Announcements

- Project 1 grades out

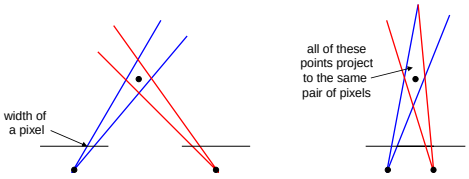
Multiview stereo

CMU's 3D Room

Readings

- S. M. Seitz and C. R. Dyer, Photorealistic Scene Reconstruction by Voxel Coloring, *International Journal of Computer Vision*, 35(2), 1999, pp. 151-173.
  > http://www.cs.washington.edu/homes/seitz/papers/ijcv99.pdf

Choosing the stereo baseline



Large Baseline **Small Baseline**

What's the optimal baseline?

- Too small: large depth error
- Too large: difficult search problem

The Effect of Baseline on Depth Estimation

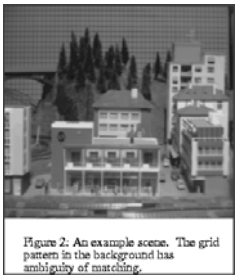
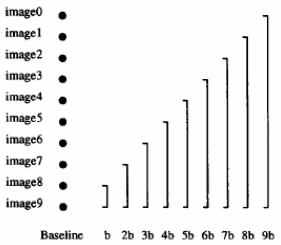
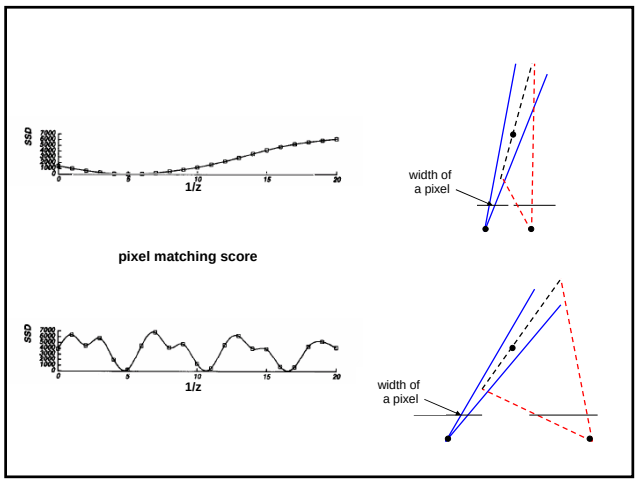
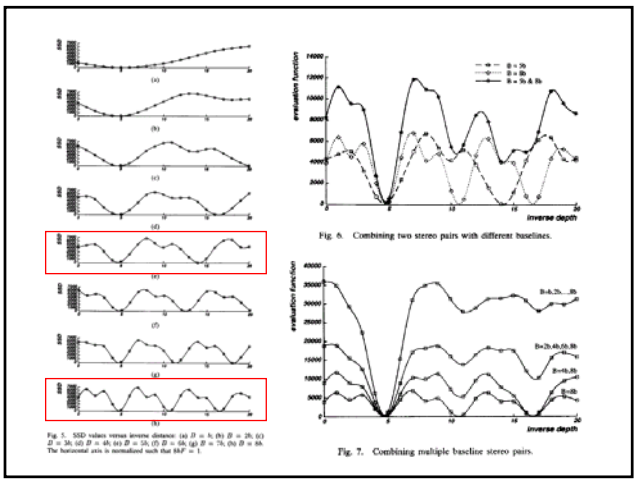


Figure 2: An example scene. The grid pattern in the background has ambiguity of matching.







Multibaseline Stereo

Basic Approach

- Choose a reference view
- Use your favorite stereo algorithm BUT
  - > replace two-view SSD with SSD over all baselines

Limitations

- Must choose a reference view (bad)
- Visibility!

CMU's 3D Room Video

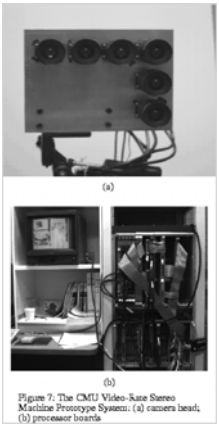
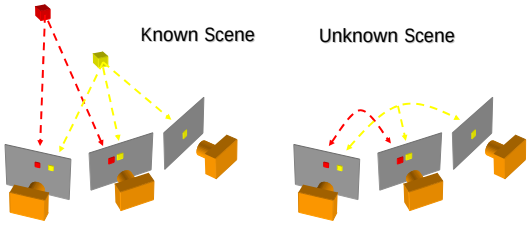


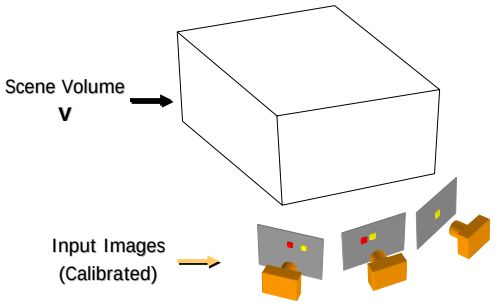
Figure 7: The CMU Video-Rate Stereo Machine Prototype System: (a) camera head; (b) processor boards

The visibility problem

Which points are visible in which images?

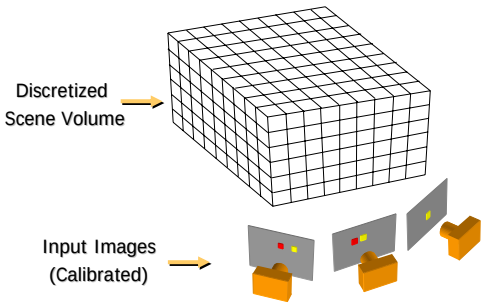


Volumetric stereo



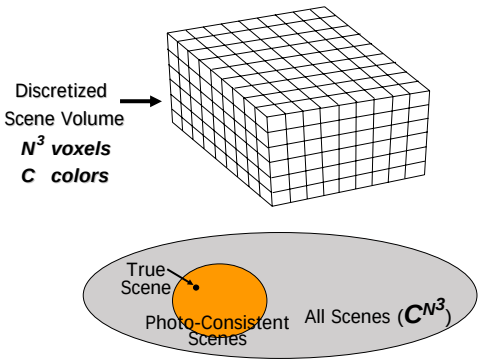
Goal: **Determine occupancy, "color" of points in V**

Discrete formulation: Voxel Coloring



Goal: **Assign RGBA values to voxels in V**
photo-consistent **with images**

Complexity and computability



Issues

Theoretical Questions

- Identify class of *all* photo-consistent scenes

Practical Questions

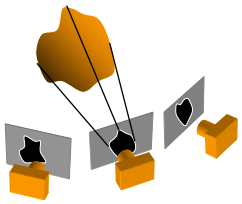
- How do we compute photo-consistent models?

Voxel coloring solutions

1. C=2 (shape from silhouettes)
   - Volume intersection [Baumgart 1974]
     > For more info: *Rapid octree construction from image sequences.* R. Szeliski, CVGIP: Image Understanding, 58(1):23-32, July 1993. (this paper is apparently not available online) or
     > W. Matusik, C. Buehler, R. Raskar, L. McMillan, and S. J. Gortler, *Image-Based Visual Hulls*, SIGGRAPH 2000 (pdf 1.6 MB)
2. C unconstrained, viewpoint constraints
   - Voxel coloring algorithm [Seitz & Dyer 97]
3. General Case
   - Space carving [Kutulakos & Seitz 98]

Reconstruction from Silhouettes (C = 2)

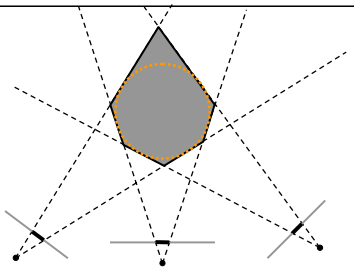
Binary Images →



Approach:

- *Backproject* each silhouette
- Intersect backprojected volumes

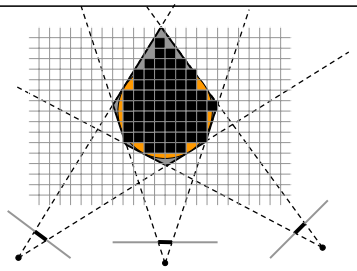
Volume intersection



Reconstruction Contains the True Scene

- But is generally not the same
- In the limit (all views) get *visual hull*
  > Complement of all lines that don't intersect S

Voxel algorithm for volume intersection



Color voxel black if on silhouette in every image

- O(?), for M images, N^3 voxels
- Don't have to search 2^{N^3} possible scenes!

Properties of Volume Intersection

Pros

- Easy to implement, fast
- Accelerated via octrees [Szeliski 1993] or interval techniques [Matusik 2000]

Cons

- No concavities
- Reconstruction is not photo-consistent
- Requires identification of silhouettes

Voxel Coloring Solutions

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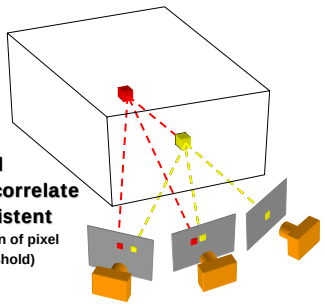
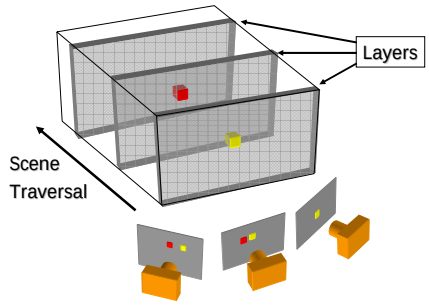
Voxel Coloring Approach



1. **Choose voxel**
2. **Project and correlate**
3. **Color if consistent**
   (standard deviation of pixel colors below threshold)

Visibility Problem: **in which images is each voxel visible?**

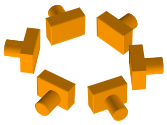
Depth Ordering: visit occluders first!



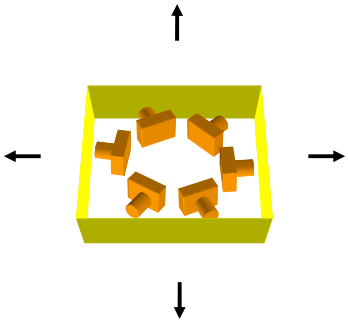
Condition: depth order is the *same for all input views*

Panoramic Depth Ordering

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

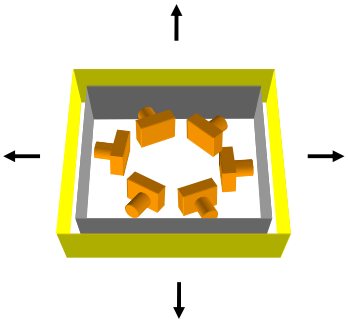


Panoramic Depth Ordering



Layers radiate outwards from cameras

Panoramic Layering



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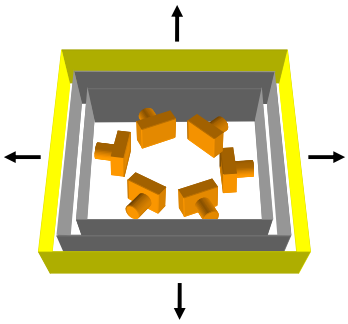


Layers radiate outwards from cameras

Compatible Camera Configurations

Depth-Order Constraint

- Scene outside convex hull of camera centers

Inward-Looking

Outward-Looking

Calibrated Image Acquisition

Calibrated Turntable

Selected Dinosaur Images

Selected Flower Images

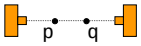
Voxel Coloring Results (Video)

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

Limitations of Depth Ordering

A view-independent depth order may not exist



Need more powerful general-case algorithms

- Unconstrained camera positions
- Unconstrained scene geometry/topology

Voxel Coloring Solutions

1. C=2 (silhouettes)
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2. C unconstrained, viewpoint constraints
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3. General Case
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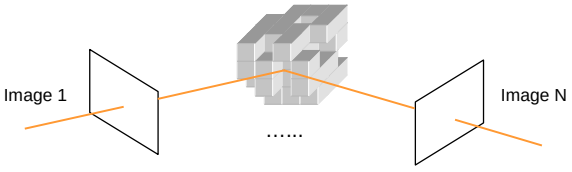
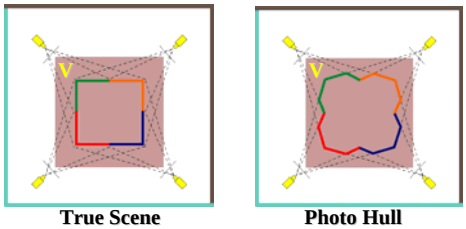
Space Carving Algorithm



Space Carving Algorithm

- 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

Which shape do you get?



True Scene **Photo Hull**

The Photo Hull *is the UNION of all photo-consistent scenes in V*

- It is a photo-consistent scene reconstruction
- Tightest possible bound on the true scene

Space Carving Algorithm

The Basic Algorithm is Unwieldy

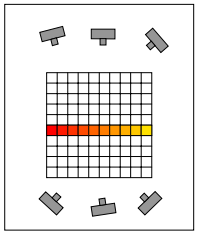
- Complex update procedure

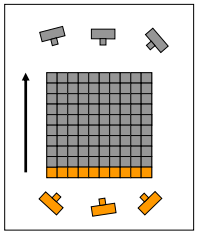
Alternative: Multi-Pass Plane Sweep

- Efficient, can use texture-mapping hardware
- Converges quickly in practice
- Easy to implement

Multi-Pass Plane Sweep

- Sweep plane in each of 6 principle directions
- Consider cameras on only one side of plane
- Repeat until convergence





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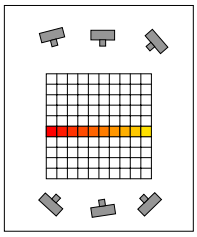

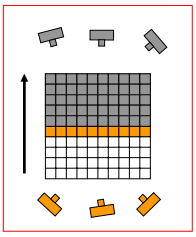

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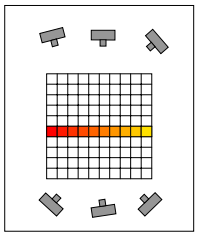

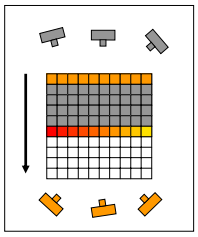

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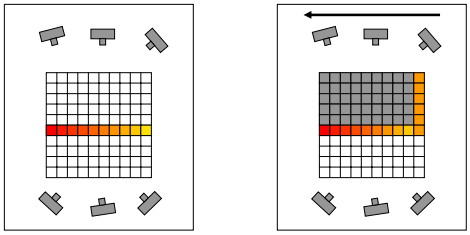

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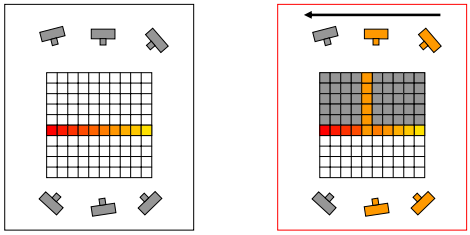

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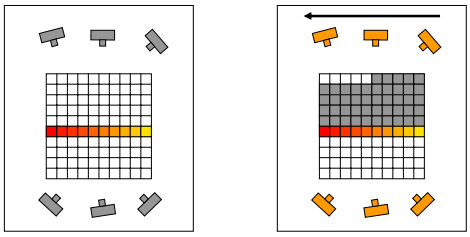

Space Carving Results: African Violet

Input Image (1 of 45)

Reconstruction

Reconstruction

Reconstruction

Space Carving Results: Hand

Input Image (1 of 100)

Views of Reconstruction

Other Approaches

Level-Set Methods ***[Faugeras & Keriven 1998]***

- Evolve implicit function by solving PDE's

Probabilistic Voxel Reconstruction ***[DeBonet & Viola 1999], [Broadhurst et al. 2001]***

- Solve for voxel uncertainty (also transparency)

Transparency and Matting ***[Szeliski & Golland 1998]***

- Compute voxels with alpha-channel

Max Flow/Min Cut ***[Roy & Cox 1998]***

- Graph theoretic formulation

Mesh-Based Stereo ***[Fua & Leclerc 1995], [Zhang & Seitz 2001]***

- Mesh-based but similar consistency formulation

Virtualized Reality ***[Narayan, Rander, Kanade 1998]***

- Perform stereo 3 images at a time, merge results