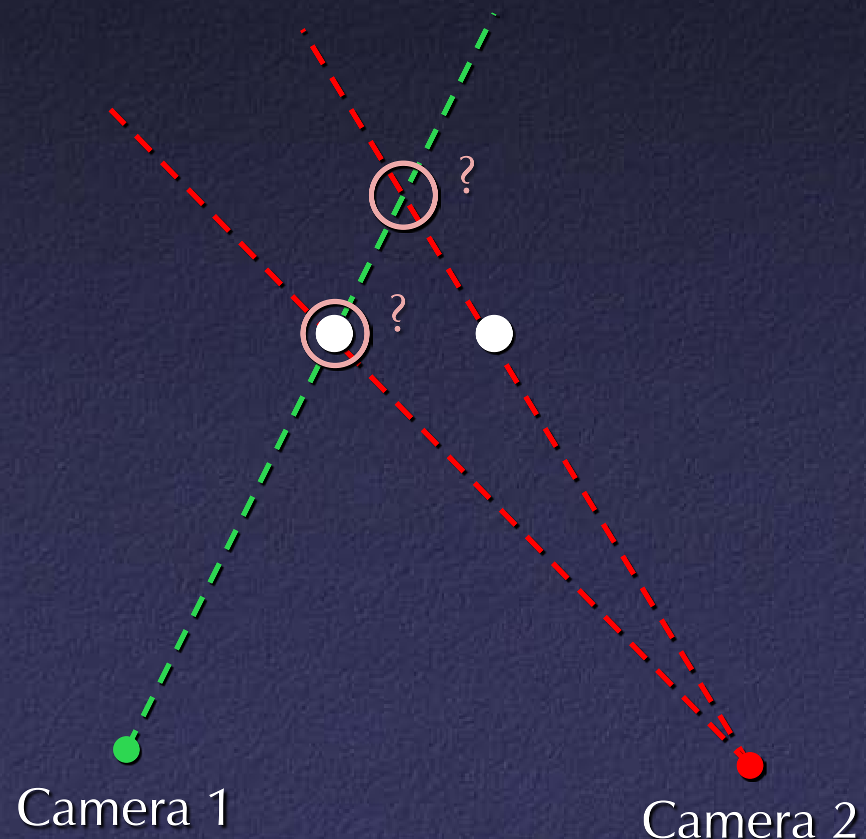
# Multiview Reconstruction

# Why More Than 2 Views?

- Baseline
  - Too short – low accuracy
  - Too long – matching becomes hard

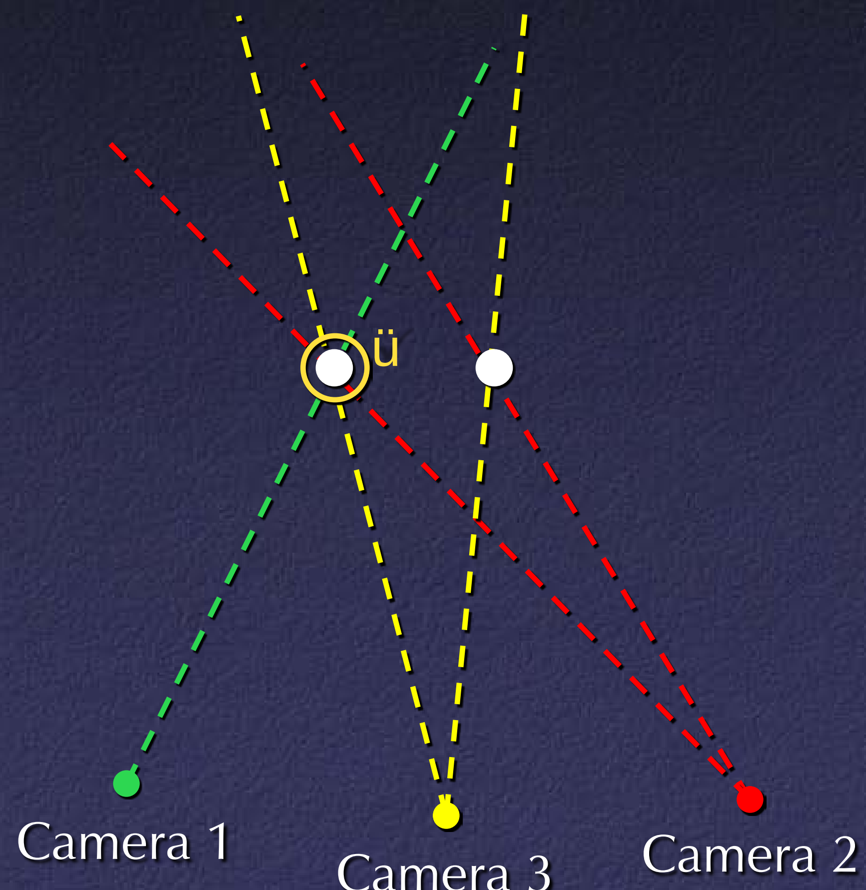
# Why More Than 2 Views?

- Ambiguity with 2 views



# Why More Than 2 Views?

- Ambiguity with 2 views



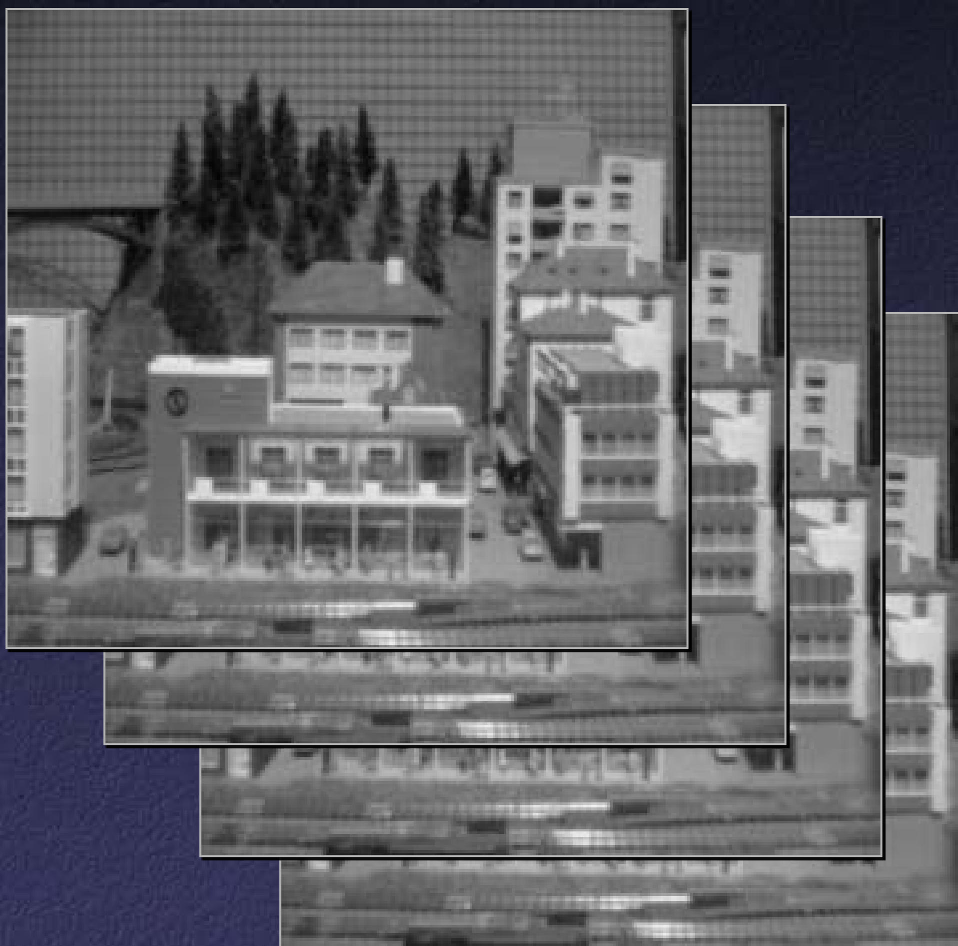
# Trinocular Stereo

- Straightforward approach to eliminate bad correspondences
  - Pick 2 views, find correspondences
  - For each matching pair, reconstruct 3D point
  - Project point into 3rd image
  - If can’t find correspondence near predicted location, reject

# Multibaseline Stereo

- Slightly different algorithm for *n* cameras:
- Pick one reference view
- For each candidate depth
  - Compute sum of squared differences to all other views, assuming correct disparity for view
- Resolves ambiguities: only correct depths will "constructively interfere"

# Multibaseline Stereo



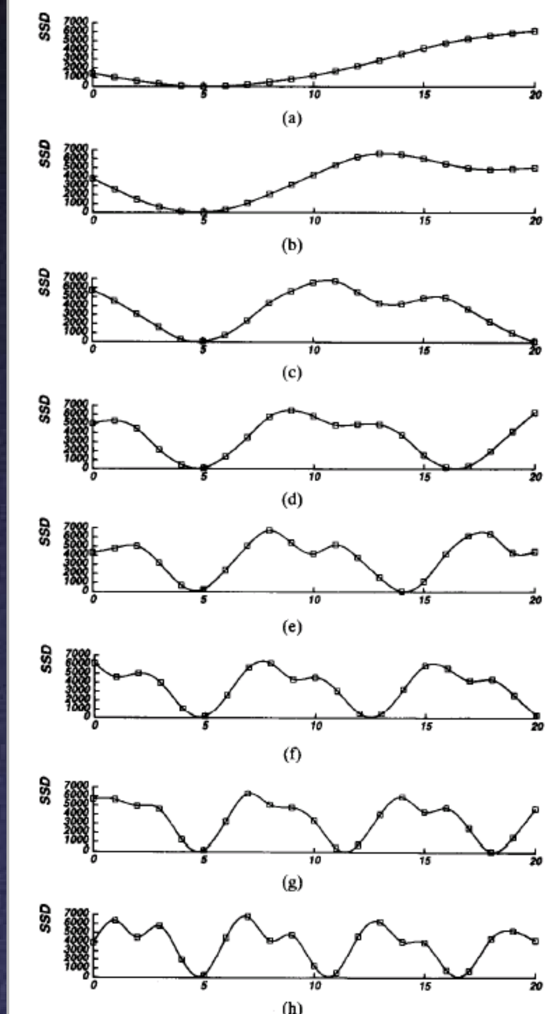
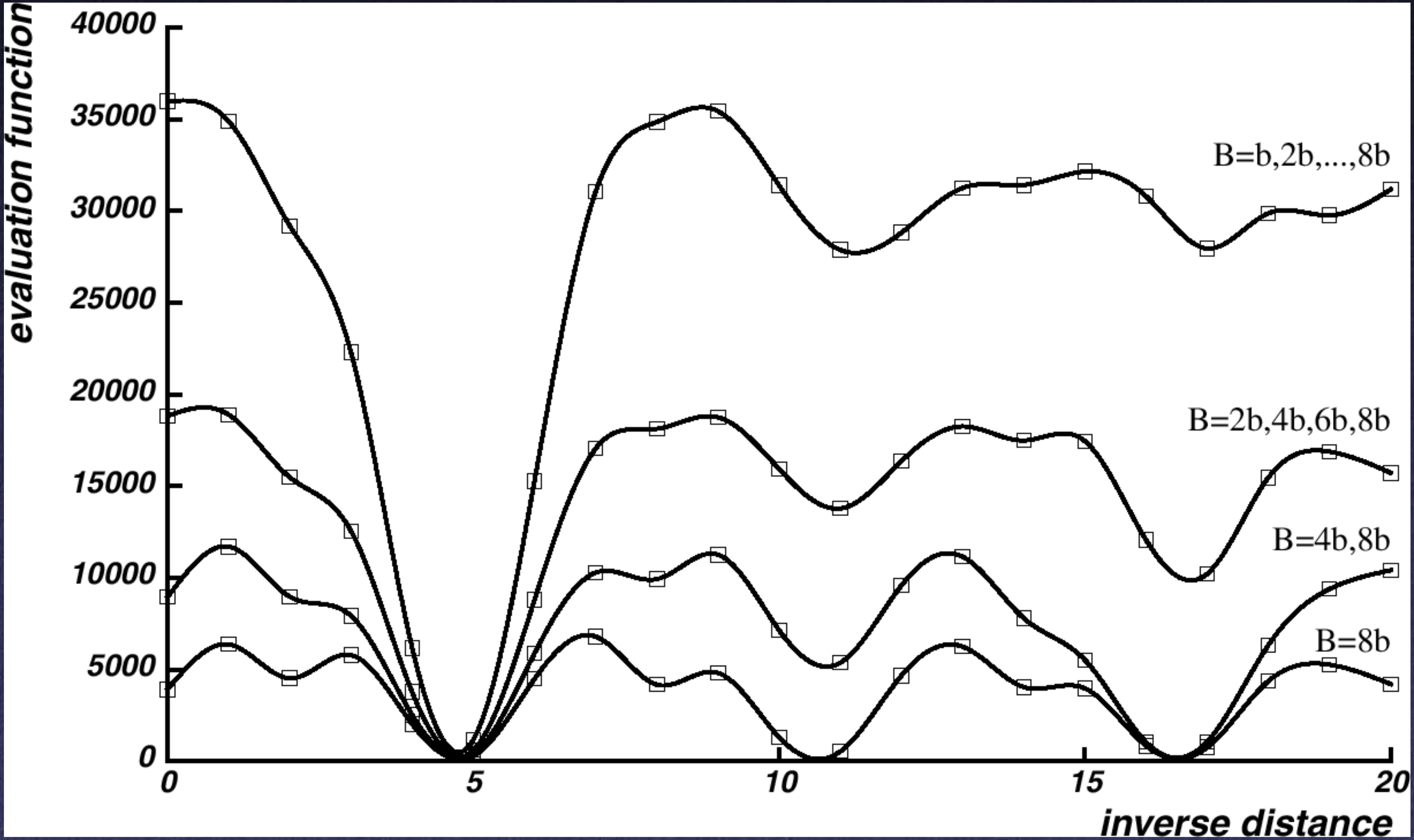


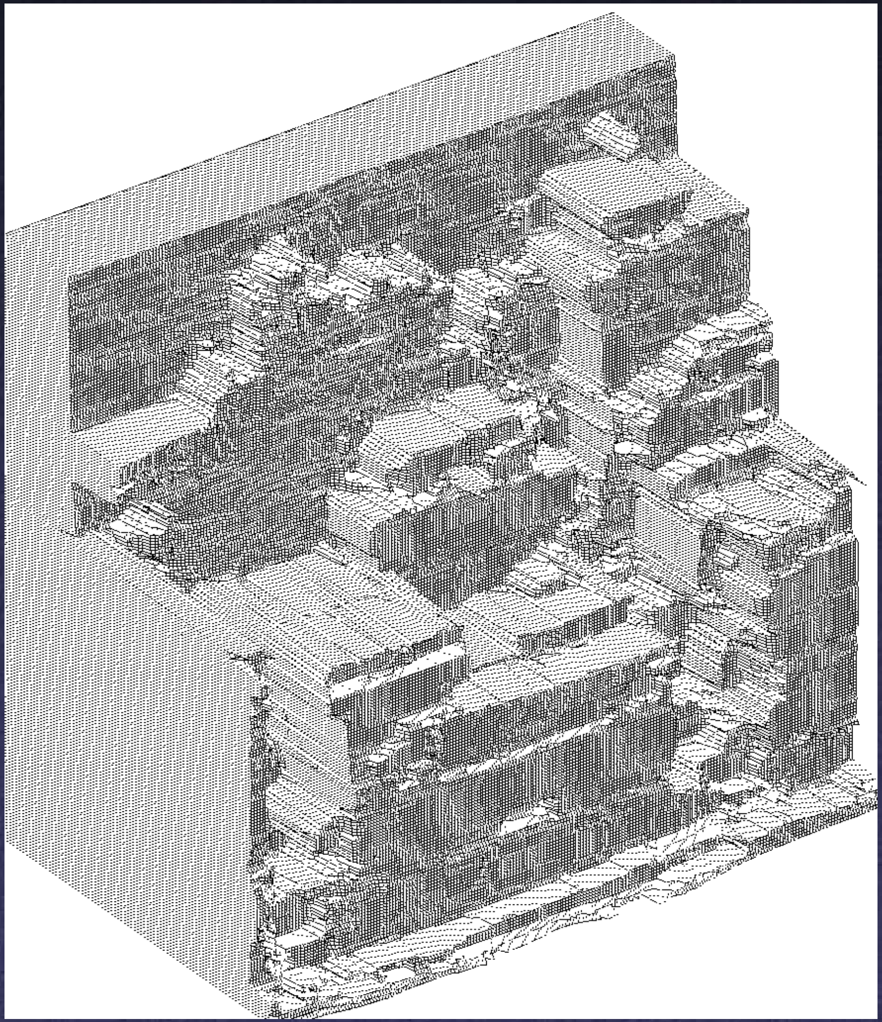

Fig. 5. SSD values versus inverse distance: (a) $B = b$; (b) $B = 2b$; (c) $B = 3b$; (d) $B = 4b$; (e) $B = 5b$; (f) $B = 6b$; (g) $B = 7b$; (h) $B = 8b$. The horizontal axis is normalized such that $8bF = 1$.

# Multibaseline Stereo

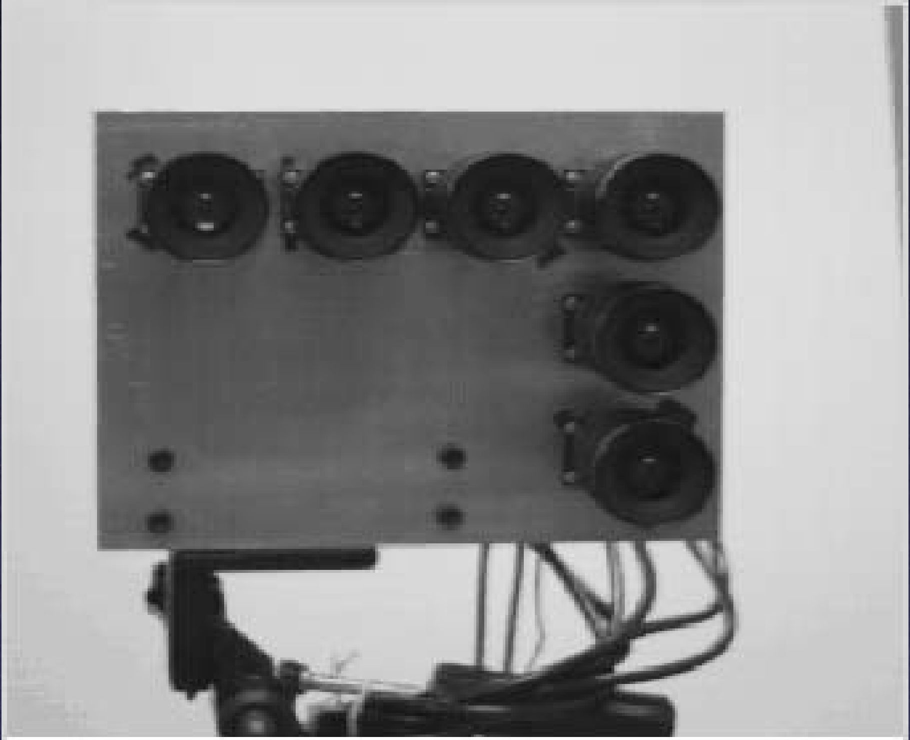



[Okutami & Kanade]

# Multibaseline Stereo Reconstruction



# Multibaseline Stereo



(a)

(b)

Figure 7: The CMU Video-Rate Stereo Machine Prototype System: (a) camera head; (b) processor boards

# Problems with Multibaseline Stereo

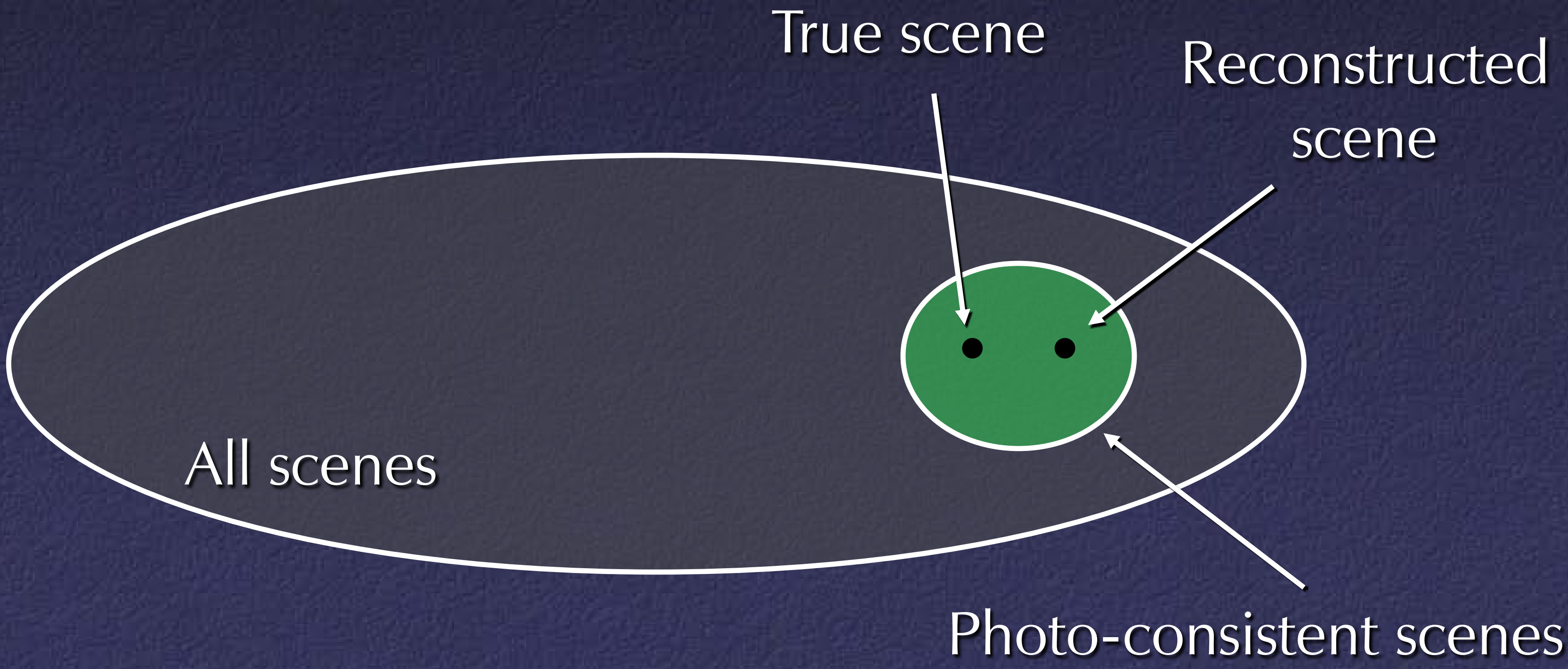
- Have to pick a reference view
- Occlusion
  - With many cameras / large baseline, occlusion becomes likely
  - Contributes incorrect values to error function

# Volumetric Multiview Approaches

- Goal: find a model consistent with images
- "Model-centric" (vs. image-centric)
- Typically use discretized volume (voxel grid)
- For each voxel, compute occupied / free
  (for some algorithms, also color, etc.)

# Photo Consistency

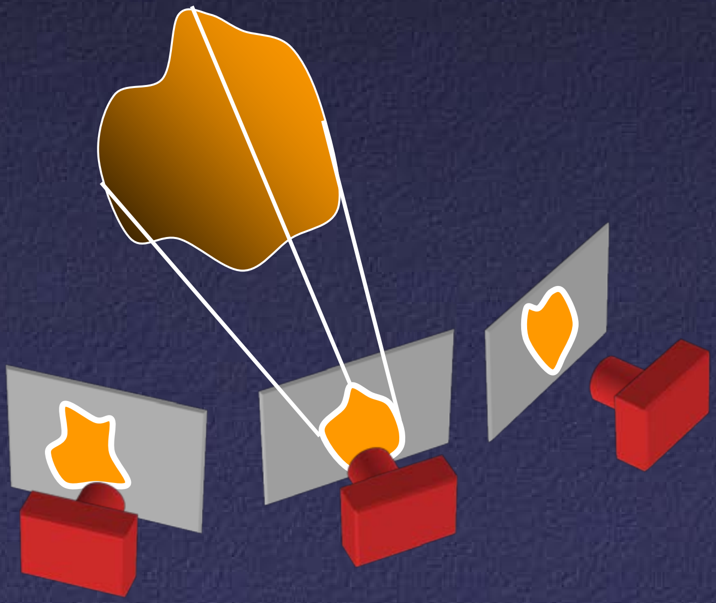
- Result: not necessarily correct scene
- Many scenes produce the same images



# Silhouette Carving

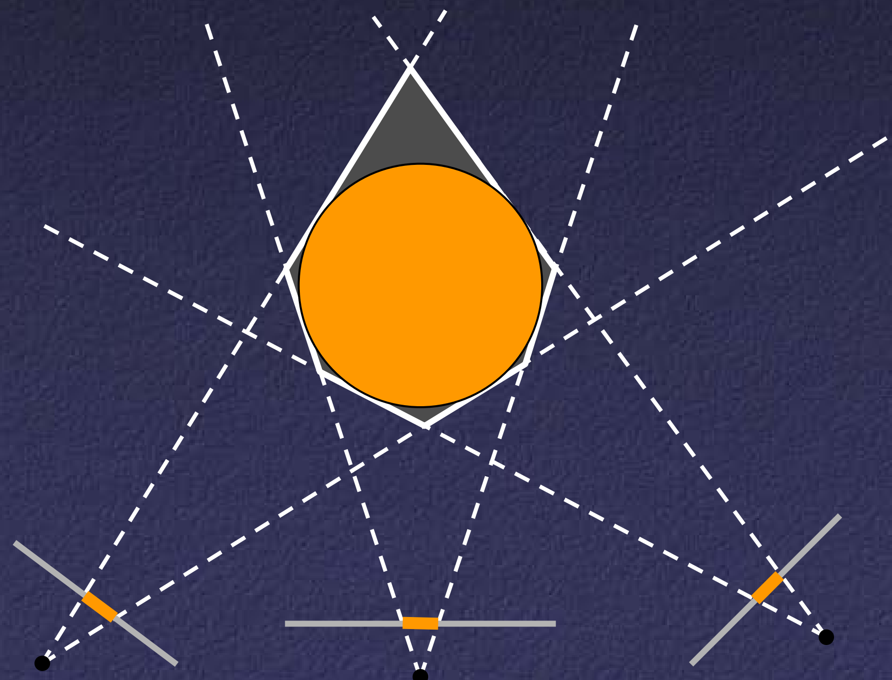
- Find silhouettes in all images
- Exact version:
  - Back-project all silhouettes, find intersection

Binary Images



# Silhouette Carving

- Find silhouettes in all images
- Exact version:
  - Back-project all silhouettes, find intersection



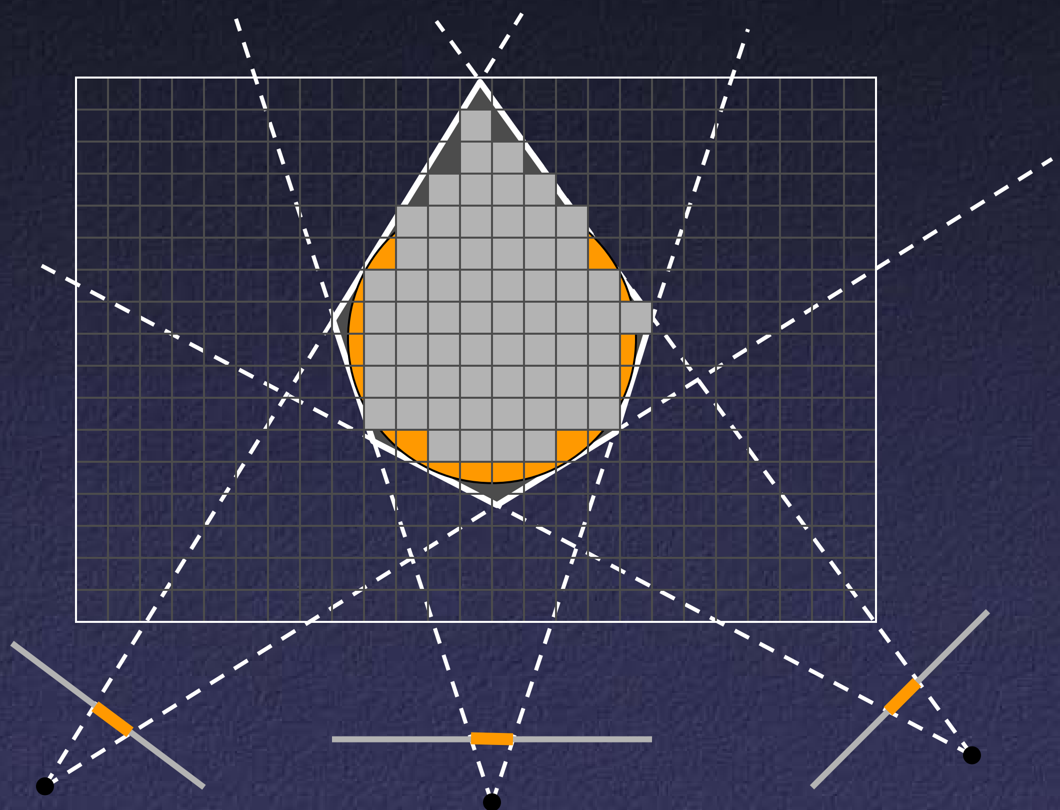
# Silhouette Carving

- Limit of silhouette carving is *visual hull* or *line hull*
- Complement of lines that don't intersect object
- In general not the same as object
  - Can't recover "pits" in object
- Not the same as convex hull

# Silhouette Carving

- Discrete version:
  - Loop over all voxels in some volume
  - If projection into images lies inside all silhouettes, mark as occupied
  - Else mark as free

# Silhouette Carving



# Voxel Coloring

- Seitz and Dyer, 1997
- In addition to free / occupied, store color at each voxel
- Explicitly accounts for occlusion

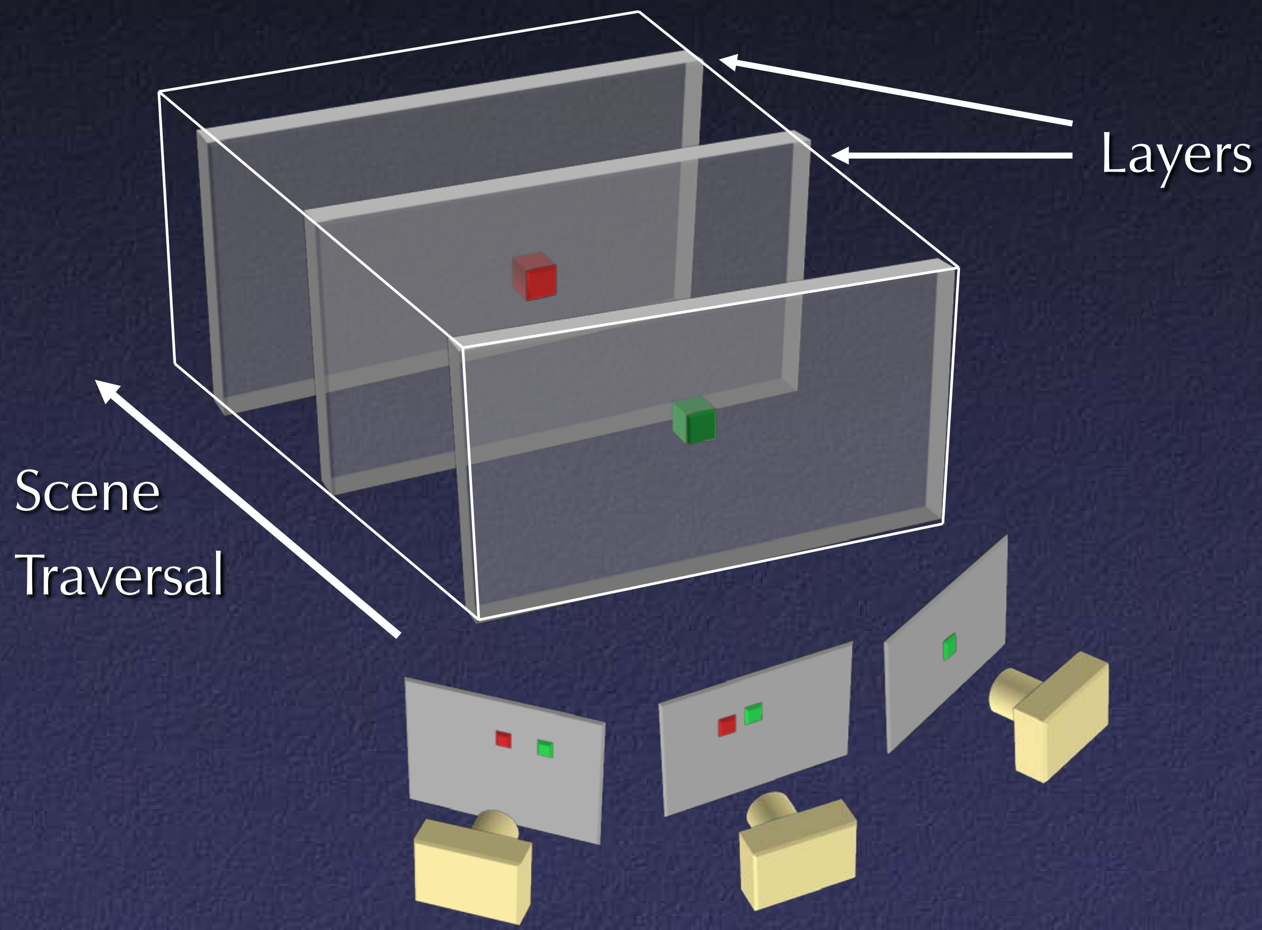
# Voxel Coloring

- Basic idea: sweep through a voxel grid
  - Project each voxel into each image
    in which it is visible
  - If colors in images agree, mark voxel with color
  - Else, mark voxel as empty
- Agreement of colors based on comparing standard deviation of colors to threshold

# Voxel Coloring and Occlusion

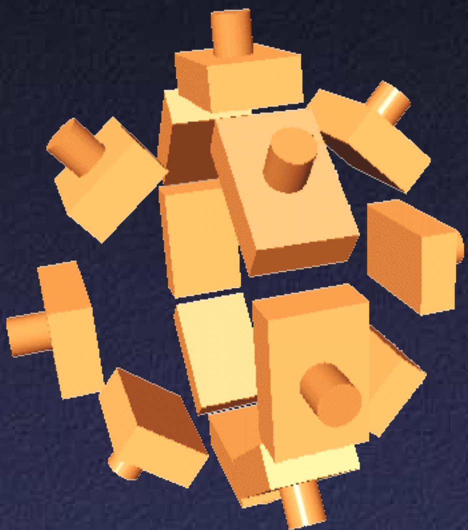
- Problem: which voxels are visible?
- Solution, part 1: constrain camera views
  - When a voxel is considered, necessary occlusion information must be available
  - Sweep occluders before occludees
  - Constrain camera positions to allow this sweep

# Voxel Coloring Sweep Order




Seitz

# Voxel Coloring Camera Positions

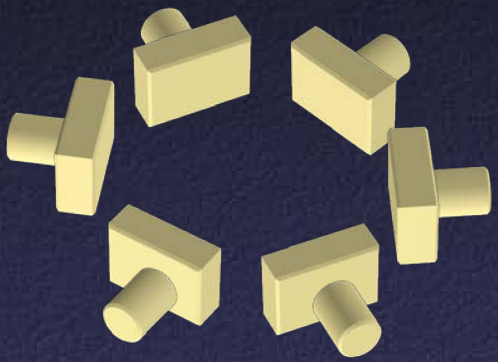


Inward-looking
Cameras above scene

Outward-looking
Cameras inside scene

Seitz

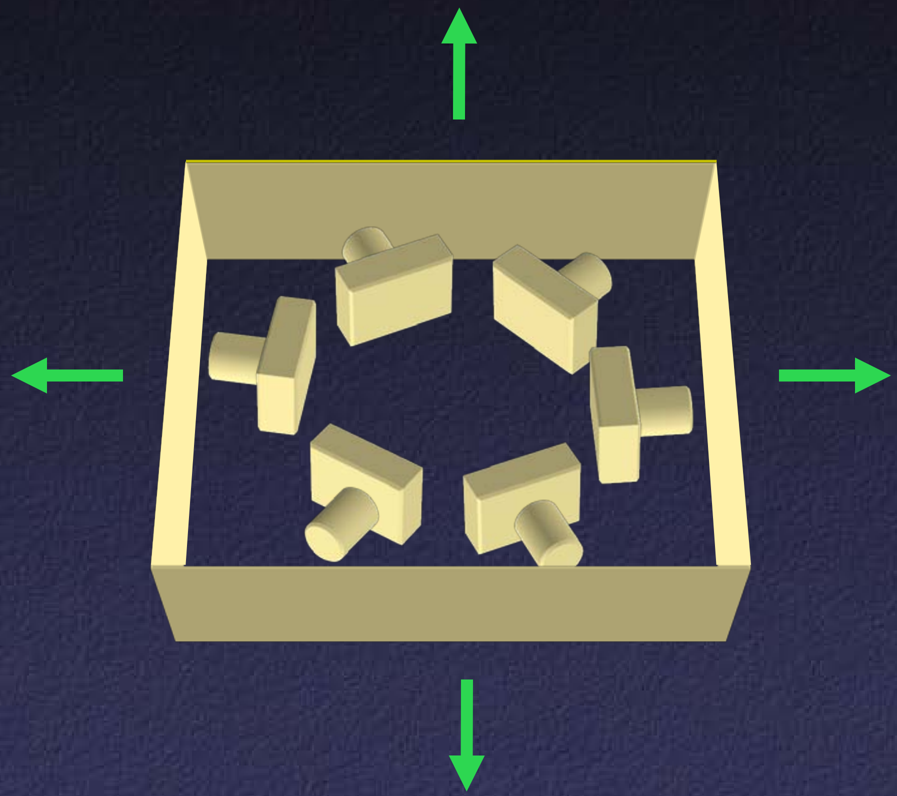
# Panoramic Depth Ordering



- Cameras oriented in many different directions
- Planar depth ordering does not apply

Seitz

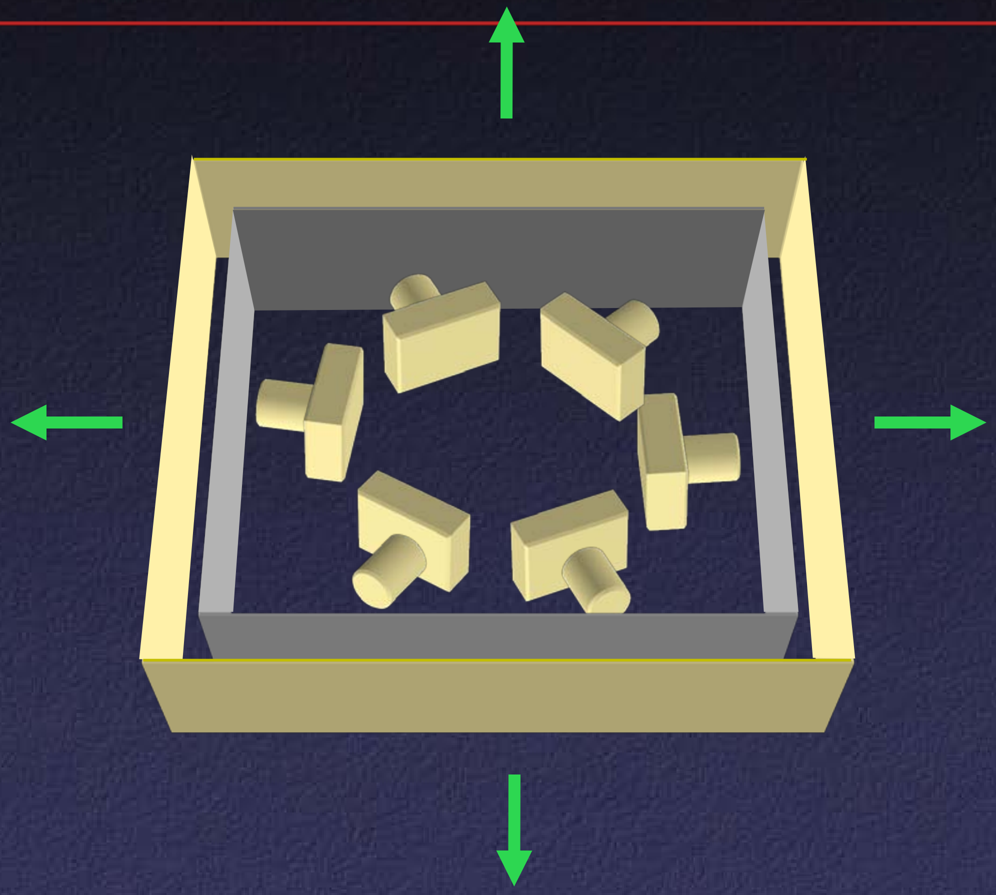
# Panoramic Depth Ordering



Layers radiate outwards from cameras

Seitz

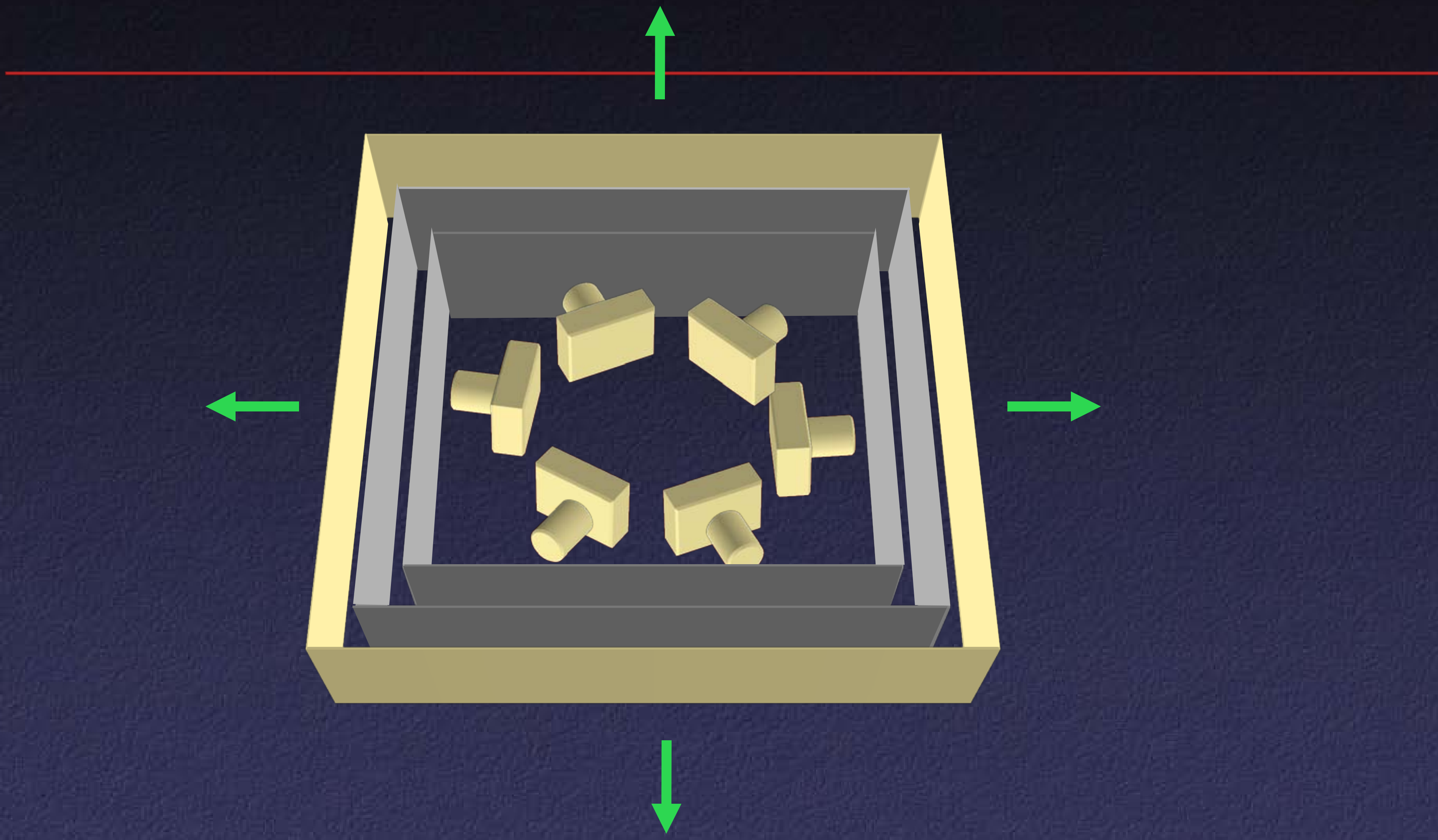
# Panoramic Depth Ordering



Layers radiate outwards from cameras

Seitz

# Panoramic Depth Ordering



Layers radiate outwards from cameras

Seitz

# Voxel Coloring and Occlusion

- Solution, part 2: per-image mask of which pixels have been used
  - Each pixel only used once
  - Mask filled in as sweep progresses

# Image Acquisition

Selected Dinosaur Images

Selected Flower Images

- Calibrated Turntable
- 360° rotation (21 images)

Seitz

# Voxel Coloring Results

Dinosaur Reconstruction
72 K voxels colored
7.6 M voxels tested
7 min. to compute
on a 250MHz SGI

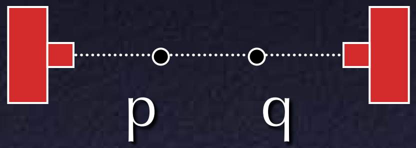
Flower Reconstruction
70 K voxels colored
7.6 M voxels tested
7 min. to compute
on a 250MHz SGI

Seitz

# Voxel Coloring Results

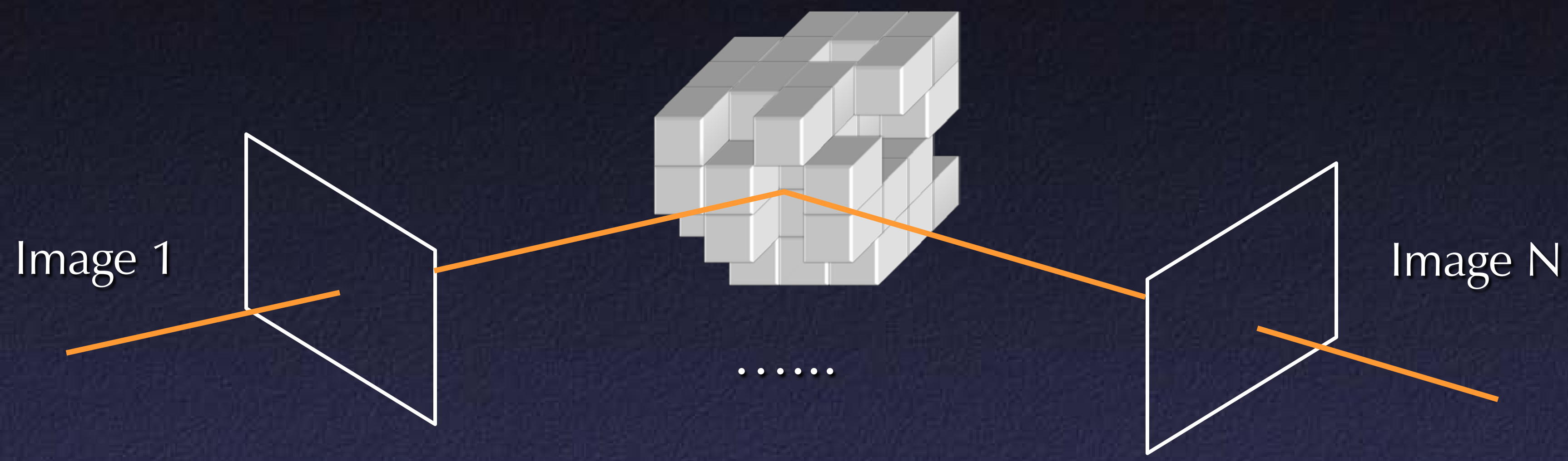
- With texture: good results
- Without texture: regions tend to “bulge out”
  - Voxels colored at earliest time at which projection into images is consistent
  - Model good for re-rendering: image will look correct for viewpoints near the original ones

# Limitations of Voxel Coloring




- A view-independent depth order may not exist
- Need more powerful general-case algorithms
  - Unconstrained camera positions
  - Unconstrained scene geometry/topology

# Space Carving



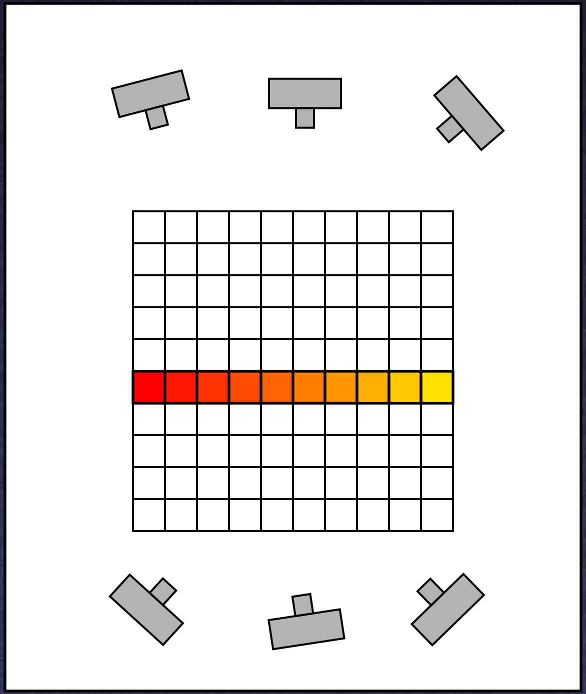

Initialize to a volume V containing the true scene
Choose a voxel on the current surface
Project to visible input images
Carve if not photo-consistent
Repeat until convergence

Kutulakos & Seitz

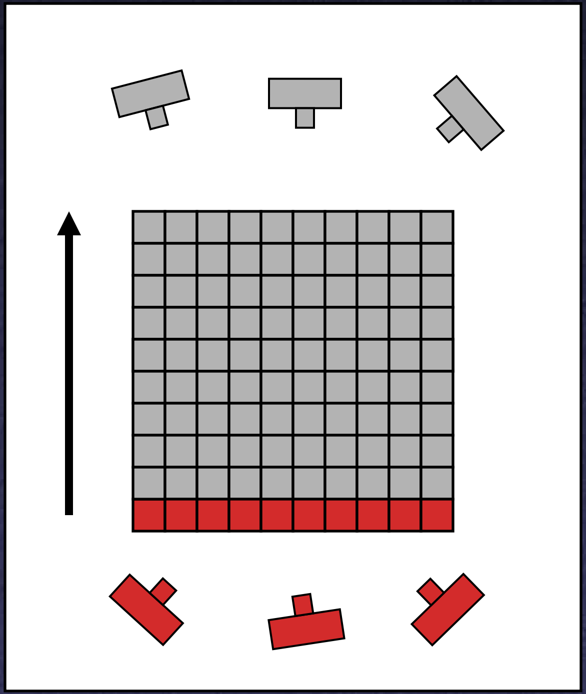
# Multi-Pass Plane Sweep

- Faster alternative:
  - Sweep plane in each of 6 principal directions
  - Consider cameras on only one side of plane
  - Repeat until convergence

# Multi-Pass Plane Sweep

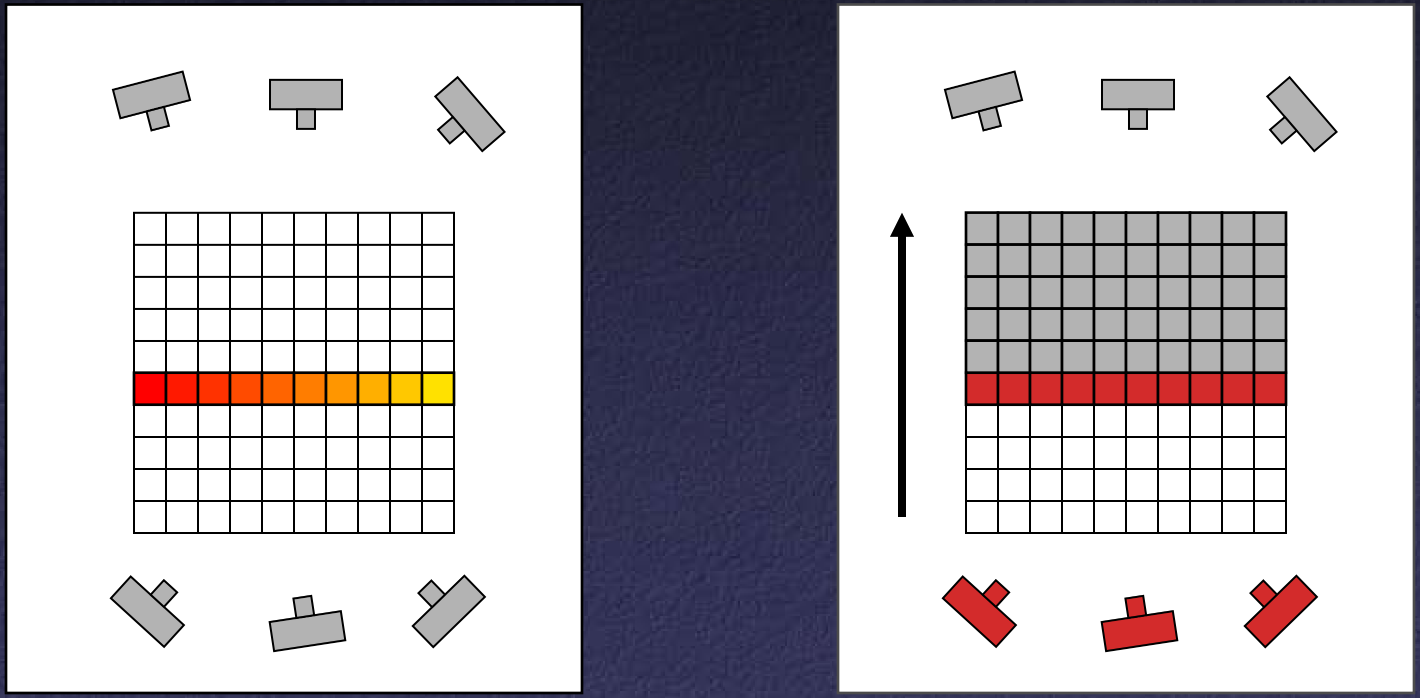


True Scene

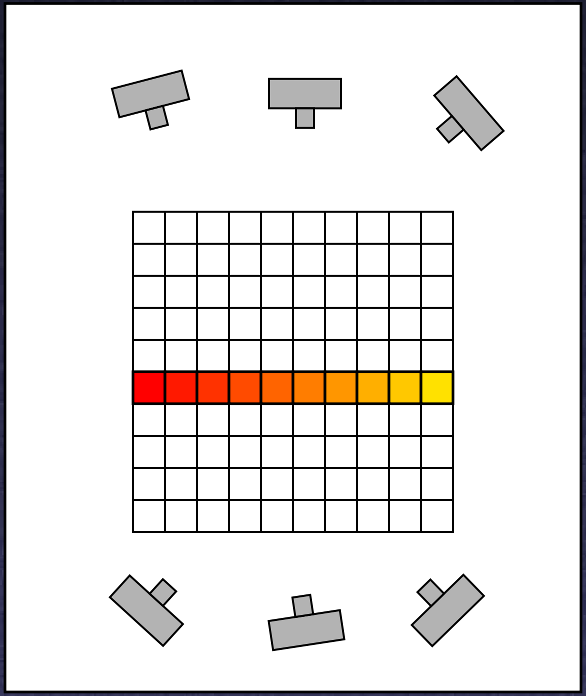


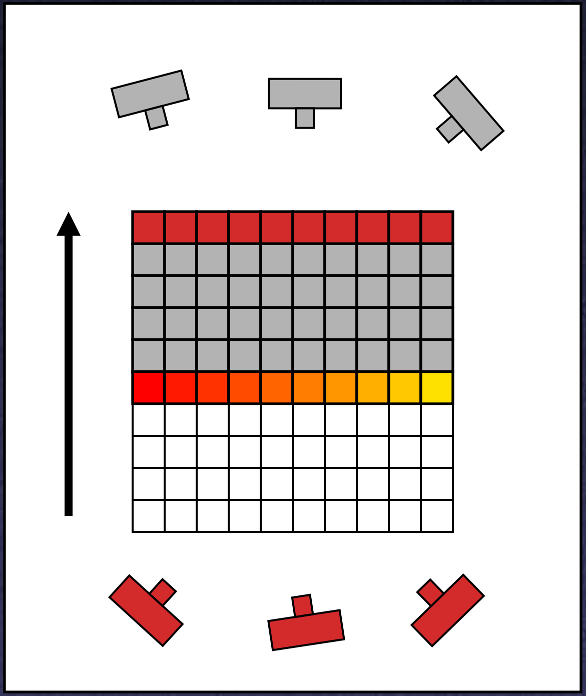
Reconstruction

# Multi-Pass Plane Sweep

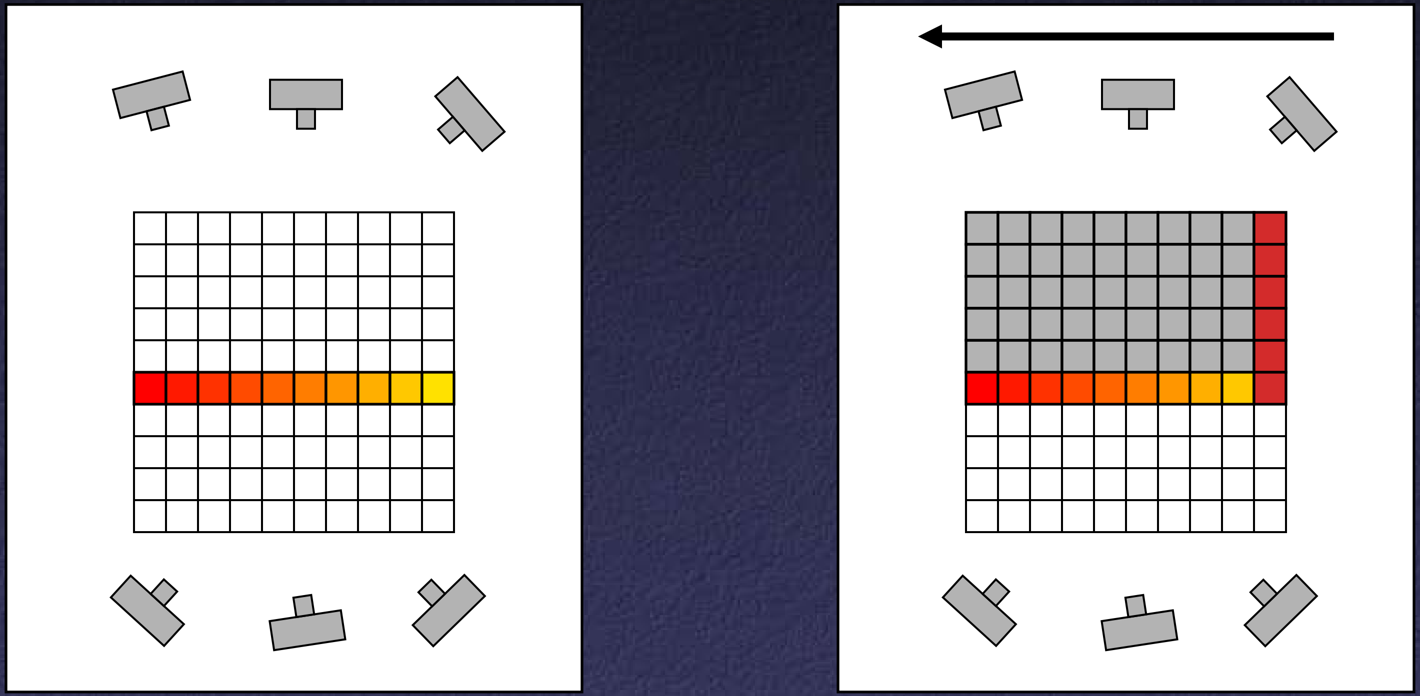


# Multi-Pass Plane Sweep

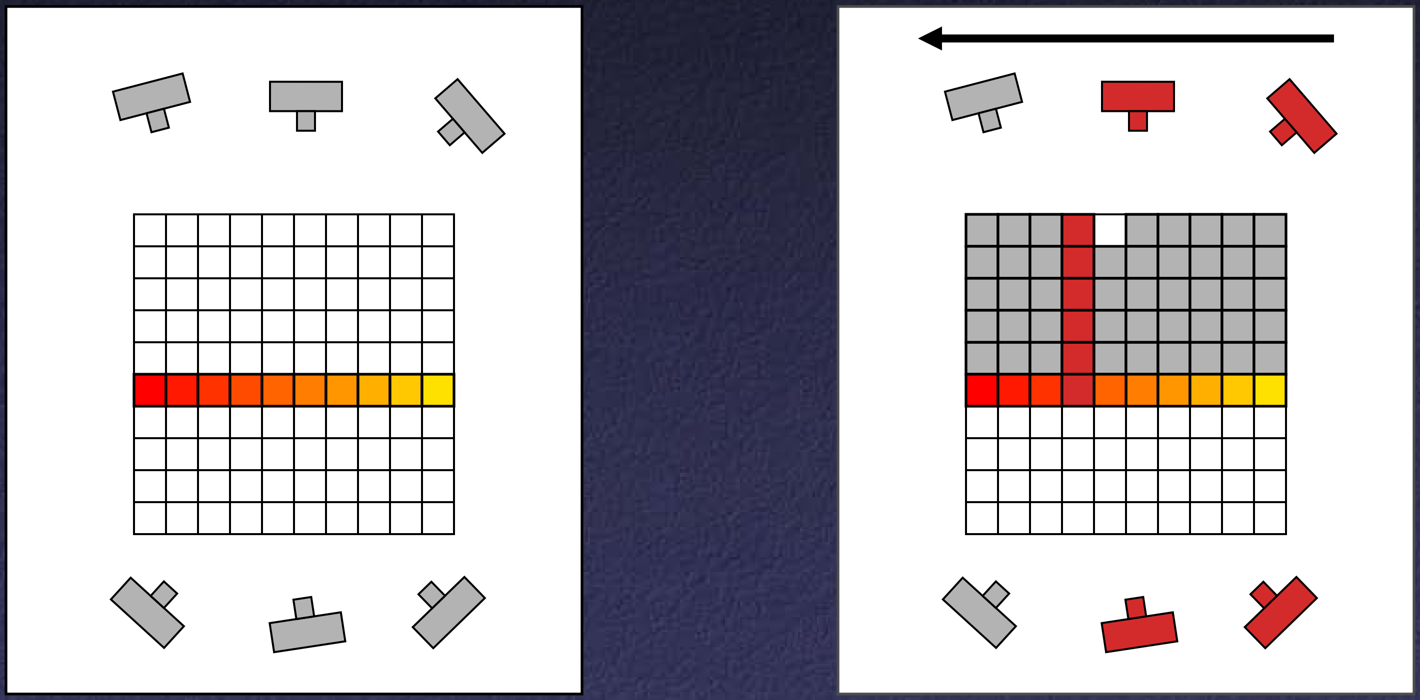




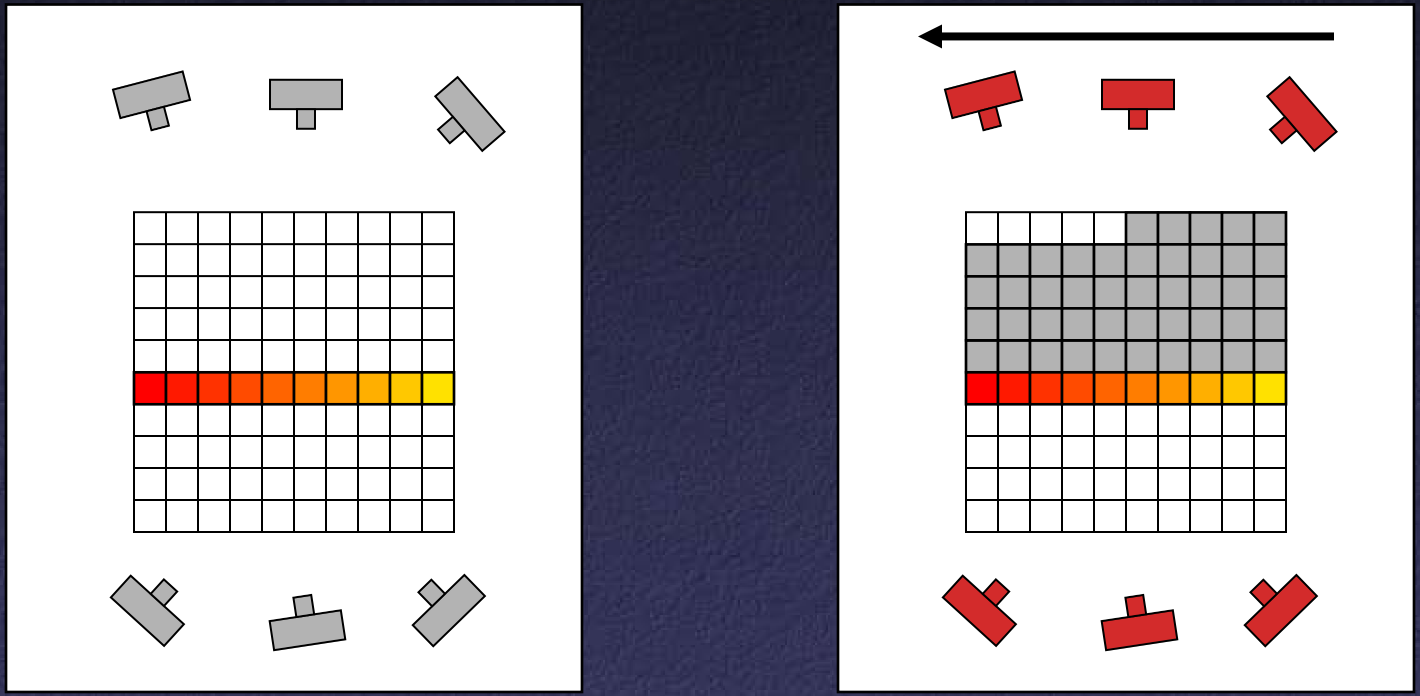
# Multi-Pass Plane Sweep



# Multi-Pass Plane Sweep



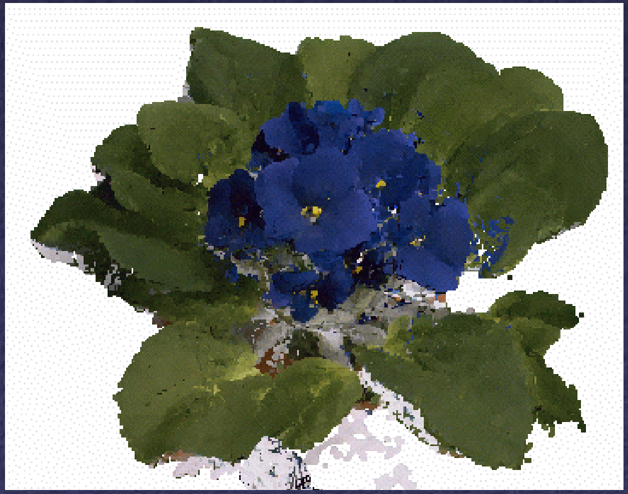
# Multi-Pass Plane Sweep



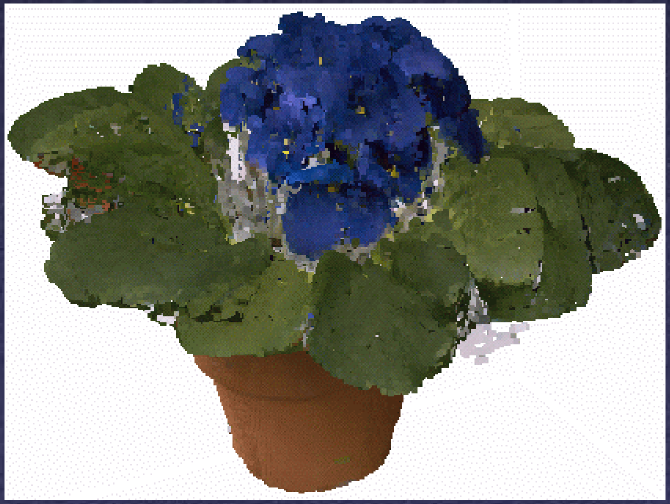
# Space Carving Results:  African Violet

Input Image (1 of 45)

Reconstruction



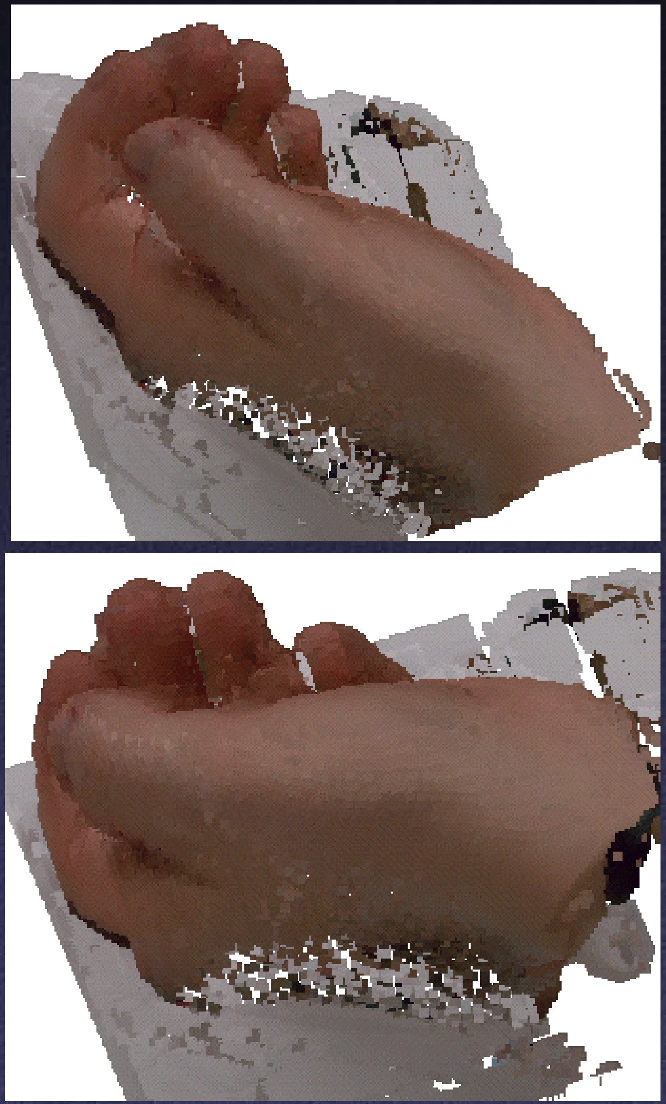
Reconstruction



Reconstruction

# Space Carving Results: Hand

Input Image
(1 of 100)



Views of Reconstruction