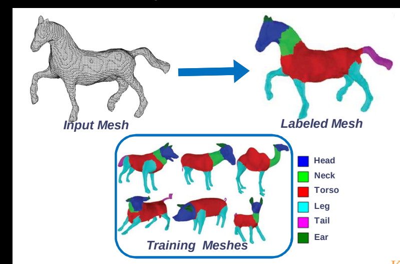
Figure 13: *Objectives used to obtain segmentations of each m*



Simari

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:

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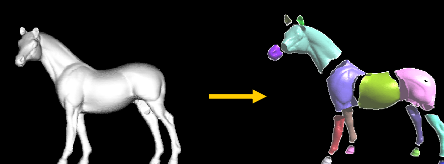

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Algorithmic Strategies

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

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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

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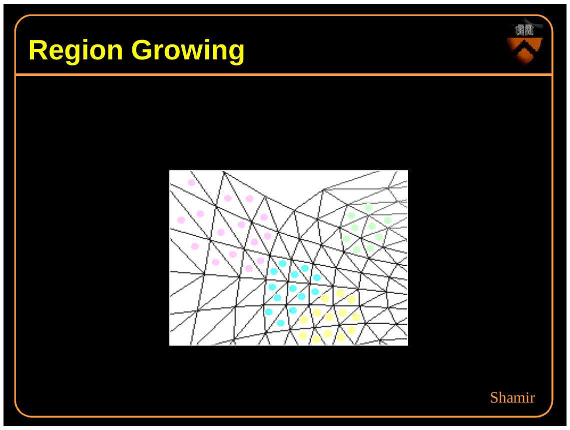
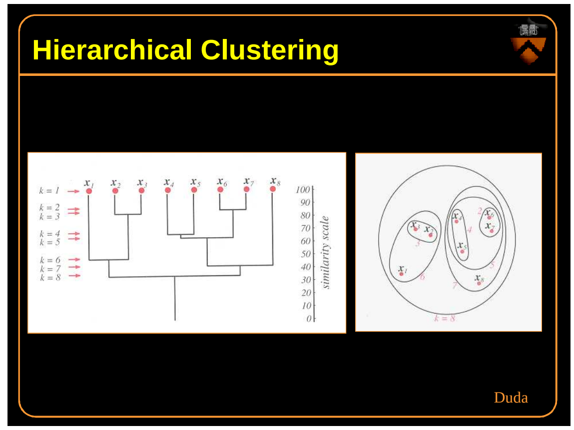
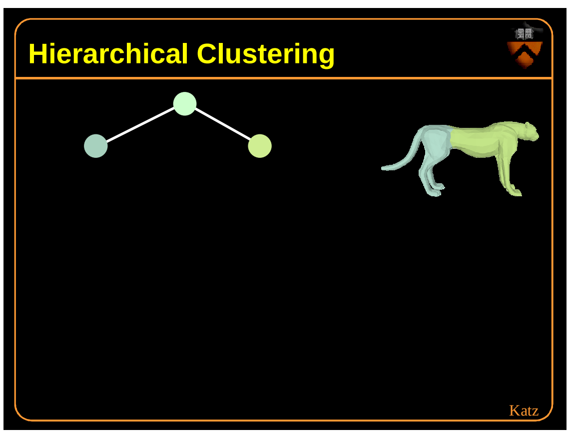
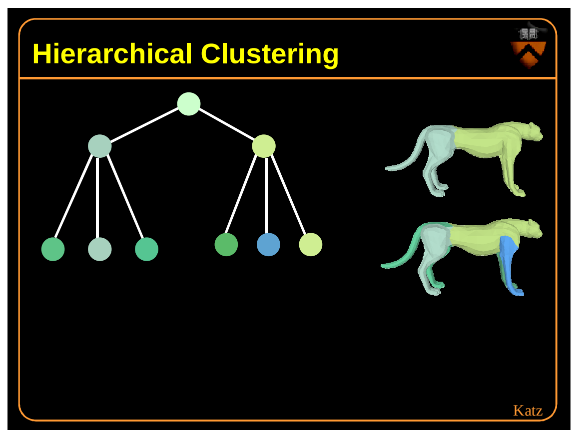

Region Growing
Shamir


Hierarchical Clustering
similarity scale
Duda


Hierarchical Clustering
Katz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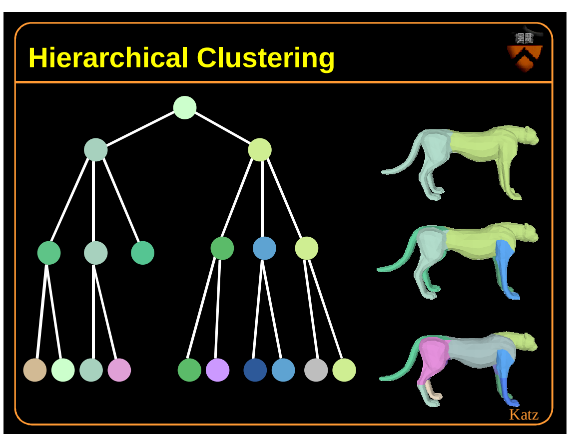
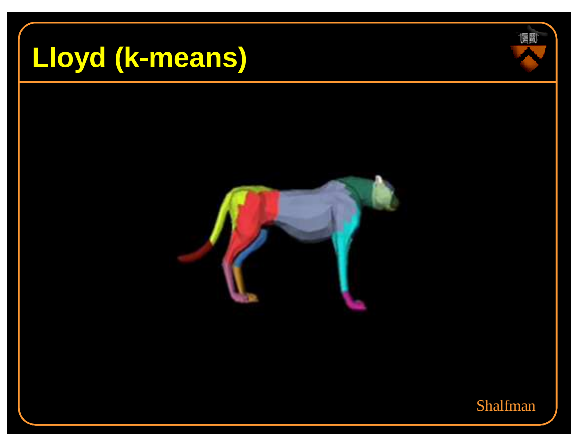
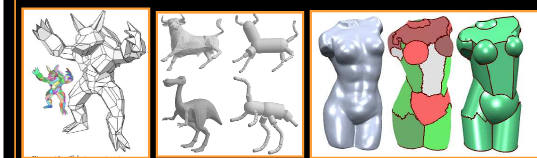

Hierarchical Clustering
Katz


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

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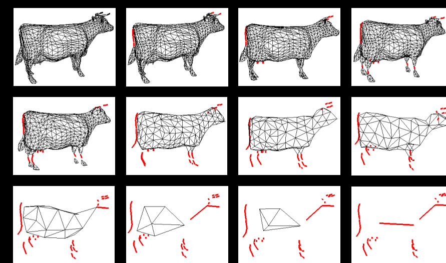
Simplification

Iterative edge collapses

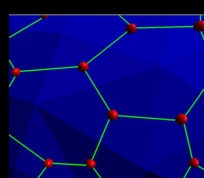


Li

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.



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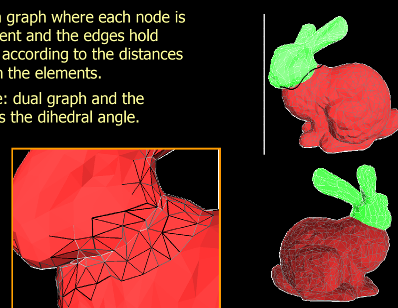

Comparison of Strategies

Strategies
- Region growing
- Hierarchical
- Iterative
- Graph cut

intensive

greedier

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

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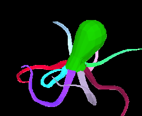
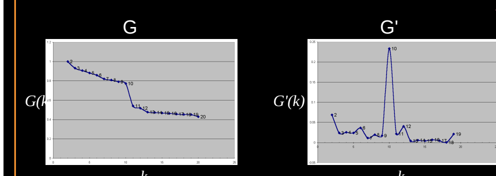
Choosing the Number of Segments



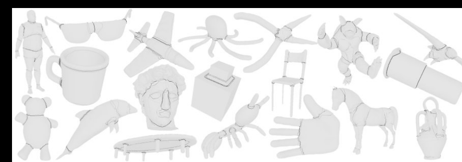


Katz

Outline

- Constraints
- Objective function
- Algorithmic strategies
- Evaluation ←

Benchmark for Mesh Segmentation



Chen09