Feature Sensitive Mesh Segmentation with Mean Shift

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Introduction (1) : Why segmentation?

- **Mesh Segmentation = basic GMP tool**
  - Shape understanding
  - Mesh simplification
  - Mesh matching, retrieval, animation
  - Texture mapping
  - ...

[Liu et al. 04]
[Cohen-Steiner et al. 04]
[Funkhouser et al. 04]
[Sander et al. 03]
Introduction (2)

What is the “meaningful” segmentation?

- Segmentation zoo ... many criteria, applications
- Perceptually meaningful features
  - High variation points of surface normals
  - Feature = normals

Main idea behind our approach:

- Enhance features via clustering the field of normals
  - No change geometry. Change normals.
- Segment a mesh according to the enhancement
Contributions

- Exploiting feature sensitivity
  - Feature enhancing method
  - Segmentation method which exploit enhanced features
Our approach

- Enhance features
- Use a segmentation method adapted to enhanced features

![Diagram showing the process of feature enhancement and segmentation.](image)
Enhancing features

- Features = points of high variation of surface normals
- Clustering normals
  - Enhancing the important features + ignoring small-scale surface details

Conventional mesh segmentation doesn’t work well because of small-scale surface details

The same segmentation method is applied to the same mesh with modified (clustered) normals
Overview Demo

• Without feature enhancement with K-means

• Feature sensitive segmentation method
Outline

• Feature enhancement
  – **Mean Shift**: What is Mean Shift?
    – Mean Shift on a mesh
• Feature sensitive segmentation
  – Segmentation algorithm
  – Demo
• Experimental results
• Conclusions
Mean Shift: overview

- Scattered data clustering in d-dim
- Theoretical foundation
- Only one intuitive parameter
  - kernel support size: $h$

D-dim feature space
scattered data
Mean Shift: overview

- **Scattered data clustering in d-dim** [Fukunaga et al. 75]
- Theoretical foundation
- Only one intuitive parameter
  - *kernel support size: h*

\[
\nabla \hat{f}(x) = \frac{2c}{Nh^{d+2}} \sum_{i=1}^{N} g \left( \left\| \frac{x - x_i}{h} \right\|^2 \right) m(x)
\]

- **Mean Shift vector**
  \[
  m(x) = \frac{\sum_{i=1}^{N} x_i g \left( \left\| \frac{x - x_i}{h} \right\|^2 \right)}{\sum_{i=1}^{N} g \left( \left\| \frac{x - x_i}{h} \right\|^2 \right)} - x
  \]

- Mode detection: \( \nabla \hat{f}(x) = 0 \)

**d-dim feature space clustering example**
Mean Shift vector: $m(x)$

- Find the local densest direction

\[
m(x) = \frac{\sum_{i=1}^{N} x_i g \left( \left\| \frac{x-x_i}{h} \right\|^2 \right)}{\sum_{i=1}^{N} g \left( \left\| \frac{x-x_i}{h} \right\|^2 \right)} - x
\]
How Mean Shift works

[Ukrainitz and Sarel]

- Objective: Find the densest region
How Mean Shift works
[Ukrainitz and Sarel]

- Objective: Find the densest region

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How Mean Shift works

[Ukrainitz and Sarel]

- Objective: Find the densest region

- Kernel support
- Center of region

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- Objective: Find the densest region
- Kernel support
- Center of region
- Center of mass
- Mean Shift vector
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- Objective: Find the densest region

- Kernel support
- Center of region
- Center of mass
- Mean Shift vector
- Converged center
- Attraction point
Outline

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  – Mean Shift: What is Mean Shift?
  – Mean Shift on a mesh
• Feature sensitive segmentation
  – Segmentation algorithm
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Feature enhancement:
Clustering mesh normals with Mean Shift

- Feature space
  - $6$-d points (position and normal) (5-d)

Face normal + its foot point (face centroid)

Feature space
Feature enhancement: Clustering mesh normals with Mean Shift

• Mean Shift process
  - converge to attraction points in 6-dim space (basin of attraction)

Face normal + its foot point (face centroid)

Feature space
Feature enhancement:
Clustering mesh normals with Mean Shift

- Back projecting normal to the original positions
  - Feature preserving normal filtering
  - Preprocessing for segmentation

Face normal + its foot point (face centroid)

Feature space
Enhanced normal example

- Noisy octahedron: (additive Gaussian noise)
- Enhanced normal
  - Normals are changed. No change geometry.
Feature preserving noise removal with Mean Shift

- Denoise with local estimated normal [Ohtake et al. 01]
- Normal estimation by Mean Shift
Feature preserving smoothing with Mean Shift

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input

$h_n = 0.5$

$h_n = 0.2$

$h_n = \infty$
Outline

• Feature enhancement
  – *Mean Shift : What is Mean Shift?*
  – *Mean Shift on a mesh*

• Feature sensitive segmentation
  – *Segmentation algorithm*
  – *Demo*

• Experimental results

• Conclusions
How to create a segmentation?

- Enhance features ≠ Segmentation
  - *Points are still scattered in the feature space*

Face normal + its foot point (face centroid)

Feature space
How to create a segmentation?

- Clustering ≠ Segmentation
  - Points are still scattered in the feature space
  - Segmentation with respecting the clustering
Feature sensitive segmentation

How can we segment the points in the feature space?

• Region growing [Shlafman 02, Sander 03, Cohen-Steiner 04, Comaniciu 02, Lèvy 02,...]
• Hierarchical clustering [Garland 01, ...]
• Spectral analysis [Liu 04, ...]
• Hybrids, others, ....
Feature sensitive segmentation

*Using iterative region growing algorithm [Lloyd 82, Shlafman et al. 02, Sander et al. 03, ...]*

- Segmentation with Volonoi-like region
  - *Calculate MST (Minimum Spanning Tree) from seeds*
  - *Seed optimization with Lloyd algorithm*

Growing from seeds with feature space distance
Feature sensitive segmentation

- Selecting distance metric is the key of growing
  - Feature
    ✓ Enhanced dihedral angle
  - Mesh connectivity
    ✓ keep topology
- Segmentation method which adapts enhanced features
- → Feature enhancement + segmentation for it
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  – *Demo*

• **Experimental results**

• Conclusions
Experimental Results (1)

- Fandisk: 12,944 tris., 20 charts

- MCGIM [Sander 03] 31.2 s
- VA [Cohen-Steiner 04] 12.7 s
- Our method
  - 0.96+26.6 sec
  - hg = 0.05, hn = 0.3
Experimental Results (2)

- Mannequin: 21,680 tris., 30 charts

- MCGIM [Sander 03] – 67.5 s

- VA [Cohen-Steiner 04] – 32.1 s

- Our method
  - 11.4+90.4 s
  - hg = 0.1, hn = 0.3
Experimental Results (3)

- Camel: 78,144 tris., 80 charts

- MCGIM
  - 1659 s

- VA
  - 256 s

- Our method
  - 11.5+1598 s
  - \( hg = 0.015, \, hn = 0.3 \)
Experimental Results (5)

- Effect of support size and segmentation

Black disk shows the geometric support size of Mean Shift

- Too small → small structure is considered features
- Too large → some features are smooth out
Experimental Results (4)

- Cow: 23,216 tris., 90 charts
- MCGIM
  - 185 s
- VA
  - 22.9 s
- Our method
  - 0.95+225 s
  - \( h_g = 0.015, h_n = 0.3 \)

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Conclusion & Feature work

• Perceptually salient segmentation
• Enhancing surface features
  → feature-sensitive
• Segmentation via clustering
• User-specified parameters
  – feature size + number of charts
• Selecting the kernel support size
• K-means clustering instead of Mean Shift? (only one parameters)
• Can be easily extended to other criteria. (Curvatures, etc.)
Questions?
(clusters of questions are also welcome)
Resources. Thank you.

• Mean Shift Intuitive description slides
  – Advanced Topics in Computer Vision, Simon Ullman, Michal Irani, and Ronen Basri, Second semester (2003/04) course, 9 Mean Shift.
    ✔ http://www.wisdom.weizmann.ac.il/~deniss/vision_spring04/lectures_full.html

• Figures with [cite name] comes from the authors' paper or their web pages

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