

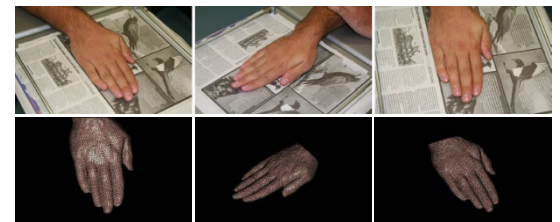
Reconstruction

CSE 455

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

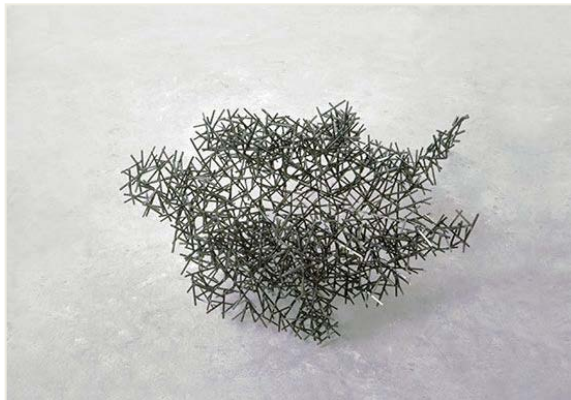
SCULPTEUR European project



Applications: art



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



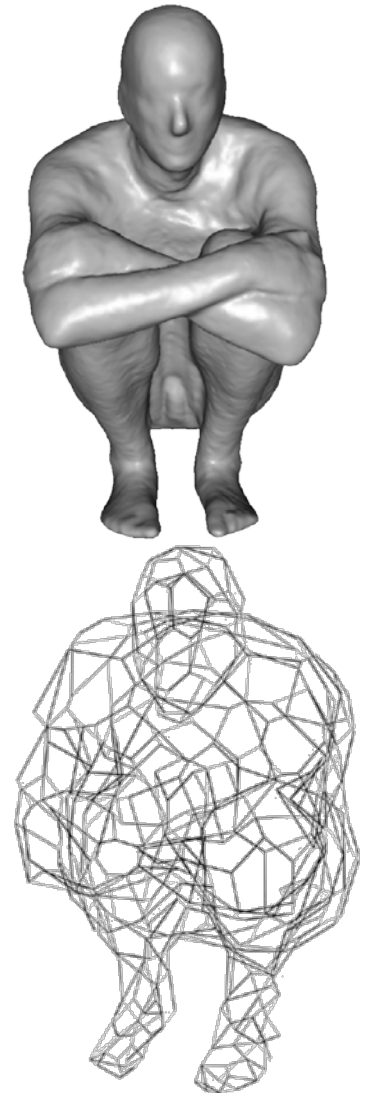
Domain Series Domain VIII Crouching
1999 *Mild steel bar 81 x 59 x 63 cm*



Applications: structure engineering



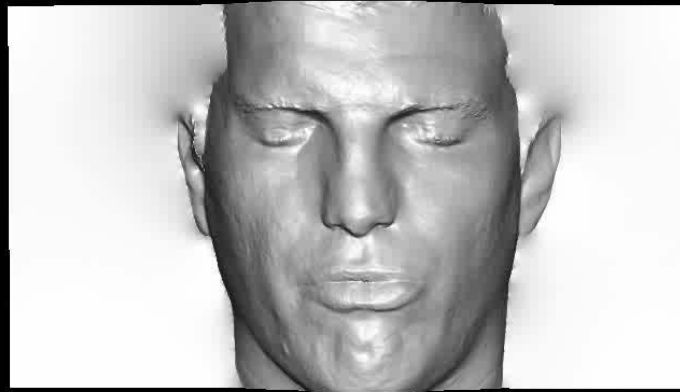
BODY / SPACE / FRAME, Antony Gormley, Lelystad, Holland



Applications: art



Applications: computer games



RECORDING
Frame rate: 5145.217578

Applications: 3D indexing

The image displays a 3D indexing application interface. It features a large grid of 3D models, a search window, and a scene view.

The search window displays the following results:

Index	Model Name	Score
0	deesse0	0.000000
1	deesse5	0.092800
5	deesse2	0.211000
6	ARCHI3203	0.236800

The scene view shows a room with a wooden floor, several tables, and various 3D models scattered on the floor. A person is visible in the background. The scene is labeled with the number 915.

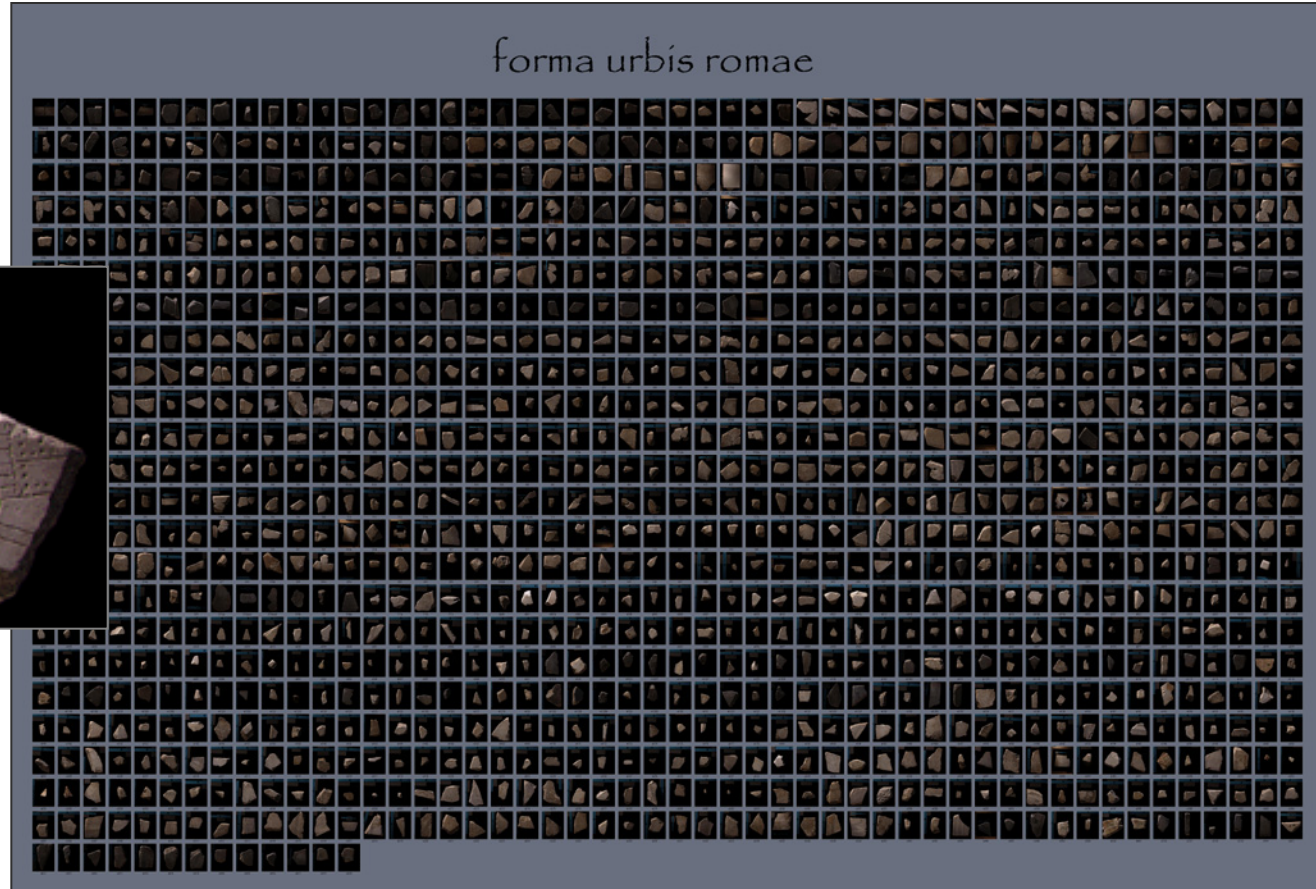
Applications: archaeology

- “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.*

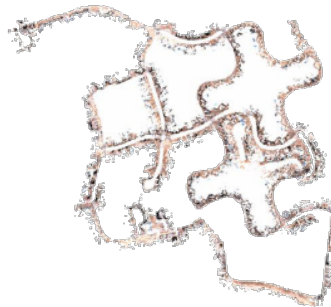


1186 fragments

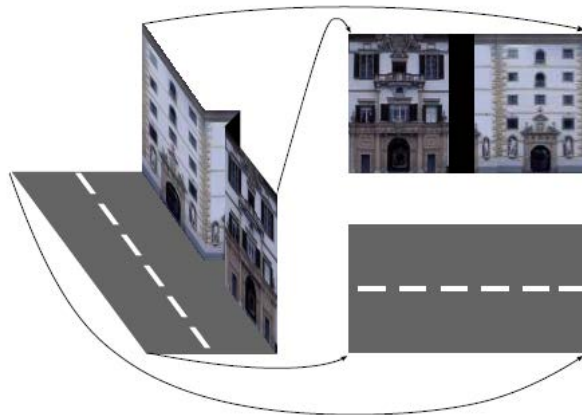
Applications: large scale modelling



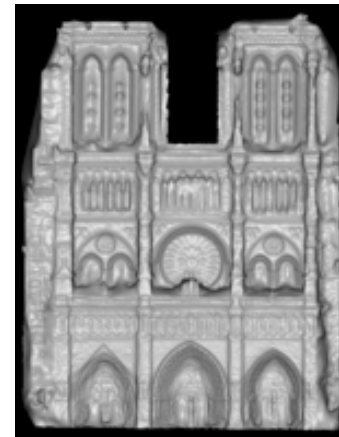
[Furukawa10]



[Pollefeys08]

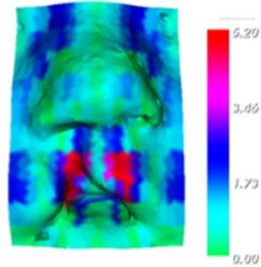
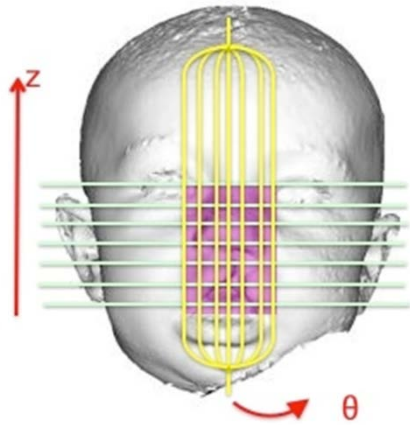


[Cornelis08]

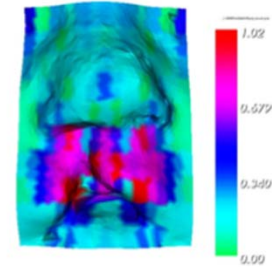


[Goesele07]

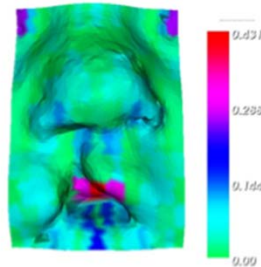
Applications: Medicine



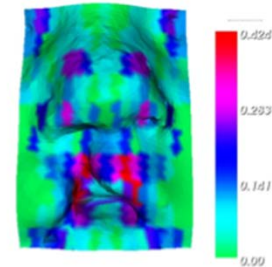
(a) Radius difference



(b) Angle difference



(c) Curvature difference

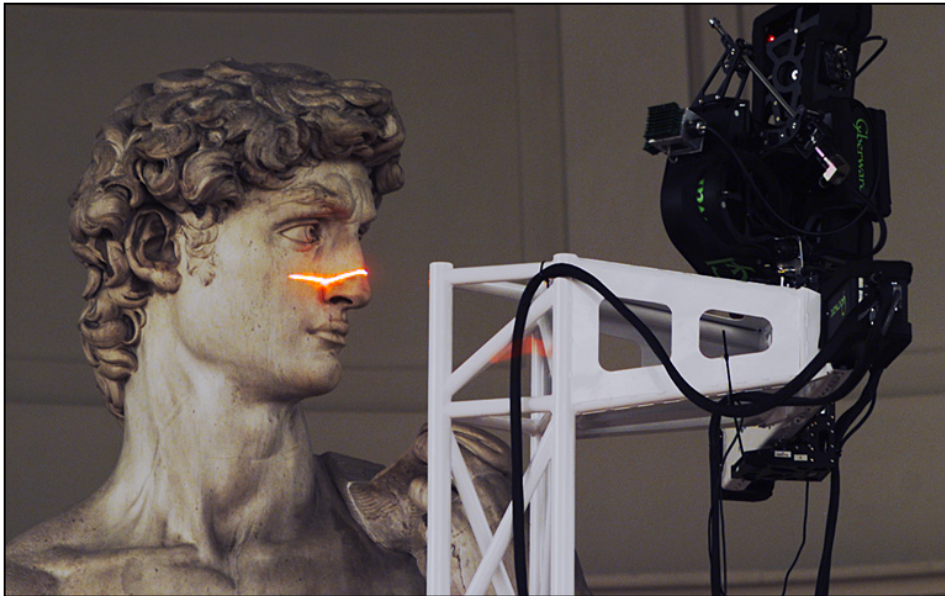


(d) Edge difference

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

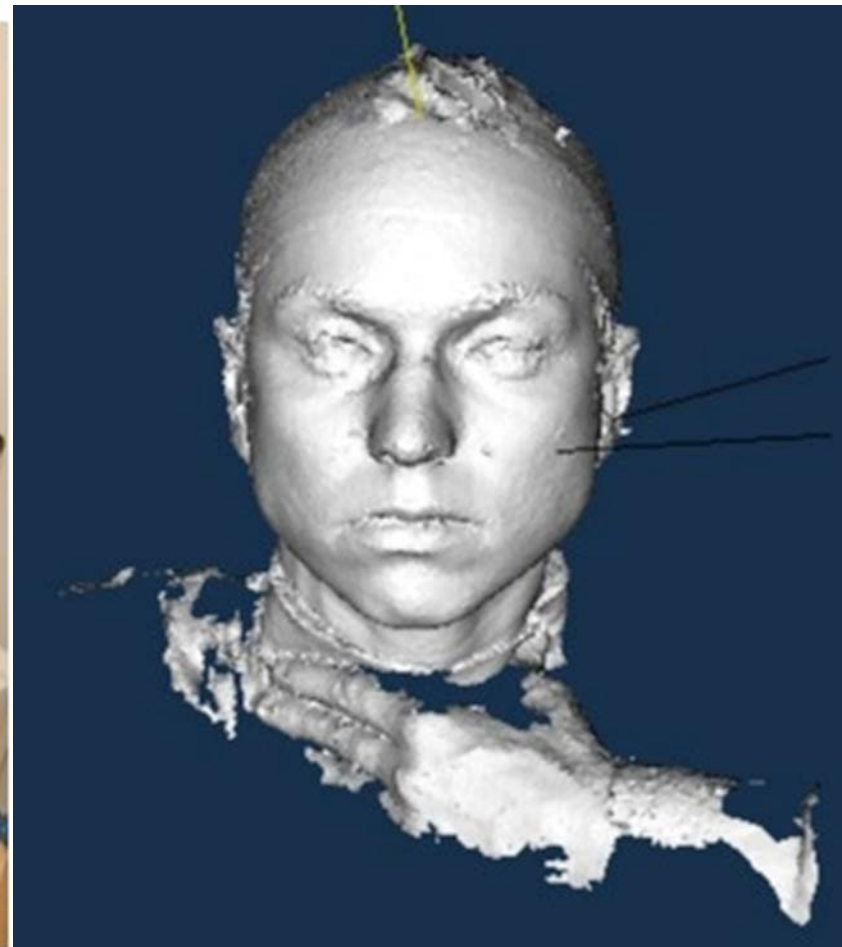


Minolta

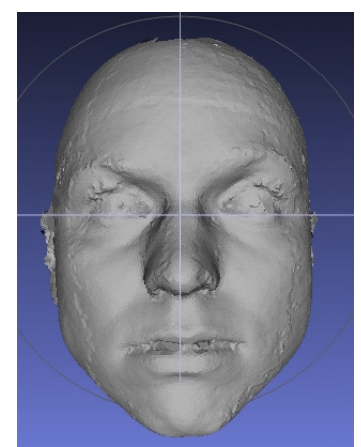
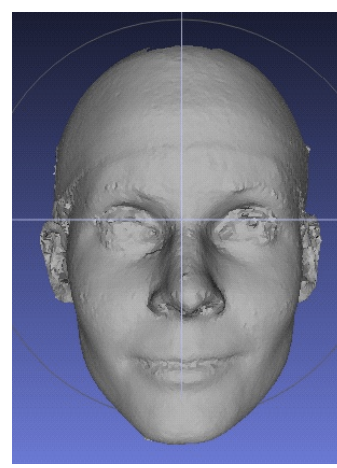
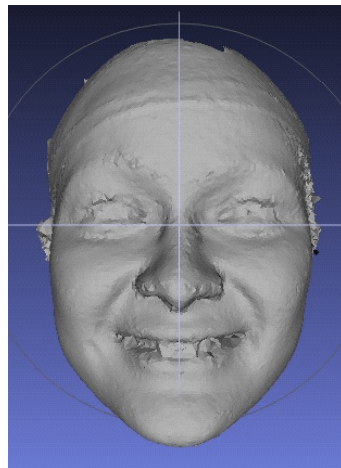
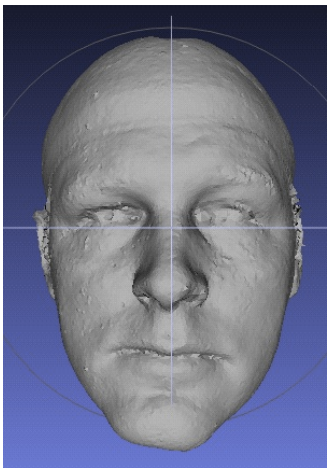
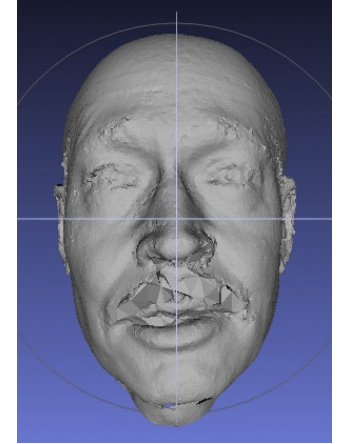
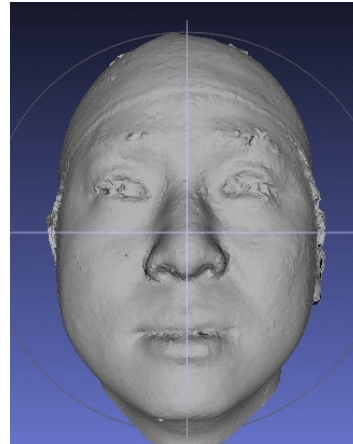
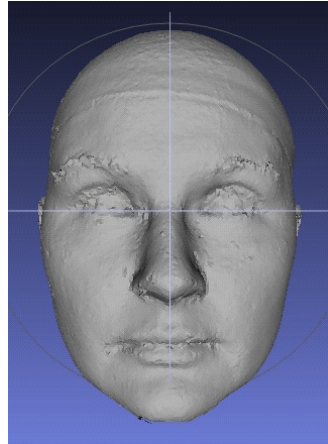
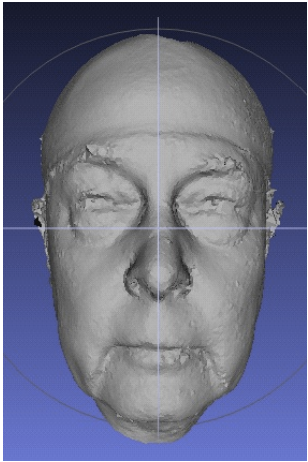


Contura CMM

Medical Scanning System

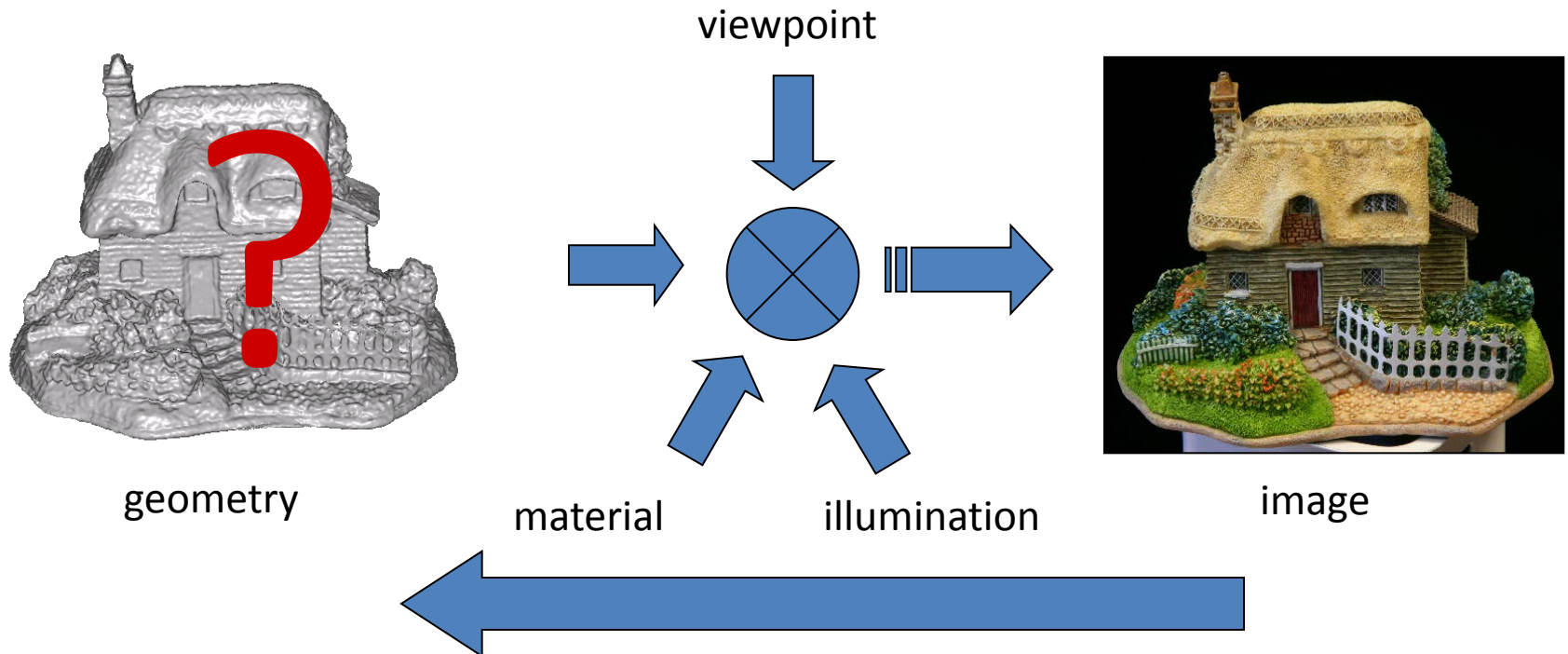


The “Us” Data Set (subset)



3d shape from photographs

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



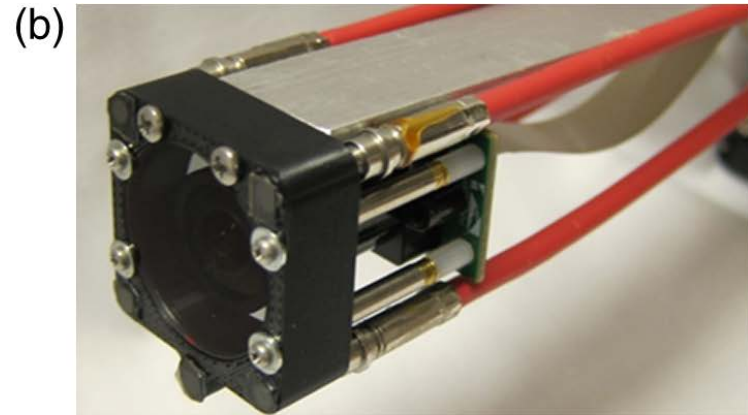
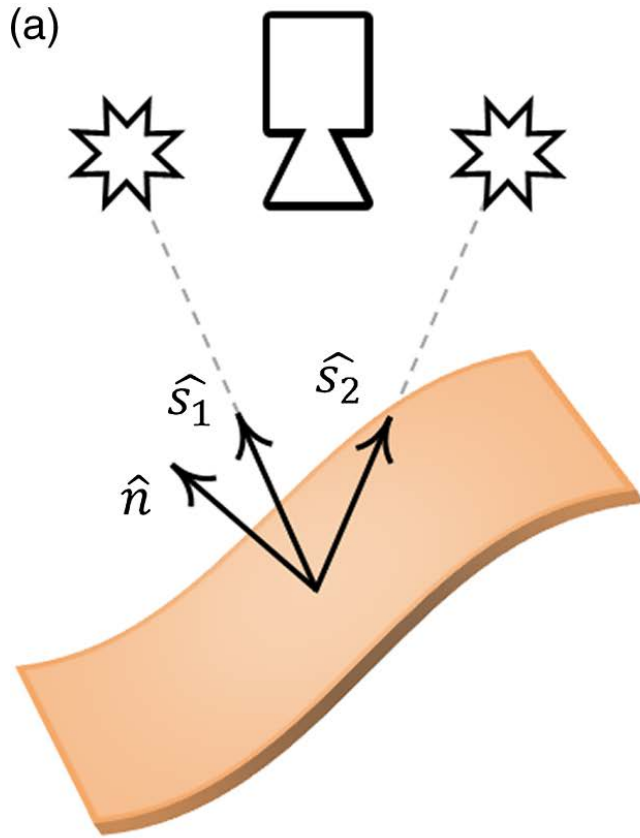
Photometric Stereo

- 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:

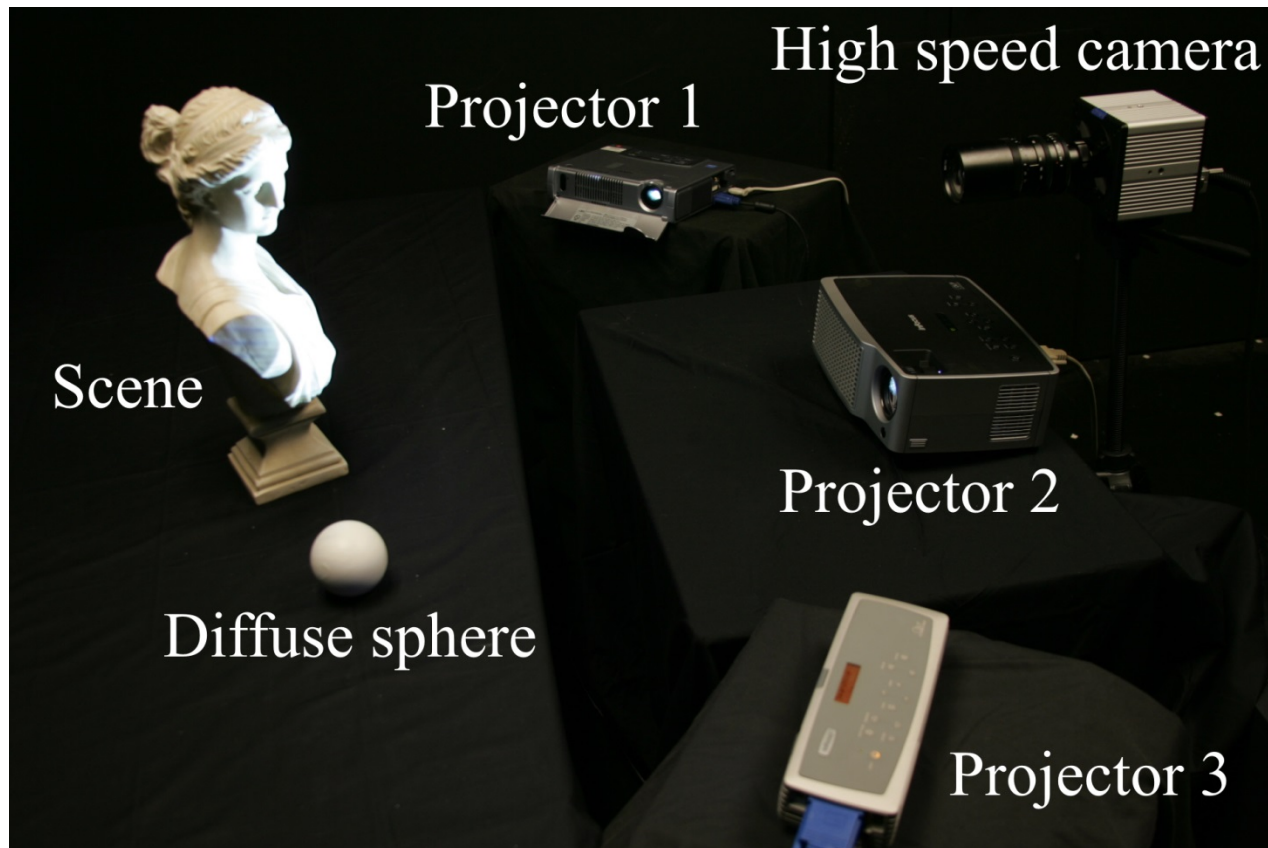
$$I = \rho \mathbf{n} \cdot \mathbf{v}$$

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

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

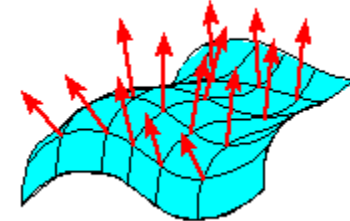
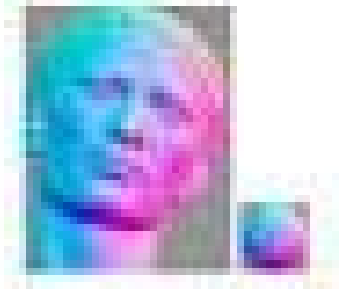
- Solving leads to a surface normal map.

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

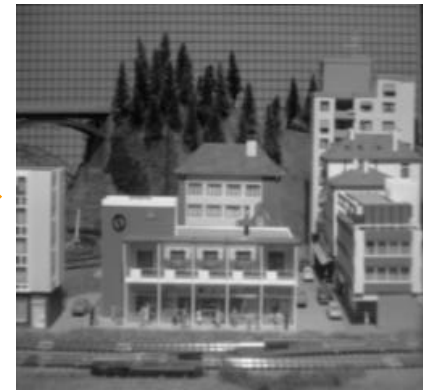
Multiple-baseline stereo



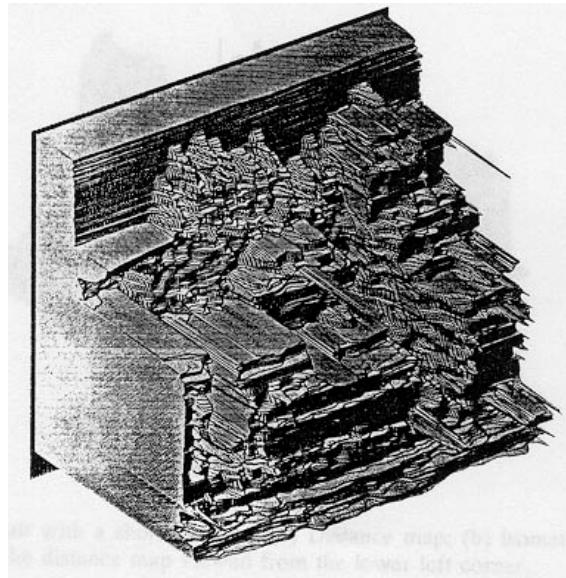
I1



I2



I10

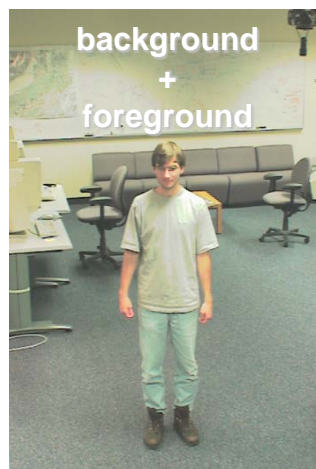
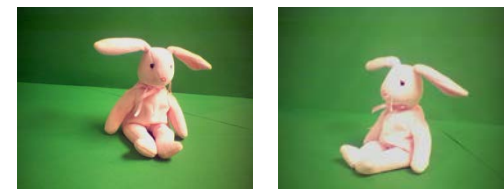


M. Okutomi and T. Kanade, ["A Multiple-Baseline Stereo System,"](#) IEEE Trans. on Pattern Analysis and Machine Intelligence, 15(4):353-363 (1993).

Reconstruction from silhouettes

Can be computed robustly

Can be computed efficiently



-



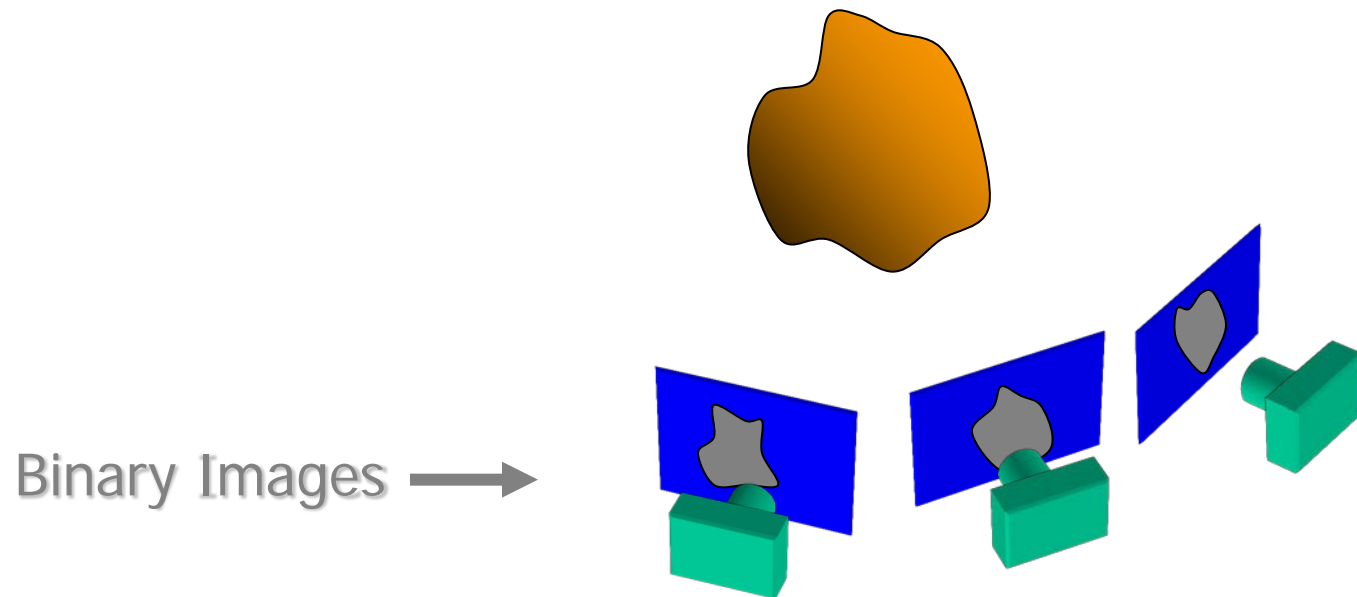
=

foreground



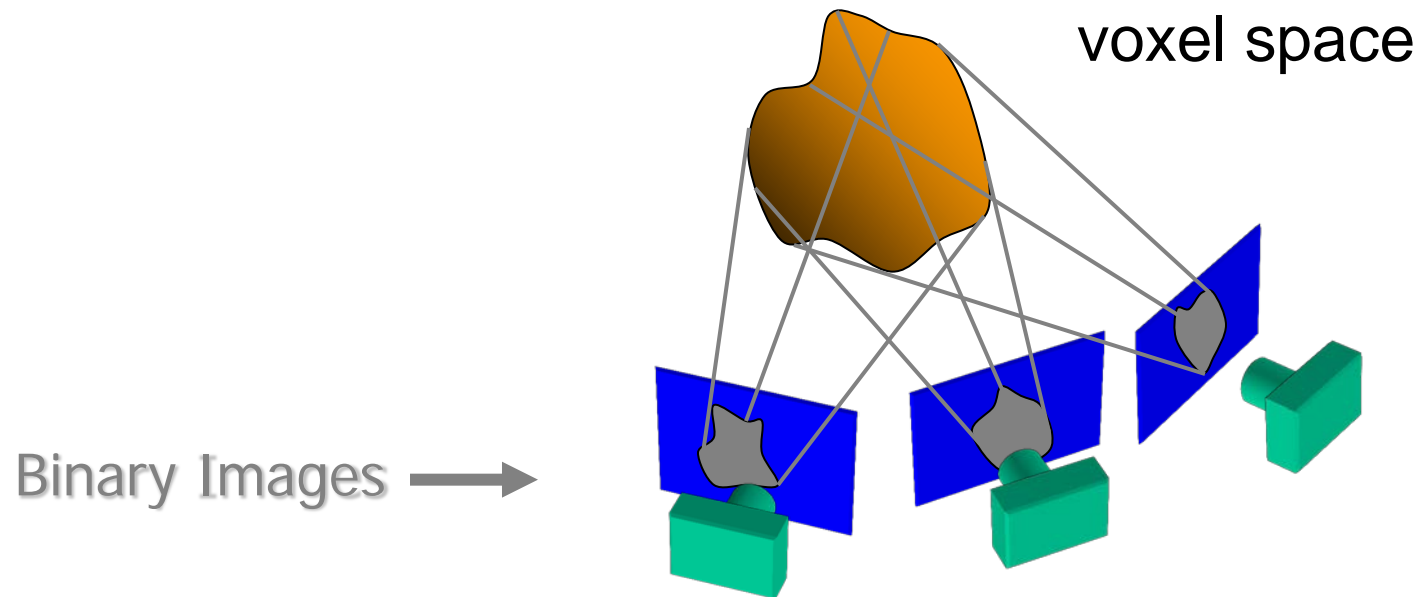
Reconstruction from Silhouettes

- 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

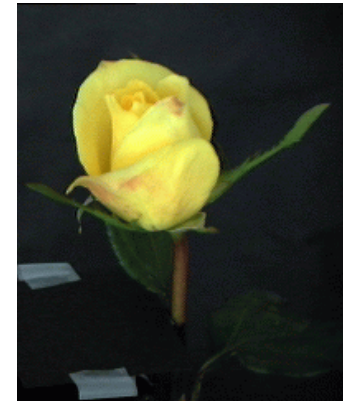
Calibrated Image Acquisition



Calibrated Turntable

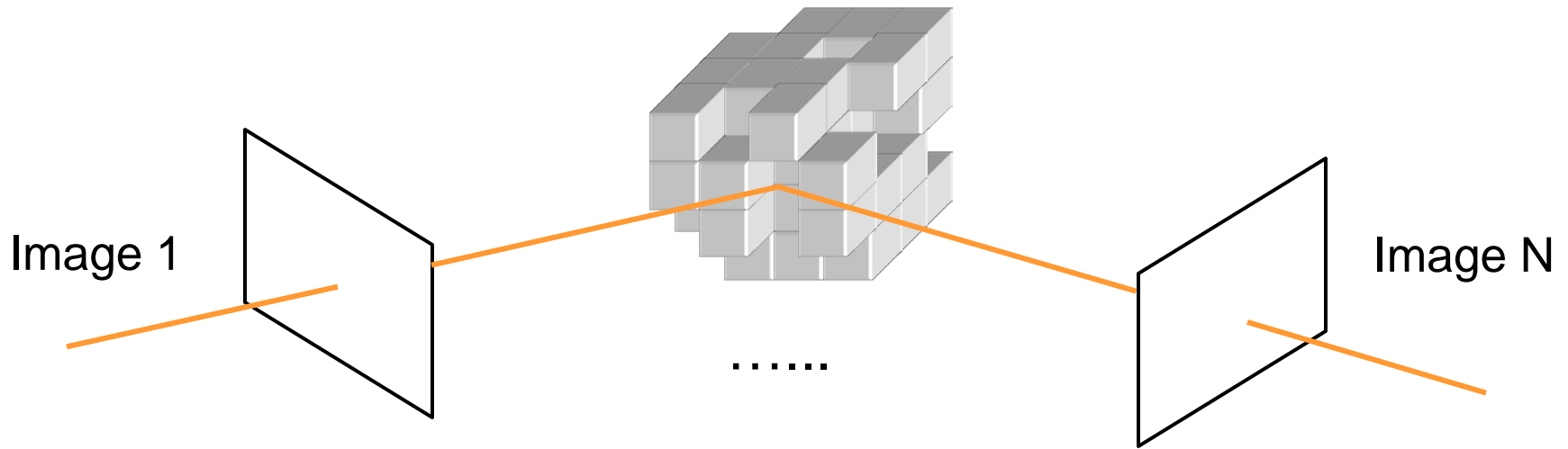


Selected Dinosaur Images



Selected Flower Images

Space Carving in General

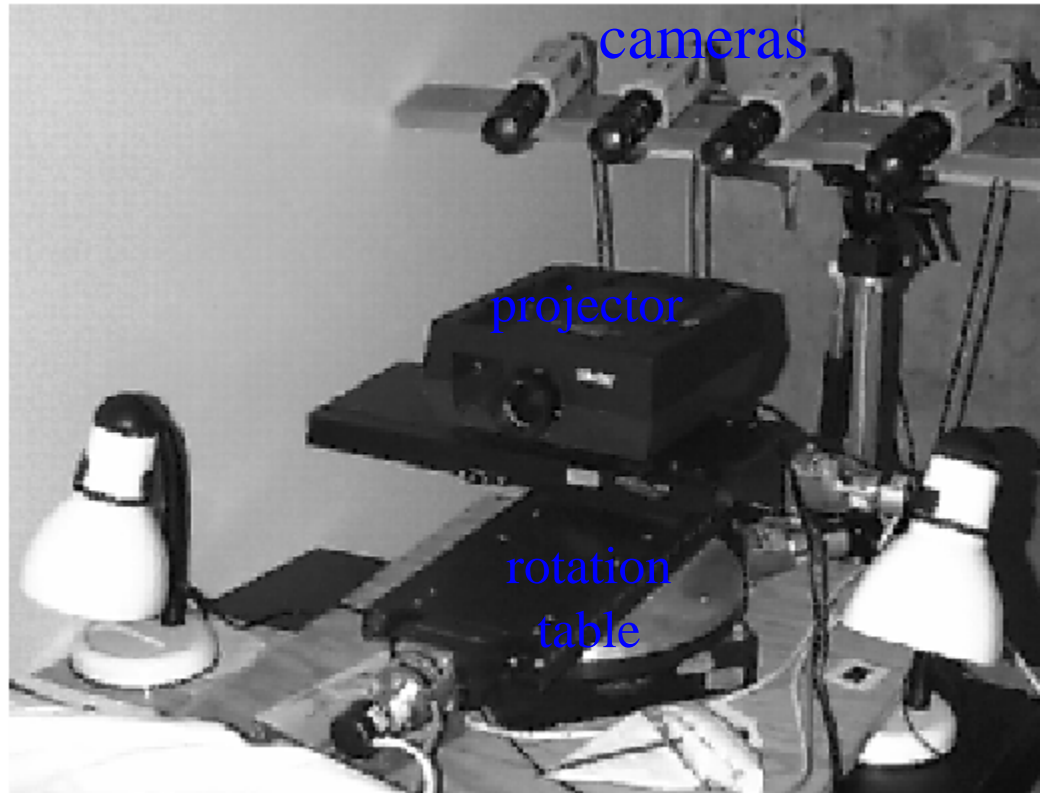


Space Carving Algorithm

- 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-stripping stereo system

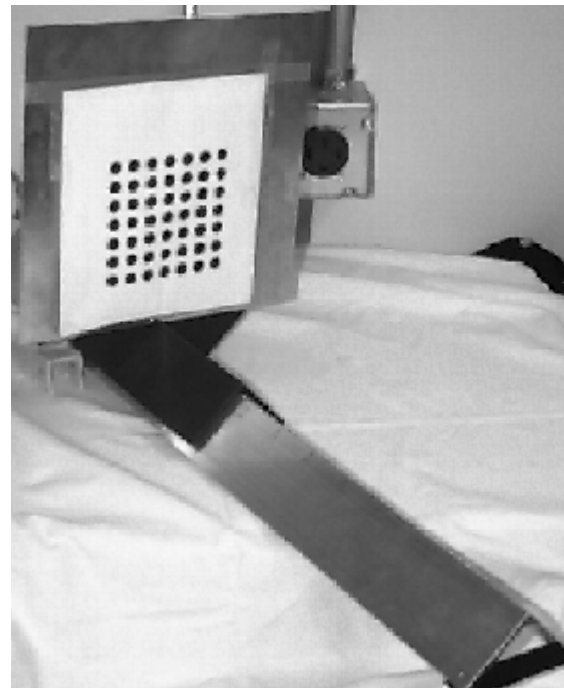
(now deceased)



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



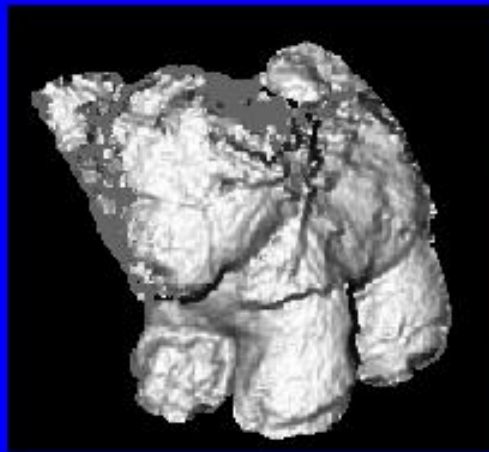
Kari	Pulli	UW
Michael	Cohen	MSR
Tom	Duchamp	UW
Hugues	Hoppe	MSR
John	McDonald	UW
Linda	Shapiro	UW
Werner	Stuetzle	UW

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.

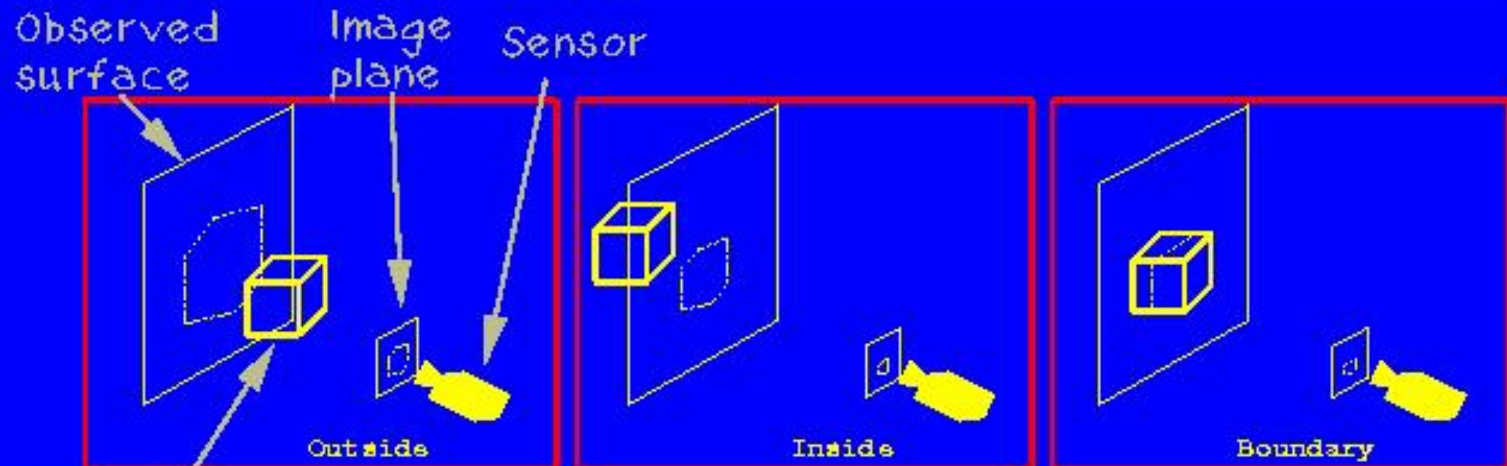
Step 3: Integration

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.

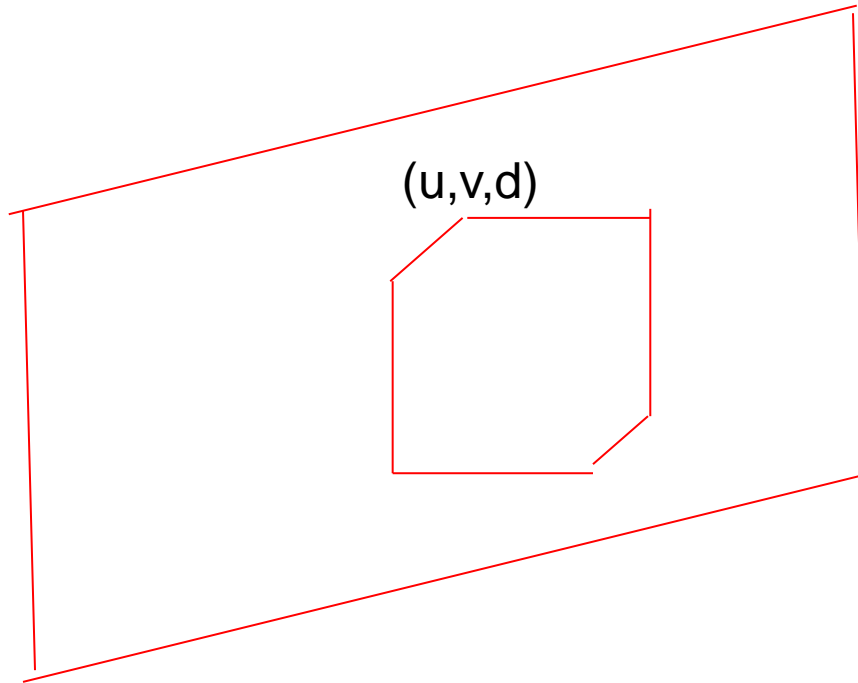
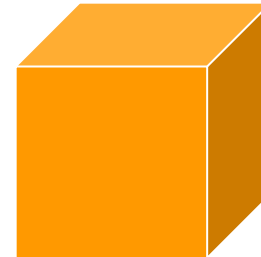


image plane
depth map

(x, y, z)



OUTSIDE

one of many cubes
in virtual 3D cube space

Several views

Processing order:
FOR EACH cube
FOR EACH view

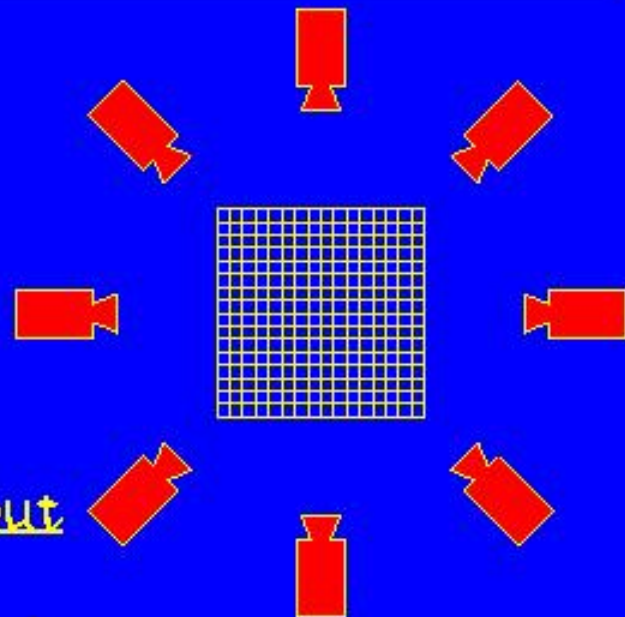
Rules:

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

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

else

=> it's at boundary

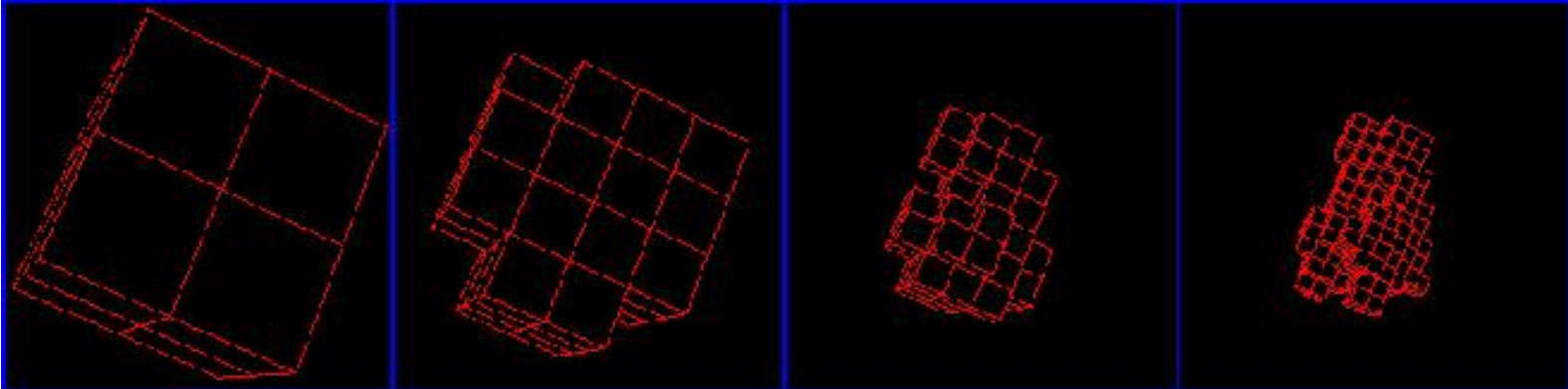


Hierarchical space carving

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

RULES:

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

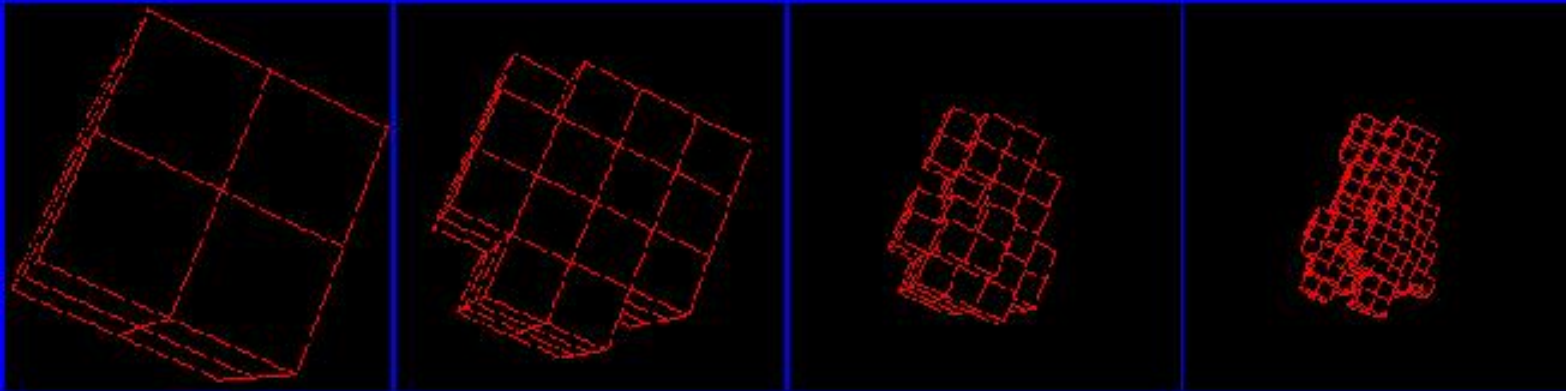


Hierarchical space carving

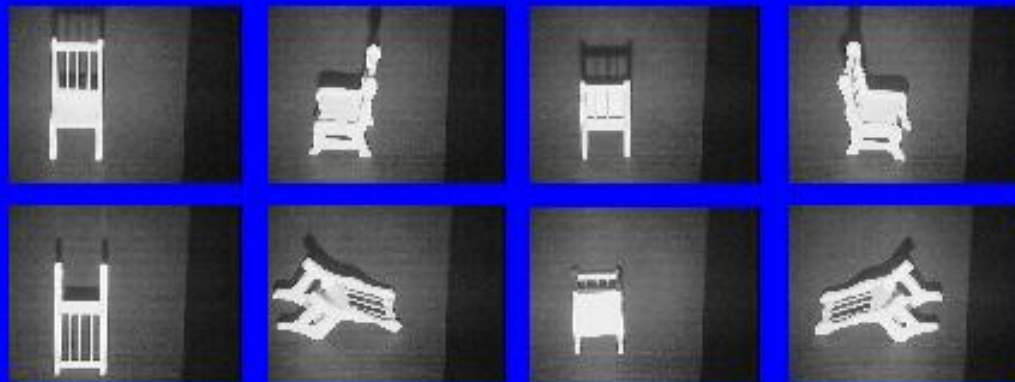
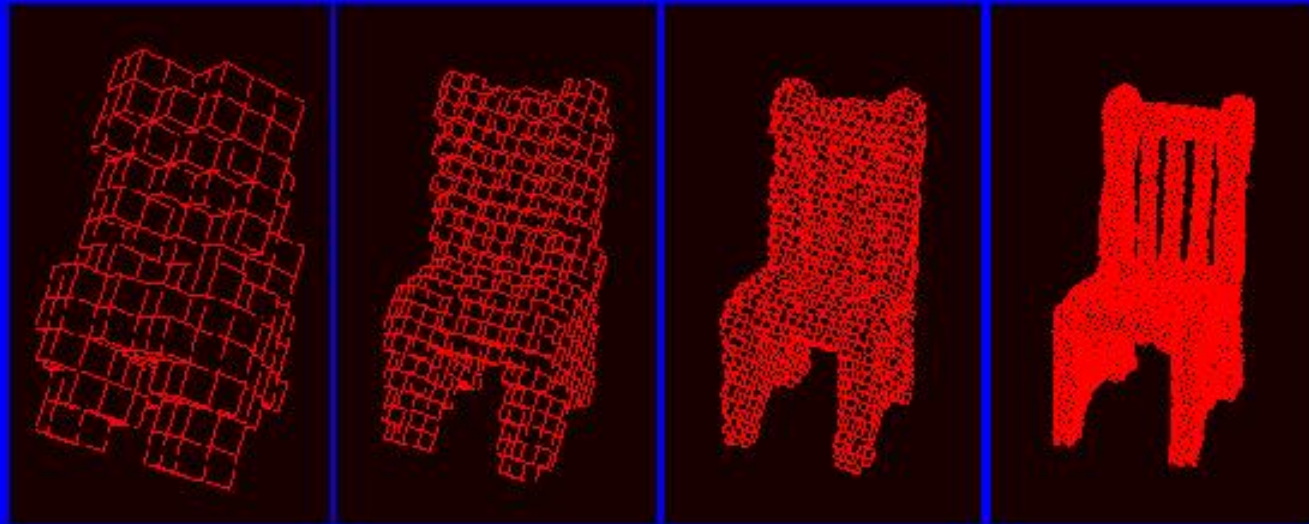
- Big cubes => fast, poor results
- Small cubes => slow, more accurate results
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RULES:

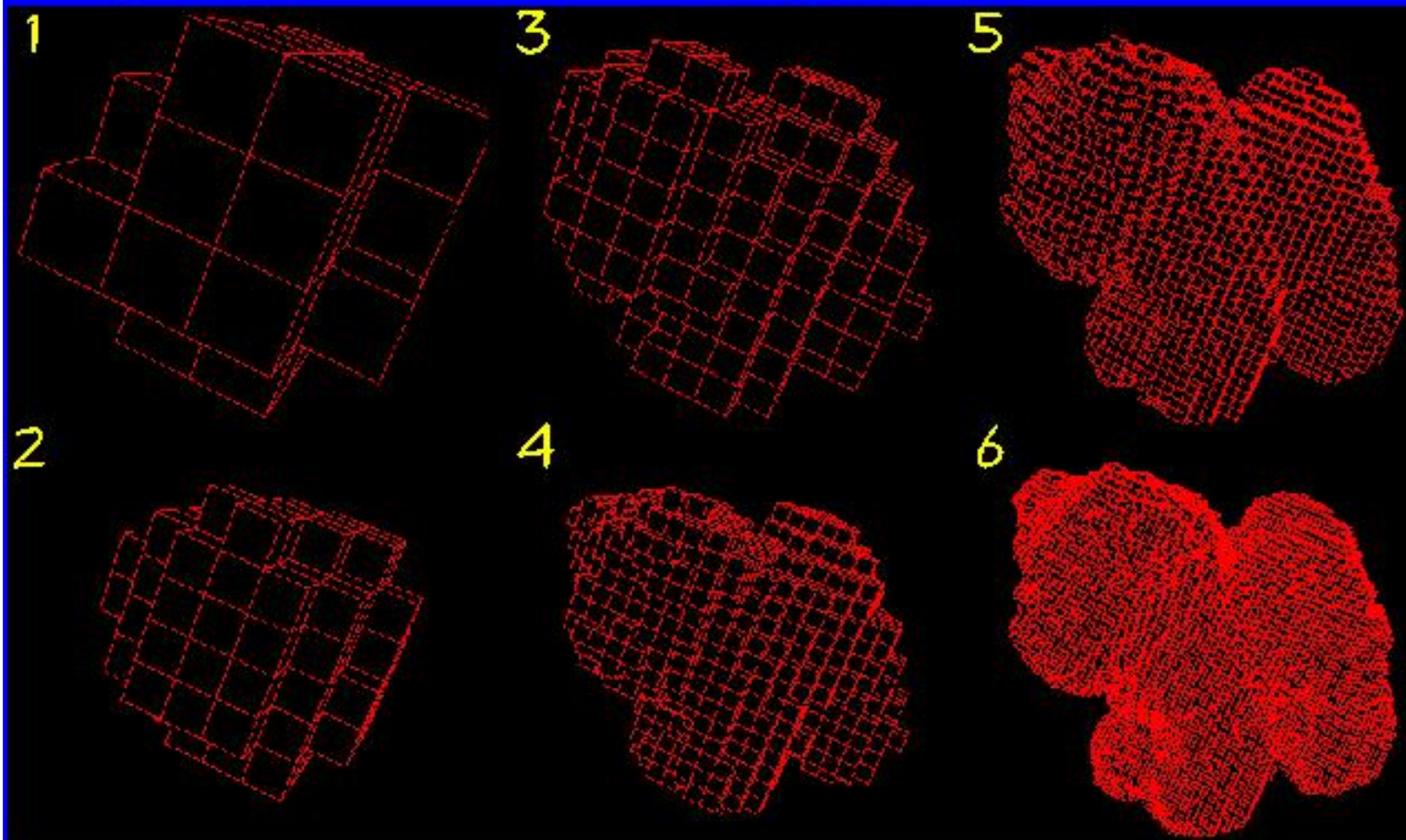
- cube's out => done
- cube's in => done
- else => recurse



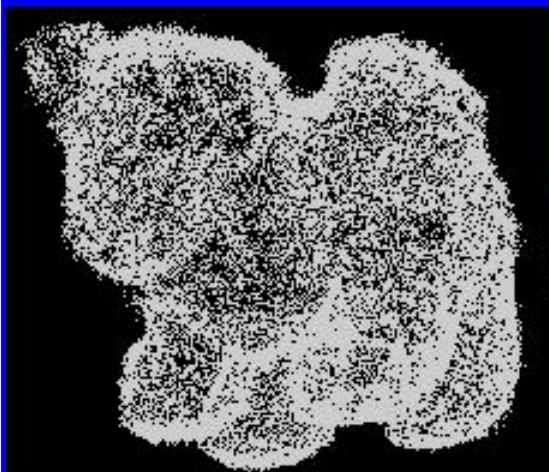
The rest of the chair



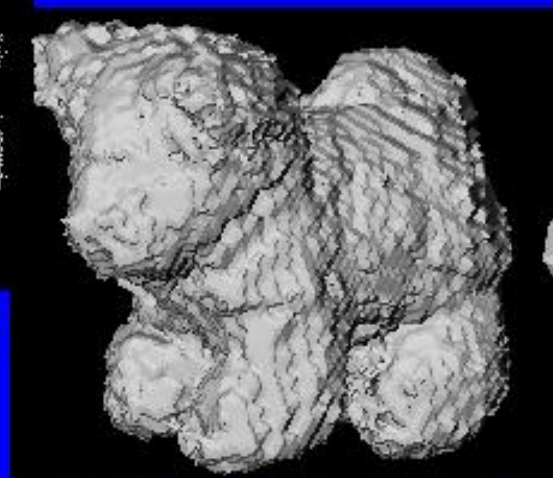
Same for a husky pup



Optimizing the dog mesh



Registered points



Initial mesh

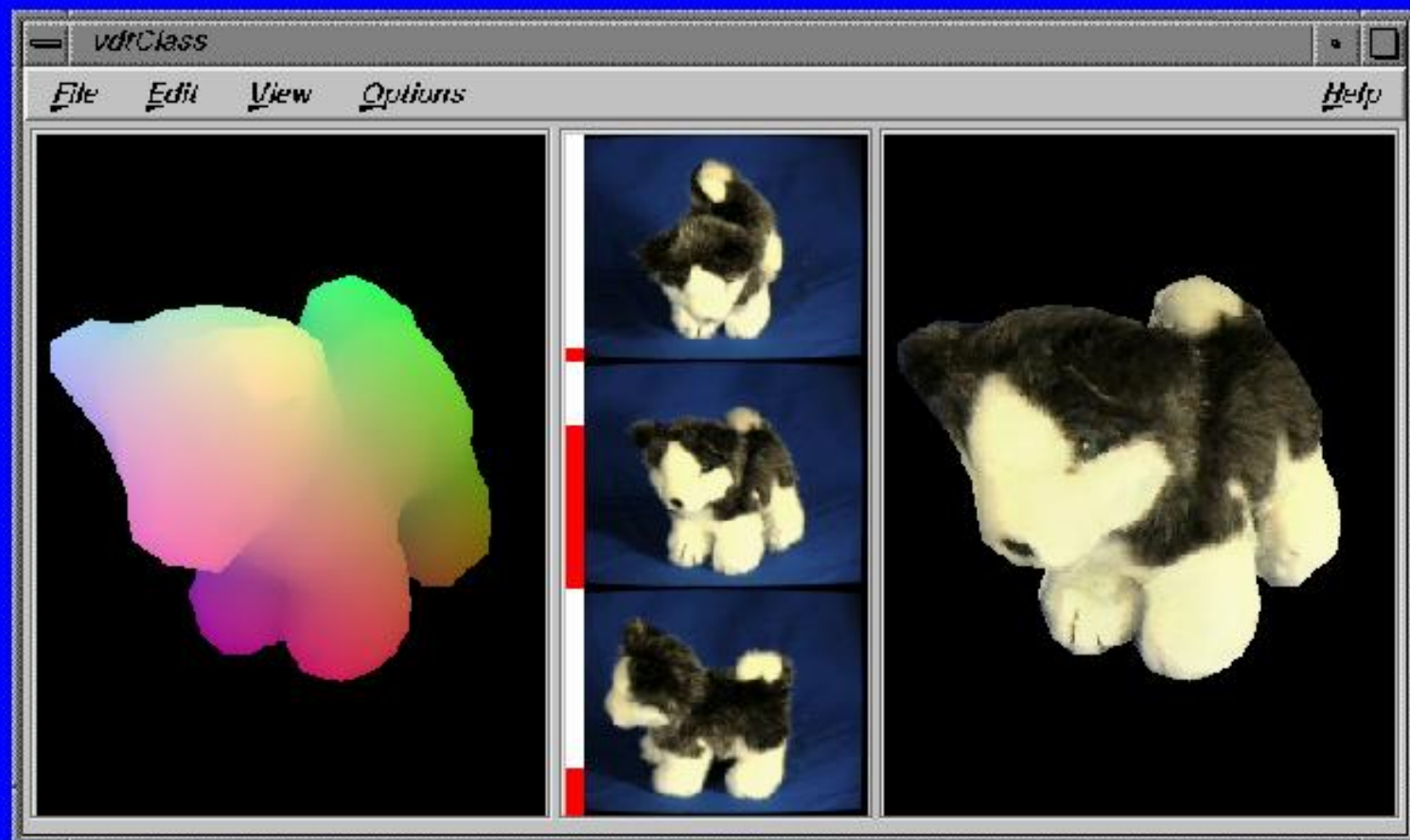


Optimized mesh

View dependent texturing



Our viewer



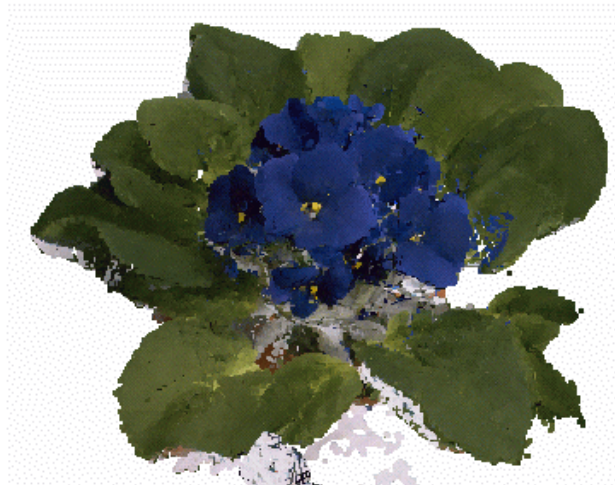
More: Space Carving Results: African Violet



Input Image (1 of 45)



Reconstruction



Reconstruction



Reconstruction

More: Space Carving Results: Hand



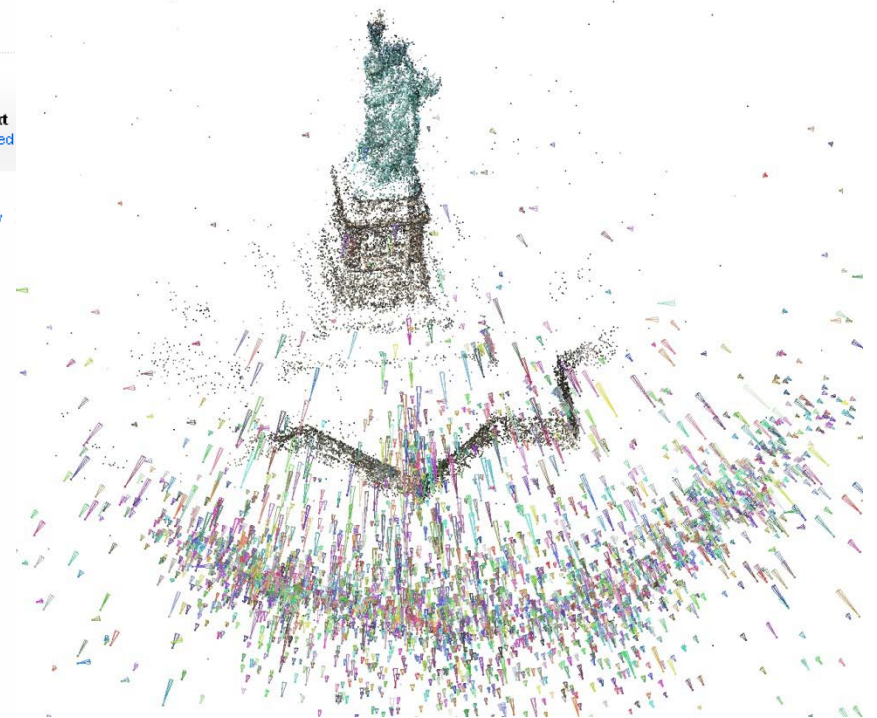
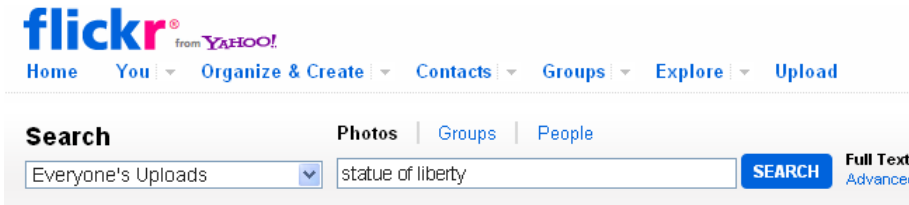
Input Image
(1 of 100)

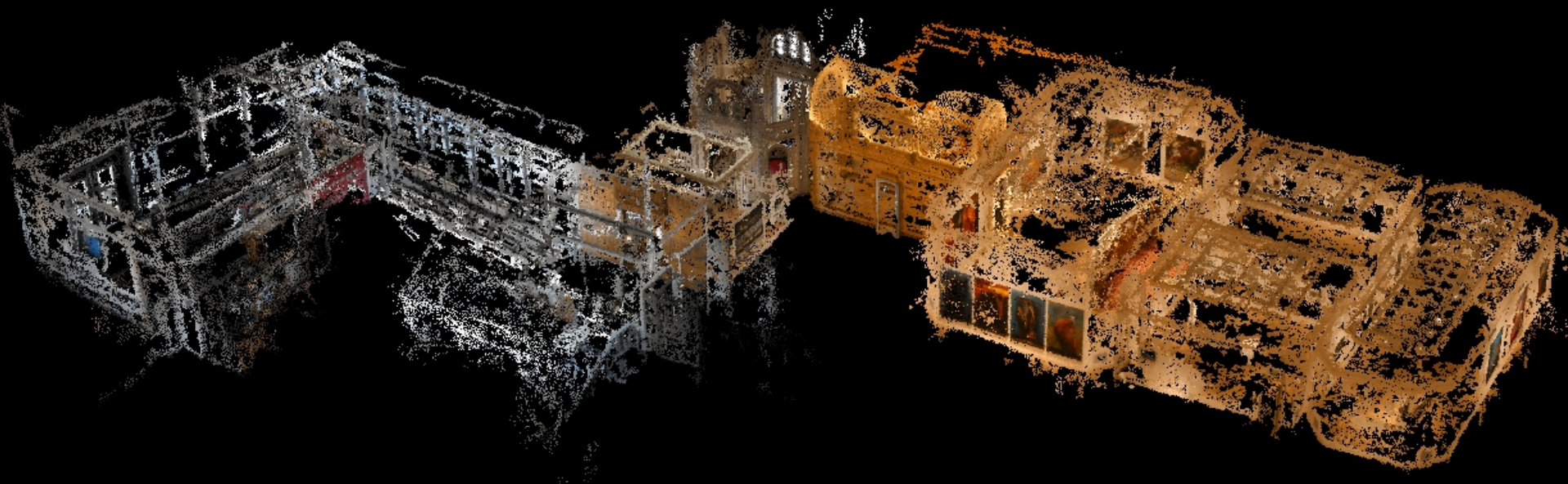


Views of Reconstruction

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





Head Reconstruction from Uncalibrated Internet Photos

Input: Internet photos in different poses and expressions

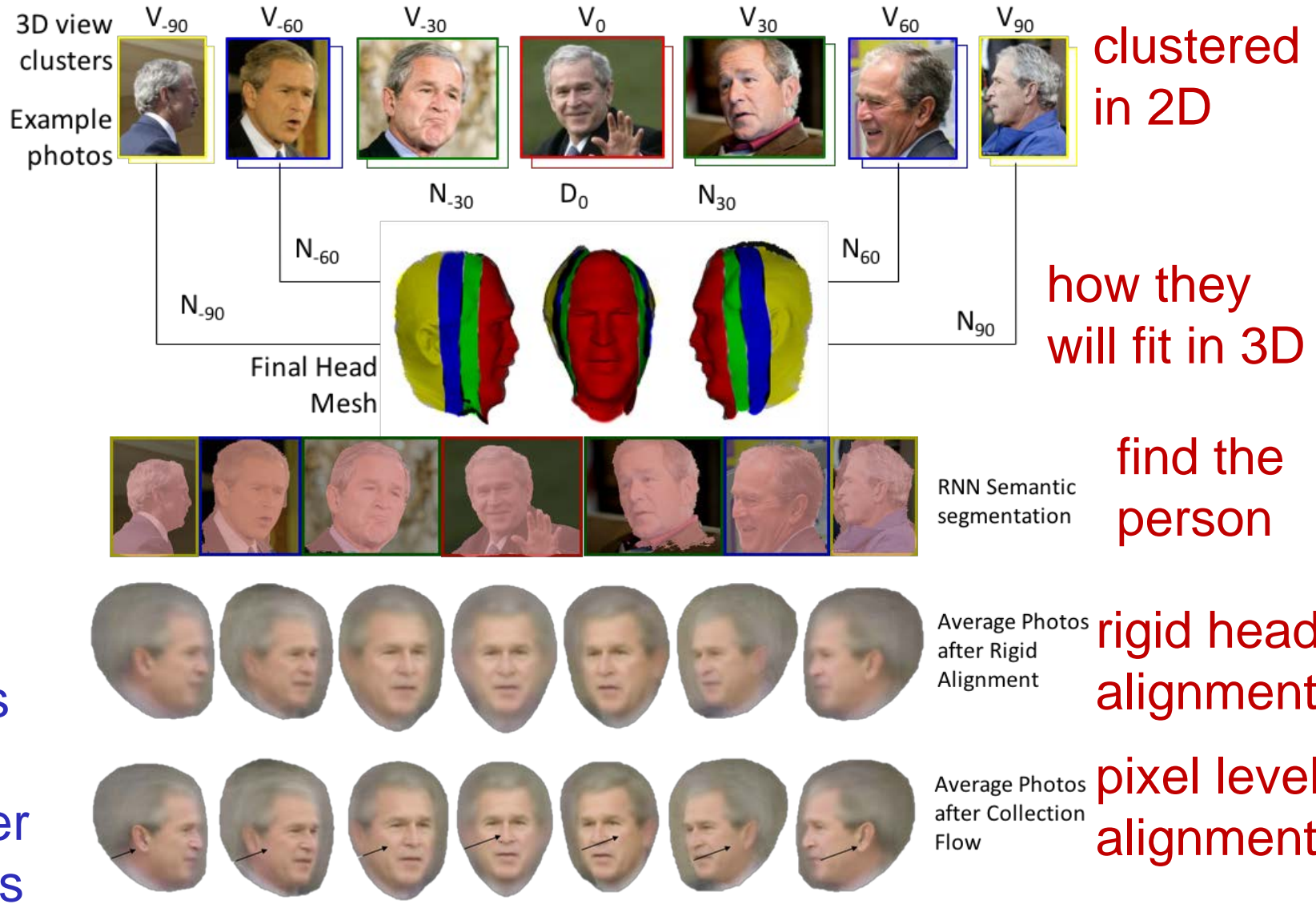


Output: 3D model of the head



work of
Shu Liang

Pose Clusters



Photometric Stereo on frontal pose

Frontal view photos to $n \times p$ matrix Q . n : number of photos, p : number of pixels of the facial mask.

Using Singular Valued Decomposition, $Q = LN$, where L is the **lighting** and N is the **surface normals**. Only the 1st 4 components are used.



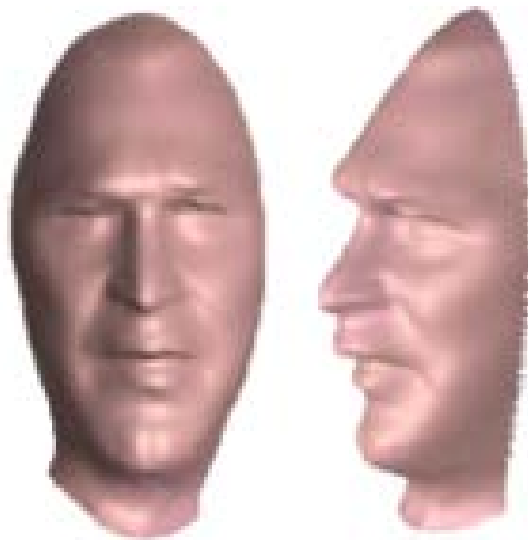
images
warped to
frontal view

reconstructed
using 4
components

Expression normalization by low-rank approximation. The first row shows the warped images, the 2nd row shows the the low rank approximated images. Note how the lighting is mostly preserved, but the facial expression is normalized.

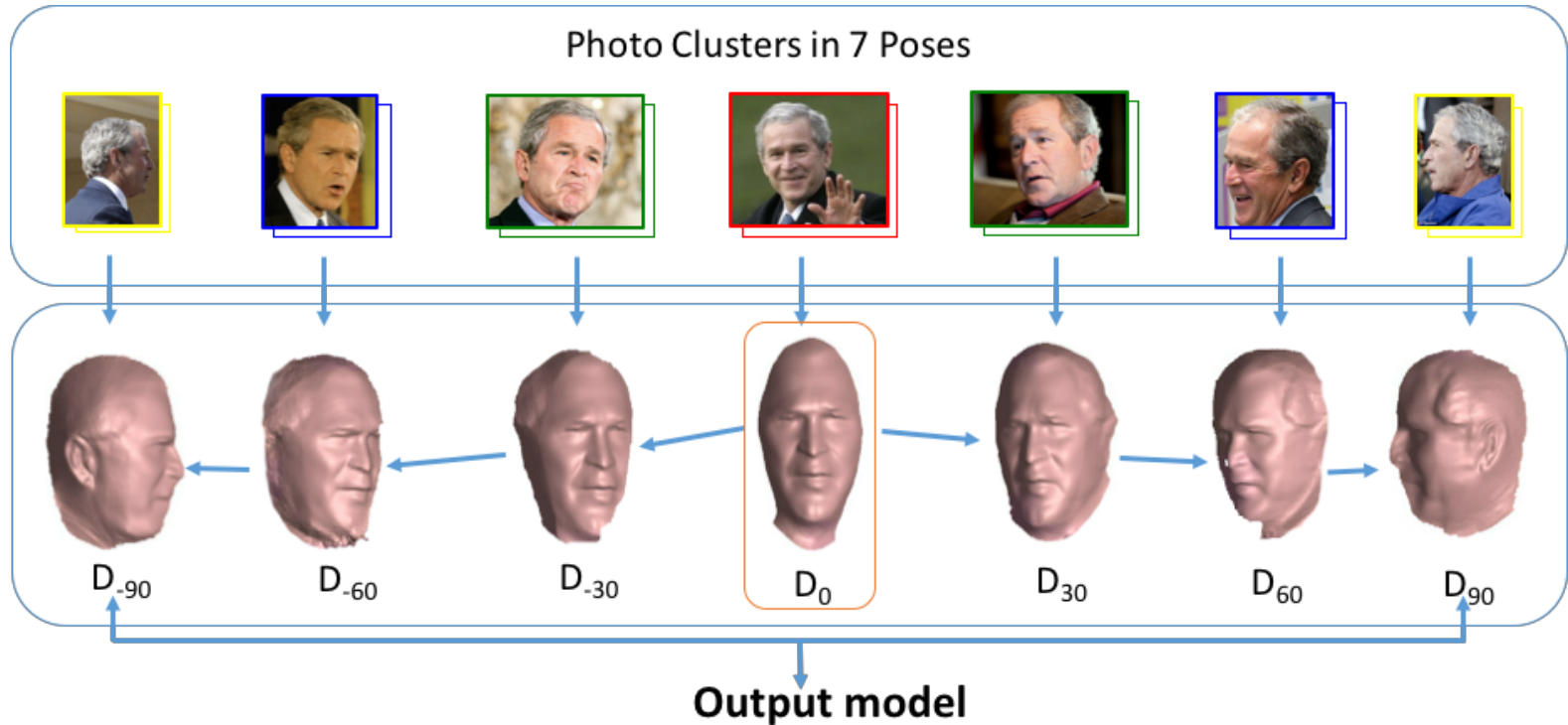
Photometric Stereo on frontal pose

1. Use SVD to compute 3D surface normals
2. Compute 3d depth map from the surface normals



3D shapes
generated from
frontal pose
shown from 2
different views

Boundary-Value Growing



- There are ambiguities in scale between the poses.
- These have to be resolved by a process that uses neighboring poses to solve ambiguities.

Results

Image

