Bridging Shape and Reflectance

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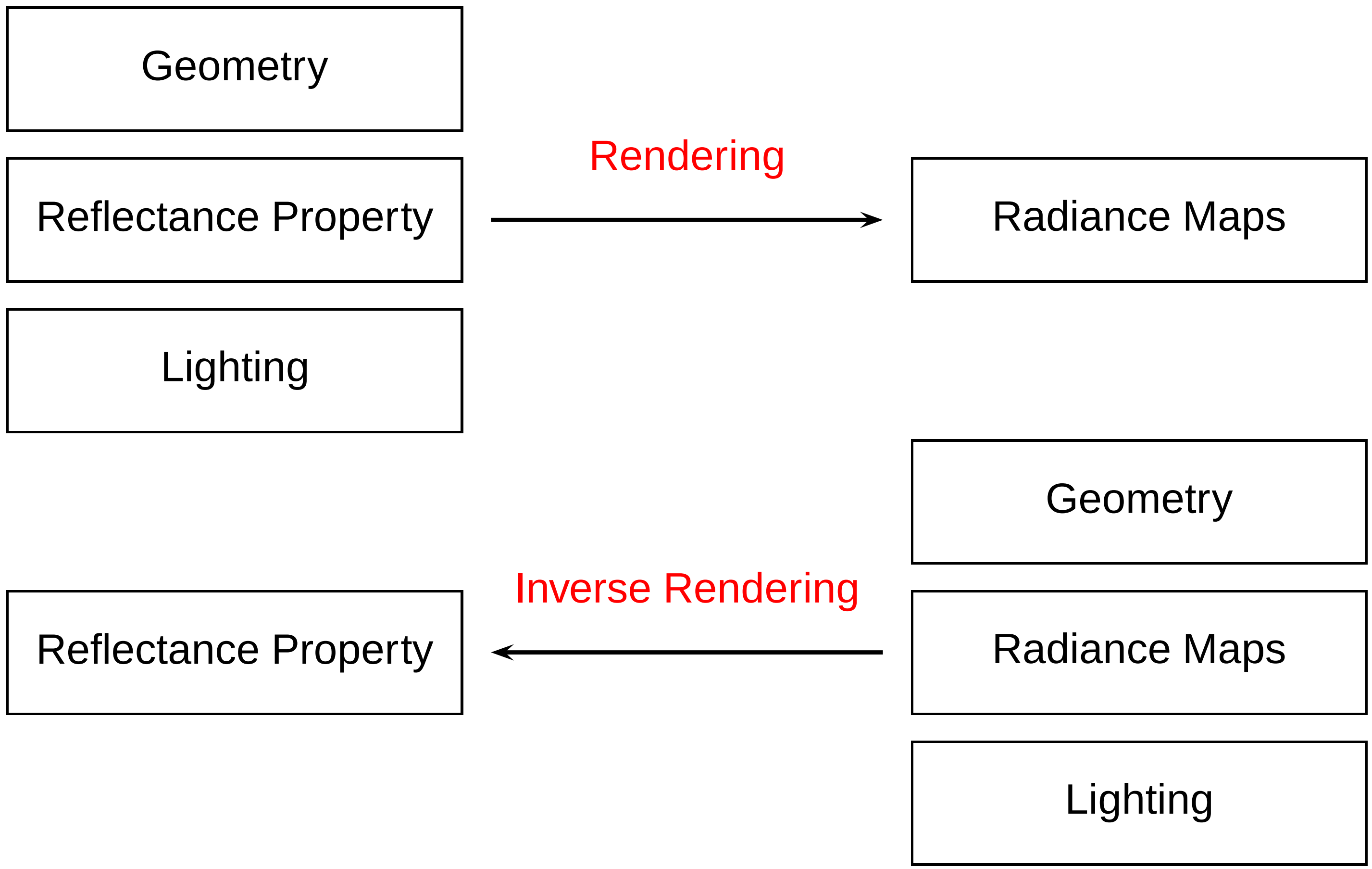
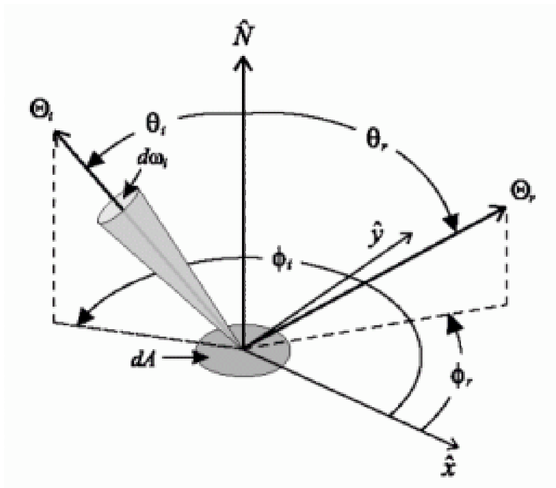
Rendering vs Inverse-Rendering



Parametric BRDF's



$$L = B \cdot I$$

$$\text{Radiance} = \text{BRDF} \cdot \text{Irradiance}$$

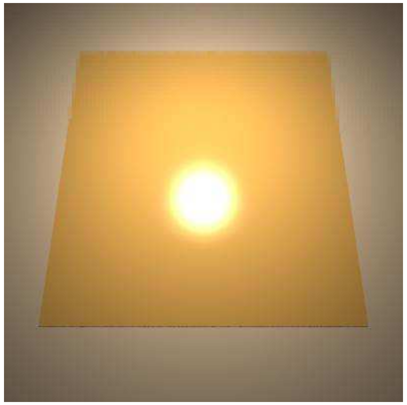
Torrence-Sparrow model

$$B_{TS}(\theta_i, \theta_o, \alpha | \rho_d, \rho_s, \sigma) = \rho_d \cos\theta_i + \frac{\rho_s}{\cos\theta_o} e^{-\alpha^2/2\sigma^2}$$

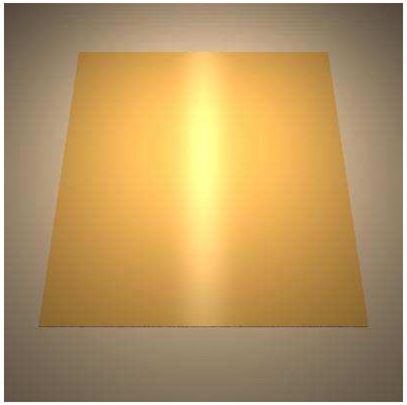
Ward model (isotropic version)

$$B_W(\theta_i, \theta_o, \delta | \rho_d, \rho_s, \sigma) = \frac{\rho_d}{\pi} + \frac{\rho_s}{4\pi\sigma^2\sqrt{\cos\theta_i \cos\theta_o}} e^{-\tan^2\delta/\sigma^2}$$

Renderings with Ward BRDF



Isotropic



Anisotropic

from Simon Premoze’s homepage (http://www.cs.utah.edu/ premoze/brdf/)

BRDF Estimation

We need to estimate BRDF at every point on the object.

Knowns		Unknowns
Radiance L		
Irradiance I	$\Longrightarrow$	BRDF parameters
Surface normal $\hat{\mathbf{n}}$		$(\rho_d,\ \rho_s,\ \sigma)$
Light source direction $\hat{\mathbf{s}}$		
Viewing direction $\hat{\mathbf{v}}$		

Difficulties in Estimation

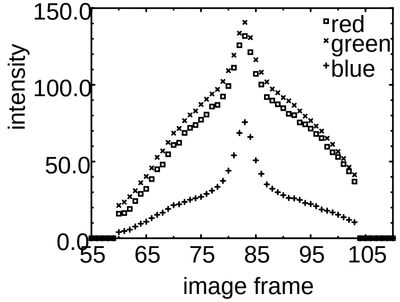
Estimation of specular parameters is difficult :

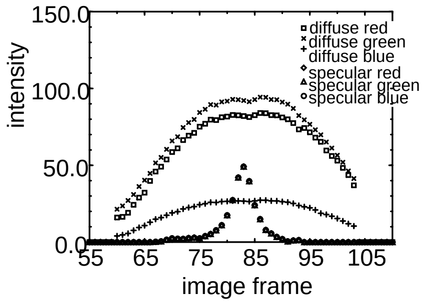
- The specular lobe is highly peaked
  - it is difficult to observe specular points in images
- The specular term is not linear
  - it requires many samples to estimate the parameter

Reflection Component Separation

We can infer the contribution of diffuse and specular part.

$$
\begin{aligned}
M &= [M_R \; M_G \; M_B] \\
&= \begin{bmatrix} \cos\theta_{i_1} & K(\theta_{o_1}, \alpha_1) \\ \vdots & \vdots \\ \cos\theta_{i_N} & K(\theta_{o_N}, \alpha_N) \end{bmatrix} \begin{bmatrix} \rho_{D,R} & \rho_{D,G} & \rho_{D,B} \\ \rho_{S,R} & \rho_{S,G} & \rho_{S,B} \end{bmatrix} \\
&= [\, G_D \; G_S \,] \begin{bmatrix} K_D^t \\ K_S^t \end{bmatrix} = G\,K
\end{aligned}
$$





Illumination Condition

Direct Illumination

- all reflected lights are from light sources
- only one reflection : light source - surface - camera

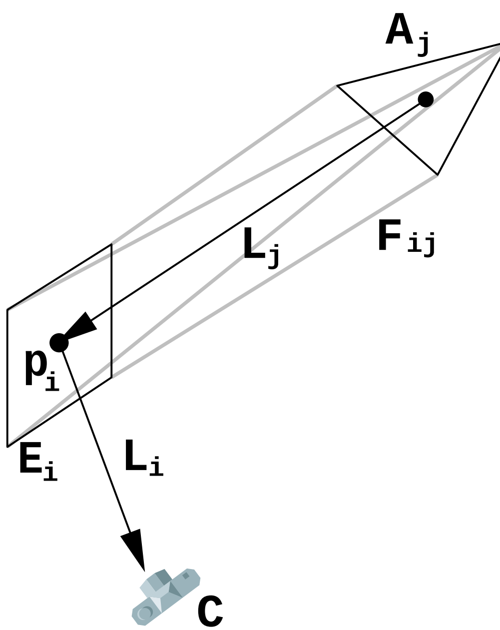
Global Illumination

- reflecting surfaces also work as light sources
- multiple reflections until being observed

Inverse Radiosity (Lambertian)

Assume Lambertian surfaces

$$\tilde{L}_i = \tilde{E}_i + \rho_i \sum_j \tilde{L}_j \tilde{F}_{ij}$$



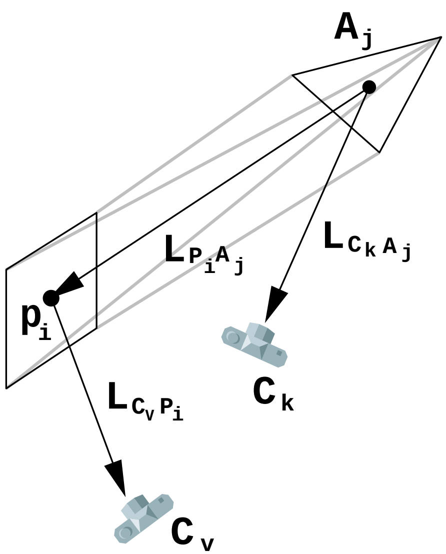
L_i	radiance (radiosity)
E_i	emission (light source)
ρ_i	albedo (BRDF)
F_{ij}	form factor between patches

$$\rho_i = (\tilde{L}_i - \tilde{E}_i) \, / \, (\sum_j \tilde{L}_j \tilde{F}_{ij})$$

Inverse Radiosity (Parametric BRDF)

$$\text{radiance} = \text{emission} + \text{diffuse} + \text{specular}$$

$$\begin{aligned}\tilde{L}_{C_v P_i} &= \tilde{E}_{C_v P_i} + \\ &+ \rho_d \sum_j L_{P_i A_j} \tilde{F}_{P_i A_j} \\ &+ \rho_s \sum_j L_{P_i A_j} K_{C_v P_i A_j}\end{aligned}$$



Inverse Radiosity (Parametric BRDF)

Radiance from one point can vary with viewing directions.

$$\begin{aligned} L_{P_i A_j} &= \tilde{L}_{C_k A_j} - S_{C_k A_j} + S_{P_i A_j} \\ &= \tilde{L}_{C_k A_j} + \Delta S_{C_k P_i A_j} \end{aligned}$$

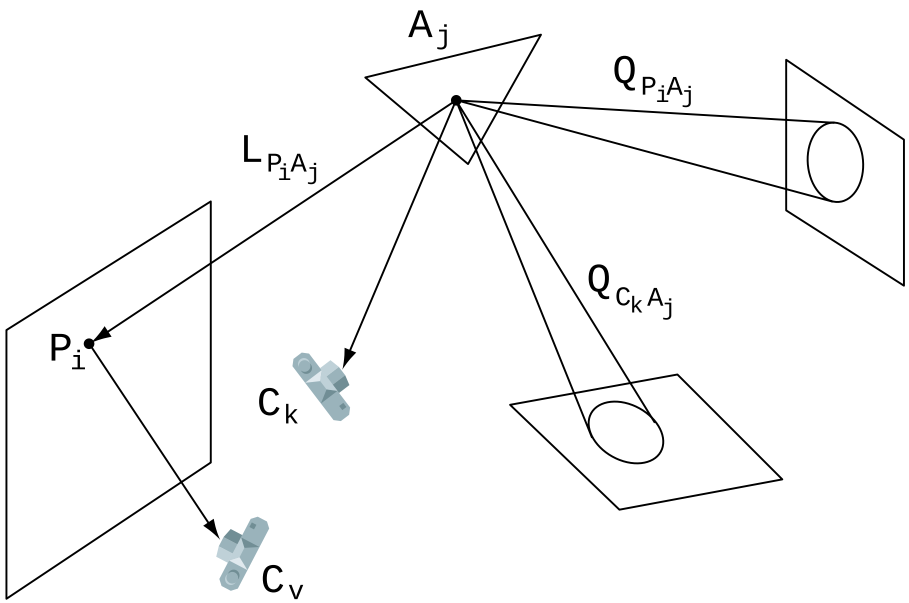
Iteratively estimate ΔS with initial guess $\Delta S = 0$

Inverse Global Illumination Algorithm

Assume constant BRDF over each patch

- Detect specular highlights on surfaces (geometrically)
- Choose sample points inside & around each highlight
- Build links between sample points and patches
- Assign L_0 with average radiance value, and $\Delta S = 0$
- Iterate
  - Update L using ΔS of each link
  - Optimize each surface's BRDF parameters
  - Estimate ΔS with new BRDF parameters

Monte-Carlo Sampling



One-bounce approximation is enough for this purpose.

Diffuse Albedo Map

Assume constant specular property over each patch

$$\rho_d(\mathbf{x}) \;=\; \pi \, \frac{Diffuse(\mathbf{x})}{Irradiance(\mathbf{x})}$$

$$Diffuse(\mathbf{x}) \;=\; L(\mathbf{x}) \;-\; Specular(\mathbf{x})$$

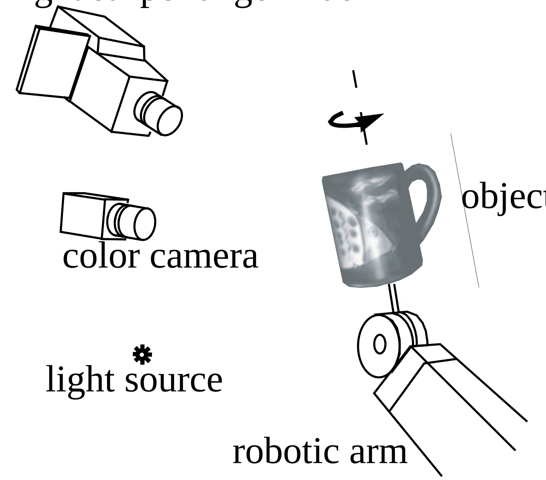
Give lower weight on sample

- which has large specularity
- whose viewing angle is grazing the surface

Geometry

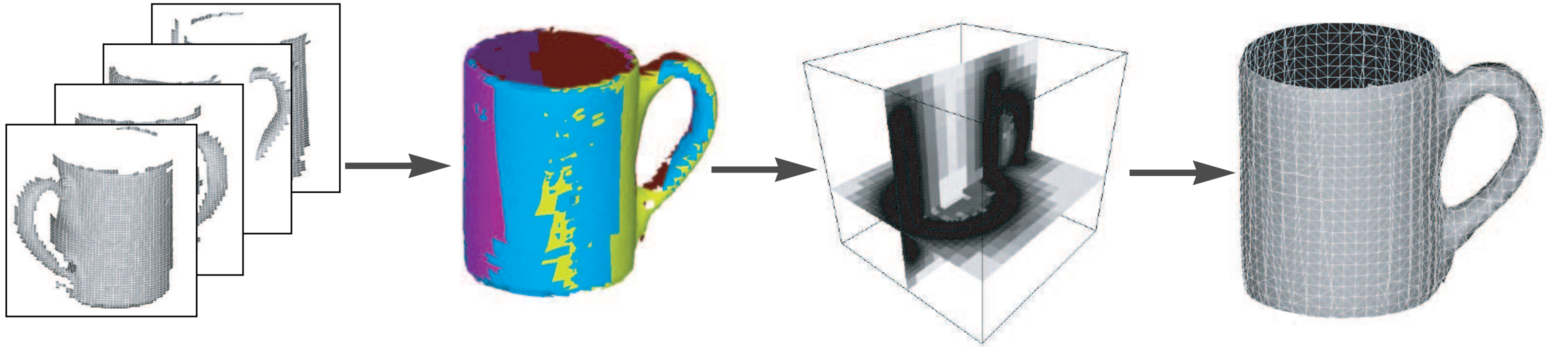
So far, we assumed that the geometry is already given.

- input by hand
- measure from the object
  - laser range finder, stereo vision, shape from X, . . .



Geometry Acquisition Procedure

1. Surface acquisition from each range image
2. Alignment of range images
3. Retrieving 3D representation
   - Merging based on a volumetric representation
   - Isosurface extraction



(a) range image acquisition (b) alignment (c) merging (d) isosurface extraction

Surface Normal Estimation

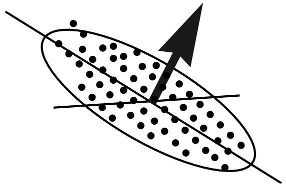
Why is the surface normal important?

BRDF is evaluated at each surface points locally.

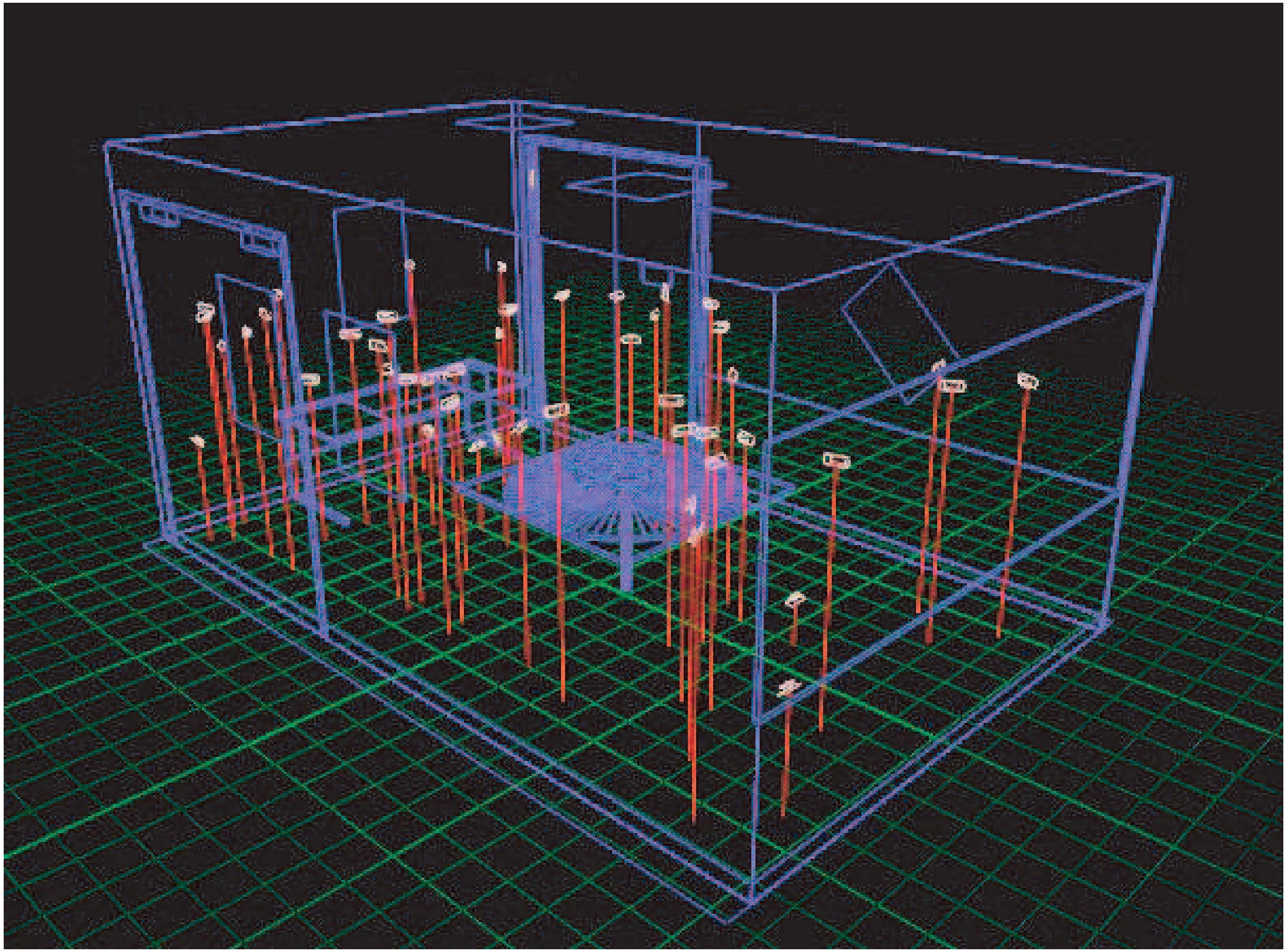
For accurate estimation, precise θ, α are required.

The eigenvector of the covariance matrix of neighbor points

$$\hat{\mathbf{n}} = Null\left(\sum_{neighbor} (\mathbf{x} - \overline{\mathbf{x}})(\mathbf{x} - \overline{\mathbf{x}})^t\right)$$



Experiment Setup : Conference Room



Result : Conference Room

(a) Initial hierarchical polygon mesh, with radiances assigned from images.

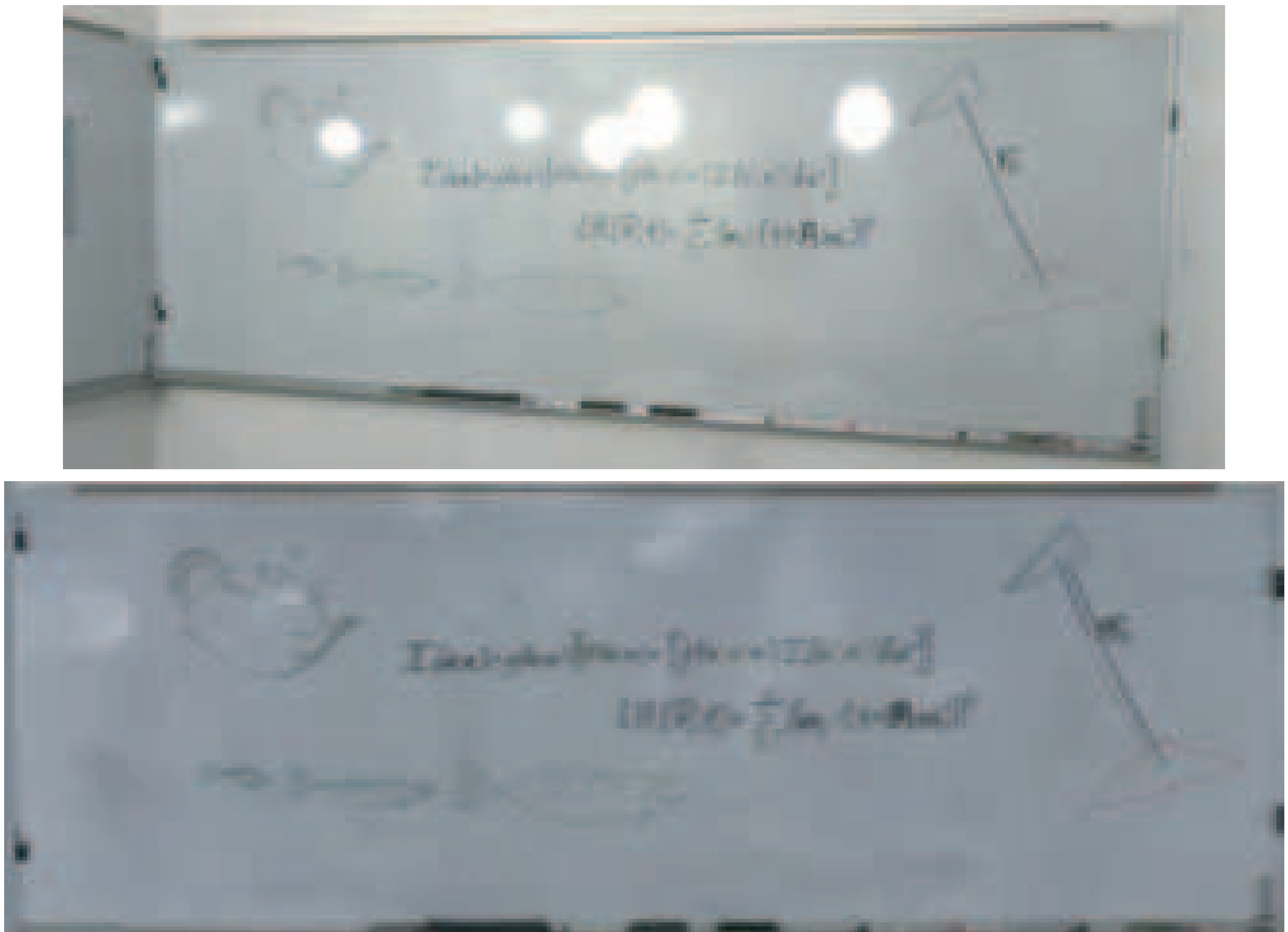
(b) Synthetic rendering of recovered properties under original illumination.

Result : Conference Room

(c) Synthetic rendering of room under novel illumination.

(d) Synthetic rendering of room with seven virtual objects added.

Result : Whiteboard



Result : Mug

Synthesized object images

input frame 50 synthesized input frame 80 synthesized

Reference

- Y. Sato, M. D. Wheeler, K. Ikeuchi, Object Shape and Reflectane Modeling from Observation, SIGGRAPH, 1997
- Y. Yu, P. Debevec, J. Malik, T. Haukins, Inverse Global Illumination: Recovering Reflectance Models for Real Scenes from Photographs, SIGGRAPH, 1999
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