Paint Mesh Cutting

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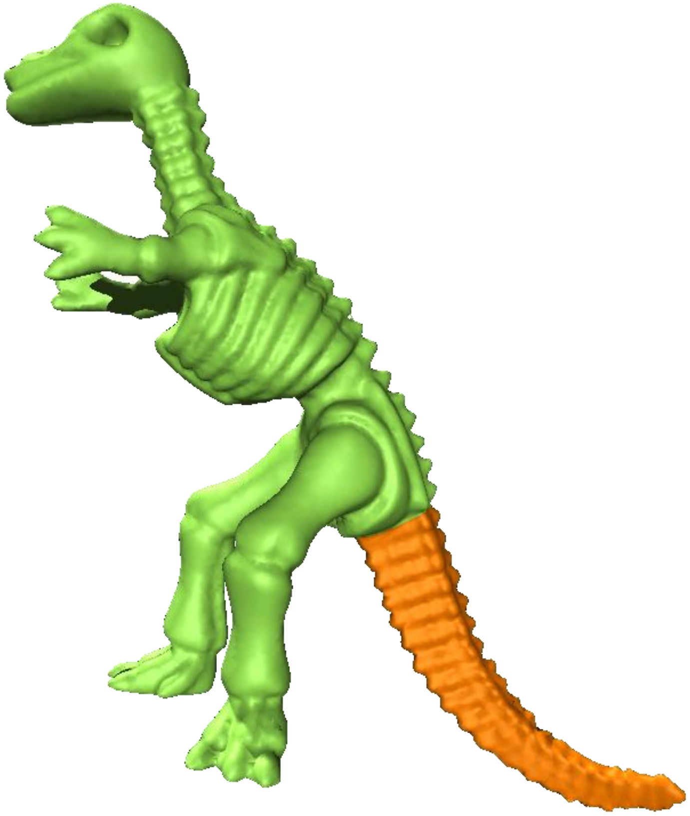
Outline

- **Related work & Motivation**
- **Basic algorithm**
  - Graph cuts based optimization
- **Paint mesh cutting system**
  - Global and local optimization
- **Results & conclusion**
  - Results
  - User study
  - Conclusion

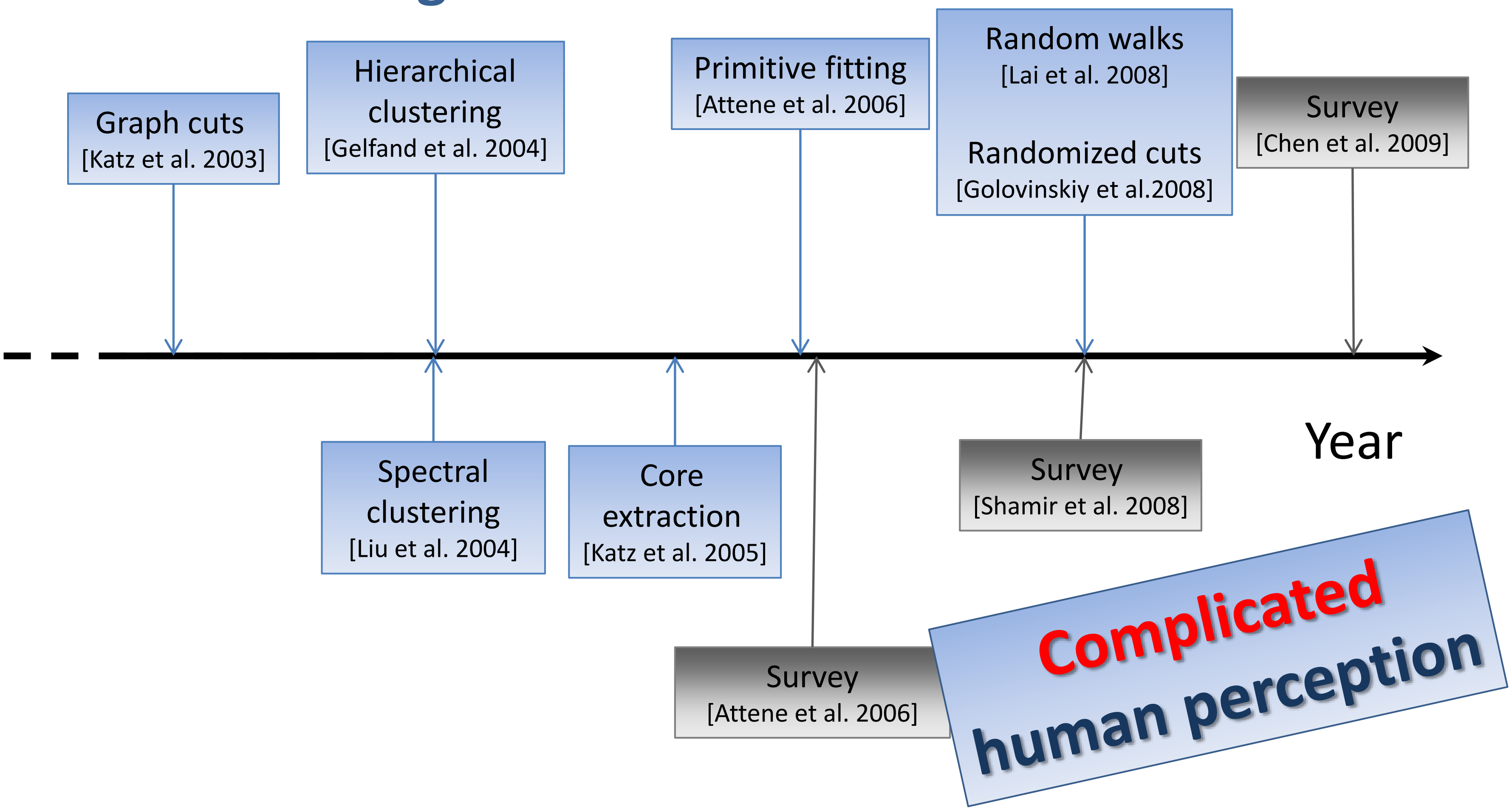
Motivation

- How to cut out its tail?



Motivation

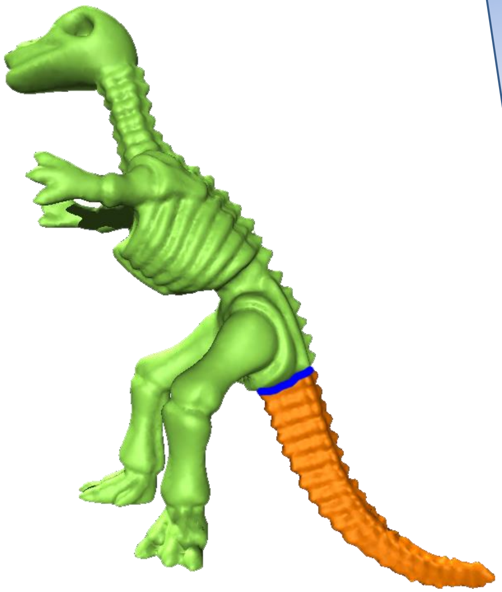
- **Automatic algorithms**



Motivation

- **Interactive** tools for mesh segmentation
  – Direct UI

Tedious
Time-consuming



Direct UI
[Funkhouser et al. 2004, Chen et al. 2009]

Motivation

- Interactive tools for mesh segmentation
  - Direct UI
  - Sketch-based UI

Motivation

- **Interactive** tools for mesh segmentation
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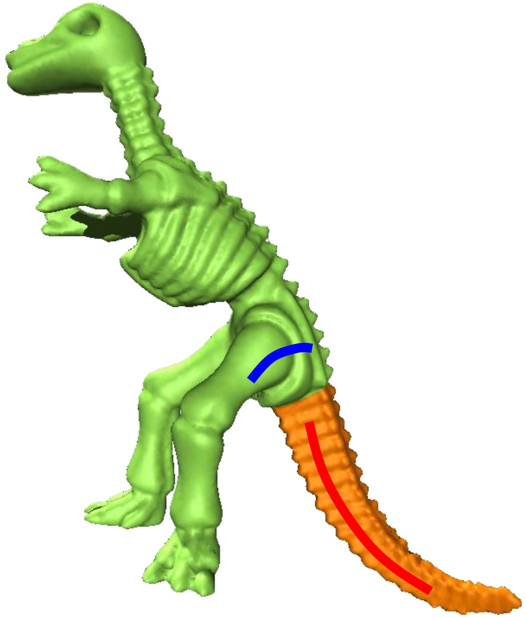
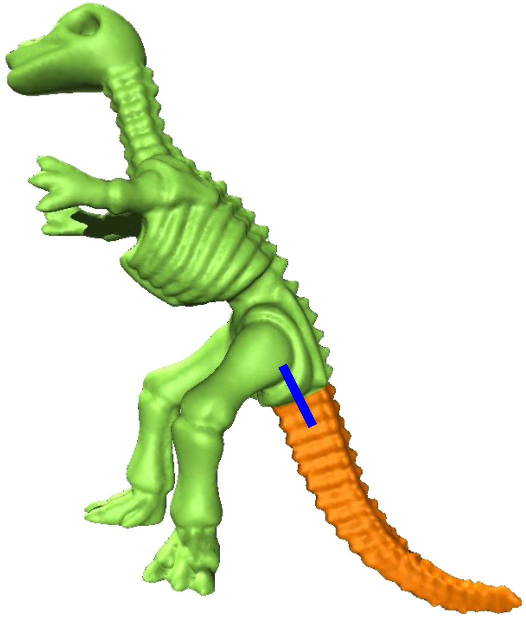


Foreground/background Brushes (FBB)
[Ji et al. 2006, Zhang et al. 2010]

Motivation

- **Interactive** tools for mesh segmentation
  - Direct UI
  - Sketch-based UI

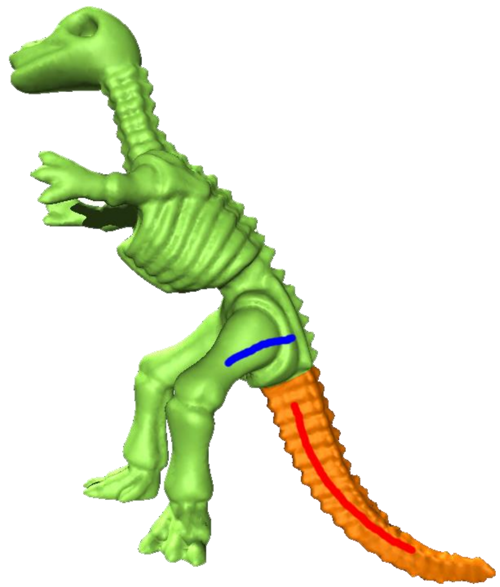


Cross-boundary Brushed (CBB)
[Zheng et al. 2010]

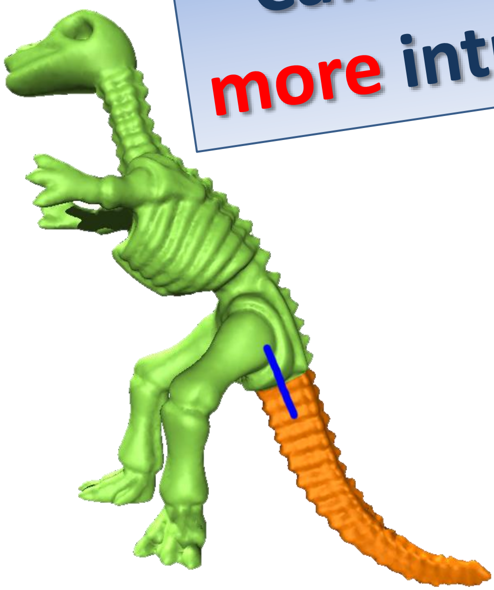
Motivation

- **Interactive** tools for mesh segmentation
  - Direct UI
  - Sketch-based UI

Can they be more intuitive?



Foreground/background Brushes (FBB)
[Ji et al. 2006, Zhang et al. 2010]



Cross-boundary Brushes (CB)
[Zheng et al. 2010]

Related Work

- Interactive image segmentation
  - Paint Selection [Liu et al. 2009]

Intuitive UI
Instant feedback

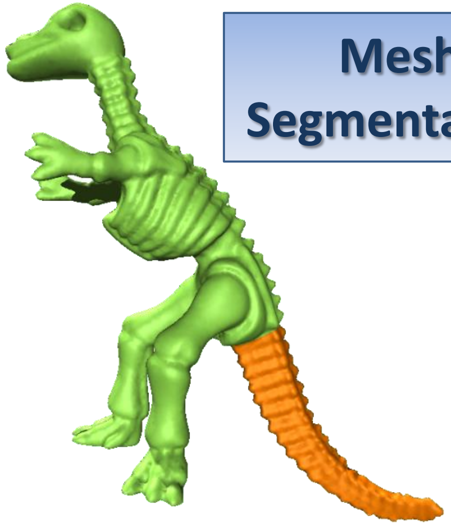
Motivation

2D

Paint Selection [Liu et al. 2009]

?

3D

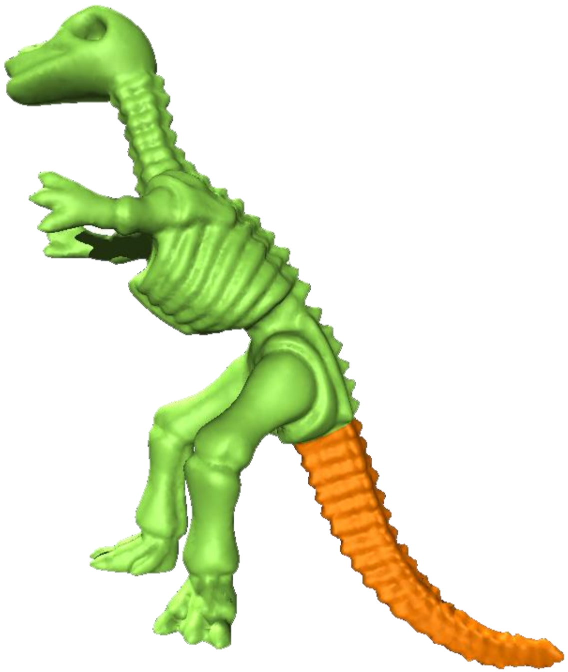


Mesh Segmentation

Motivation

Eurographics 2011
LLANDUDNO UK
11-15 April 2011

- Our **Goal**
  - Easy and simple
  - Natural manner
  - Specify user intention intuitively
  - Instant feedback



What you paint is what you get!

This Work

This Work

Optimization

- **Minimize the Energy**

$$E(L) = \sum_{v \in \mathcal{V}} E_d(l_v) + \lambda \sum_{(v,u) \in \mathcal{E}} E_s(l_v, l_u)$$

$E_d(\cdot)$ **data term**, the penalty of assigning a label l_v to vertex v (1-**foreground**, 0-**background**).

$E_s(\cdot,\cdot)$ **smoothness term**, the penalty for assigning different labels to two adjacent vertices v and u.

Data Term – $E_d(\cdot)$

- How to define the penalty in data term?

$$E_d\left(l_v\right) = l_v \cdot L_v^f + \left(1 - l_v\right) \cdot L_v^b$$

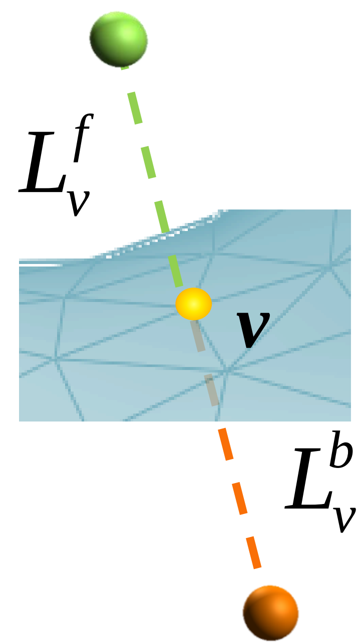
$$L_v^f = -\ln\left(p_f M\left(v\right) + \varepsilon\right)$$

$$L_v^b = -\ln\left(p_b M\left(v\right) + \varepsilon\right)$$

→ Probability

$M\left(v\right)$ ⟵ Surface Metric ?

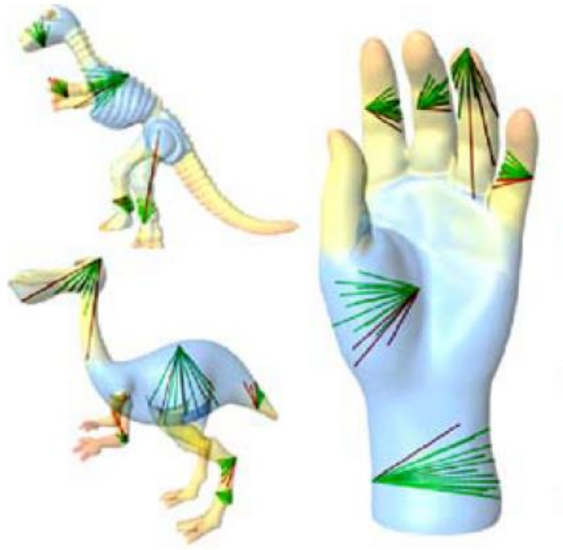
Foreground - 1

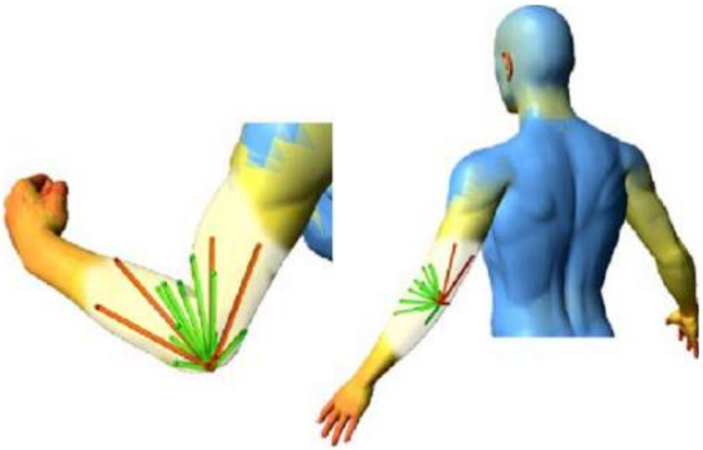


Background - 0

Surface Metric

- **Shape diameter function(SDF)** [Shamir et al. 2008]
  - Rely on volume information
  - Insensitive to noise
  - Insensitive to pose variation

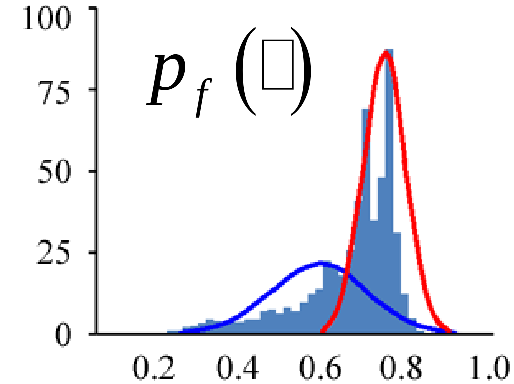




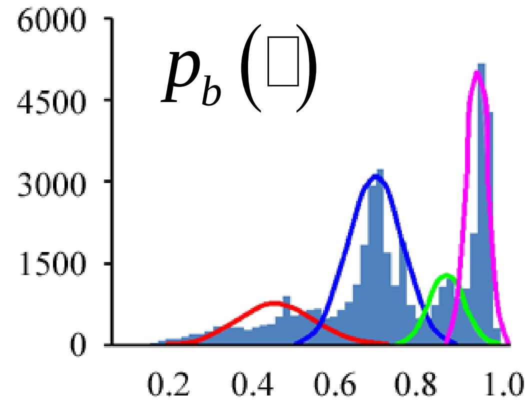
Build SDF Models

Build SDF Models

Gaussian Mixture Model (GMM)



Foreground



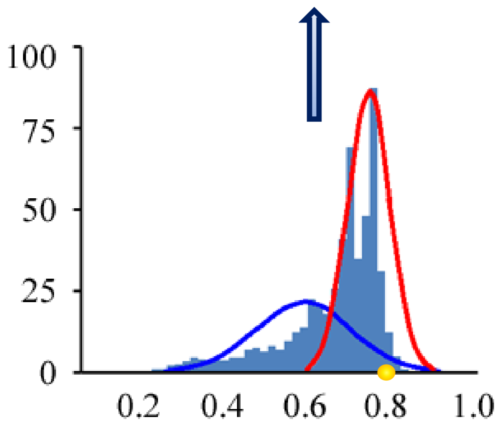
Background

Data Term – $E_d(\cdot)$

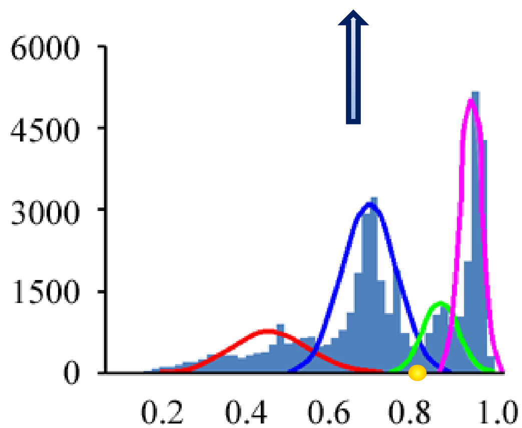
- **Data Term**

$$E_d(l_v) = \begin{cases} (1-l_v)\cdot K, & \forall v \in S^f \\ l_v \cdot L_v^f + (1-l_v)\cdot L_v^b, & otherwise \end{cases}$$

$$L_v^f = -\ln\left(p_f M(v) + \varepsilon\right) \qquad L_v^b = -\ln\left(p_b M(v) + \varepsilon\right)$$



Foreground



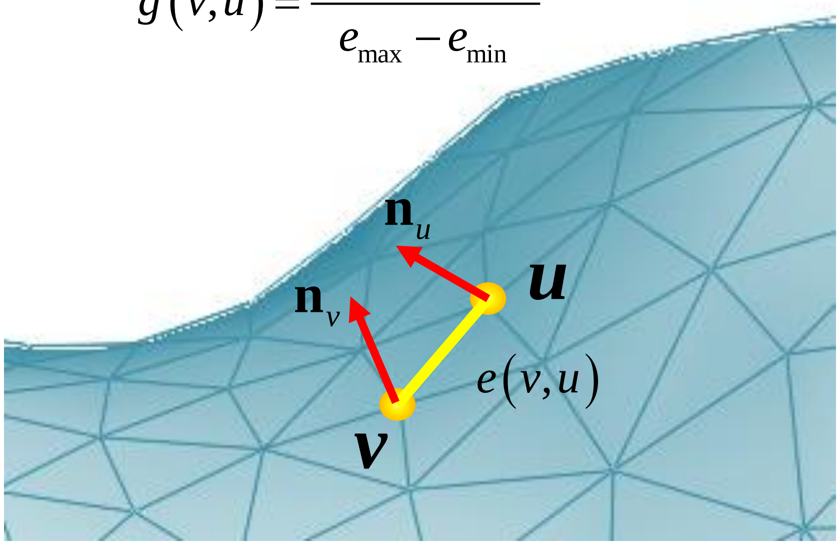
Background

Energy Terms

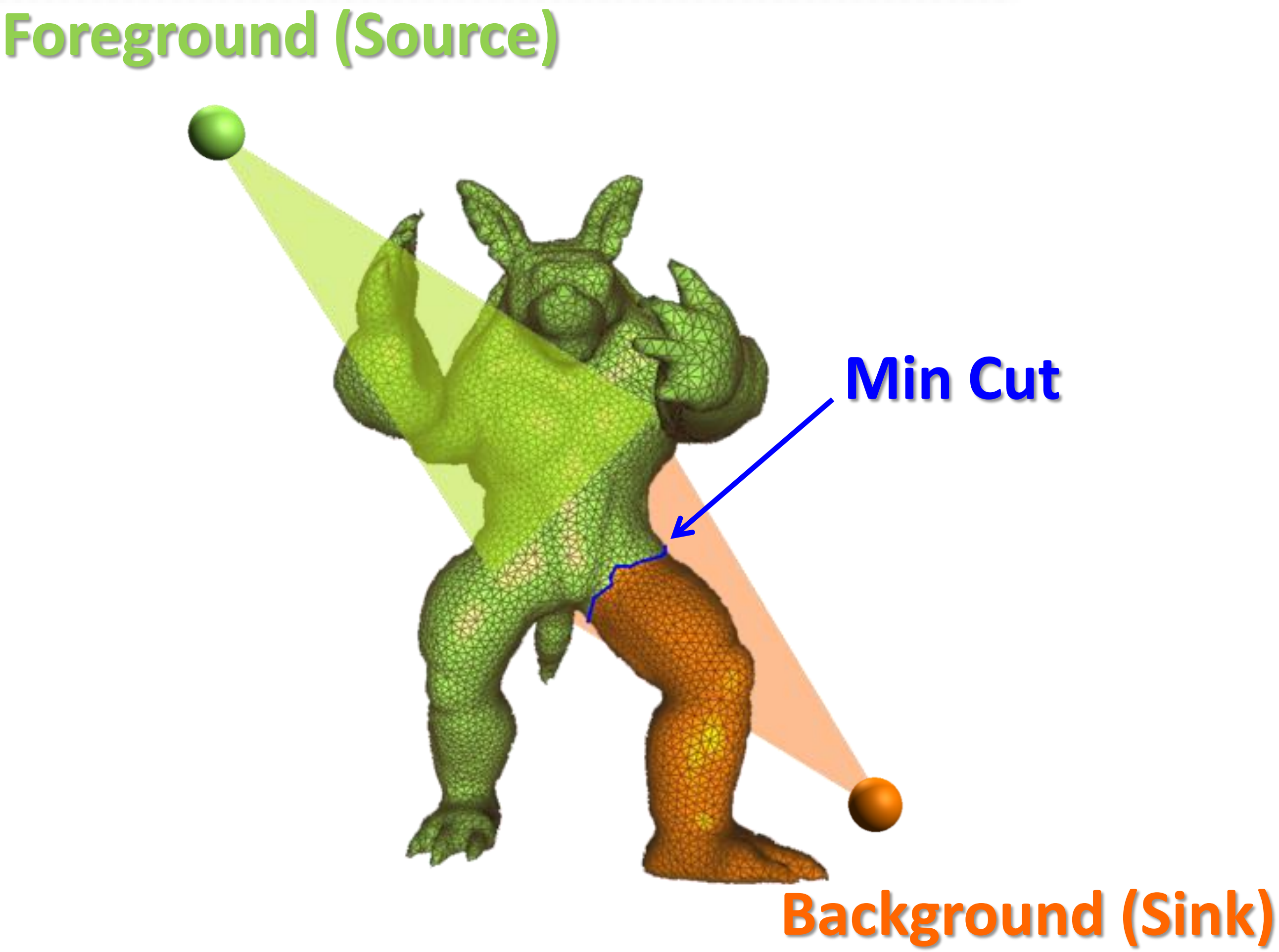
- Data Term
- Smoothness Term

$$E_s(l_v, l_u) = -|l_v - l_u| \cdot \ln\left(\left(1-\beta\right)n(v,u) + \beta g(v,u)\right)$$

$$n(v,u) = \frac{1 - \mathbf{n}_v \cdot \mathbf{n}_u}{2} \qquad g(v,u) = \frac{e(v,u) - e_{\min}}{e_{\max} - e_{\min}}$$



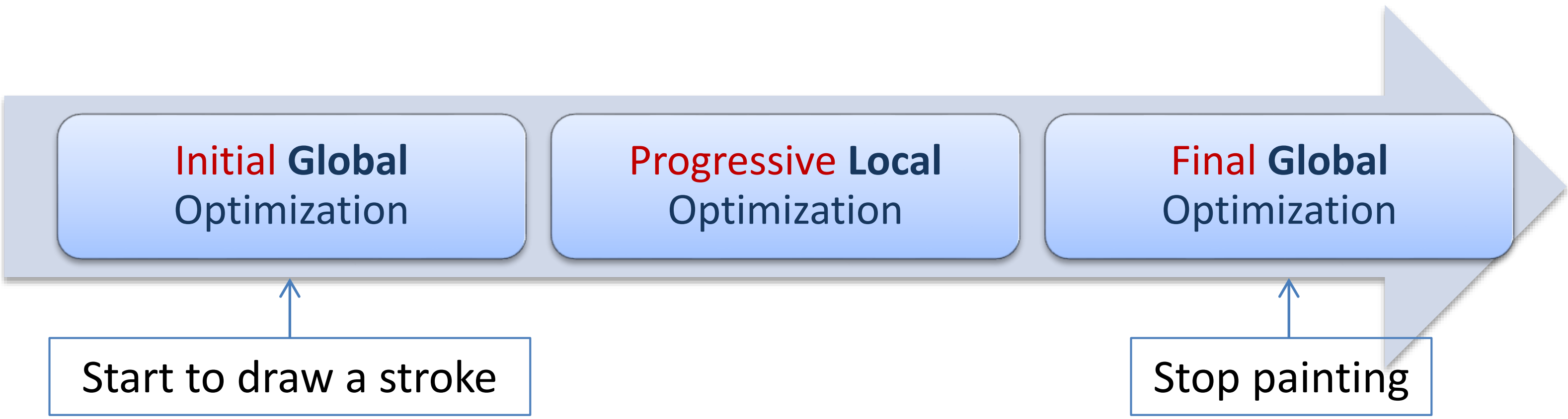
Graph Cuts



[Boykov and Jolly 2001]

System Overview

- **Progressive expansion algorithm**



- **Goal**
  - simple and easy to use
  - instant feedback (usually under 0.1 sec.)
  - expand the foreground continuously

Initial Global Optimization

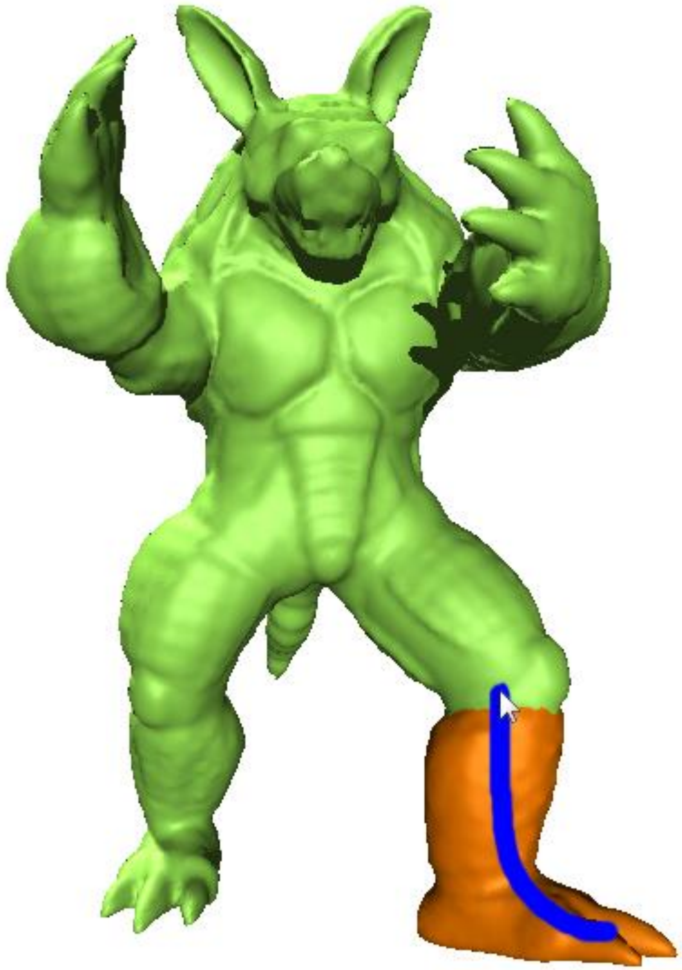
Eurographics 2011
LLANDUDNO UK
11-15 April 2011

Algorithm

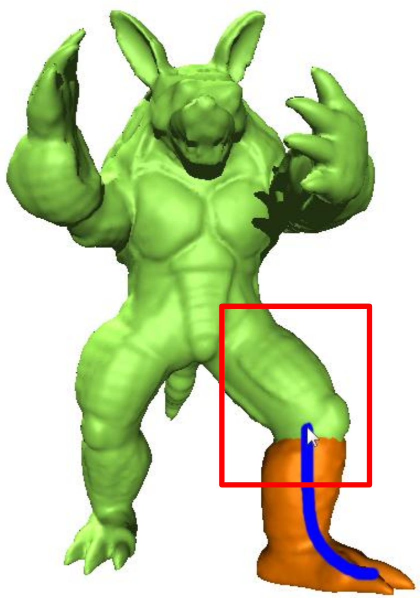
- Compute SDF values.
- Construct global graph.
- Build the background GMM model $p_b(\cdot)$ with 4 components.
- Build the foreground GMM model $p_f(\cdot)$ with 2 components.
- Apply the graph cuts optimization.

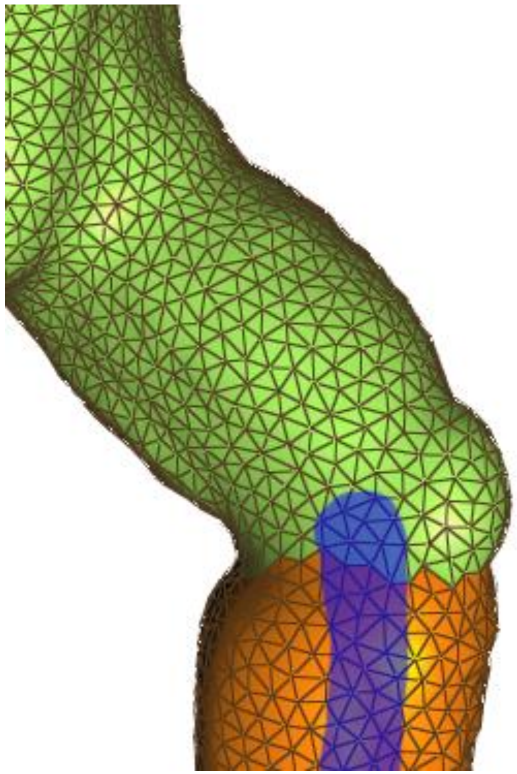
Progressive Local Optimization

Progressive **Local** Optimization



Progressive Local Optimization

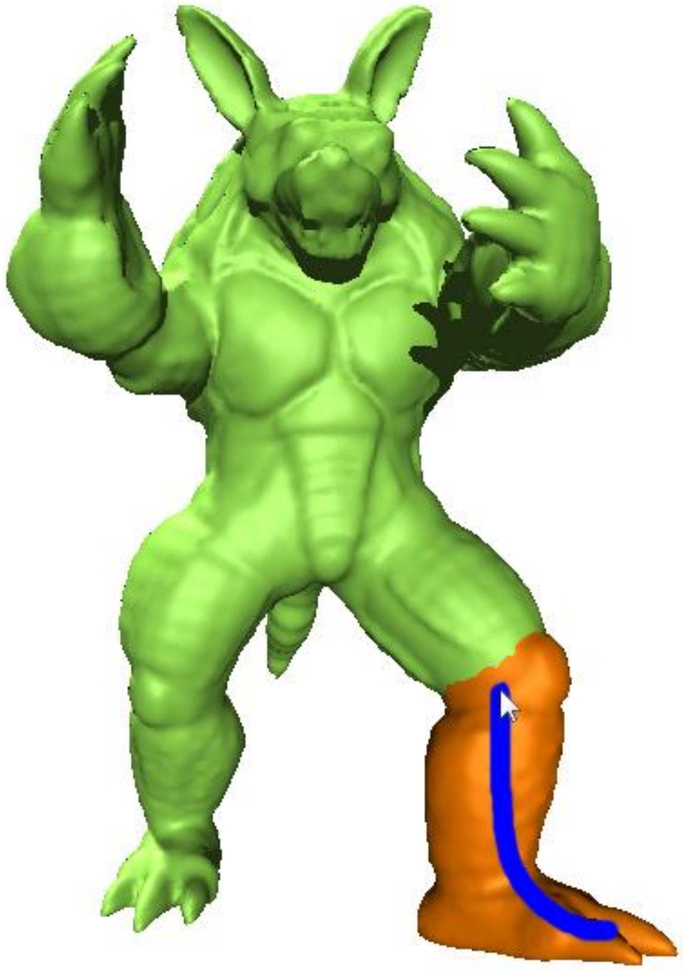




Algorithm

- Construct local graph.
- Build $p_f(\cdot)$ with 1 components.
- Update background sample vertices.
- Update $p_b(\cdot)$.
- Apply graph cuts optimization to local graph.

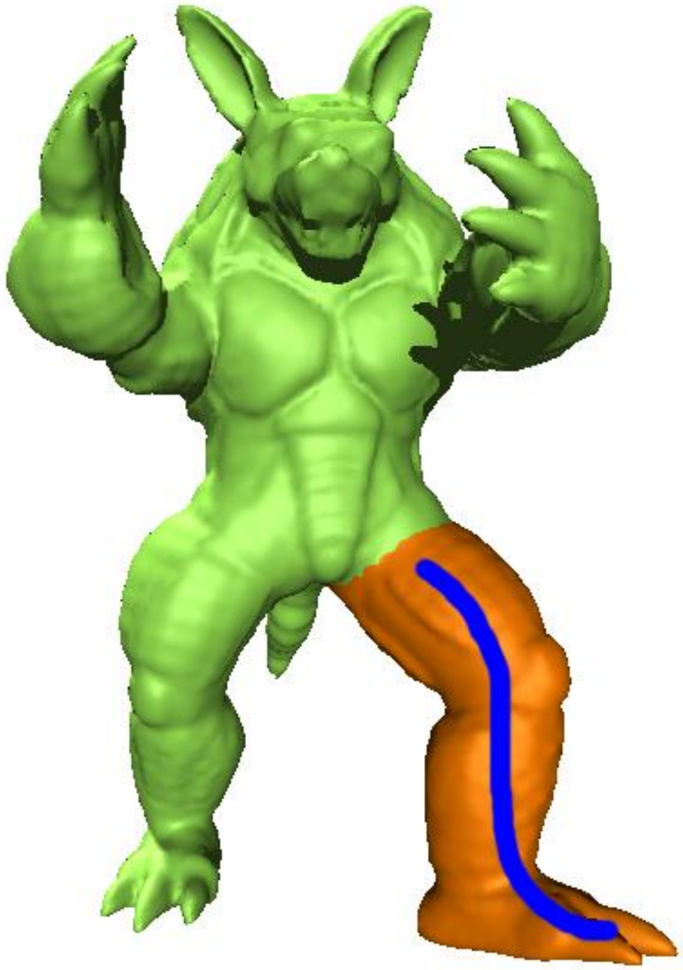
Progressive Local Optimization



Algorithm

- Construct local graph.
- Build $p_f(\cdot)$ with 1 components.
- Update background sample vertices.
- Update $p_b(\cdot)$.
- Apply graph cuts optimization to local graph.

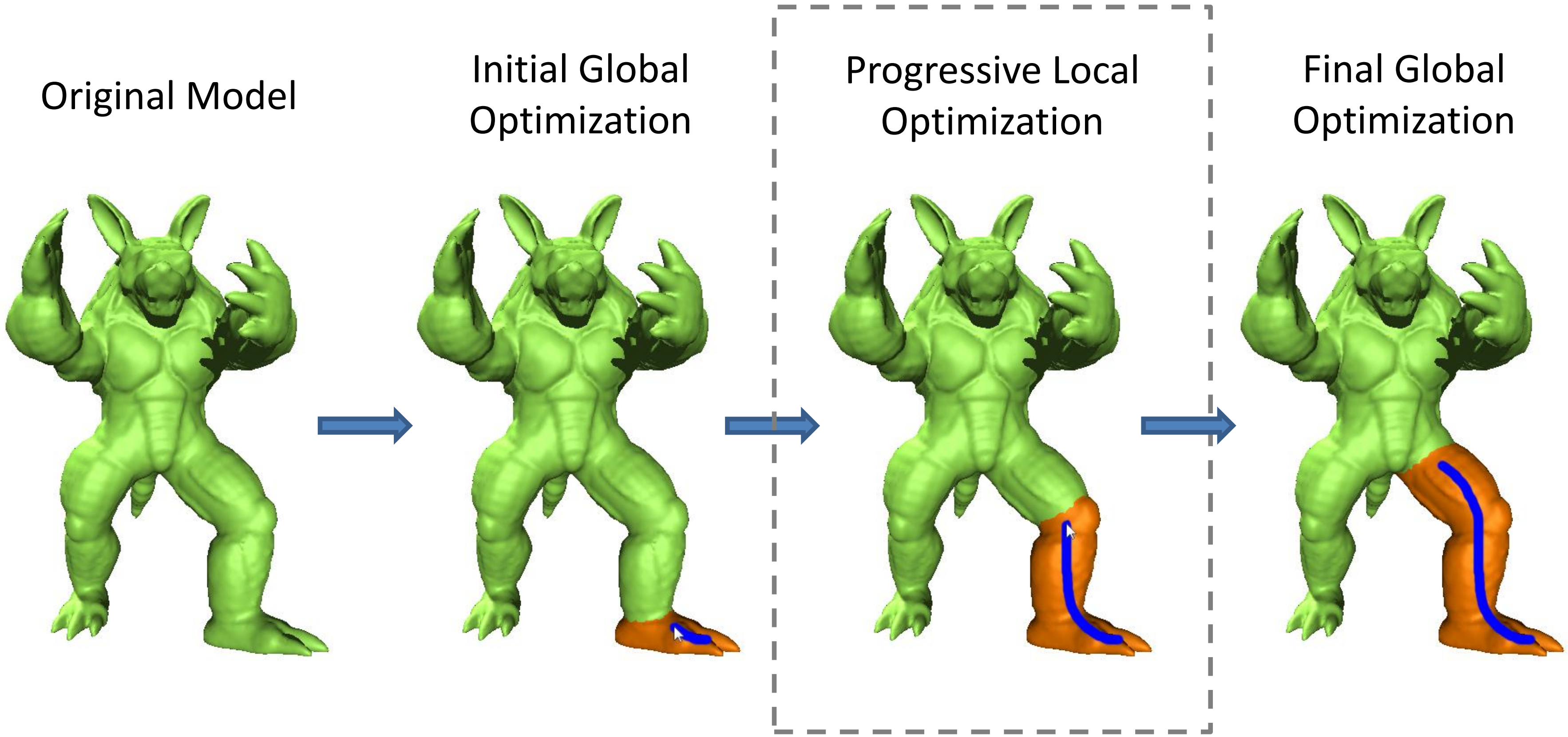
Final Global Optimization



Algorithm

- Update $p_f(\cdot)$ with 2 components.
- Update $p_b(\cdot)$ with 4 components.
- Apply the graph cuts optimization.

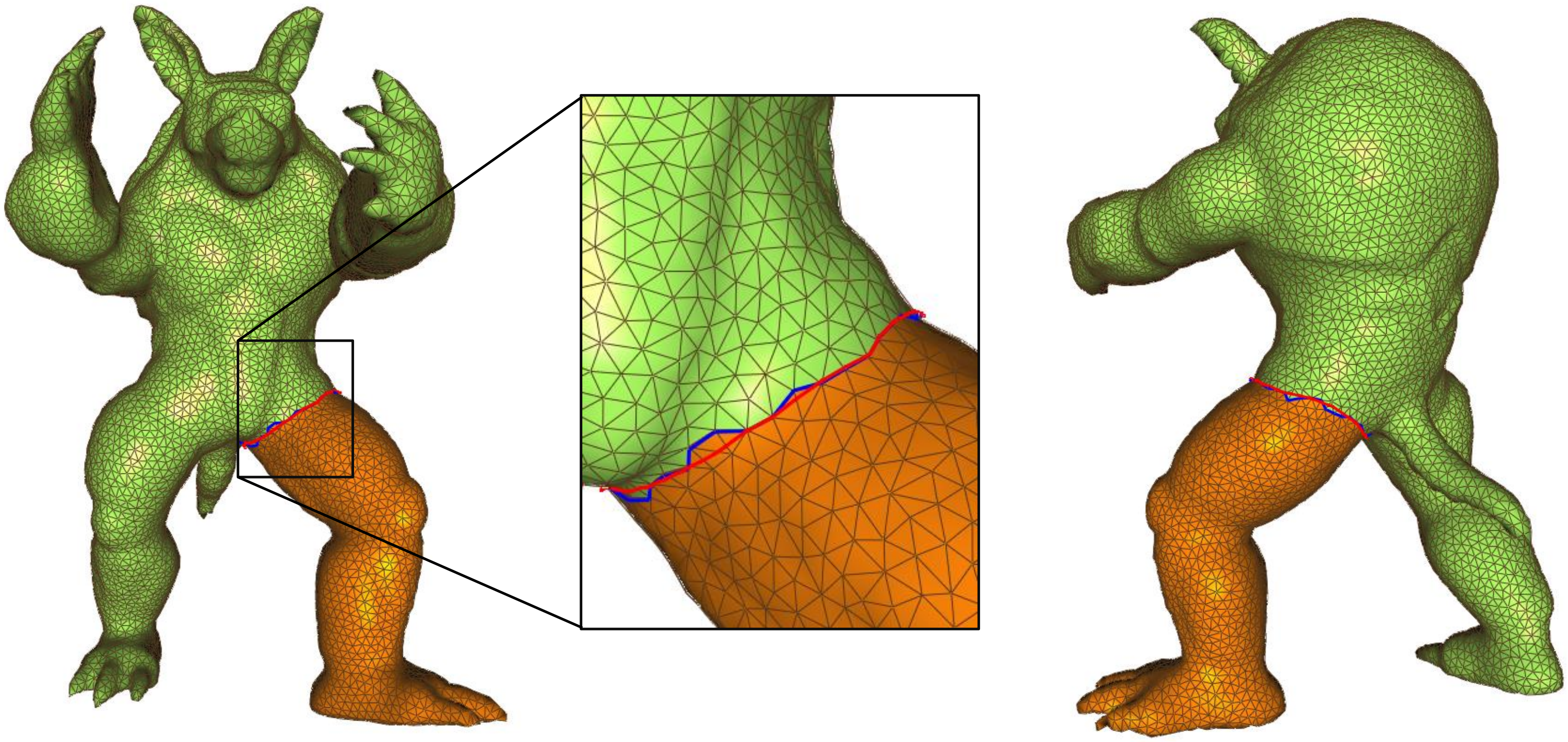
Flow Chart


Original Model
Initial Global Optimization
Progressive Local Optimization
Final Global Optimization

Implementation Details

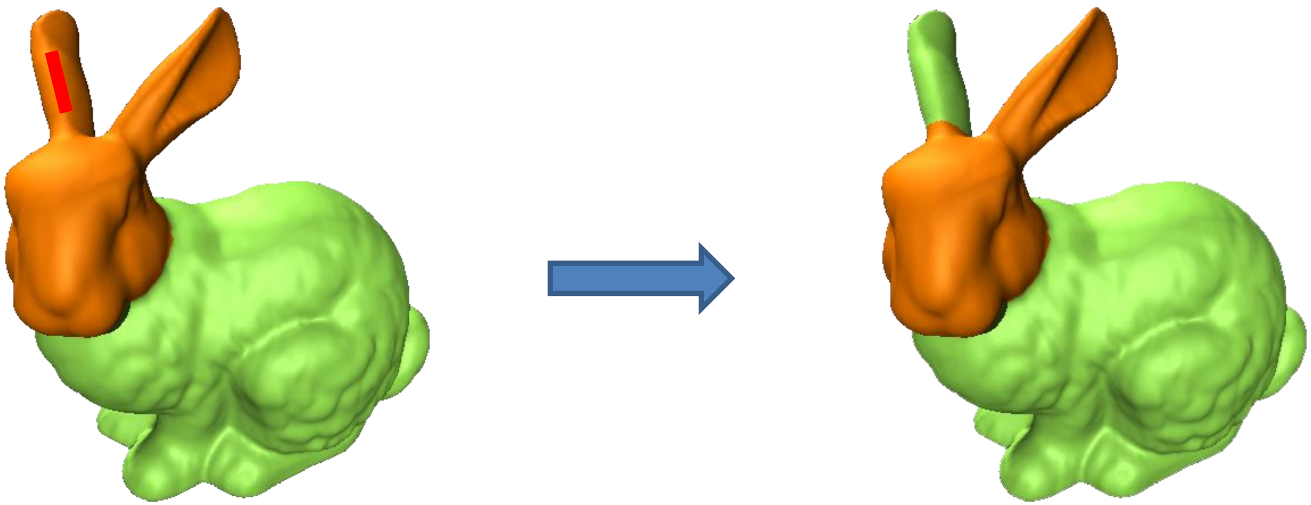
Implementation Details

- **Cutting boundary refinement**
  - Boundary smoothing by ***snakes*** on mesh [Ji et al. 2006]



Implementation Details

- Cutting boundary refinement
- **Background painting**



$$E_d(l_v) = \begin{cases} (1-l_v)\cdot K, & \forall v \in S^f \\ l_v \cdot K, & \forall v \in S^b \\ l_v \cdot L_v^f + (1-l_v)\cdot L_v^b, & otherwise \end{cases}$$

Implementation Details

- Cutting boundary refinement
- Background painting
- **Speedup**
  - Computation of SDF values
    - Interpolation using the Poisson equation [Kovacic et al. 2010]
  - Graph cuts optimization
    - Parallel graph-cut method [Srandmark et al. 2010]

Results

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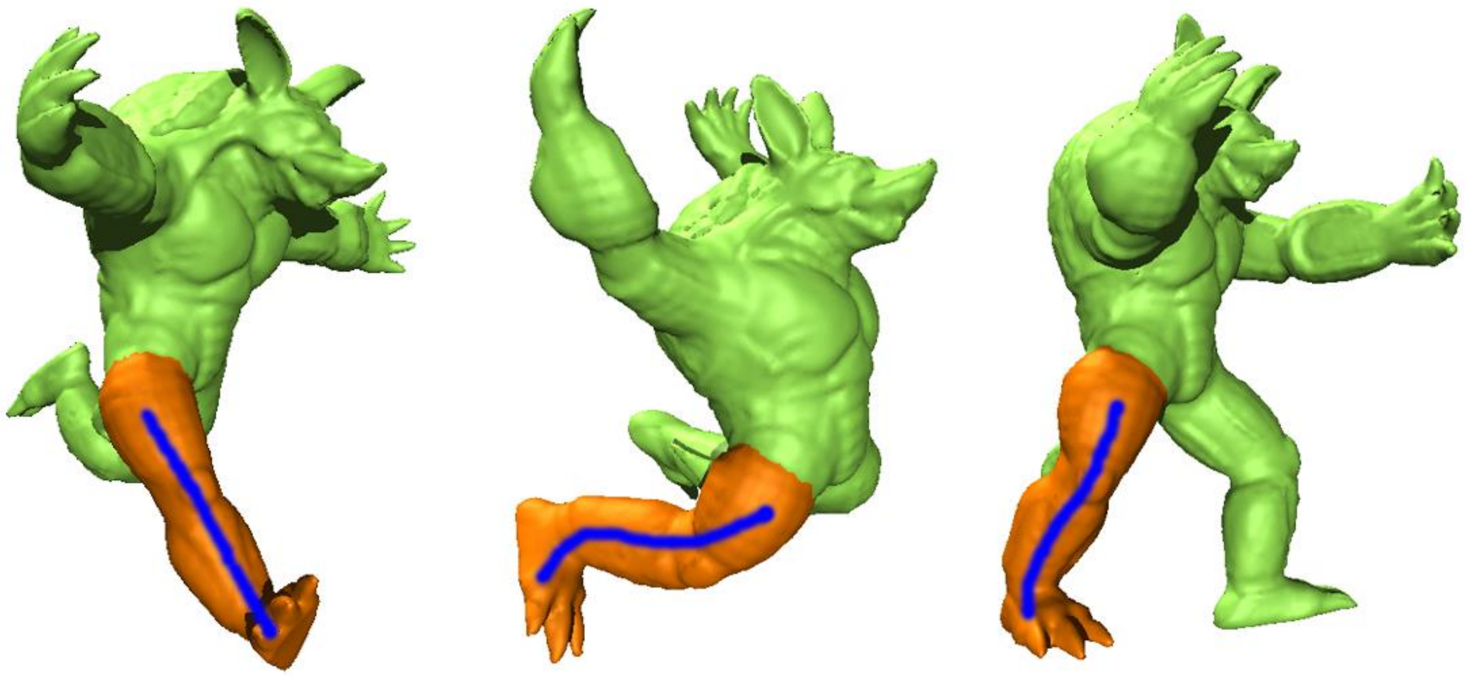
Results

Results

- **Independent on specific brushes**

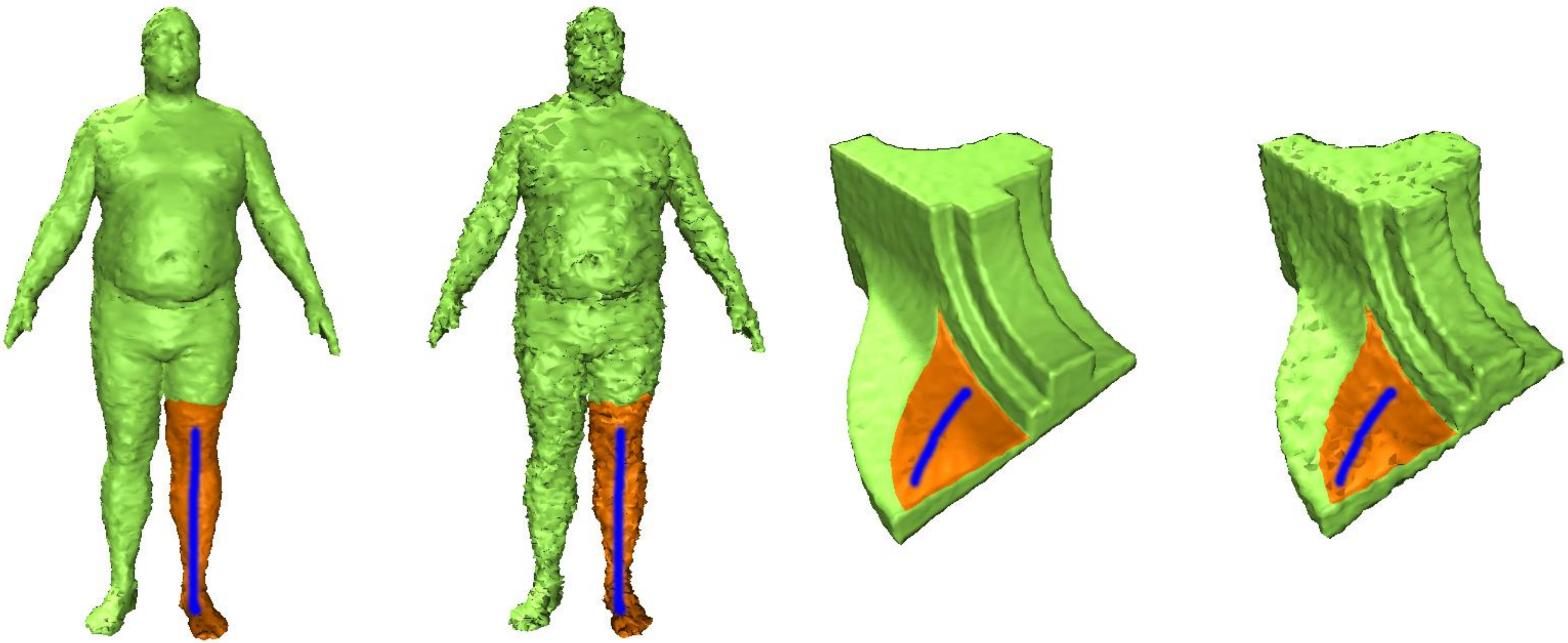
Results

- **Insensitive to pose variation**



Results

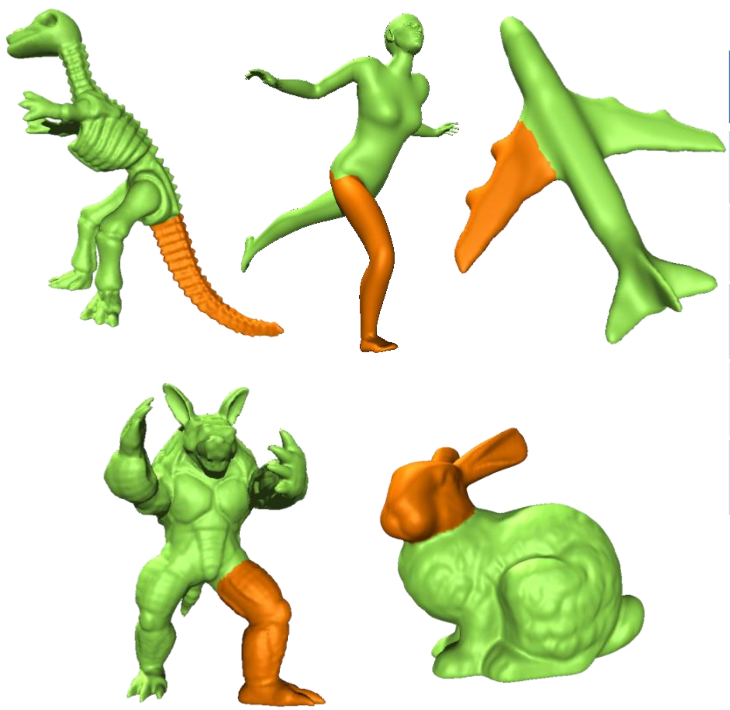
- **Insensitive to noise**



10% 40% 10% 30%

Results

- **Running time**



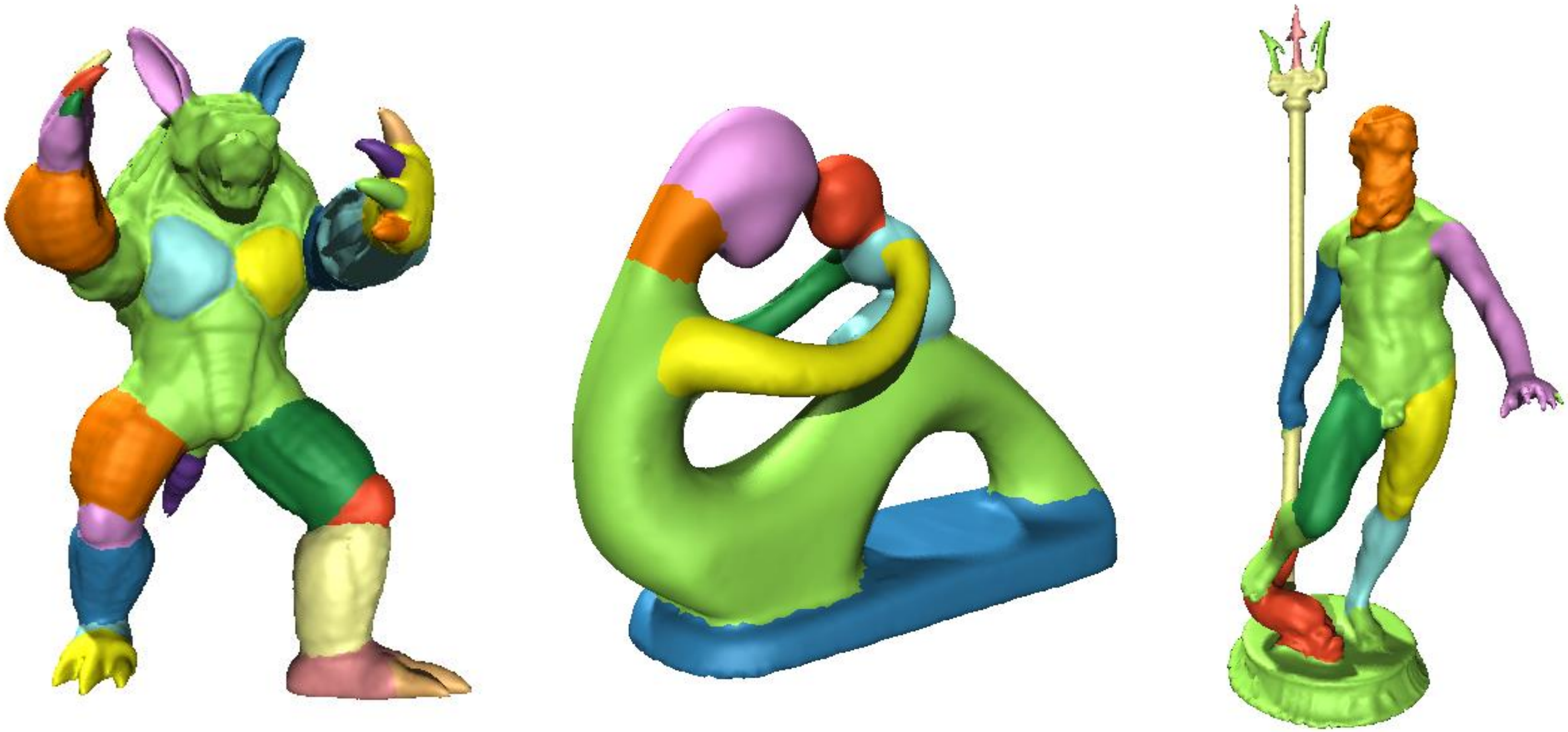
< 100 ms

Model	# Vertex	T_1 (ms)	T_2 (ms)	T_3 (ms)
Dino	28,150	53	10	178
Woman	5,691	8	6	27
Airplane	6,797	12	5	24
Armadillo	25,193	36	10	120
Bunny	34,835	54	11	248

* T_1, T_2, T_3 denote the computation time of the three steps in our algorithm, i.e., the initial global optimization, averaged local optimization, and the final global optimization, respectively.

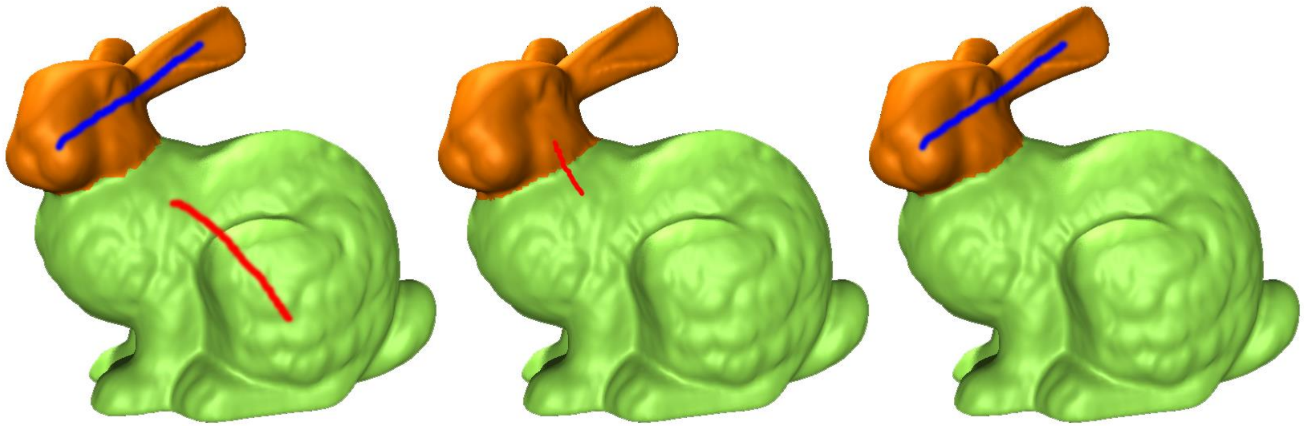
Results

- More



User Study

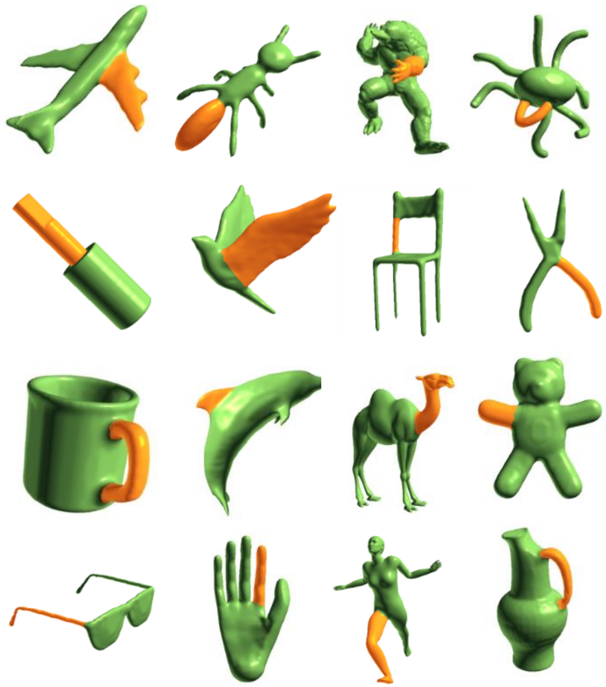
- **Three sketch-based user interface algorithms**
  - Foreground/background brushes (FBB) [Ji et al. 2006]
  - Cross boundary brushes (CBB) [Zheng et al. 2010]
  - Foreground brushes (FB) - Paint Mesh Cutting



FBB CBB FB

User Study

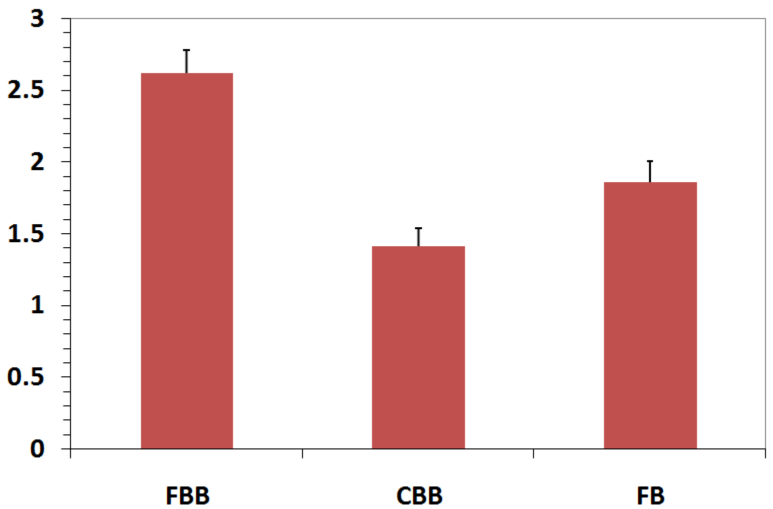
- **Assignment**
  - 16 participants
  - 16 models
  - Each participant test 6 models by using 3 algorithms respectively.
  - A short questionnaire
    - Accuracy
    - Efficiency
    - User intention
    - The favorite algorithm



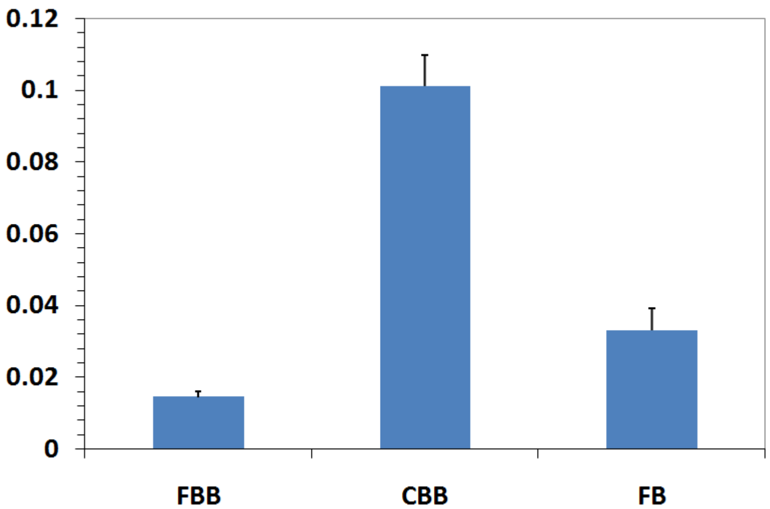
Corpus

Analysis

- Interaction time



Averaged time and standard error of user interactions



Averaged time and standard error of the segmentation algorithm

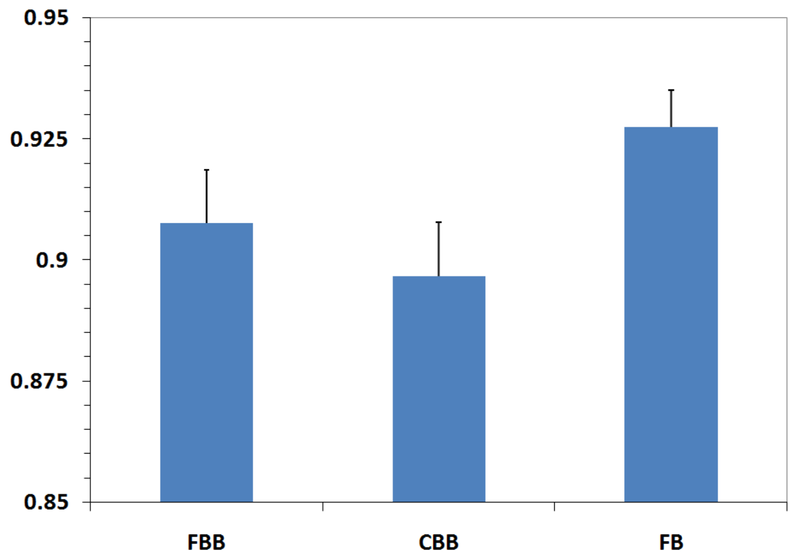
Analysis

- **Accuracy**
  - Region-based measure [McGuinness et al. 2010]

$$BJI(S_1, S_2) = \frac{\left\| S_1^0 \cap S_2^0 \right\|}{\left\| S_1^0 \cup S_2^0 \right\|}$$

- **Subjective evaluation**

Order	Algorithm
1	FB
2	CBB
3	FBB



Comparison of accuracy for three tools: averaged BJI value and standard error.

Limitations & Future Work

- It is difficult to cut out the partial part for smooth surfaces.
- User need to specify many strokes to cut out some semantic parts from highly-detailed regions.

Conclusion

- Novel tool for interactive mesh segmentation
- Obtain the cutting results instantly
- Provide users a favorable experience on cutting mesh surfaces
- **What you paint is what you get!**

Thanks!

Acknowledgements

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  - National Natural Science Foundation of China (61070071)
  - 973 National Key Basic Research Foundation of China (No. 2009CB320801)
- *Jie Xu* for video narration