Mesh Segmentation

Thomas Funkhouser

(most slides by Ark 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.

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.

Motivation

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

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

Analysis

Create: a set \( S \) of submeshes \( M_i \), that partition the faces of \( M \) into disjoint subsets.

Animation

Collision detection
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 $C$

Outline

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.

---

**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

- Average geodesic distance to other points

---

**Distances**

Triangles in same segment ought to be close

- Discontinuities in functions of distance indicate possible boundaries

---

**Distances with Spectral Embedding**

- Linkage-based (local info.)
- In-spectral domain
- Spectral clustering

---

Zhang
Normal direction, Dihedral Angles

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

Smoothness, Curvature

Concave creases indicate good segmentation boundaries

Diameter

Distinguish between thin and thick parts in a model

Convexity

Parts generally should be convex and compact

Symmetry

Segments should be locally symmetric

Combining many properties

Randomized cuts

(a) Input mesh  (b) Randomized Cuts  (c) Partition Function
Segmenting and Labeling

Multi-objective mesh segmentation

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

Outline

Constraints
Objective function
Algorithmic strategies
Evaluation

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 be 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
**Primitive Fitting**

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

- Planes
- Cylinders
- Spheres, cylinders, & rolling ball surfaces

**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.

**Comparison of Strategies**

Strategies
- Region growing
- Hierarchical
- Iterative
- Graph cut

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

**Choosing the Number of Segments**

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.
Outline
Constraints
Objective function
Algorithmic strategies
Evaluation

Benchmark for Mesh Segmentation
Chart09