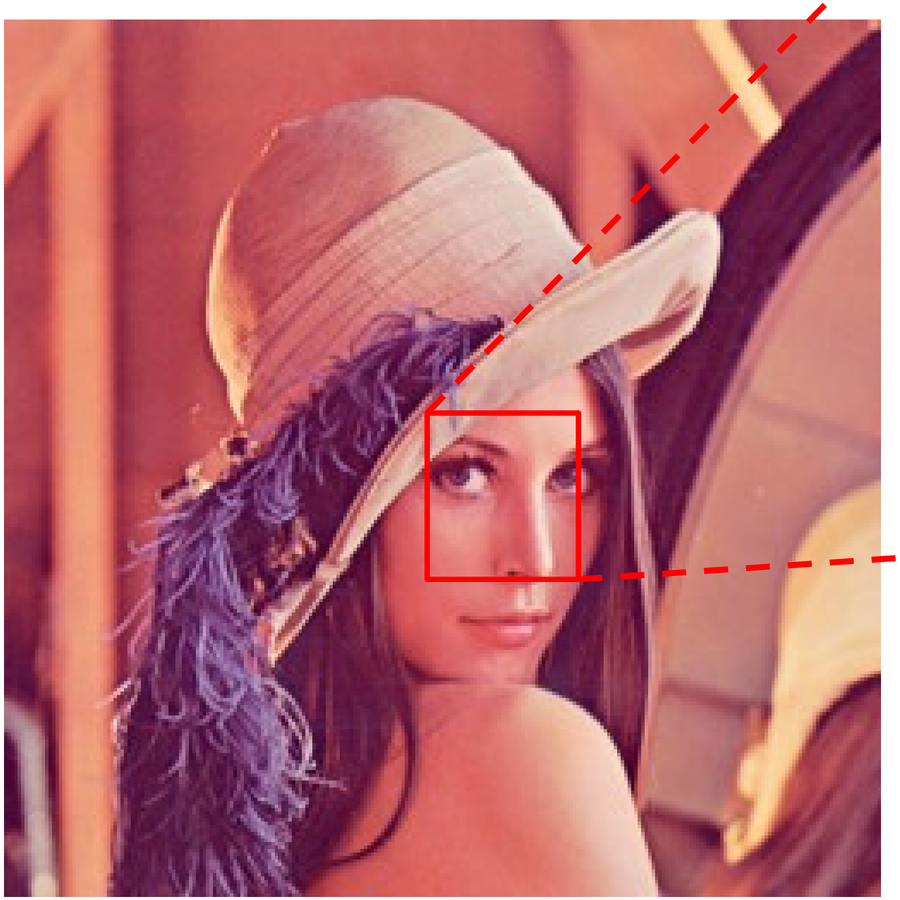
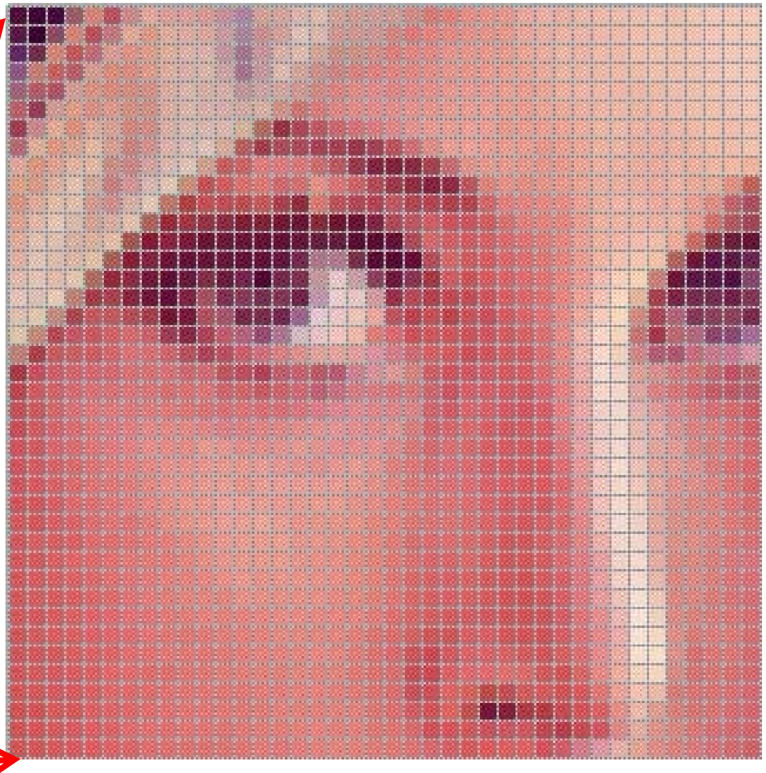
Graphics&Geometric Computing Lab @USTC

Shape Segmentation

Ligang Liu
Graphics&Geometric Computing Lab
USTC
http://staff.ustc.edu.cn/~lgliu

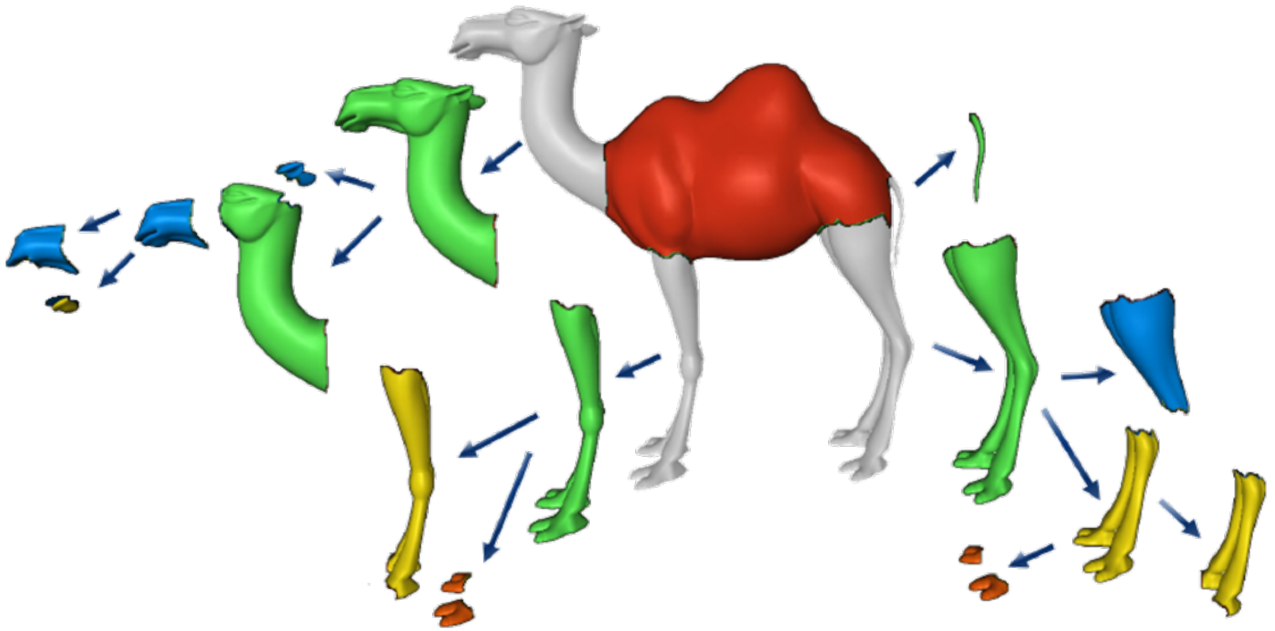
Pixels or Objects ?





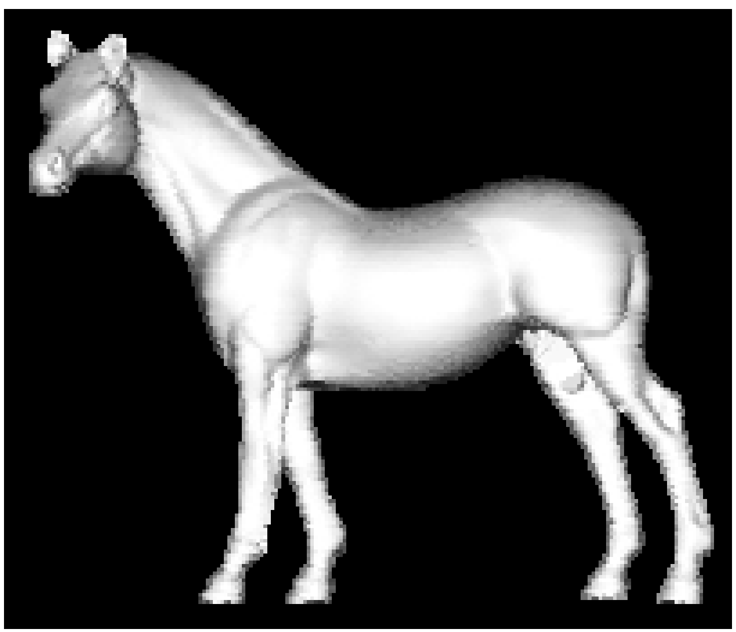
Human Perception

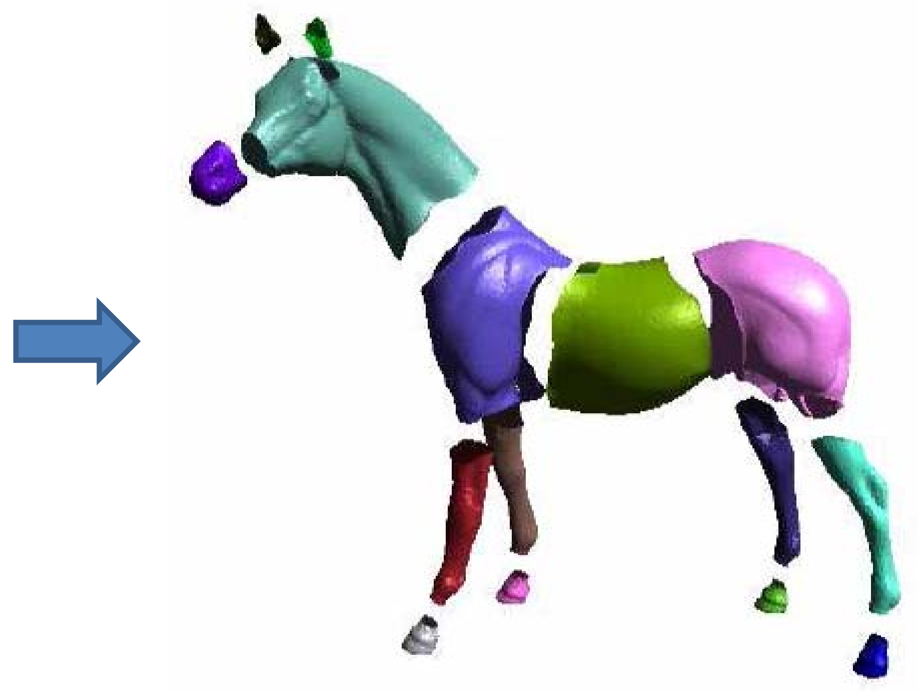
- Examining human image understanding many works indicate that recognition and shape understanding are based on structural decomposition of the shape into smaller parts.



Segmentation

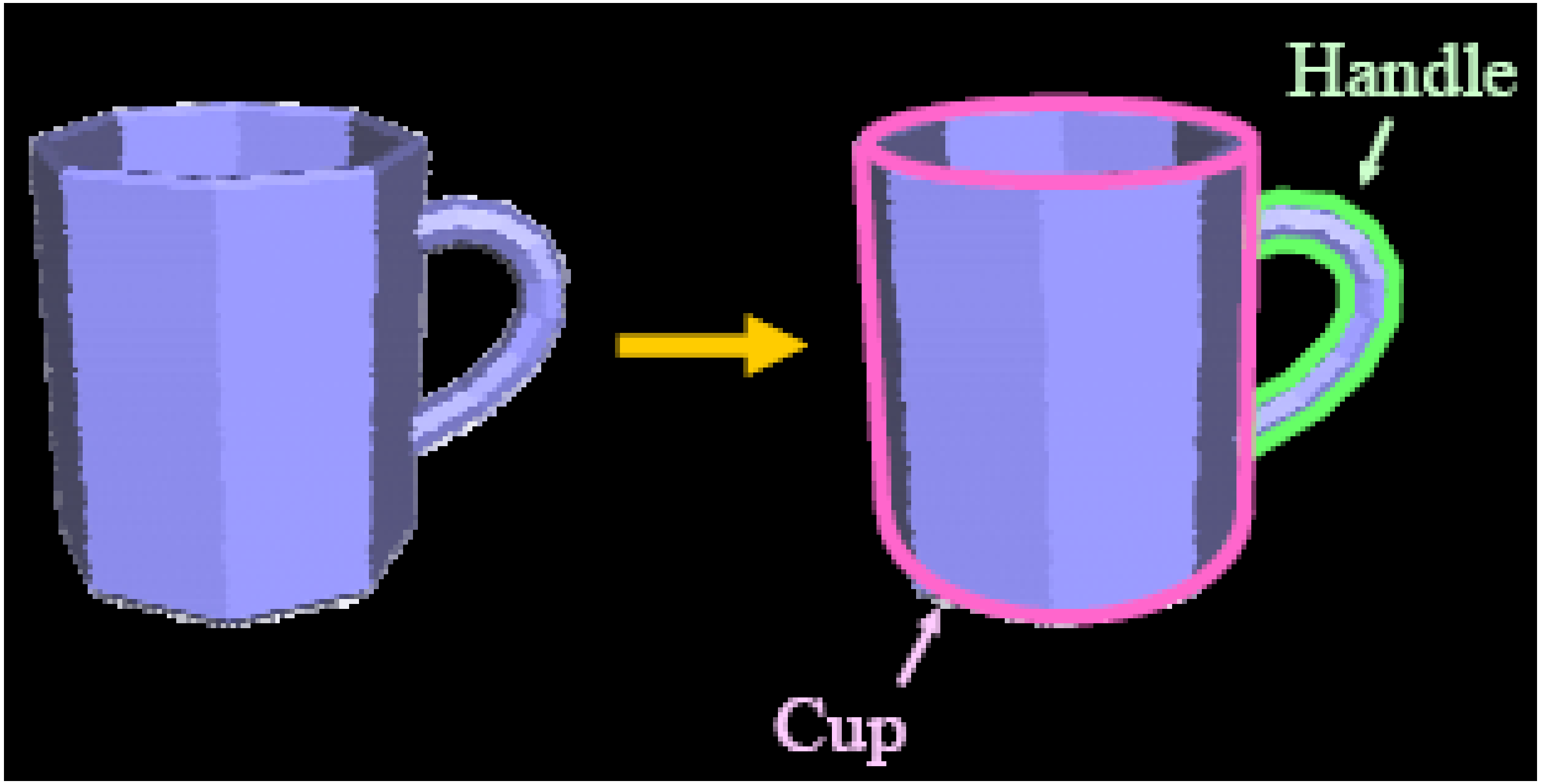
- Input: a mesh M={V,E,F}
- Output: a set of submeshes M_i that partition the faces of M into disjoint subsets





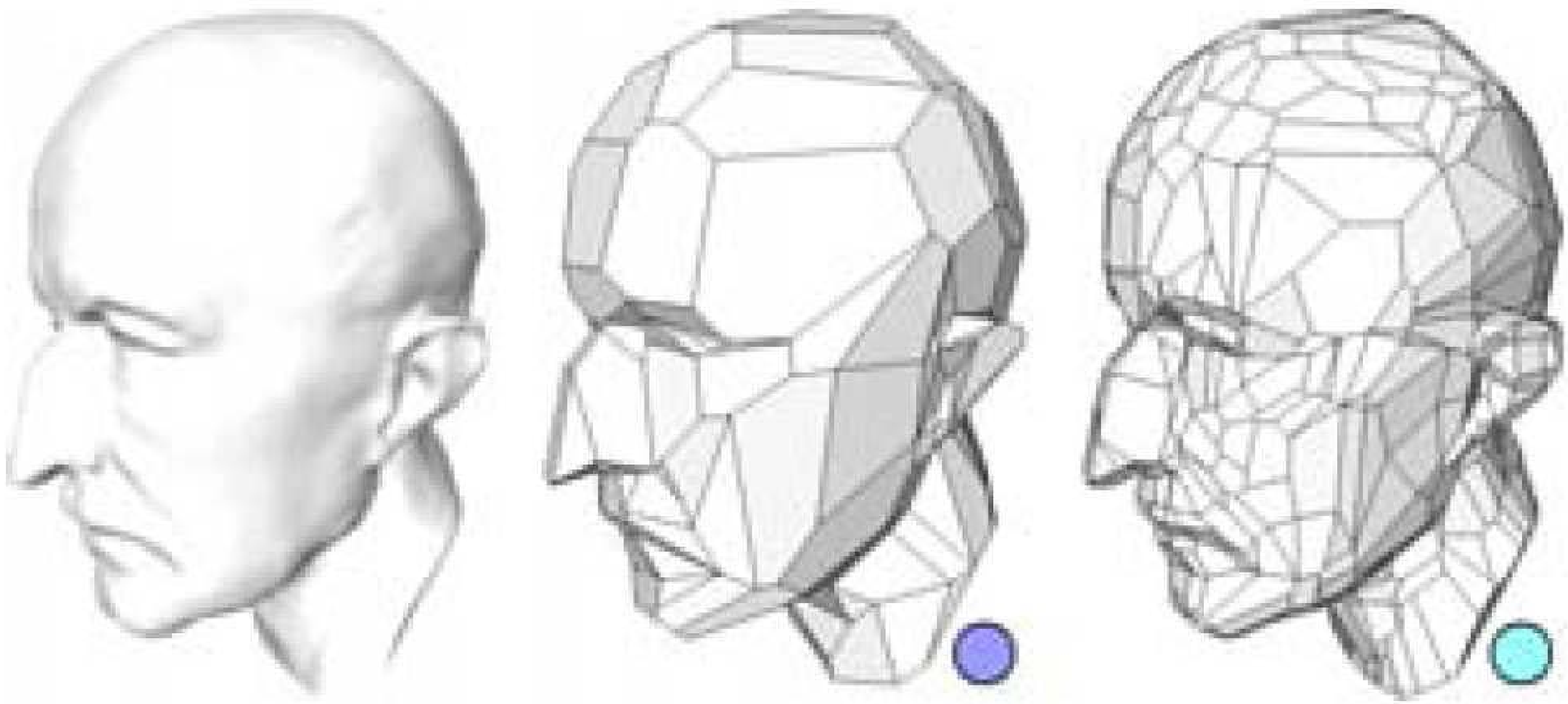
Applications

- Analysis



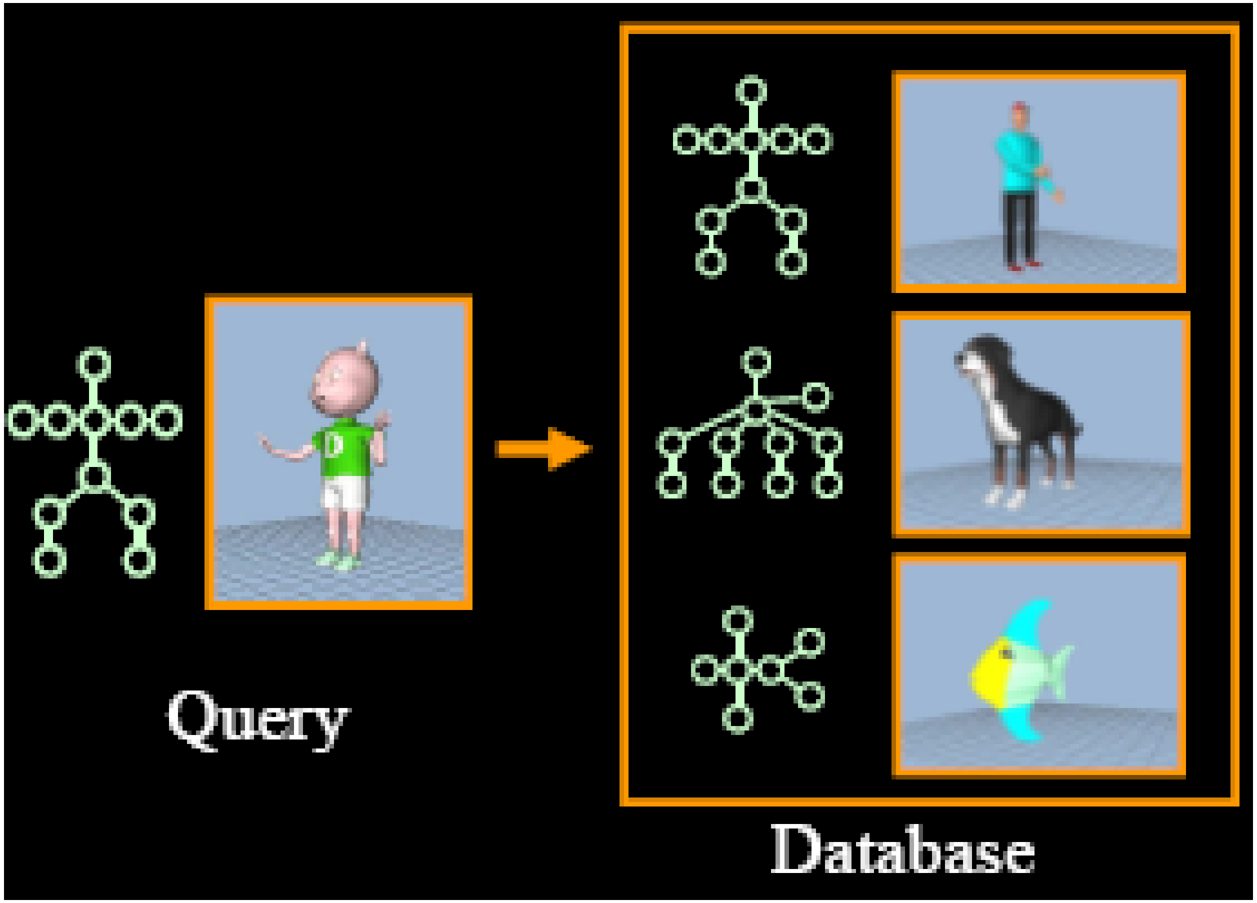
Applications

- Representation



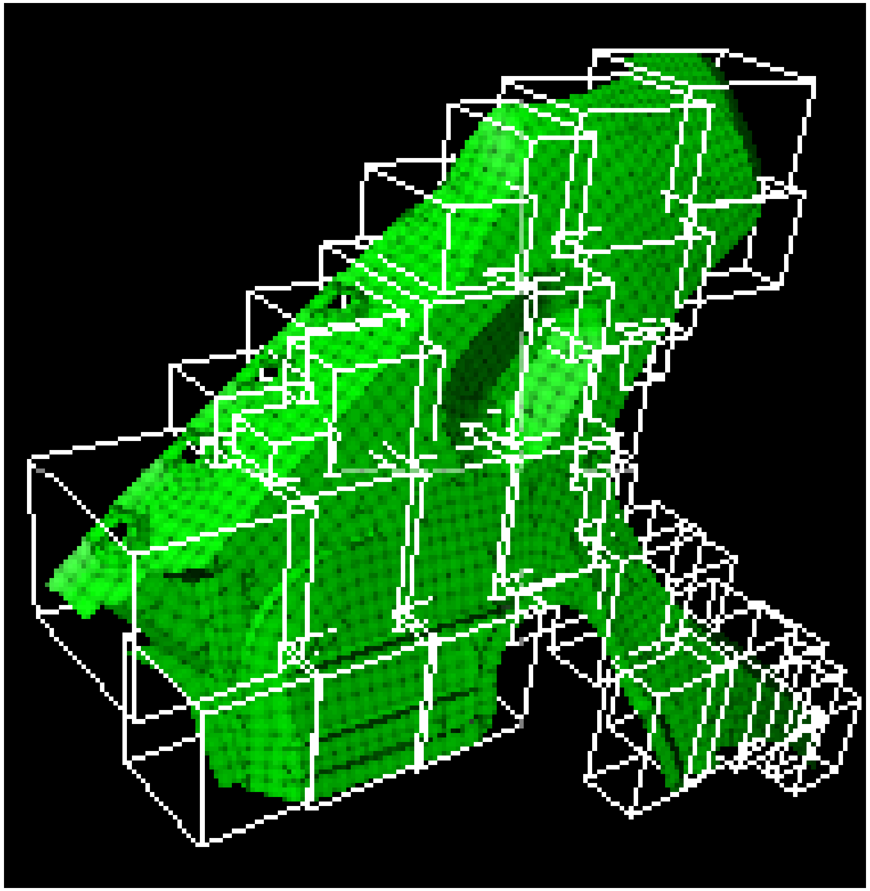
Applications

- Recognition



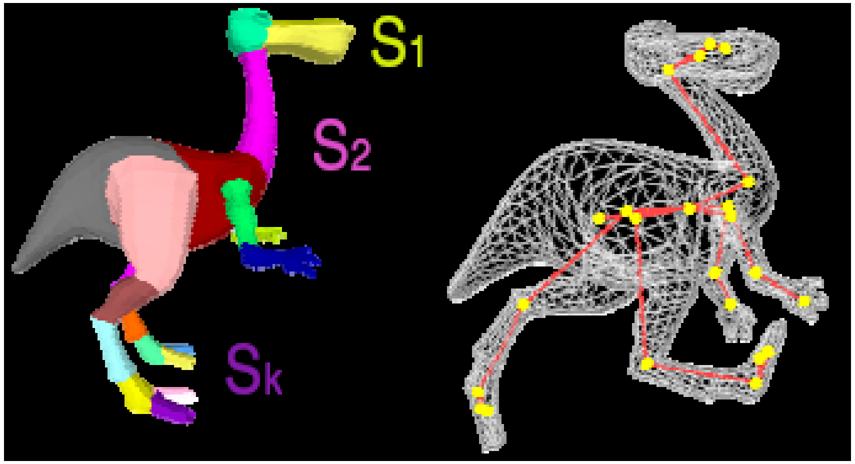
Applications

- Collision detection



Applications

- Animation

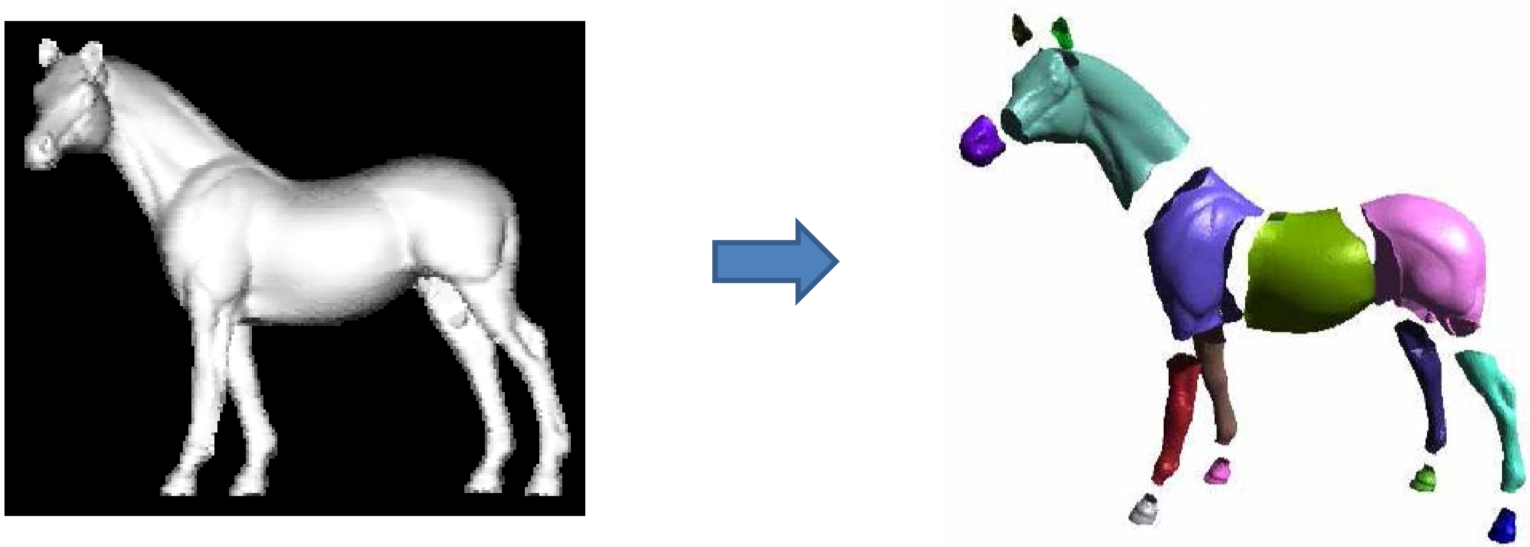


Applications

- Modeling

Problem

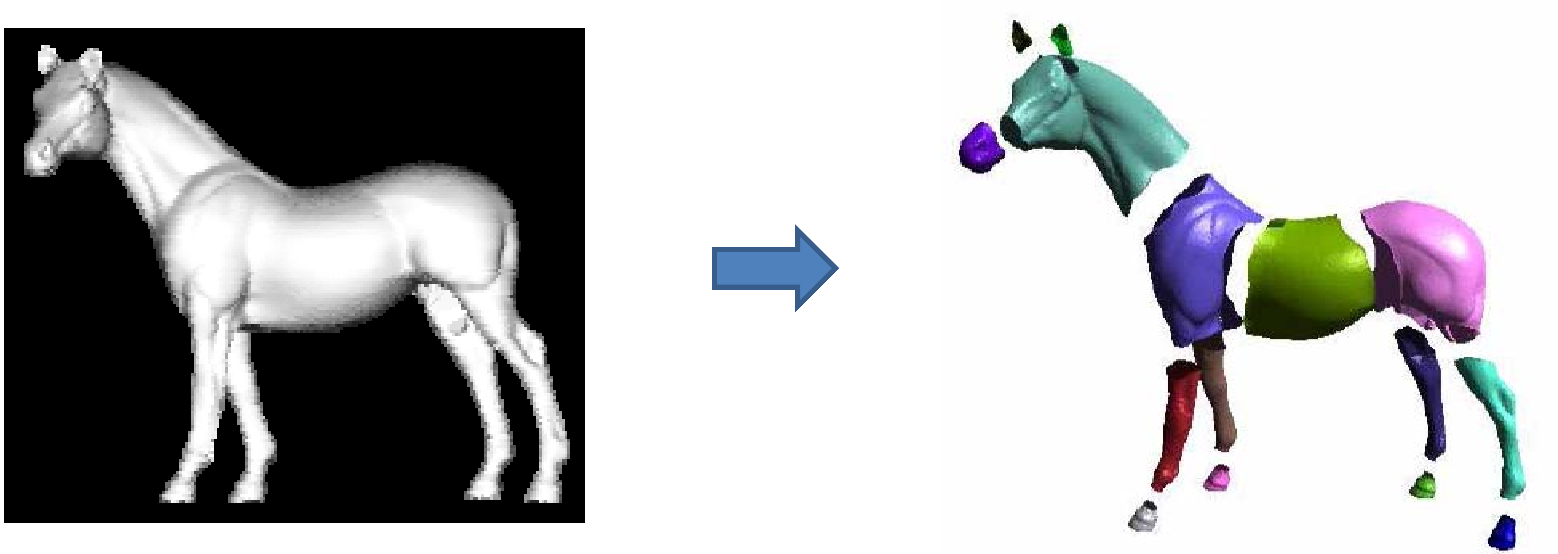
- Input: a mesh M={V,E,F}
- Output: a set of submeshes M_i that partition the faces of M into disjoint subsets



Formulation

- Input: a mesh M={V,E,F}
- Output: a set of submeshes M_i that partition the faces of M into disjoint subsets

that minimizes an object function J under a set of constraints C

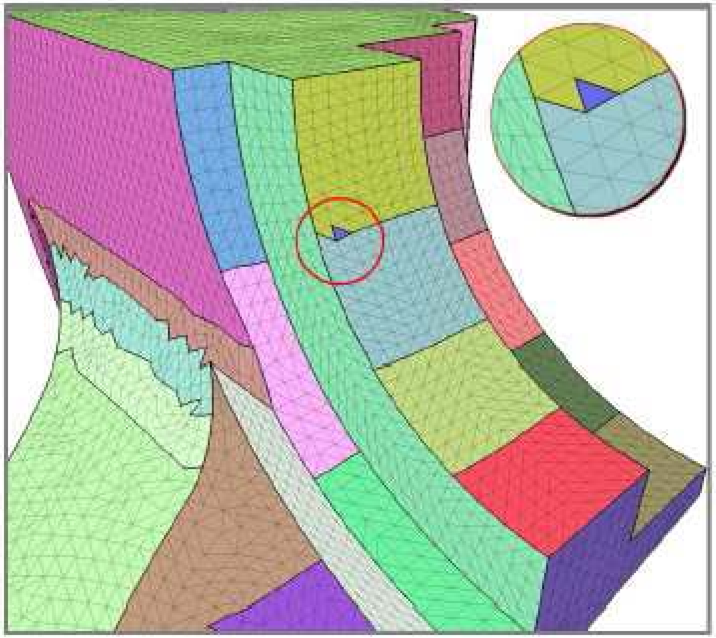


Outline

- 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



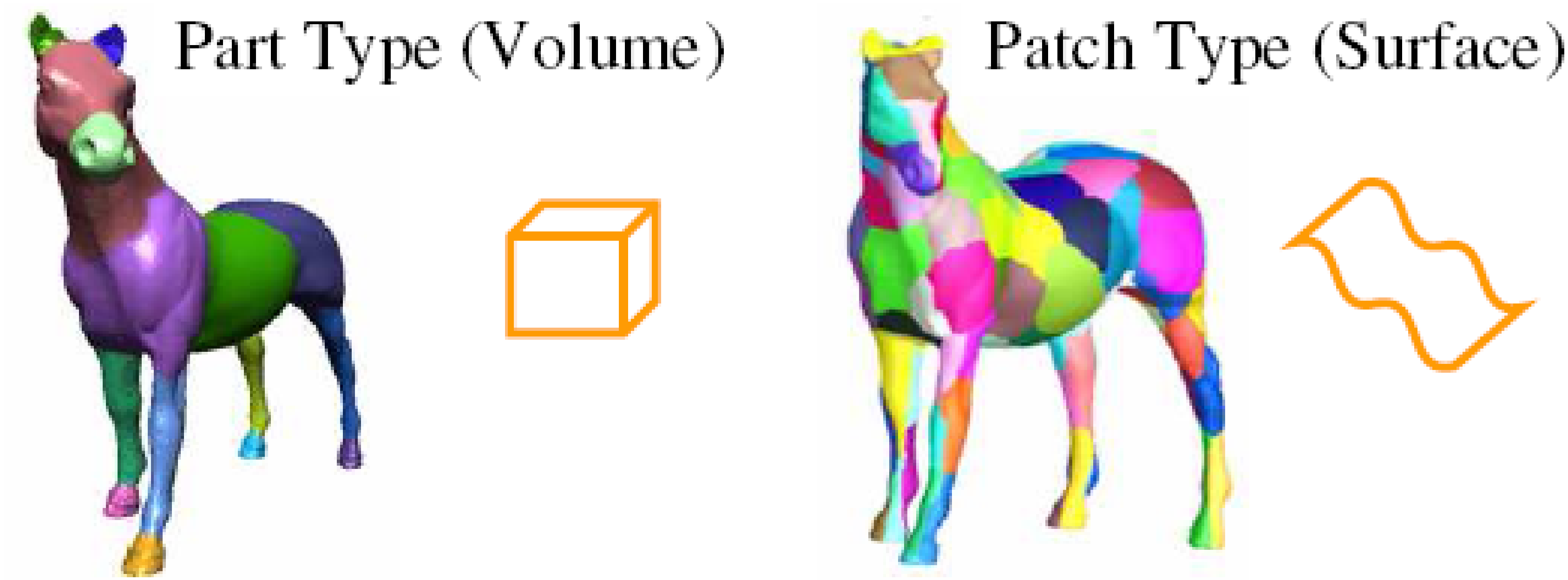
Objective Function

Objective Function

- How “good” a segmentation is?
  - Number of segments?
  - Surface properties?
  - Boundary properties?
  - Global shape properties?
  - Match examples?
  - Semantics?
  - etc.

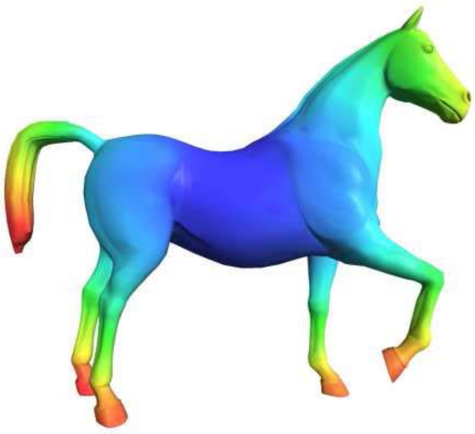
Two Types of Segmentations

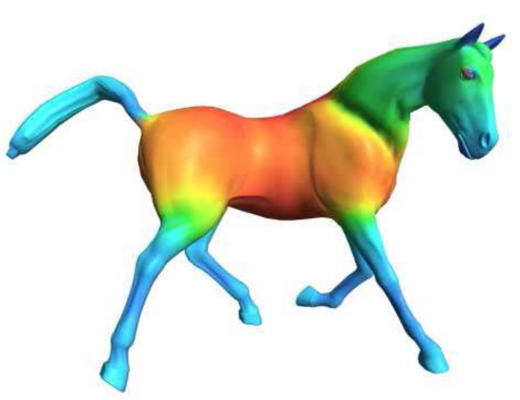
- Different applications



Objective Function

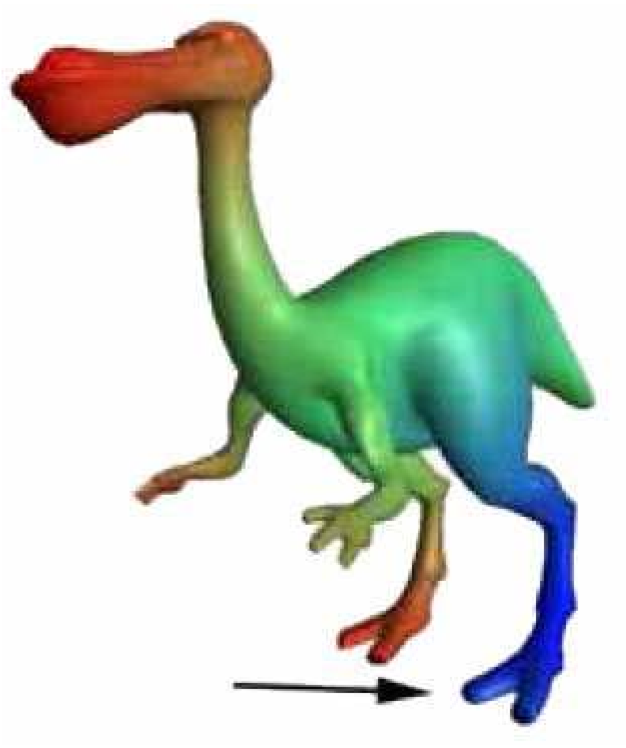
- Mesh attributes to consider:
  - Distances
  - Normal directions
  - Smoothness, curvature
  - Shape diameter
  - Distance to proxies
  - Convexity
  - Symmetry
  - etc.



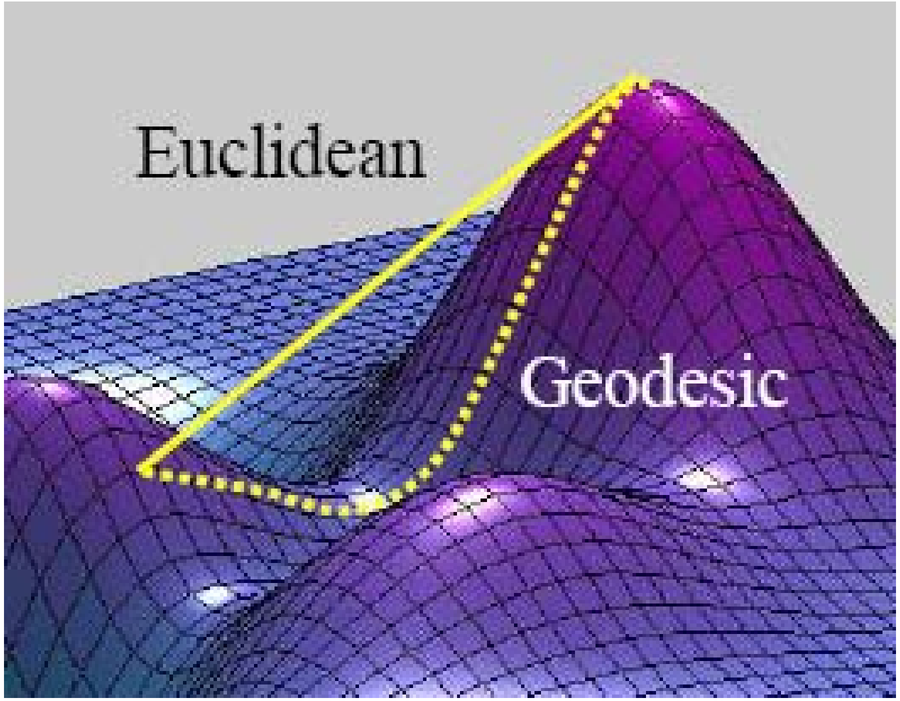


Distances

- Triangles in same segment ought to be close

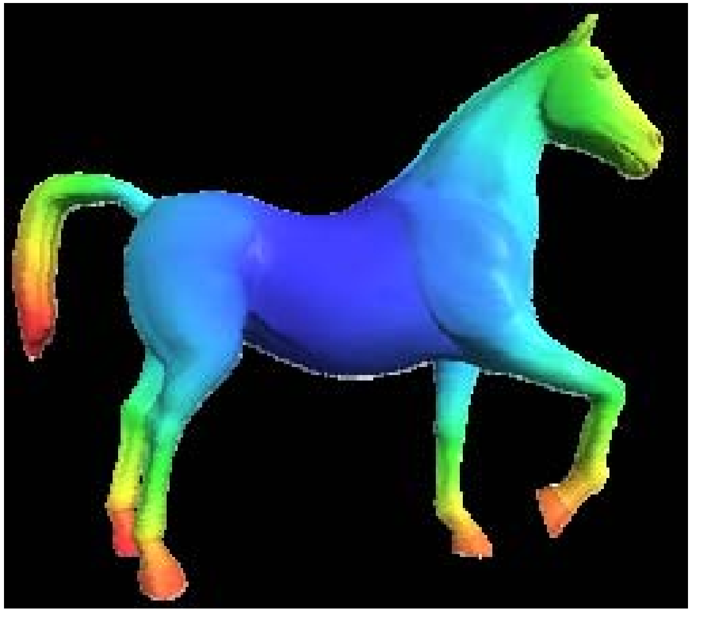


Field of geodesic distance



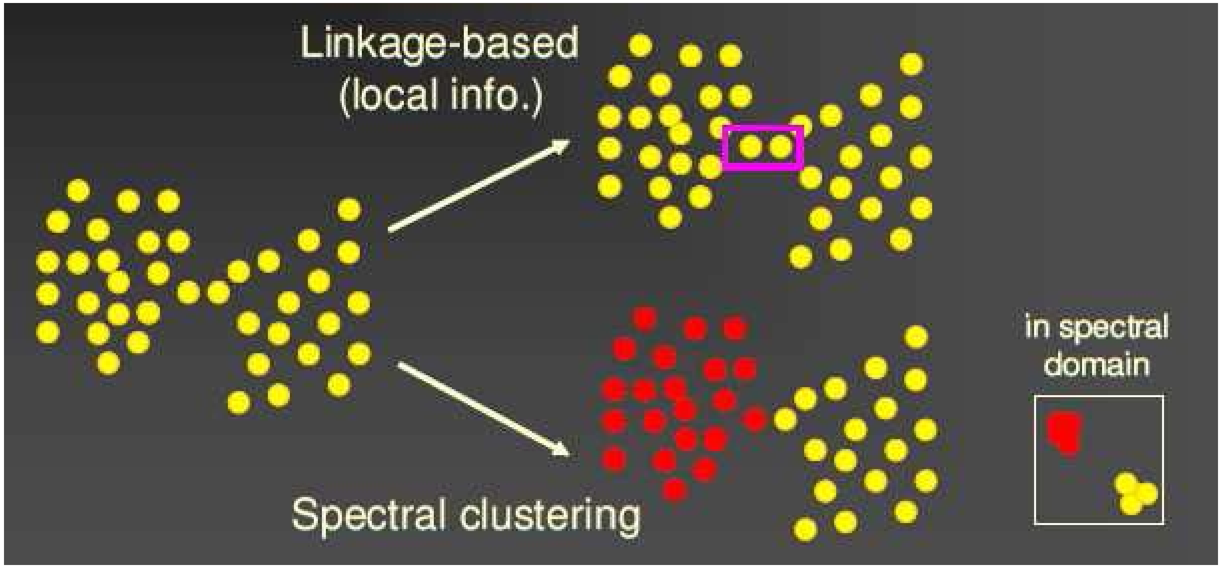
Distances

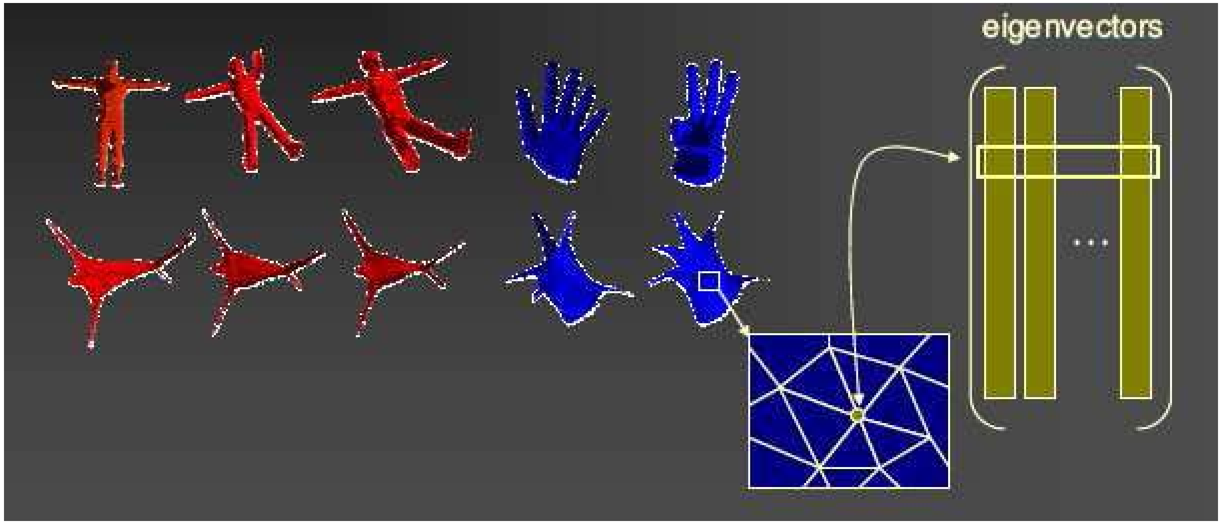
- Triangles in same segment ought to be close Discontinuities in functions of distance indicate possible boundaries



Average geodesic distance to other points

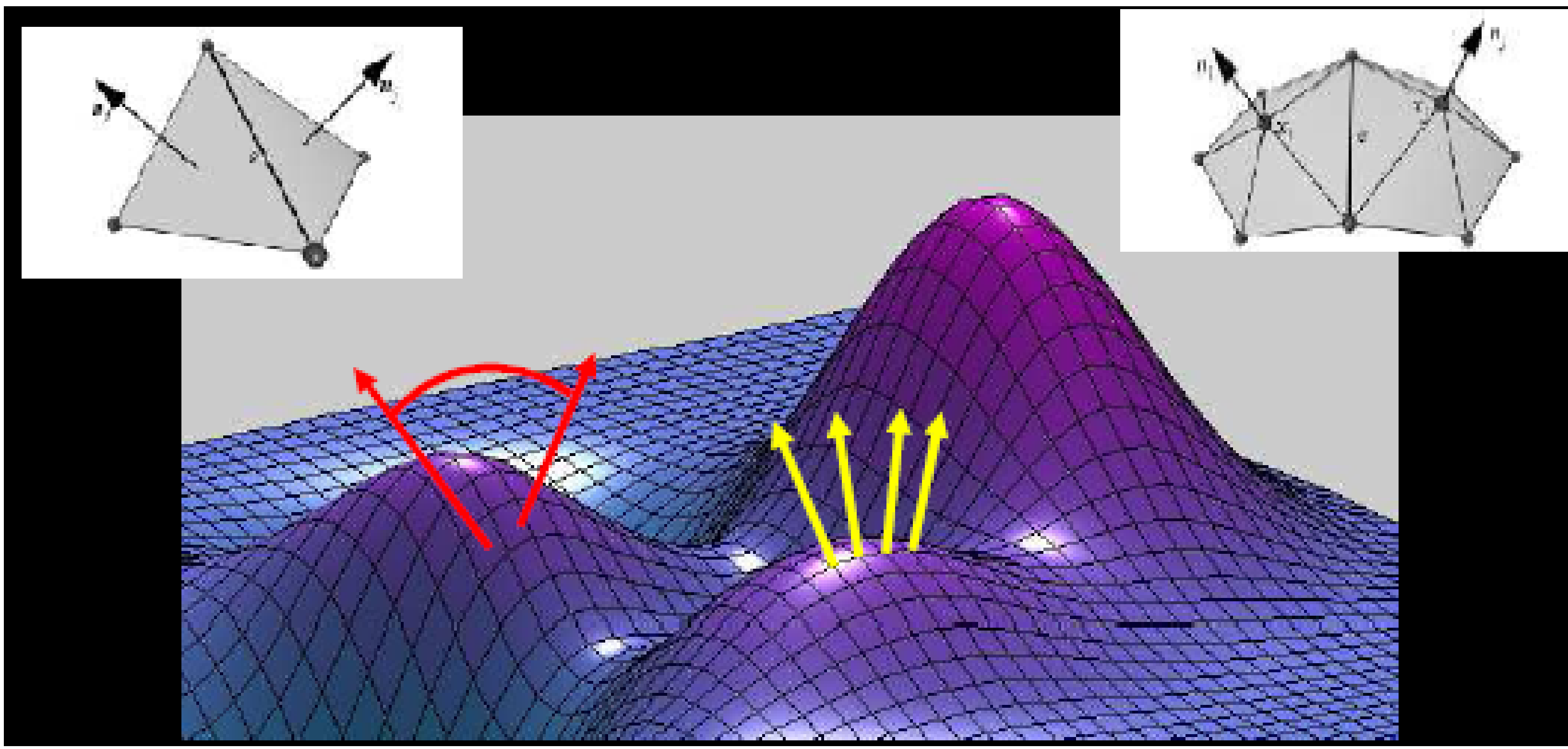
Distances with Spectral Embedding



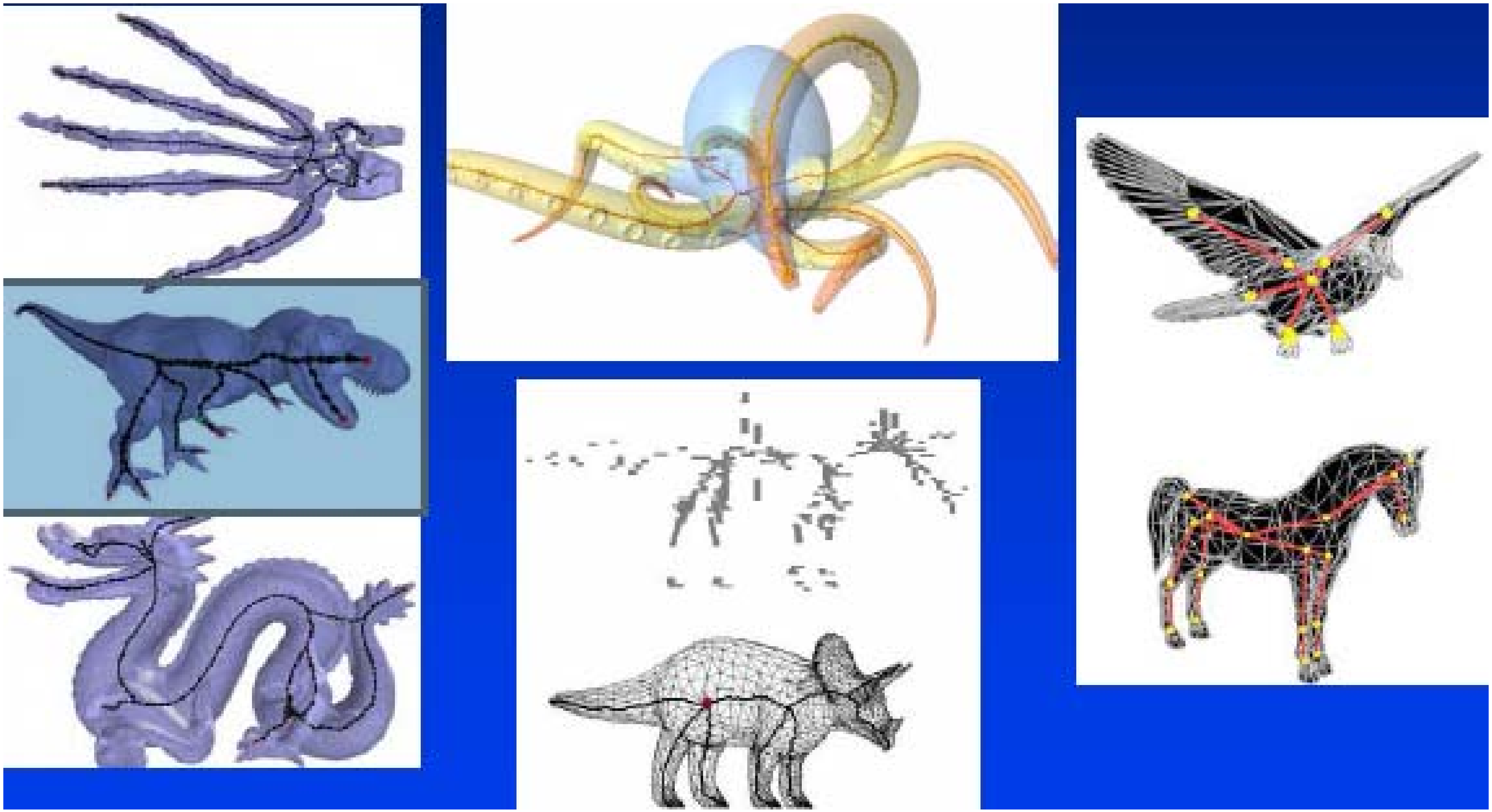


Normal direction, Dihedral Angles

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

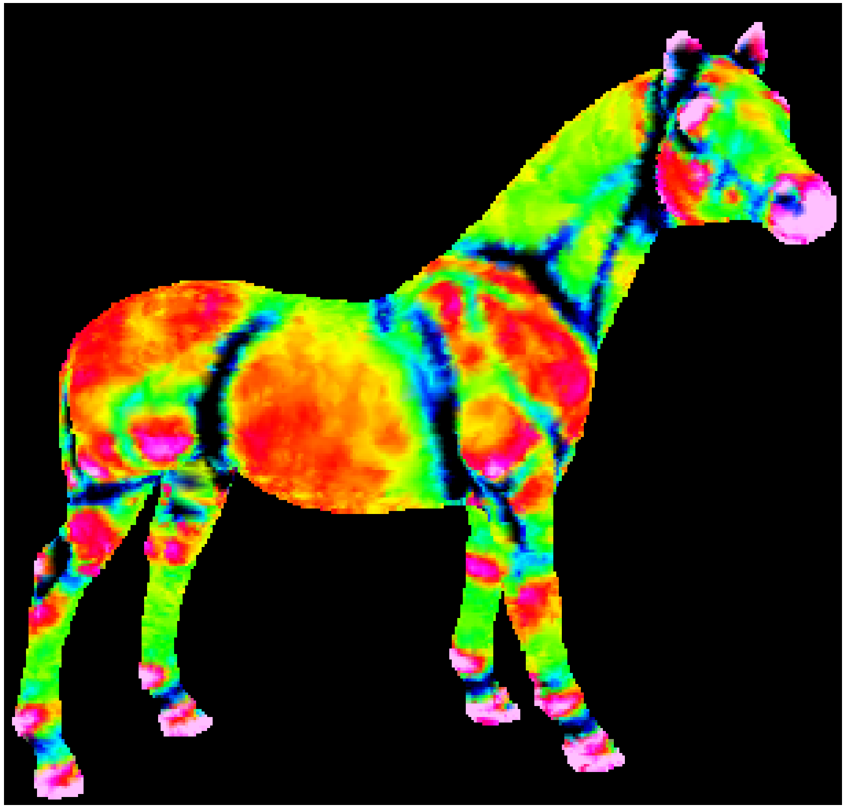


Skeletons



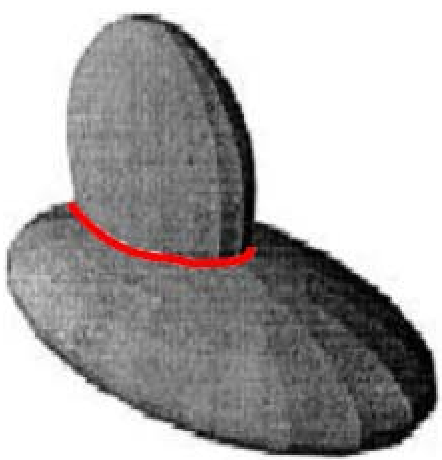
Smoothness, Curvature

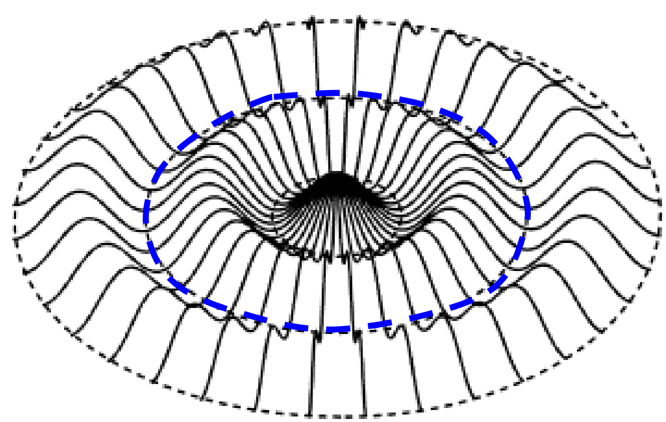
- Concave creases indicate good segmentation boundaries



Minimal Rule

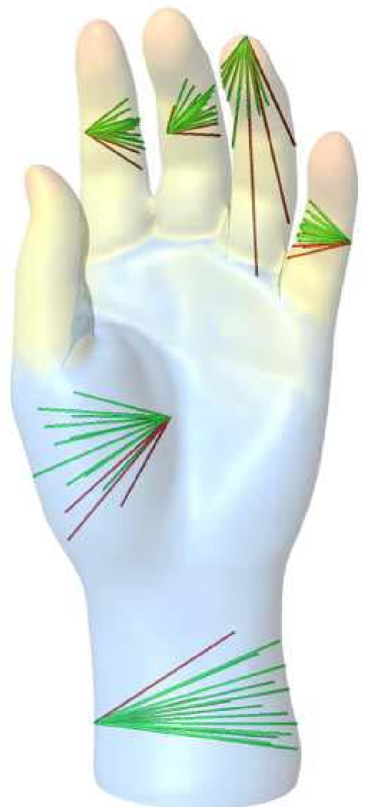
- Psychological study [Hoffman et al. 84]
  - All *negative minima* of the principal curvatures form boundaries between parts
    - decompose 3D shapes at concave creases





Diameter

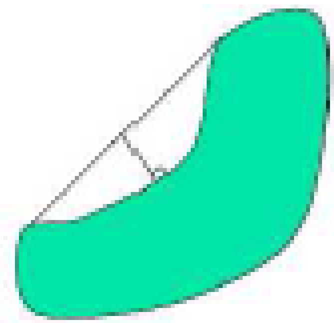
- Distinguish between thin and thick parts in a model



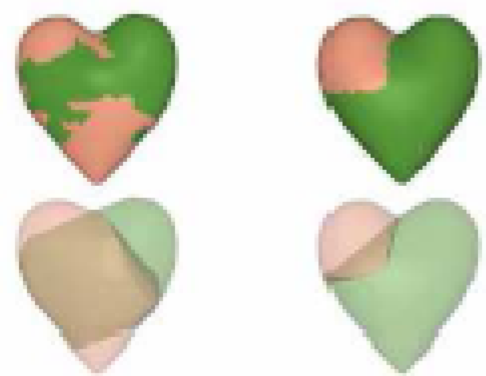
Convexity

- Parts generally should be convex and compact

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

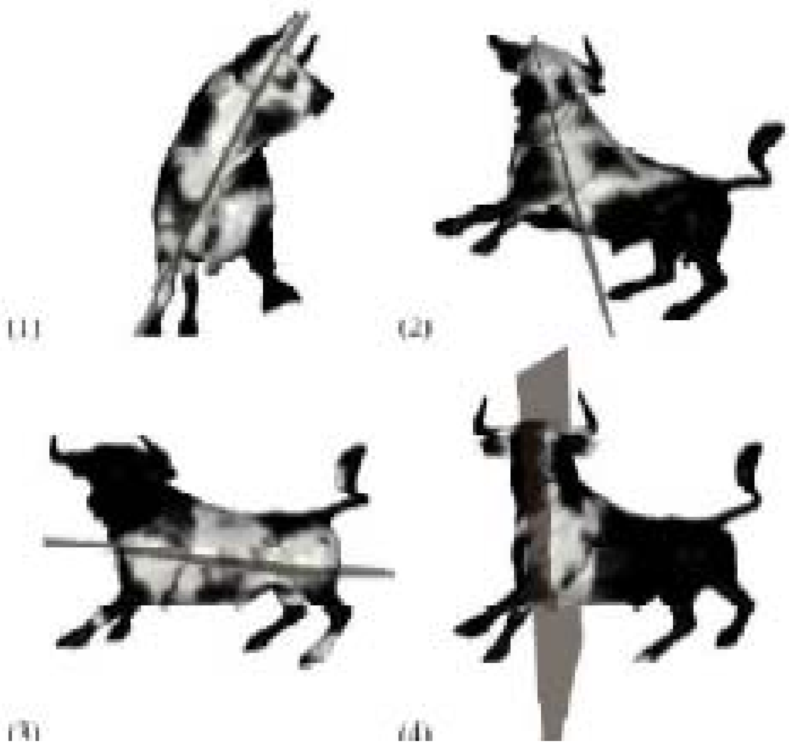


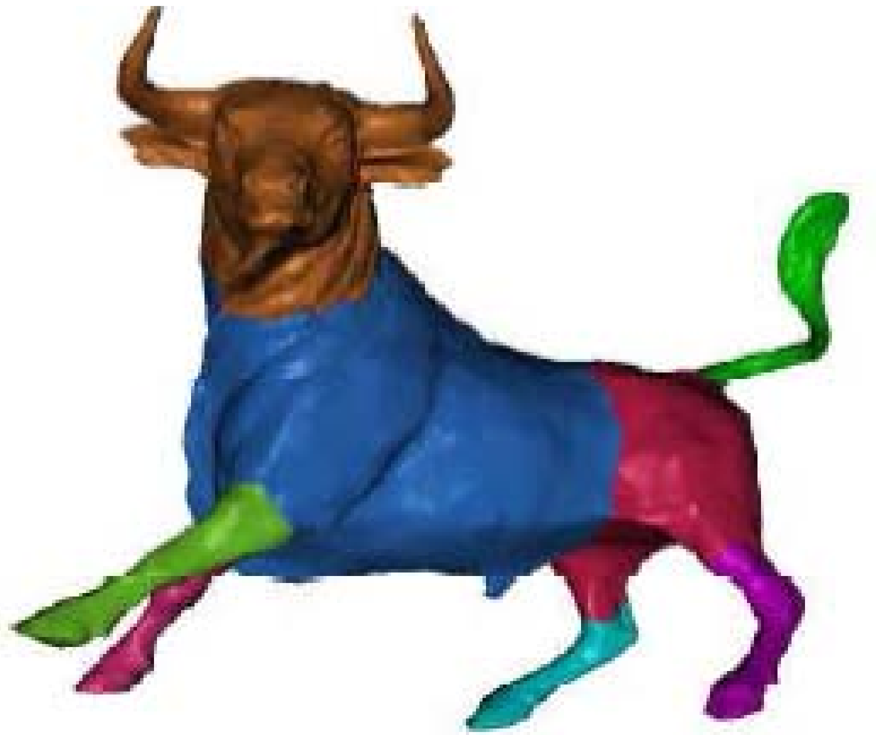
$$\textbf{Compactness} = \frac{area(C)}{volume(C)^{2/3}}$$



Symmetry

- Segments should be locally symmetric

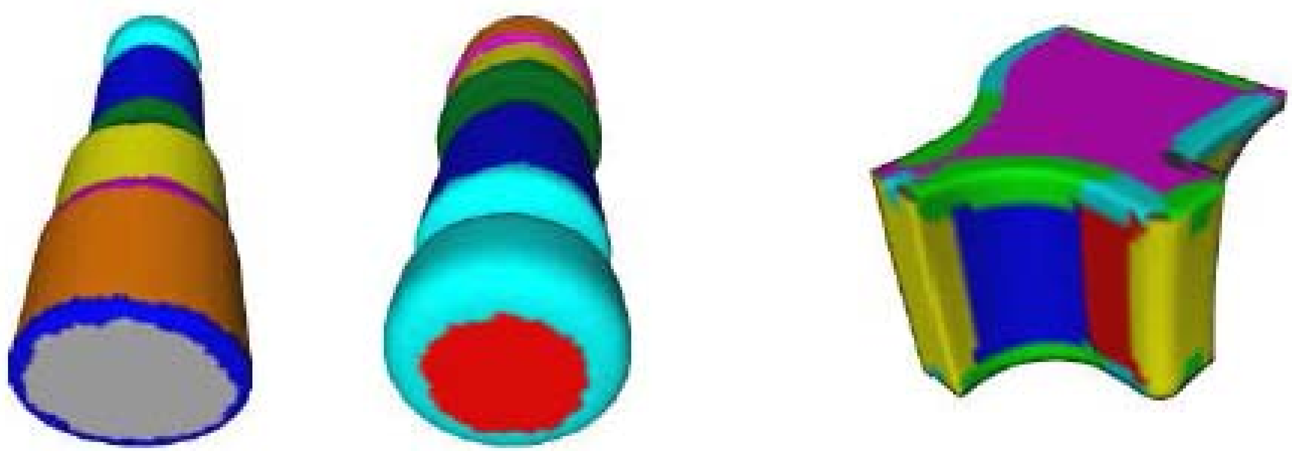




Slippage

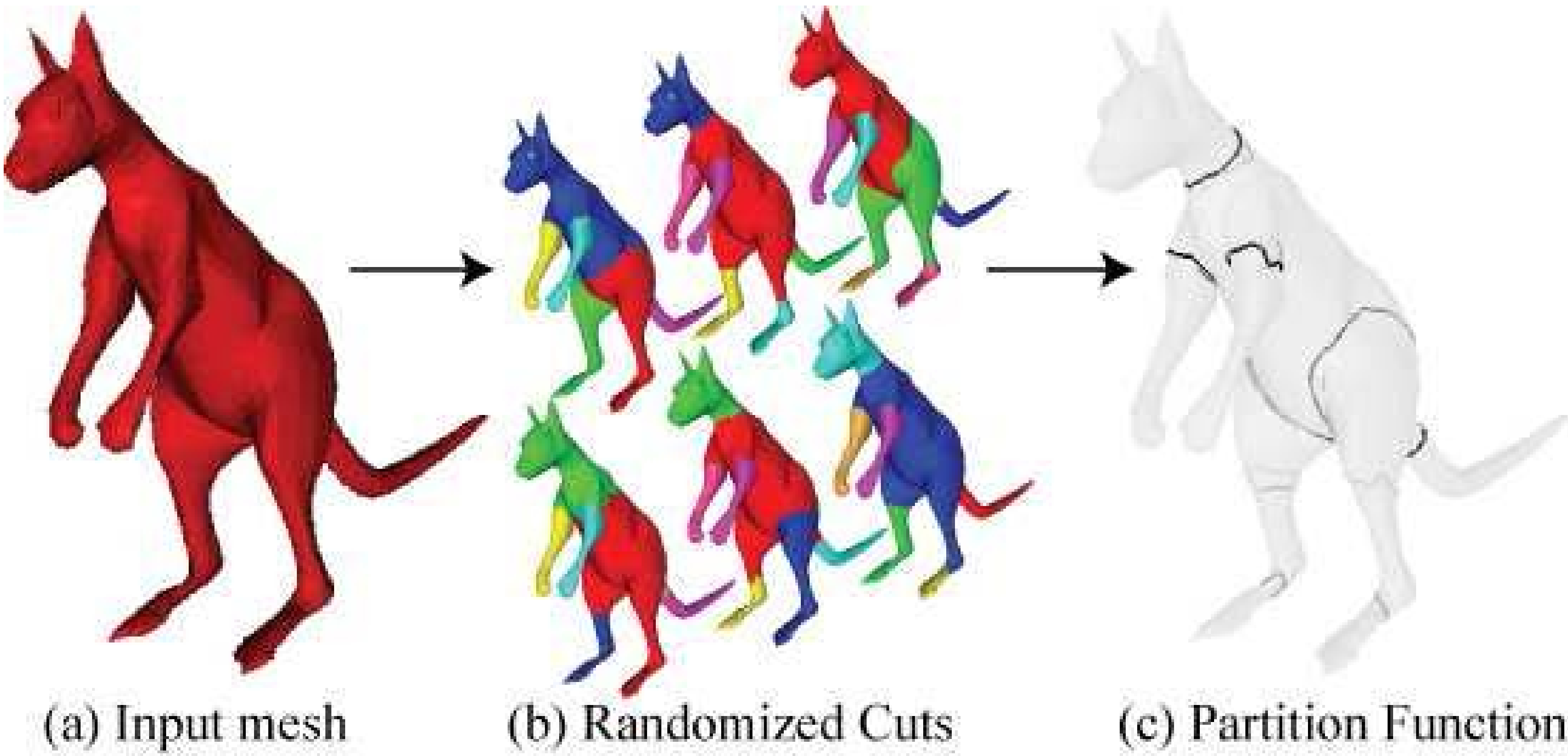
- Slippable motions are rigid motions which, when applied to a shape, slide the transformed version against the stationary version without forming any gaps.

$$\min_{[rt]} \sum_{i=1}^{n} ((r \times p_i + t) \cdot n_i)^2$$



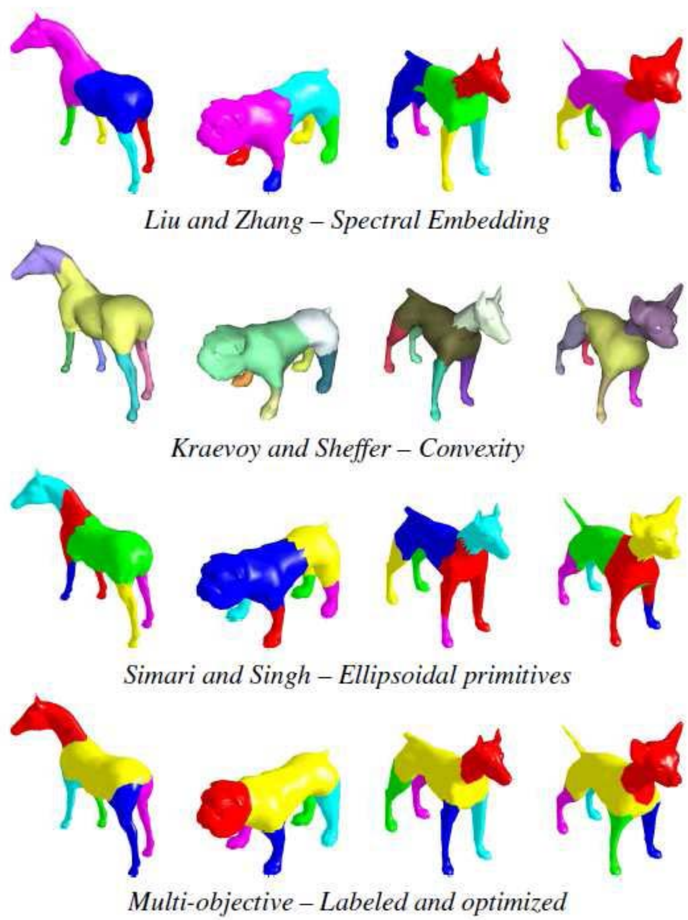
Combining many properties

- Randomized cuts [Sig 2009]



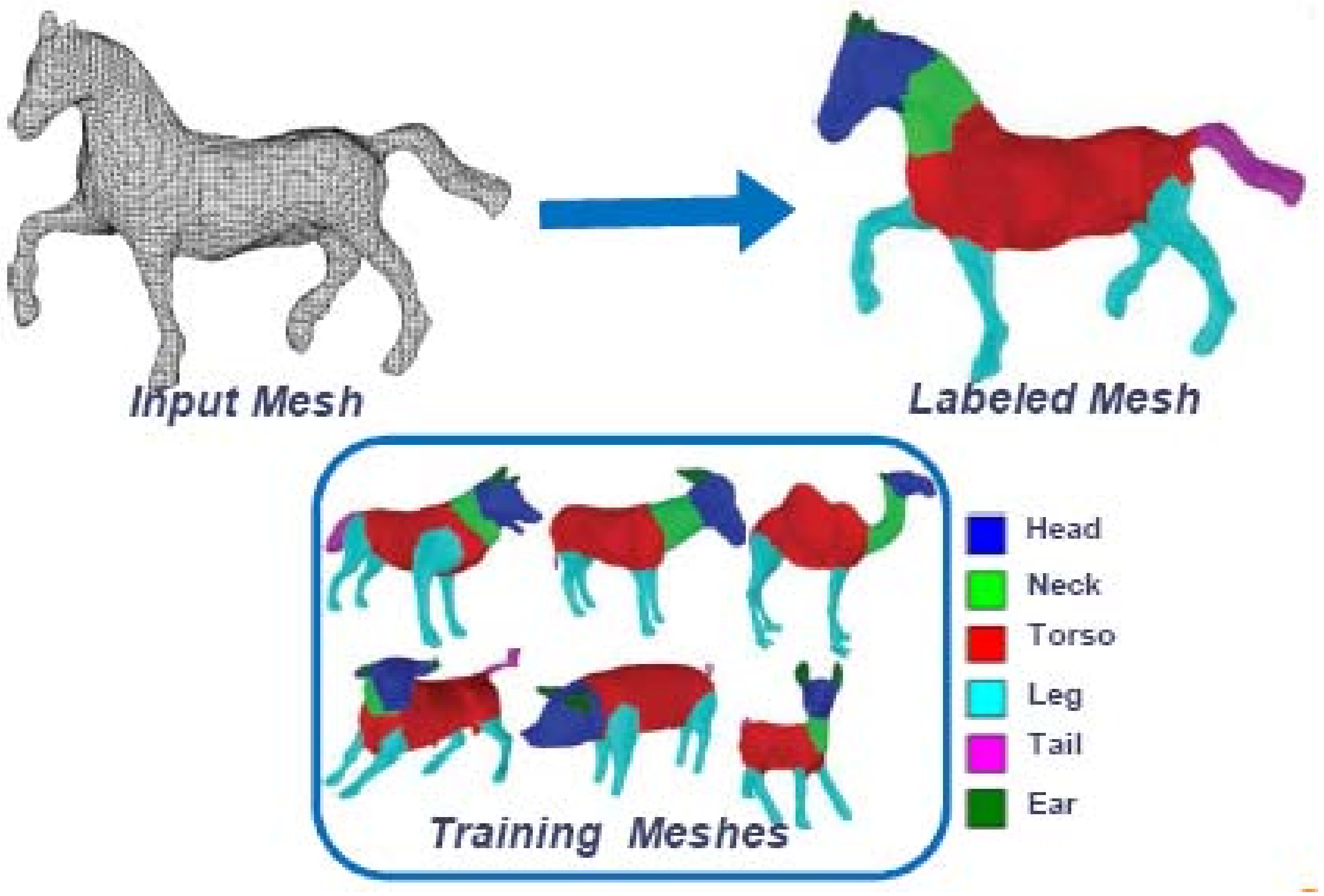
Segmenting and Labeling

- Multi-objective mesh segmentation [SGP 08]



Segmenting and Labeling

- Learning based [Sig 2010]



Application: Simplification

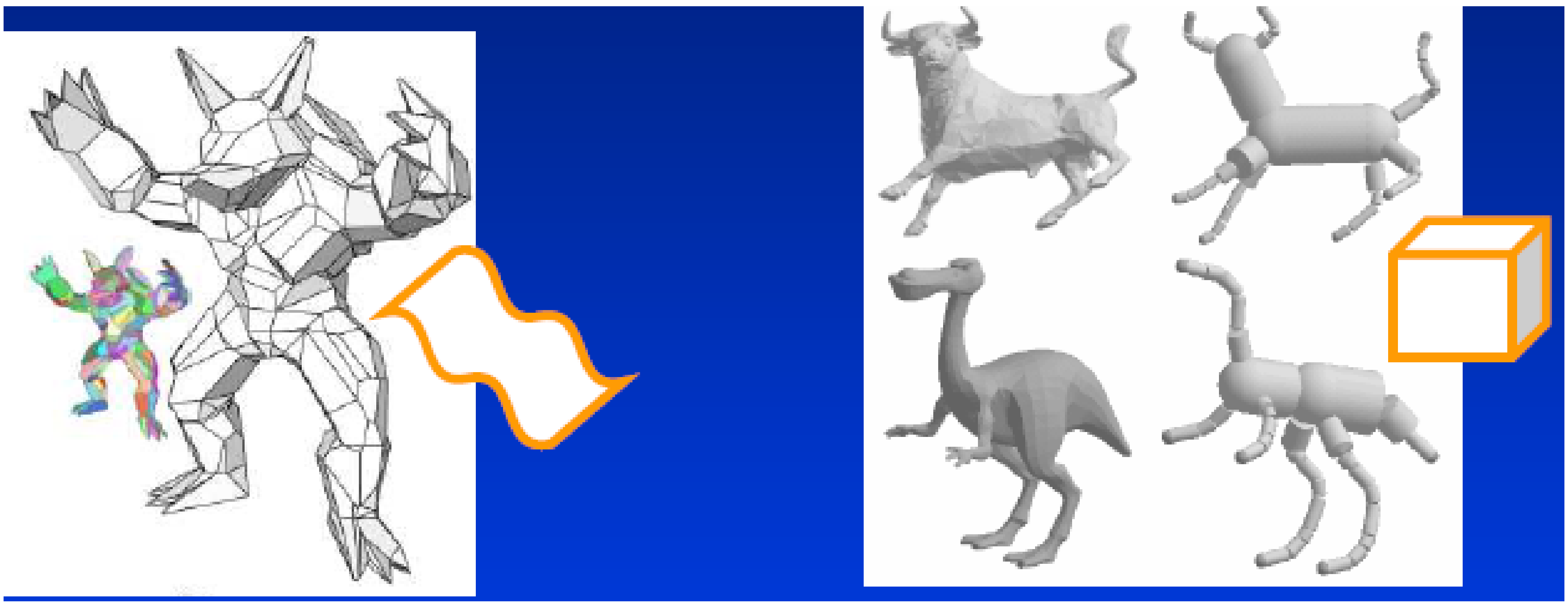
Shape Simplification

- We want to approximate a complex model (shape) with a simpler one. Similar to an approximation theory problem:
  - Replacing complex mathematical objects with simpler ones, while keeping the primal information content.

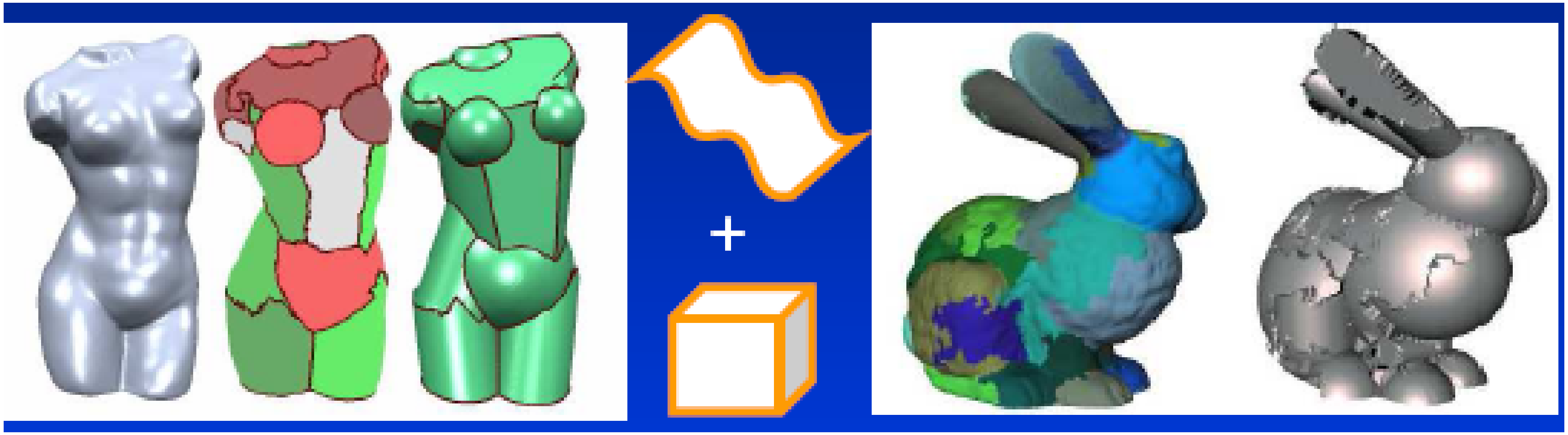
Planar Patches

- Variational shape approximation [Sig 2004]

Planes or Cylinders



Spheres, Cylinders, Rolling Ball Surfaces



Strips & Quasi-Developable Surfaces

Algorithmic Strategies

Algorithmic Strategies

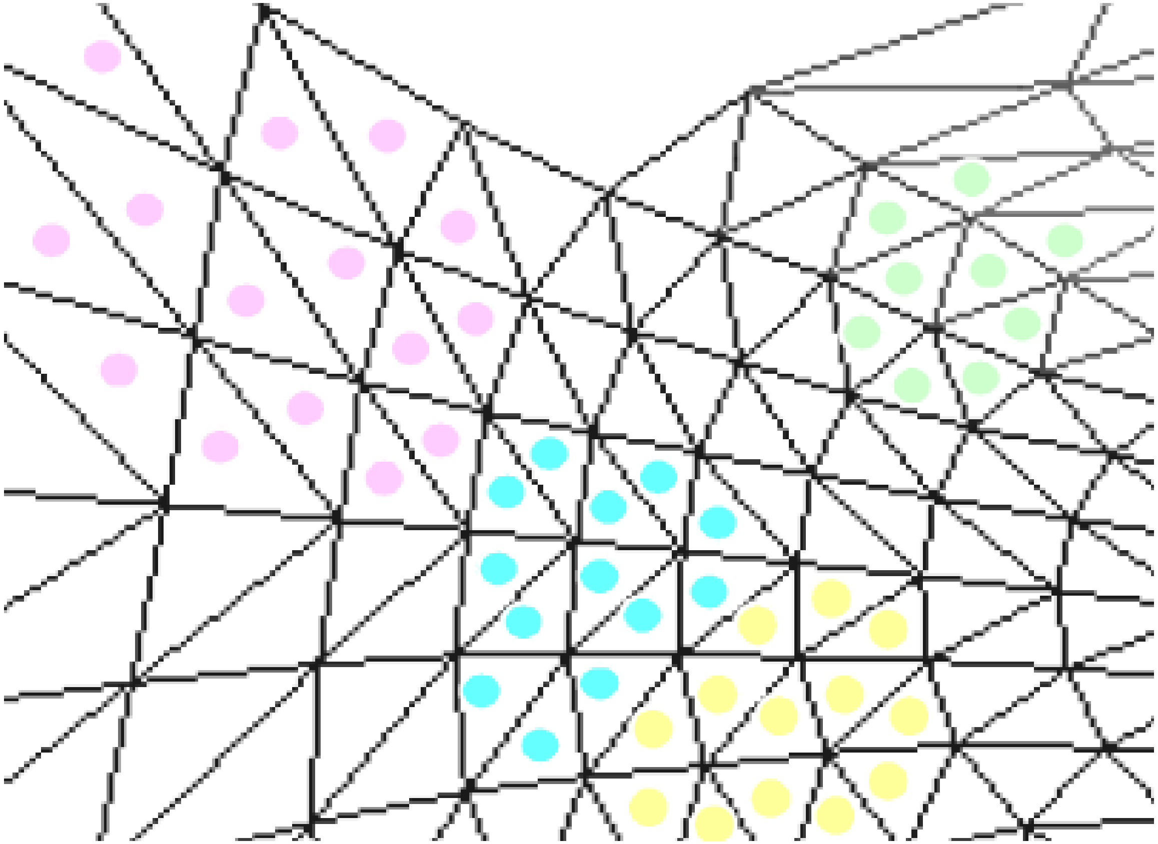
- If |M| = n and |S| = k, then the search space of possible mesh decompositions is of order k^n.
  - NP-complete
  - Must revert to approximation algorithm

Segmentation as Clustering

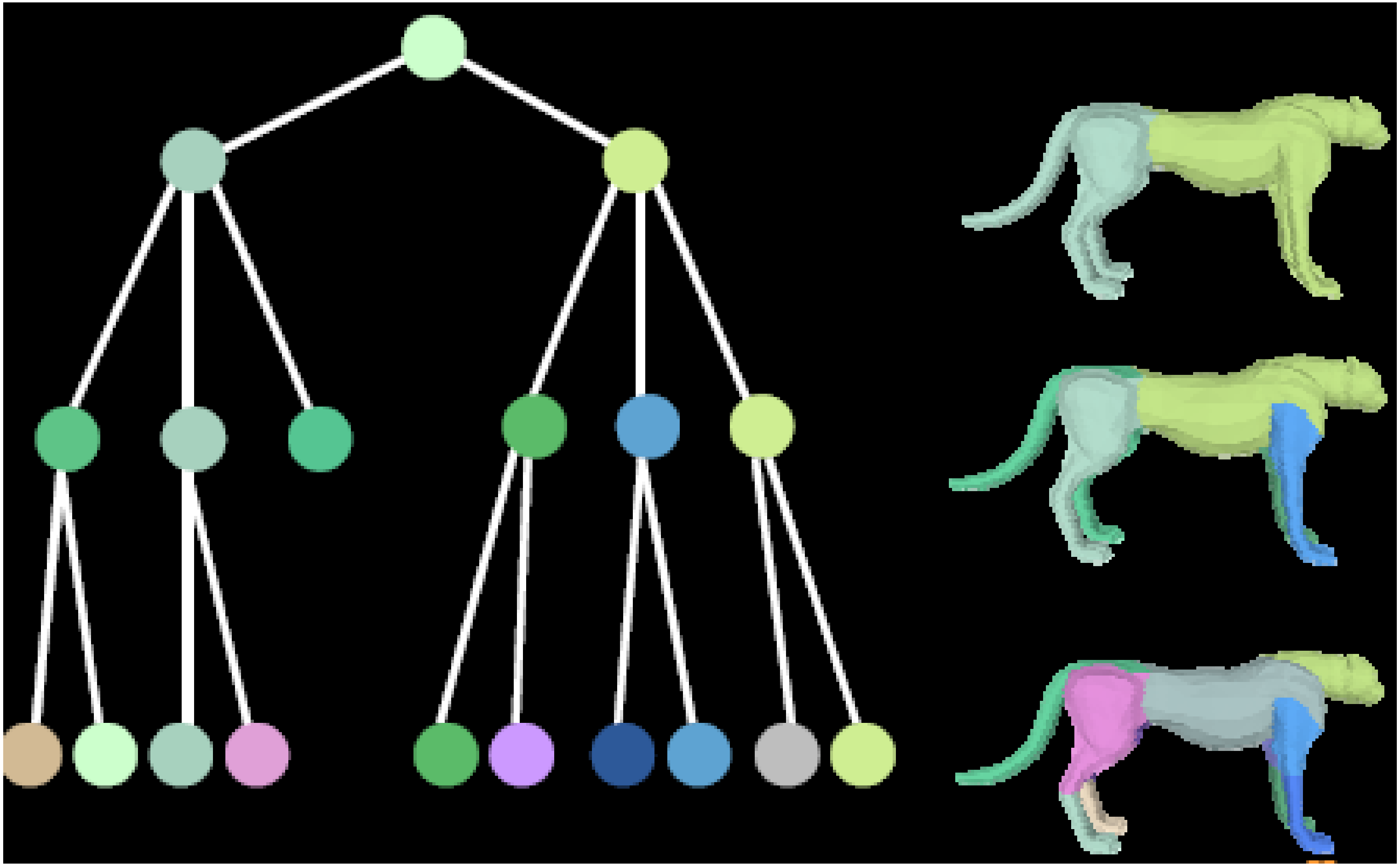
- The basic segmentation problems can viewed as assigning primitive mesh elements to sub meshes
  - Clustering problem
  - Well-studied in machine learning
- Most segmentation strategies have basis in classic clustering algorithms:
  - Region growing (local greedy)
  - Primitive fitting (model-based)
  - Hierarchical clustering (global greedy)
  - K-means (iterative)
  - Graph Cut

Region Growing

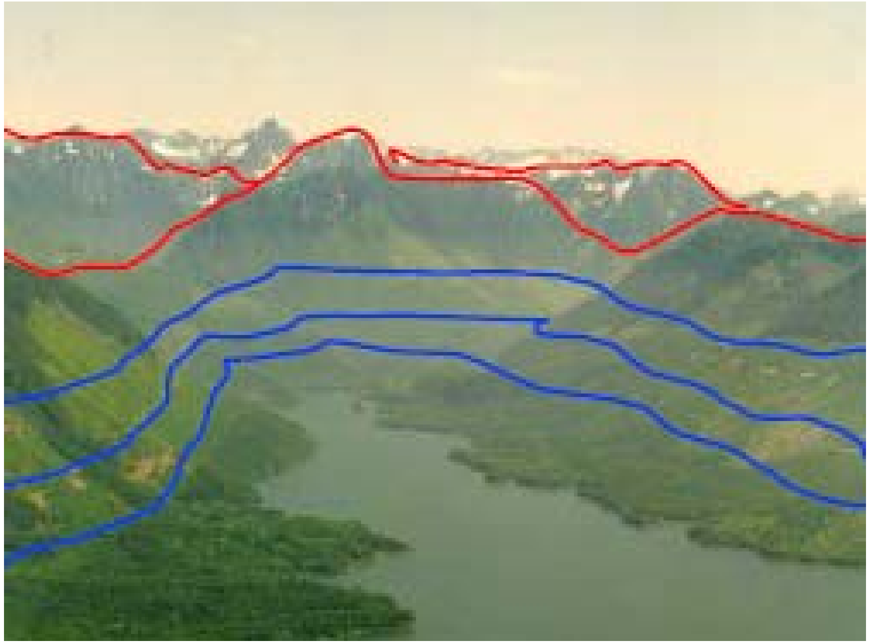
- Growing regions started from seeds

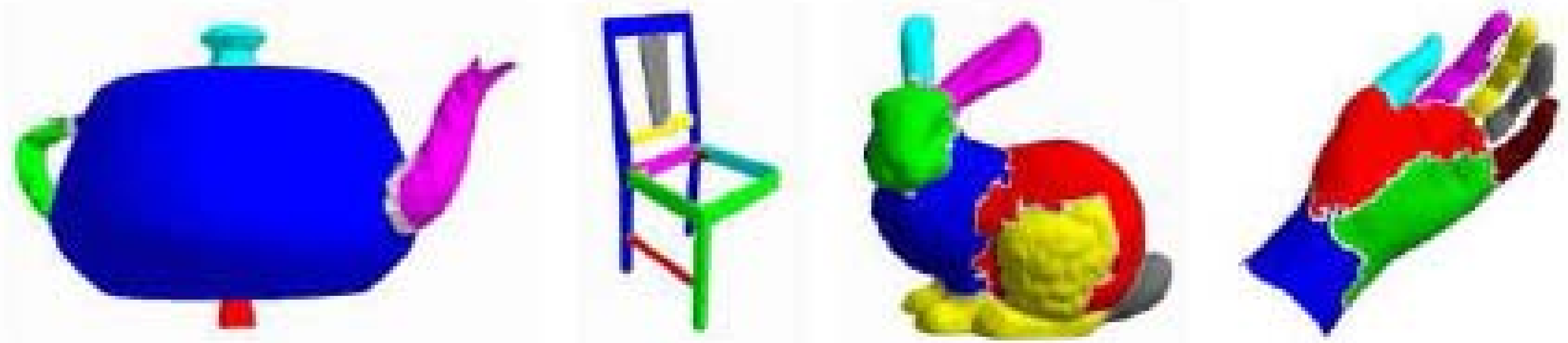


Hierarchical Clustering



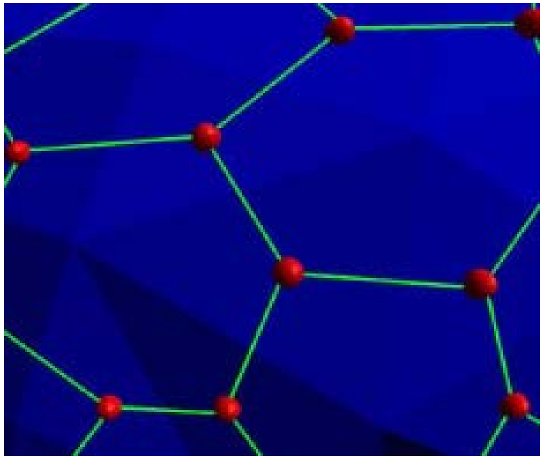
Watershed

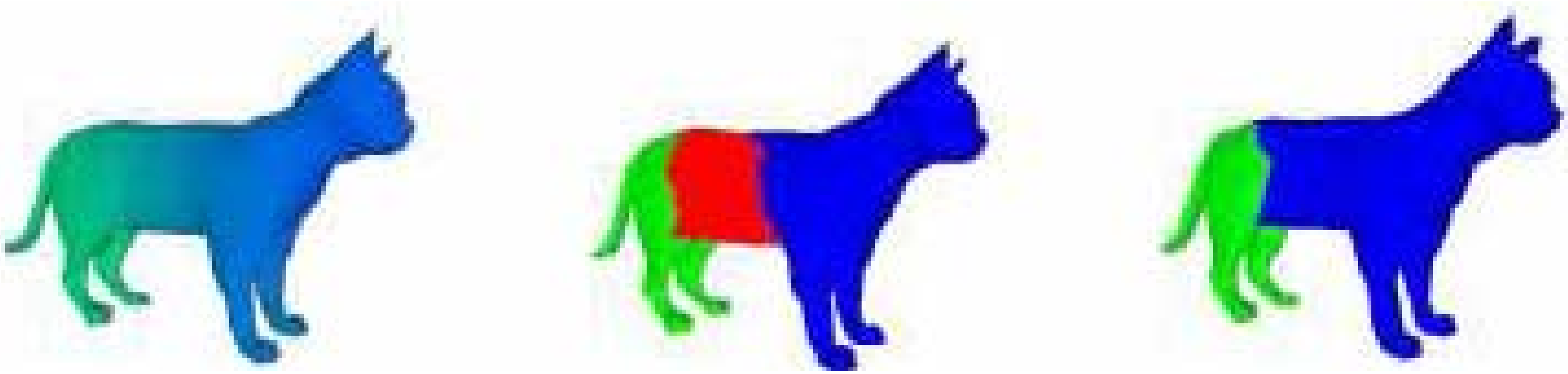




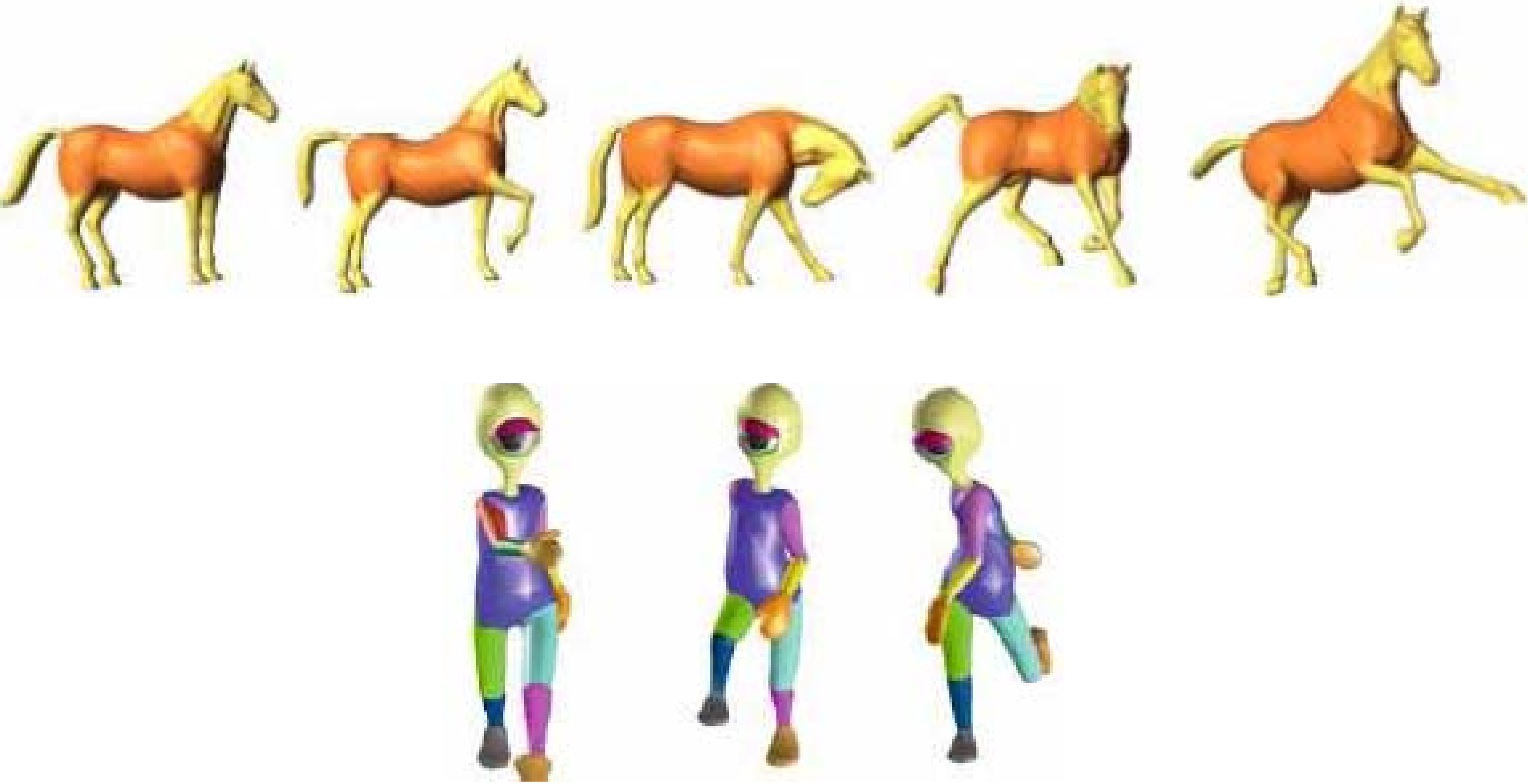
Graphcuts

- Find min-cut





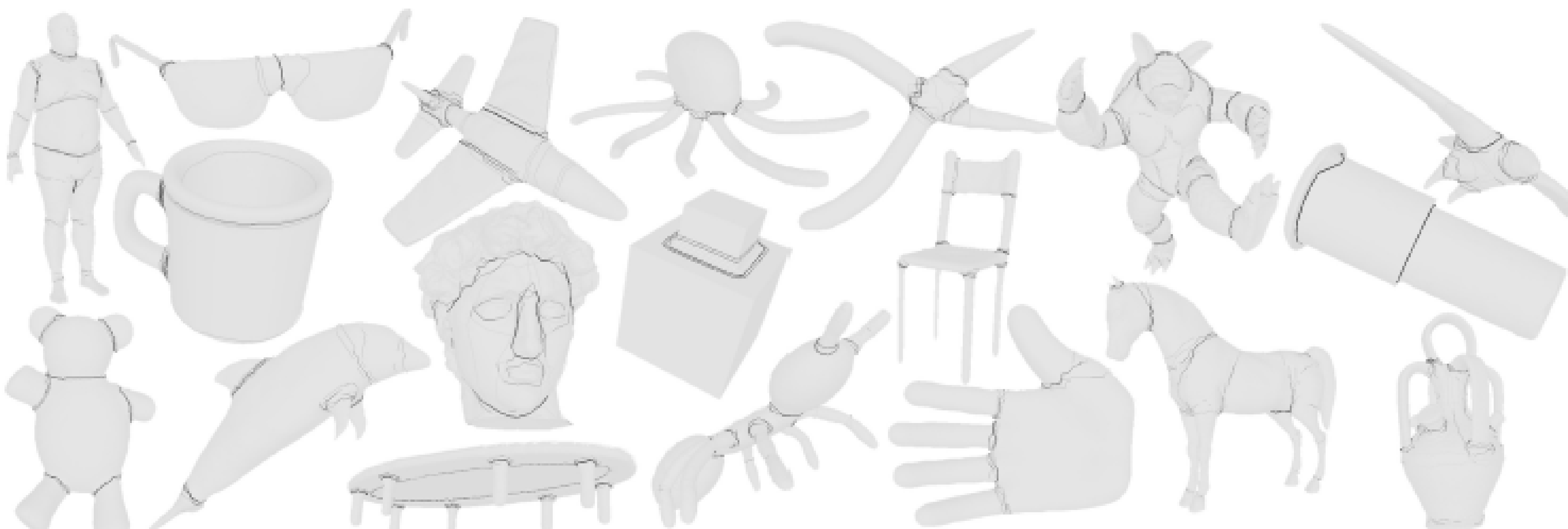
Pose Invariant



Evaluation

Benchmark for Segmentation

- A Benchmark for 3D Mesh Segmentation, Siggraph 2009



Summary

- Many applications use mesh segmentation as a substage
- Segmentation usually has more effect on the results than seem to be realized
- 3D segmentation is still a very difficult problem – and still in its infancy, e.g. compared to image segmentation (hundreds of papers).
- More advanced coherency issues should be addressed such as pose invariance, extracting similar parts and shapes over similar objects and more…

Discussion