

# **A Volumetric Method for Building Complex Models from Range Images**

Brian Curless

Marc Levoy

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Computer Graphics Laboratory  
Stanford University

# Introduction

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## Goal

Given a set of aligned, dense range images, we want to reconstruct a manifold that closely approximates the surface of the original model.

# Desirable Properties

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- Representation of range uncertainty
- Utilization of all range data
- Incremental and order independent updating
- Time and space efficiency
- No restrictions on topological type
- Robustness
- Ability to fill holes in the reconstruction

## Previous work

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### From unorganized points

- Parametric (polygonal)
- Edelsbrunner92, Boissonat94
- Implicit (volumetric)
- Hoppe92, Bajaj95

# From range surfaces

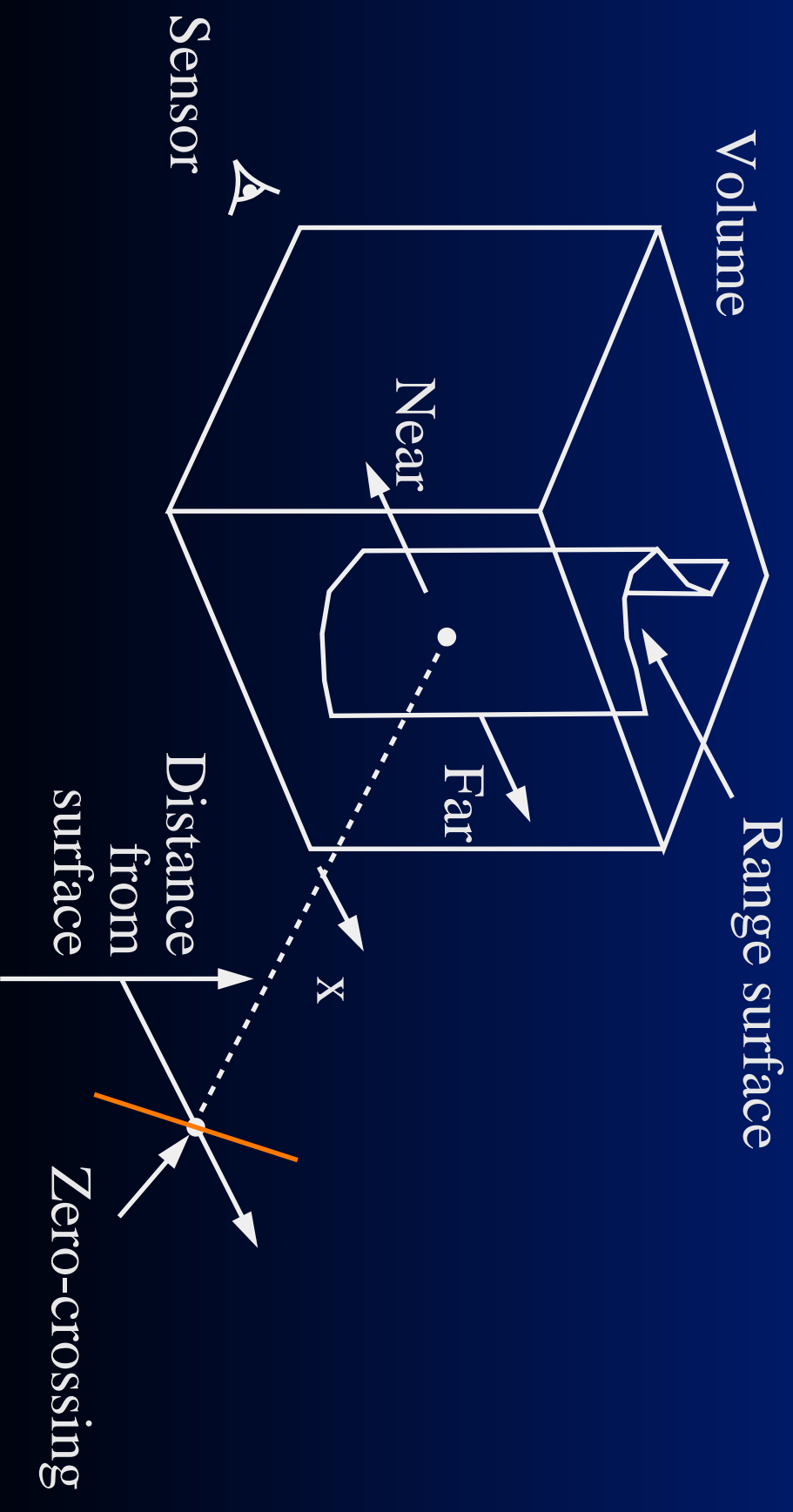
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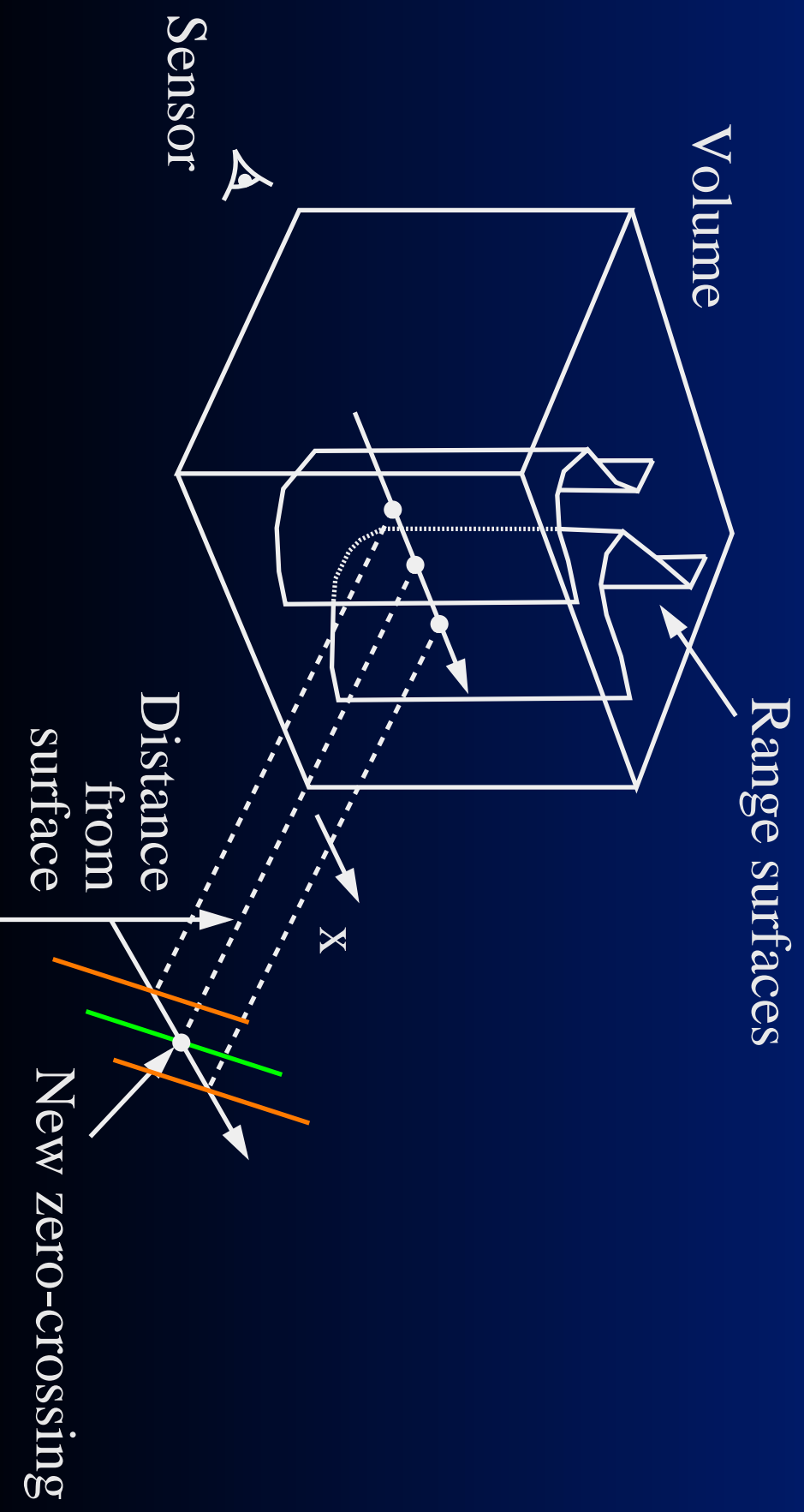
- Parametric (polygonal)
  - Turk94, Rutishauser94, Soucy95
- Implicit (volumetric)
  - Grosso88, Succci90, Hilton96

# Volumetric method

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- For a set of range images,  $R_1, R_2, \dots, R_N$ , we construct signed distance functions  $d_1(\mathbf{x}), d_2(\mathbf{x}), \dots, d_N(\mathbf{x})$ .
- We combine these functions to generate the cumulative function,  $D(\mathbf{x})$ .
- We extract the desired manifold as the isosurface,  $D(\mathbf{x}) = 0$ .



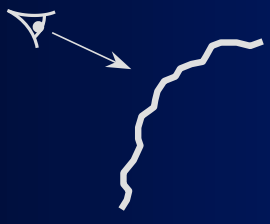




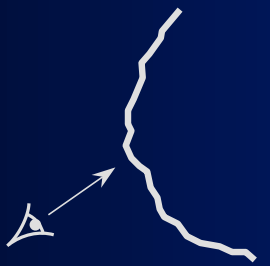


Surfaces

Scan #1



Scan #2

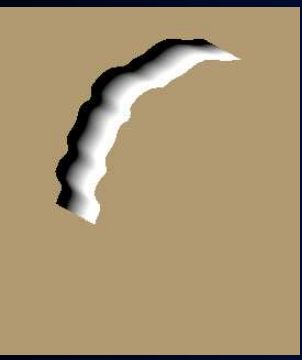


Combination

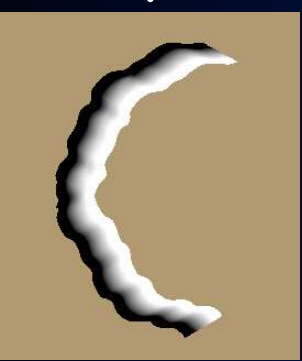
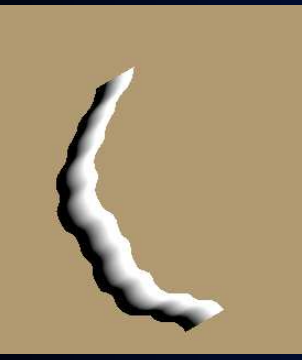


Isosurface  
extraction

Distance  
Functions

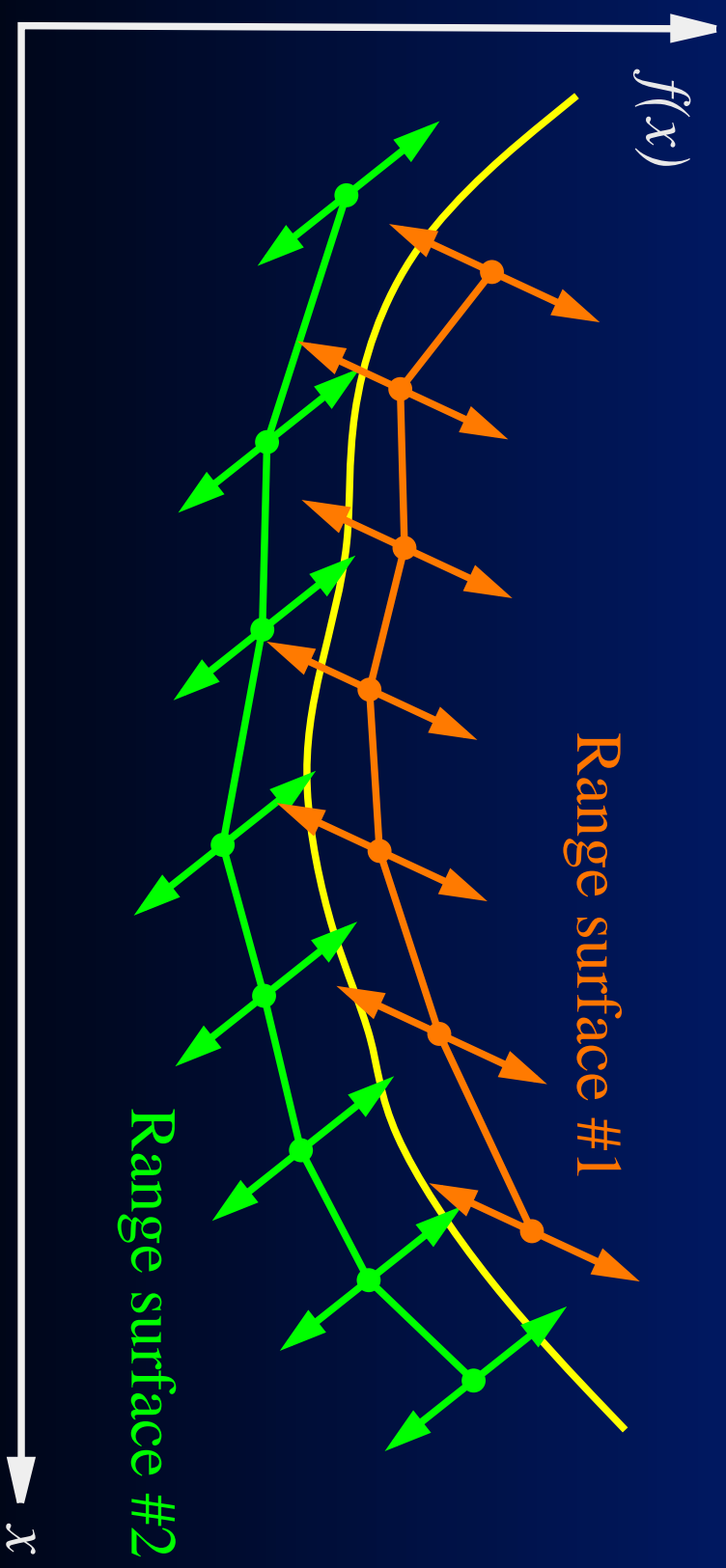


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# Least squares solution

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Error per point

$$E(f) = \sum_{i=1}^N \int d_i^2(x, f) dx$$

Error per range surface

Finding the  $f(x)$  that minimizes  $E$  yields the optimal surface.

This  $f(x)$  is exactly the zero-crossing of the combined signed distance functions.

# Hole filling

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We have presented an algorithm that reconstructs the observed surface. Unseen portions appear as holes in the reconstruction.

A hole-free mesh is useful for:

- Fitting surfaces to meshes
- Manufacturing models (e.g., stereolithography)
- Aesthetic renderings

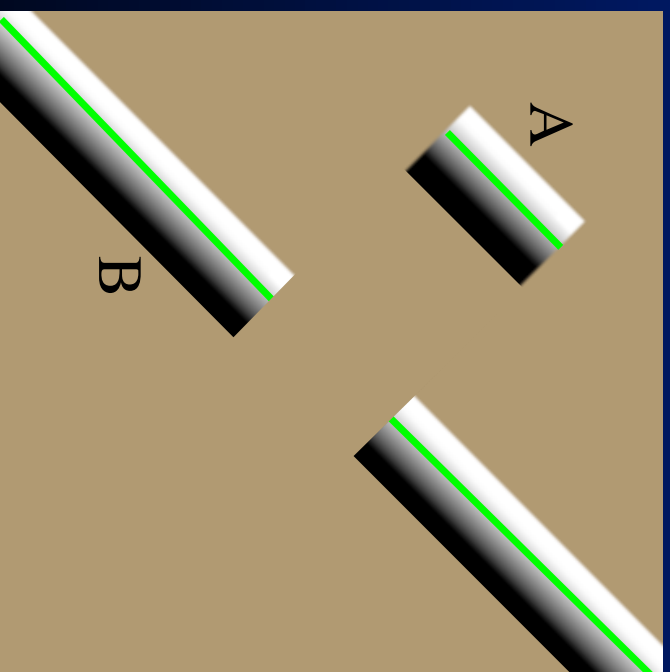
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We can fill holes in the polygonal model directly, but such methods:

- are hard to make robust
- do not use all available information

# *Without space carving*

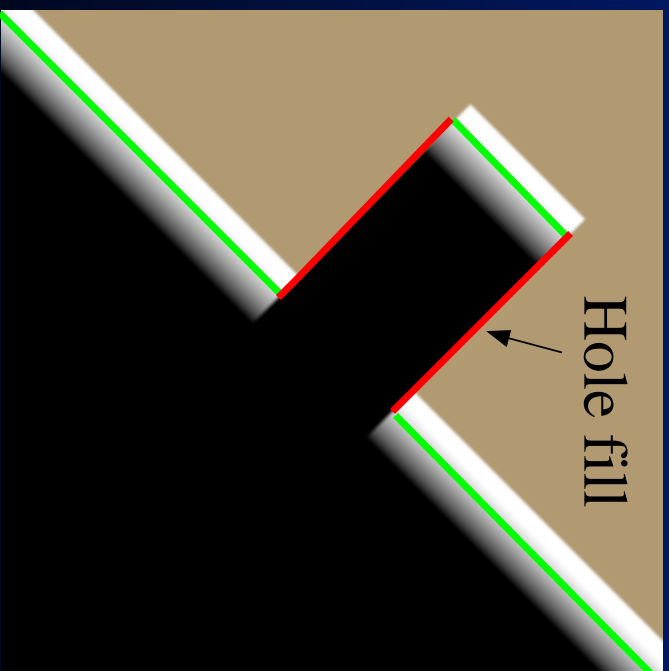
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Sensor

# *With space carving*

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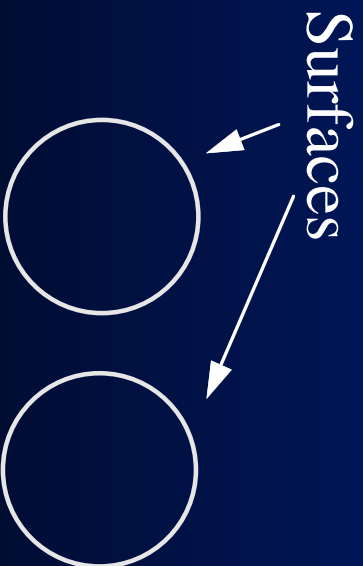
Sensor

- Unseen
- Empty
- Near surface

# Carving *without* a backdrop

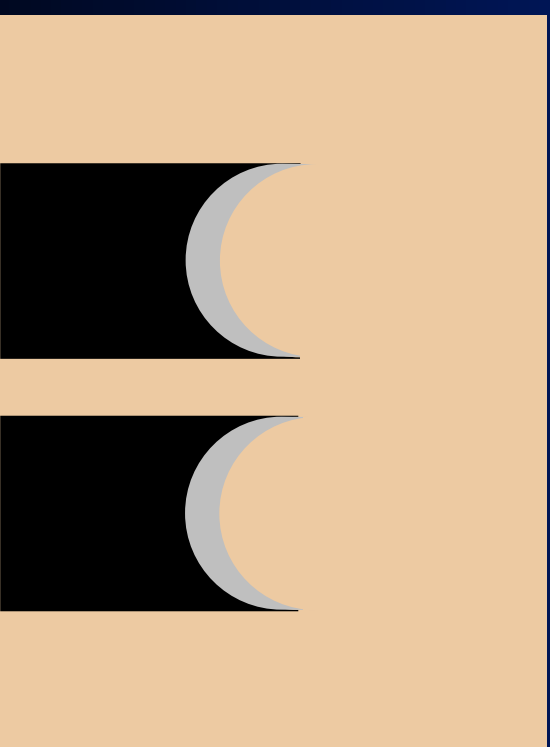
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Scanning scenario



∇ Sensor

Volumetric slice



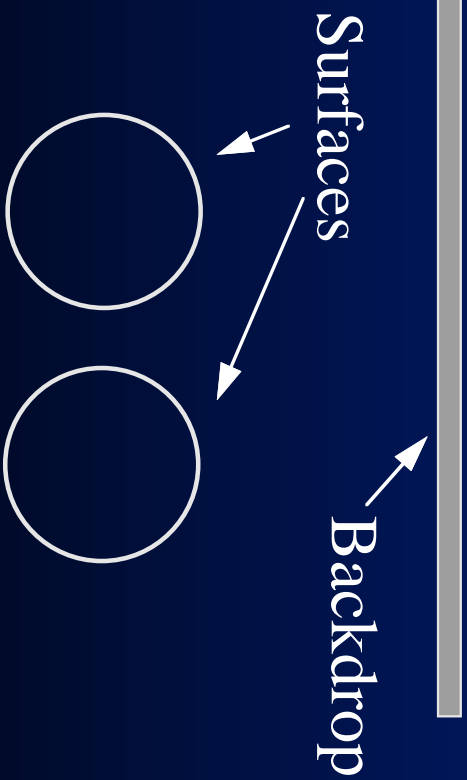
∇



# Carving with a backdrop

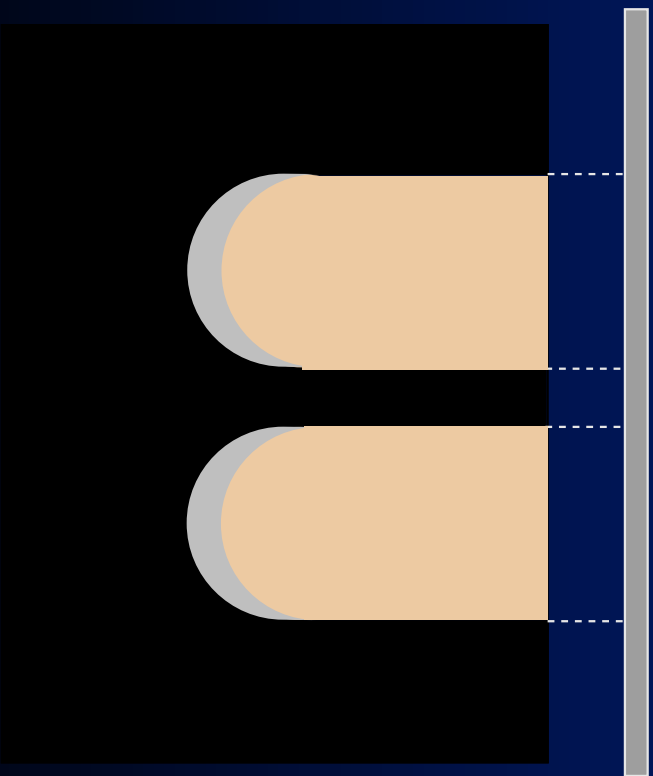
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Scanning scenario



∇ Sensor

Volumetric slice



∇

# Typical data size

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- 60 scans
- 10 million input vertices
- 100 million voxels

# Software optimizations

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- Run-length encoded data structures
- Memory coherent traversal
- Binary depth trees
- Restricted marching cubes

# Results

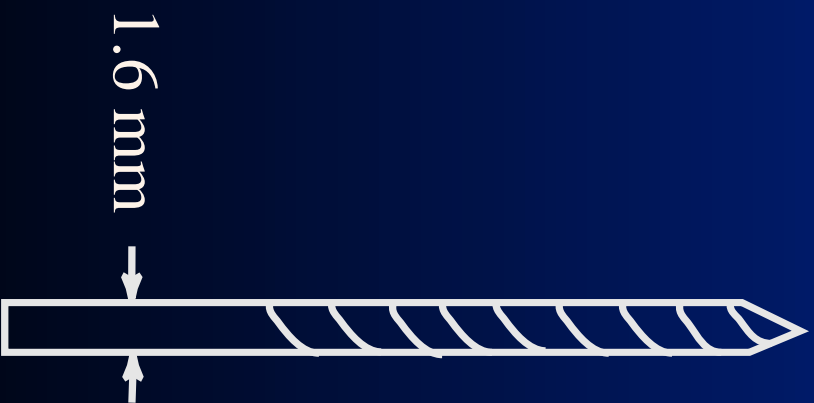
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We have tested the algorithm on several models to explore:

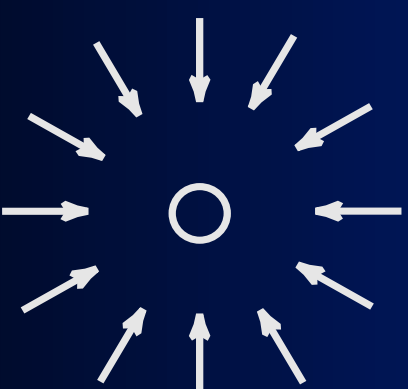
- Robustness (drill bit)
- Effectiveness of hole filling (dragon)
- Attainable level of detail (Happy Buddha)

# Drill bit

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Side view of drill bit



Plan view with  
sensing directions

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## Plan view

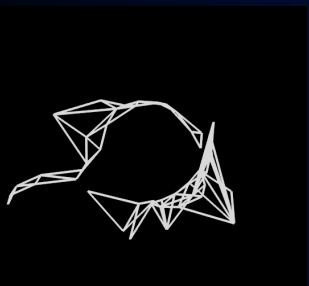
Unorganized  
points



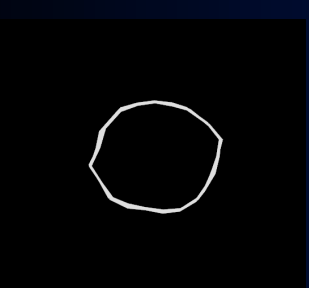
Range  
surfaces



Zippered  
mesh



Volumetric  
mesh

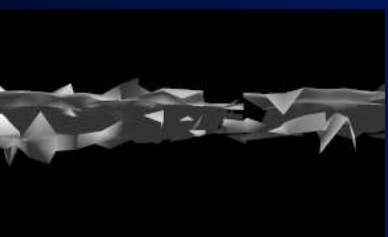


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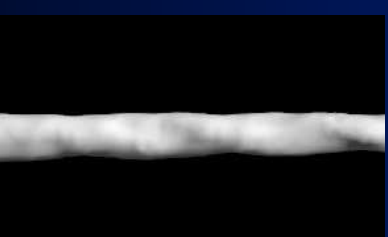
## Side view



Photograph of  
painted drill bit



Zippered  
mesh

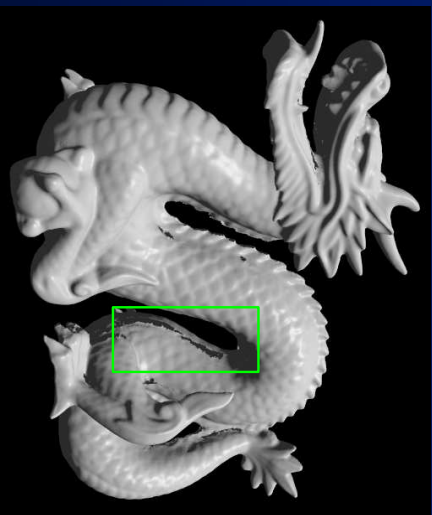


Volumetric  
mesh

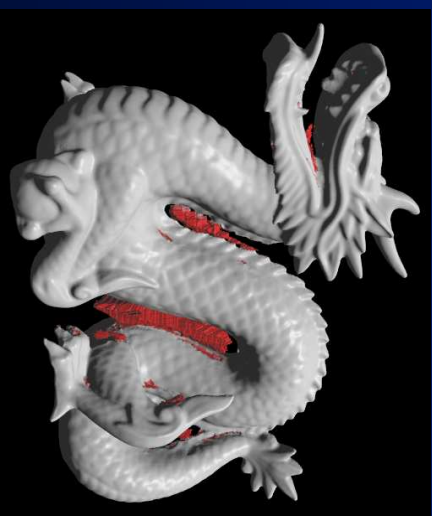
# Dragon

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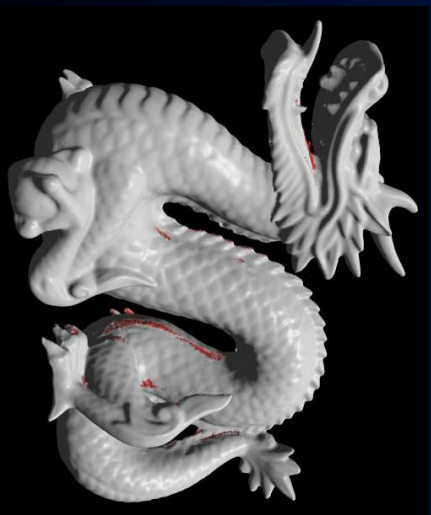
1.  
No hole  
filling



2.  
Hole filling  
without  
backdrop



3.  
Hole filling  
with  
backdrop



4.  
Smoothed



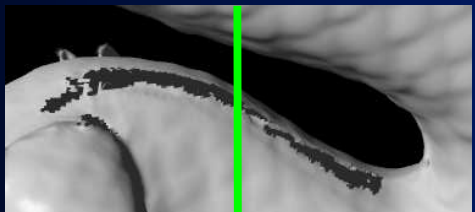




Close-up  
of the belly

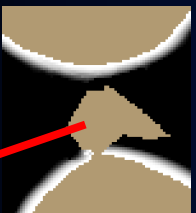
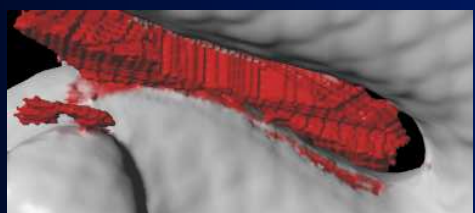
Volumetric  
slices

1



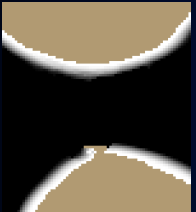
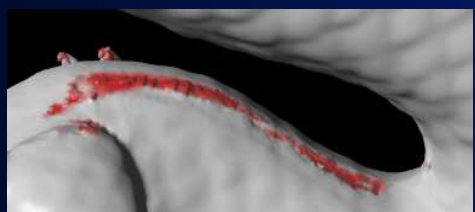
Gap

2



Uncarved

3



4



# Happy Buddha: from original...

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Original  
model

Painted  
original

Range  
surface

# ...to hardcopy

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Before  
hole filling

After  
hole filling

Hardcopy

# Data sizes for Happy Buddha

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Number of scans: 60

Input triangles: 10 million

Voxel grid: 400x1000x400

Storage: 640 MB w/o RLE  
49 MB w/ RLE

Output triangles: 2.6 million (55 MB)

# Execution times for Happy Buddha

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Time to scan: 1-2 hours

Time to align: 3-4 hours

Time to merge: 47 min. (w/o hole fill)

3 hr 17 min. (w/ hole fill)

Total time: 5-10 hours

# Limitations

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- Optical scanning
  - Surface points must be accessible
  - Surface reflectance affects results
- Volumetric algorithm
  - Thin surfaces and sharp corners

## Future work

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- Carving from video/image silhouettes
- Next best view, including backdrops
- Large-scale scenes
- Surface color acquisition

# Acknowledgments

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David Addleman, George Dabrowski... Cyberware scanner  
Julie Dorsey, Pat Hanrahan... Rendering tips  
Homan Igehy... Triangle rasterizer  
Phil Lacroute... Optimization suggestions  
Bill Lorensen... Marching cubes tables  
Tamara Munzner... Video production  
Matt Pharr... Accessibility shader  
Afra Zomorodian... Scanning script engine



# Check it out...

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Now available:

- Software
- Range data
- Surface reconstructions

Go to:

<http://www-graphics.stanford.edu/software>