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# Reconstruction *in the round* with Photometric Normals

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# Uniform albedo Lambertian objects (with highlights)

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- **Challenging objects**
- **Lack of features makes correspondences hard**
- **Silhouette and shading are only available cues**

# Photometric stereo

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- **Single Viewpoint**
- **Move light-source for each image**
- **Same pixel always corresponds to same surface point**
- **With known light directions can estimate *n***
- **Integrate normals to get depth map**

$$i = \mathbf{l}^{\mathrm{T}}\mathbf{n}$$

# Photometric stereo



- To get more than depth-maps, we need multiple-viewpoints…
- … and in that case pixels are no longer automatically in correspondence
- However, if some correspondence is given, photometric stereo can proceed as usual

- Our strategy:
  1. Estimate light directions & intensities
  2. Evolve a surface using photometric stereo with approximate correspondences from the current surface (starting from visual hull)

# 1. Light estimation

- **Three surface points with known surface normals and their image intensities are enough to estimate a directional light source**

$$\mathbf{l} = [\mathbf{n_a}\;\mathbf{n_b}\;\mathbf{n_c}]^{-1} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

- **But where do you get these three points ?**

# 1. Light estimation

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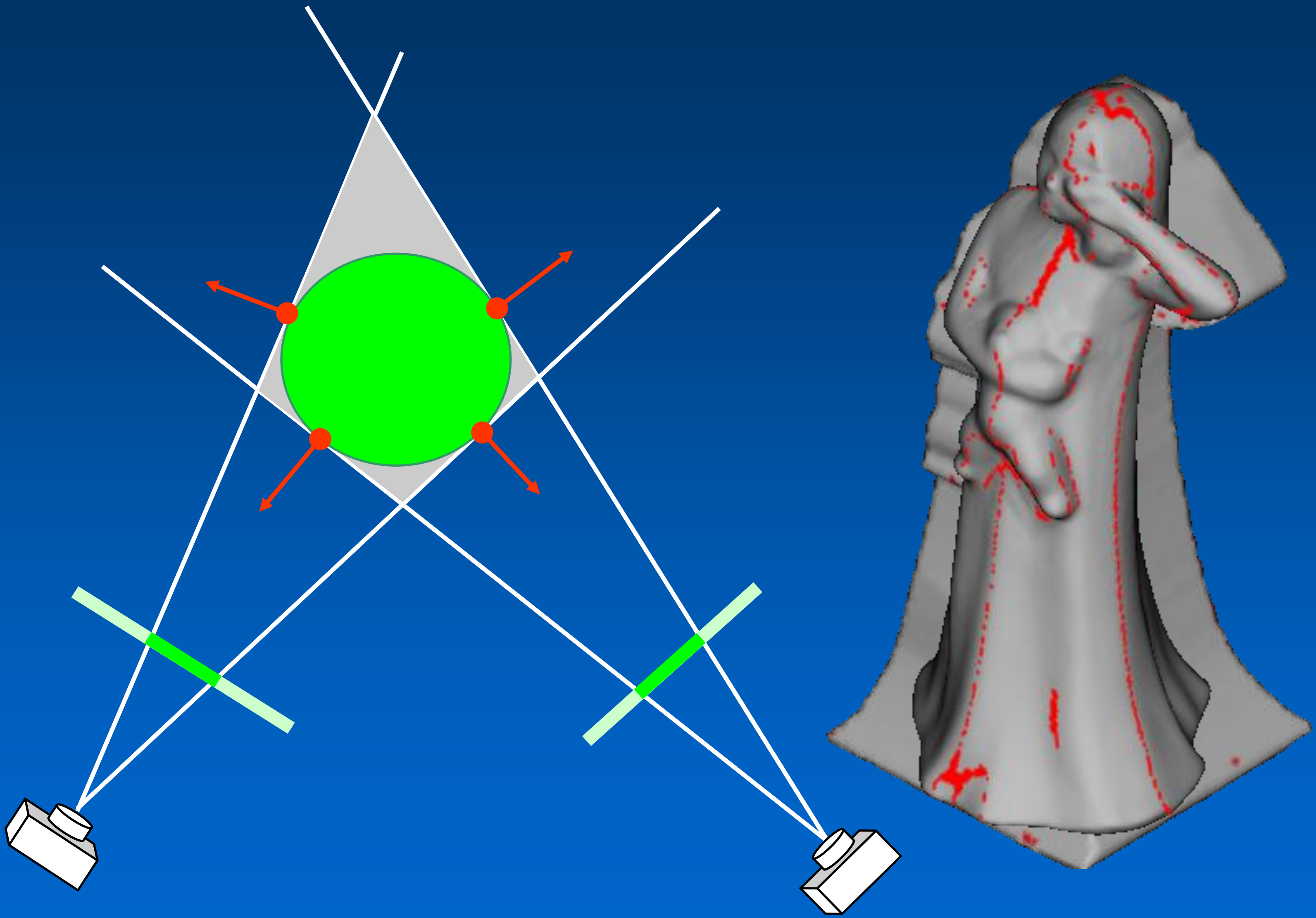
- **Answer: From the visual hull**

# 1. Light estimation



# 1. Light estimation

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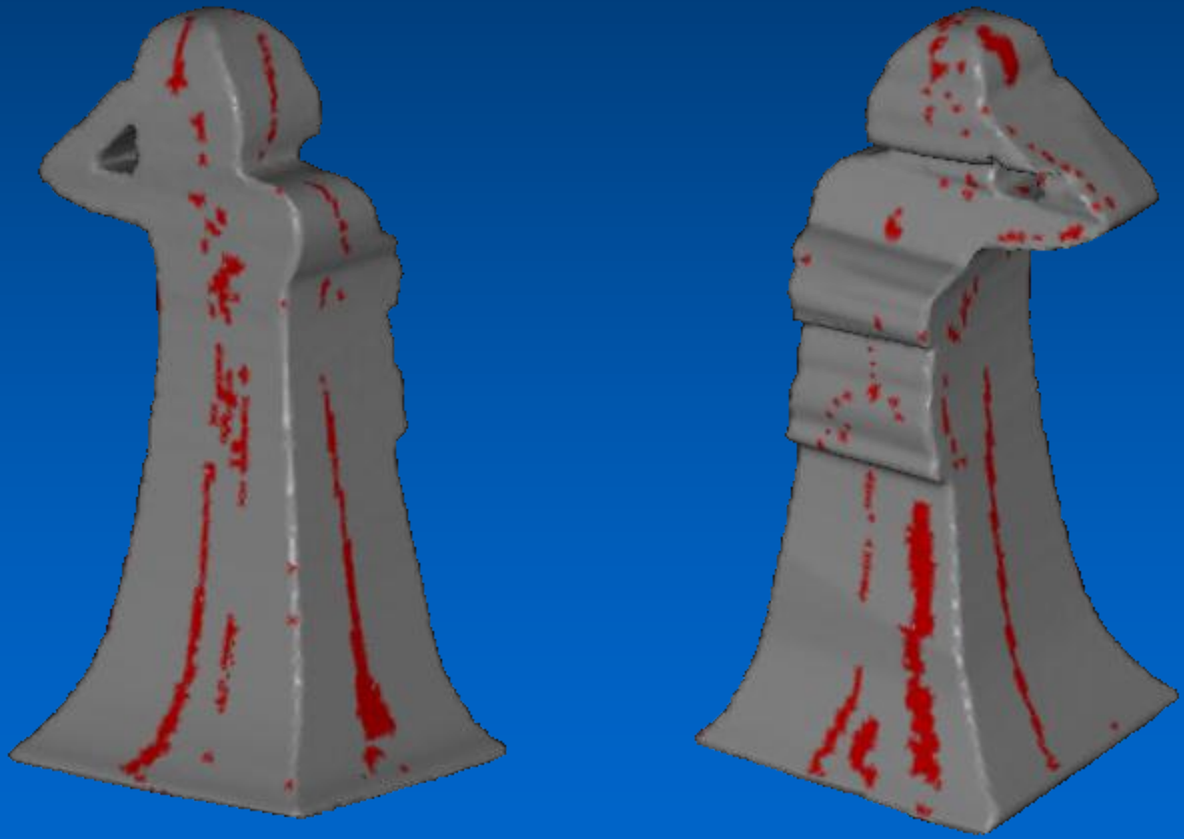
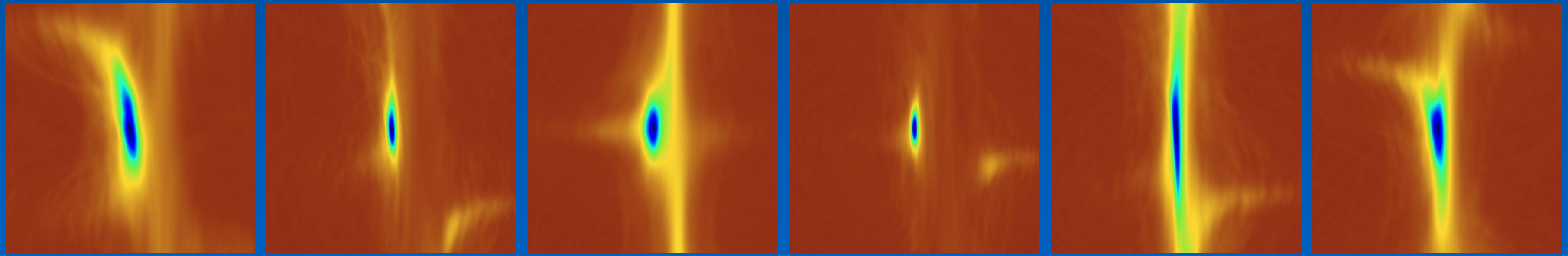
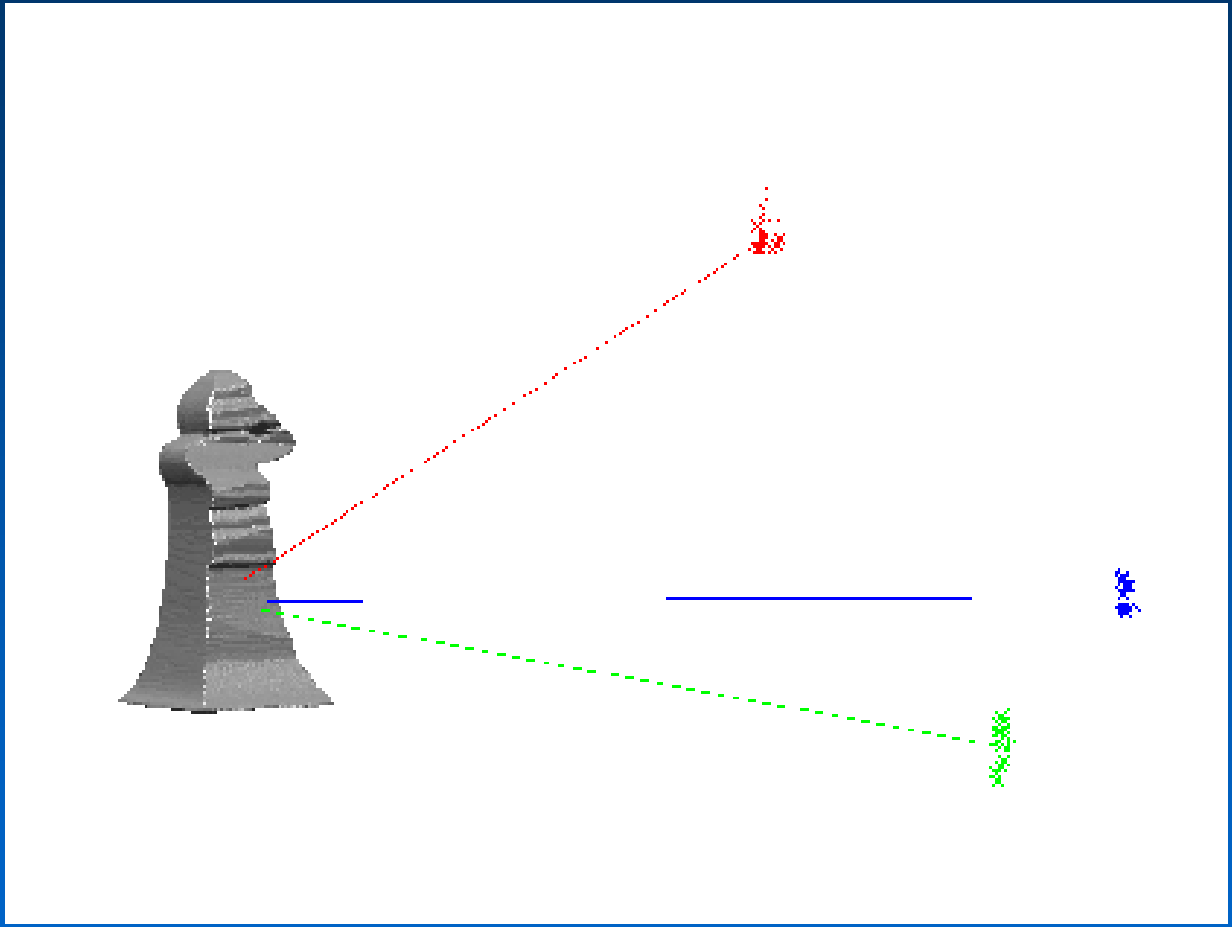
- **Recover generators by random sampling**



# Accuracy of light estimation



# 1. Light estimation



# 2. Multi-view photometric stereo

- Mesh with vertices $x_1,\ldots,x_M$
- And faces $f=1,\ldots,F$
- Define photometric normals $v_1,\ldots,v_F$
- Minimise sum of two energies
  - $E_m$ with respect to $x_1,\ldots,x_M$
  - $E_v$ with respect to $v_1,\ldots,v_F$

$$E_m\left(\mathbf{x_1},\ldots,\mathbf{x_M};\mathbf{v_1},\ldots,\mathbf{v_F}\right)=\sum_{f=1}^{F}\left\|\mathbf{n_f}-\mathbf{v_f}\right\|^2 A_f$$

$$E_v\left(\mathbf{v_1},\ldots,\mathbf{v_F};\mathbf{x_1},\ldots,\mathbf{x_M}\right)=\sum_{f=1}^{F}\sum_{k\in\mathcal{V}_f}\left(\mathbf{l_k}^T\mathbf{v_f}-i_{f,k}\right)^2$$

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# 2. Multi-view photometric stereo

- **evolution**

Reconstruction in the Round
Using Photometric Normals

Paper ID #548

Mesh Evolution

# Full algorithm for uniform objects

Capture images of object.

Extract silhouettes.

Recover camera motion and compute visual hull.

Estimate light directions and intensities in every image

Initialise a mesh with vertices $\mathbf{x}_1 \ldots \mathbf{x}_M$ and faces $f = 1 \ldots F$ to the object's visual hull.

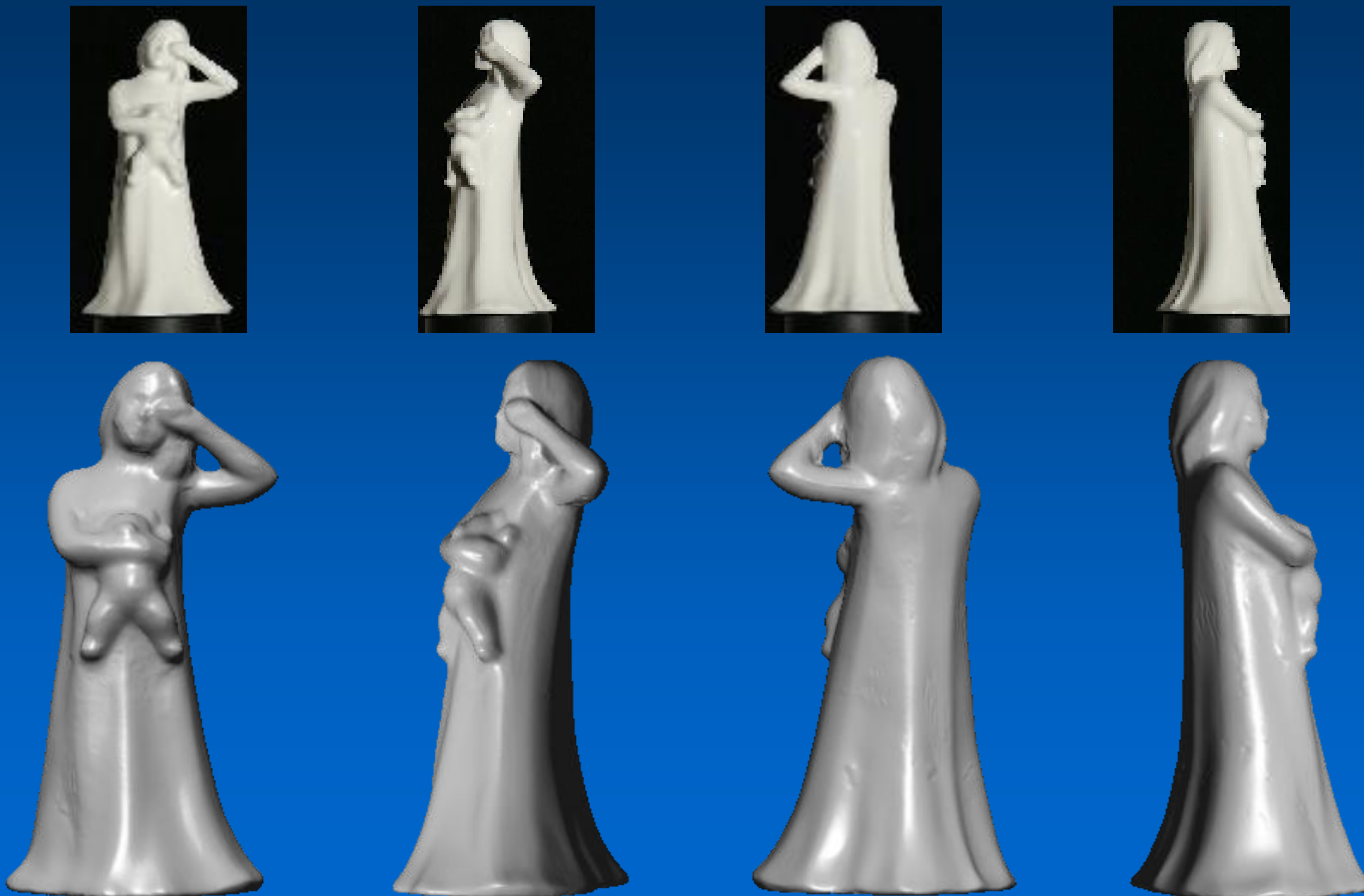
**while** mesh-not-converged **do**

  Optimise $E_v$ with respect to $\mathbf{v}_1 \ldots \mathbf{v}_F$.

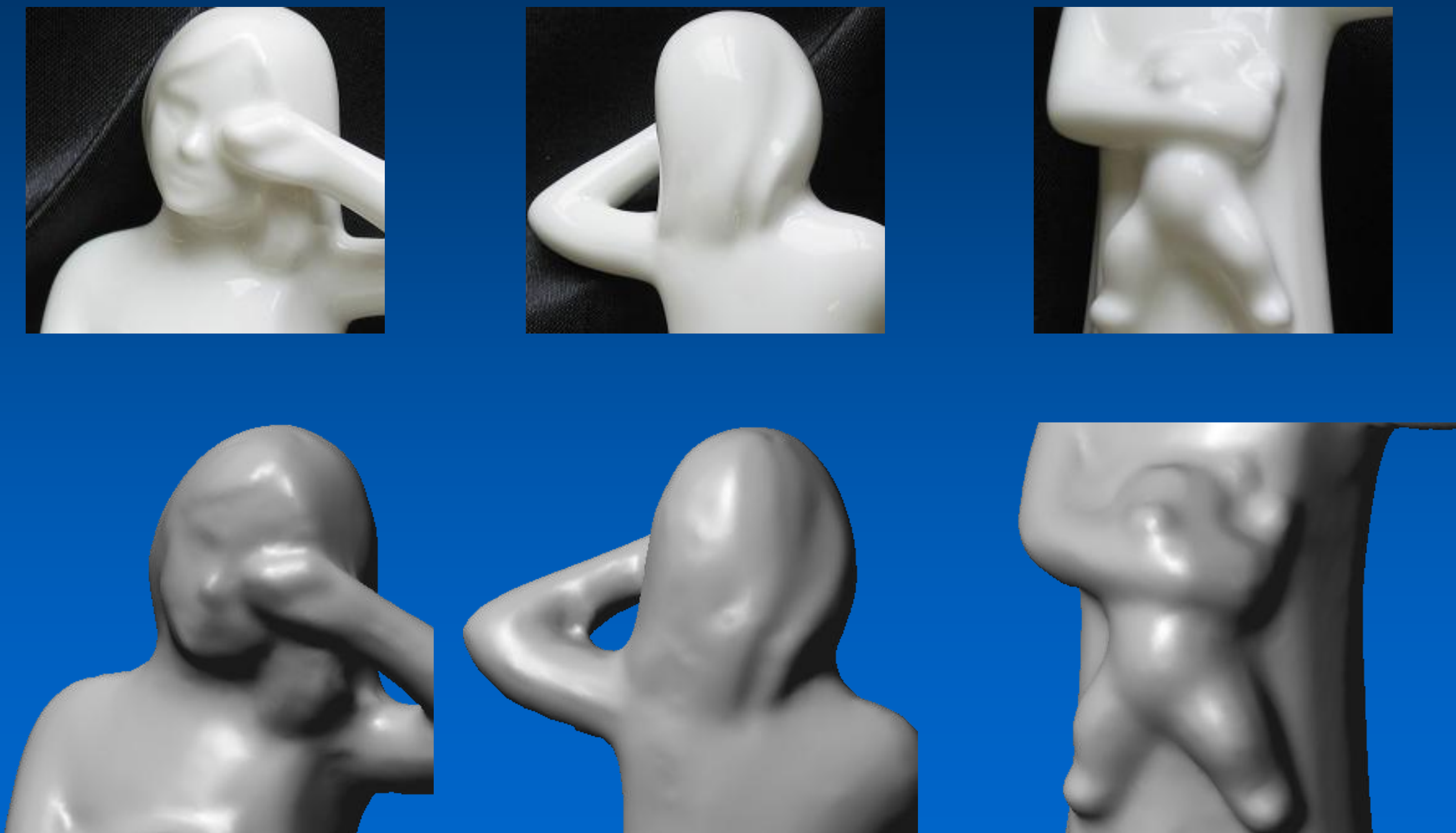
  Optimise $E_m$ with respect to $\mathbf{x}_1 \ldots \mathbf{x}_M$.

**end while**

# Results



# Results



# Results

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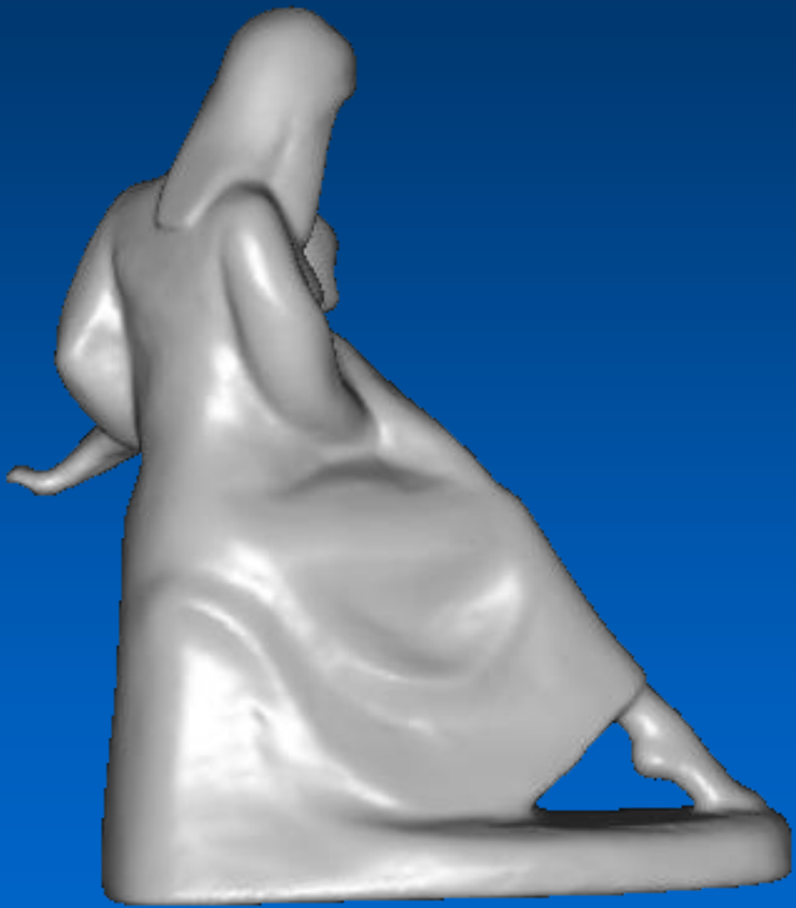

# Results – Fitzwilliam museum

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**Buddha**

- **For multi-albedo objects the technique can improve the results of state-of-the-art correspondence based techniques e.g.** [Hernandez et al 2004]

**Multi-view Dense Stereo**
[Hernandez et al 2004]

**Multi-view Photometric Stereo**

# Results – Fitzwilliam museum

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**Multi-view Dense Stereo**
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**Multi-view Photometric Stereo**