A Comparative Evaluation of Foreground/Background Sketch-based Mesh Segmentation Algorithms

Min Meng  Lubin Fan  Ligang Liu

Zhejiang University, China
Mesh Segmentation

Modeling

Morphing

Shape Editing

Deformation

Texture Mapping

Shape Retrieval

“I want to cut out the head part of the bunny model”
Foreground/background Sketch-based UI

• User Interface
  – Easy mesh cutting [Ji et al. 2006]
  – [Wu et al. 2007]
  – [Lai et al. 2008]
  – [Xiao et al. 2009]
  – ...

• Easy to use
Motivation

• Current State
  – Lots of algorithms
  – Different results and performance levels
  – No work on the quantitative evaluation

How well the approaches perform?
This Work

- The **first** evaluation of sketch-based mesh segmentation algorithms
  - 5 state-of-the-art algorithms
  - 100+ participants
  - A software platform
  - A ground-truth segmentation data set
  - Extensive analysis
  - Valuable insights
Related Work on Evaluation

• **Automatic Mesh Segmentation**
  – Mesh segmentation - a comparative study [Attene et al. 2006]
  – A survey on mesh segmentation techniques [Shamir 2008]
  – A benchmark for 3D mesh segmentation [Chen et al. 2009]
    • 7 automatic mesh segmentation algorithms
    • Publicly available data set & software
Related Work on Evaluation

• Image
  – Image Segmentation
    • A comparative evaluation of interactive segmentation algorithms [McGuinness et al. 2010]
  – Image Retargeting
    • A Benchmark for Image Retargeting [Rubenstein et al. 2010]
Outline

• Evaluated Algorithms
• Date Set
• Evaluation System
  – Training Mode
  – Evaluation Mode
• Experiment
• Analysis
• Conclusion
## Evaluated Algorithms

<table>
<thead>
<tr>
<th>Method</th>
<th>Algorithms</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region growing</td>
<td>[Ji et al. 2006] * [Wu et al. 2007]</td>
<td>EMC</td>
</tr>
<tr>
<td>Bottom-up aggregation</td>
<td>[Xiao et al. 2009] *</td>
<td>HAE</td>
</tr>
<tr>
<td>Graph-cut</td>
<td>[Brown et al. 2009] *</td>
<td>GCS</td>
</tr>
</tbody>
</table>

**Note:**
- The evaluated algorithms are marked by *.
- For further details, please refer to the original papers.
Constructing the Data Set

• Our Data Set
  – Based on the Princeton database [Chen et al. 2009]
  – 18 categories
Constructing the Data Set

- **Our Data Set**
  - Based on the Princeton database [Chen et al. 2009]
  - 18 categories
  - 5 models in different poses from each category
  - One part for each model
Constructing the Data Set

• **Our Data Set**
  - Based on the Princeton database [Chen et al. 2009]
  - 18 categories
  - 5 models in different poses from each category
  - One part for each model
Constructing the Data Set

• Our Data Set
  – Based on the Princeton database [Chen et al. 2009]
  – 18 categories
  – 5 models in different poses from each category
  – One part for each model
  – Assistant images
Evaluation System

• System Overview

Evaluation Panel

Main Window
Evaluation System

- System Overview
Training Mode

- Training Process
Evaluation Mode

Begin Task

Timer

Task
1/5 task

Time Left
240 sec.
Evaluation Mode

- Algorithm’s name
- Users’ interactions;
- Segmentation results;
- Time of interaction;
- Run time of the algorithm.
Experiment

• Task for each participant
Experiment

- Task for each participant

Finish task with 5 segmentation algorithms in unknown order.

Data Pack

Test model

Participant

Record
Experiment

• Task for each participant

Segment all models.

Participant

Data Pack

Test model
Experiment

- Questionnaire
  - Personal information part
    - Gender, age, education background, experience on geometry processing
  - Algorithm part
    - How easily the users specified the segmentations?
    - How fast they carried out their initial segmentations?
    - How accurate they considered their initial segmentations?
    - How fast they refined their segmentations?
    - How accurate they considered their final segmentations?
    - How stable is the method?
    - Rate the algorithm by considering the general performance.
Experiment

• User statistics
  – 105 participants.
  – 30 participants have experience in geometry processing,
  – 40 participants are familiar with human-computer interaction.
  – Most of them are computer science graduates.
Experiment

• Collected experiments
  – One month.
  – 2625 segmentations collected
    • 2310 accepted
    • 315 discarded
  – Each model was segmented an average of 5 times by each algorithm
Criteria of Evaluation

- **Accuracy**
  - The degree to which the extracted part corresponds to the ground-truth

- **Efficiency**
  - The amount of time or effort required to perform the desired segmentation

- **Stability**
  - The extent to which the same result would be produced over different segmentation sessions when the user has the same intention
**Accuracy Measurement**

- **Boundary Matching**
  
  The matching degree between the cut boundaries of two interactive segmentations
  
  – Cut discrepancy (NCD) [Chen et al. 2009]
Accuracy Measurement

• **Region Difference**

  The consistency degree between the parts of interest produced by interactive segmentations in our study
  
  – Hamming distance (**NHD**) [Chen et al. 2009]
  – Rand index (**RI**)
  – Global/Local consistency error (**NGCE, NLCE**)
  – Binary Jaccard index (**JI**) [McGuinness et al. 2010]

• **Normalized Measures**

  – the higher the number, the better the segmentation
Analysis

• **Accuracy**
  – Boundary Matching
  – Region Difference

• **Efficiency**
  – Interactive time
  – Updating time for new sketches
  – Number of interactions

• **Stability**

• **User feedback**

• **Comparison with automatic algorithms**
Accuracy

• Boundary Accuracy

Boundary Accuracy

Variance of Accuracy
Accuracy

- Region Accuracy

![Graph showing Region Accuracy and Variance of Accuracy](image)
Efficiency

- Interactive time

![Bar chart showing average time for different categories: EMC, RWS, HAE, GCS, HFM.](chart.png)
Efficiency

- Updating time for new sketches
Efficiency

- Number of interactions
**Stability**

- **Averaged normalized coverage**

The percentage of triangles with the same labels (foreground or background) found when using different user inputs per model, averaged across all models for each algorithm.

![Graph showing average normalized coverage for different algorithms](image)
User Feedback

• Perceived accuracy

![Graph showing perceived accuracy for different methods: EMC, RWS, HAE, GCS, HFM.](image)

![Bar chart showing boundary accuracy for different methods: EMC, RWS, HAE, GCS, HFM.](image)

![Multi-bar chart showing region accuracy for different methods: avgNHD, avgRI, avgNLCE, avgNGCE, avgJL.](image)
User Feedback

- Feedback for Each Algorithm
vs. Automatic Algorithms

- **Automatic Algorithms**
  - Randomized cuts algorithm (RC) [Golovinskiy et al. 2008]
  - Segmentation results are from the Princeton segmentation database [Chen et al. 2009]
Summary

Object

• No interactive algorithm is better than all the others.
• EMC performs better:
  – The region growing scheme is very efficient.
  – Capture the geometry features
  – Quick feedback

Subject

• Efficient refinement
• Few interactions
• Instant feedback

Fast feedback and quick update process are more important than accuracy.
Conclusion

• Evaluation methodology for foreground/background sketch-based interactive mesh segmentation algorithms
• A software platform for evaluation
• Extensive user experiments
• Thorough analysis
• Valuable insights

Future Work

• Expand corpus and ground-truth
• Different sketch-based user interfaces
More details

• **Webpage:**
  

• **Supplementary file**

• **Share the data (soon!)**
  
  – Data set
  
  – Segmentation tasks and assistant images
  
  – User data
  
  – Analysis data
A Comparative Evaluation of Foreground/Background Sketch-based Mesh Segmentation Algorithms

Min Meng    Lubin Fan    Ligang Liu

Zhejiang University, China