

# Toward Practical 3D Photography

Kyros Kutulakos

`kyros@cs.rochester.edu`

University of Rochester

Rochester, NY USA

# 3D Photography

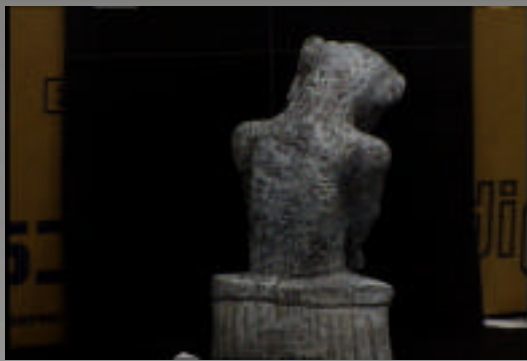
Making the capture of photo-realistic 3D scene models as simple as taking a 2D picture



**Approach--Theory & algorithms that answer one question**

What do  $N$  arbitrary photographs of an arbitrarily-shaped scene tell us about the scene's 3D shape?

# 3D Photographs from 2D Images



# Capturing Reality from 2D Photos & Videos

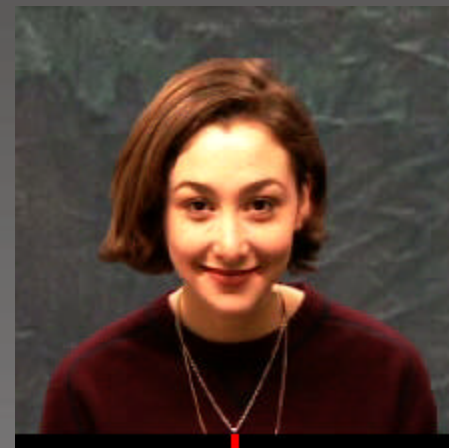
Shape



Shape + Reflectance



Shape + 3D Motion



(from Shoedl et al, 2000)

## Participants

Rahul Bhotika

Fred Marcus

Li Qi

Steve Seitz (UW)

David Fleet (Xerox PARC)

Rodrigo Carceroni

Benno Heigl (U. Erlangen)

Rodrigo Carceroni

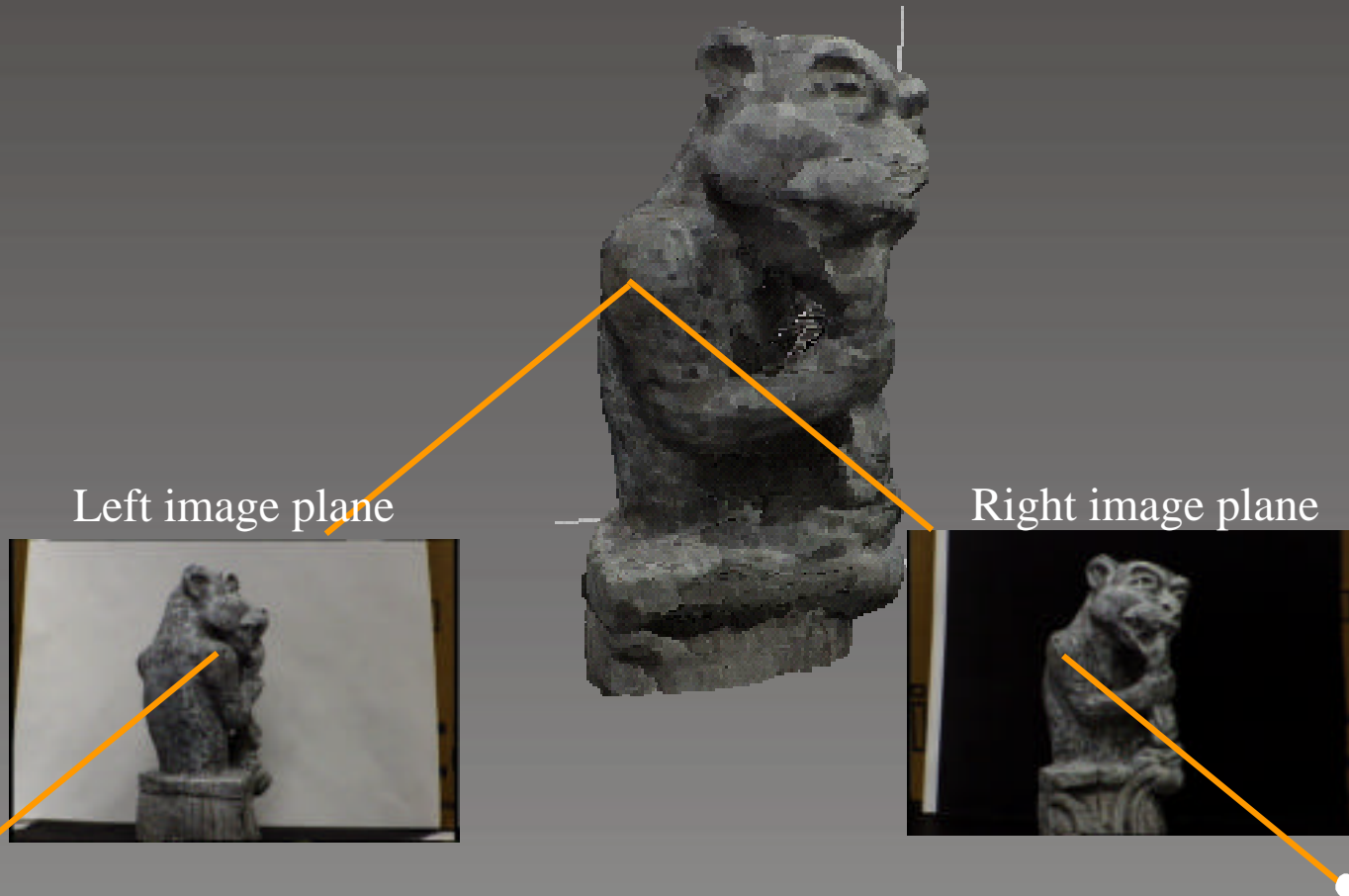
David Sankel

## 3D Shape from One 2D Photo

In the absence of a priori shape information, one photo provides no constraints on 3D shape



# Triangulation



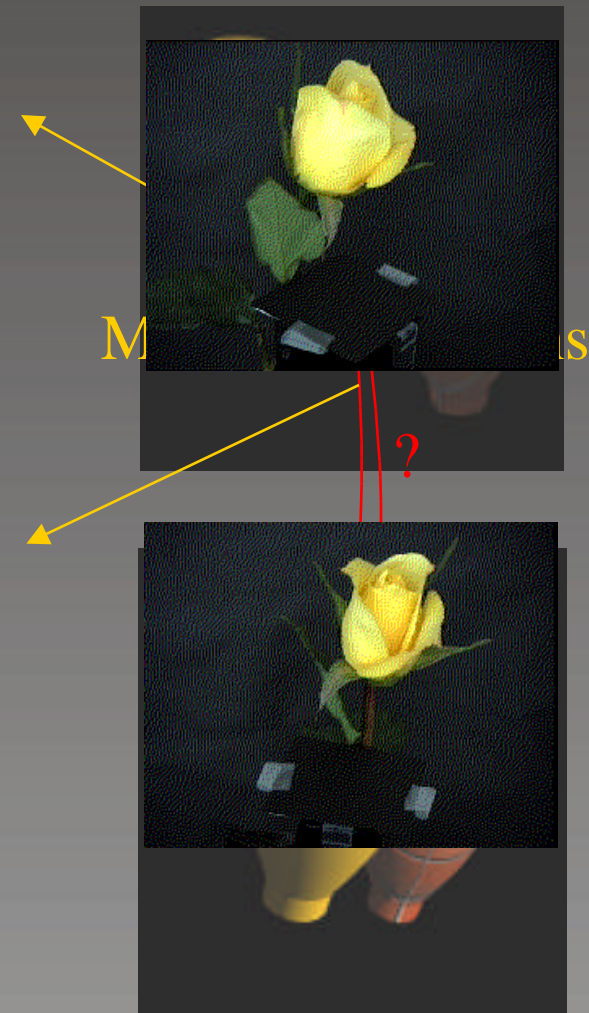
## Basic idea of stereo vision:

If we know the projection in two photographs of a scene point, we can compute the point's position in space

# 3D Shape from Multiple 2D Photos

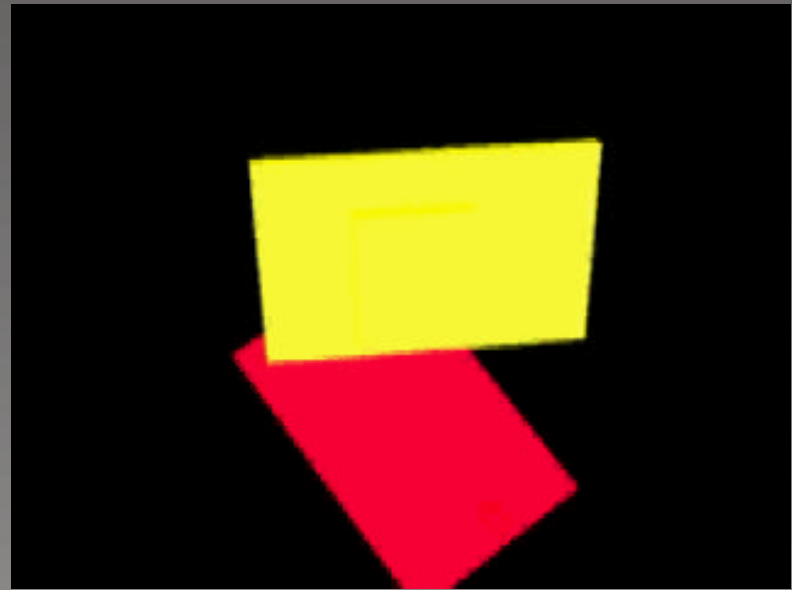
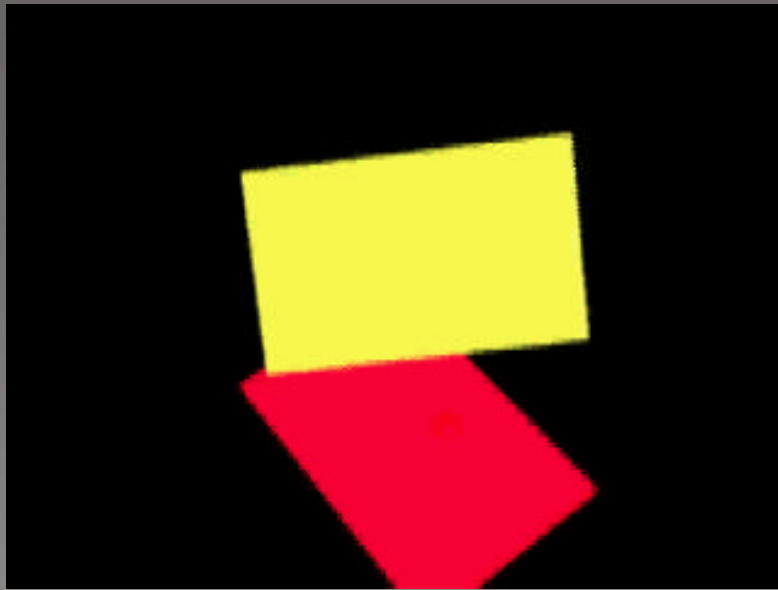
## Key problems

- Establishing pixel correspondences
- Determining visibility
- Handling complex object reflectance & shadows
- Computing camera position
- Guaranteeing photo-realism
- Understanding 3D shape ambiguities



## 3D Shape from Multiple 2D Photos

While multiple photos constrain 3D shape, they do not always determine it uniquely



# Photo-Consistent 3D Shapes

Shape  
Definition

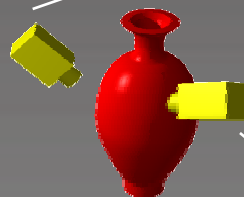
$$V \subseteq R^3$$



Reflectance  
Assignment

Radiance Scene  
Assignment Illumination

$$R_V: Surf(V) \times S^2 \quad \langle r, g, b \rangle$$



Shape  
Projection

rendered  
photos



Image  
Consistency

input  
photos



?  
=

?  
=

view<sub>1</sub>  
lights<sub>1</sub>

view<sub>2</sub>  
lights<sub>1</sub>

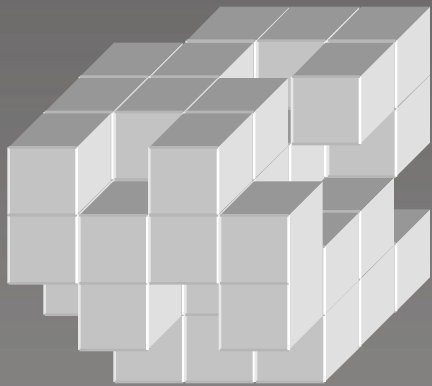
General scene reconstruction problem:

Compute a 3D shape  $V \subseteq R^3$  & radiance assignment  $R_V$  that together reproduce all input photos

# 3D Shapes

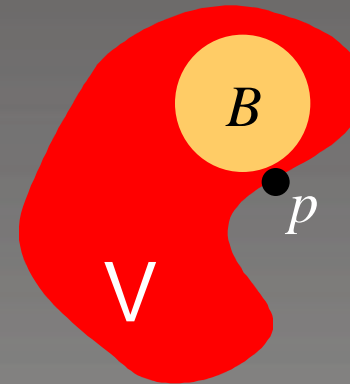
- Requirement: shapes always occupy a volume in space
- No additional geometry or topology requirements imposed

Discrete Case



**Discrete 3D Shape Definition**  
an arbitrary collection of voxels  
on a discrete volumetric grid

General Case

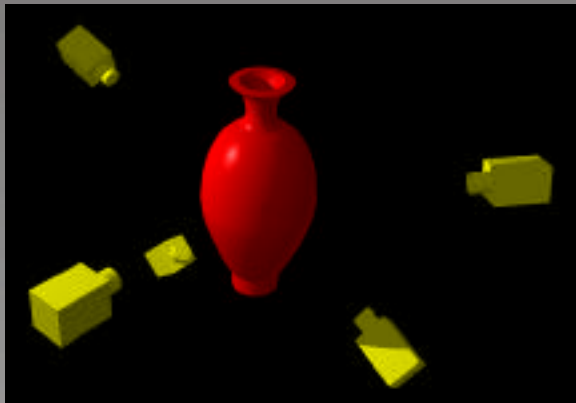


**General 3D Shape Definition**  
any closed set  $V \subseteq \mathbb{R}^3$  for which  
every  $p \in V$  is infinitesimally  
near an open  $\varepsilon$ -ball  $B \subset V$

## Photo-Consistency Theory: Objectives

- Characterize equivalence class of photo-consistent shapes under specific assumptions about scene radiance (e.g., Lambertian)
- Provably compute at least one photo-consistent shape
- Establish the computed shape's relationship to all other 3D solutions
- Incorporate measurement errors & uncertainty into framework

reconstructing objects



reconstructing environments



# The Photo Hull (Discrete Case)

Definition: Photo Hull of a volume

$$= \{ V \mid V \subseteq \text{is a photo-consistent shape} \}$$

photo-consistent  
subsets of

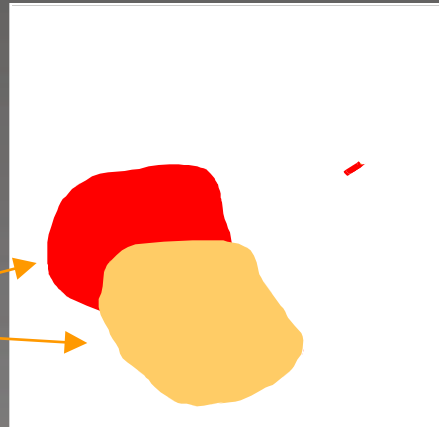


Photo Hull Theorem (discrete case)

is a photo-consistent shape

(  $R$  such that  $R$  reproduce all photos)

# The Photo Hull (General Case)

Definition: Photo Hull of a volume

$$\begin{aligned} &= \{ V \mid V \subseteq \text{ is a photo-consistent shape} \} \\ &= \text{closure}( \ ) \end{aligned}$$

photo-consistent  
subsets of

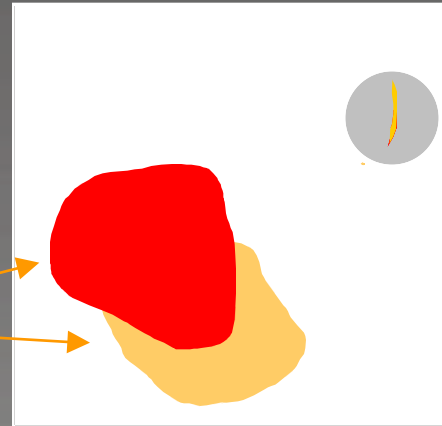


Photo Hull Theorem (general case)

is a directionally  $\varepsilon$ -photo-consistent shape

# 3D Photography By Space Carving

Sequence 1: Gargoyle

16 Calibrated Images  
Resolution: 768x484

# 3D Photography By Space Carving

Reconstructed Gargoyle

Initial volume: 51 million voxels

Carved volume: 215,000 surface voxels

Computation time: 250 mins

# Toward Practical 3D Photography

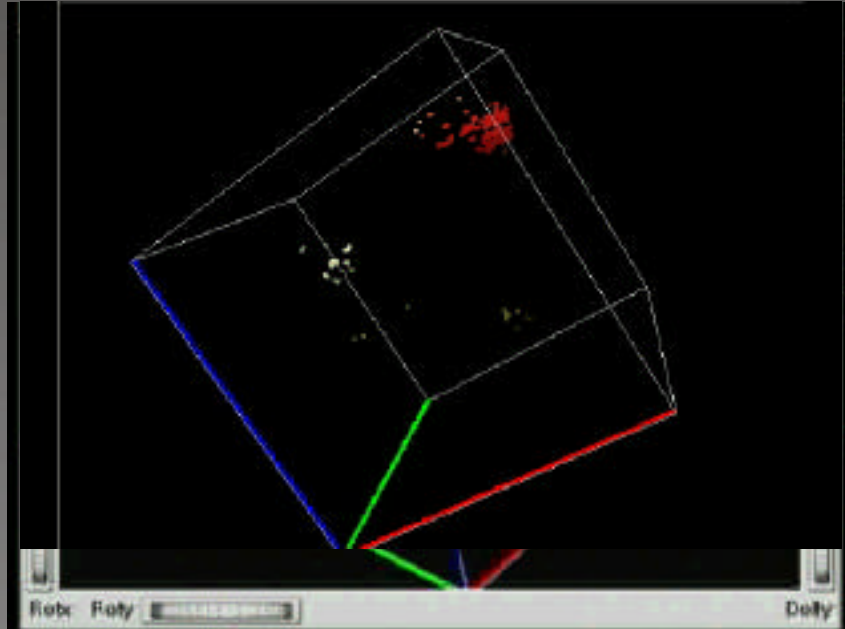


How can we

- develop fast multi-resolution reconstruction algorithms?
- reconstruct a scene that is not perfectly stationary?
- recover shape from photos with inaccurate calibration?
- recover shape from noisy photos?

# Toward Practical 3D Photography

Cactus sequence (2 out of 27 photos)



Difficulties:

- Very complex surface geometry
- Calibration errors ( 1-4 pixels)
- Low-quality images
- “Mixed” pixels & CCD color filter artifacts



# Capturing Reality: Some Key Challenges

Transparency



Global illumination effects



[Timetrack Videos]

# Concluding Remarks

## Photo-consistency theory features

- algorithm-independent analysis of N-view reconstruction problem
- global interactions between shape, visibility, reflectance & illumination taken into account
- no restrictions on viewpoint distribution, scene shape
- simple & efficient algorithms with provable convergence properties
- photo-realistic reconstructions