The IBM Pieta Project: A Historical Perspective

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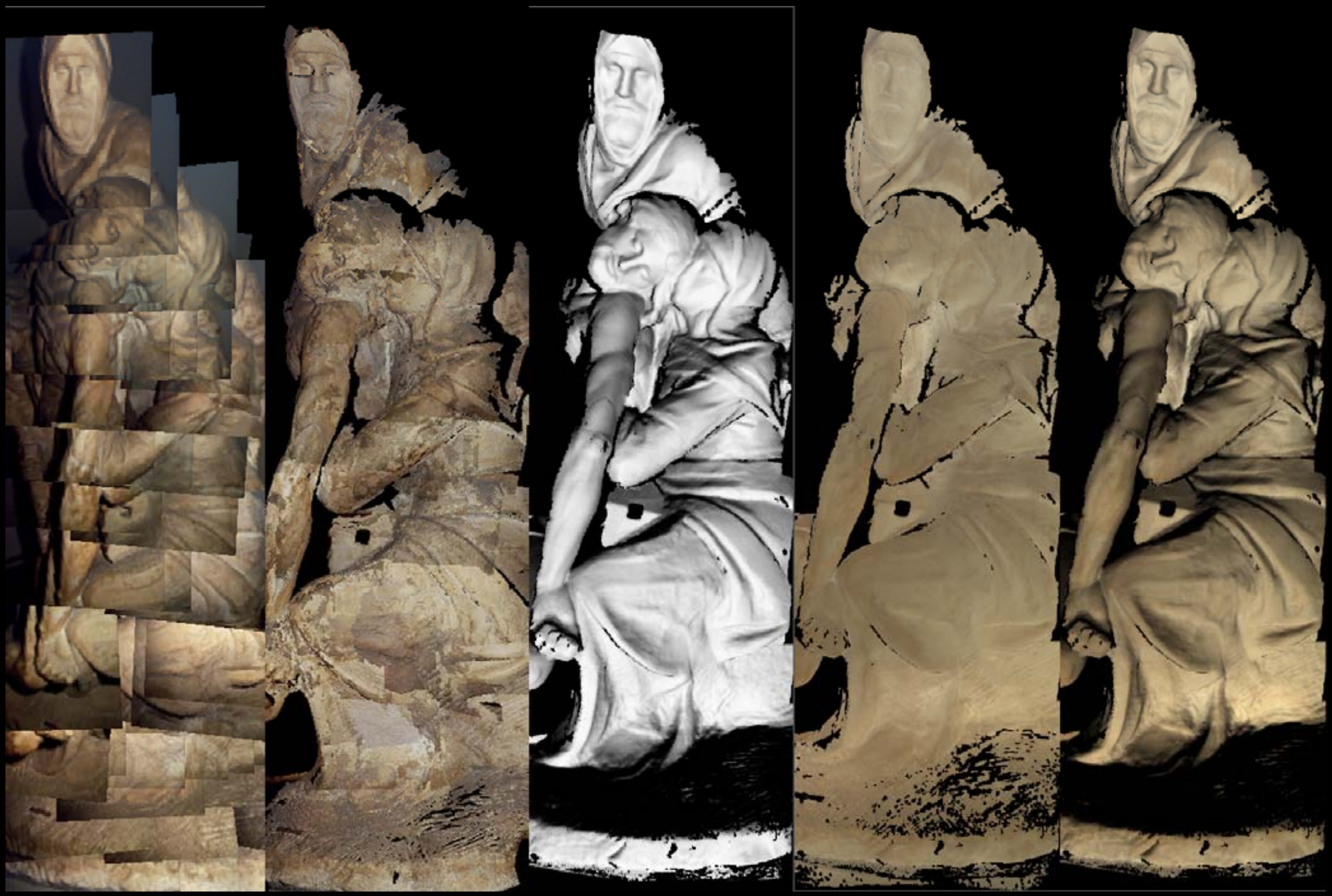
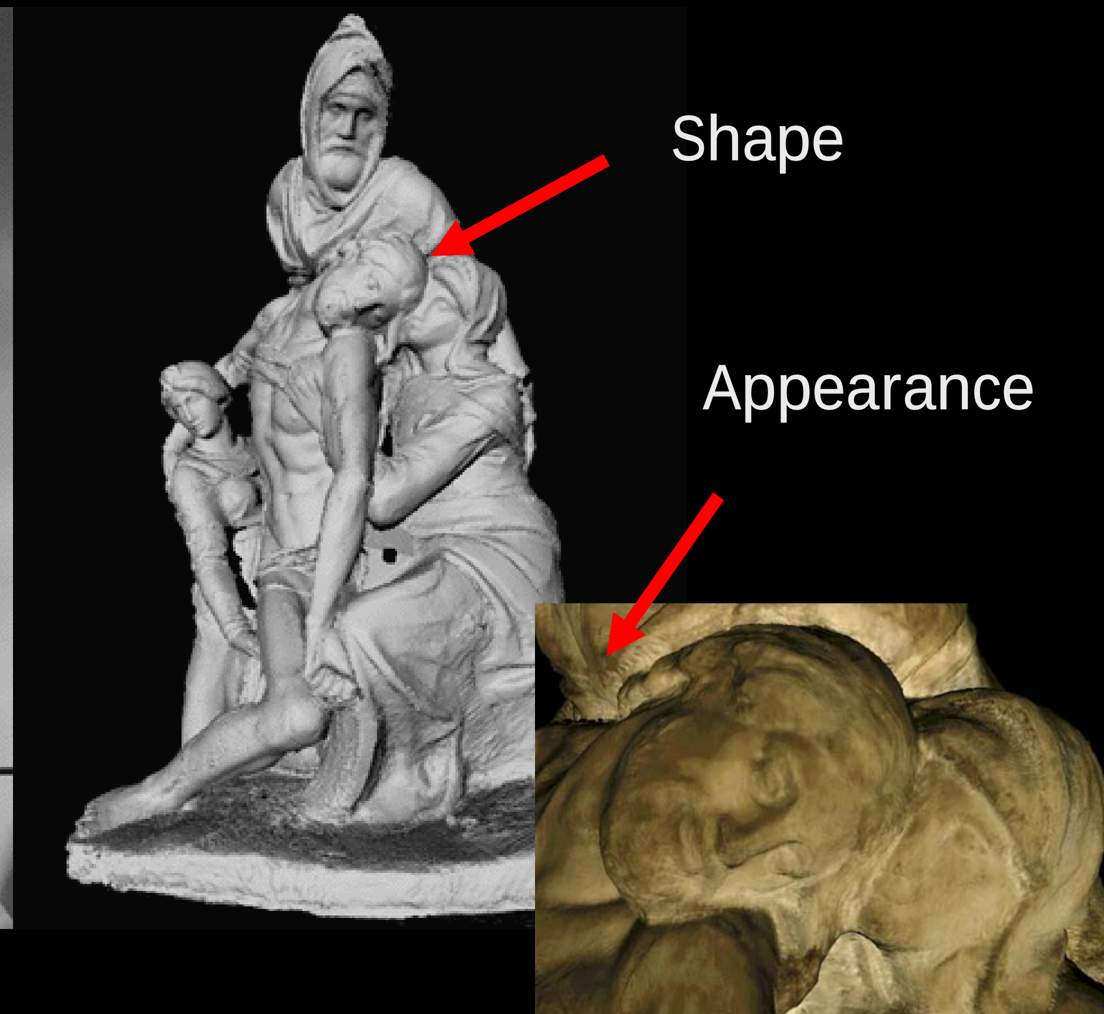
Brown University



IBM Pietà 3D Scanning Project : 1998-2000

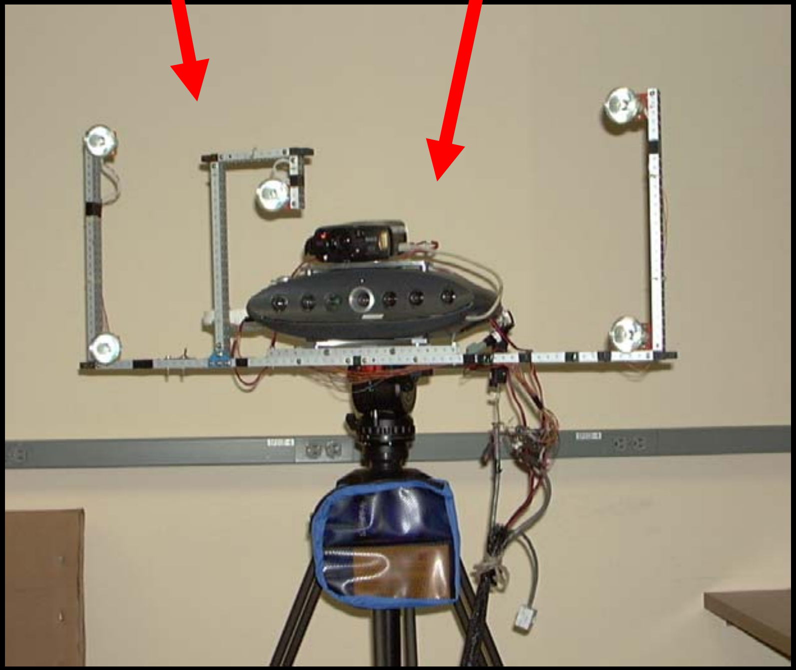


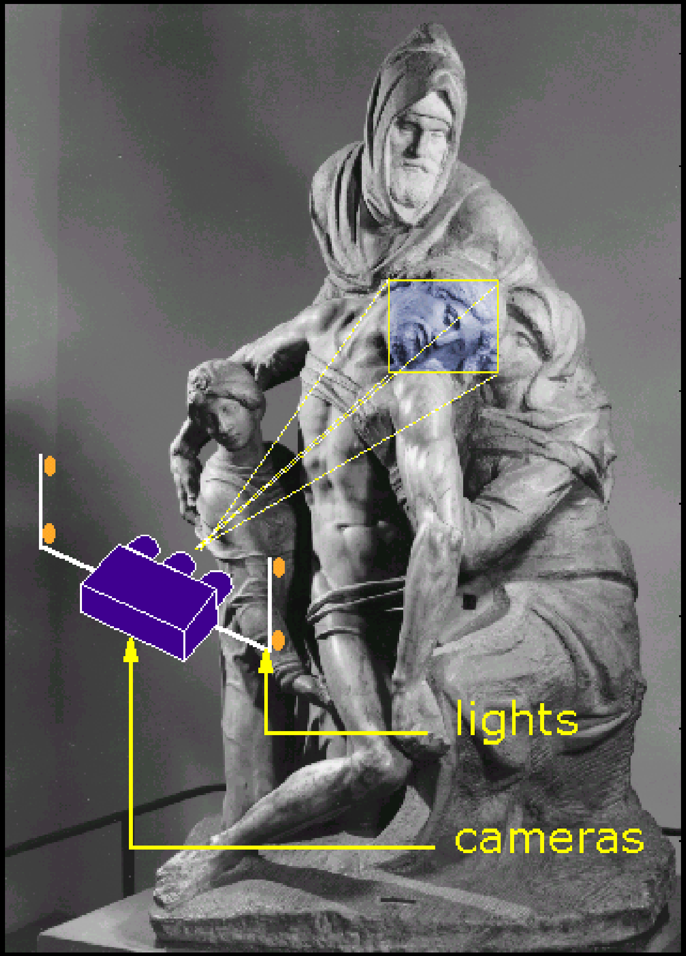
http://www.research.ibm.com/pieta

Data Capture: Range + multi-texture

5 point light sources

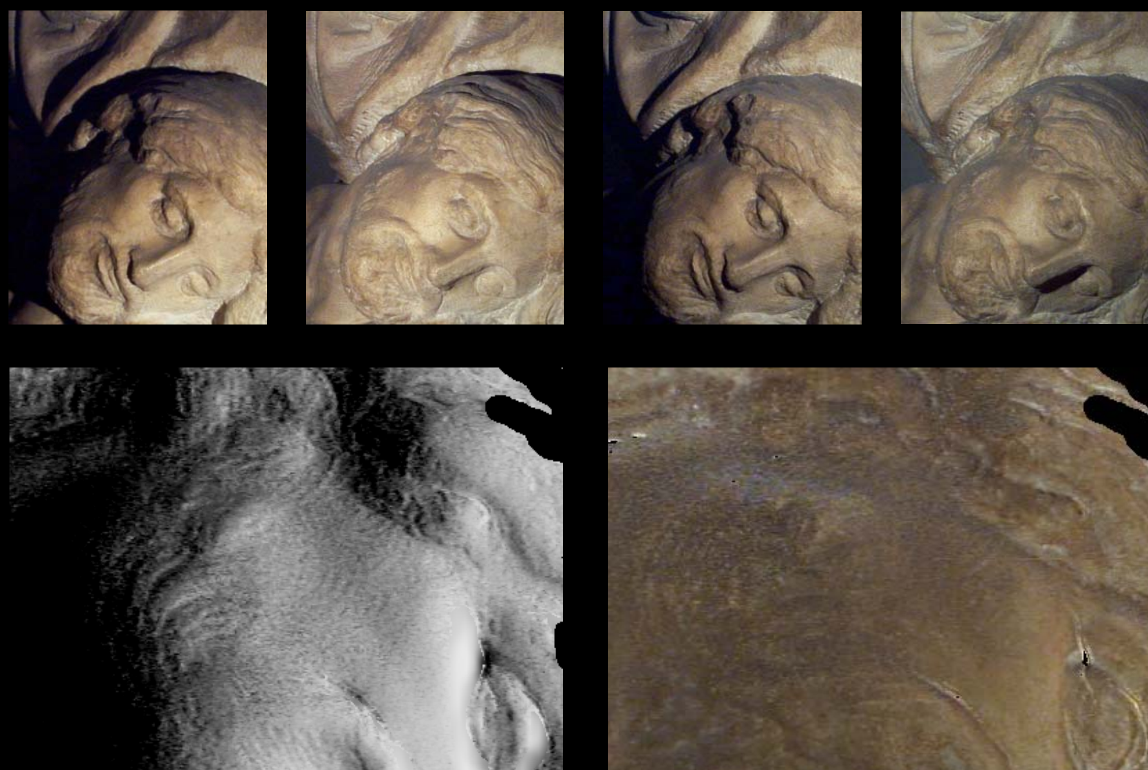
“Virtuoso” Multi-baseline Stereo camera





Photometric capture   Our Addition

- Same viewpoint, different lighting
- Resolution of .5mm with Virtuoso built-in camera
- Compute reflectance and normals per pixel

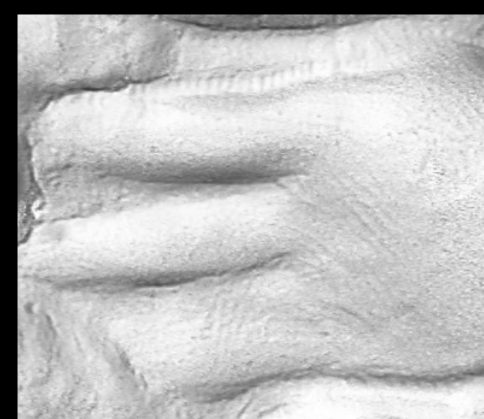


Capturing ~800 scans (1998)

Design Considerations: Length Scales

2. 25m

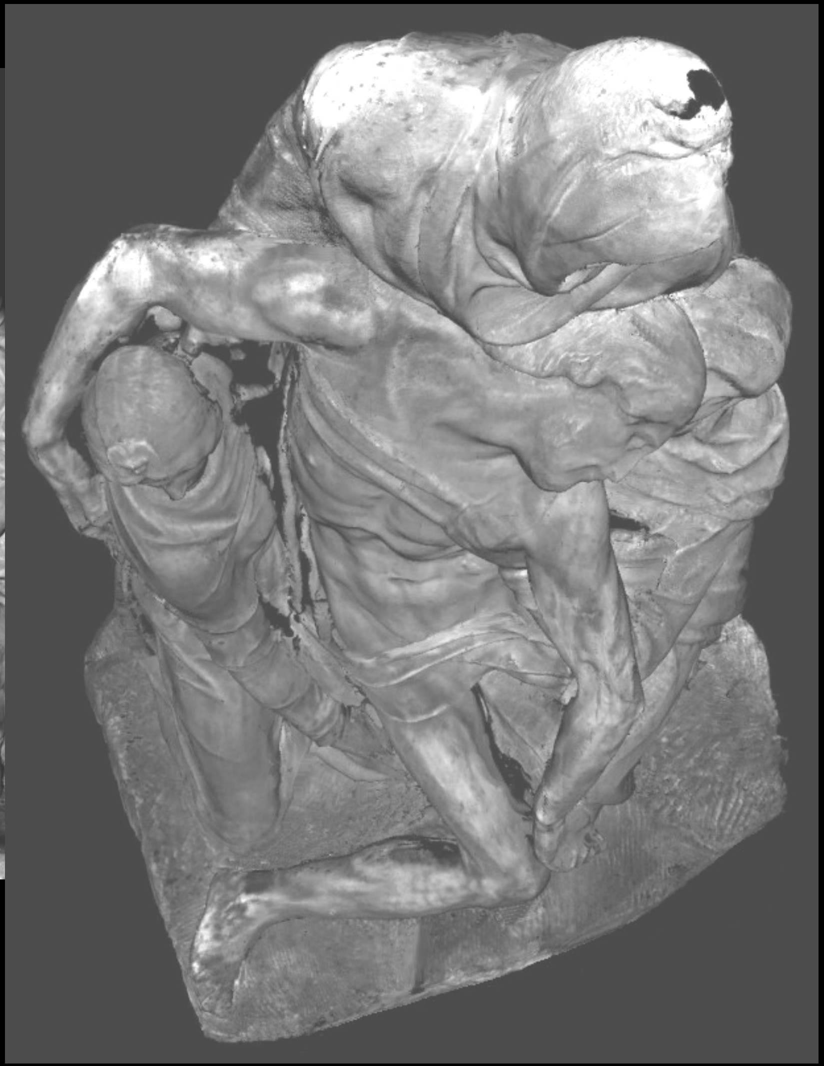
Examine on the scale of
Meters to study
proportion, design



O. 15m

Examine on the scale of
millimeters to study
Tool marks

Controlled Views

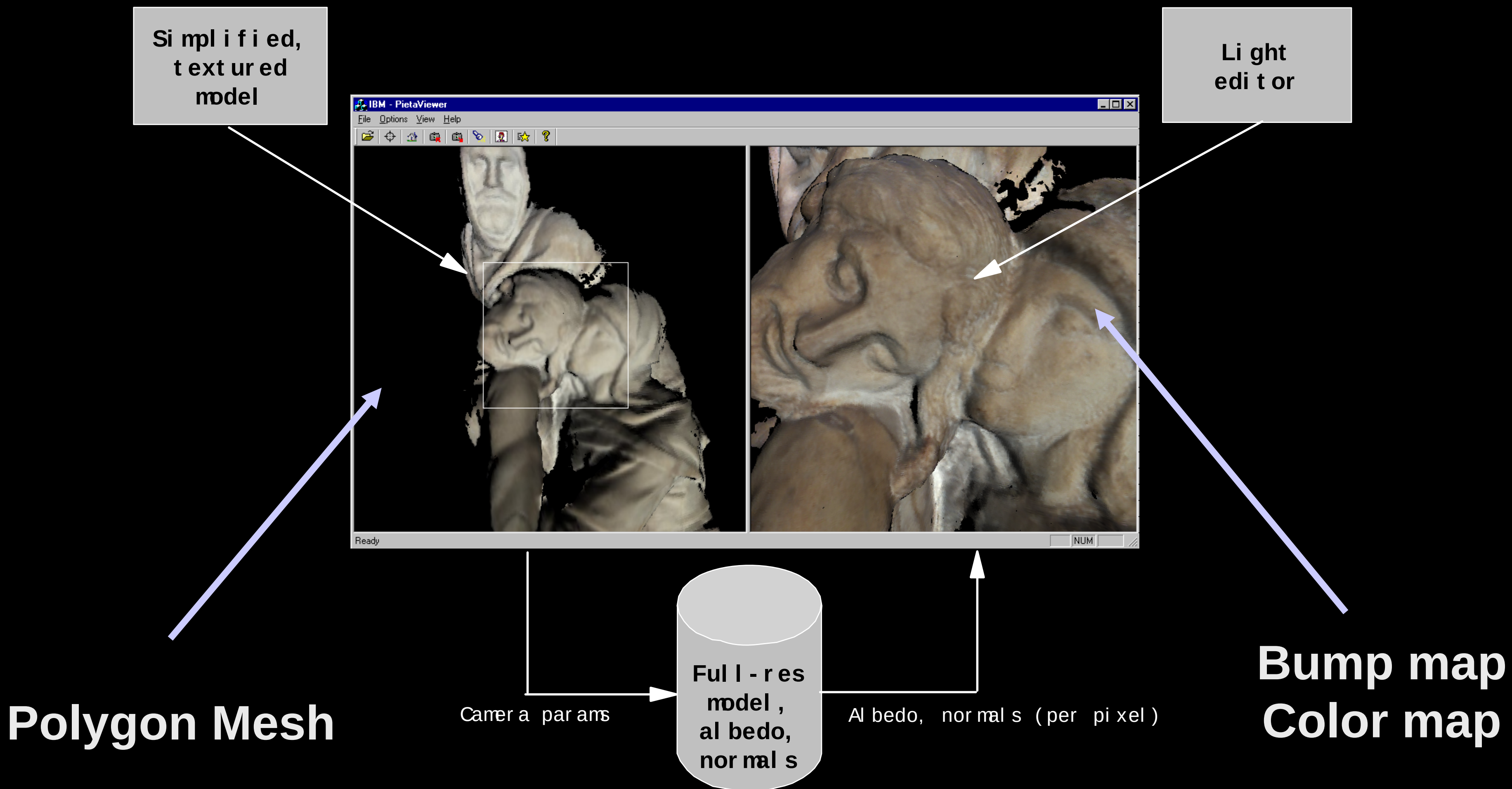


How was sculpture supposed to be view?

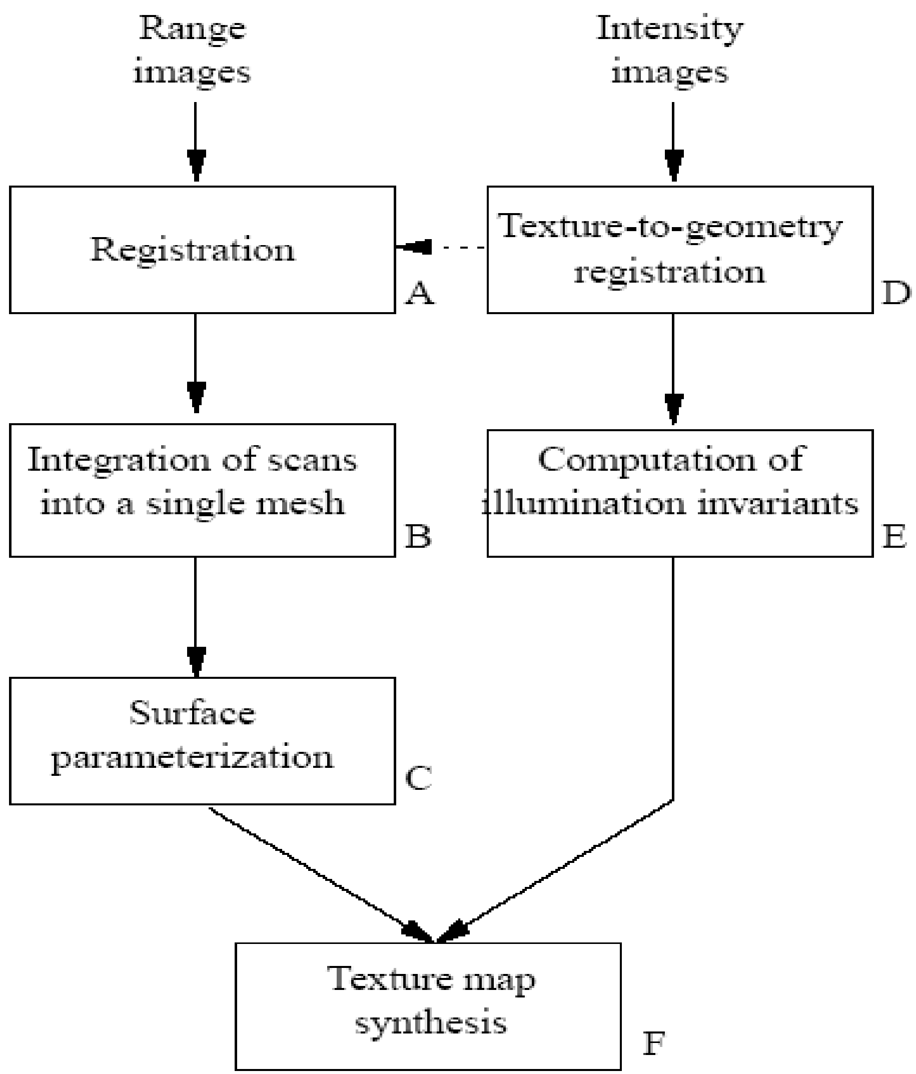
Orthographic and Impossible Views

How was sculpture constructed?

Representation for Interactive Viewing

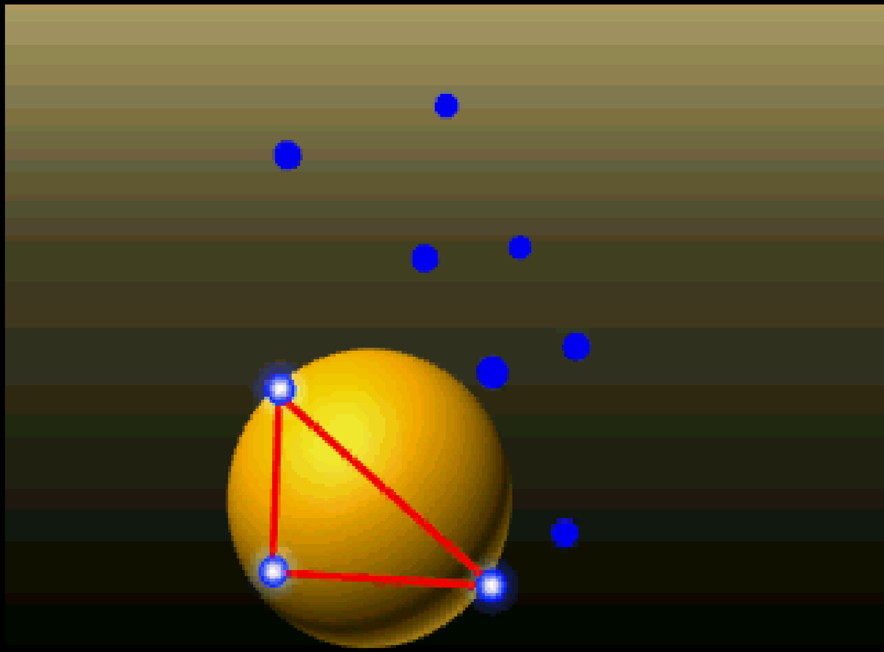


Reconstruction Pipeline

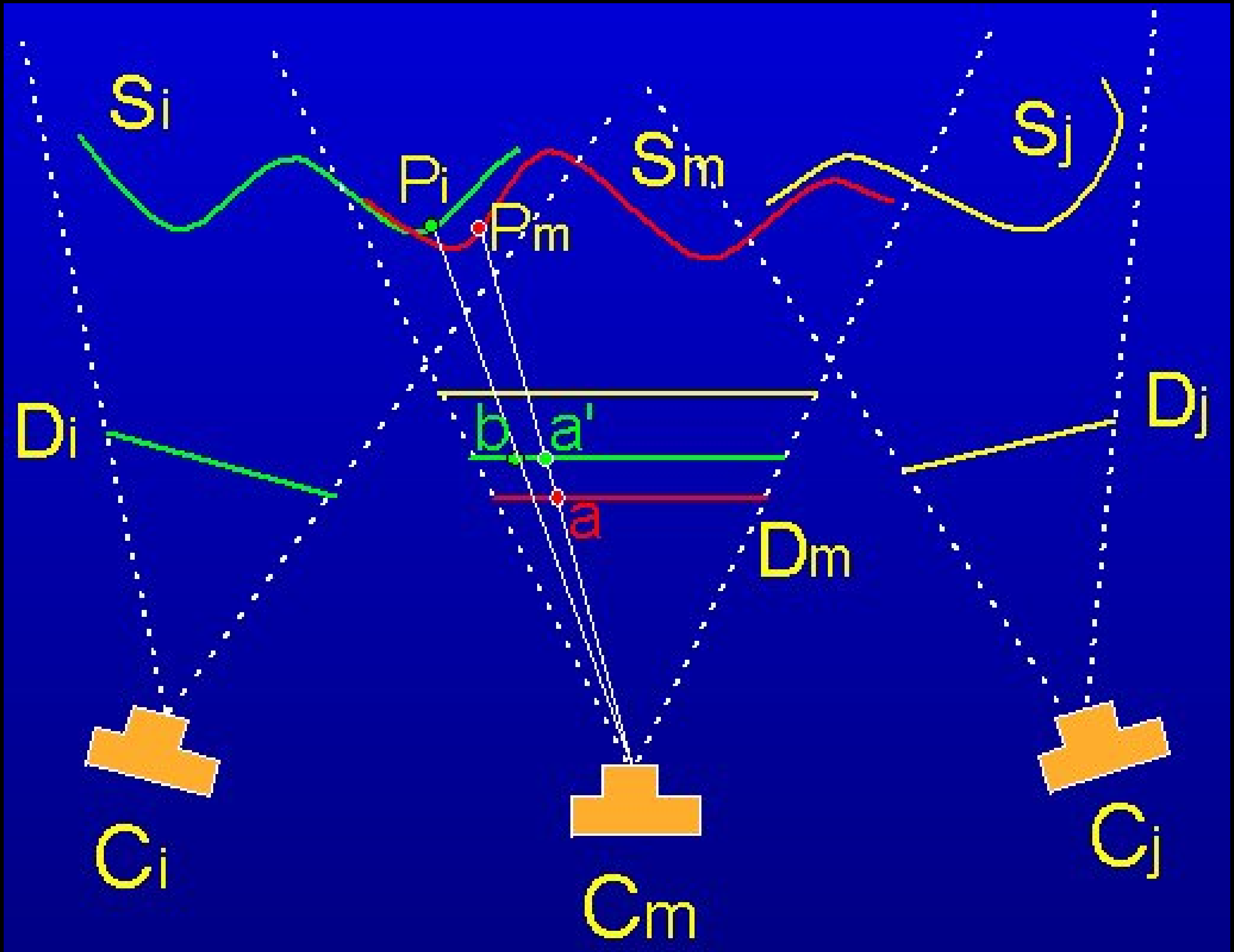

Range
images
Intensity
images
Registration
A
Texture-to-geometry
registration
D
Integration of scans
into a single mesh
B
Computation of
illumination invariants
E
Surface
parameterization
C
Texture map
synthesis
F

Ball Pivoting

- To create a mesh from a point cloud
  A ball "walks" over the point cloud, creating a triangle for every three points it touches



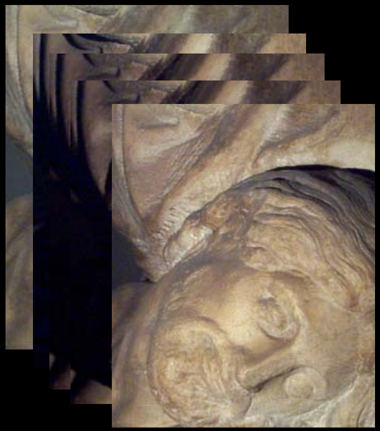
Improving Registration:
Using Textures to Refine Alignment



Pieta` Project

Photometric Processing

- Computing colors and normals consistent with underlying geometry and each other



color images for
five light positions

SHAPE FROM SHADING

We can infer shape from a monocular image if the ilumination and surface properties are known. If multiple images are available under different illumination directions, we can compute the surface orientation at each point in the image.

Reflectance Functions: First, we need to know how a surface reflects incident light energy. A common model is a diffuse or Lambertian surface. This is a surface that reflects incident light energy equally in all viewing directions. The amount of this light energy is proportional to the cosine of the angle between the surface normal and the light source direction.

$$\Phi(n, s, v) = \rho \, cos(i)$$

where i is angle between surface normal $\mathbf{n}$ and light souce direction $\mathbf{s}$, and $\mathbf{v}$ is viewing (camera direction). ρ is the albedo of the surface; it is a gain that determines what percentage of the light is transmitted by the surface versus absorbed. ρ will be high for smooth, glossy objects and lower for rough objects. We will assume it to be a constant over the surface; i.e. a homogeneous surface material.

If we examine the equation below, we see that if the lighting direction $\mathbf{s}$ and viewing direction $\mathbf{v}$ are known, then the brightness at a point in the image is simply a function of the surface normal and the albedo (which we assume is constant over the surface).

$$\Phi(n, s, v) = \rho \, cos(i)$$

PHOTOMETRIC STEREO

If we have a Lambertian surface, and we shine a known light source on it, we generate a reflectance map that can be characterized for each pixel in the image as:

$$\begin{aligned} I_k(u, v) &= \rho \, cos(i_k) \\ &= \rho \, (s_k \cdot \mathbf{n}) \end{aligned}$$

The intensity at a pixel is proportional to the incident angle. Given three light source directions, $s_1, \; s_2 \; s_3$, we can create a matrix equation $\mathbf{I} \; = \; \rho \, \mathbf{S} \, \mathbf{n}$:

$$\begin{bmatrix} I_1(u, v) \\ I_2(u, v) \\ I_3(u, v) \end{bmatrix} = \rho \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}$$

Since $\mathbf{n}$ is a unit vector, we can solve for ρ and $\mathbf{n}$:

$$\rho \; = \| \, \mathbf{S}^{-1} \, \mathbf{I} \, \| \; ; \; \mathbf{n} \; = \; \frac{1}{\rho} \, \mathbf{S}^{-1} \, \mathbf{I}$$

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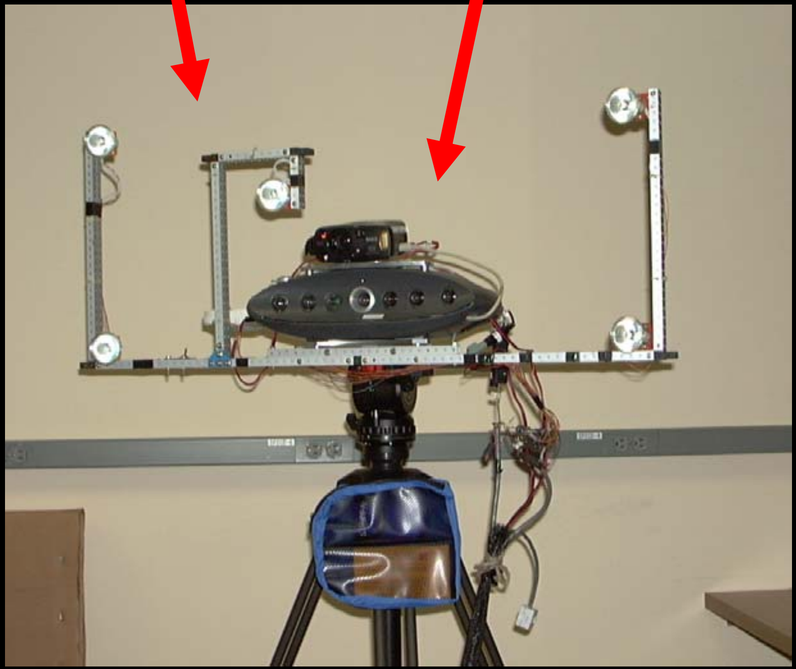
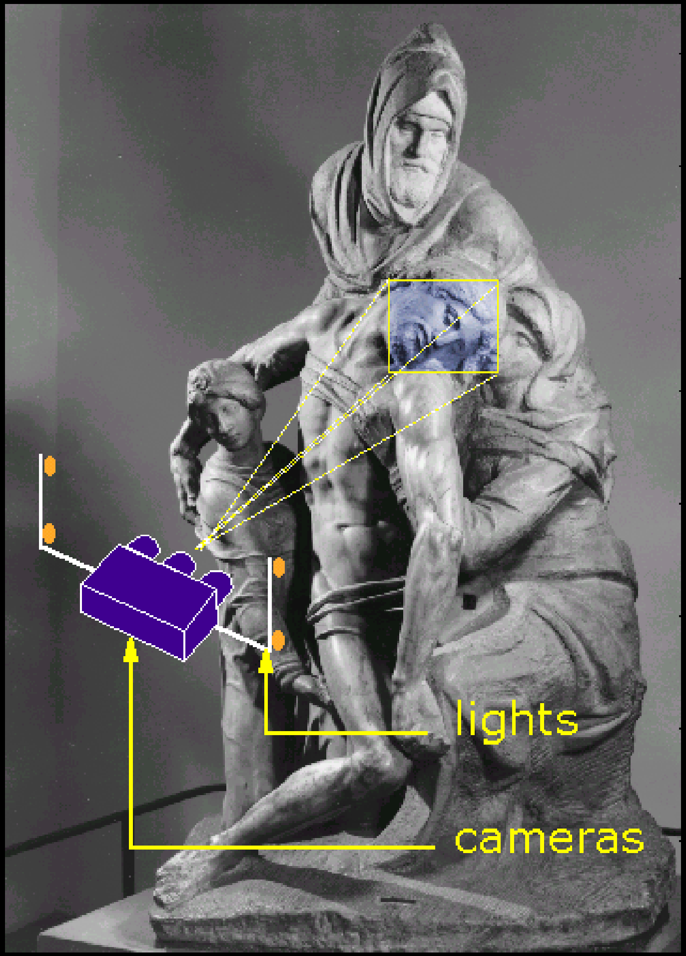
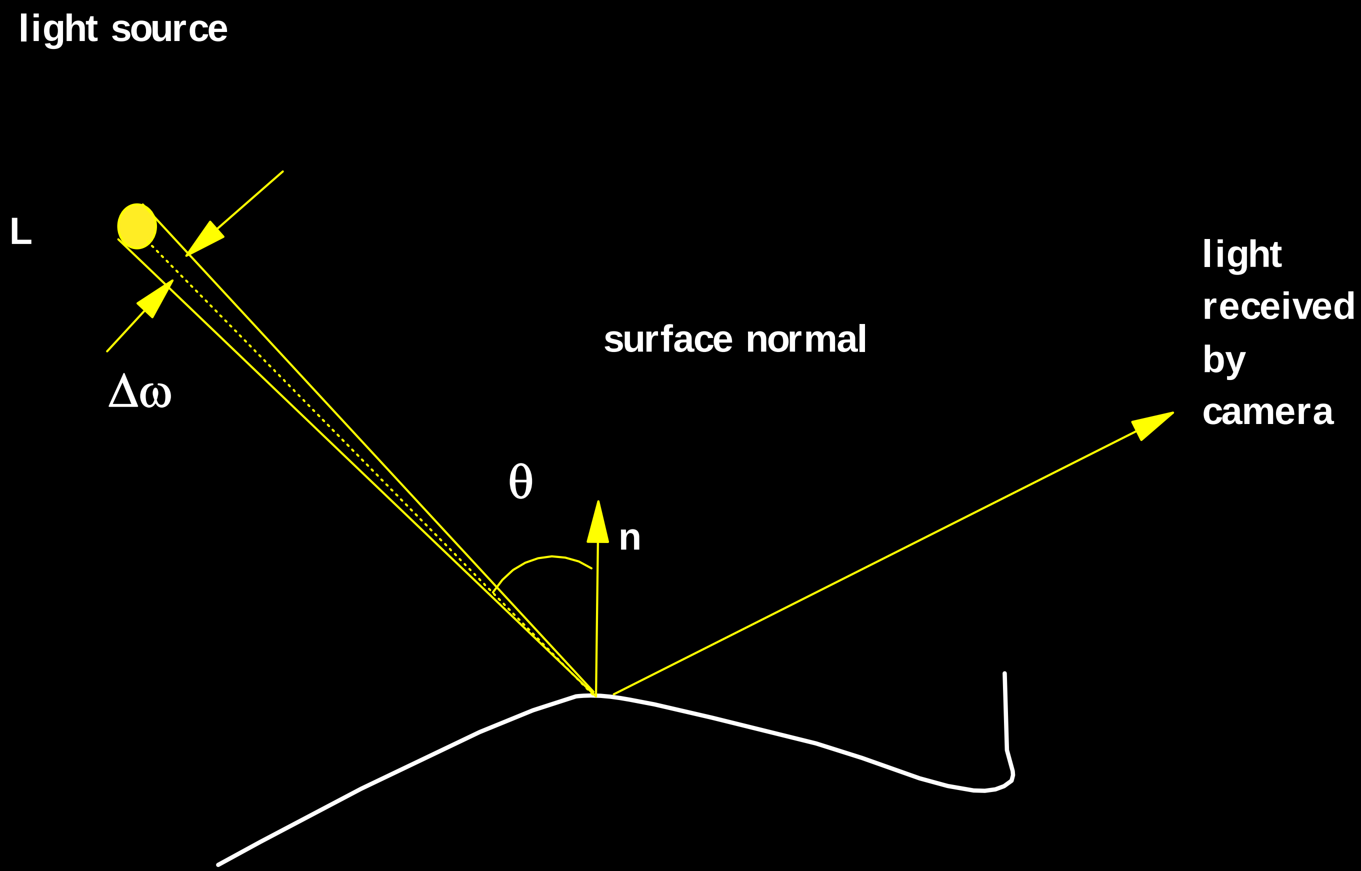
5 point light sources

“Virtuoso” Multi-baseline
Stereo camera



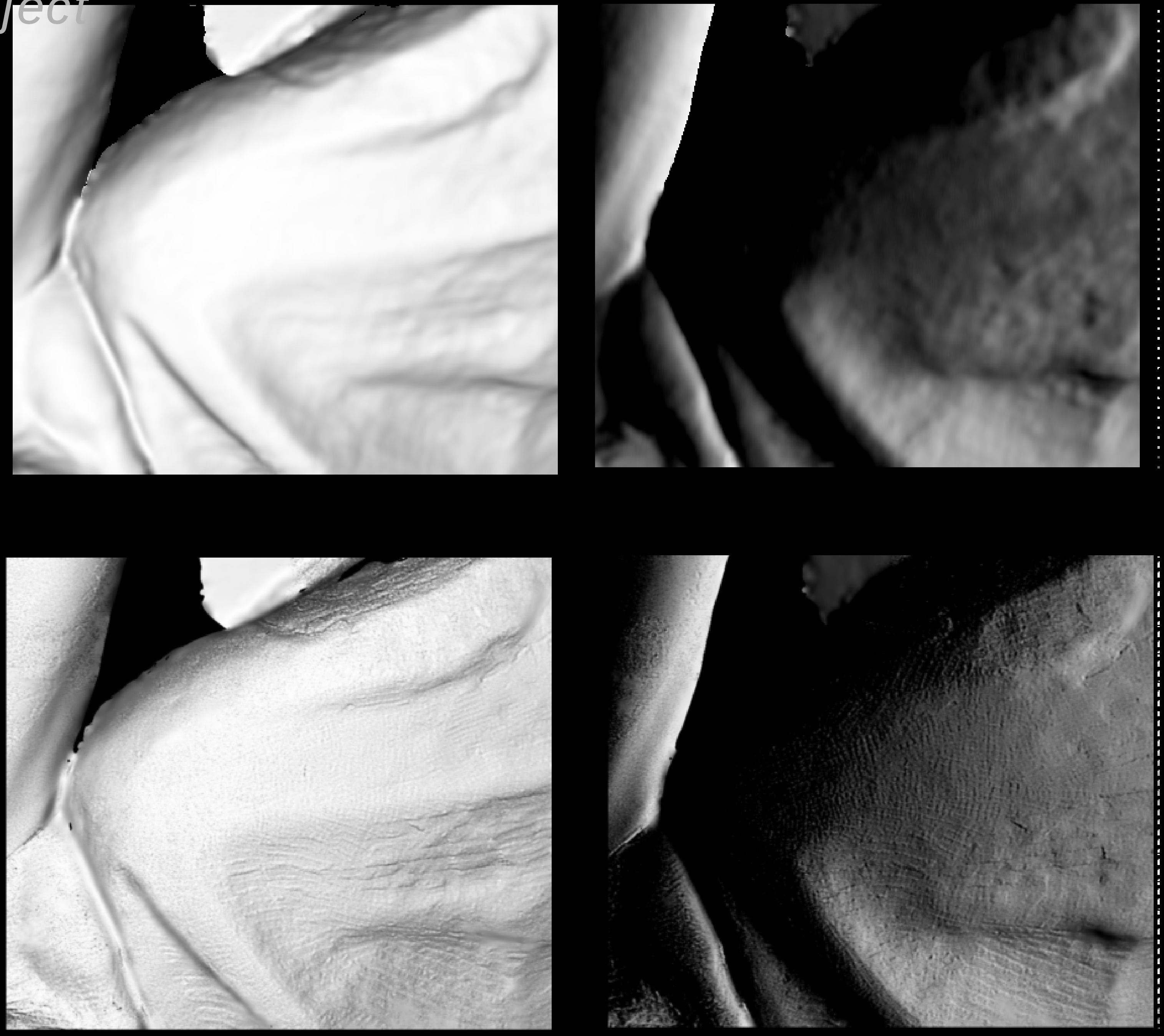


Pieta` Project

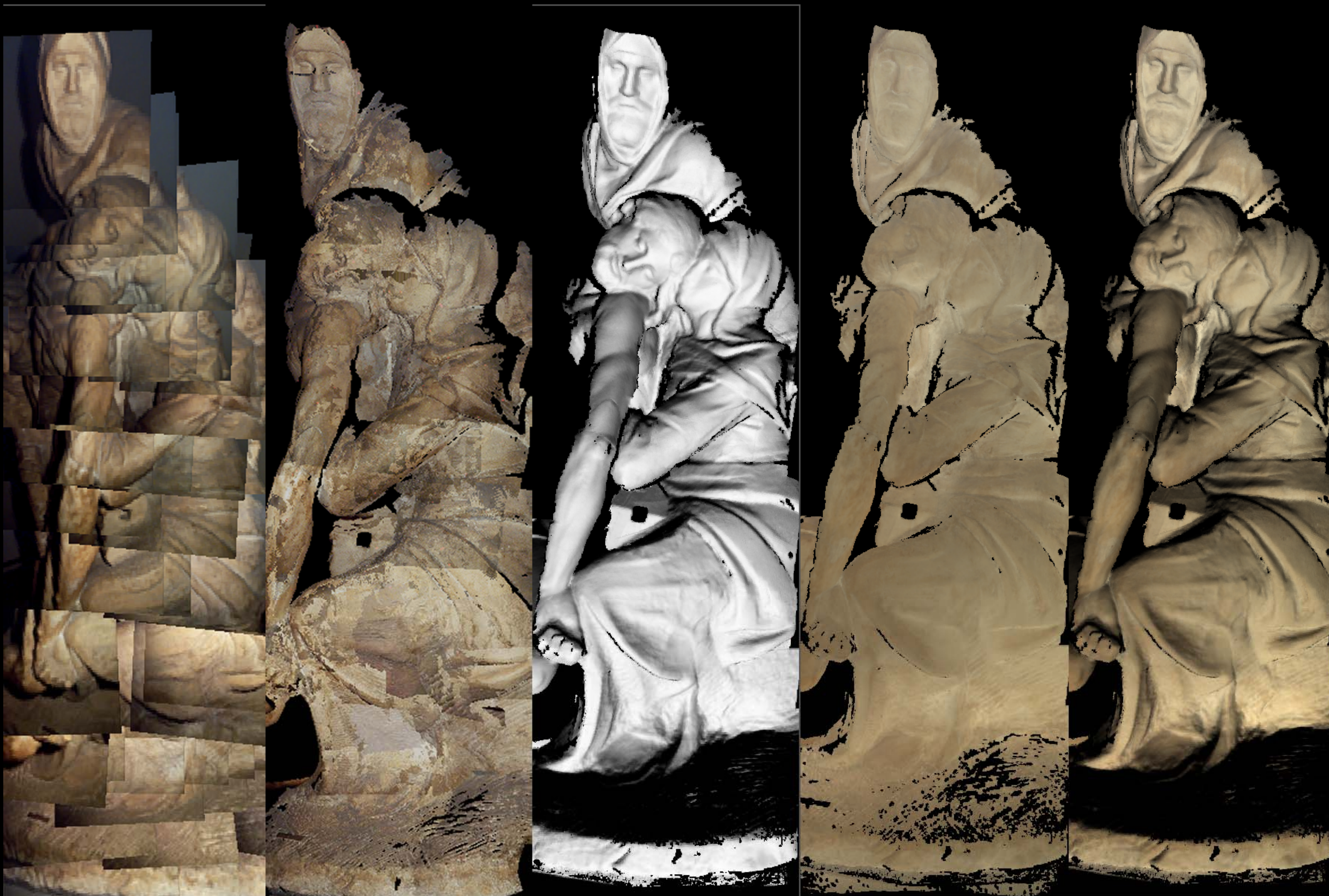


$$L_r = \rho L \cos\theta \Delta\omega / \pi$$

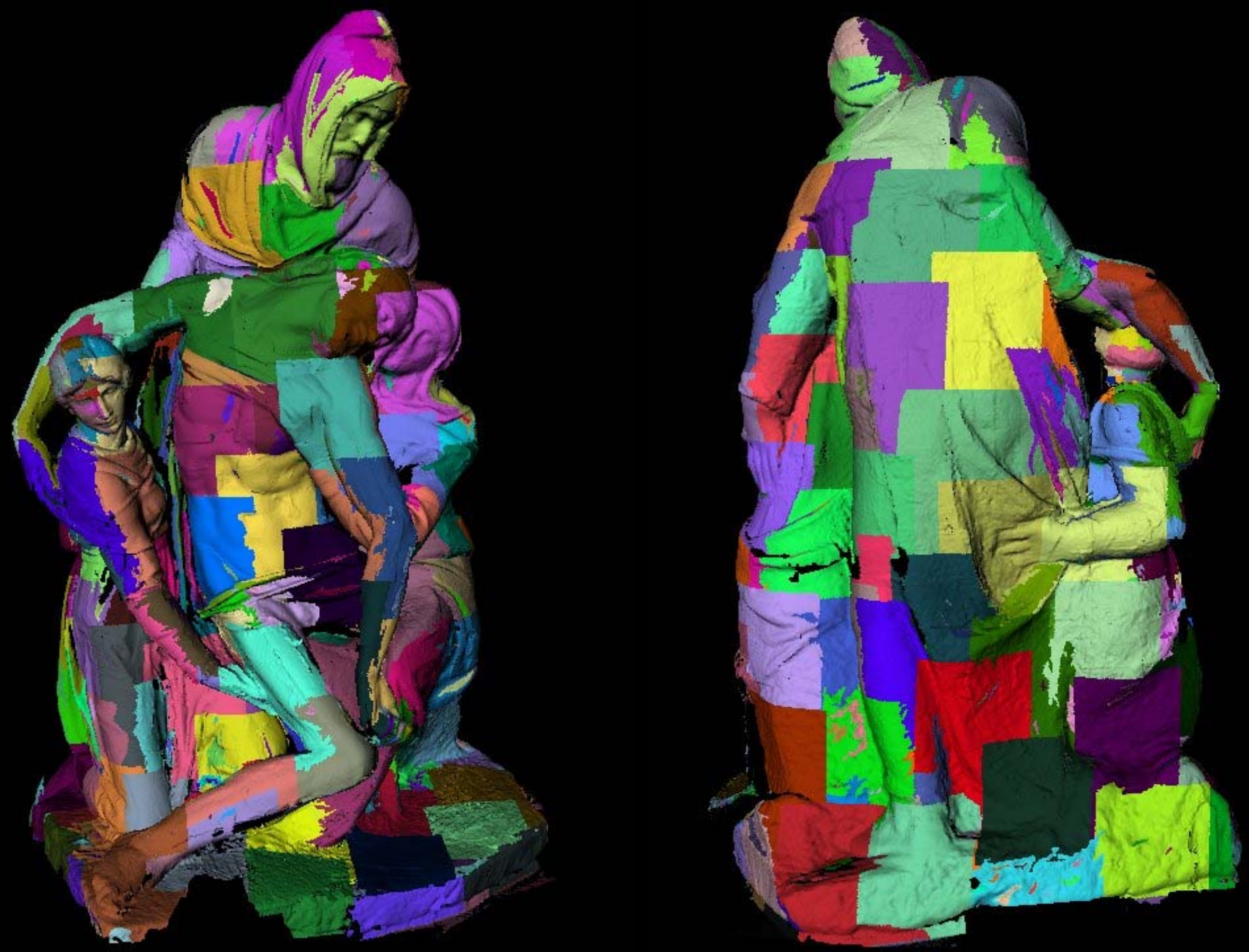
Pieta` Project



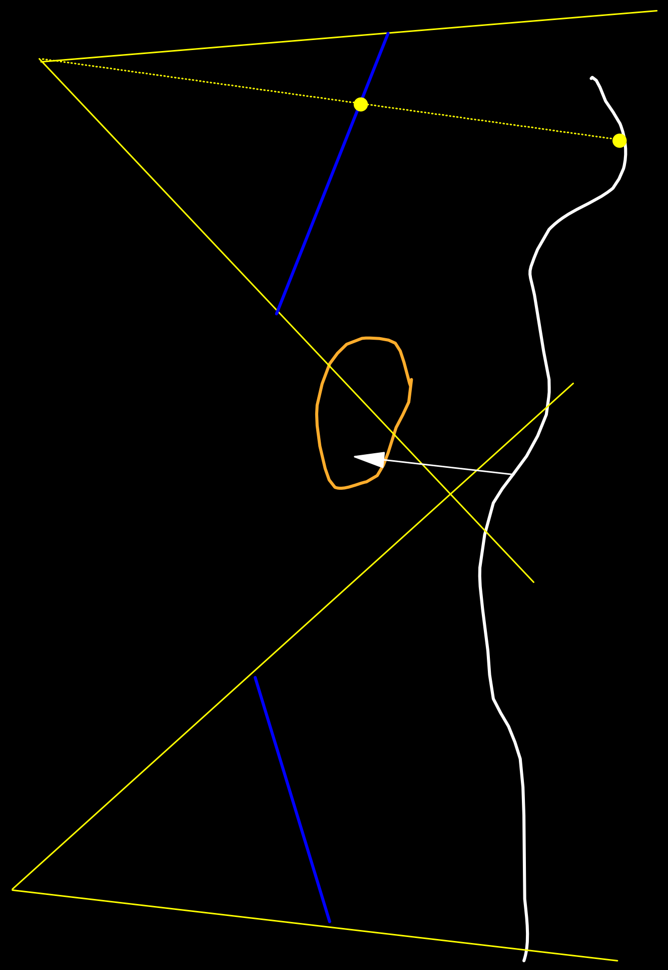
Pieta` Project



Remapping Unique Texture

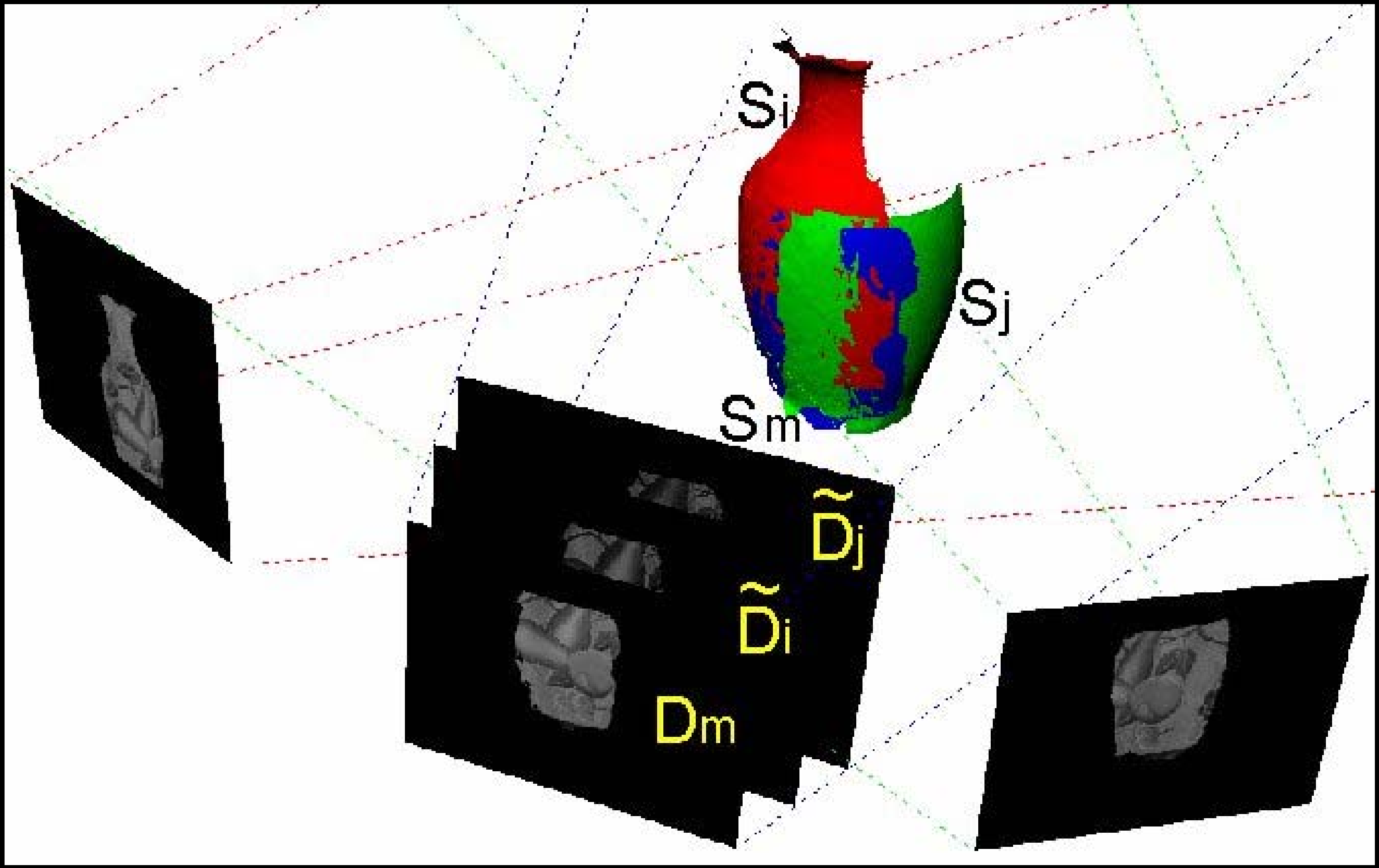


Blend textures with weights based on data reliability



```
for each patch
  for each camera pos
    compute tex coords
    init z-buffer with depth map
    render weights
    for tex in {alb, np, nm}
      render textured patch
      acctex += rendered*weight
      accwgt += weight
    end
  end
  normalize
  save the three images
end
```

Pieta` Project



Pieta` Project

Captured

Geometric registration

Single photometric

Texture registration

Pieta` Project