Quantification of gaseous structures with volumetric reconstruction from visual hulls

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Introduction

- Methane gas (CH_4) one of the most harmful greenhouse gases
- Increasing emissions of CH_4 from landfills/municipal waste (3%-19% of amounts of anthropogenic sources world wide)
- Fixed point measurements
- Limited accuracy

Background

- Quantitative volumetric quantification is difficult with existing fixed point measuring techniques
- Special-purpose IR imaging can make gas plums visible in 2D images (Åhlén et al., 2010)
- Goal: Estimation of 3D volumes from 2D camera images

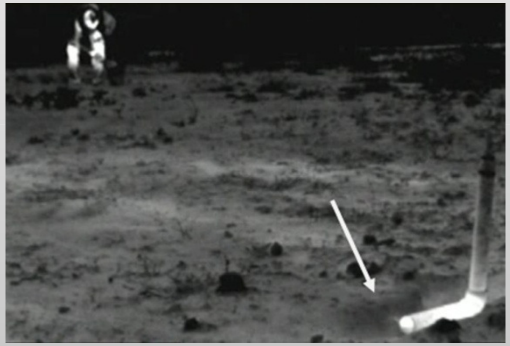
Related work

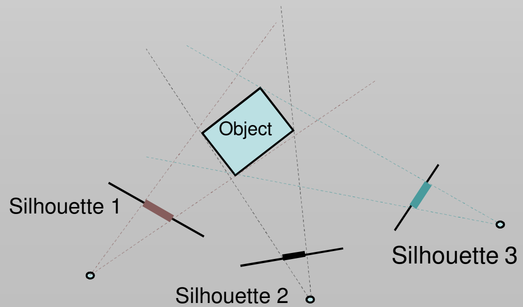
Multi-View Geometry (Hartley&Zisserman, 2003)

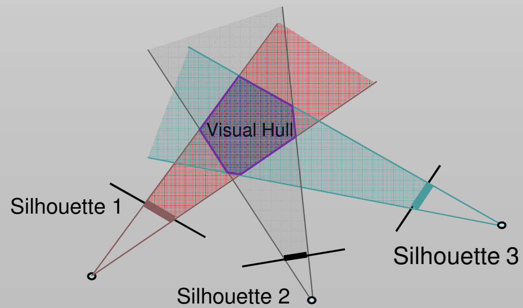
- Visible surface triangulation from point clouds
- Point correspondences are used to determine camera relations needed for 3D triangulation

Shape-from-Silhouette based 3D reconstruction (space carving)

- The Visual Hull concept (Laurentini,1997)
- 2D silhouette and camera parameters define a general cone in 3D
- Intersection volume of several cones forms the visual hull







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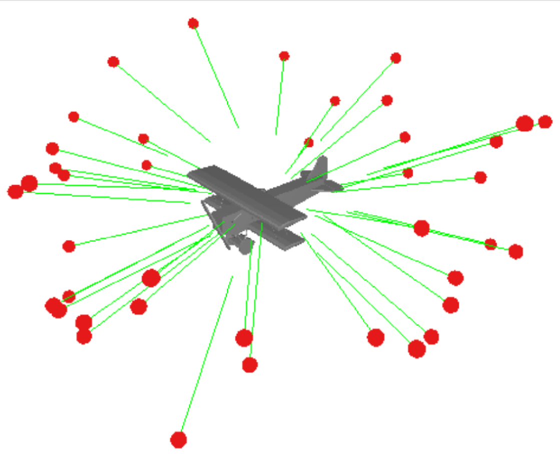
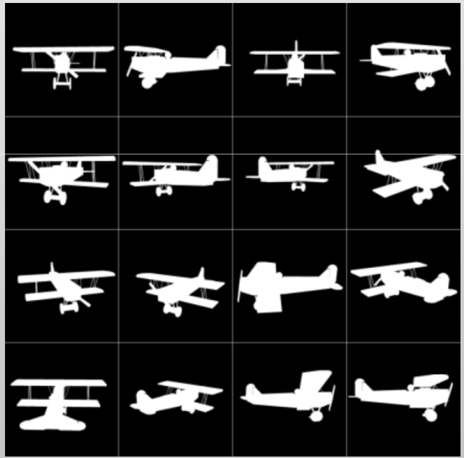
Visual Hulls - Properties

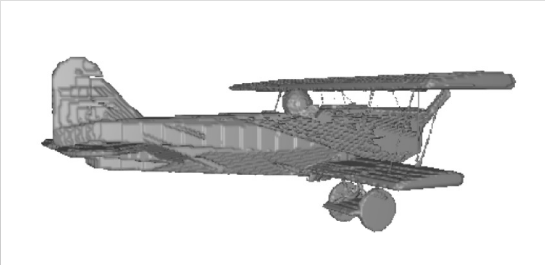
Quality of Visual Hull reconstructions



40 randomly chosen camera positions



16 binary silhouettes

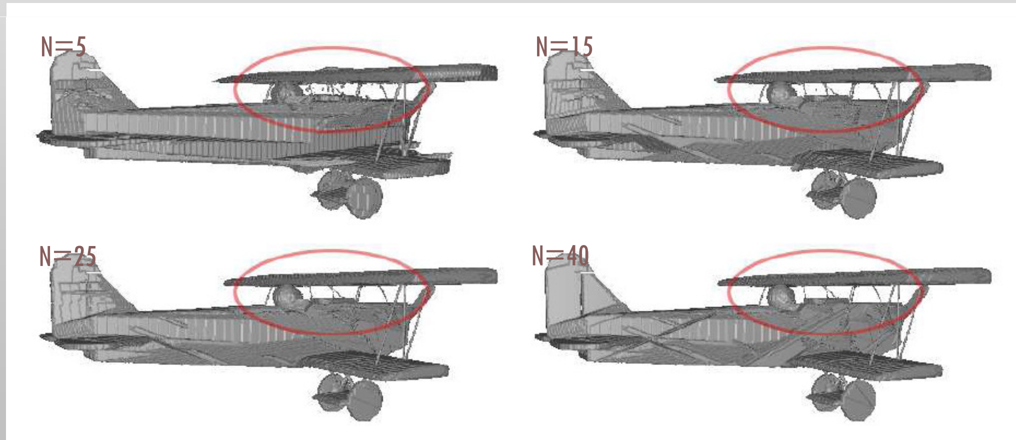


3D reconstruction result using a 512^3 voxel grid

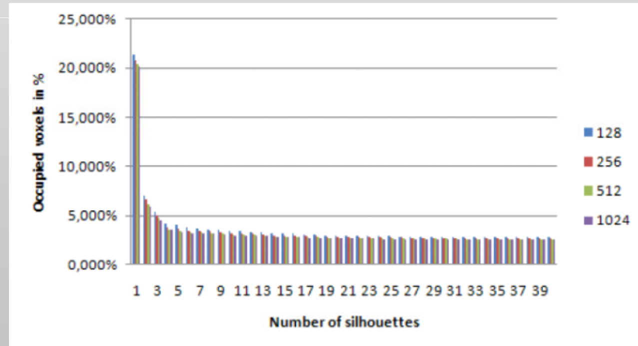
Visual Hulls - Properties

Quality of Visual Hull reconstructions (Fredriksson 2011)

- Salient visual artifacts exist for 40 and more silhouettes
- Volume converges rather quickly – but unknown ground truth



Reconstruction results for different number N of silhouette images



Percentage of occupied voxels using a 512^3

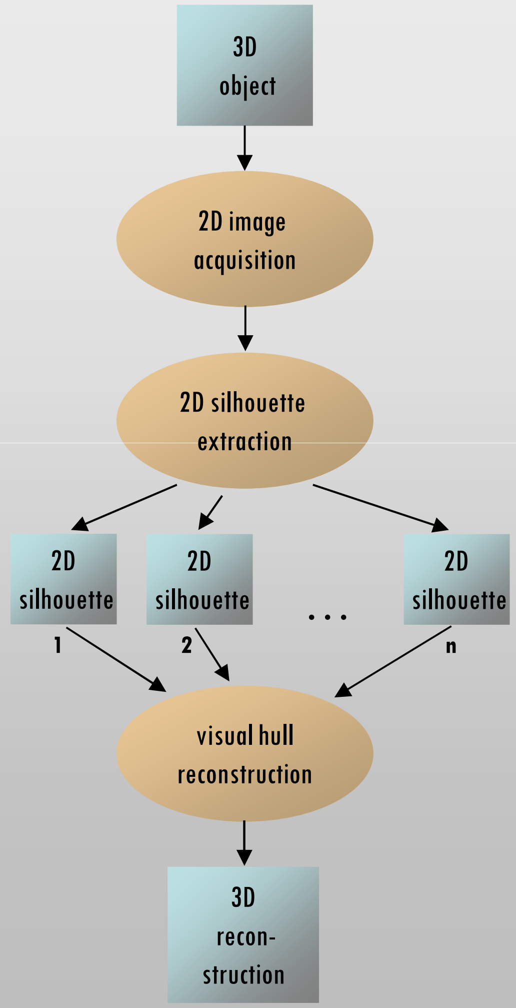
Visual Hulls for Volume Estimation

Estimation Volume of Gaseous Structures

- Visual quality is not important
- Visual details contribute little to volume

Research objective:

Identifying the sources of variation in measurement



Visual Hulls for Volume Estimation

Estimation Volume of Gaseous Structures

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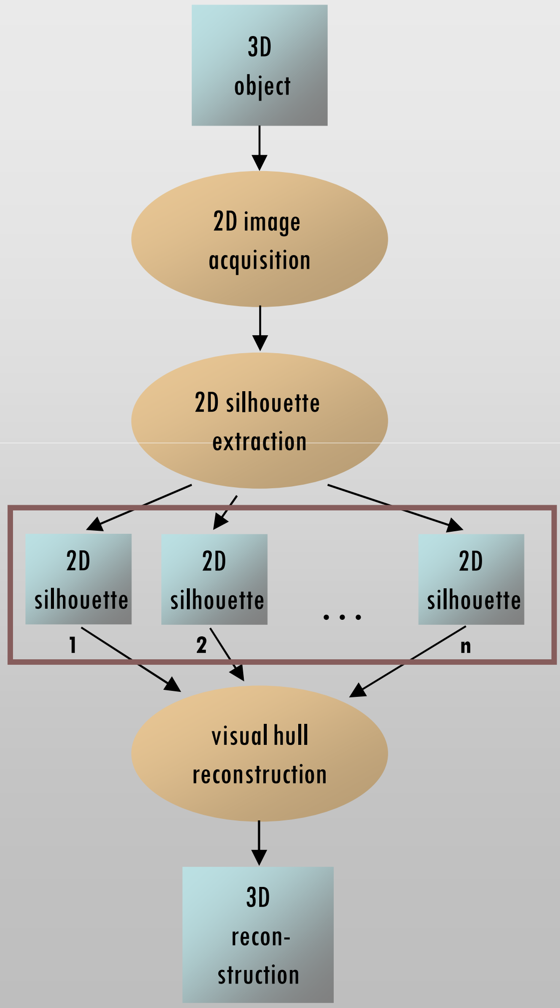
Research objective:

Identifying the sources of variation in measurement

a) Number of camera views (practically limited)



Visual Hulls for Volume Estimation

Estimation Volume of Gaseous Structures

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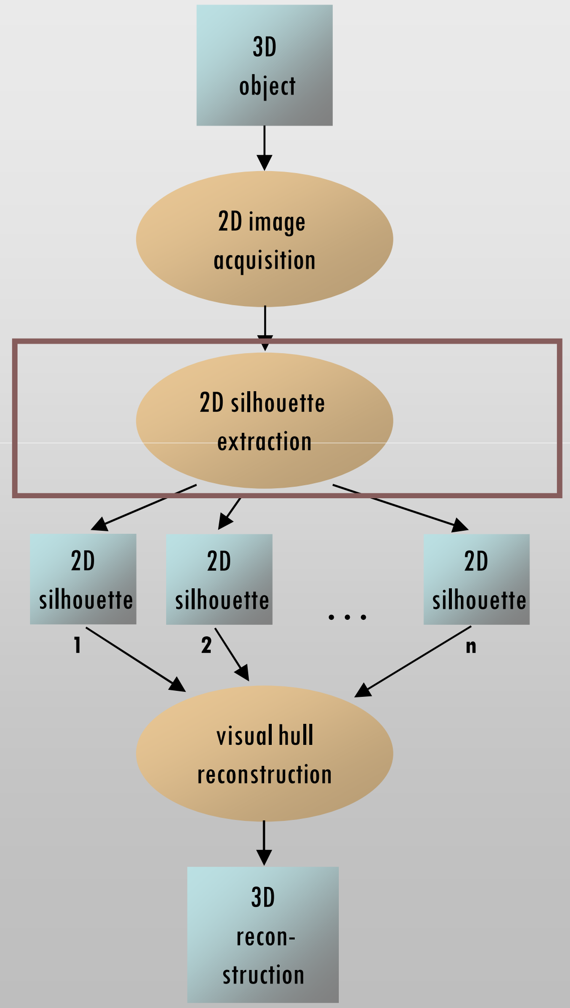
Research objective:

Identifying the sources of variation in measurement

a) Number of camera views (practically limited)

b) Variation of silhouette extraction (segmentation accuracy)



Visual Hulls for Volume Estimation

Estimation Volume of Gaseous Structures

- Visual quality is not important
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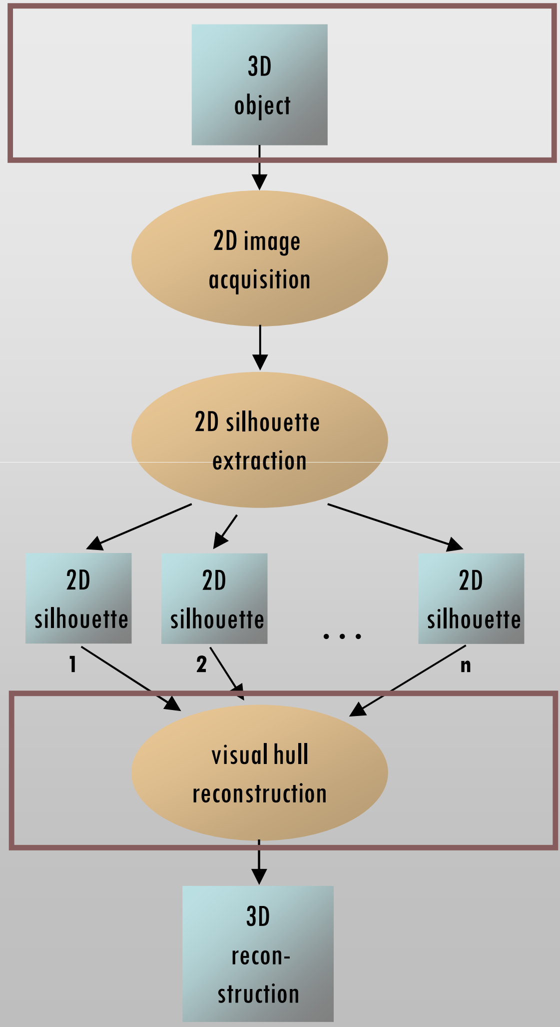
Research objective:

Identifying the sources of variation in measurement

a) Number of camera views (practically limited)

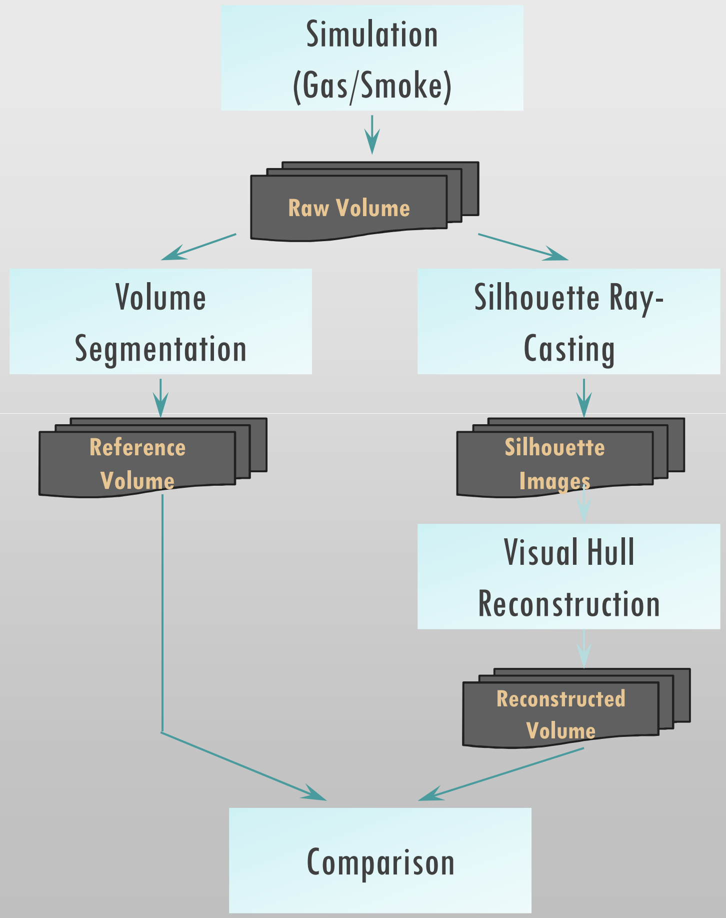
b) Variation of silhouette extraction (segmentation accuracy)

c) Base-line bias/offset (depending on object structure)



Evaluation Method

General Approach



Evaluation Method

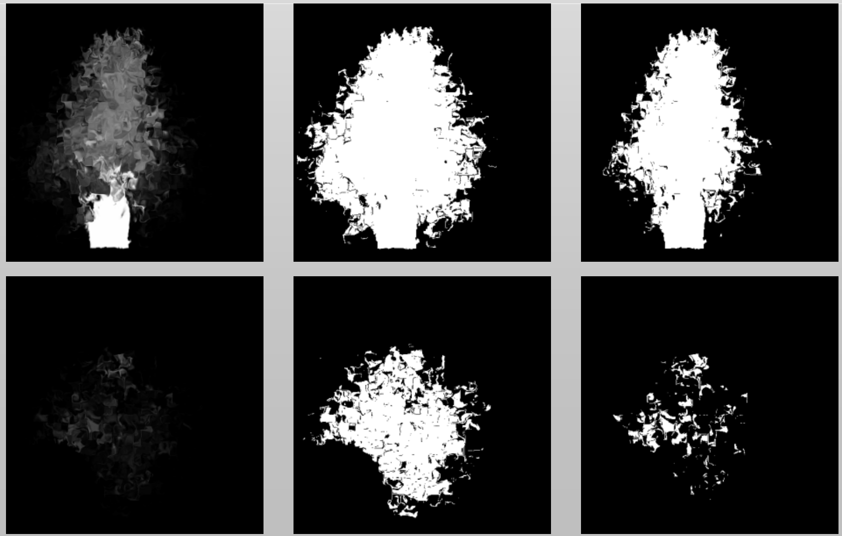
Ground Truth Data Generation:

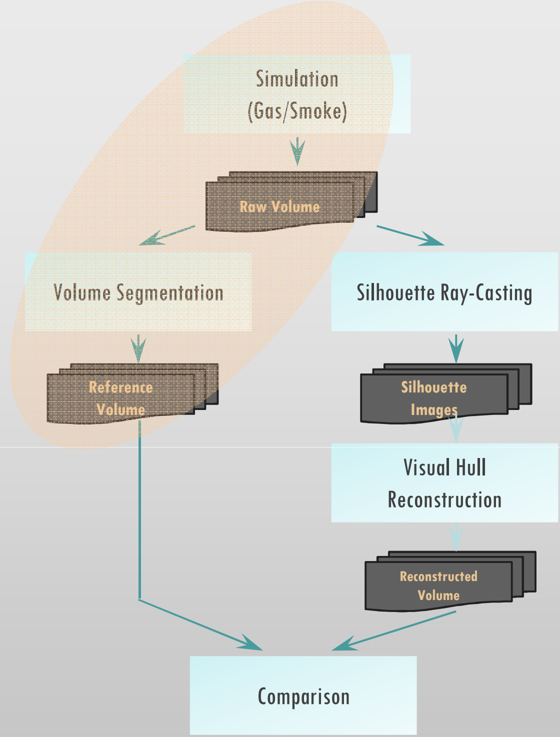
Wavelet Turbulence Simulation (Kim et al., 2008)
We used source-code at http://www.cs.cornell.edu/~tedkim/wturb/source.html

Naïve implementation and randomly sampling volumes from a time series

Volume size: 512^3 size, scalar data

Segmentation using thresholds t ranging between 1% - 40%





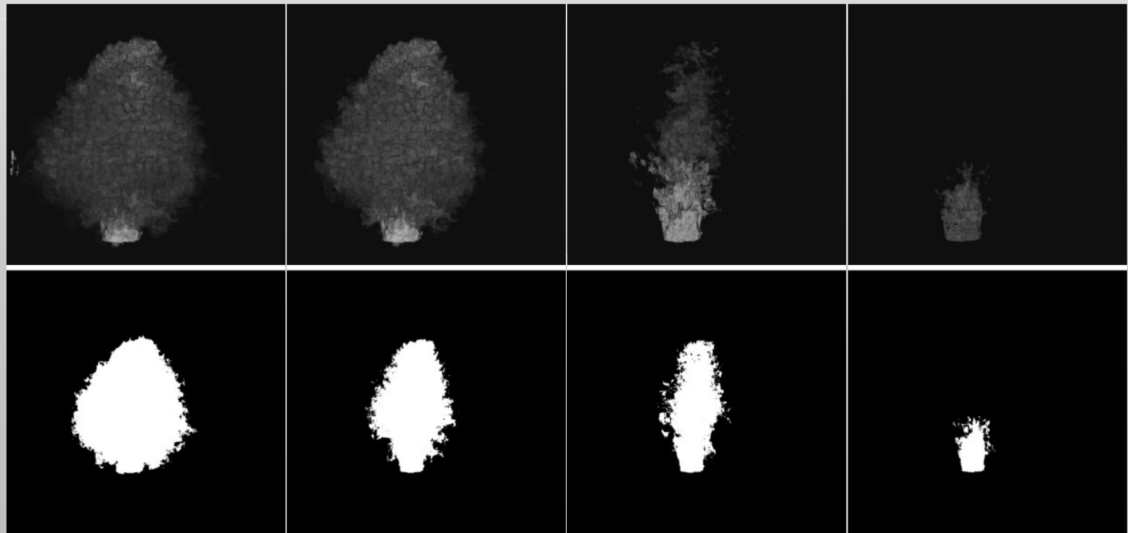
Evaluation Method

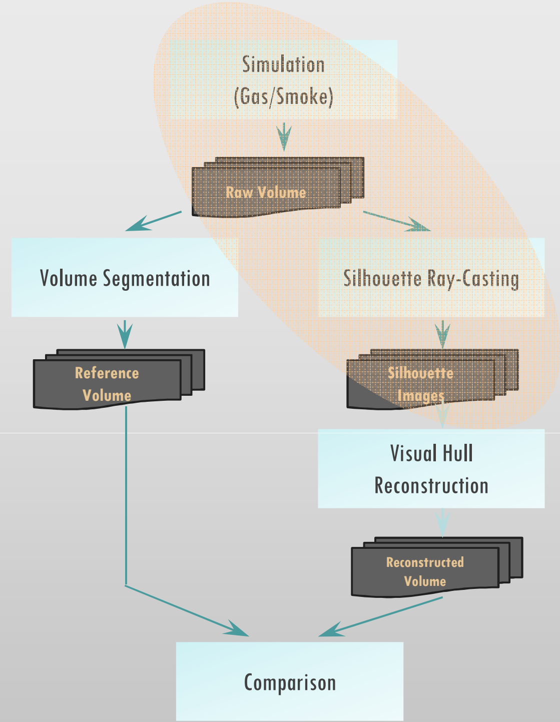
Controlled Silhouette Generation:

Synthetic data + Synthetic camera ⟶ Control of image formation process

GPU-Based Volume Ray-Caster

Renders volume binary silhouettes based on same classification criteria





Evaluation Method

Visual Hull Reconstruction:

GPU-based, multi-pass render algorithm

Slice-by-slice reconstruction of volume

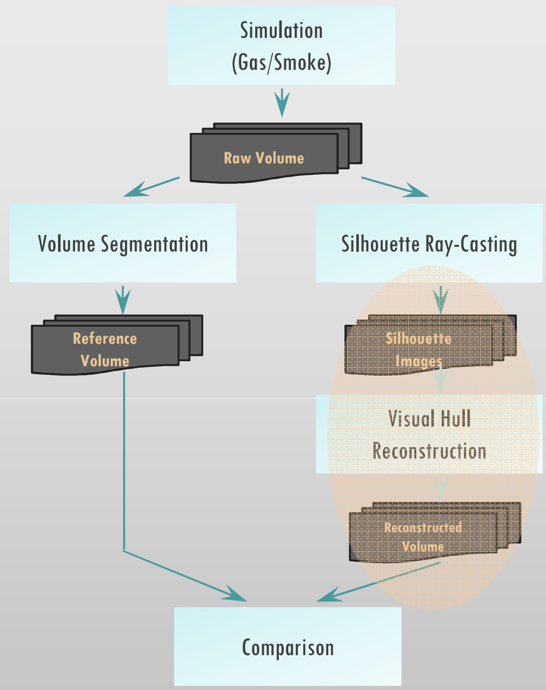
Use 2D projective texture mapping to render silhouettes

Stencil-buffer used to count region overlap

Transfer render buffer to 3D volume data

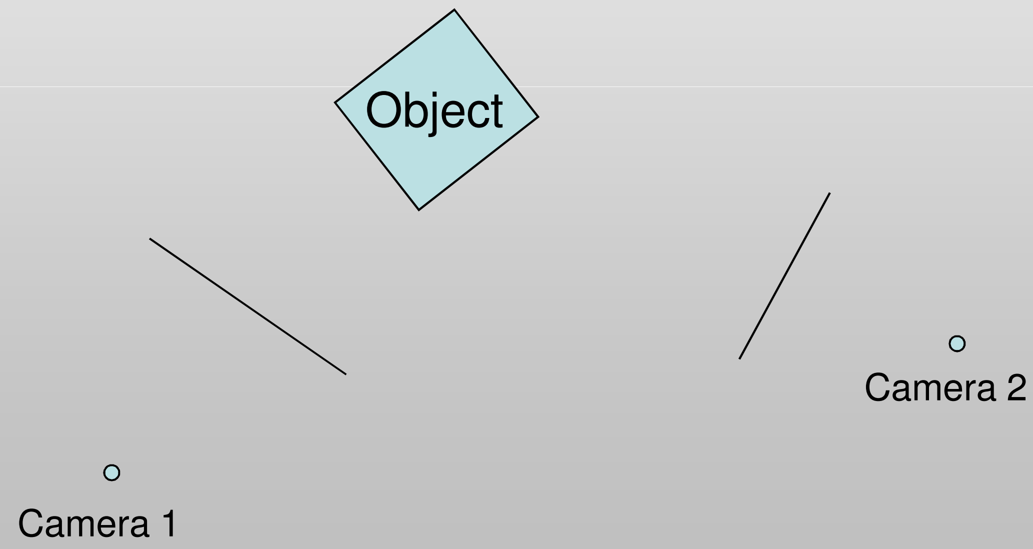
z Rendering passes for a volume of size $x * y * z$ voxels

n screen filling polygons per pass for n fifferent silhouettes



Implementation of VH algorithm

1. Silhouette acquisition
   (here 2 views only)



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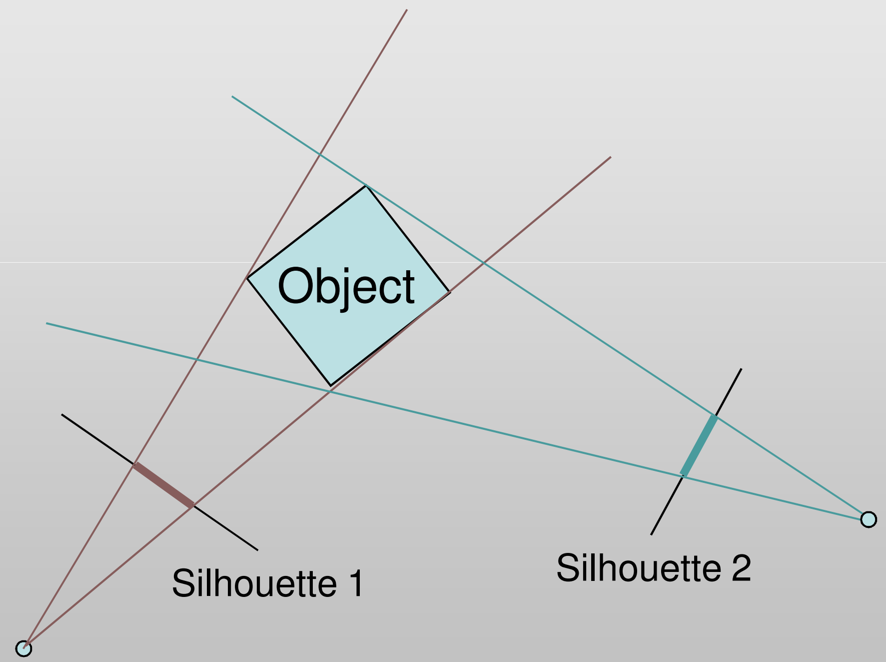
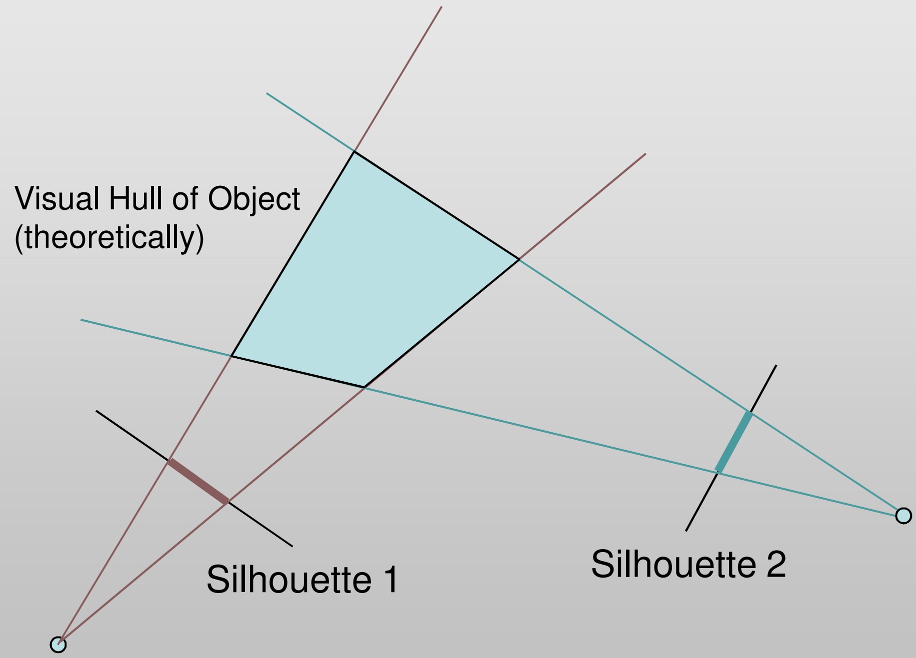


Implementation of VH algorithm

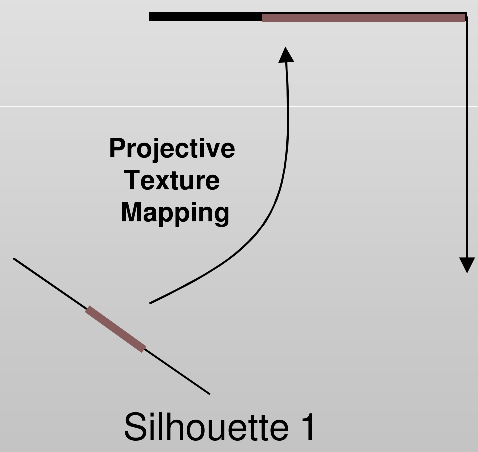
2. The Visual Hull (Analytical Result)



Implementation of VH algorithm

3. Volumetric Reconstruction

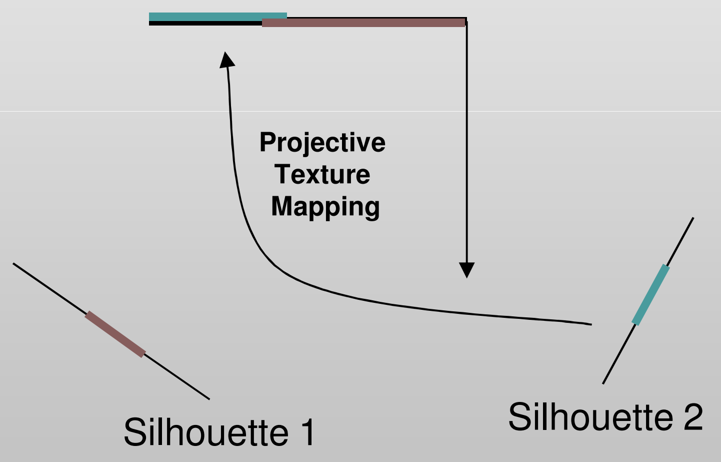
- Render Screen Filling Quads
- Project silhouette 1 on quad



Implementation of VH algorithm

3. Volumetric Reconstruction

- Render Screen Filling Quad
- Project silhouette 1 on quad
- Project silhouette 2 on quad



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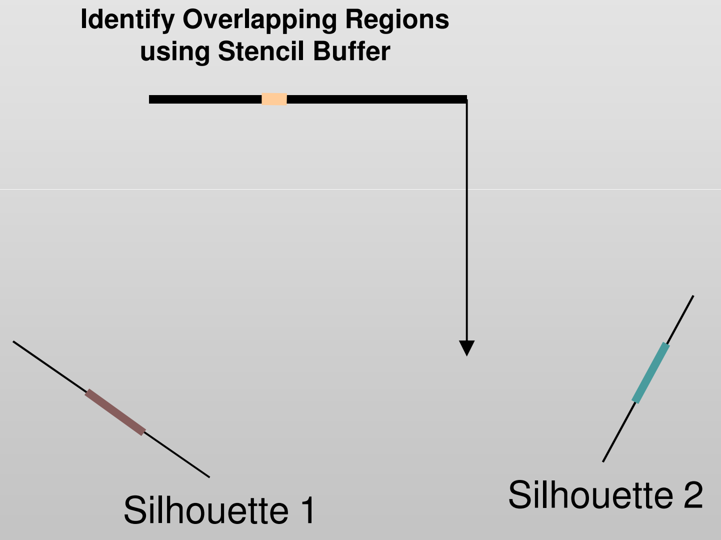
Implementation of VH algorithm

3. Volumetric Reconstruction

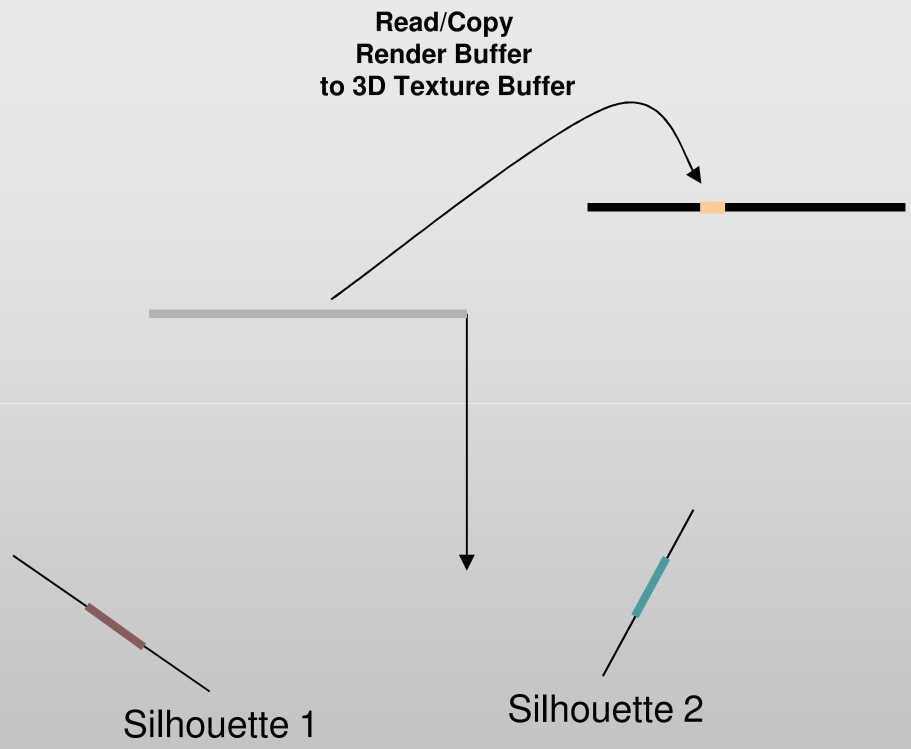
- Render Screen Filling Quad
- Project silhouette 1 on quad
- Project silhouette 2 on quad
- Keep only pixels, where all silhouettes have been drawn



Implementation of VH algorithm

3. Volumetric Reconstruction

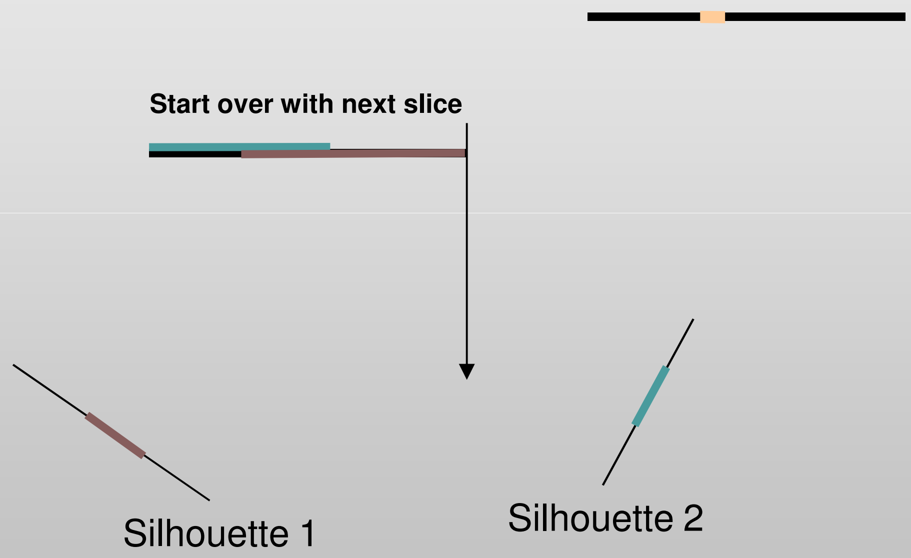
- Render Screen Filling Quad
- Project silhouette 1 on quad
- Project silhouette 2 on quad
- Keep only pixels, where all silhouettes have been drawn
- Save render buffer



Implementation of VH algorithm

3. Volumetric Reconstruction

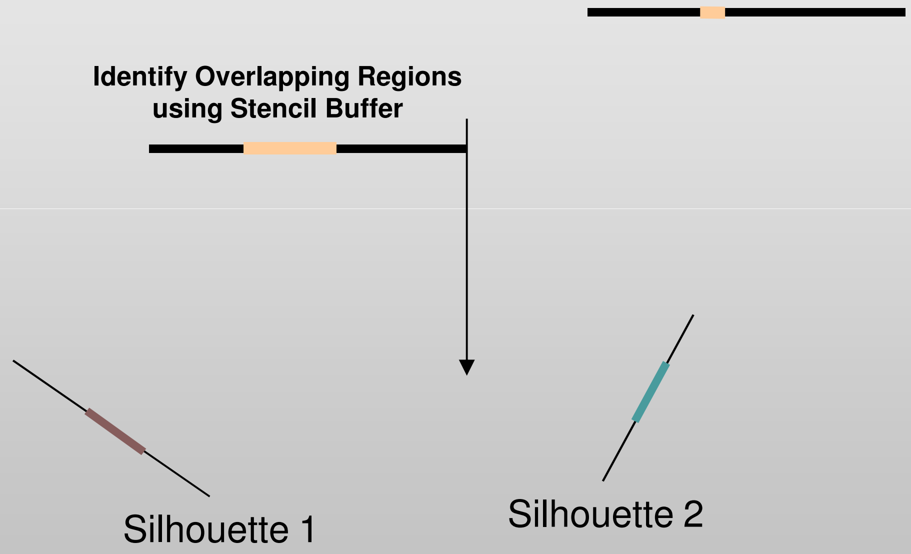
...render next slice/polygon...



Implementation of VH algorithm

3. Volumetric Reconstruction

identify overlap...

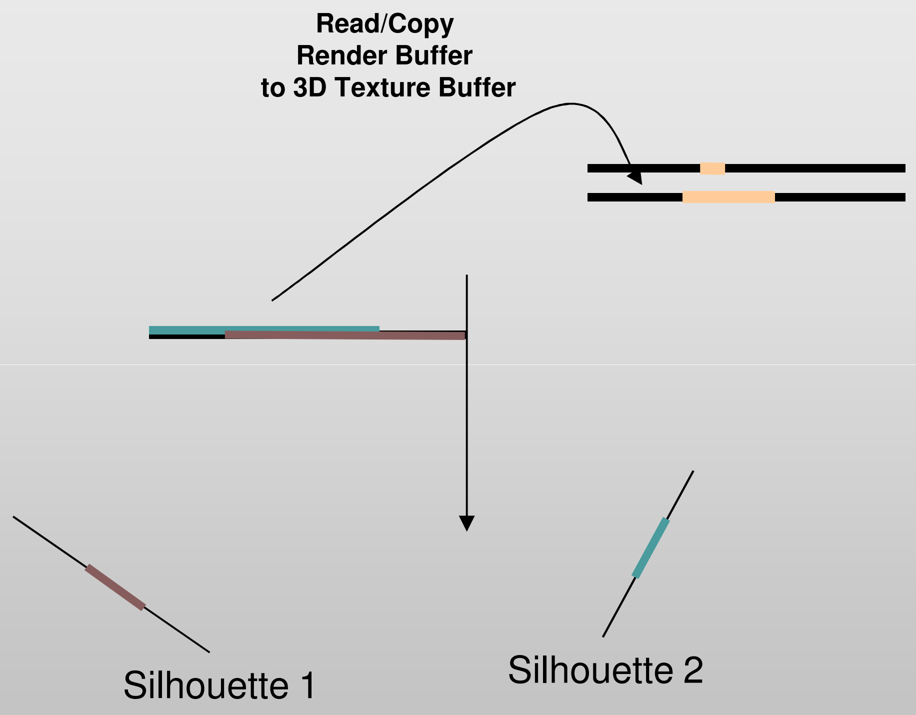


Implementation of VH algorithm

3. Volumetric Reconstruction

read/copy render buffer

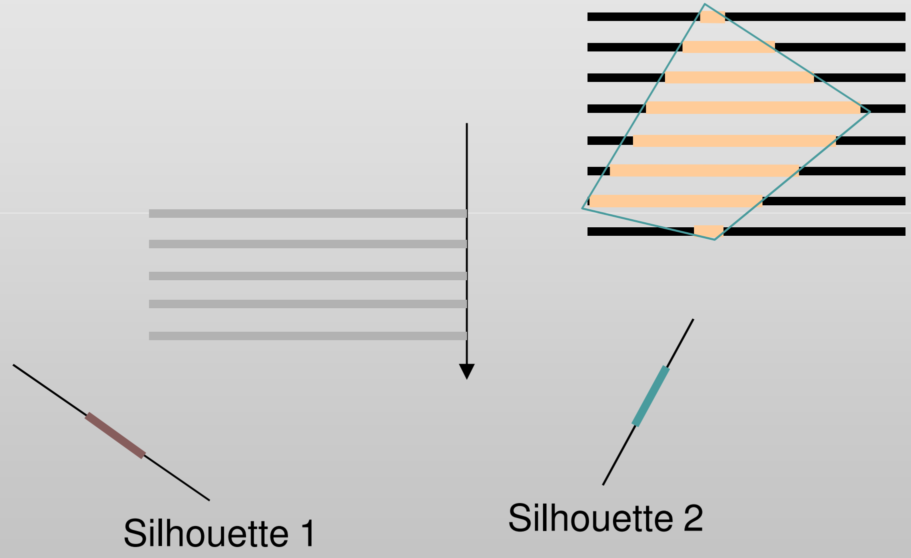
and render next slice



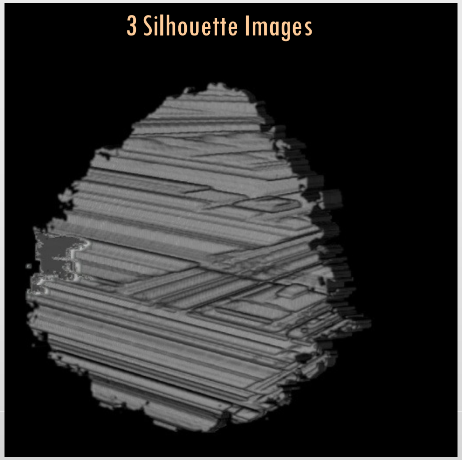
Implementation of VH algorithm

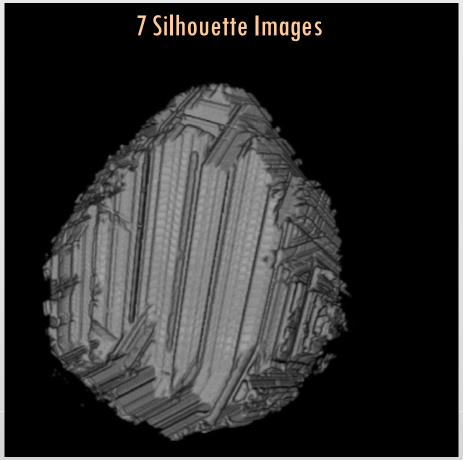
3. Volumetric Reconstruction

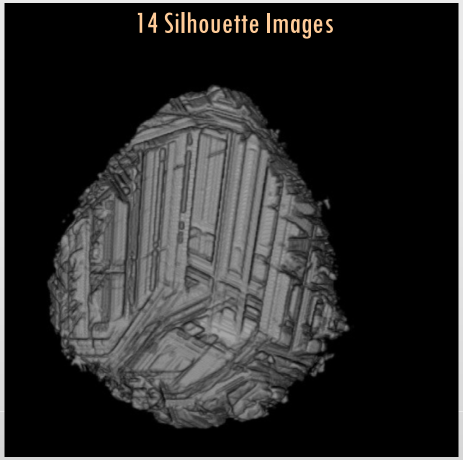
...repeat for remaining slices...



Results of the Reconstruction







- Reconstruction results for varying numbers of silhouette images
- Segmentation threshold $t = 1\%$

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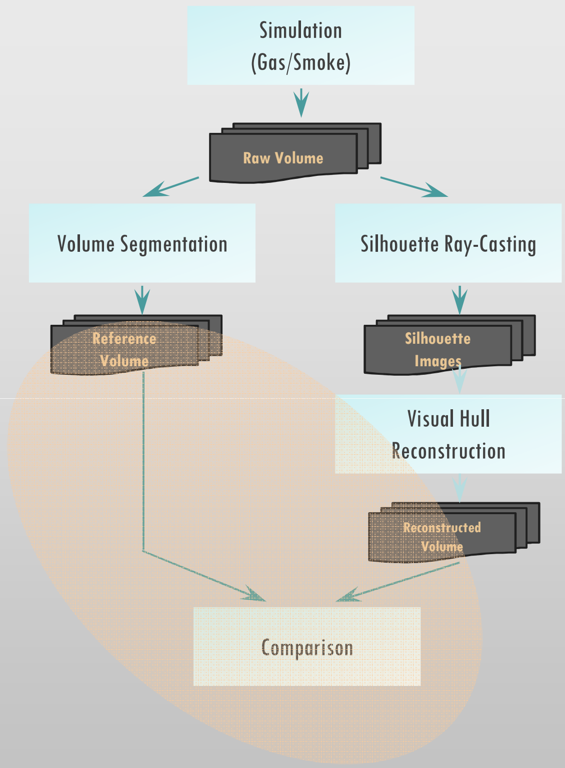
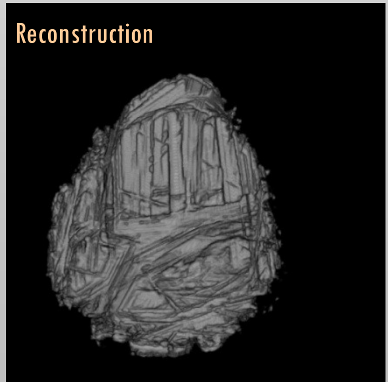
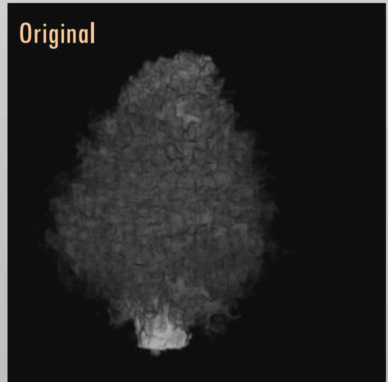
Evaluation

Volumetric comparison:

- Same threshold for ground truth data and silhouette generation
- Compare original volume with reconstructed volume
- Volumetric enumeration of original O and reconstruction R
- Ratio R/O for varying n and t

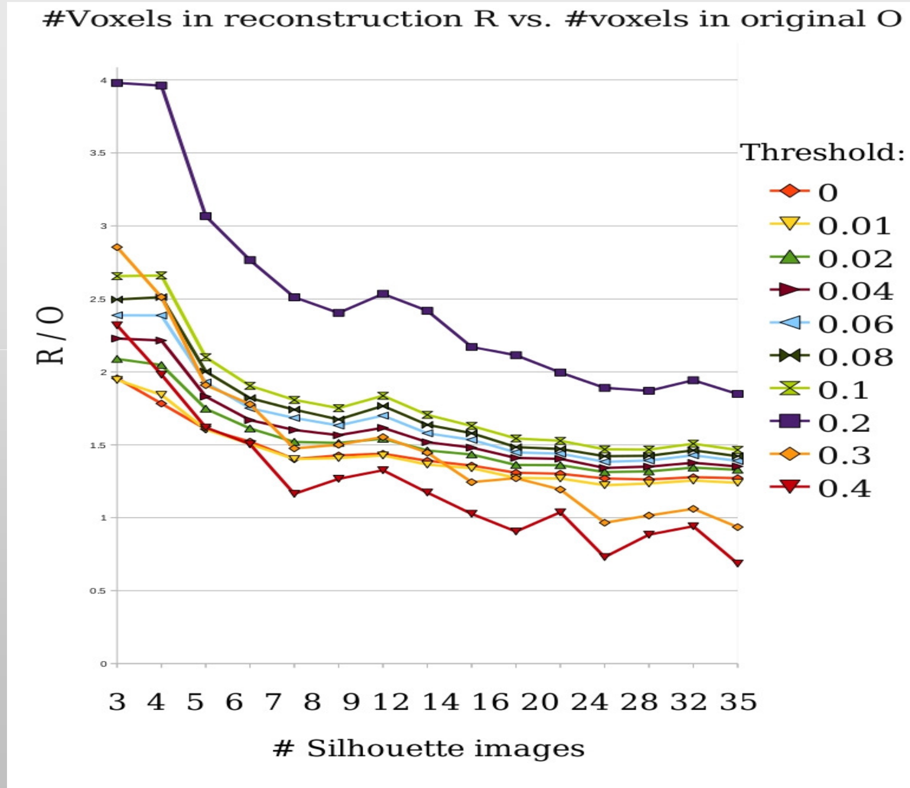






Results & conclusions

- Rapidly converging volume size
- Systematic overestimation (~150%)
- Segmentation accuracy as important
- 8 camera views seem sufficient for volumetric estimation



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Thank you for your attention!

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