EECS 442 – Computer vision

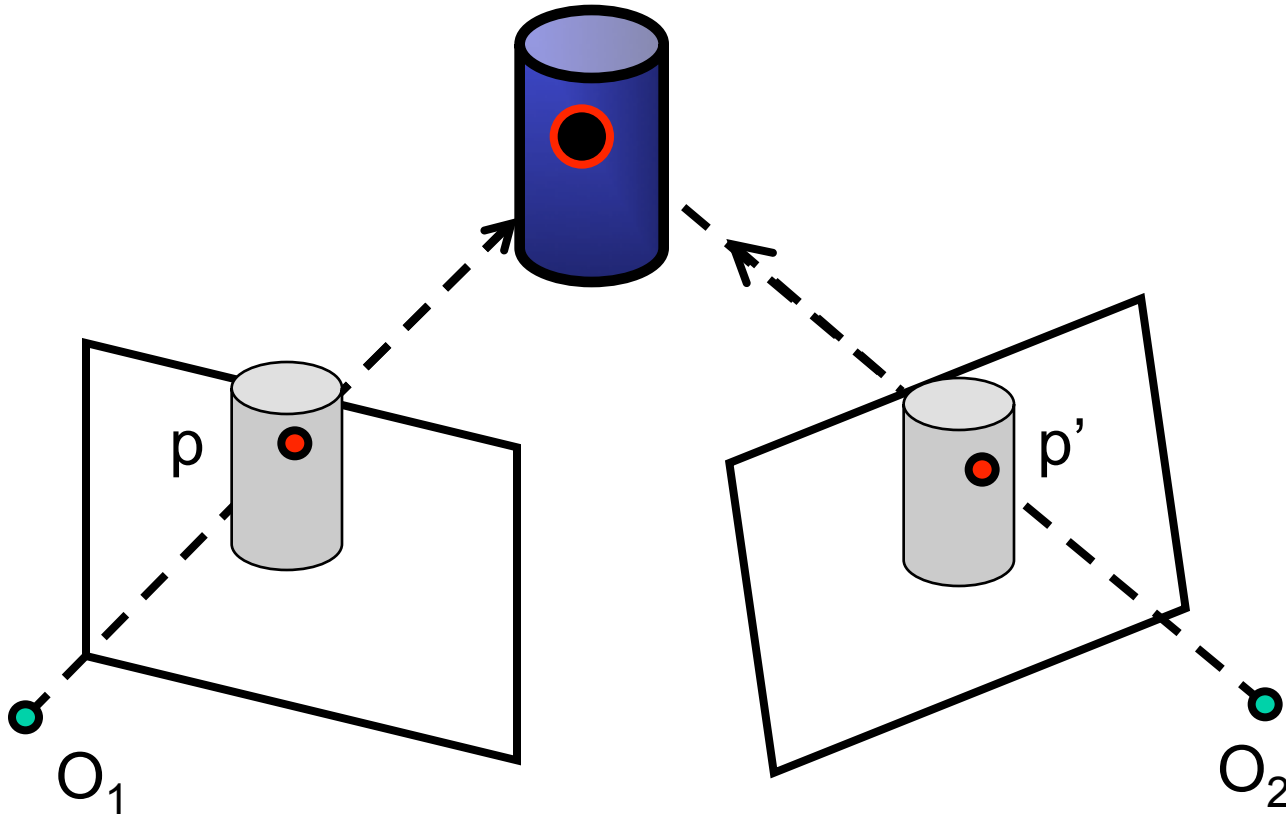## Announcements

- Midterm feedback

EECS 442 – Computer vision

Volumetric stereo

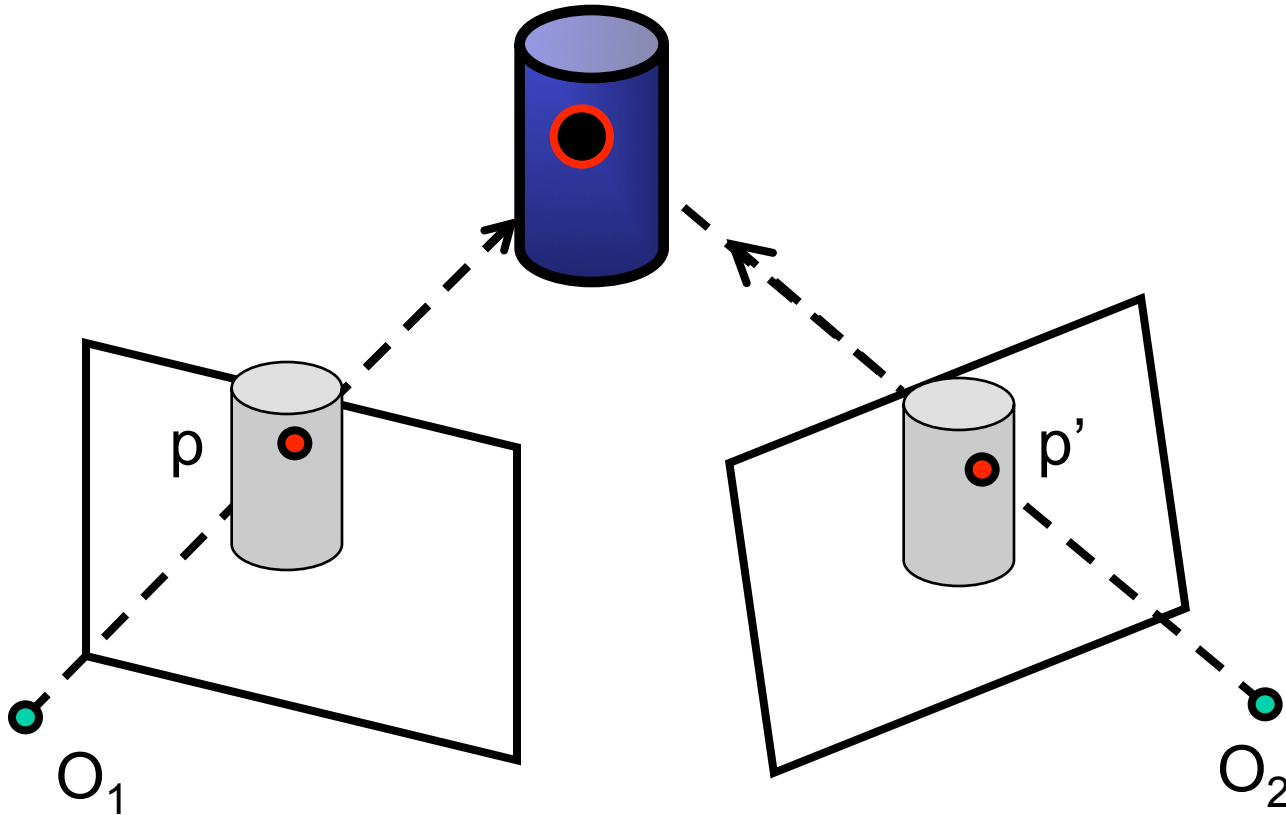- Definition
- Shape from Contours
- Voxel coloring

"Traditional" Stereo

Goal: estimate the position of P given the observation of P from two view points

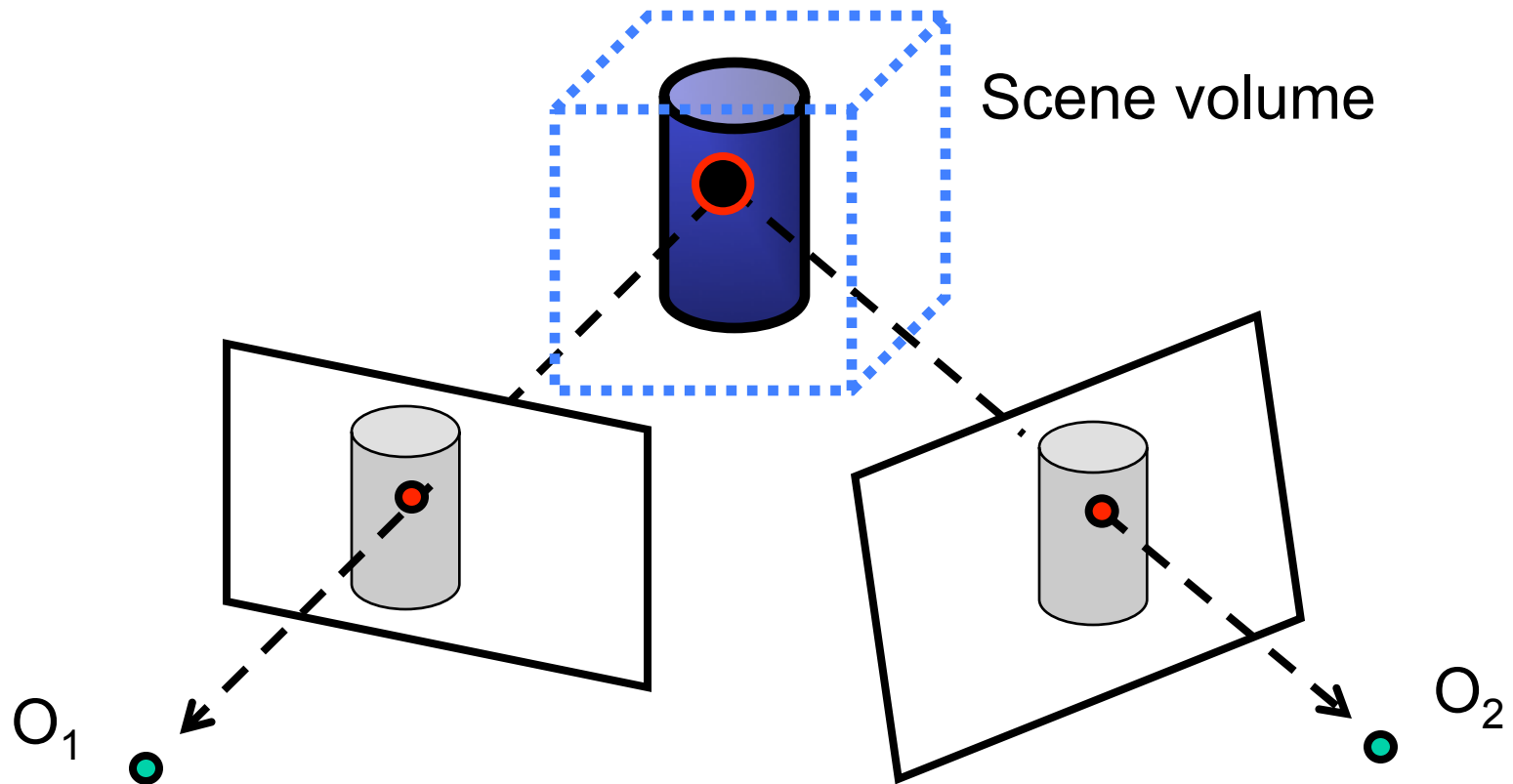Assumptions: known camera parameters and position (K, R, T)

"Traditional" Stereo

Subgoals:
1. Solve the correspondence problem
2. Use corresponding observations to triangulate

Volumetric stereo

Scene volume

O_1 O_2

1. Hypothesis: pick up a point within the volume
2. Project this point into 2 (or more) images
3. Validation: are the observations consistent?

Assumptions: known camera parameters and position (K, R, T)

Consistency based on cues such as:

- Contours/silhouettes
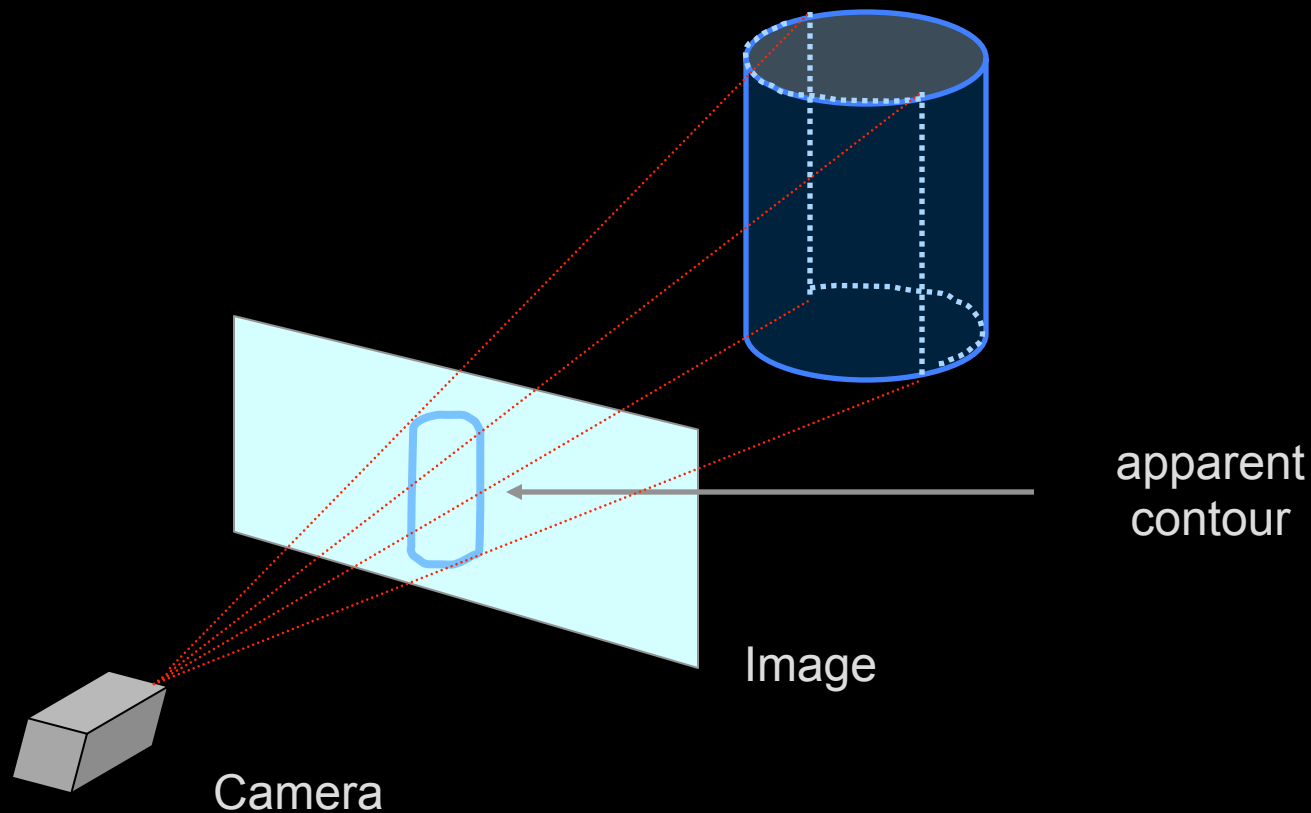- Colors

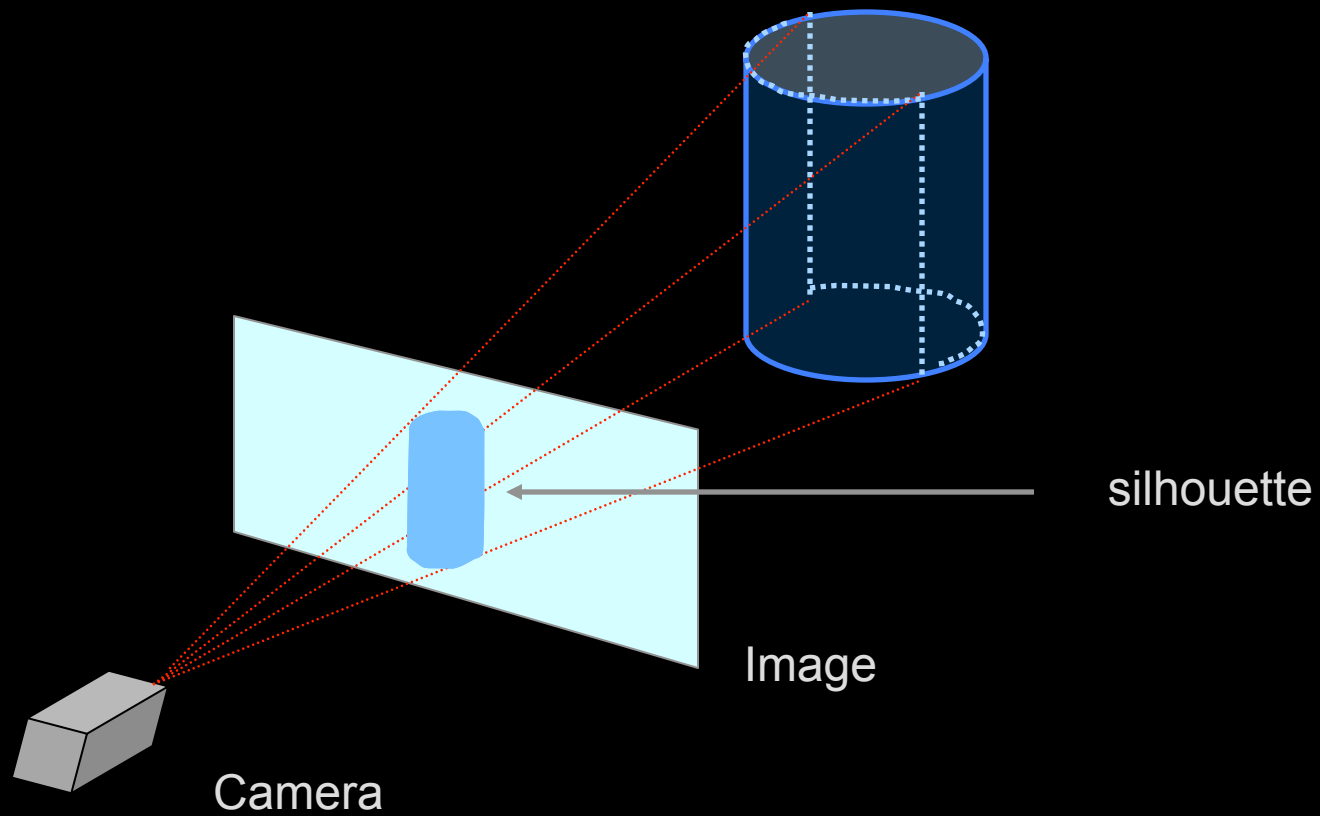# Contours are a rich source of geometric information

Apparent contour

DEFINITION: projection of the locus of points on the surface which separate the visible and occluded parts on the surface

[sato & cipolla]

apparent contour

Image

Camera

Silhouettes

silhouette

Image

Camera

Why contours are interesting visual cues?

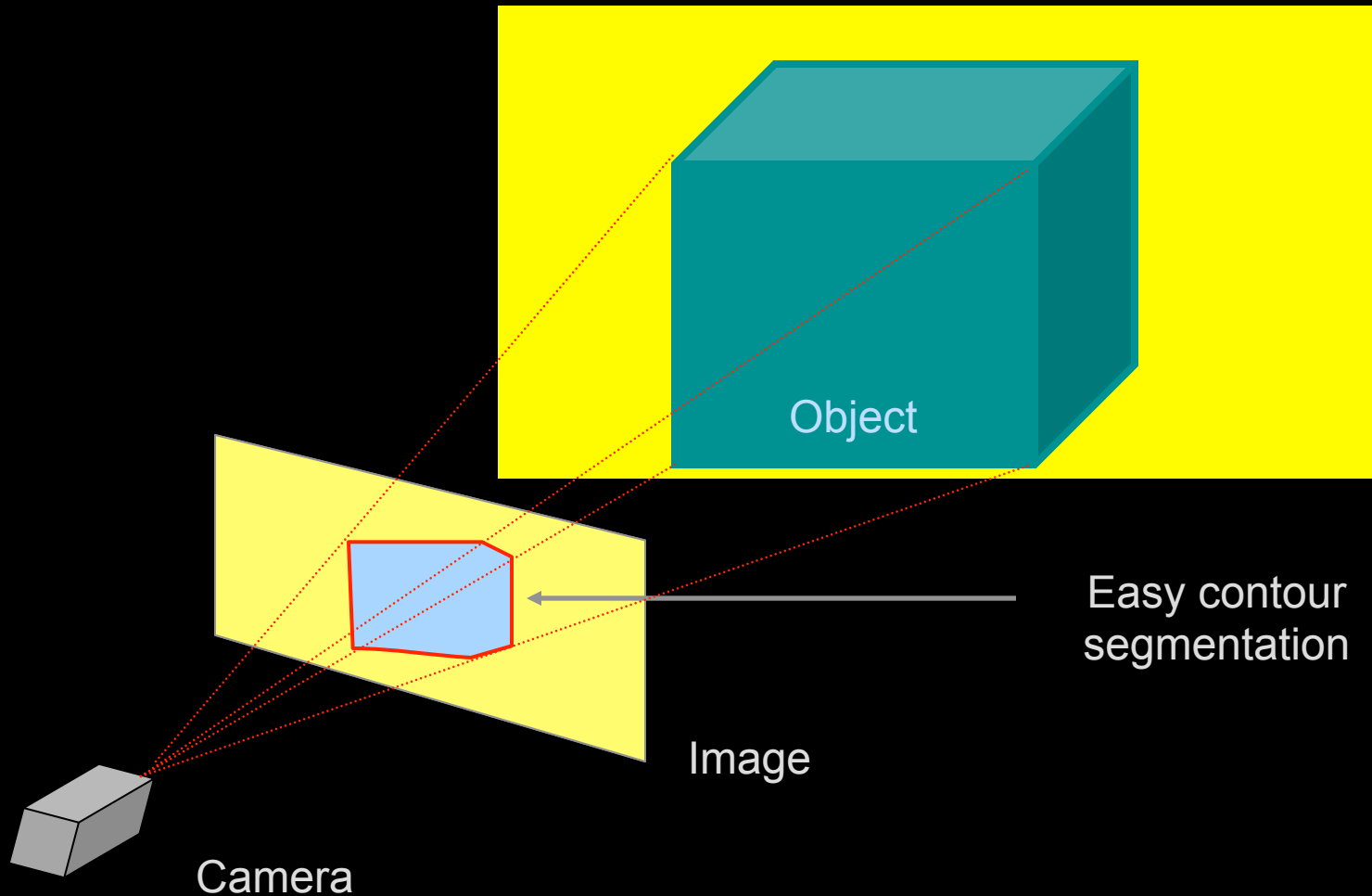❖ Provide information in absence of other visual cues

No texture

No shading

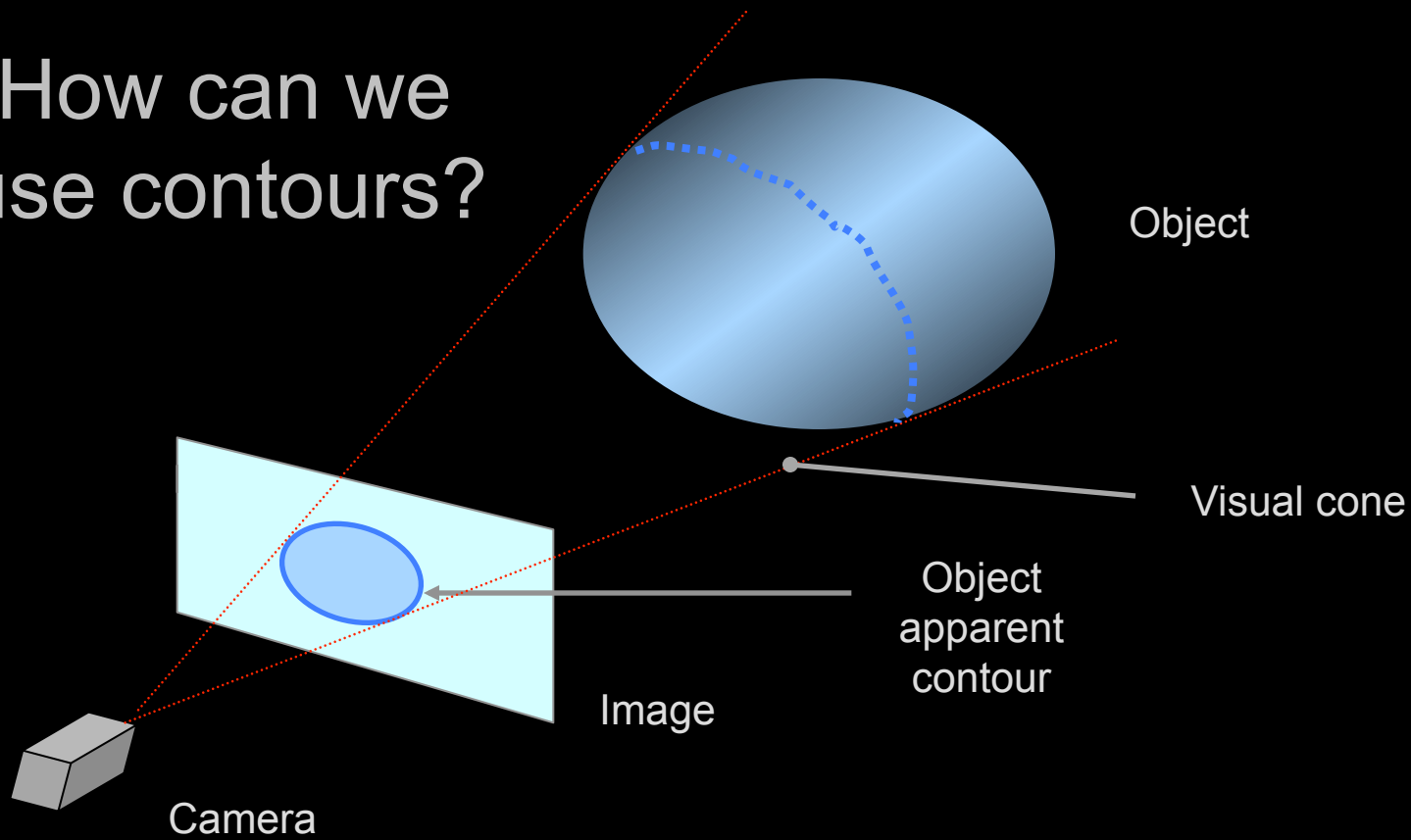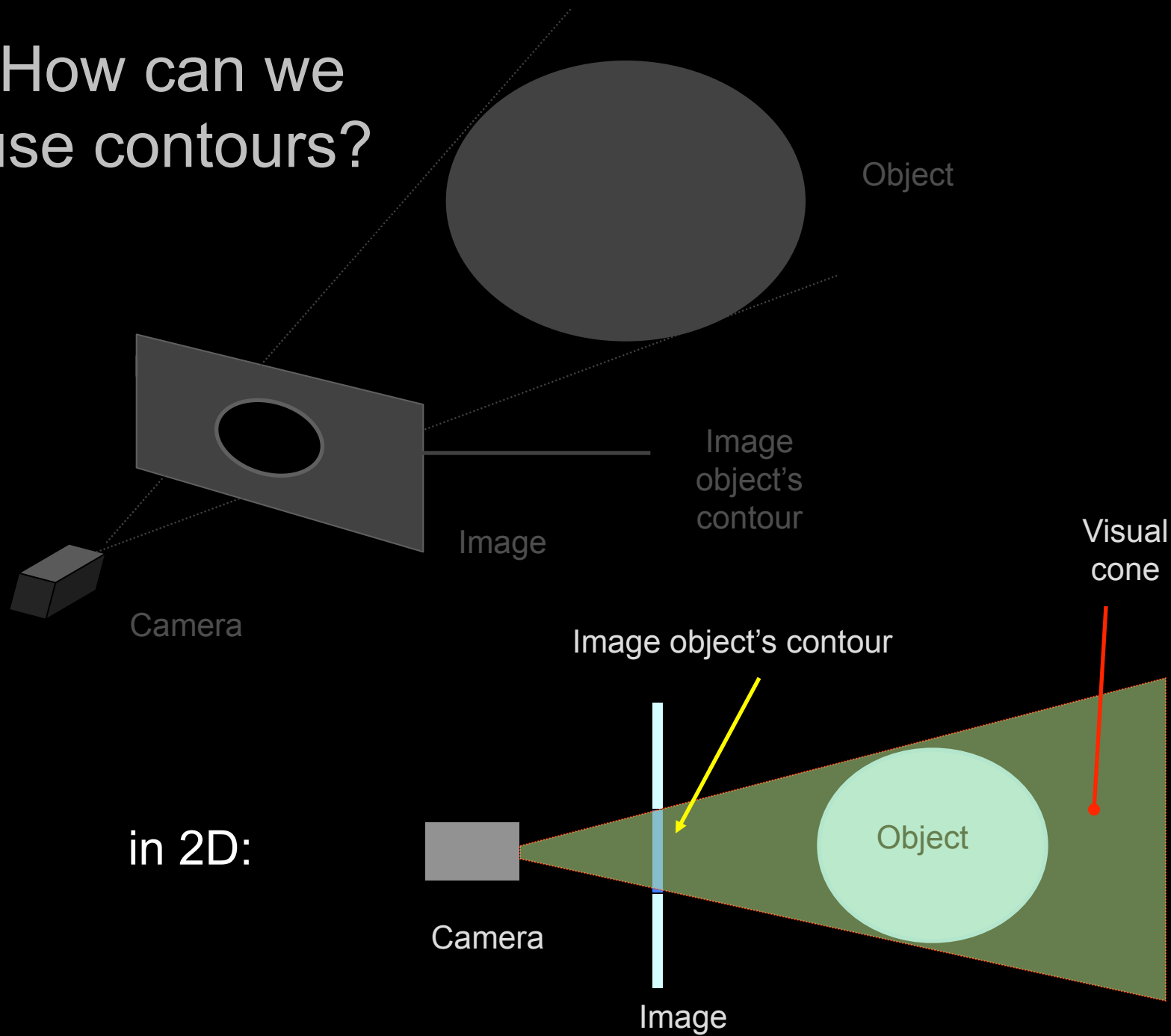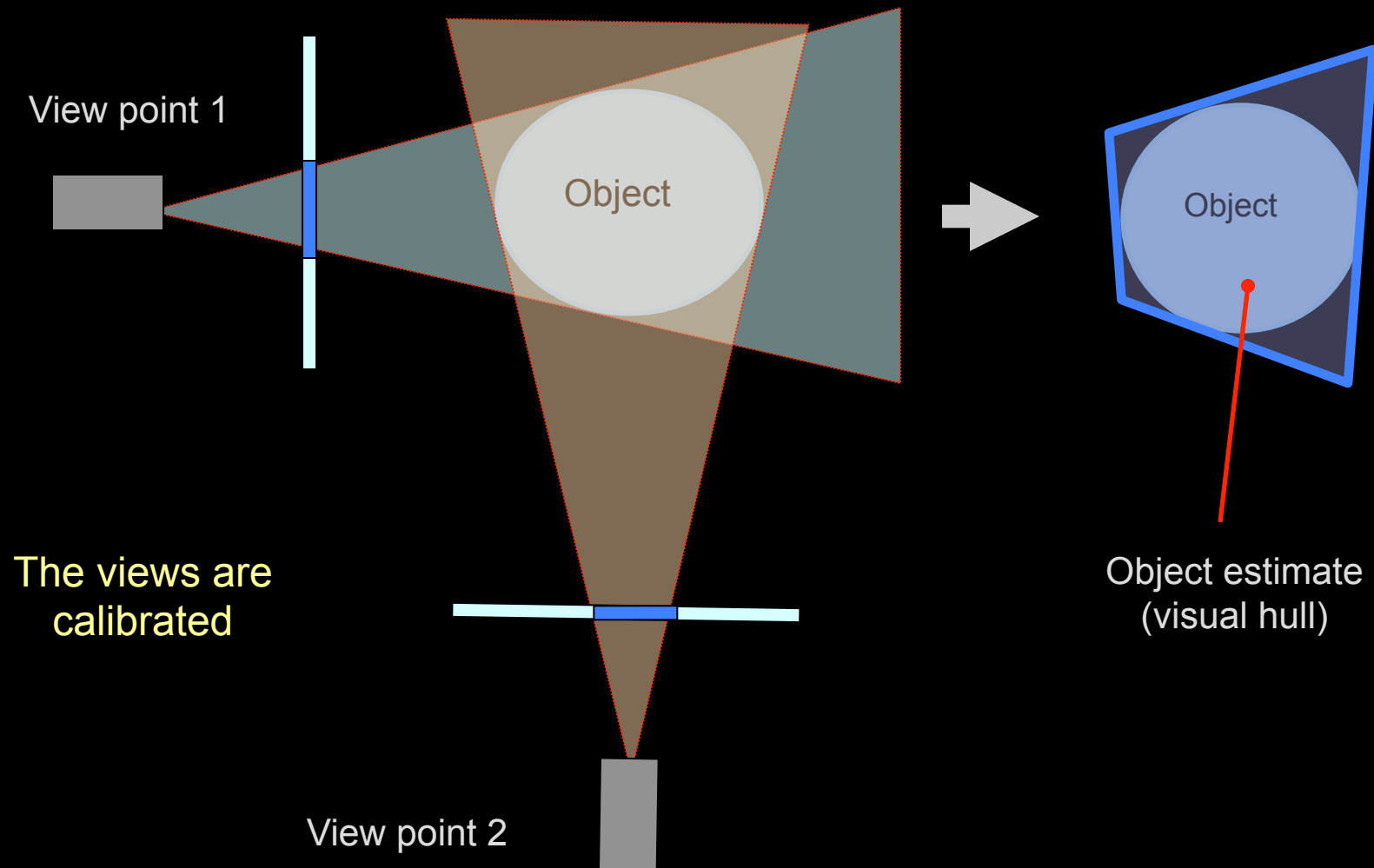# Why contours are interesting visual cues?

❖ Relatively easy to detect

Object

Easy contour segmentation

Image

Camera

How can we use contours?

Object

Visual cone

Object apparent contour

Image

Camera

How can we use contours?

Object

Image object's contour

Image

Camera

Visual cone

Image object's contour

in 2D:

Camera

Object

Image

View point 1

Object

The views are calibrated

View point 2

Object

Object estimate (visual hull)

how to perform visual cones intersection?

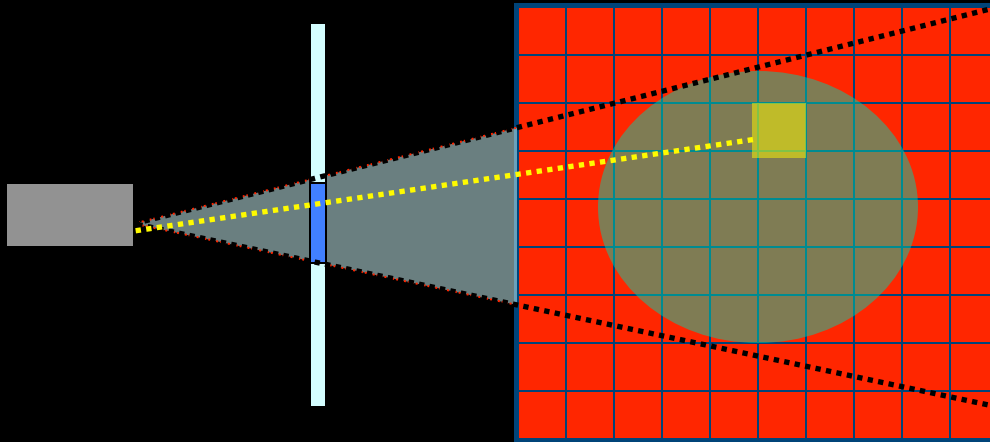❖ decompose visual cone in polygonal surfaces

(among others: Reed and Allen '99)
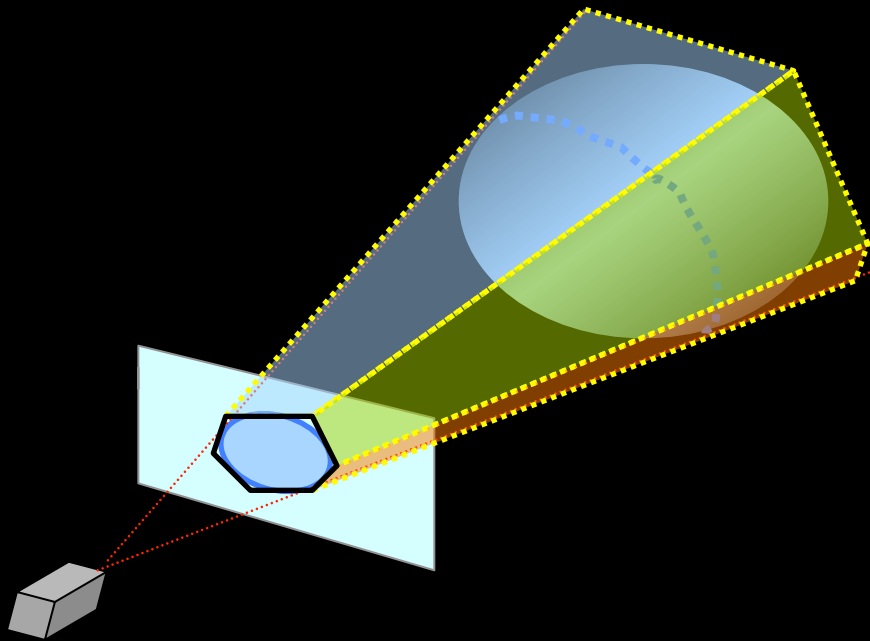
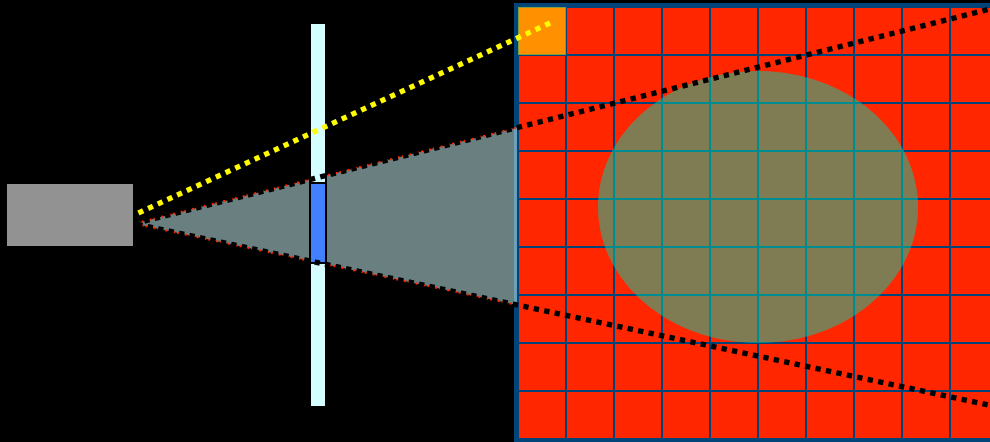# Using contours/silhouettes in volumetric stereo
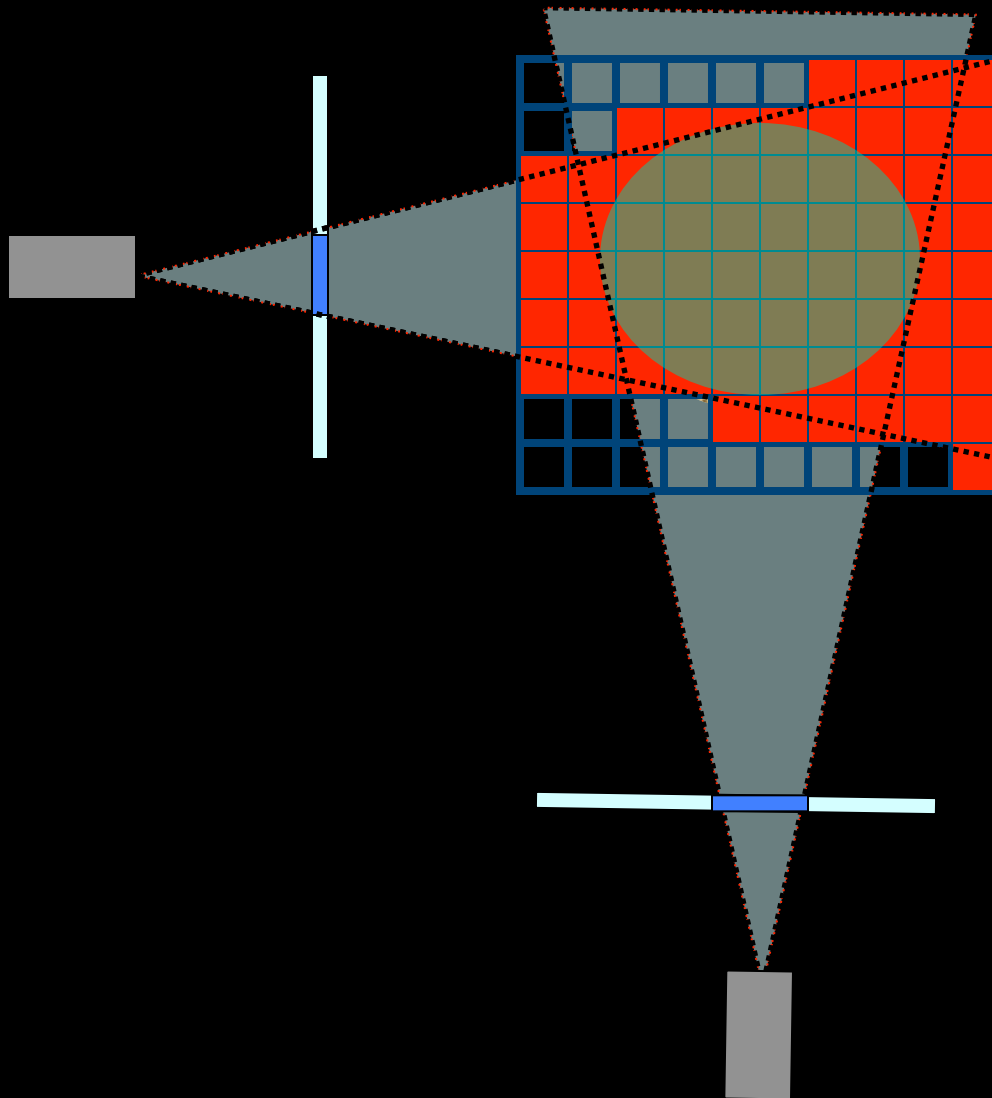also called Space carving

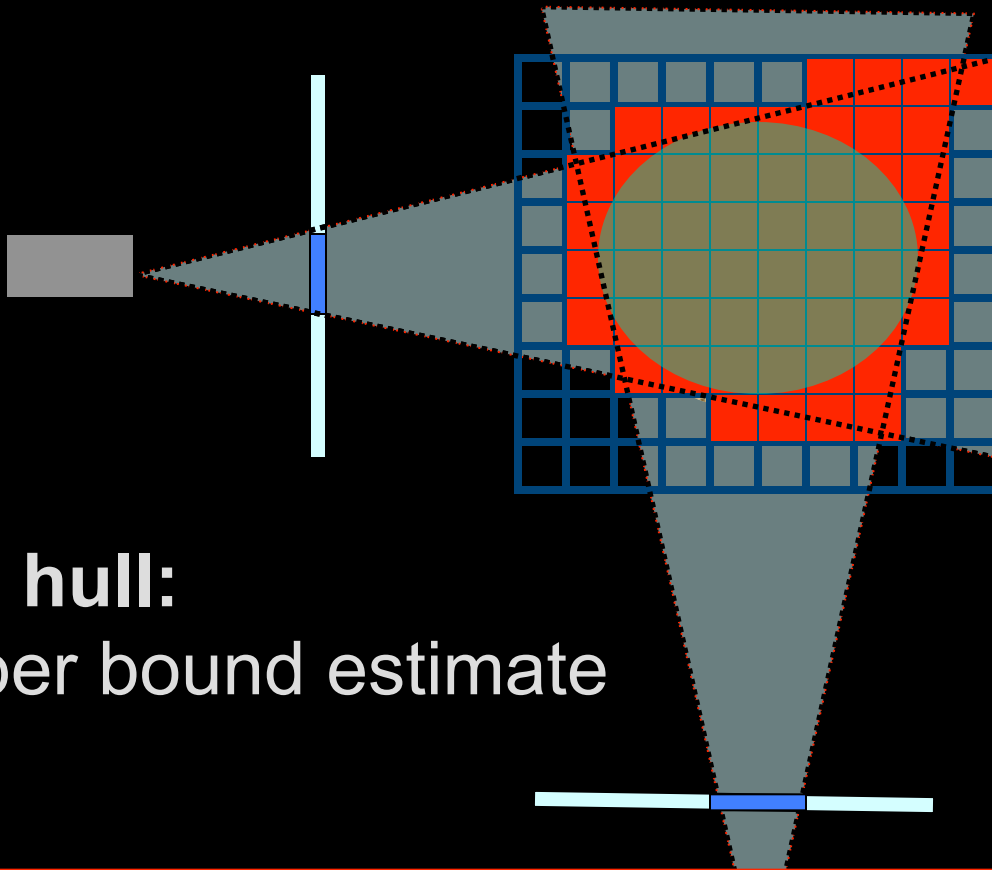[Martin and Aggarwal (1983)]
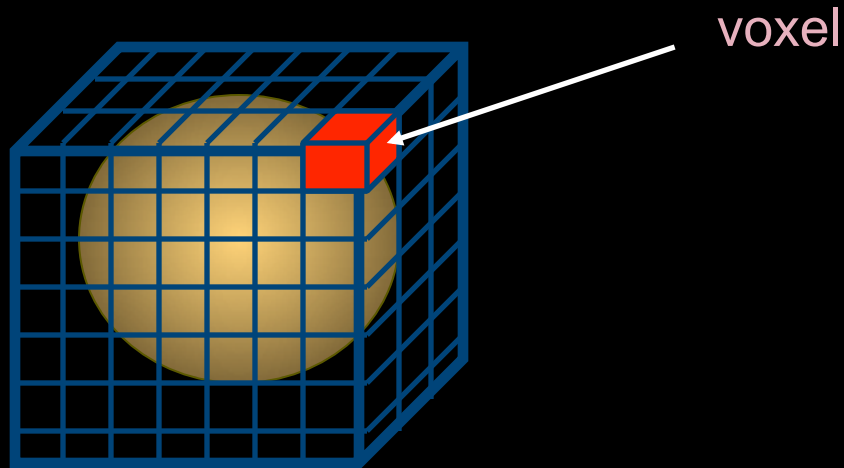
voxel

Computing visual hull in 2D

Computing visual hull in 2D

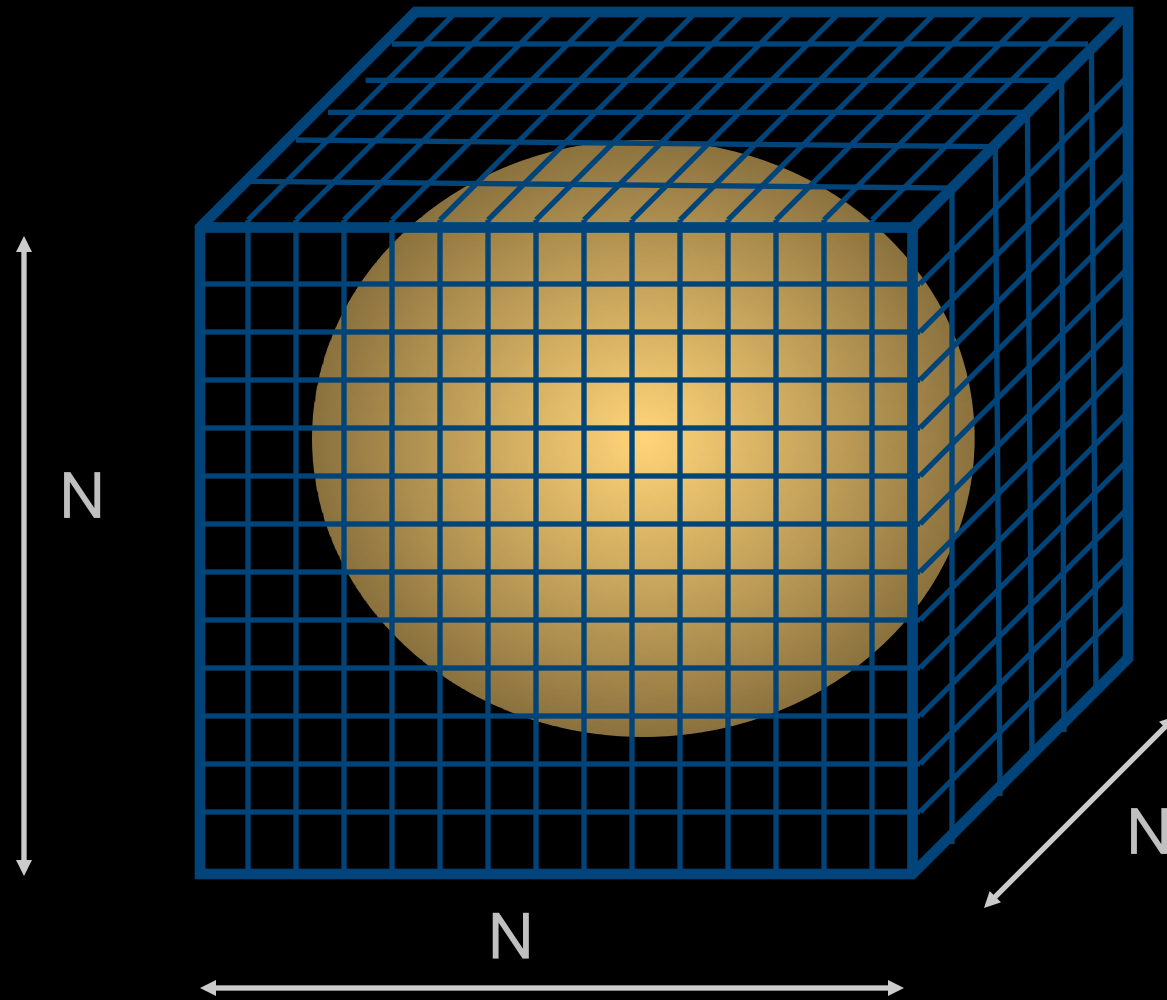# Computing visual hull in 2D

Computing visual hull in 2D
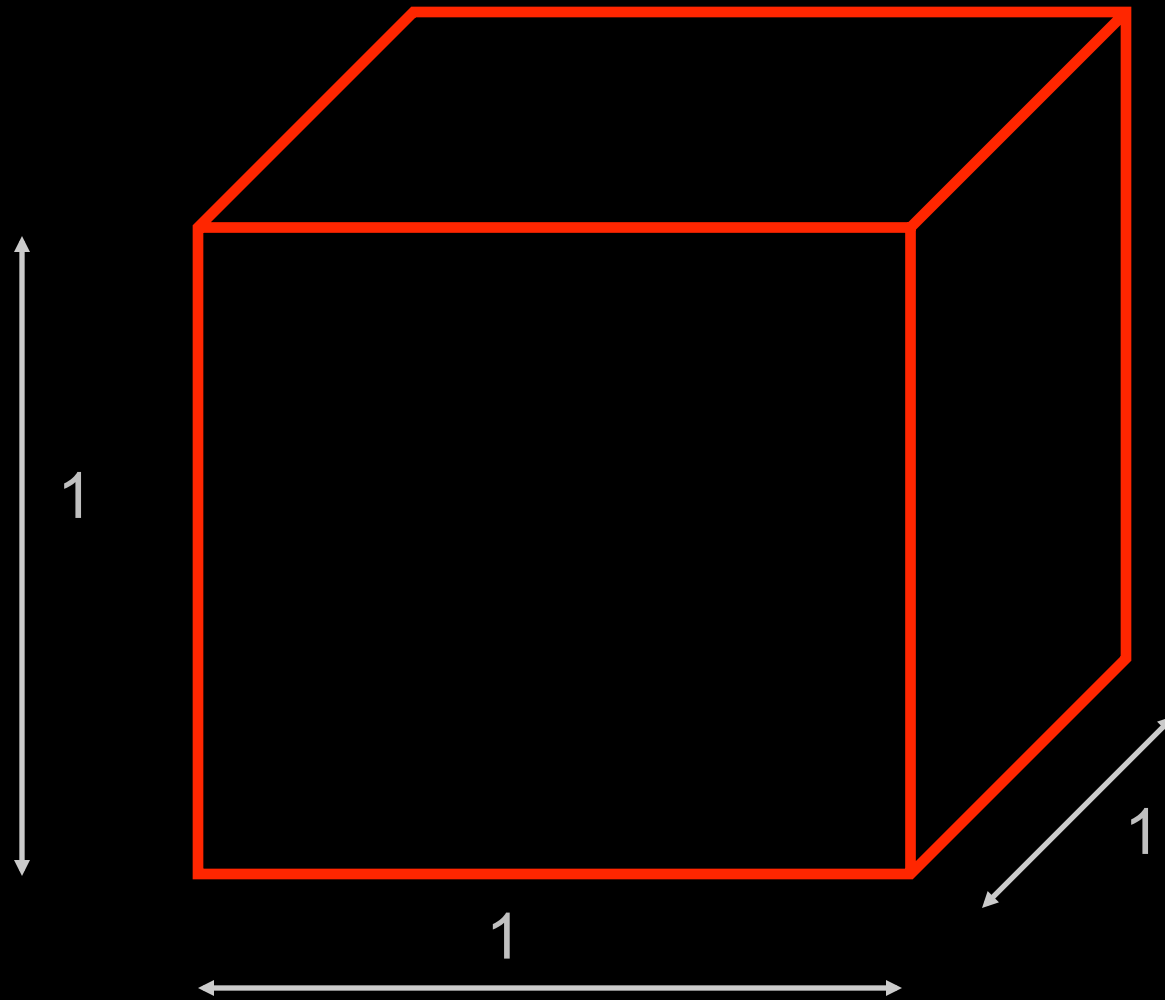

Visual hull:
an upper bound estimate

Consistency:

A voxel must be projected into a silhouette in each image

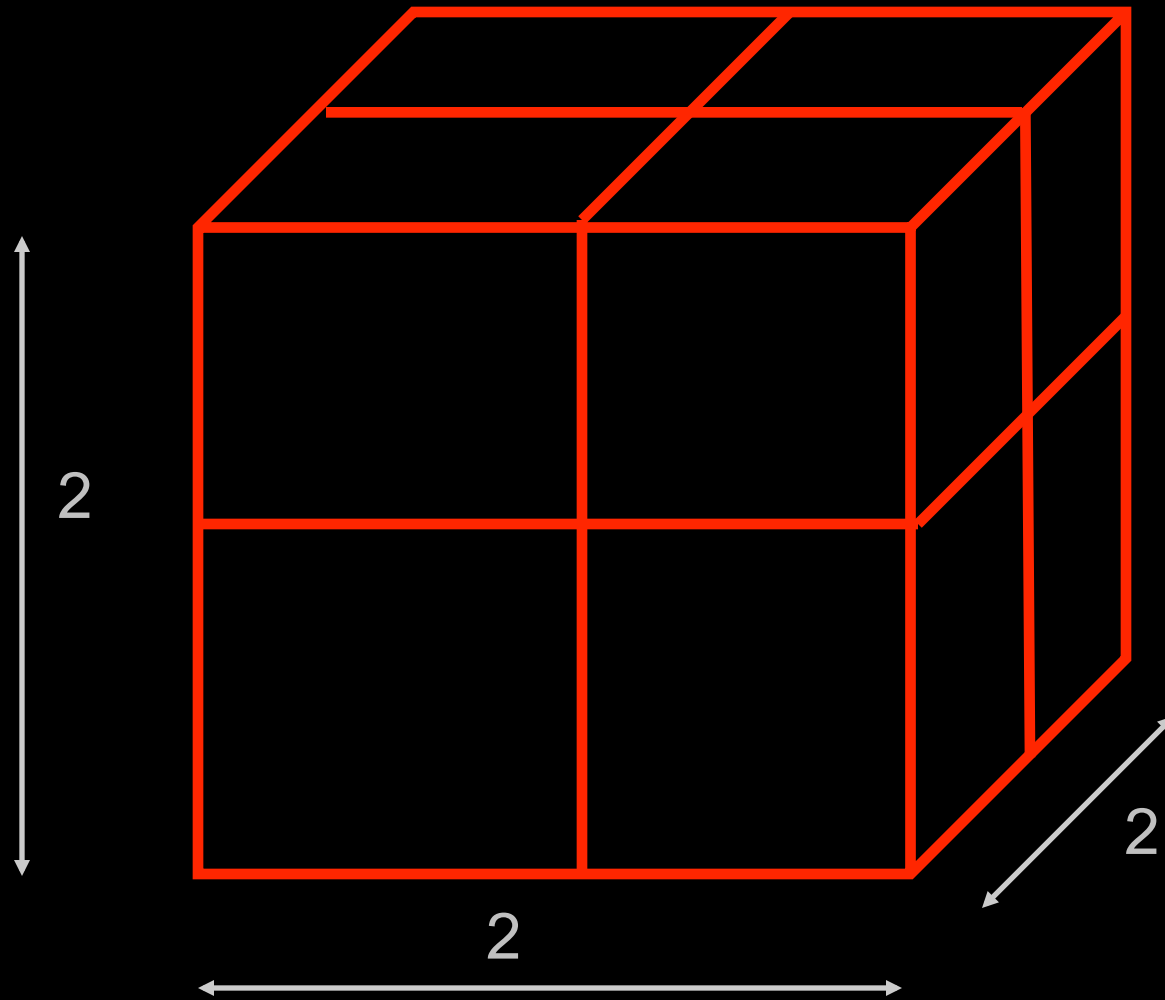# Space Carving
has complexity … $O(N^3)$

N

N

N

❖ Octrees
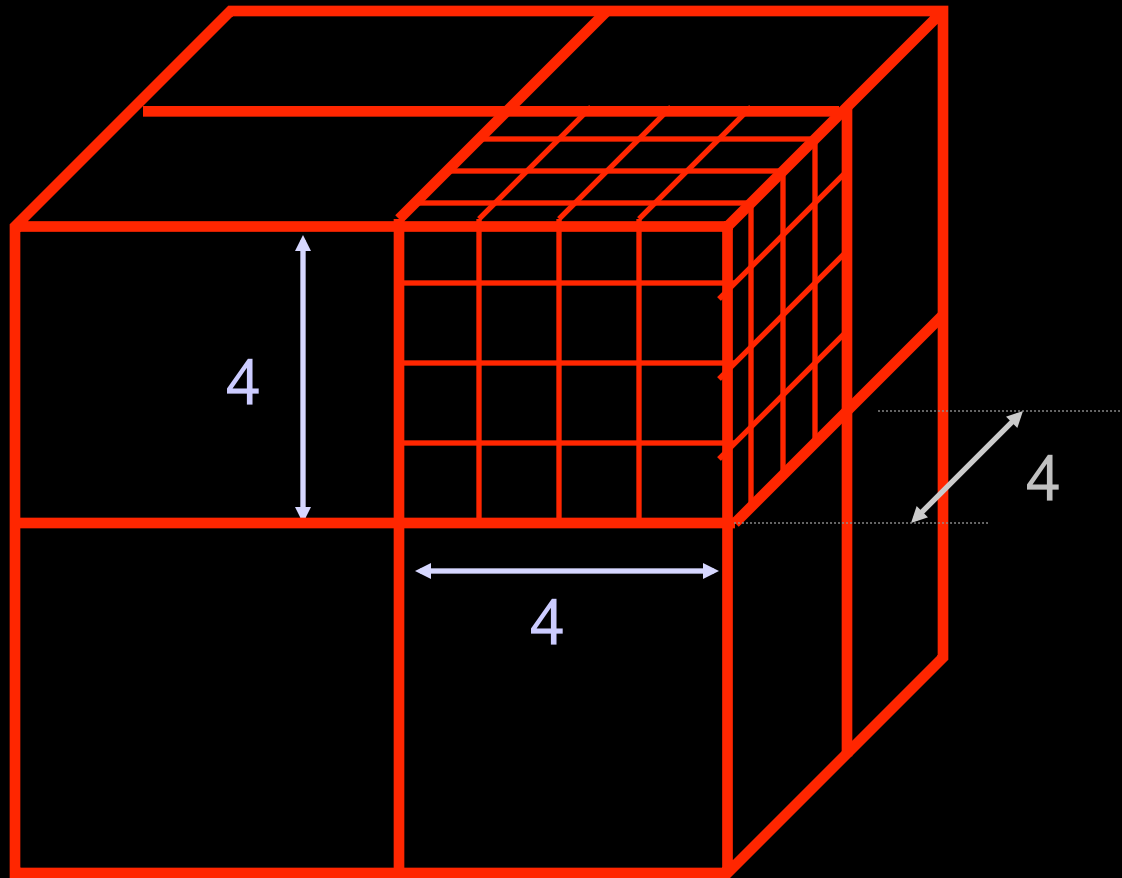 (Szeliski '93)

Complexity reduction: octrees
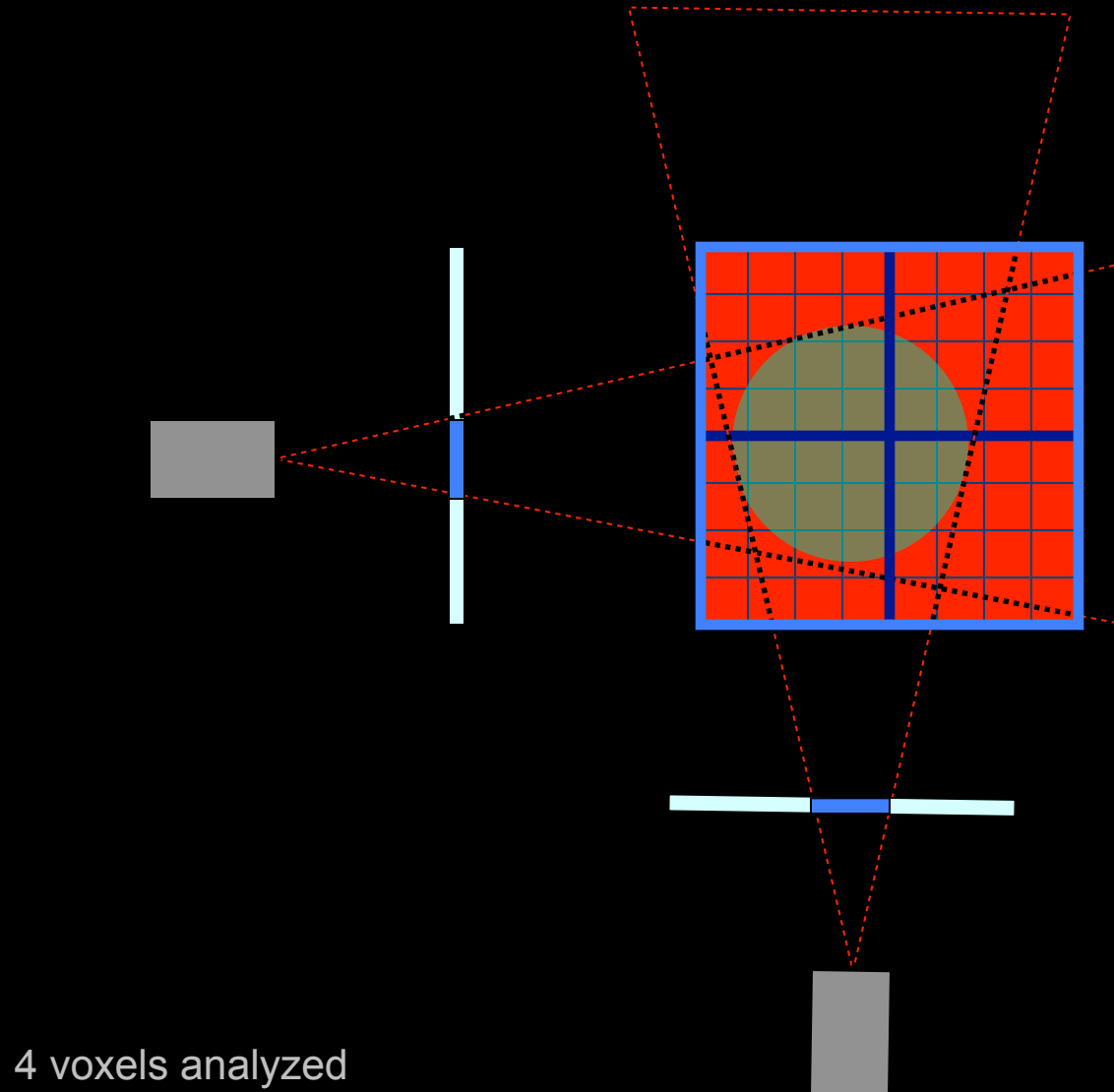
Complexity reduction: octrees

Subdiving volume in voxels of progressive smaller size
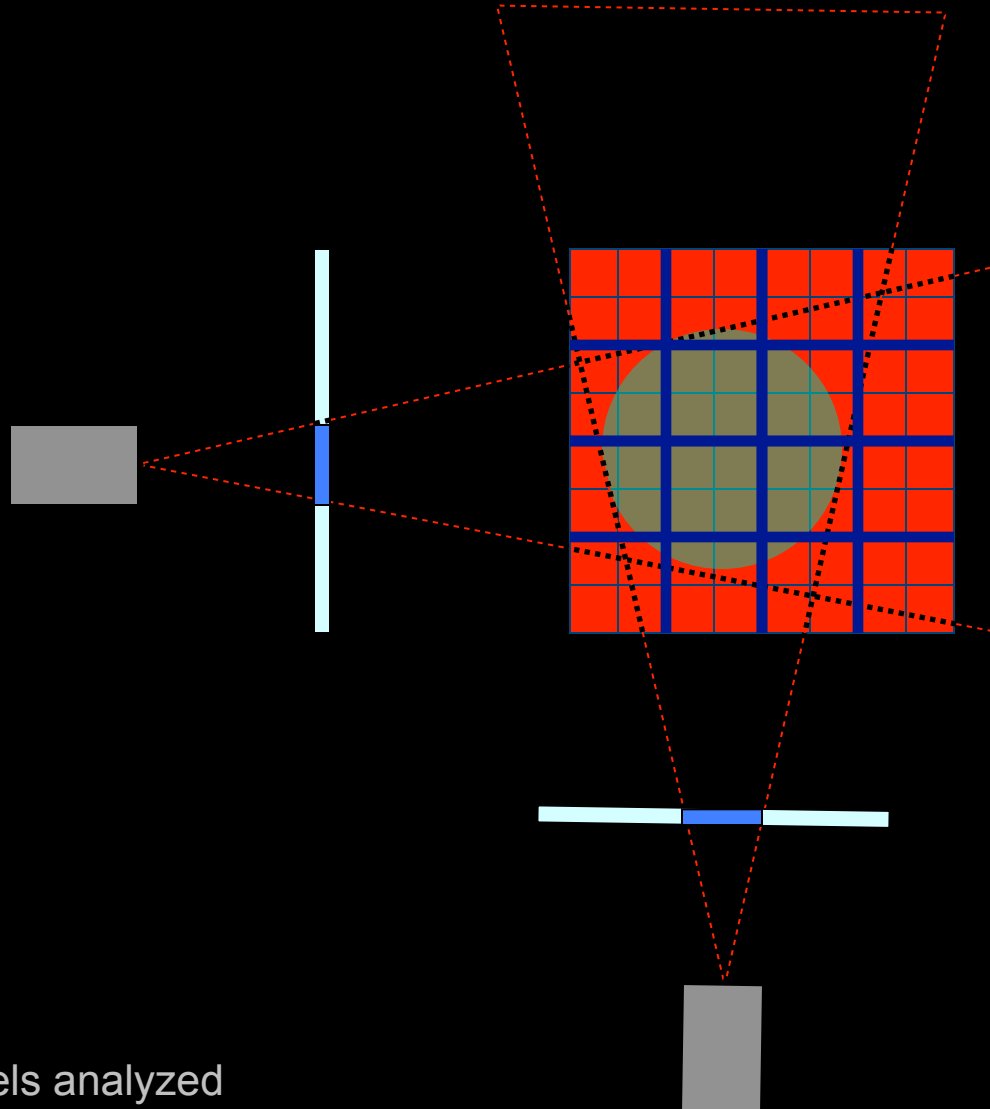
Complexity reduction: octrees
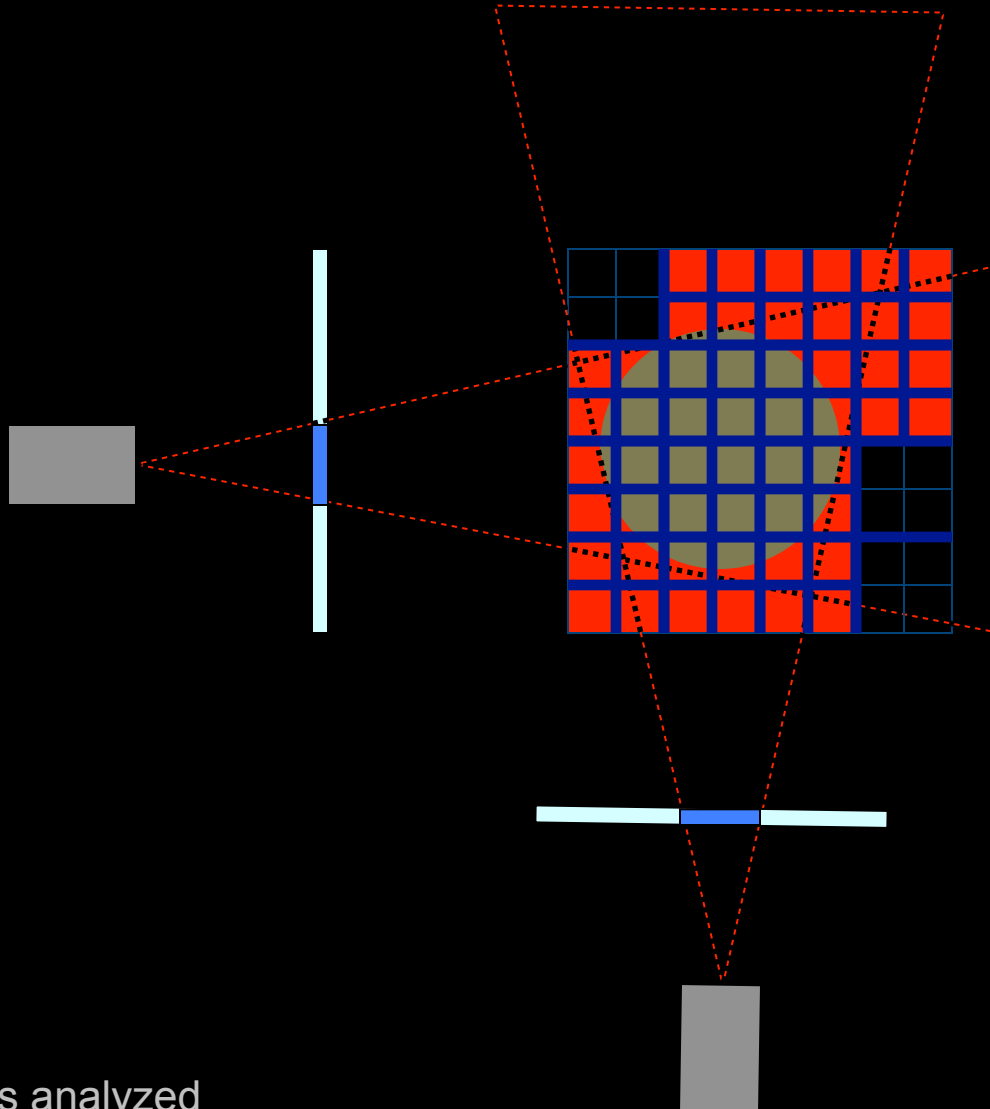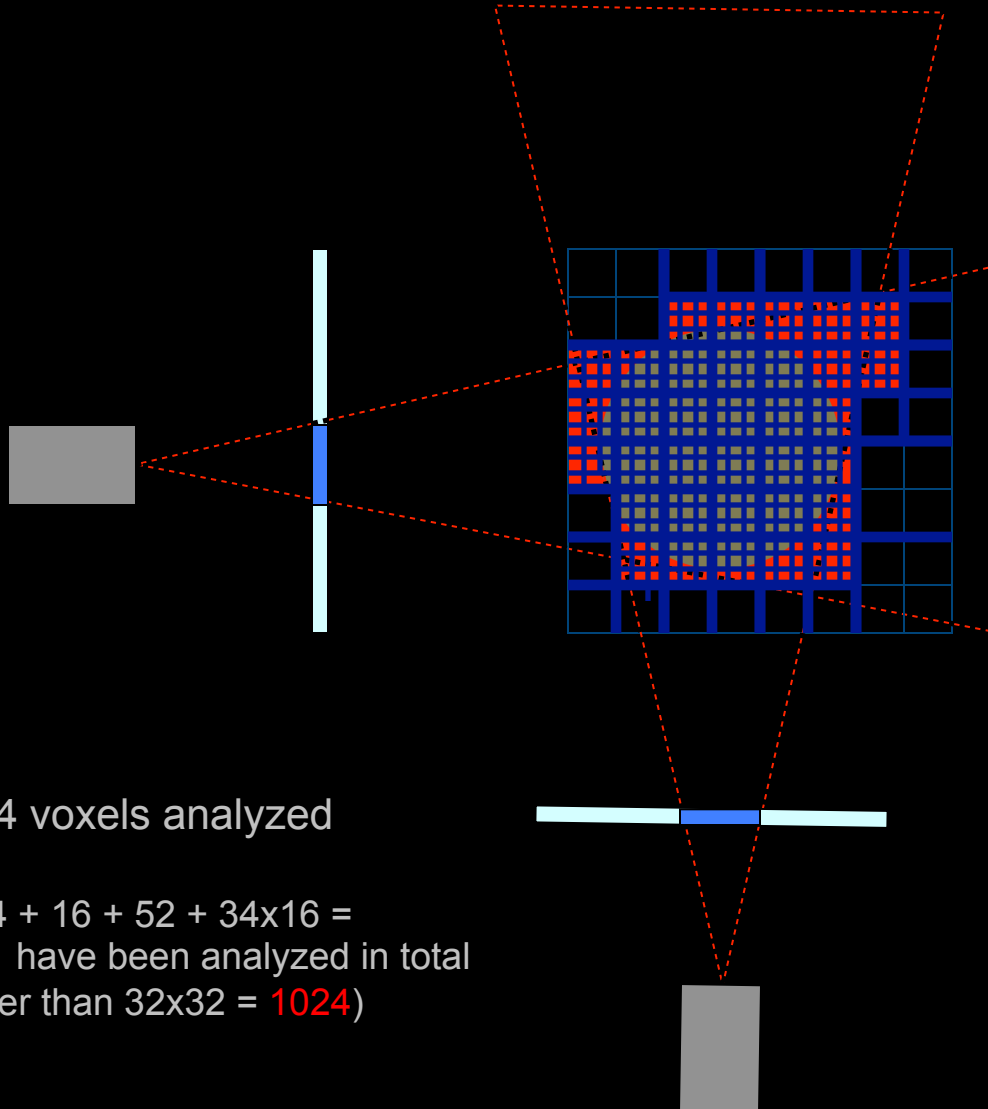
Complexity reduction: 2D example

4 voxels analyzed

Complexity reduction: 2D example

16 voxels analyzed

Complexity reduction: 2D example
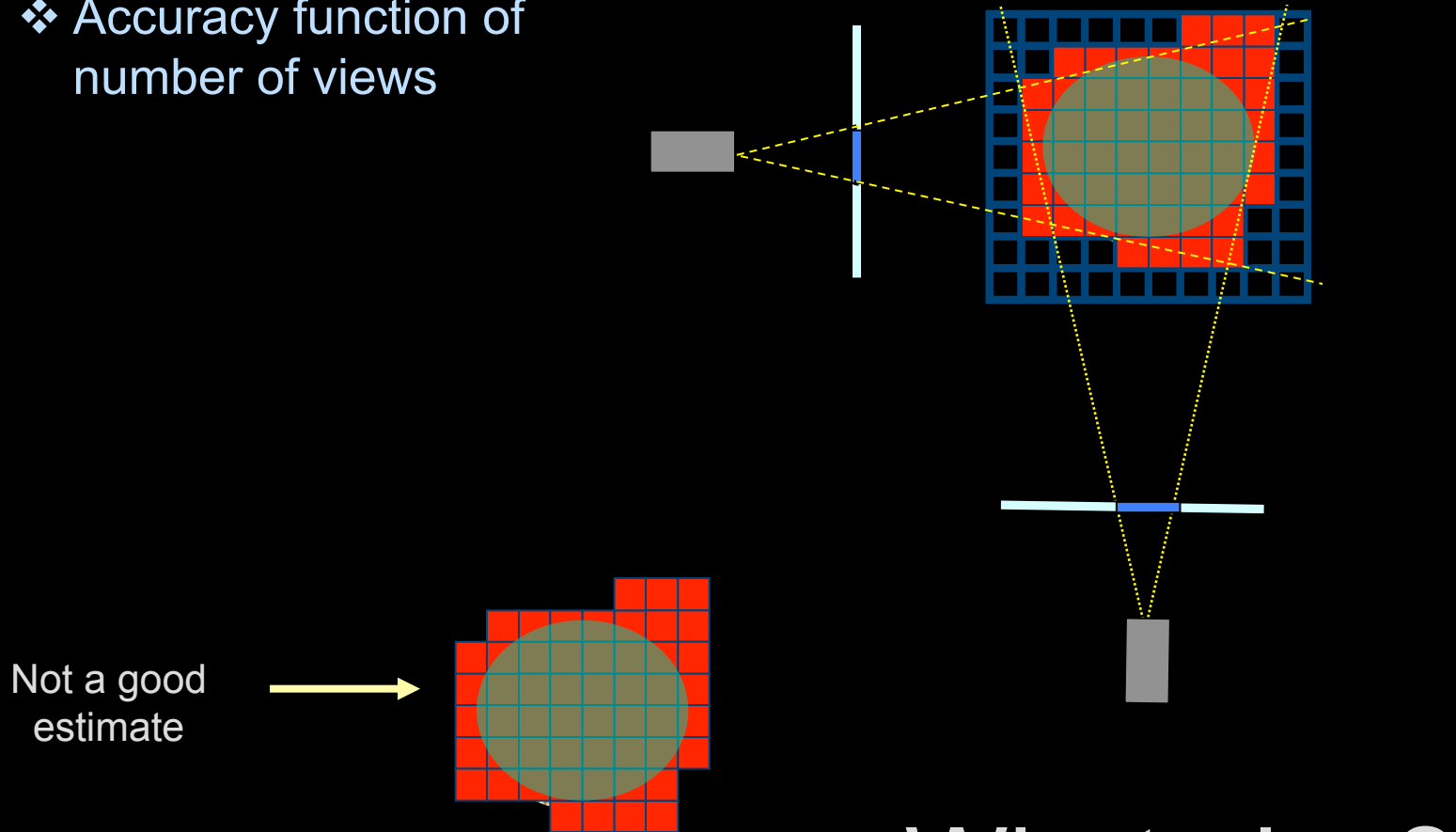
52 voxels analyzed

Complexity reduction: 2D example

16x34 voxels analyzed

1+ 4 + 16 + 52 + 34x16 =
617 voxels have been analyzed in total
(rather than 32x32 = 1024)

Advantages of space carving

❖ Robust and simple

❖ No need to solve for correspondences

Limitations of space carving

❖ Accuracy function of number of views
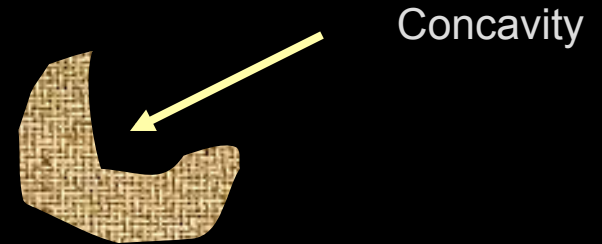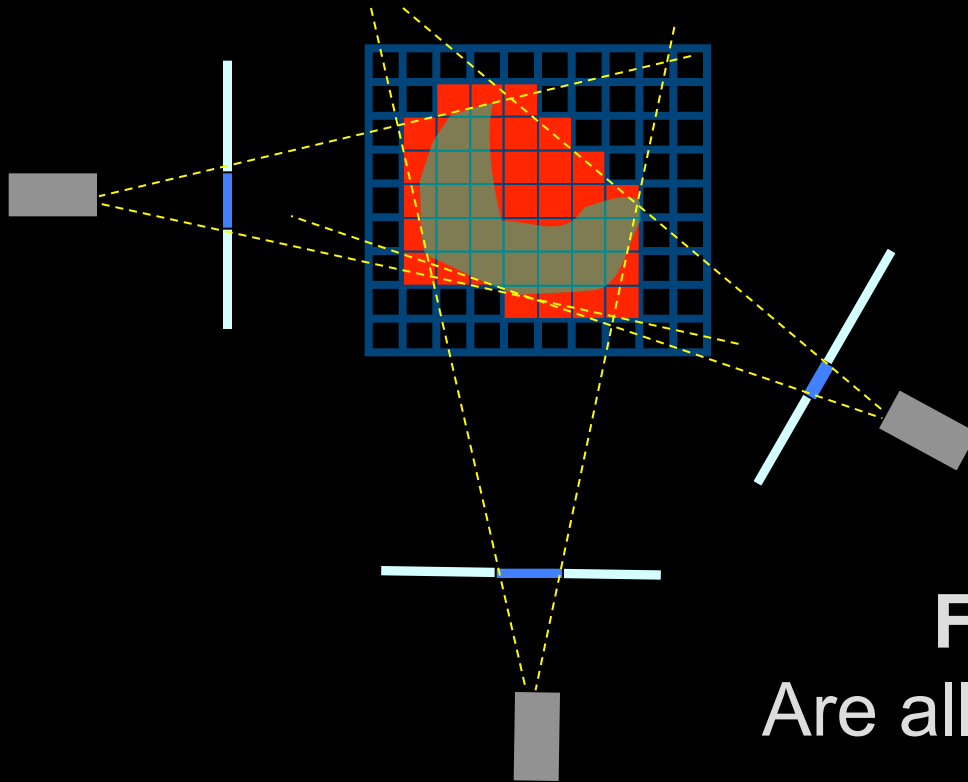
Not a good estimate →

What else?

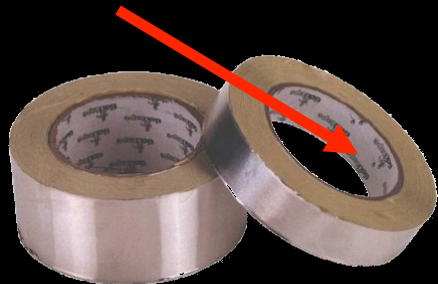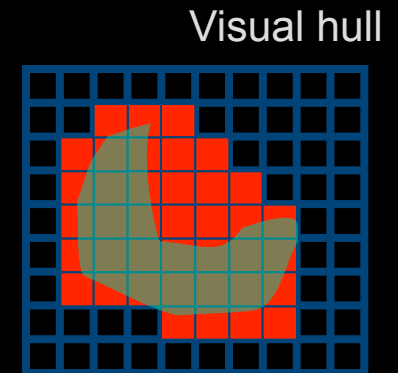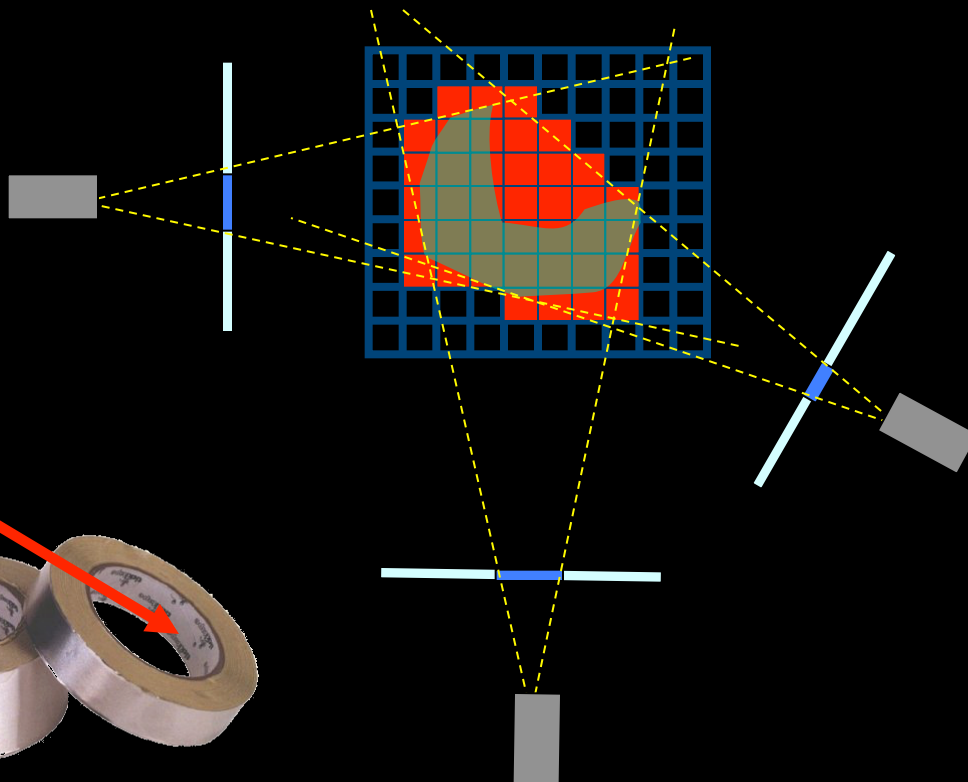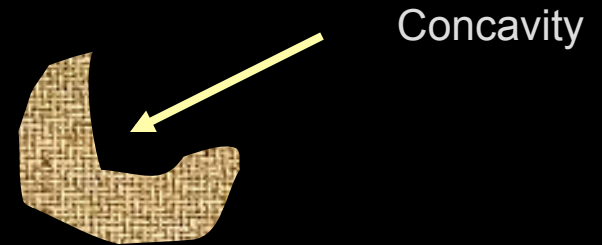# Limitations of space carving

❖   Concavities
     are not modeled

Concavity

For 3D objects:
Are all types of concavities
problematic?

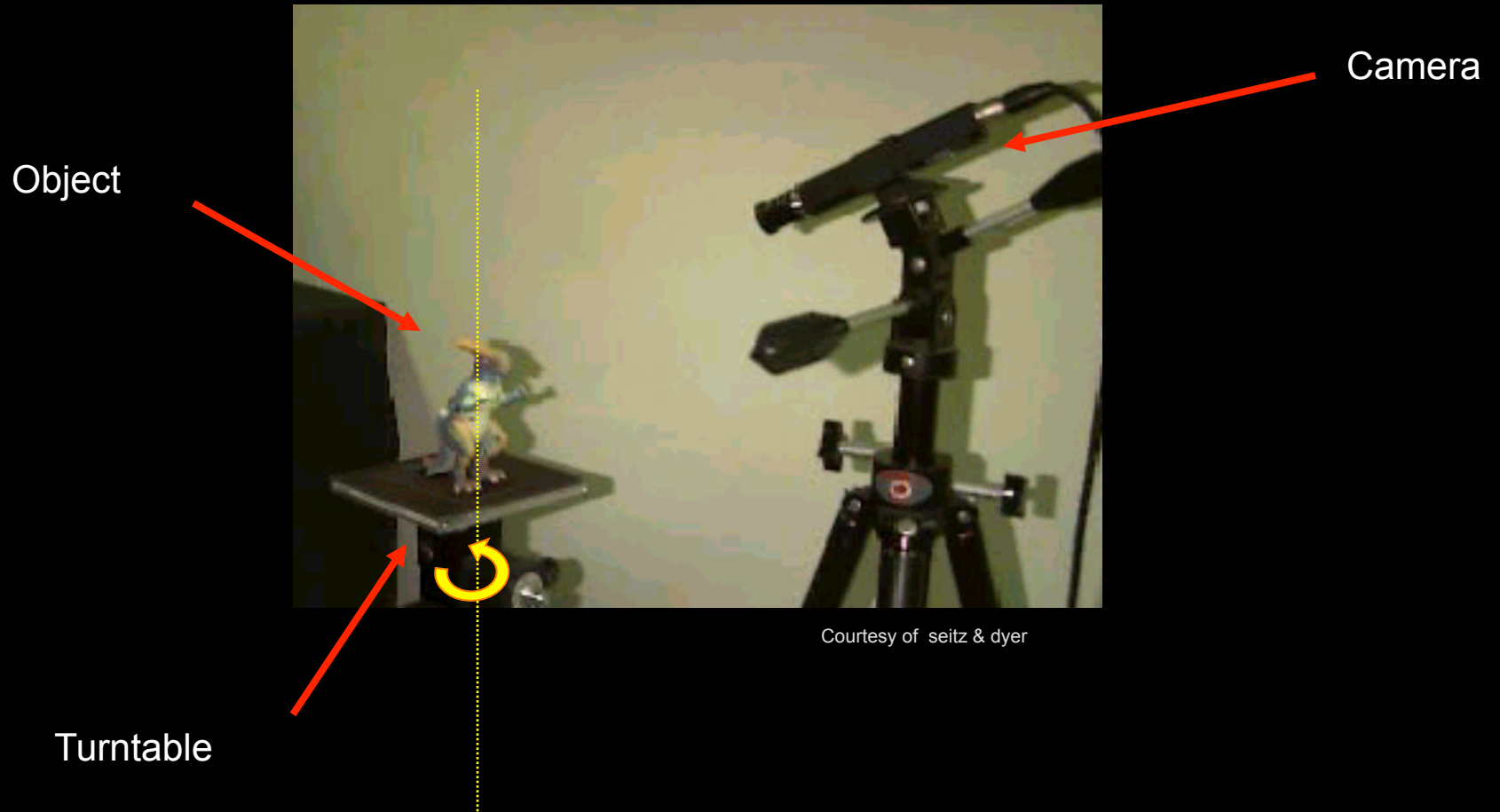# Limitations of space carving

❖ **Concavities
are not modeled**

Concavity

Visual hull
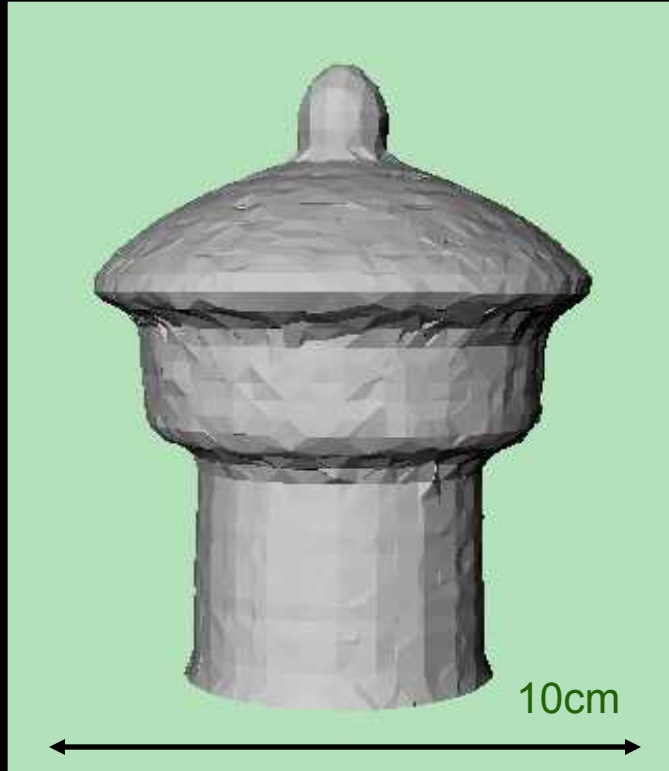
❖ Laurentini (1995)

Closest approximation

Conservative

(hyperbolic regions are ok)

Space carving: a classic setup

Camera

Object

Turntable

Courtesy of seitz & dyer

Space carving: a classic setup

Space carving: Experiments
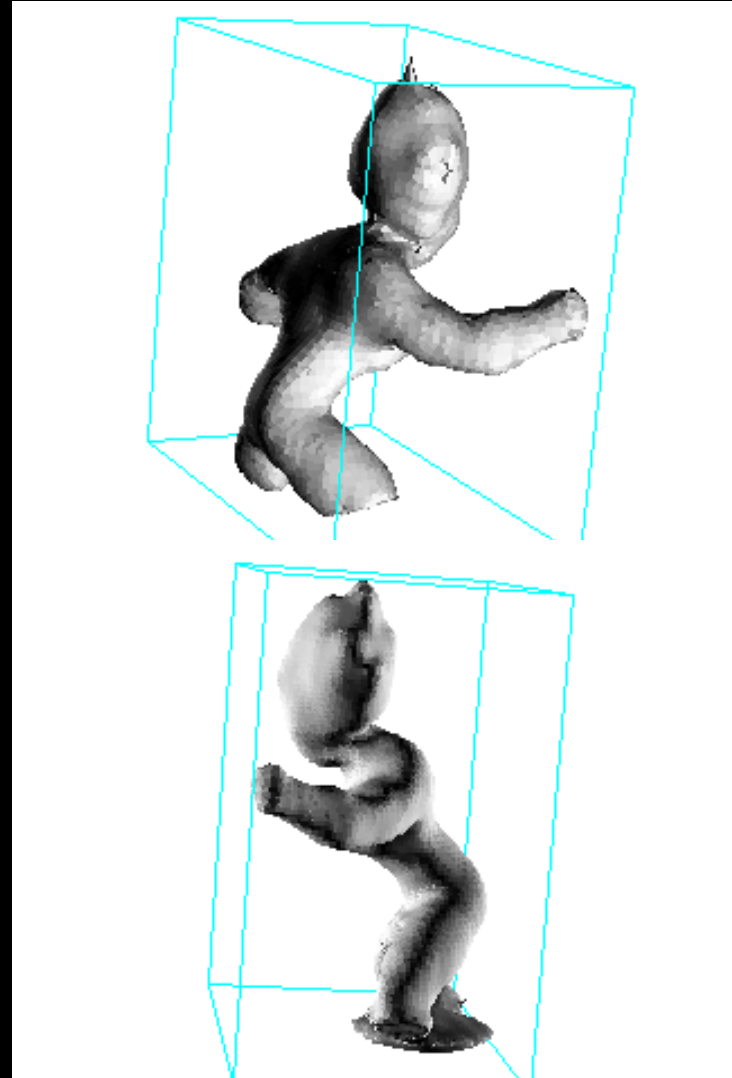

❖ 24 poses (15°)

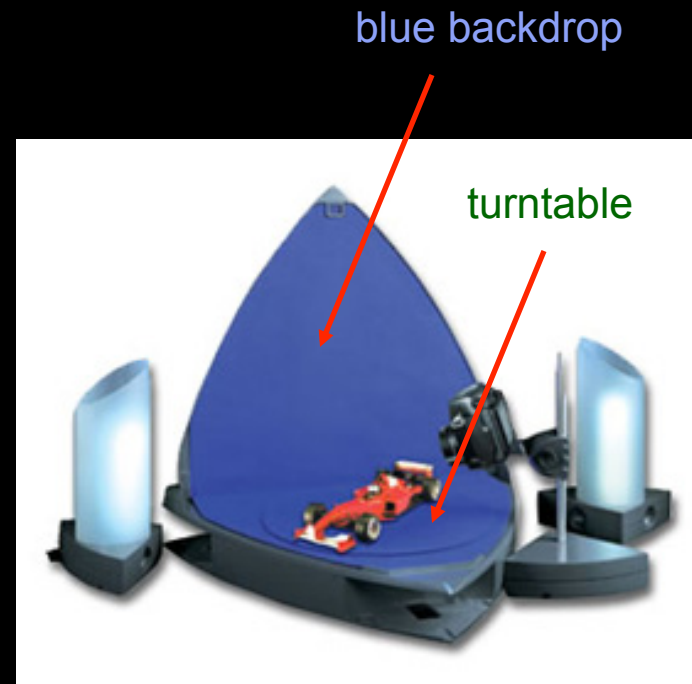❖ voxel size = 2mm

10cm

6cm

Space carving: Experiments

30 cm
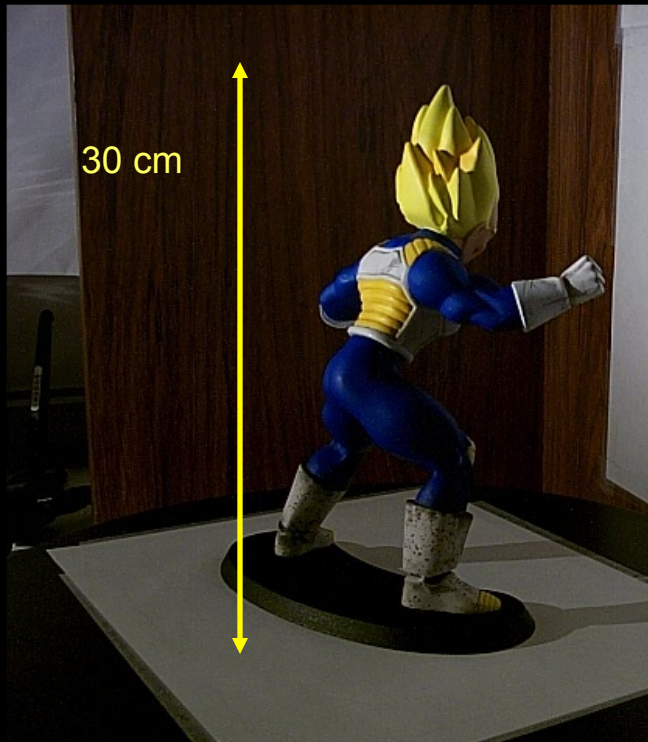
❖ 24 poses (15°)

❖ voxel size = 1mm

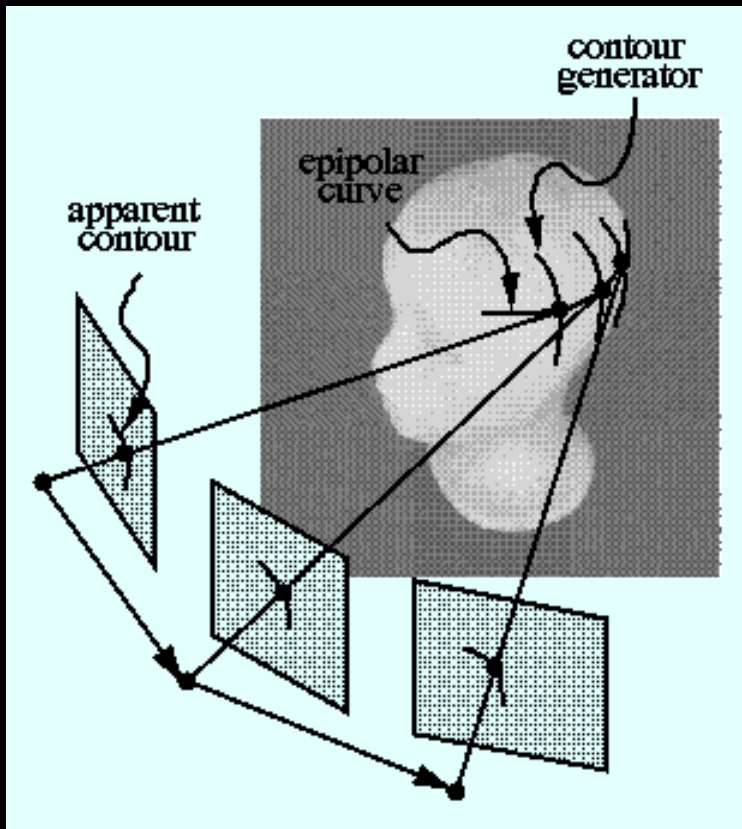# Space carving: Conclusions

❖ Robust

❖ Produce conservative estimates

❖ Concavities can be a problem

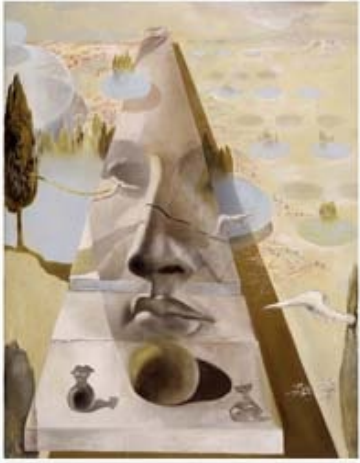❖ Low-end commercial 3D scanners

blue backdrop

turntable

Contours in the computer vision literature

Analyzing changes in apparent contours

Picture from of Sato & Cipolla

❖ Giblin and Weiss (1987)

❖ Cipolla and Blake (1992)

❖ Vaillant and Faugeras (1992)

❖ Ponce ('92), Zheng('94)

❖ Furukawa et al. ('05…)

Volumetric stereo

- Definition
- Shape from Contours
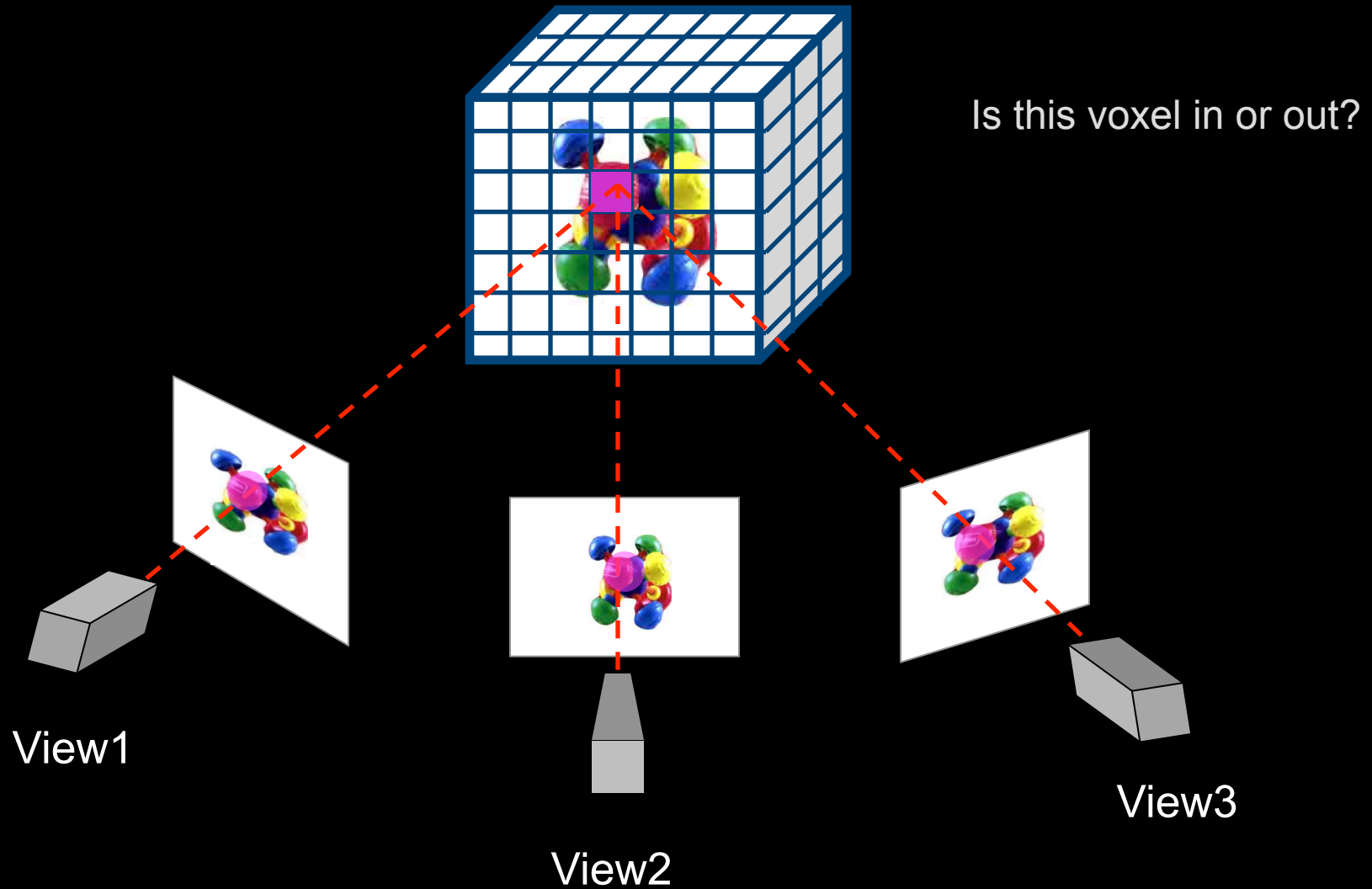- Voxel coloring

Voxel Coloring
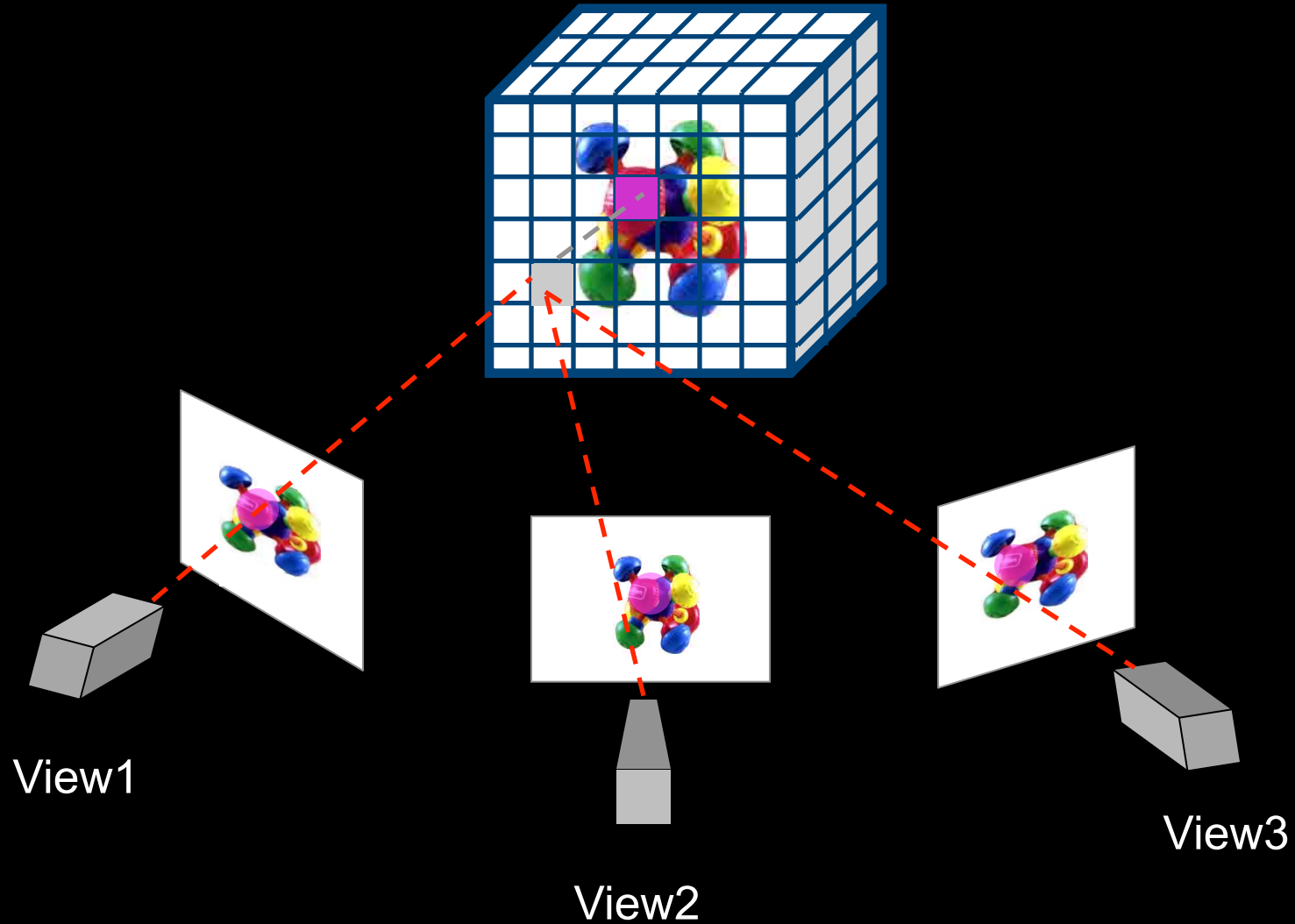
Seitz & Dyer ('97)
R. Collins (Space Sweep, '96)

❖ color/photo-consistency

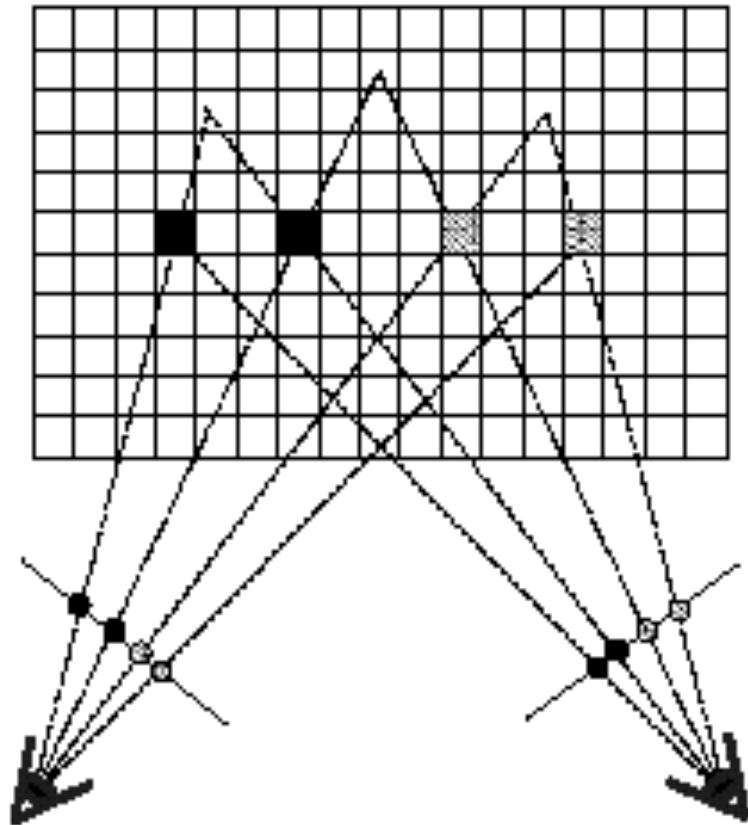❖ Jointly model structure and appearance

Basic idea

Is this voxel in or out?

View1

View2

View3
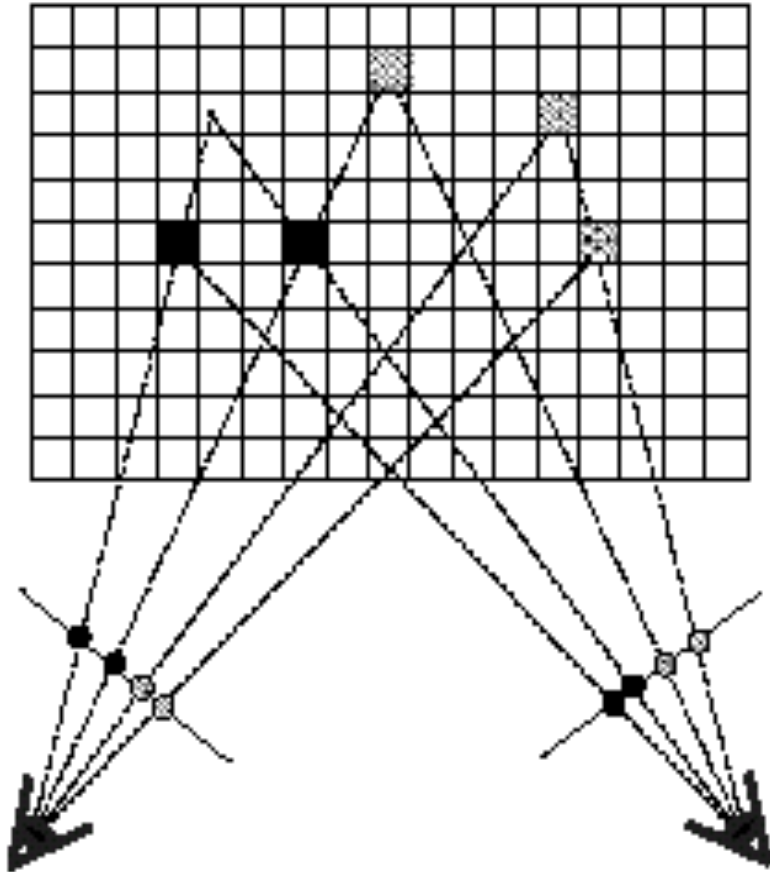
Basic idea

View1

View2

View3

Uniqueness

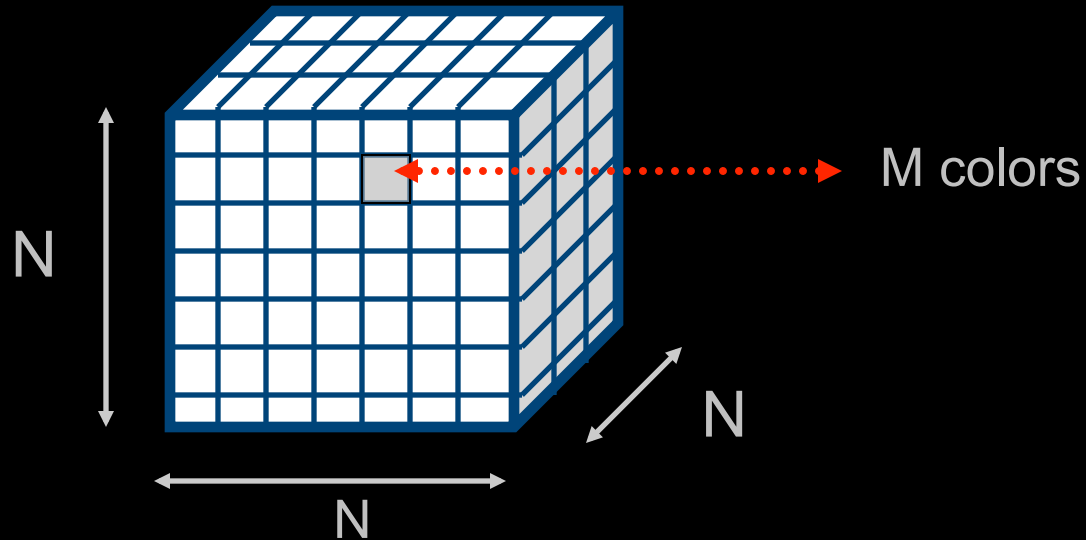Multiple consistent scenes

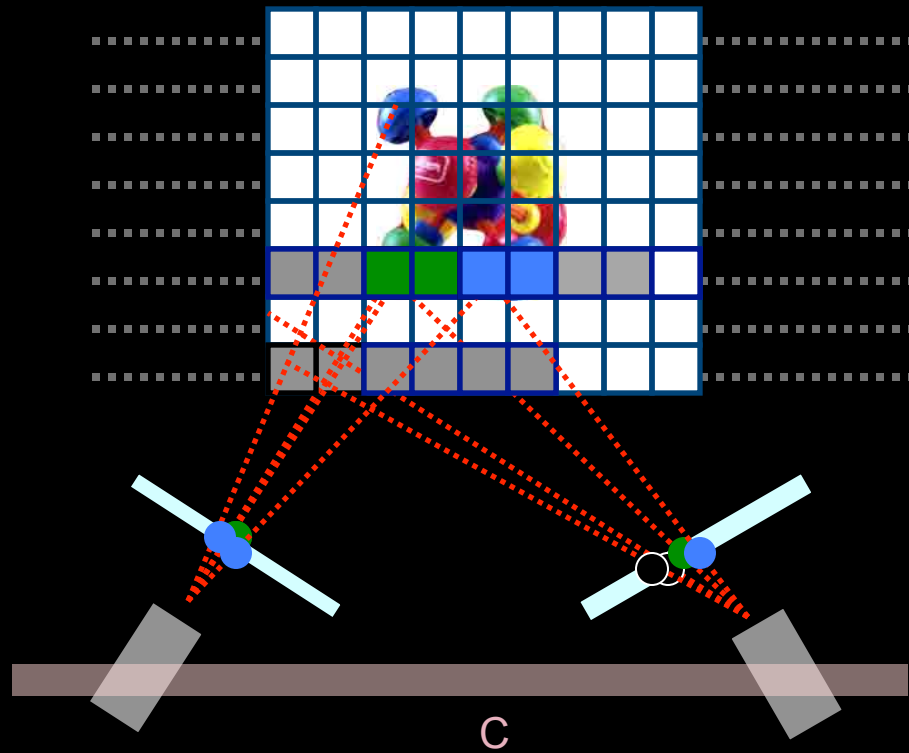# Uniqueness

Multiple consistent scenes

Tractability

- ❖ Combinatorial number   possible assignments!

- ❖ Exhaustive search not feasible

- ❖ Use *visibility constraint*

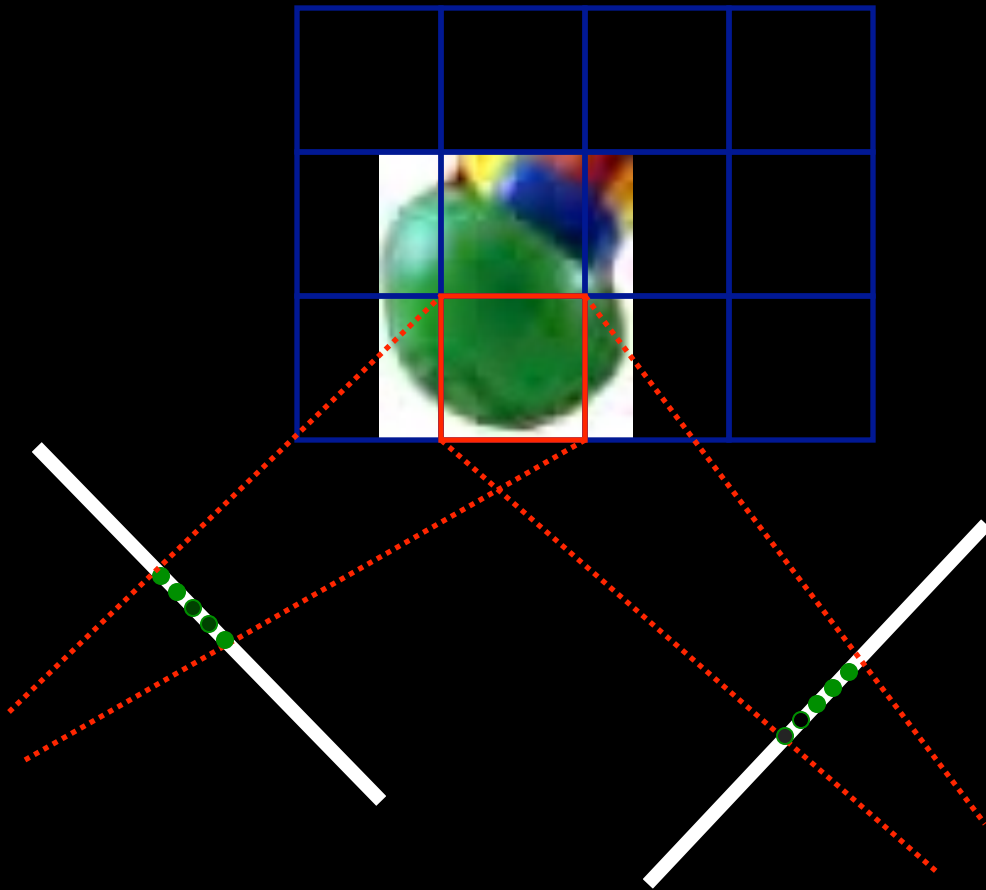# The algorithm

C

Algorithm complexity

❖ voxel coloring visits each N^3 voxels only once

❖ project each voxel into L images

$\rightarrow$ O(L N^3)

NOTE: not function of the number of colors
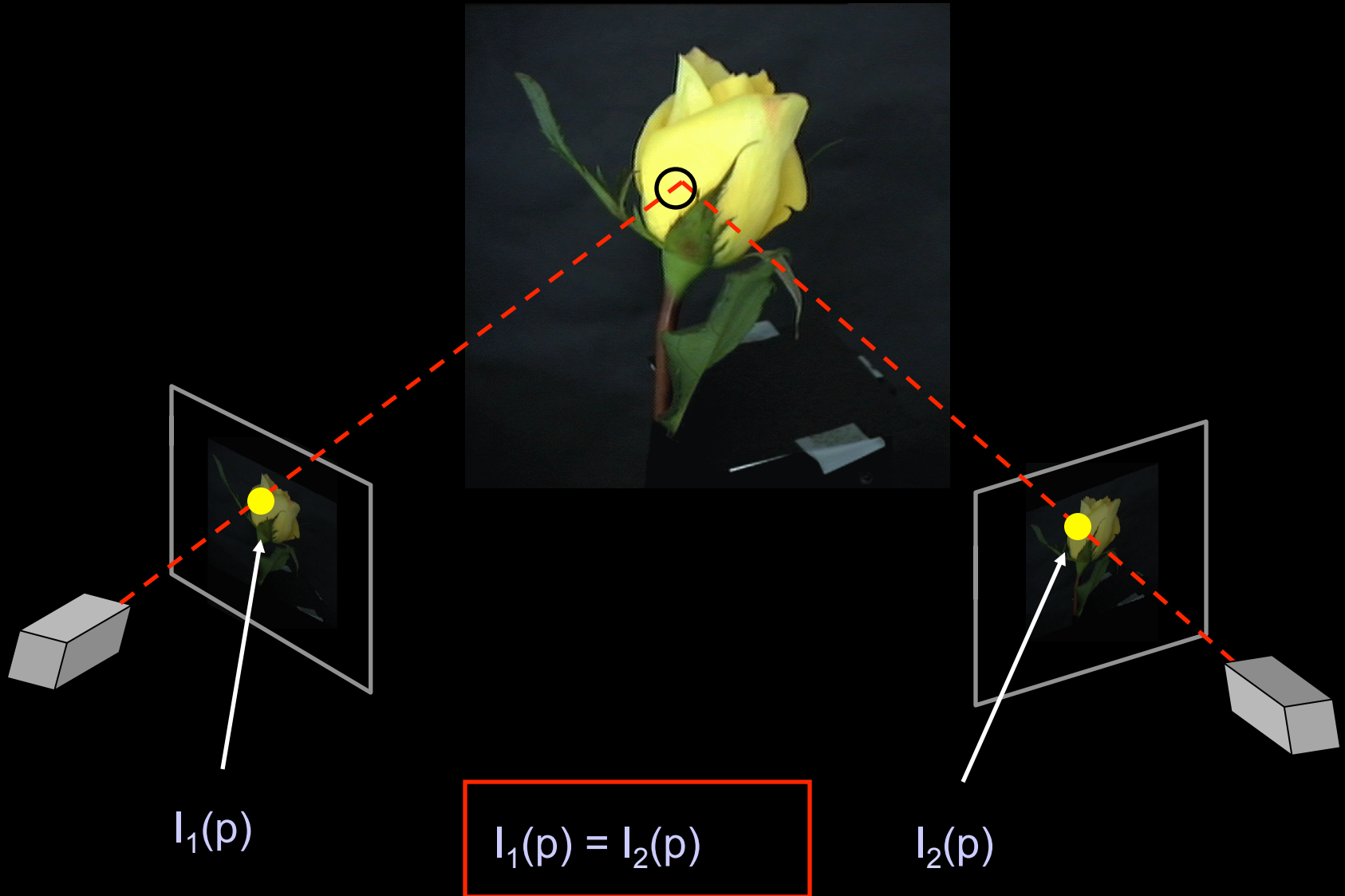
Photoconsistency test

$$\lambda = \text{corr} \left(\quad , \quad \right)$$

Image 1   Image 2

If λ < Thresh → voxel consistent

A critical assumption: Lambertian surfaces

$I_1(p)$

$I_1(p) = I_2(p)$

$I_2(p)$

Non Lambertian surfaces

Experimental results

Dinosaur

- ❖ 72 k voxels colored
- ❖ 7.6 M voxels tested
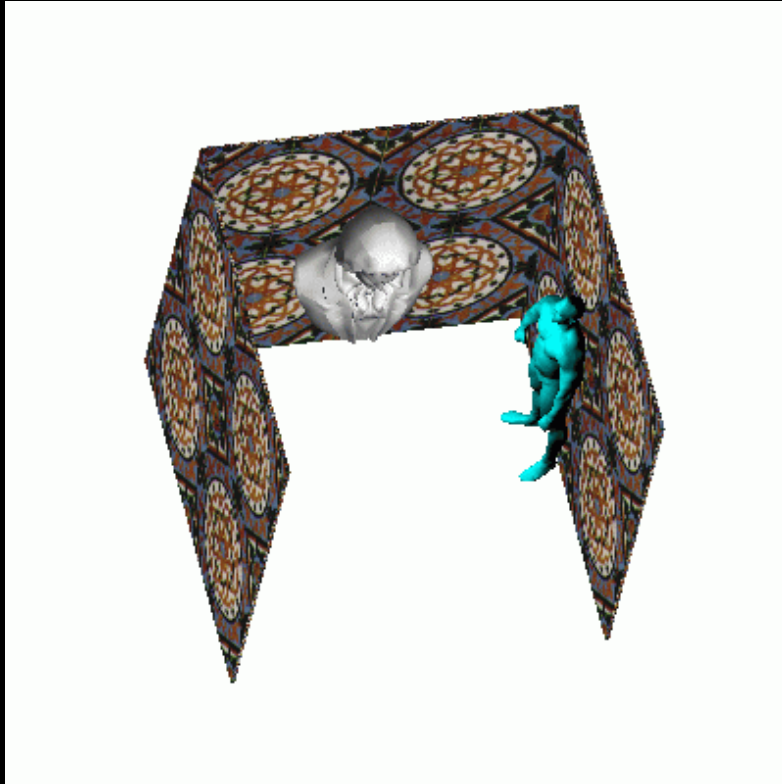- ❖ 7 min to compute on a 250MHz
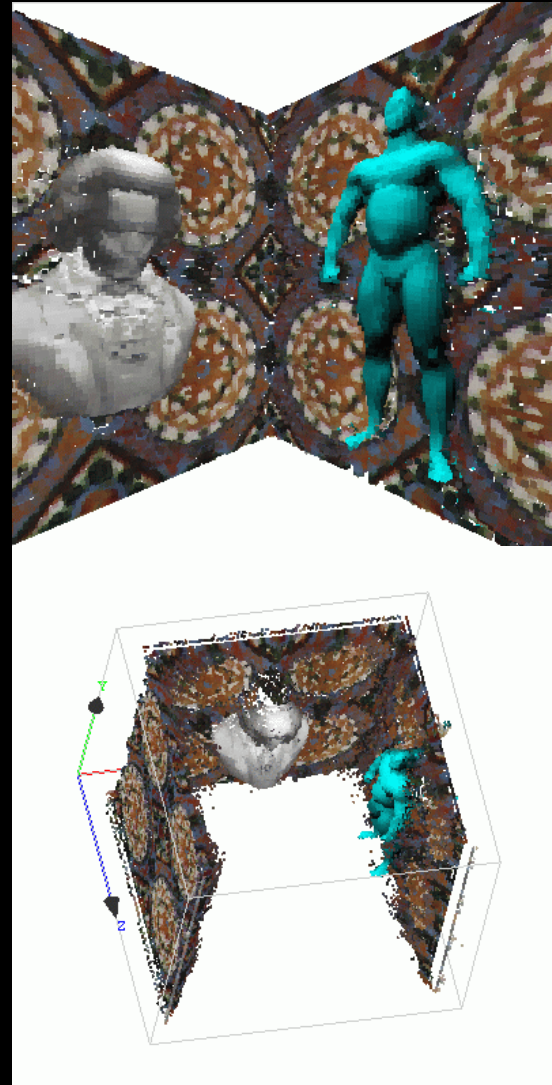
Experimental results

Flower

❖ 70 k voxels colored
❖ 7.6 M voxels tested
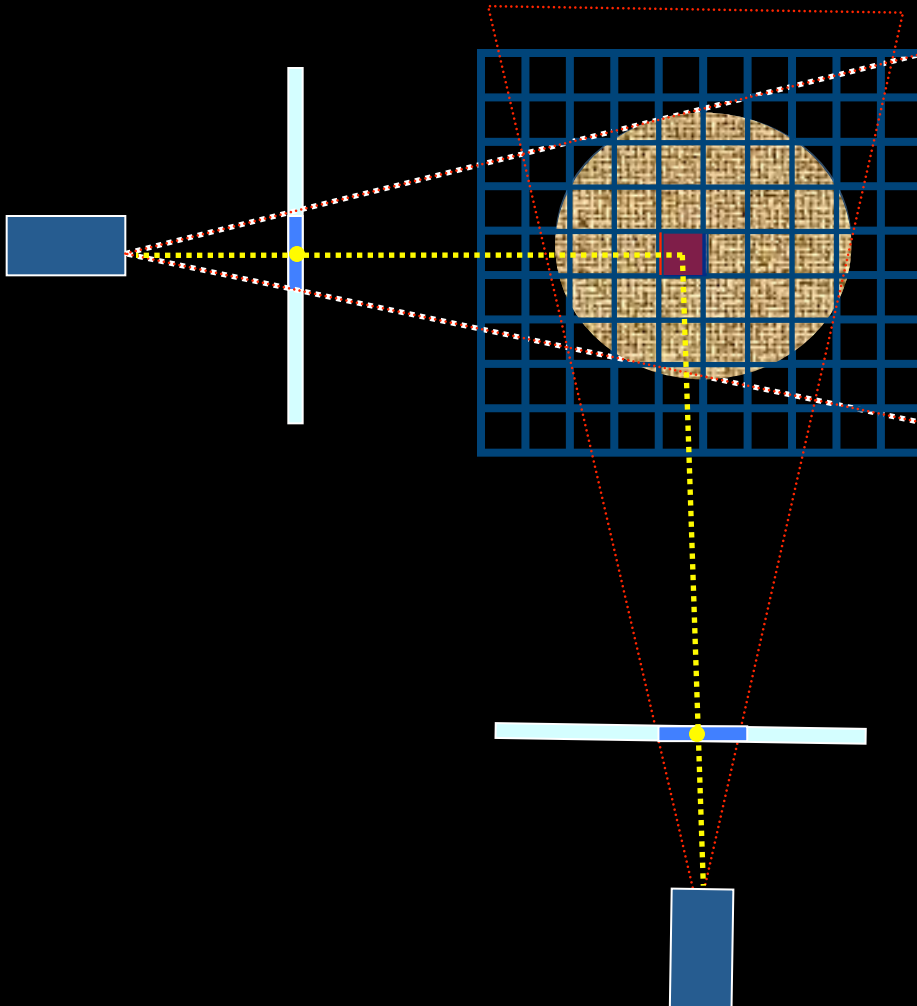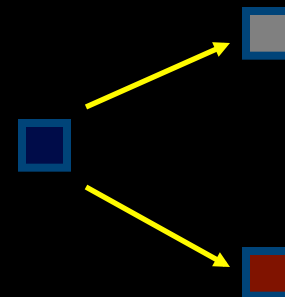❖ 7 min to compute on a 250MHz

Experimental results

Room + weird people

space carving

❖ Space carving is a binary voxel coloring

Voxel coloring: conclusions

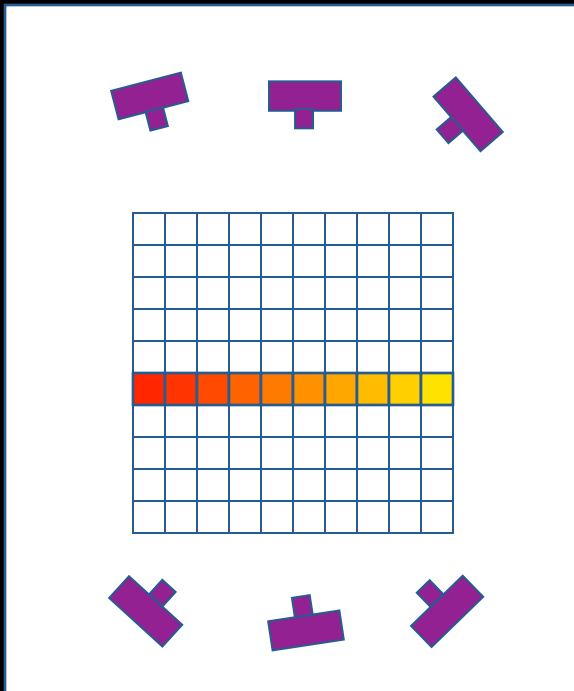❖ model intrinsic scene colors and texture

❖ no assumptions on scene topology
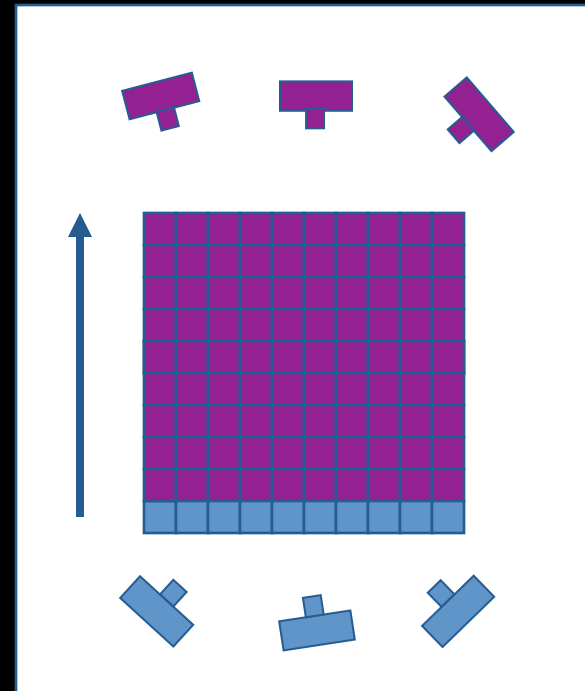
Voxel coloring: conclusions

Good things:

❖ model intrinsic scene colors and texture

❖ no assumptions on scene topology

❖ Constrained camera positions

❖ Lambertian assumption

Multi-Pass Plane Sweep

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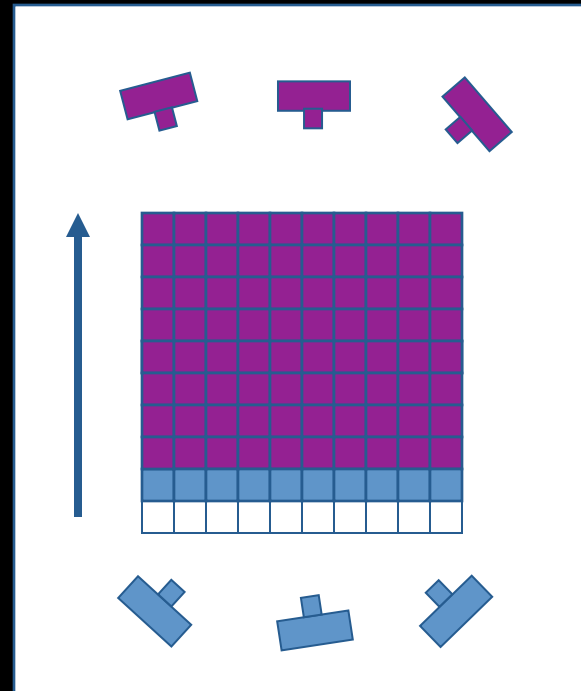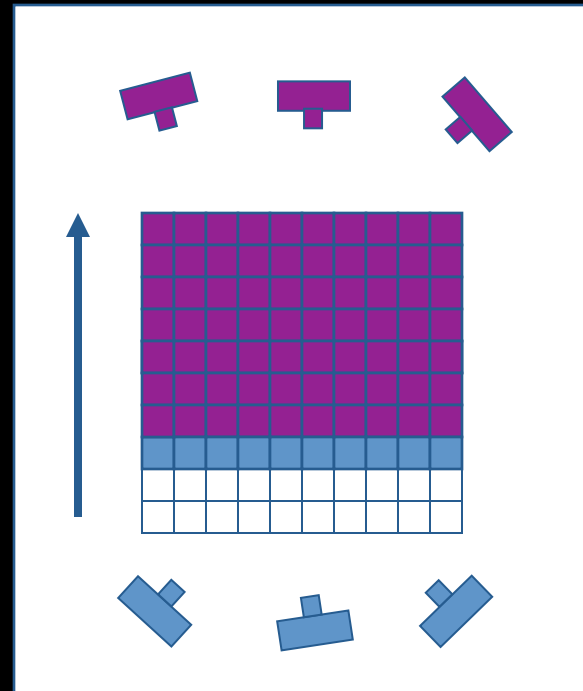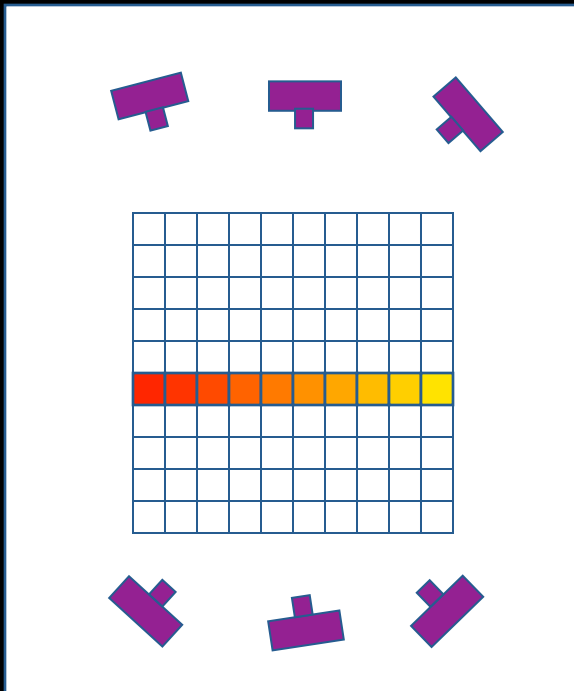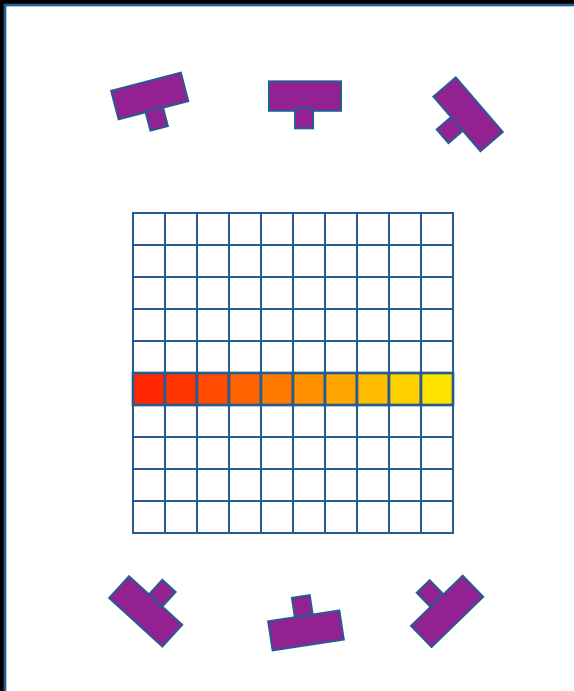- Repeat until convergence

True Scene

Reconstructio
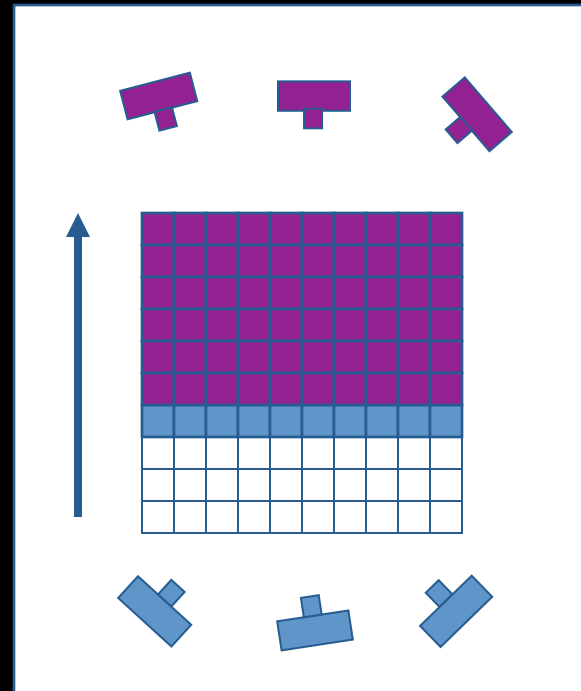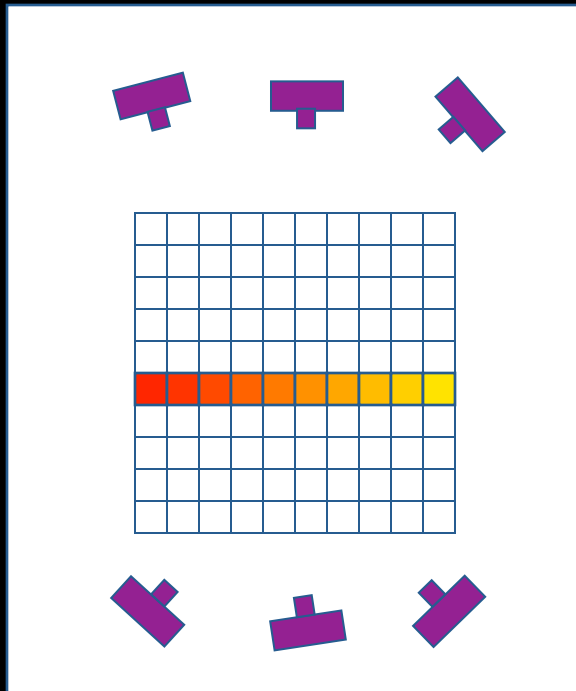
Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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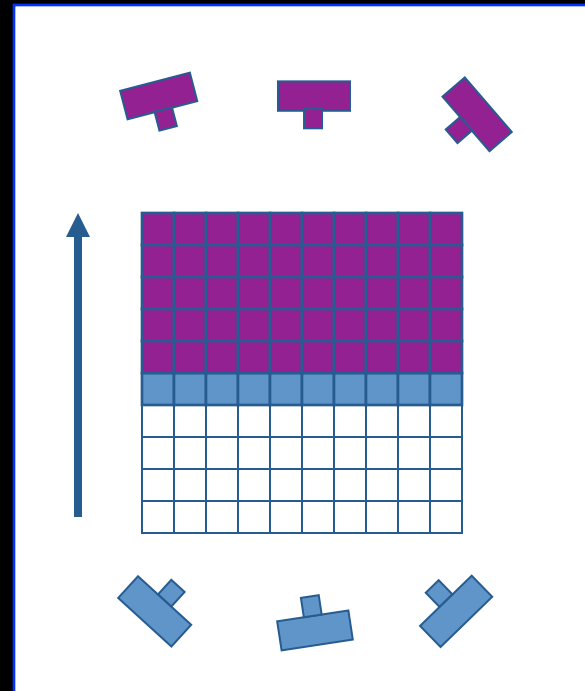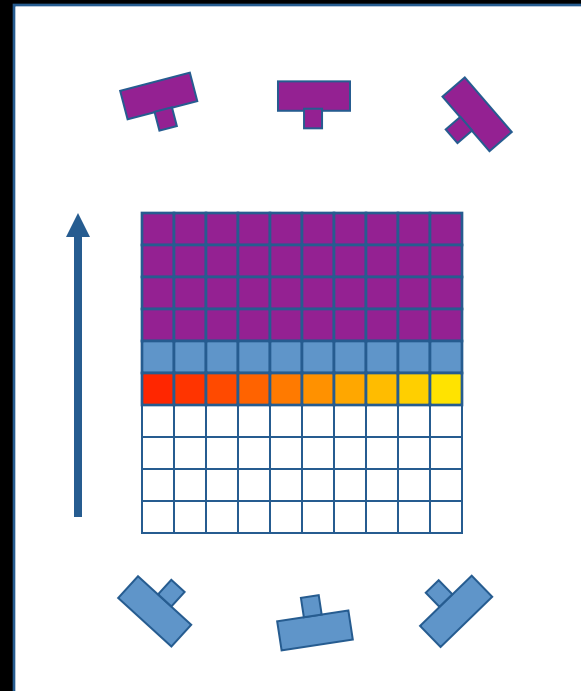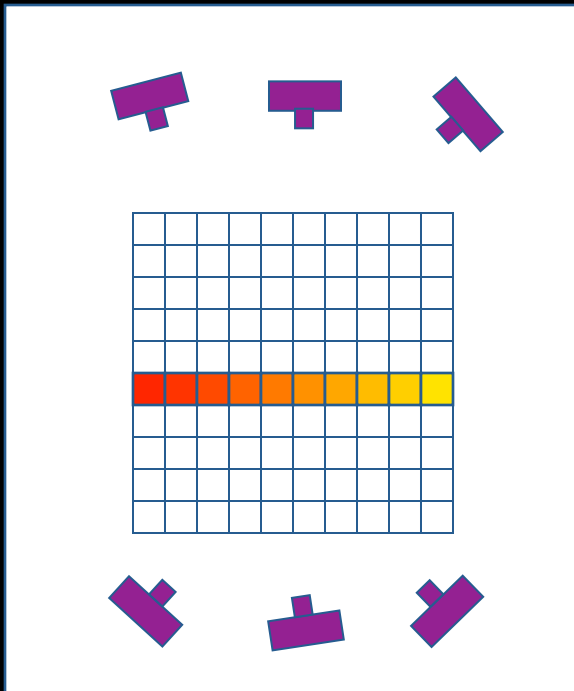- Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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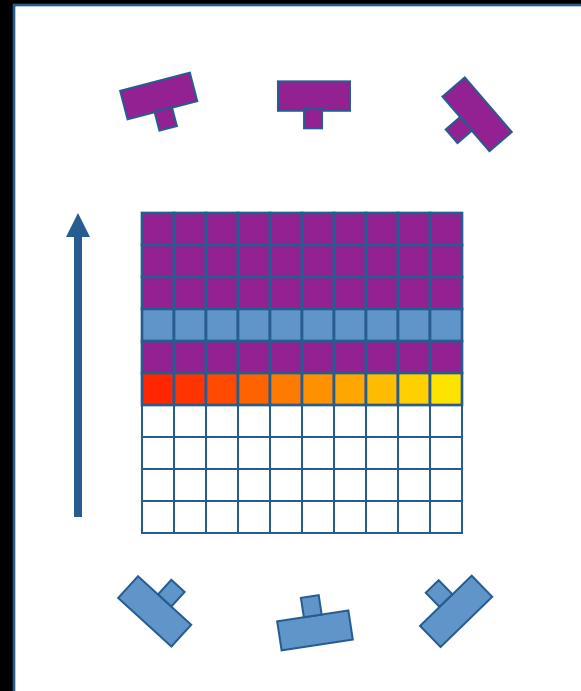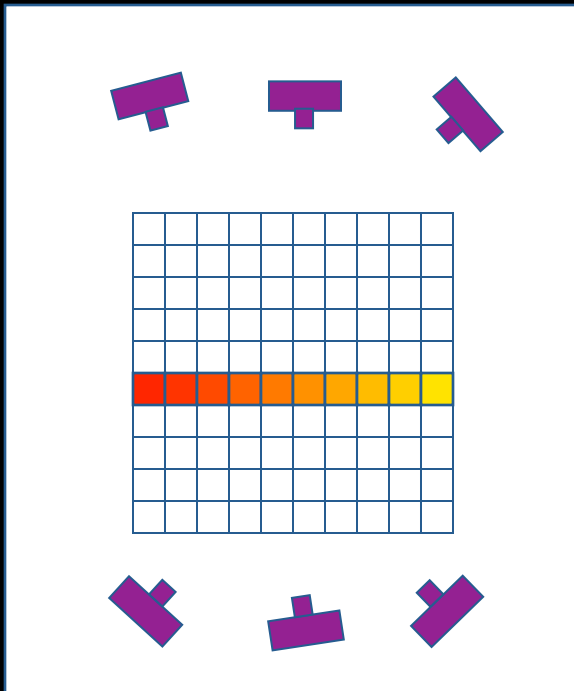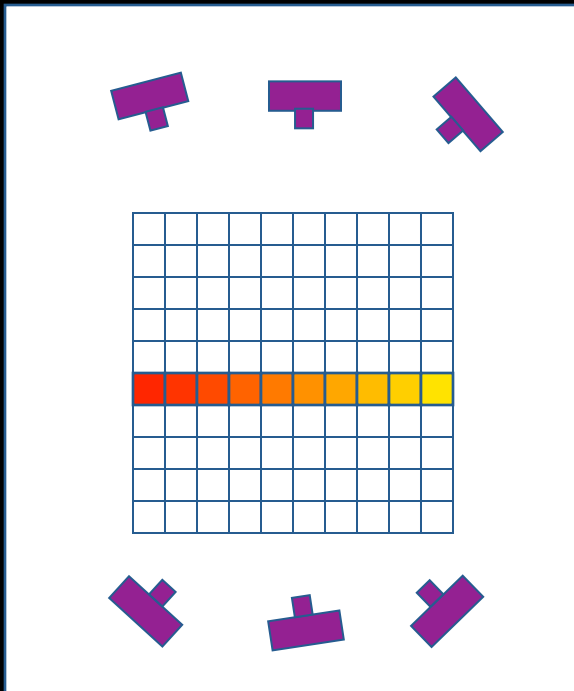- Repeat until convergence

Multi-Pass Plane Sweep

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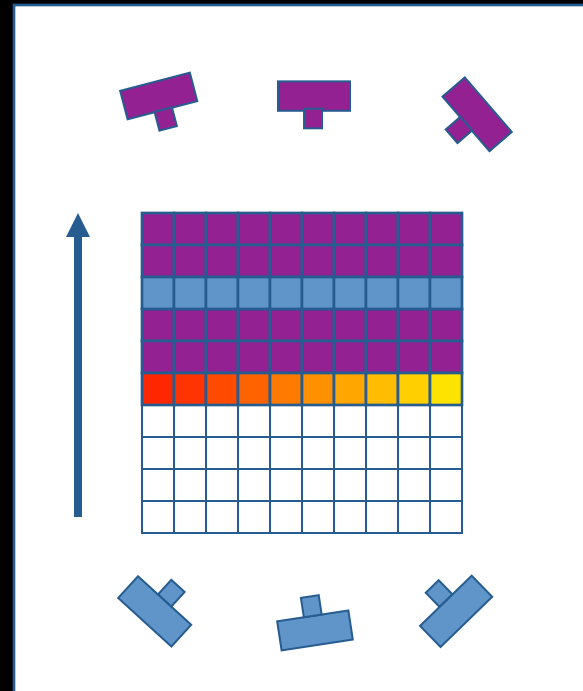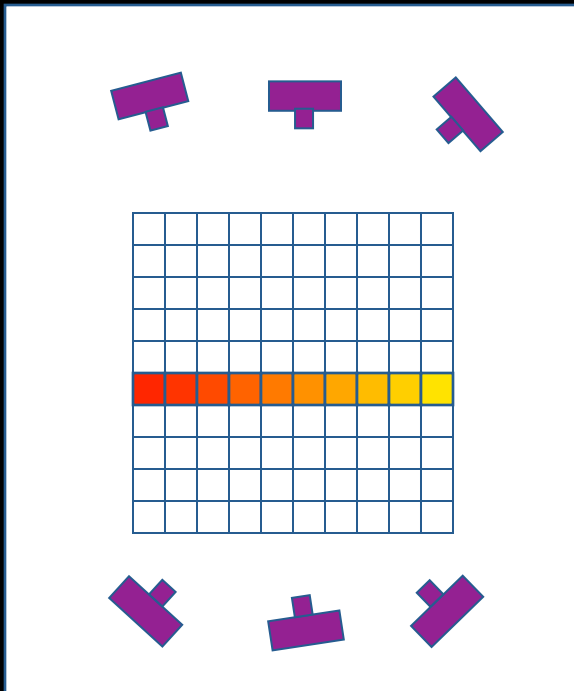- Repeat until convergence

Multi-Pass Plane Sweep

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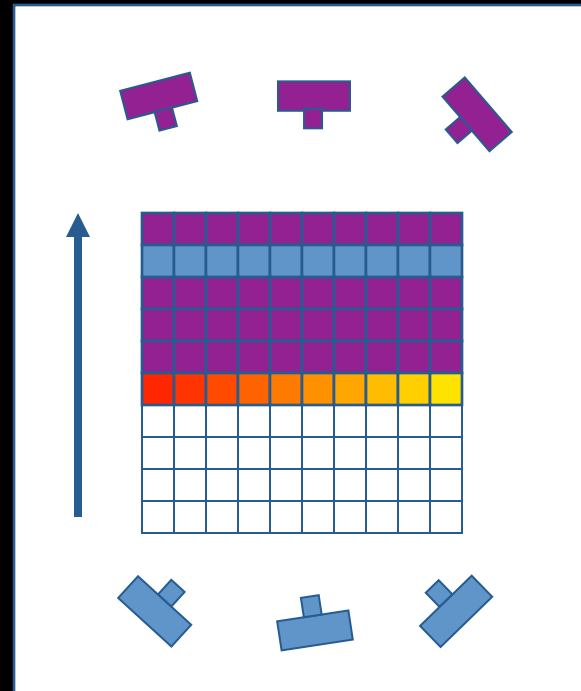- Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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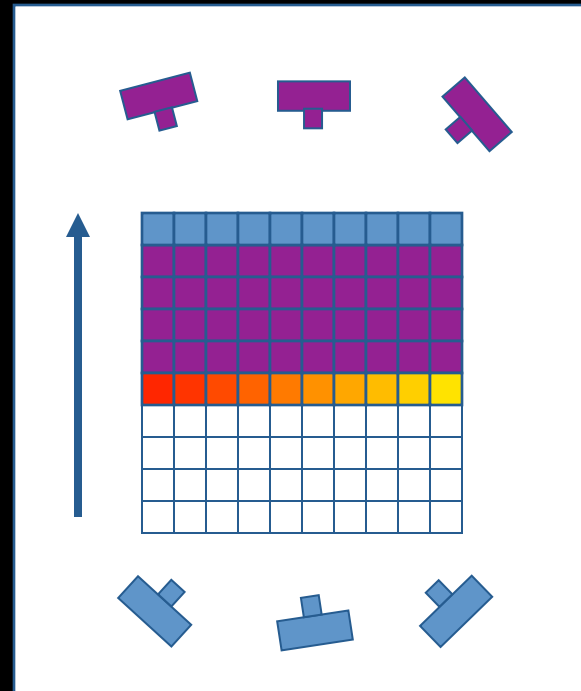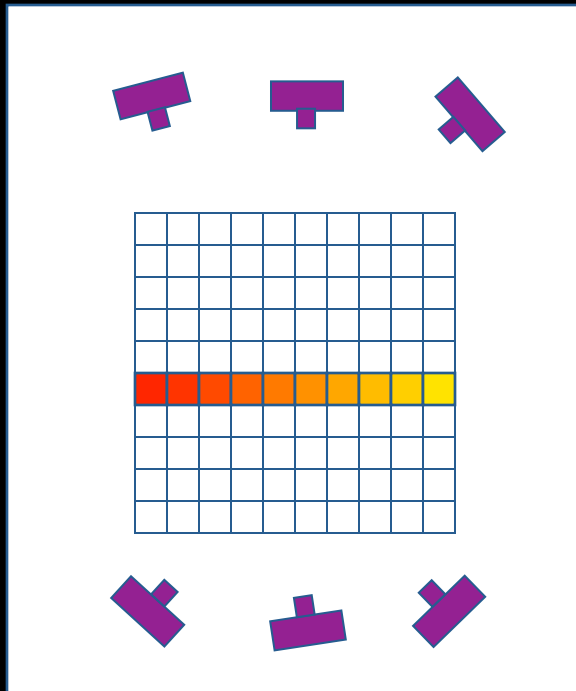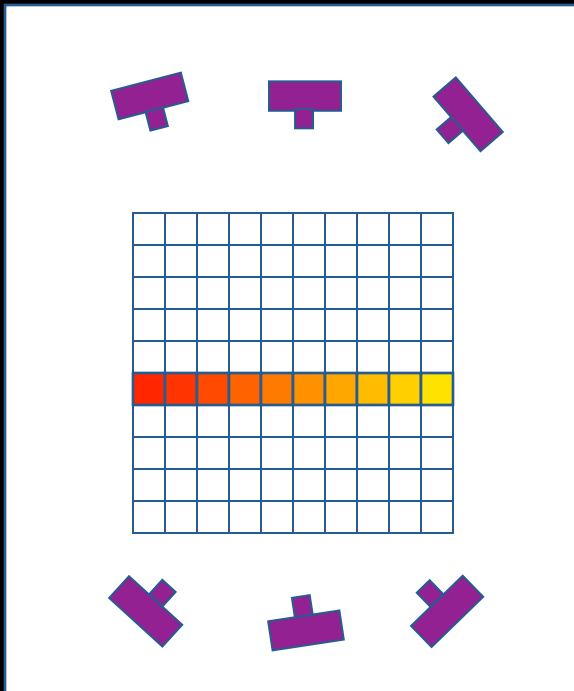– Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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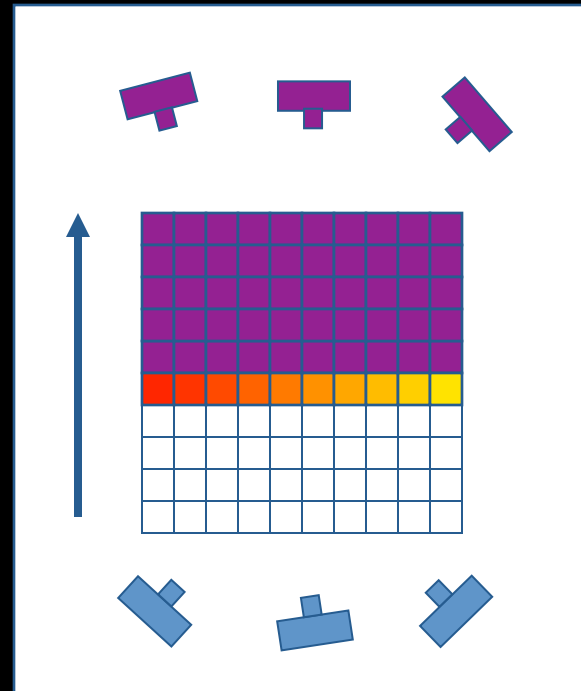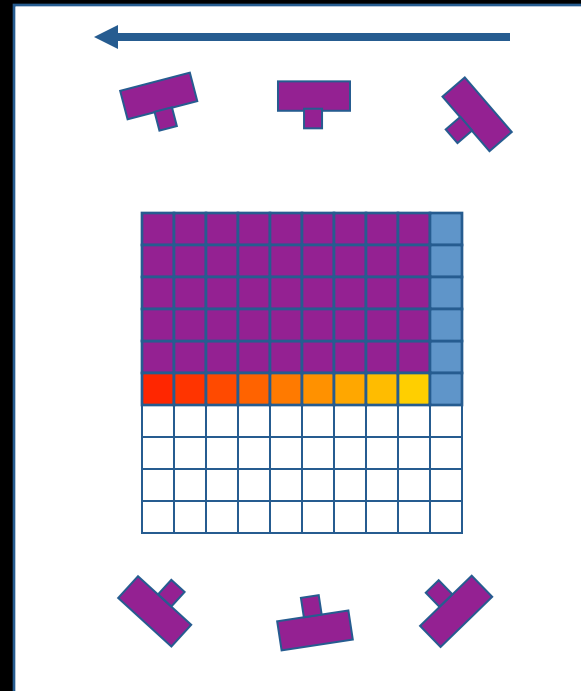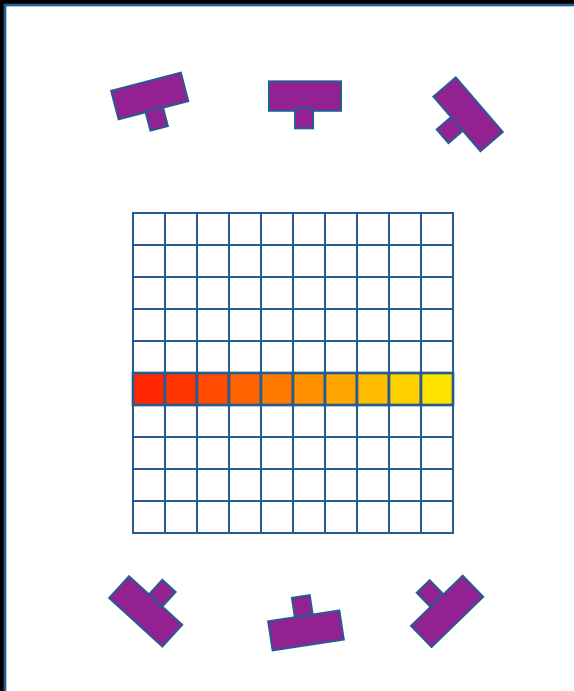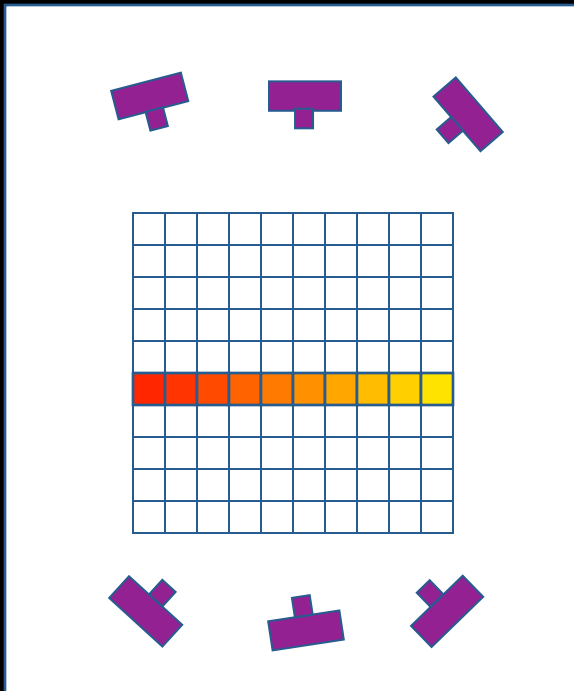- Repeat until convergence

Multi-Pass Plane Sweep

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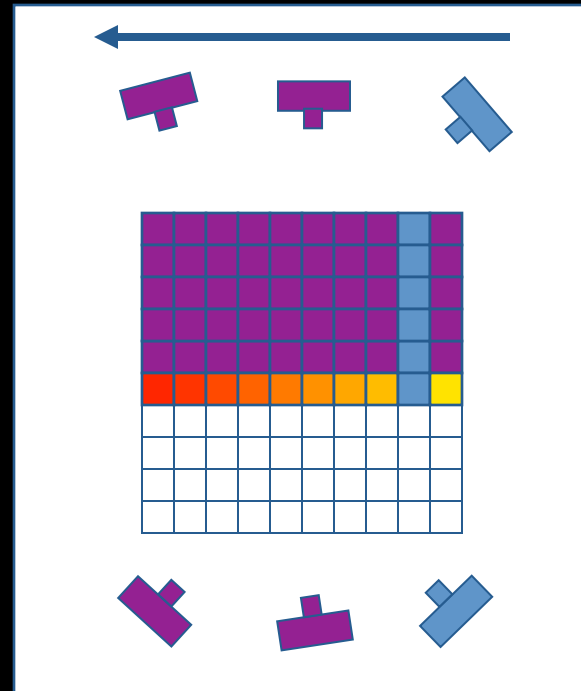- Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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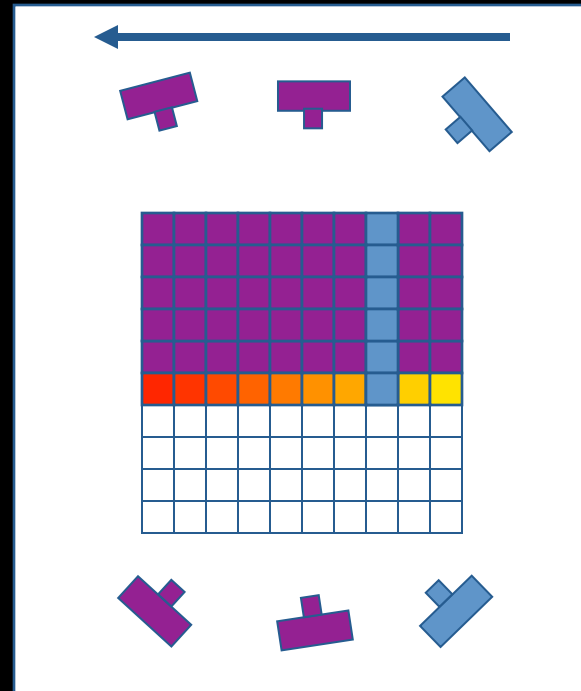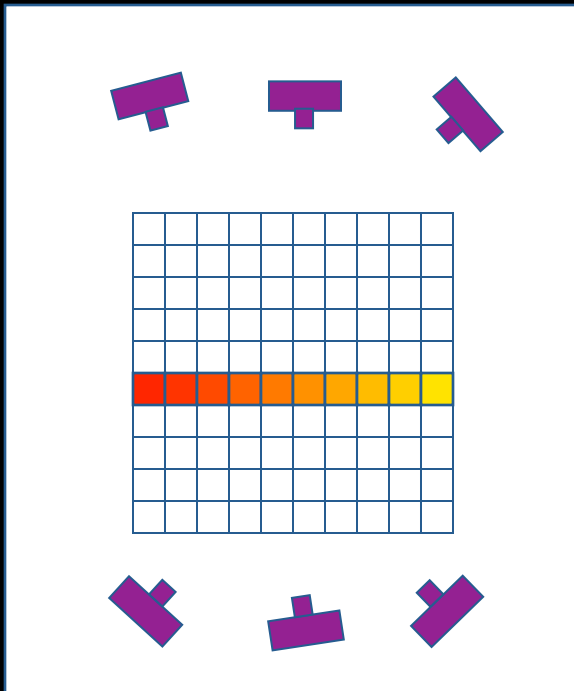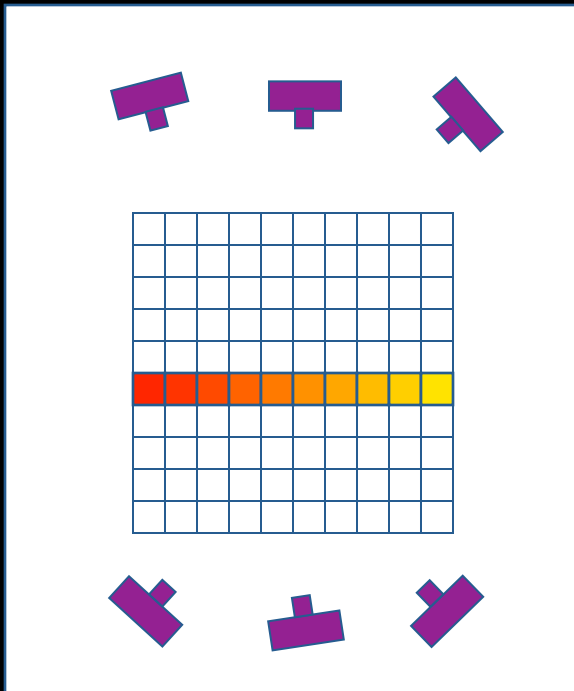- – Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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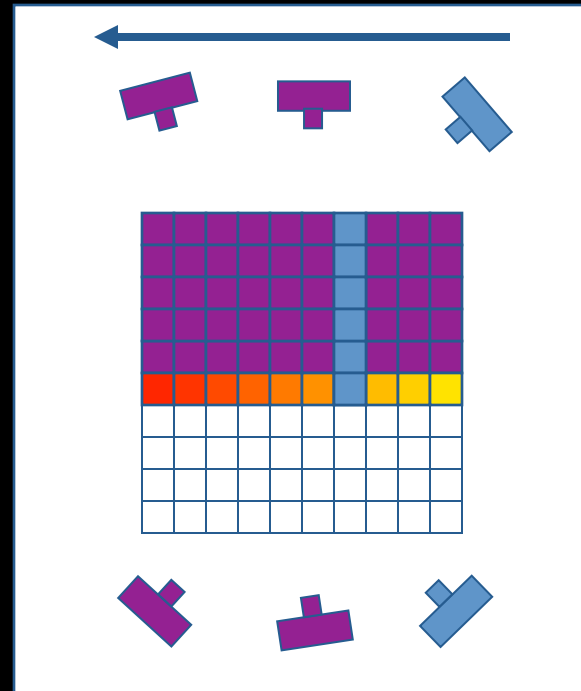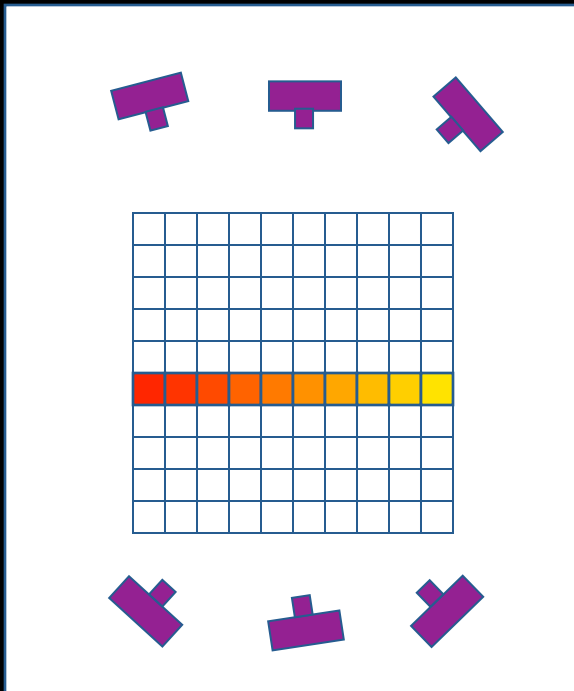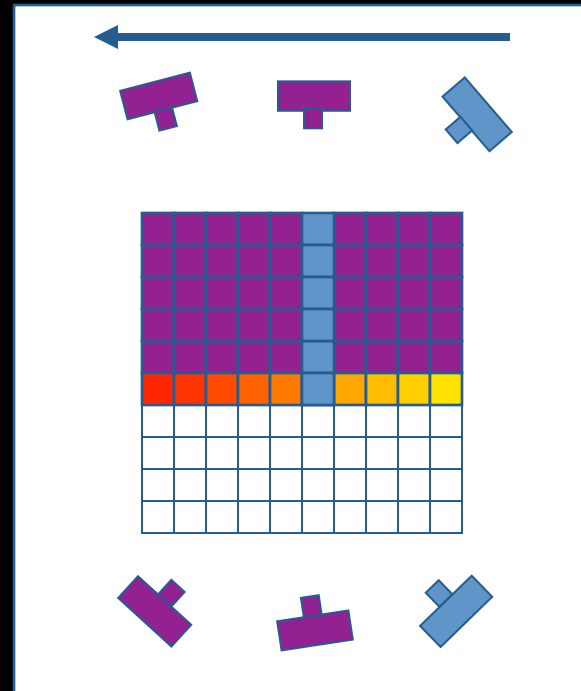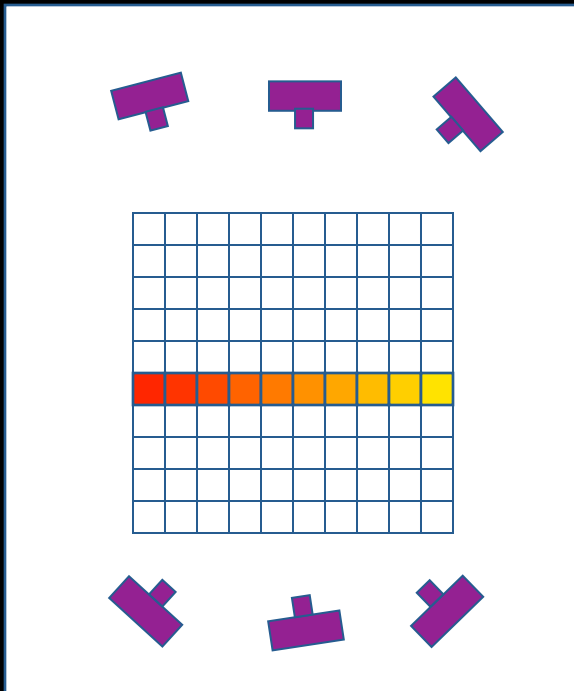- Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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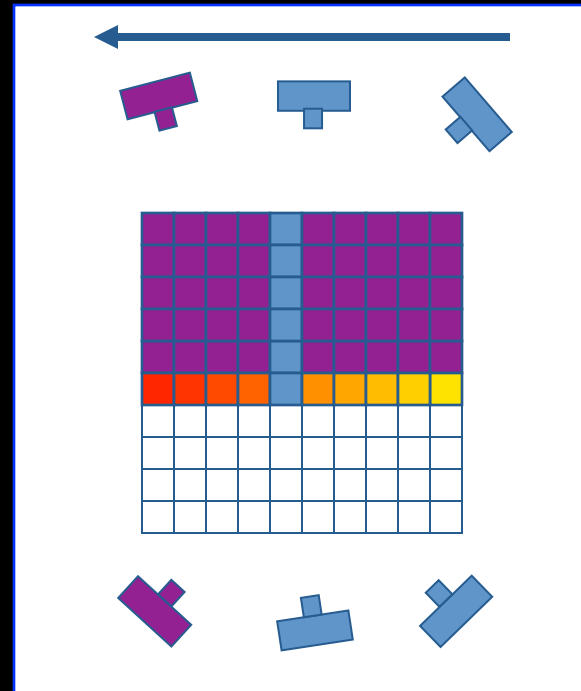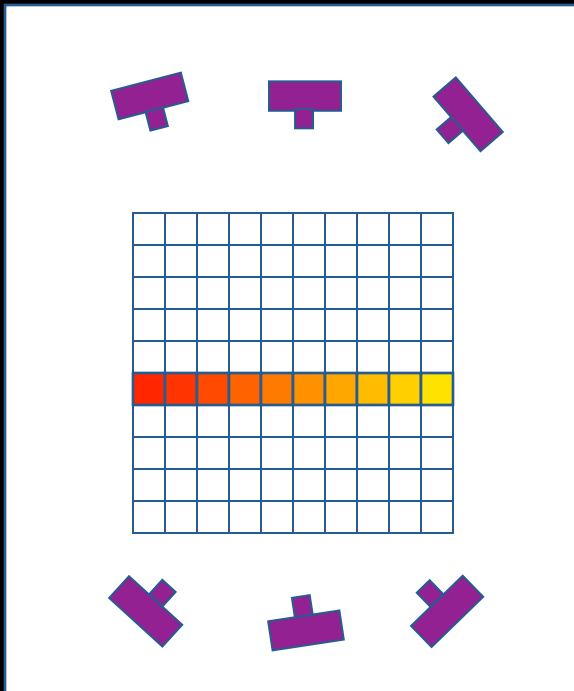– Repeat until convergence

Multi-Pass Plane Sweep

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

Multi-Pass Plane Sweep

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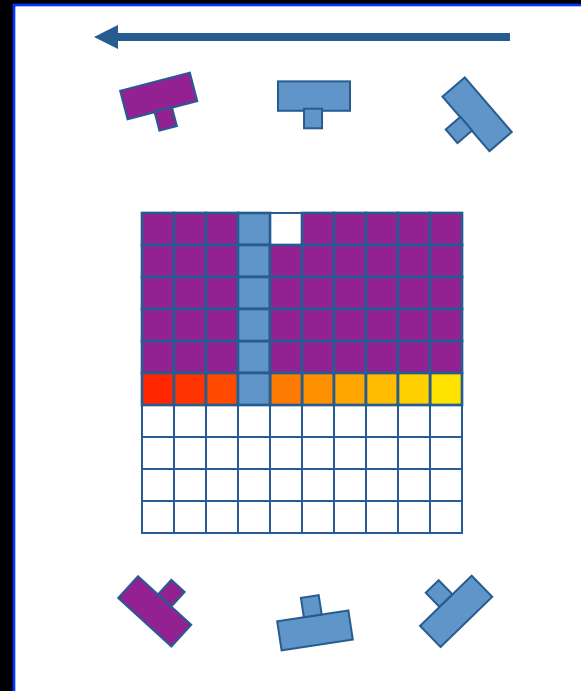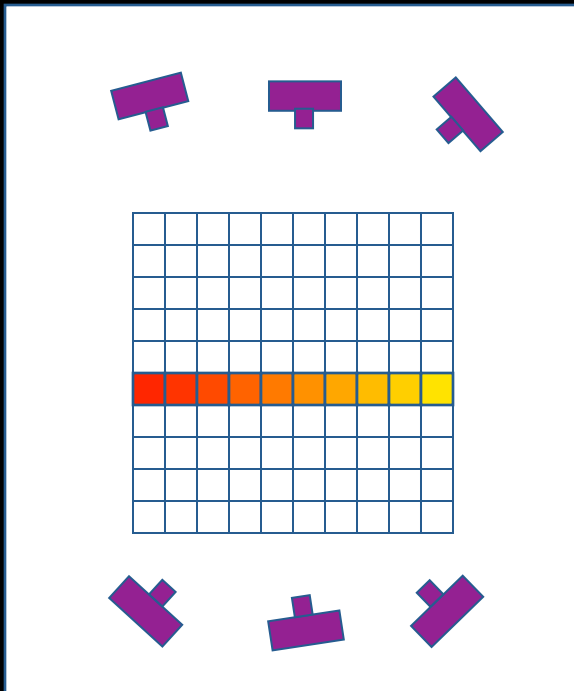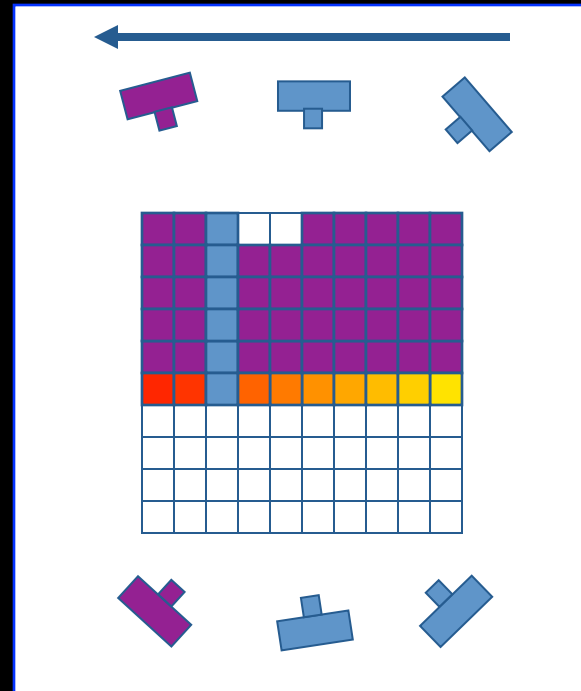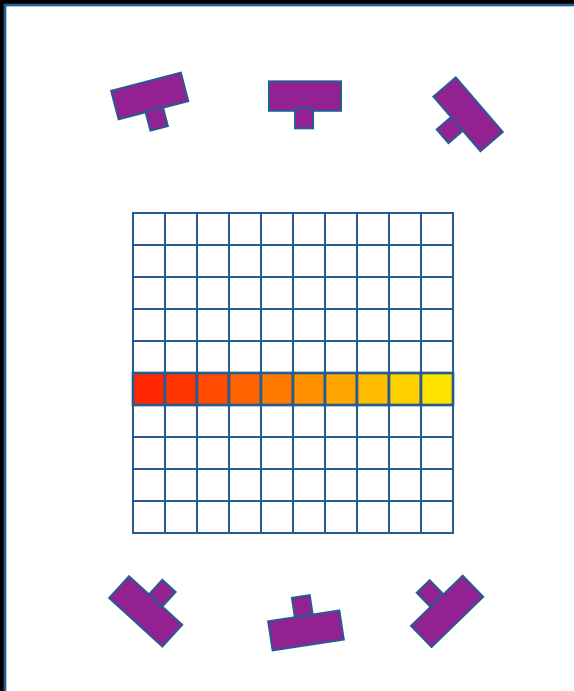- Repeat until convergence

Multi-Pass Plane Sweep

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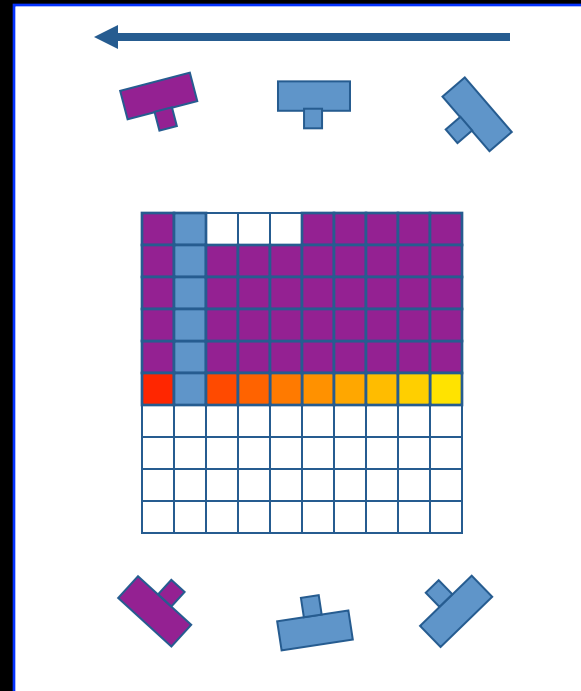- Repeat until convergence

Multi-Pass Plane Sweep

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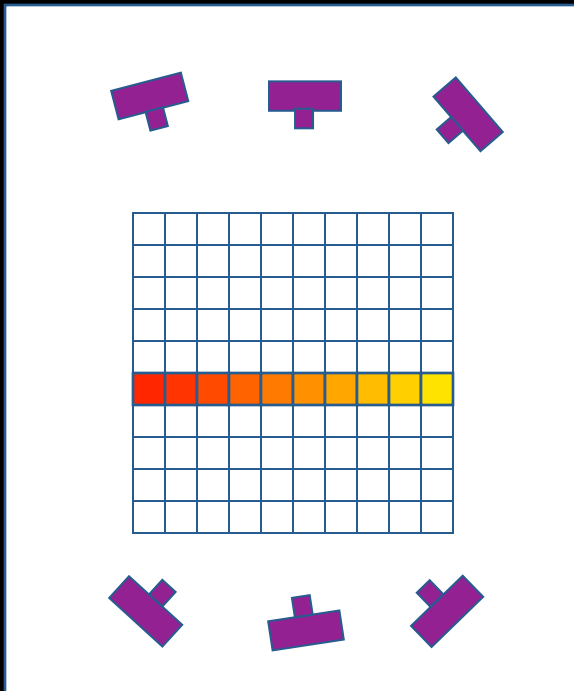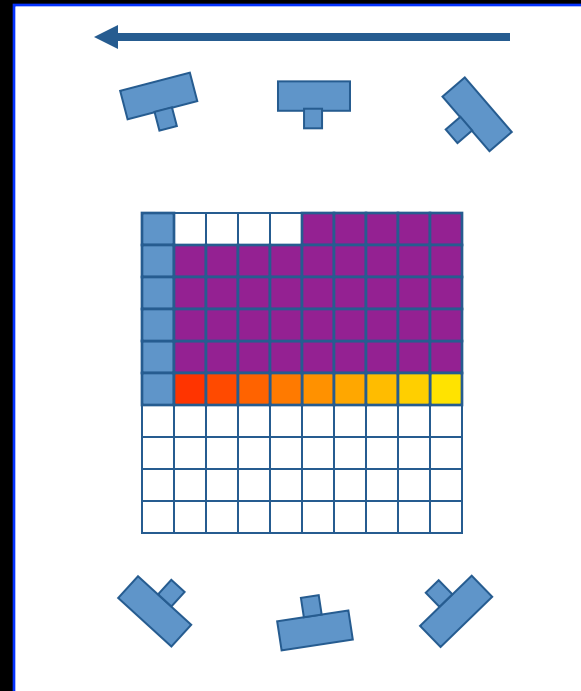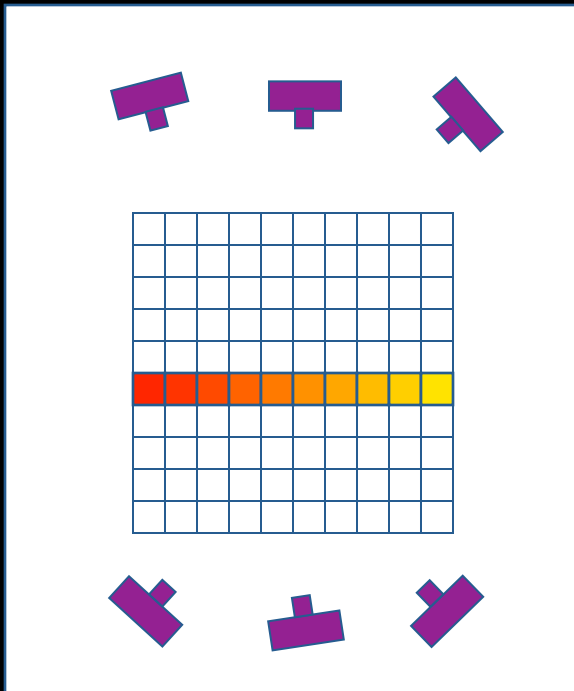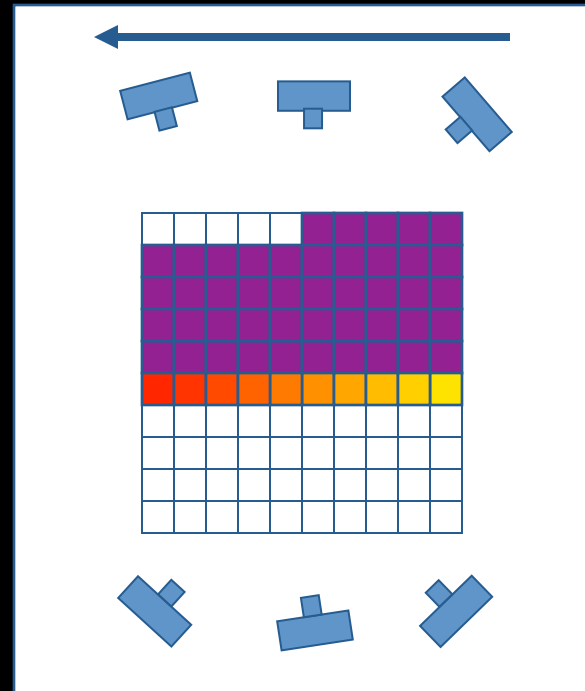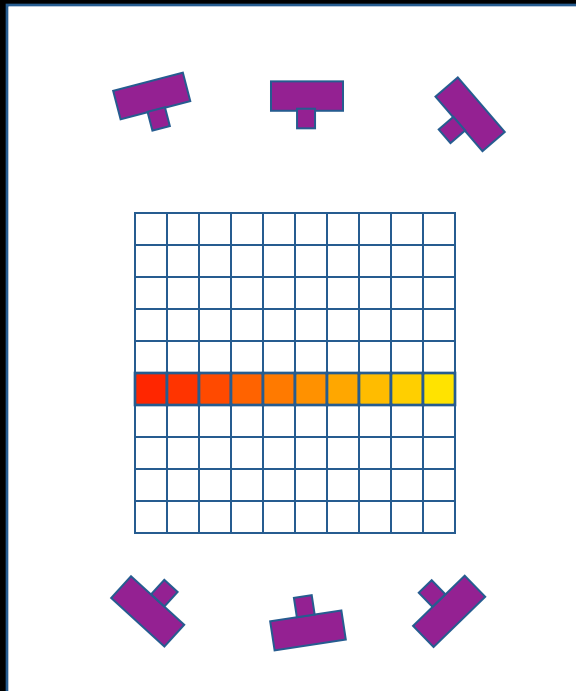- Consider cameras on only one side of plane
- Repeat until convergence

Space Carving Results: African Violet

Input Image (1 of 45)

Reconstruction

Reconstruction

Reconstruction

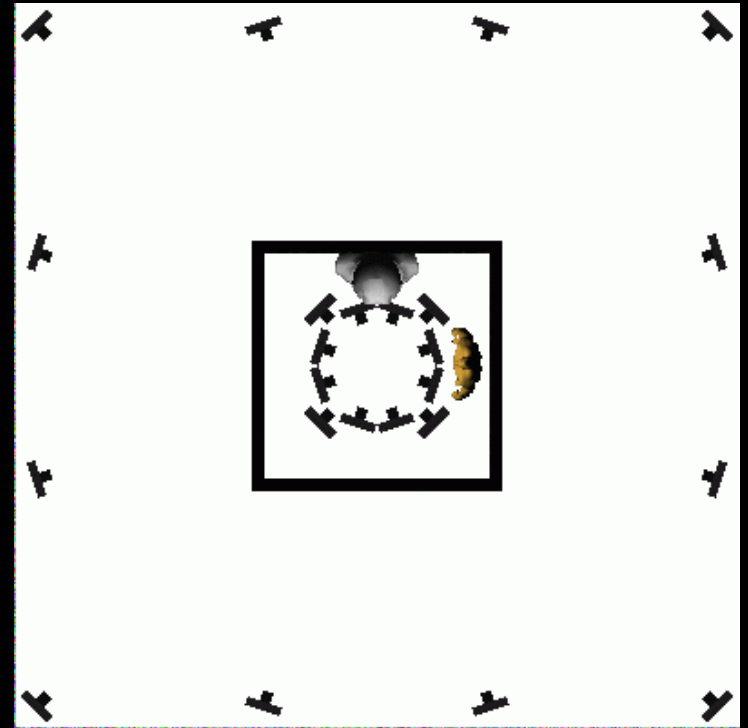# Space Carving Results: Hand

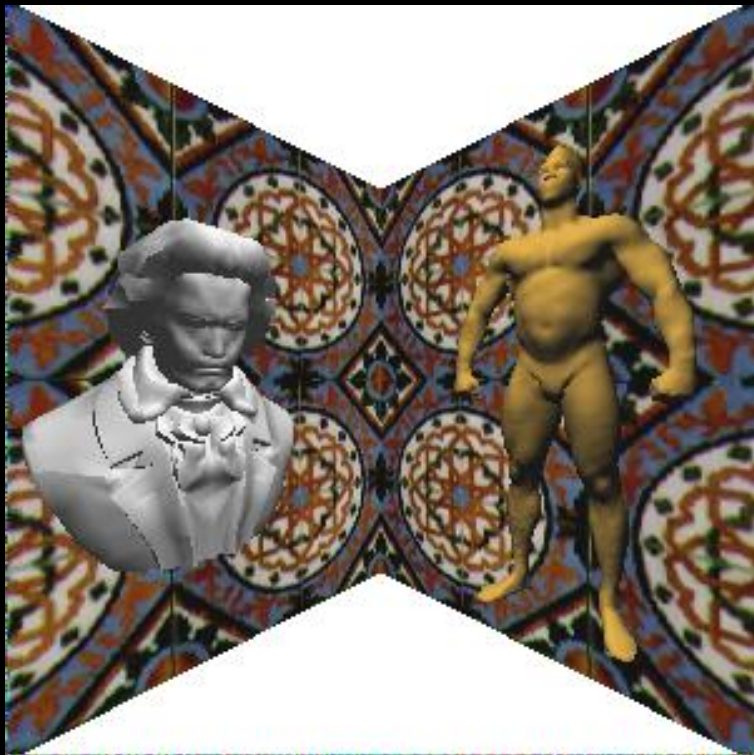**Input Image
(1 of 100)**

Views of Reconstruction

House Walkthrough

- 24 rendered input views from inside *and* outside

Space Carving Results: House

Input Image
(true scene)

Reconstruction
370,000 voxels

Space Carving Results: House

Input Image
(true scene)

Reconstruction
370,000 voxels

Space Carving Results: House

New View (true scene)   **Reconstruction**

New View
(true scene)   **Reconstruction**   **Reconstruction**
(with new input view)

Further contributions

❖ A Theory of Space Carving

(Kutulakos & Seitz '99)

   ❖ Voxel coloring in more general framework

   ❖ No restrictions on camera position

❖ Probabilistic Space Carving

(Broadhurst & Cipolla, ICCV 2001)

(Bhotika, Kutulakos et. al, ECCV 2002)

❖ Shadow Carving

Savarese et al., IJCV 2006

Next lecture…

Fitting and Matching