

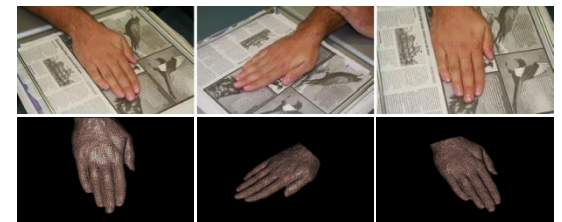
Reconstruction

EE/CSE 576

Linda Shapiro

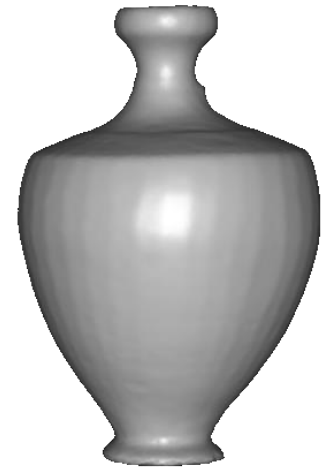
3D model

- “Digital copy” of real object
- Allows us to
 - Inspect details of object
 - Measure properties
 - Reproduce in different material
- Many applications
 - Cultural heritage preservation
 - Computer games and movies
 - City modelling
 - E-commerce



Applications: cultural heritage

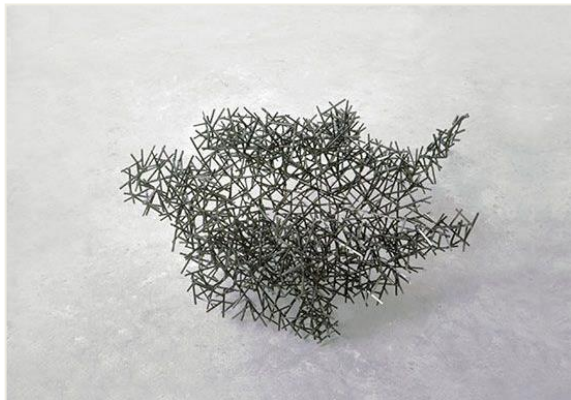
SCULPTEUR European project



Applications: art



Block Works Precipitate III 2004
Mild steel blocks 80 x 46 x 66 cm



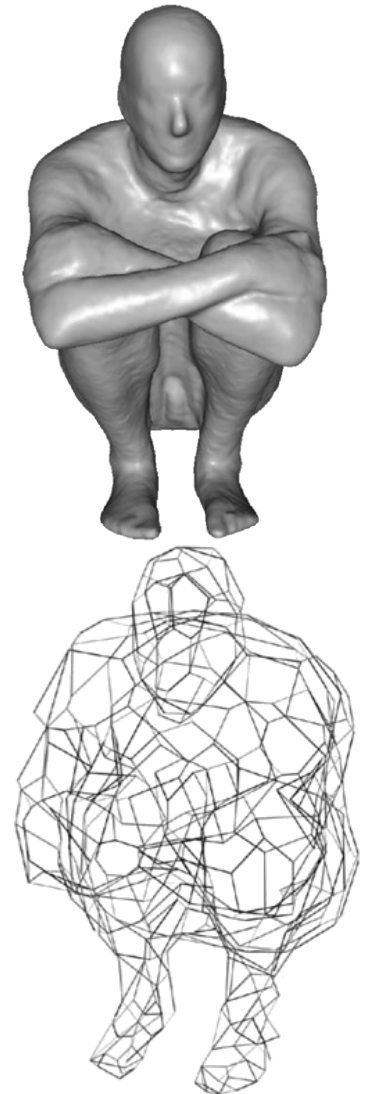
Domain Series Domain VIII Crouching
1999 *Mild steel bar 81 x 59 x 63 cm*



Applications: structure engineering



BODY / SPACE / FRAME, Antony Gormley, Lelystad, Holland



Applications: 3D indexation

The image displays a 3D indexation interface. On the left, a large 3D model of a female torso is shown. To its right, a grid of smaller 3D models is displayed, with four models highlighted and labeled with IDs and similarity scores:

0 : deesse0 0.000000	1 : deesse5 0.092800
5 : deesse2 0.211000	6 : ARCHI3203 0.236800

Below the grid, several blue question marks are placed over the models, indicating a search or selection process. On the right, a photograph shows a museum gallery with various artifacts on display, including vases, plates, and other objects. The gallery has wooden floors and white walls. The number 915 is visible in the bottom right corner of the photograph.

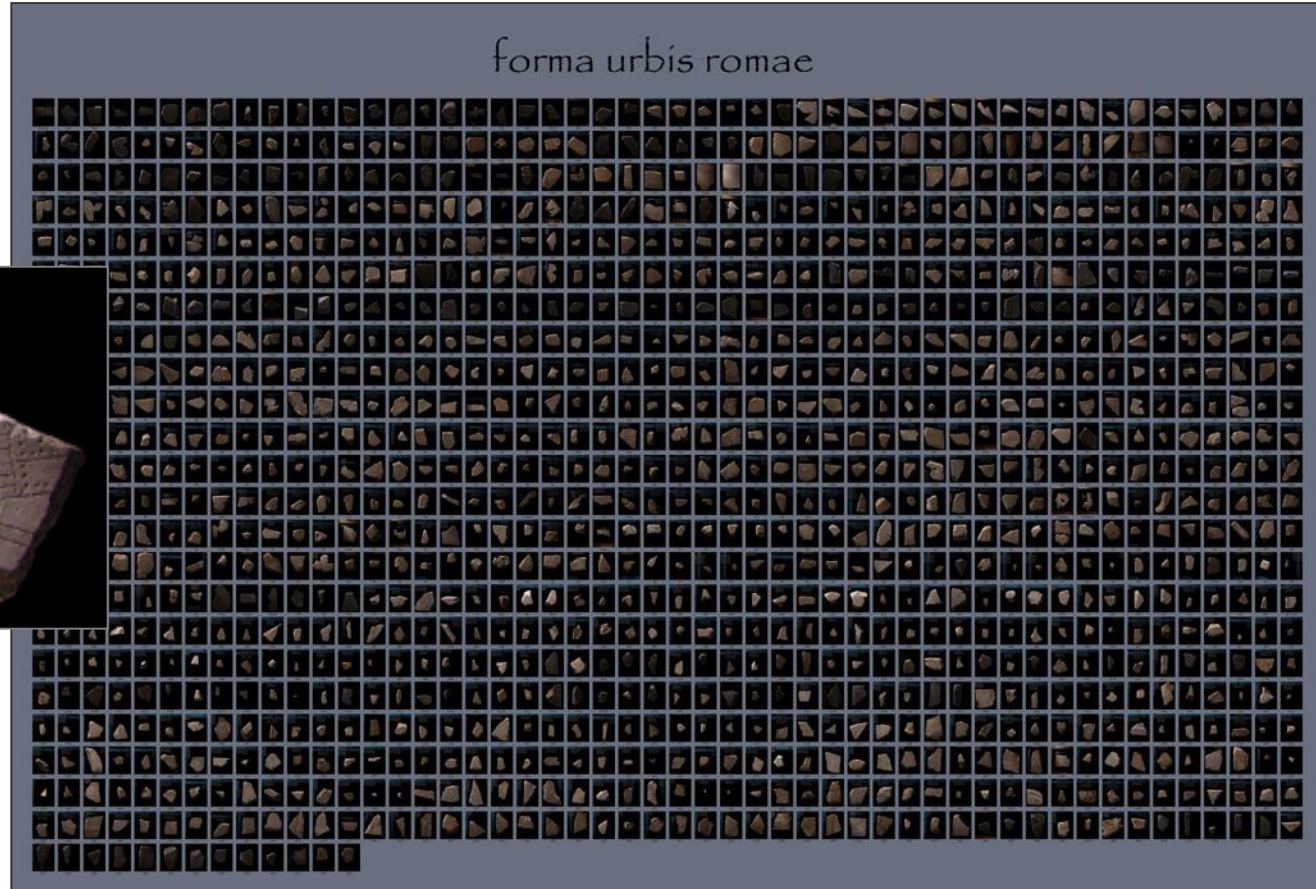
Applications: archaeology

- “forma urbis romae” project

Fragments of the City: Stanford's Digital Forma Urbis Romae Project

David Koller, Jennifer Trimble, Tina Najbjerg, Natasha Gelfand, Marc Levoy

*Proc. Third Williams Symposium
on Classical Architecture,
Journal of Roman Archaeology
supplement, 2006.*



1186 fragments

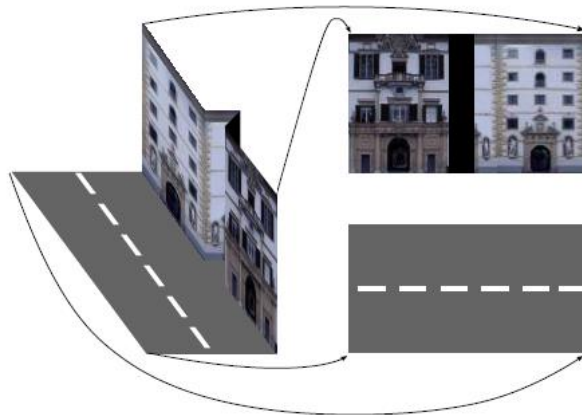
Applications: large scale modelling



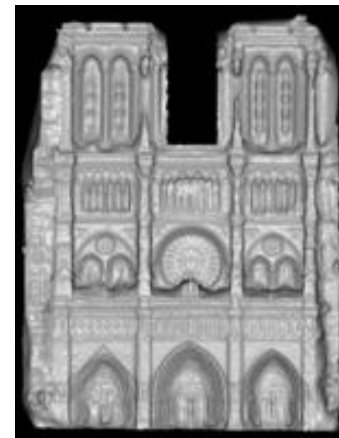
[Furukawa10]



[Pollefeys08]

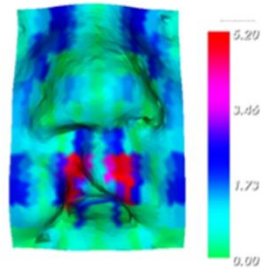
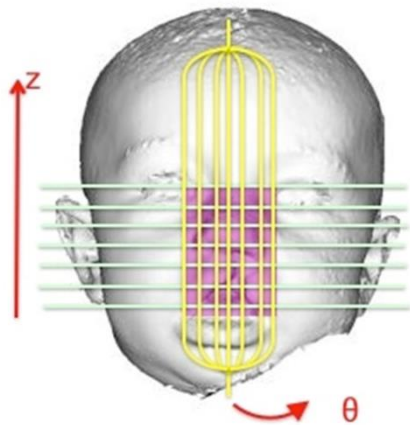


[Cornelis08]

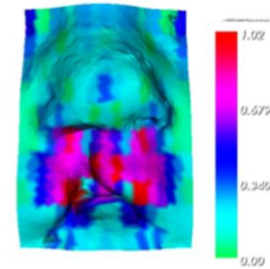


[Goesele07]

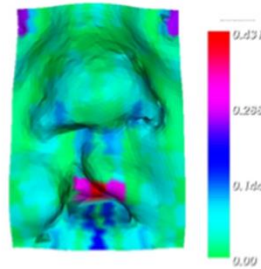
Applications: Medicine



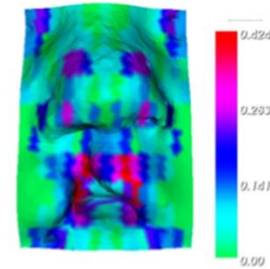
(a) Radius difference



(b) Angle difference



(c) Curvature difference

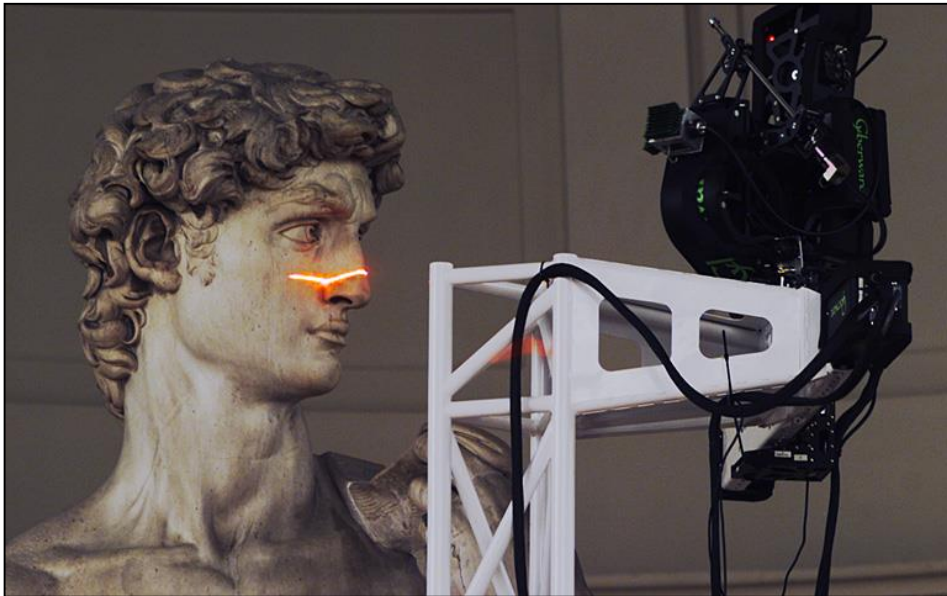


(d) Edge difference

expert's order	1	2	3	4	5	6	7	8	9	10
images										
learning	1	3	2	4	5	6	8	9	7	10
a-lmk	1	2	3	5	6	4	8	7	9	10
mirror	1	2	4	8	5	6	9	3	7	10
m-lmk	1	2	3	4	5	6	9	7	10	8
plane	1	2	3	5	4	6	7	9	10	8

Scanning technologies

- Laser scanner, coordinate measuring machine
 - Very accurate
 - Very Expensive
 - Complicated to use

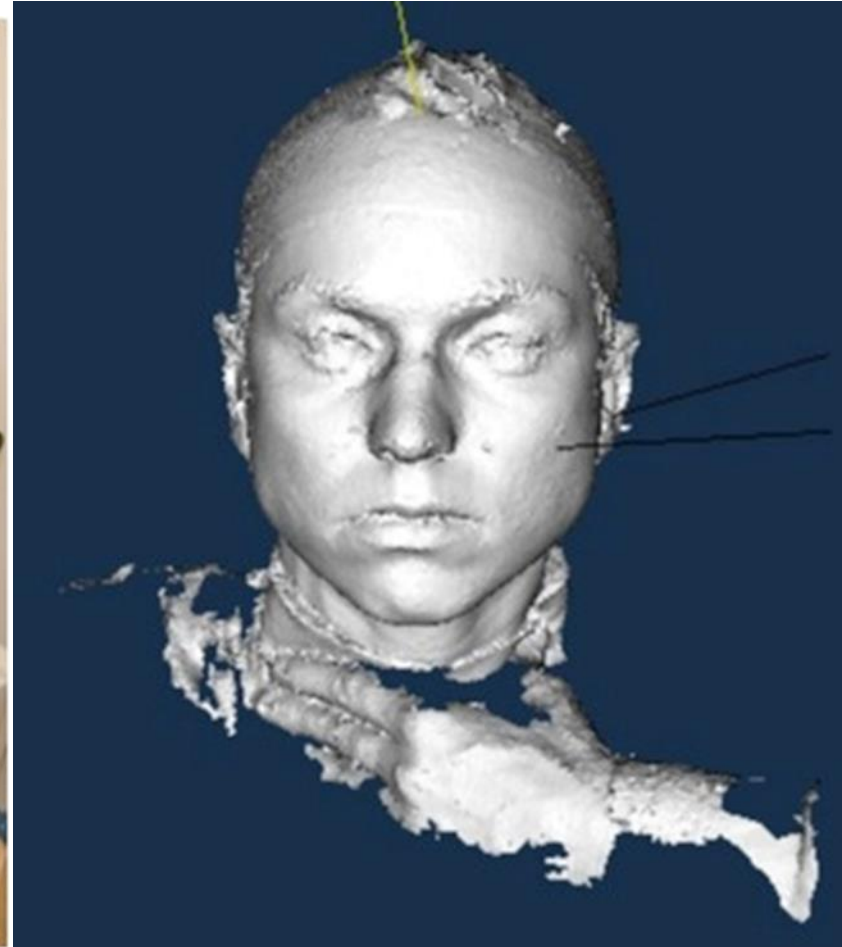


Minolta

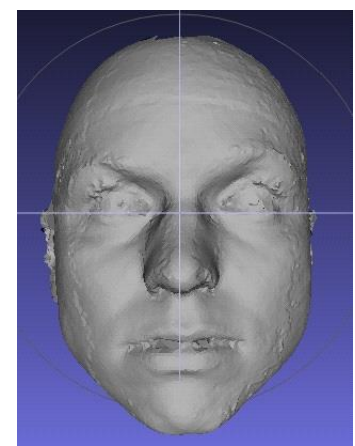
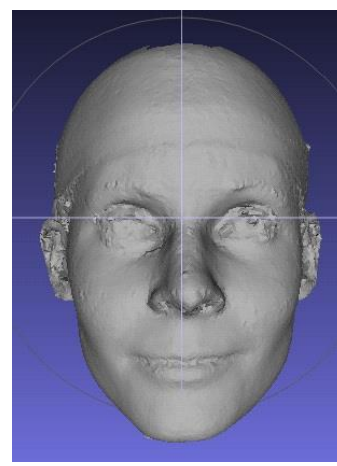
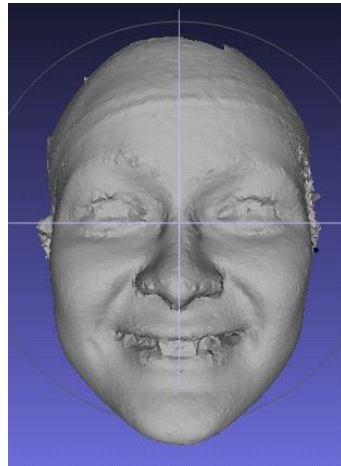
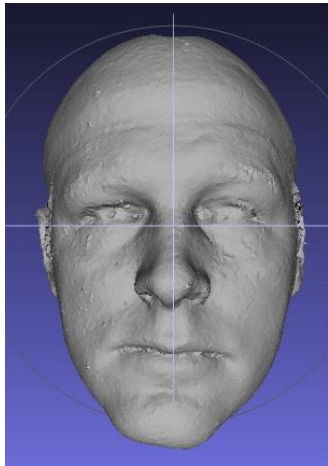
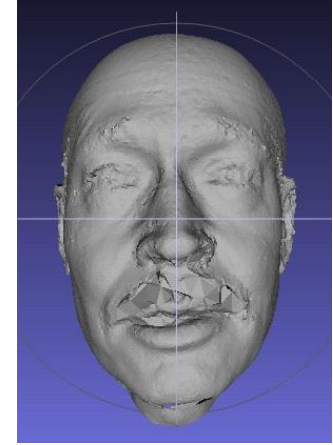
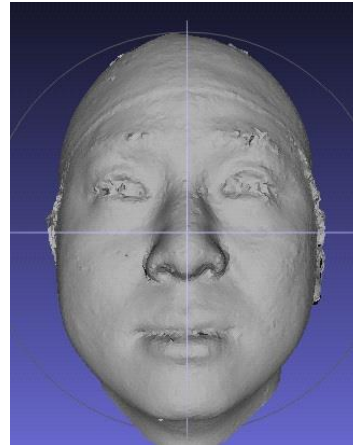
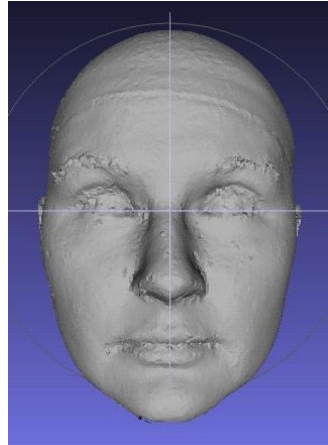
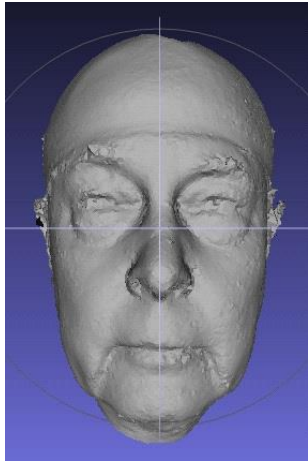


Contura CMM

Medical Scanning System

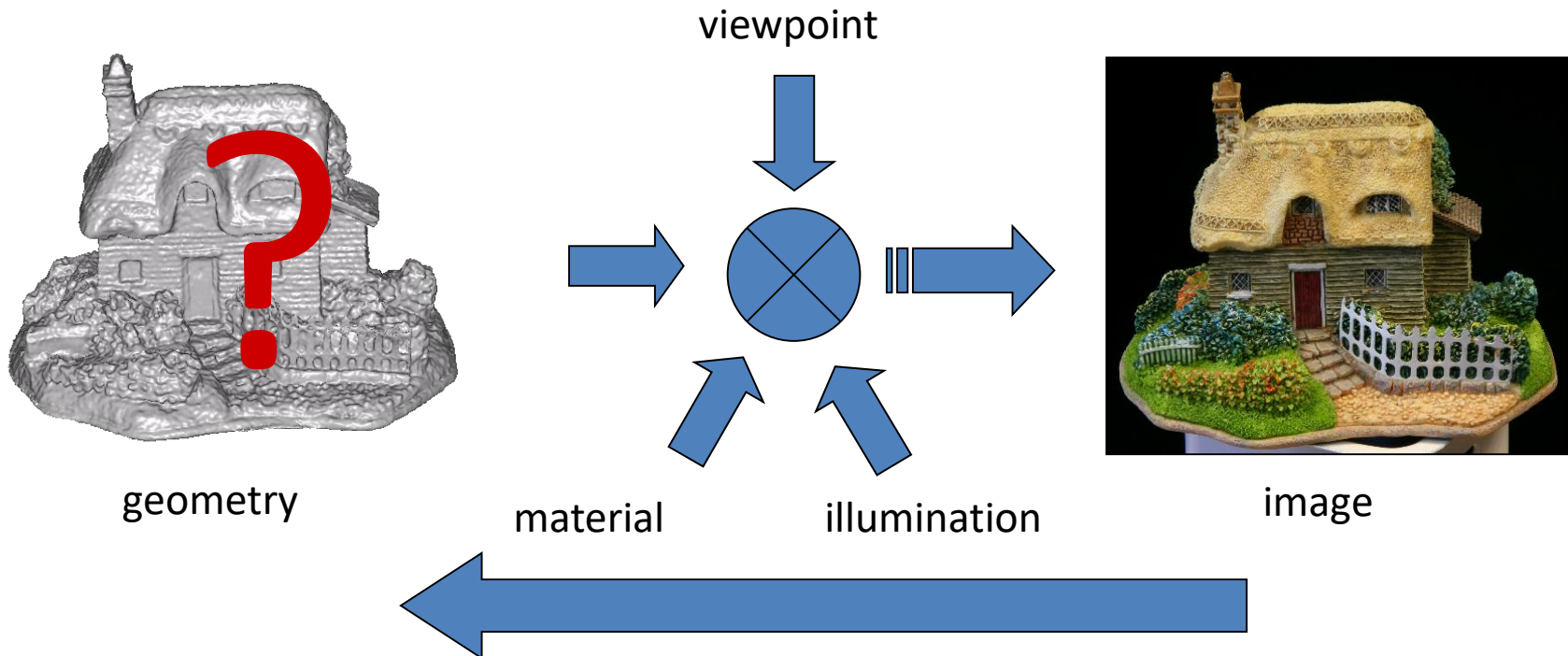


The “Us” Data Set (subset)



3d shape from photographs

“Estimate a 3d shape that would generate the input photographs given the same material, viewpoints and illumination”



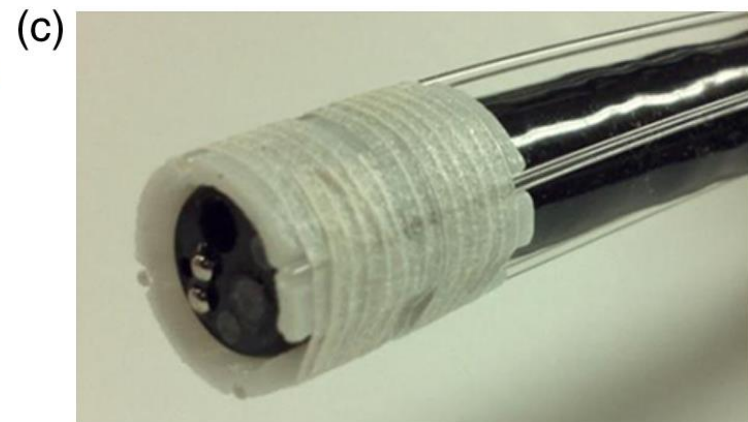
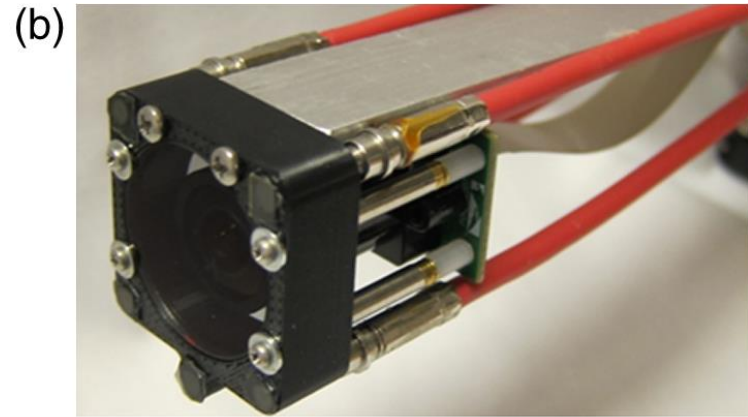
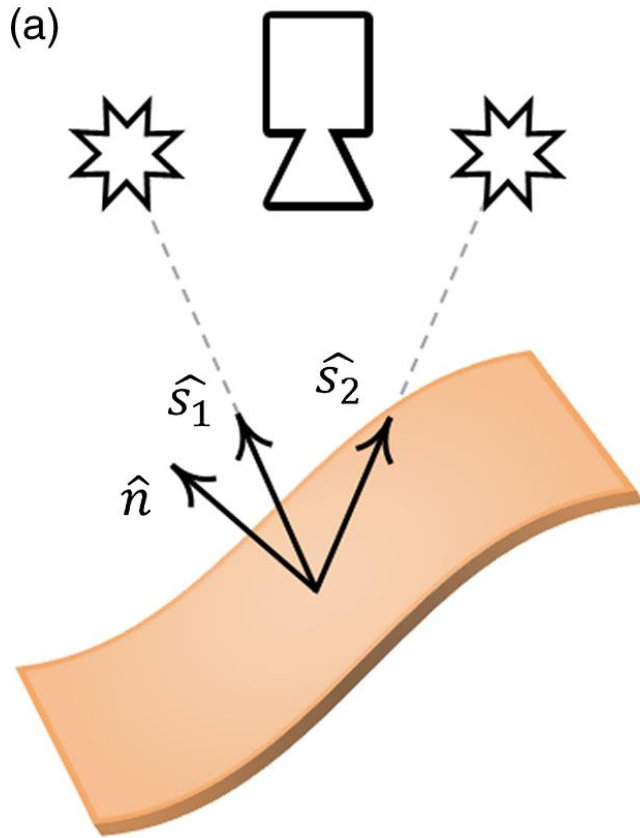
Photometric Stereo

- Estimate the surface normals of a given scene given multiple 2D images taken from the *same* viewpoint, but under *different lighting* conditions.
- **Basic photometric stereo** required a Lambertian reflectance model:

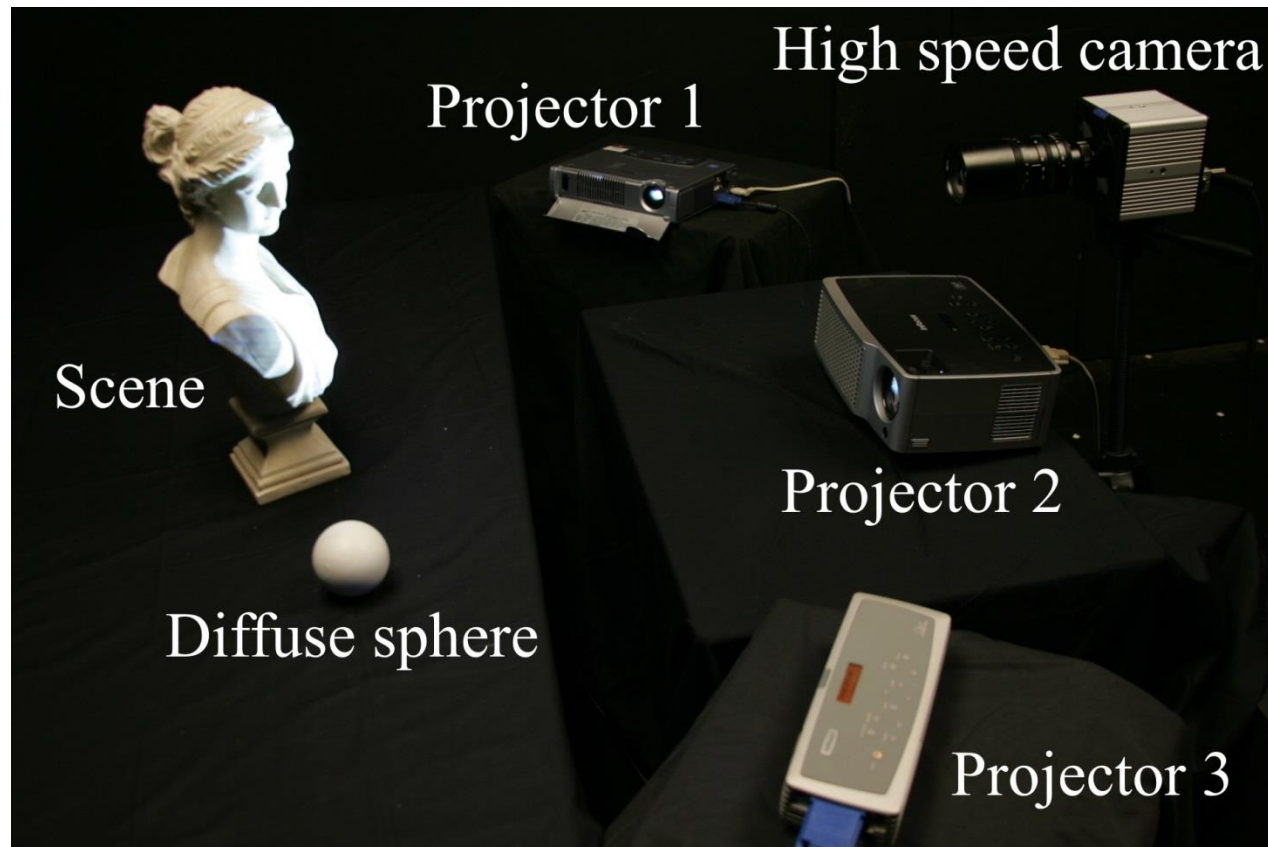
$$I = \rho \mathbf{n} \cdot \mathbf{v}$$

where I is pixel **intensity**, \mathbf{n} is the **normal**, \mathbf{v} is the **lighting direction**, and ρ is diffuse albedo constant, which is a reflection coefficient.

Basic Photometric Stereo



Basic Photometric Stereo



Basic Photometric Stereo

- K light sources
- Lead to K images $R_1(p,q), \dots, R_K(p,q)$ each from just one of the light sources being on
- For any (p,q) , we get K intensities I_1, \dots, I_K
- Leads to a set of linear equations of the form

$$I_k = \rho \mathbf{n} \cdot \mathbf{v}_k$$

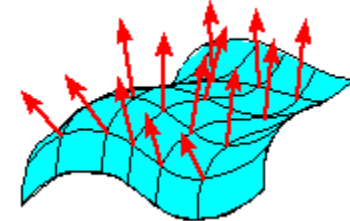
- Solving leads to a surface normal map.

Photometric Stereo

Inputs



3D normals



3d shape from photographs

Photograph based 3d reconstruction is:

- ✓ practical
- ✓ fast
- ✓ non-intrusive
- ✓ low cost
- ✓ Easily deployable outdoors
- ✗ “low” accuracy
- ✗ Results depend on material properties

Reconstruction

- Generic problem formulation: given several images of the same object or scene, compute a representation of its 3D shape



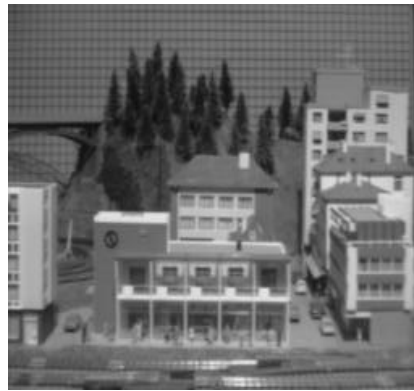
Reconstruction

- **Generic problem formulation:** given several images of the same object or scene, compute a representation of its 3D shape
- **“Images of the same object or scene”**
 - Arbitrary number of images (from two to thousands)
 - Arbitrary camera positions (camera network or video sequence)
 - Calibration may be initially unknown
- **“Representation of 3D shape”**
 - Depth maps
 - Meshes
 - Point clouds
 - Patch clouds
 - Volumetric models
 - Layered models

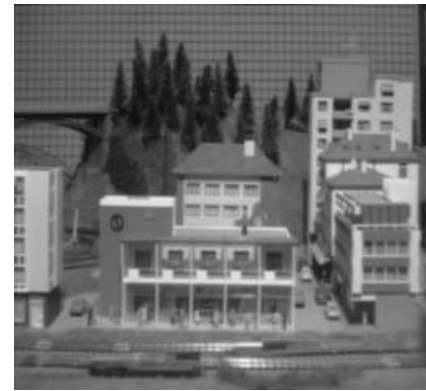
Multiple-baseline stereo



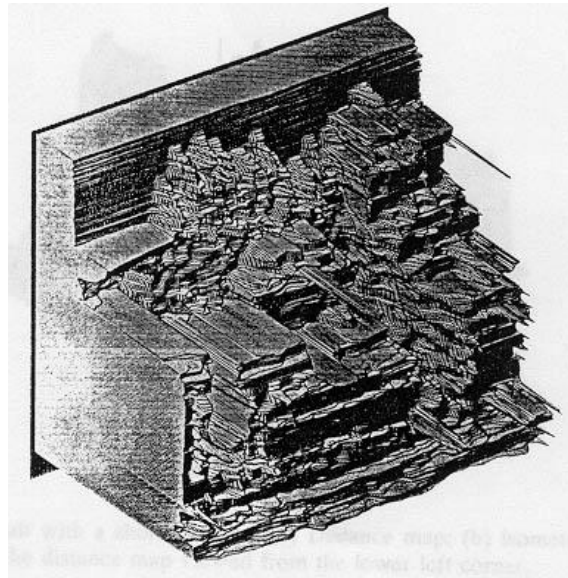
I1



I2



I10

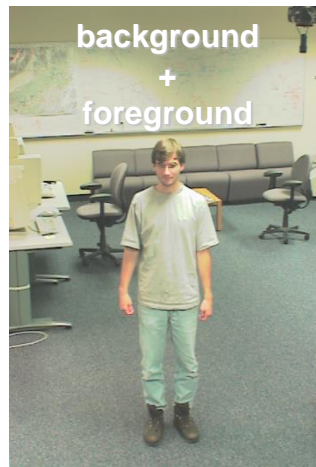
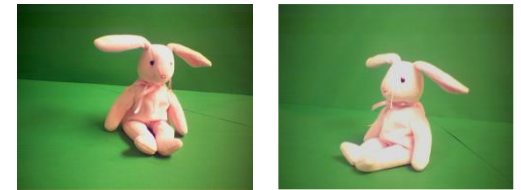


M. Okutomi and T. Kanade, ["A Multiple-Baseline Stereo System,"](#) IEEE Trans. on Pattern Analysis and Machine Intelligence, 15(4):353-363 (1993).

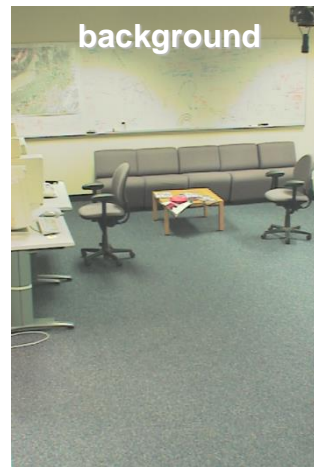
Reconstruction from silhouettes

Can be computed robustly

Can be computed efficiently



-



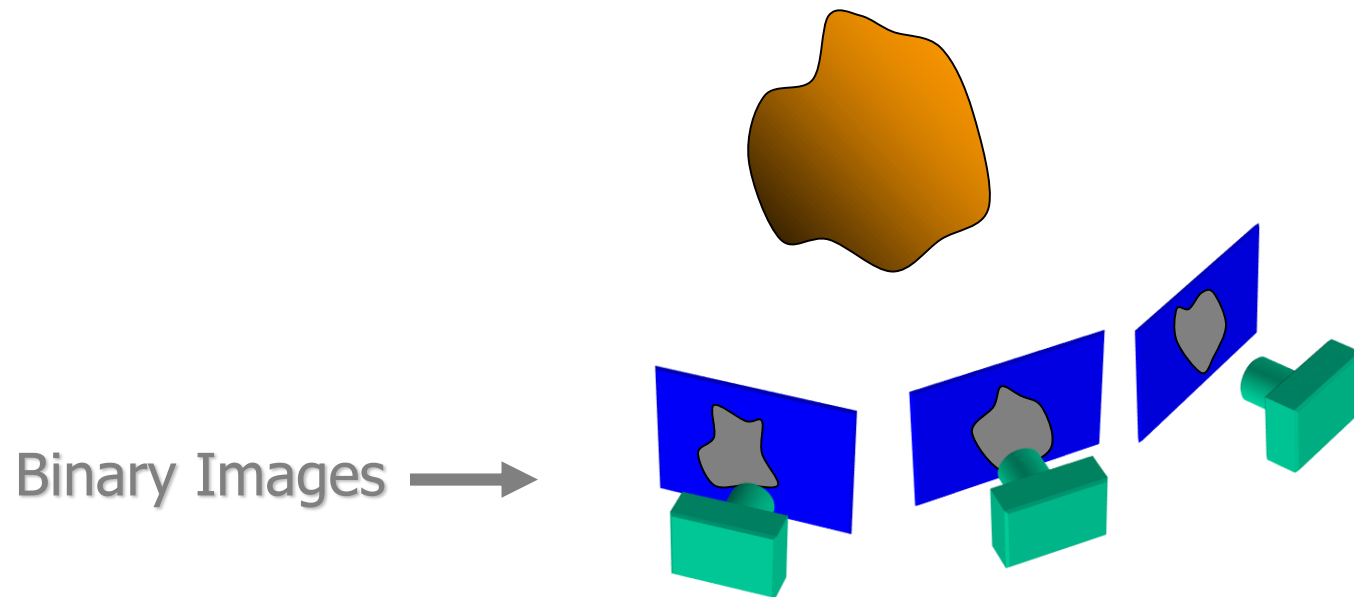
=

foreground



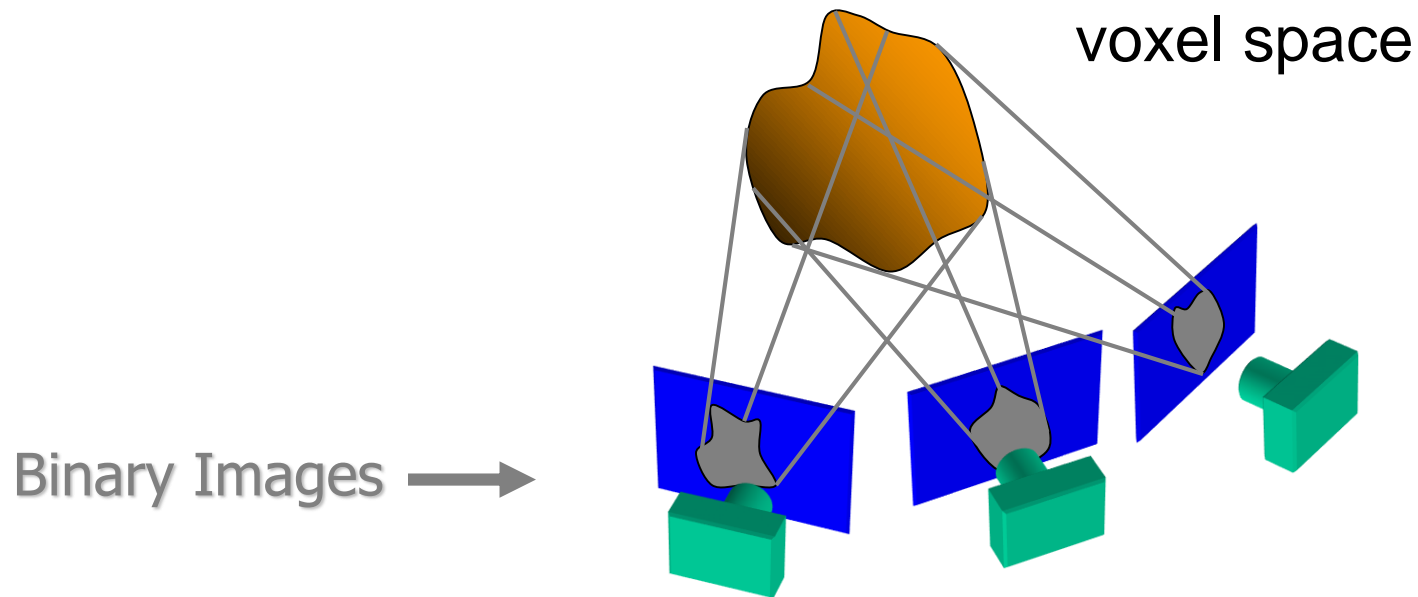
Reconstruction from Silhouettes

- The case of binary images: a voxel is **photo-consistent** if it lies inside the object's silhouette in **all** views



Reconstruction from Silhouettes

- The case of binary images: a voxel is **photo-consistent** if it lies inside the object's silhouette in **all views**



Finding the silhouette-consistent shape (*visual hull*):

- *Backproject* each silhouette
- Intersect backprojected volumes

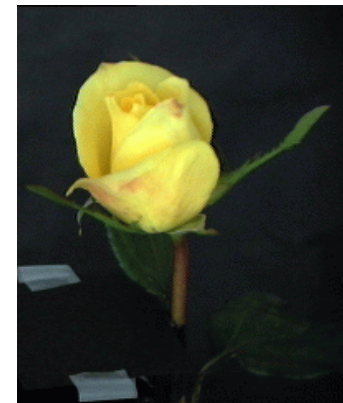
Calibrated Image Acquisition



Calibrated Turntable

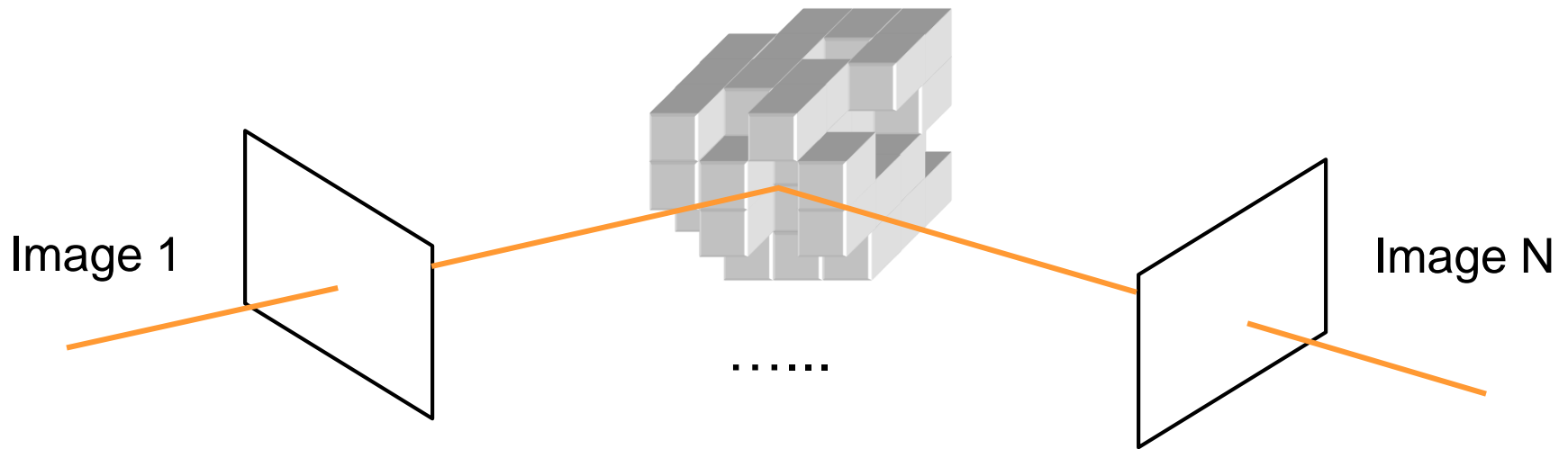


Selected Dinosaur Images



Selected Flower Images

Space Carving in General

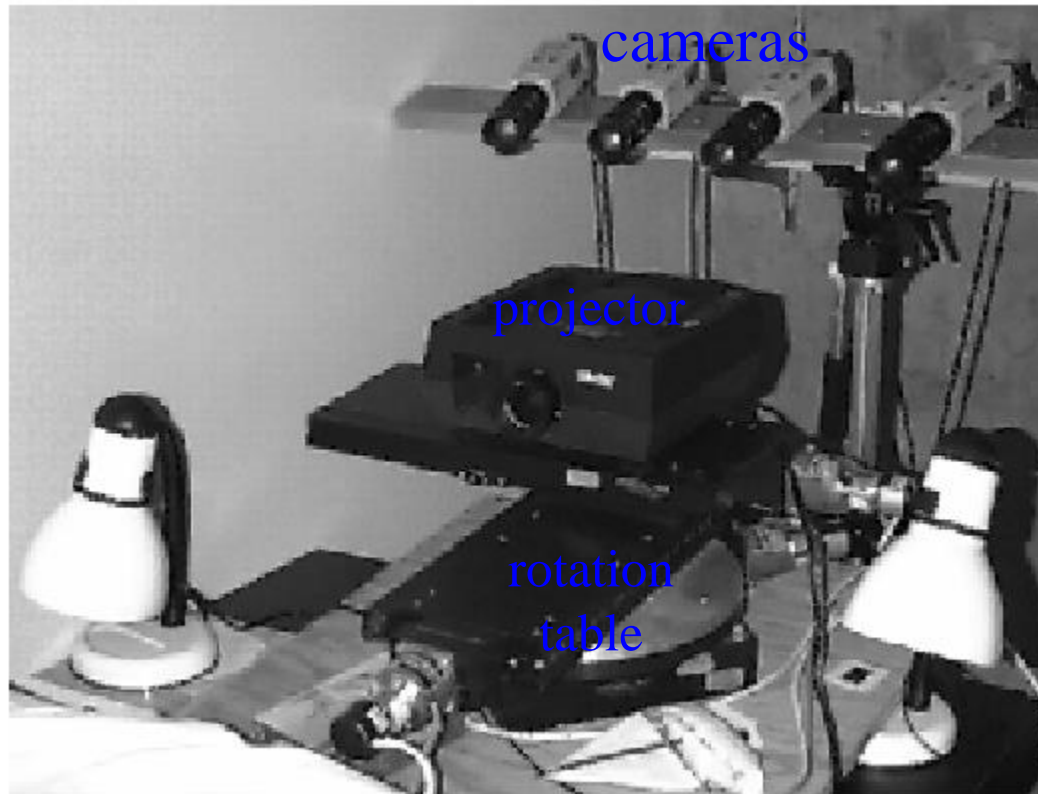


Space Carving Algorithm

- Initialize to a volume V containing the true scene
- Choose a voxel on the outside of the volume
- Project to visible input images
- Carve if not photo-consistent (inside object's silhouette)
- Repeat until convergence

Our 4-camera light-striping stereo system

(now deceased)



3D
object

Calibration Object

The idea is to snap images at different depths and get a lot of **2D-3D point correspondences**.



Surface Modeling and Display from Range and Color Data



Kari	Pulli	UW
Michael	Cohen	MSR
Tom	Duchamp	UW
Hugues	Hoppe	MSR
John	McDonald	UW
Linda	Shapiro	UW
Werner	Stuetzle	UW

UW = University of Washington
Seattle, WA USA
MSR = Microsoft Research
Redmond, WA USA

Introduction

Goal

- develop robust algorithms for constructing 3D models from range & color data
- use those models to produce realistic renderings of the scanned objects



Surface Reconstruction

Step 1: Data acquisition

Obtain range data that covers the object. Filter, remove background.

Step 2: Registration

Register the range maps into a common coordinate system.

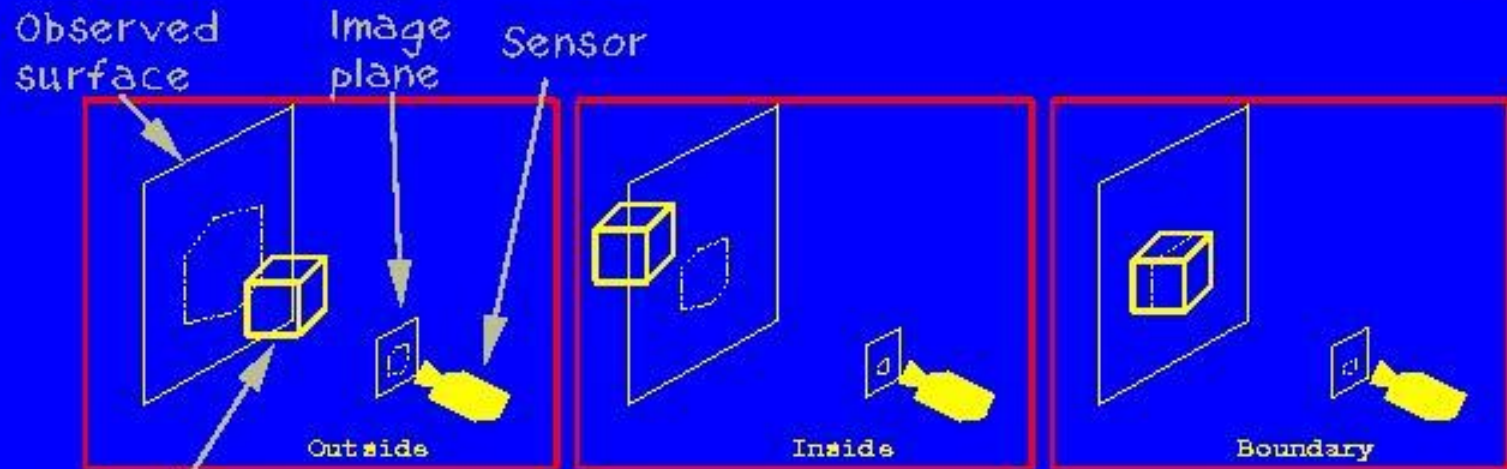
Step 3: Integration

Integrate the registered range data into a single surface representation.

Step 4: Optimization

Fit the surface more accurately to the data, simplify the representation.

Carve space in cubes



Volume under consideration

Label cubes

- Project cube to image plane (hexagon)
- Test against data in the hexagon

3D space is made up of many cubes.

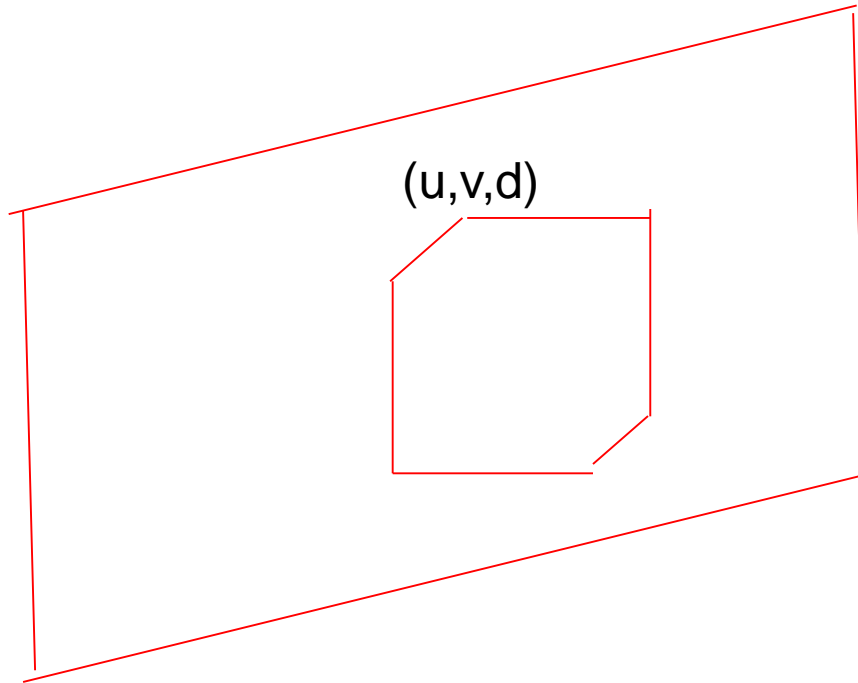
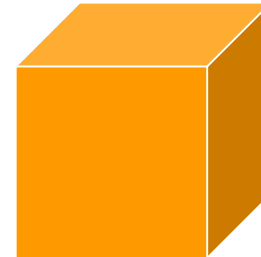


image plane
depth map

(x,y,z)



OUTSIDE

one of many cubes
in virtual 3D cube space

Several views

Processing order:
FOR EACH cube
FOR EACH view

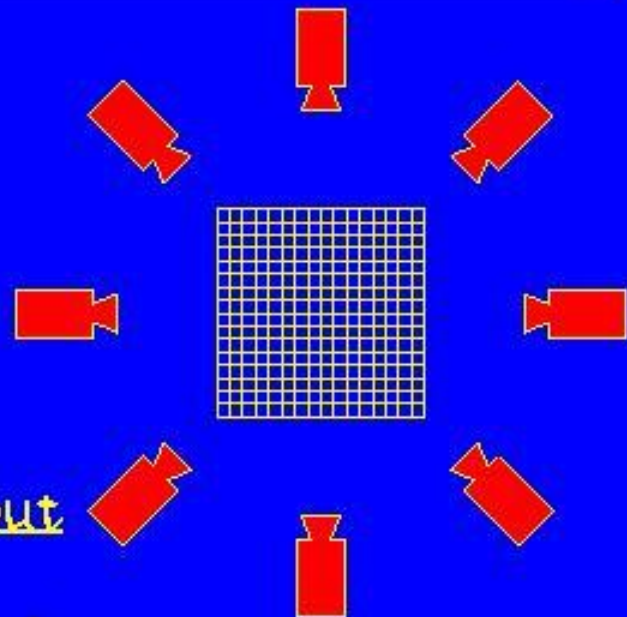
Rules:

any view thinks cube's out
=> it's out

every view thinks cube's in
=> it's in

else

=> it's at boundary

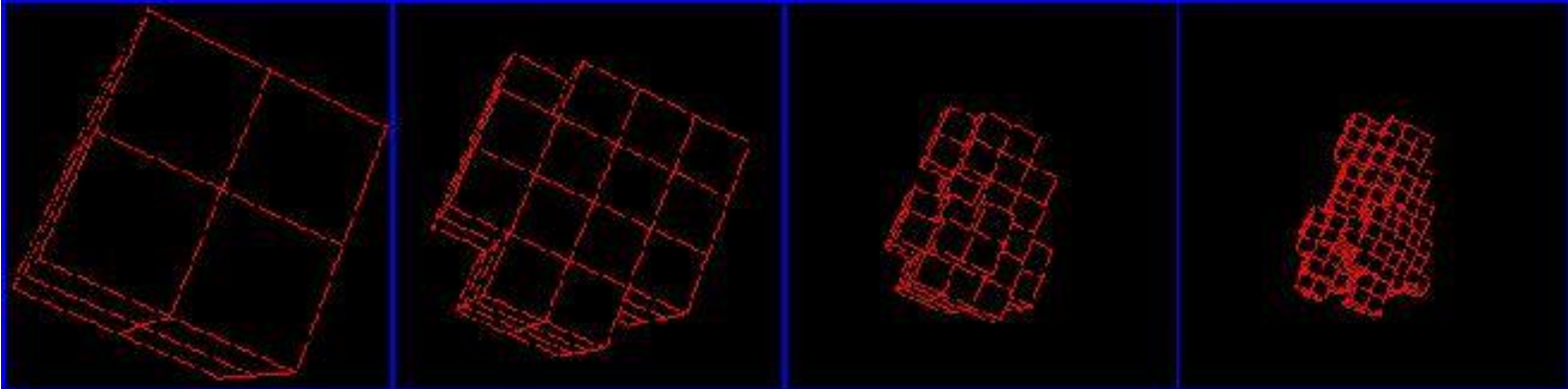


Hierarchical space carving

- Big cubes => fast, poor results
- Small cubes => slow, more accurate results
- Combination = octrees

RULES:

- cube's out => done
- cube's in => done
- else => recurse

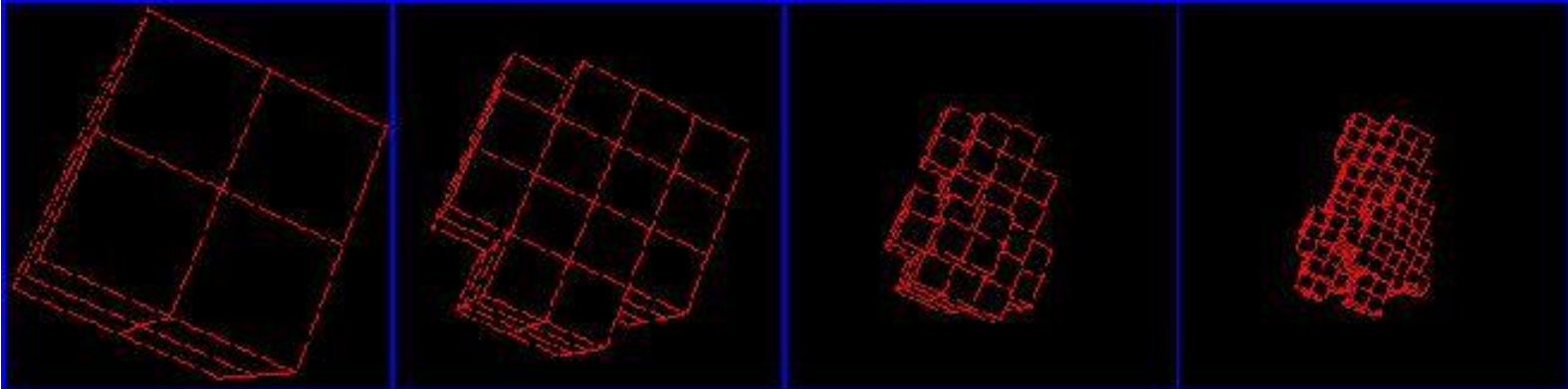


Hierarchical space carving

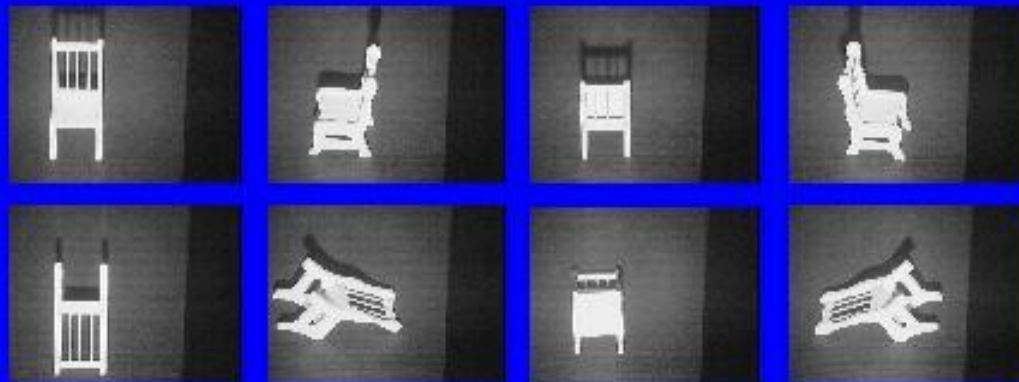
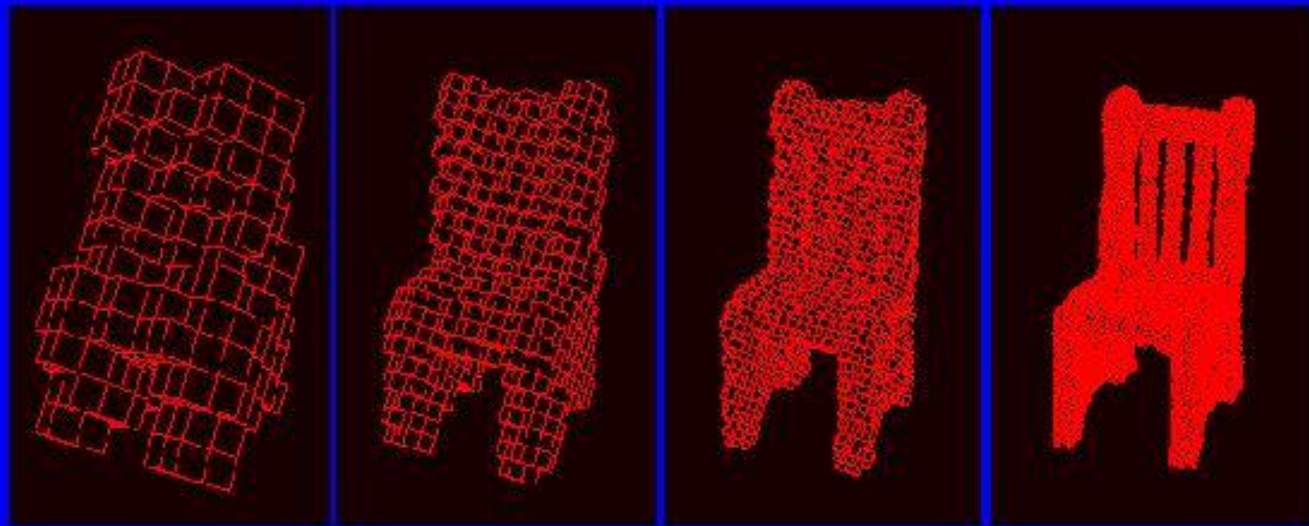
- Big cubes => fast, poor results
- Small cubes => slow, more accurate results
- Combination = octrees

RULES:

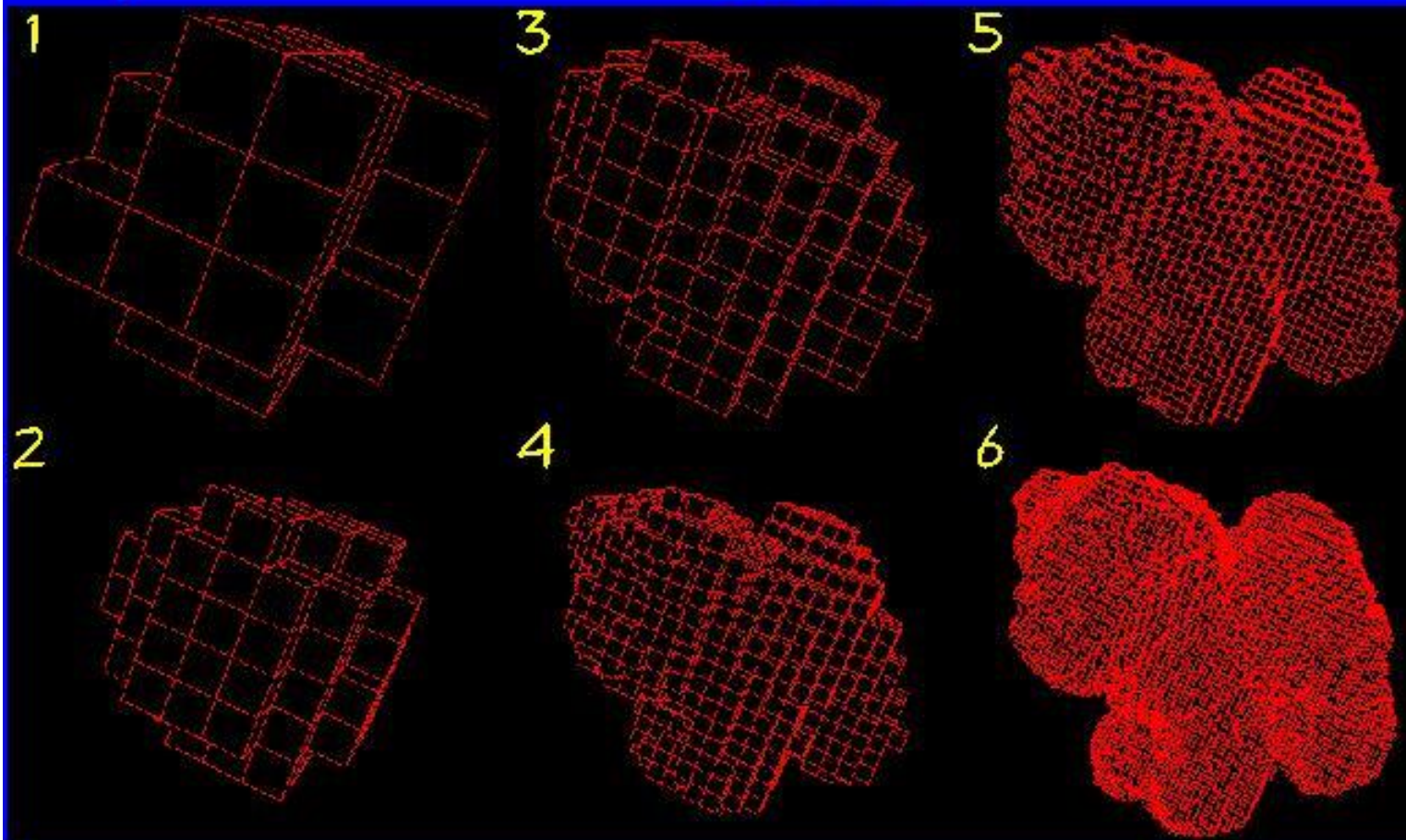
- cube's out => done
- cube's in => done
- else => recurse



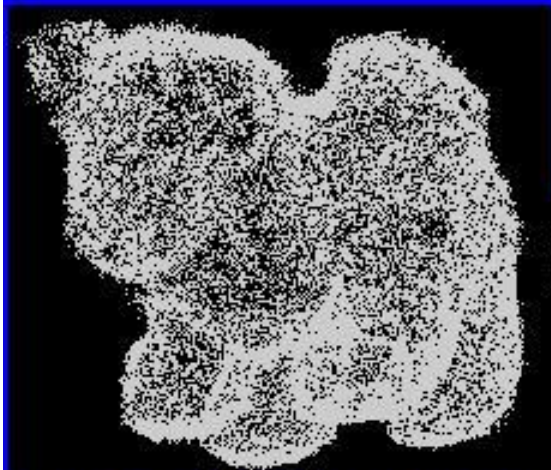
The rest of the chair



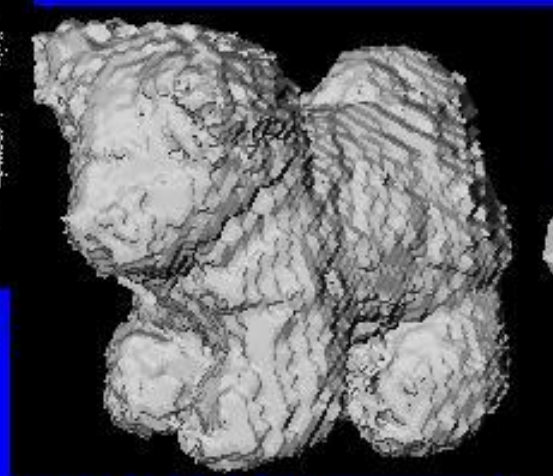
Same for a husky pup



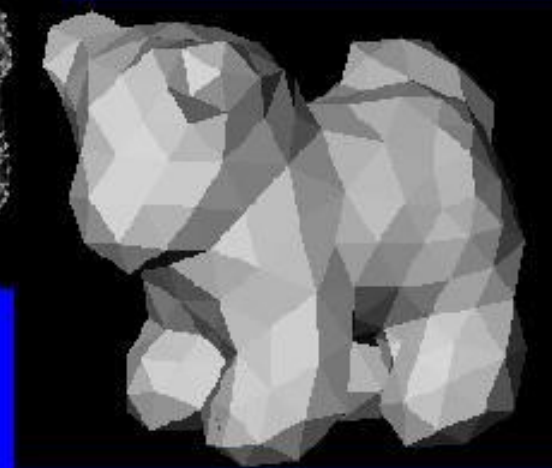
Optimizing the dog mesh



Registered points



Initial mesh

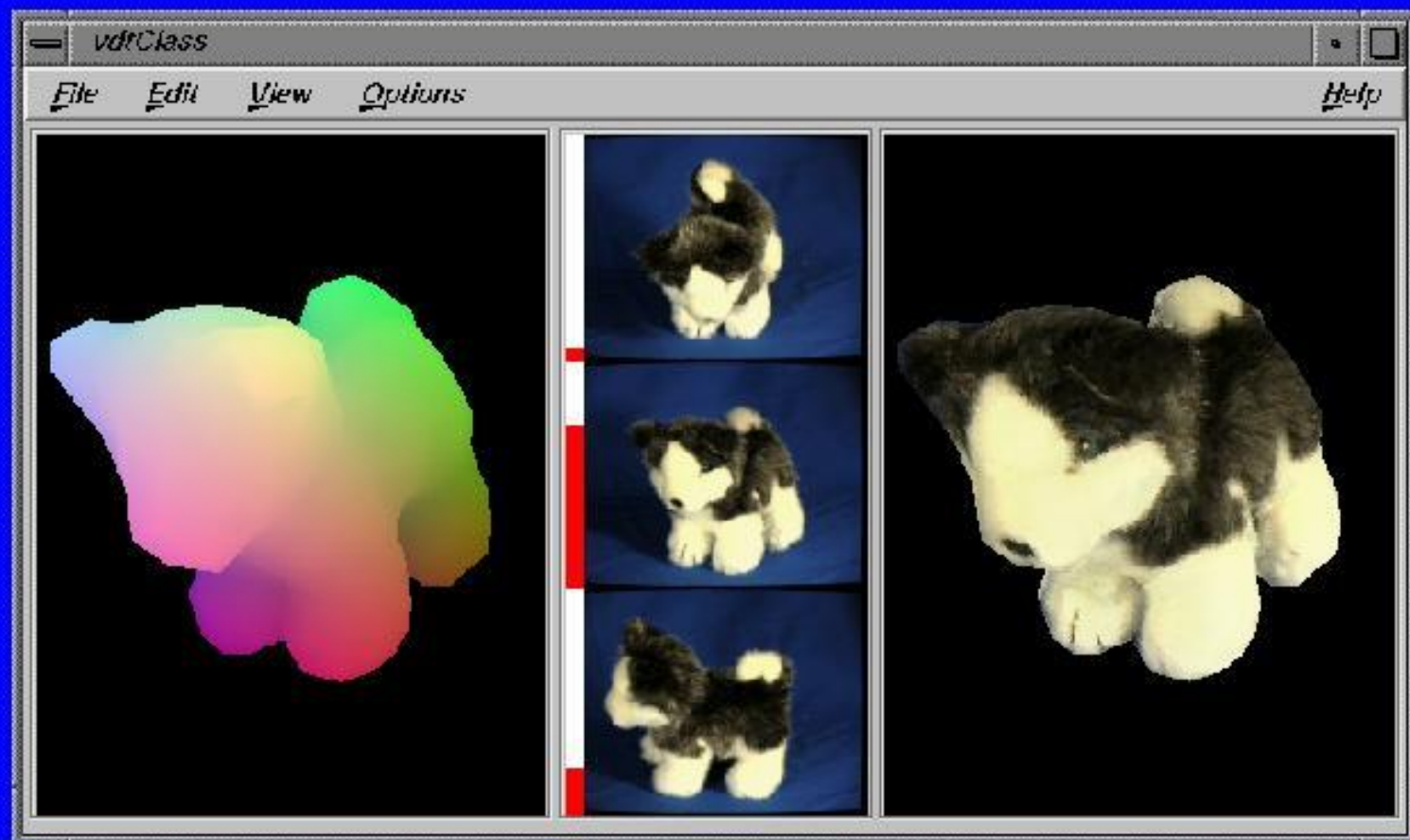


Optimized mesh

View dependent texturing



Our viewer



More: Space Carving Results: African Violet



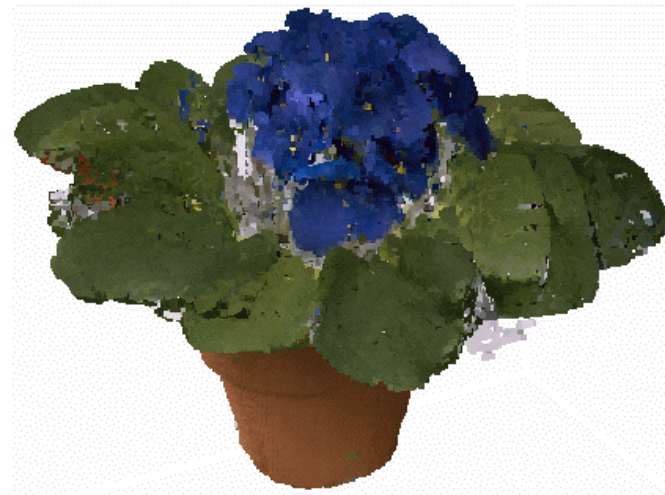
Input Image (1 of 45)



Reconstruction



Reconstruction



Reconstruction

More: Space Carving Results: Hand



**Input Image
(1 of 100)**



Views of Reconstruction

Stereo from community photo collections

- Up to now, we've always assumed that camera calibration is known
- For photos taken from the Internet, we need *structure from motion* techniques to reconstruct both camera positions and 3D points. (SEE POSTED VIDEO)



Sort: **Relevant** | Recent | Interesting View: **Small** | Medium | Detail | Slideshow



From EdZa



From micbaun



From rafaj



From lepublicnme



From Jesus...



From Julio...



From StephiGra...



From alabs



From BigMs.Take



From laurenbou...



From laurenbou...



From StephiGra...



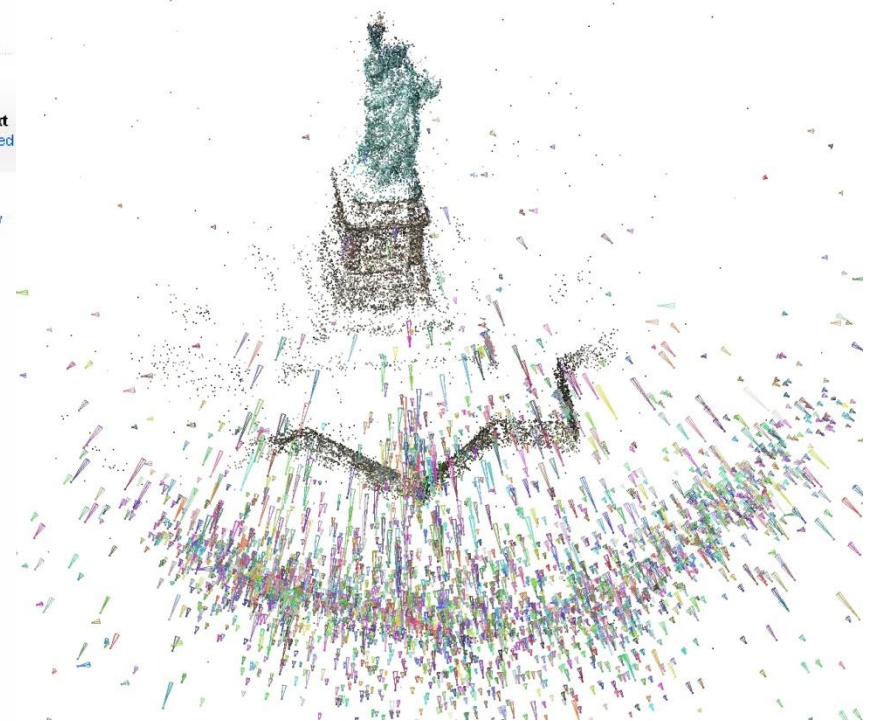
From dmp0309

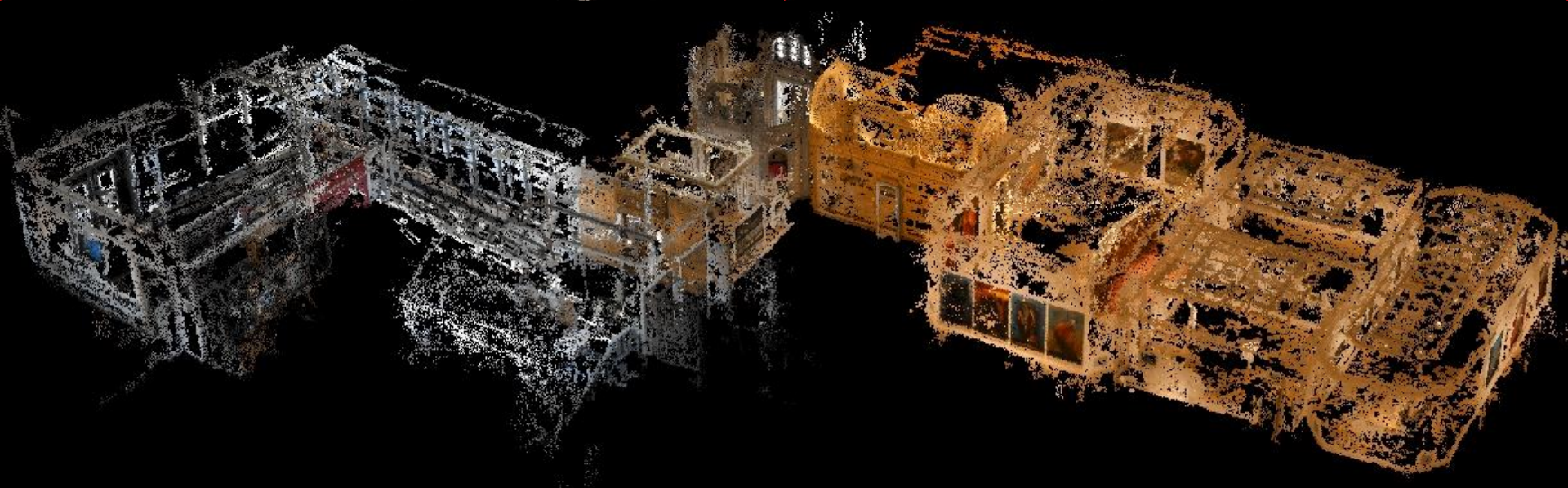


From laverrue



From Mojumbo22...





Head Reconstruction from Uncalibrated Internet Photos

Input: Internet photos in different poses and expressions



Output: 3D model of the head



work of
Shu Liang