Surface Normal Deconvolution:
Photometric Stereo for Optically Thick Translucent Objects

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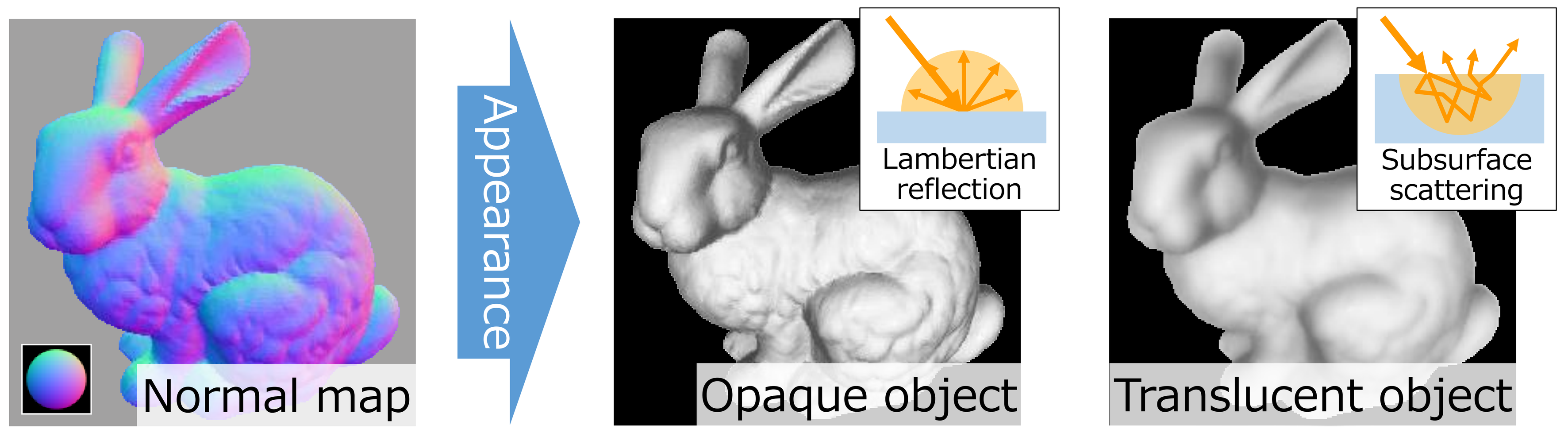
Background

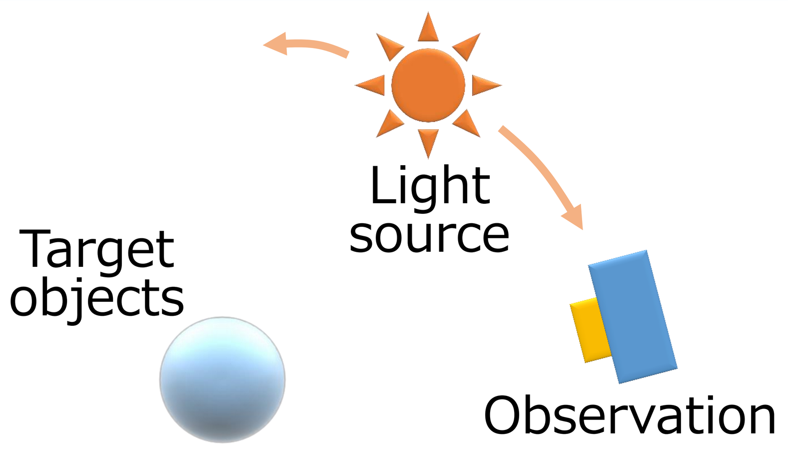
Appearance of translucent object is smoother than actually it is, due to subsurface scattering



Problem setting

Estimate surface normal from observed images with

- Fixed observation
- Known lighting directions
- Shadow free image

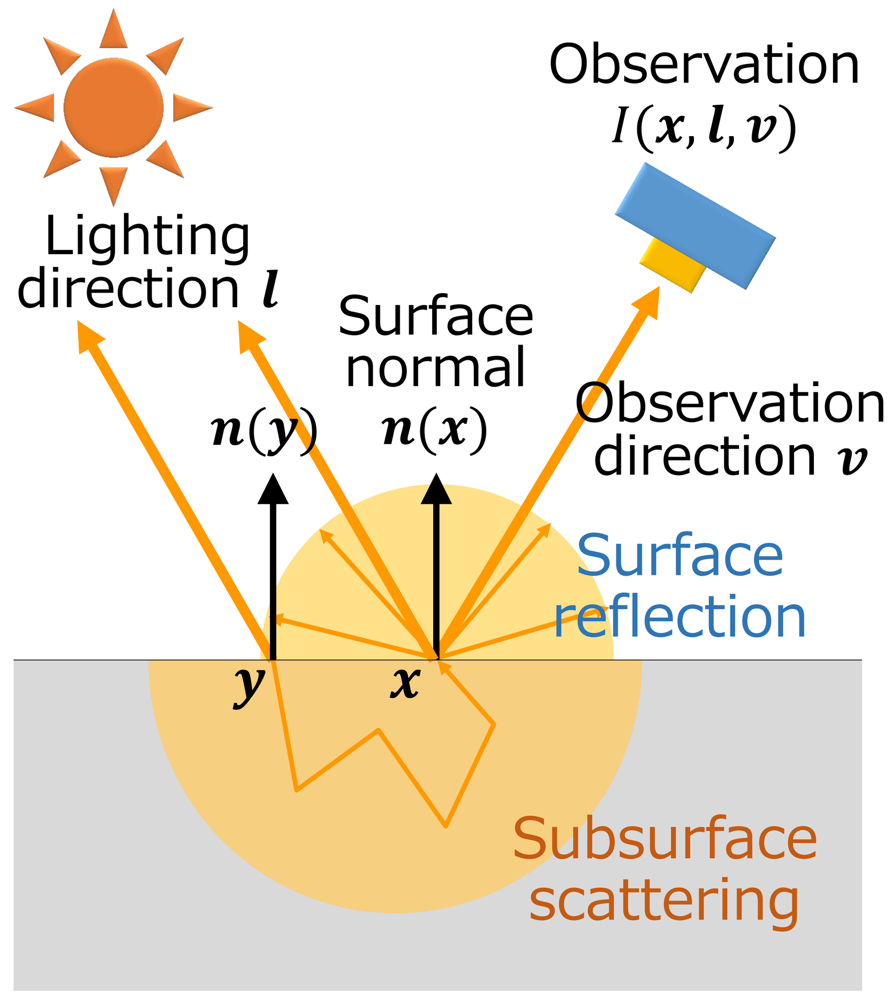


Idea: Approximation of subsurface scattering on translucent object

Observation $I(\boldsymbol{x},\boldsymbol{l},\boldsymbol{v}) = \rho\boldsymbol{n}(\boldsymbol{x})^T\boldsymbol{l} + \gamma F_t(\boldsymbol{v},\boldsymbol{n}(\boldsymbol{x}),\eta)\int_{\boldsymbol{y}} R(\boldsymbol{x},\boldsymbol{y})F_t(\boldsymbol{l},\boldsymbol{n}(\boldsymbol{y}),\eta)\boldsymbol{n}(\boldsymbol{y})^T\boldsymbol{l}d\boldsymbol{y}$

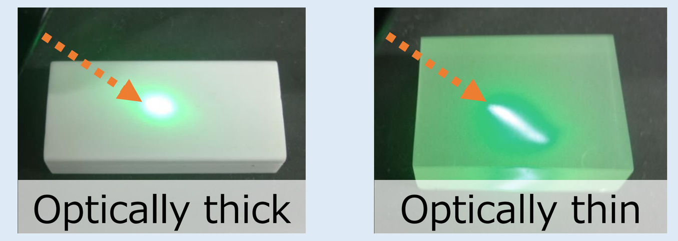
Surface reflection — Subsurface scattering

ρ: reflection ratio, γ: scattering ratio
F_t: Fresnel transmission
η: refractive index



Approximate Fresnel term as constant with assumption on target object

Subsurface scattering is invariant to incident and observation direction
➡ **Optically thick translucent object**

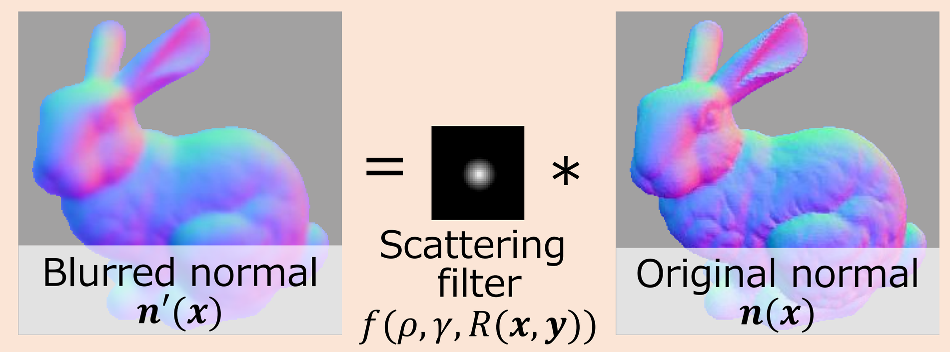


$$\approx \rho\boldsymbol{n}(\boldsymbol{x})^T\boldsymbol{l} + \gamma'\int_{\boldsymbol{y}} R(\boldsymbol{x},\boldsymbol{y})\boldsymbol{n}(\boldsymbol{y})^T\boldsymbol{l}d\boldsymbol{y}$$

$$= \rho'\left(f(\rho,\gamma',R(\boldsymbol{x},\boldsymbol{y})) * \boldsymbol{n}(\boldsymbol{x})\right)^T\boldsymbol{l}$$

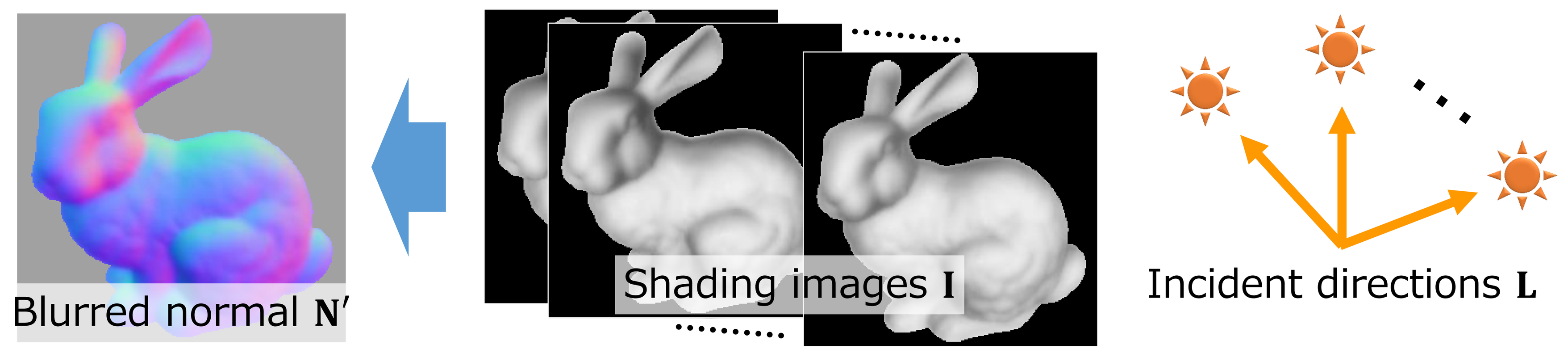
$$= \rho'\boldsymbol{n}'(\boldsymbol{x})^T\boldsymbol{l}$$

Convolution with scattering filter

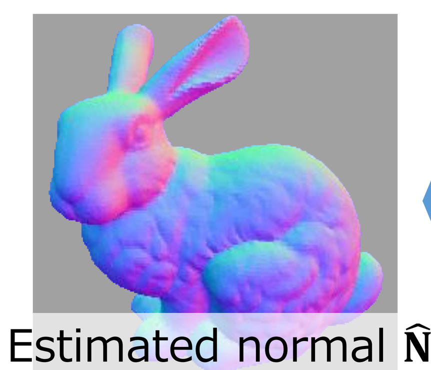


Estimation algorithm

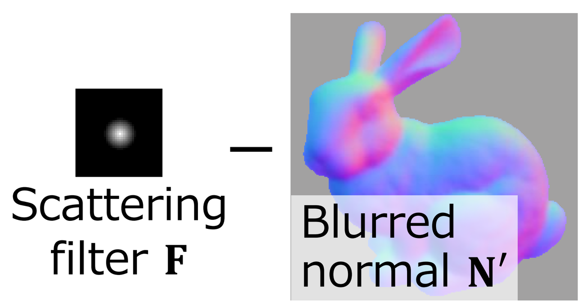
1. Lambertian photometric stereo



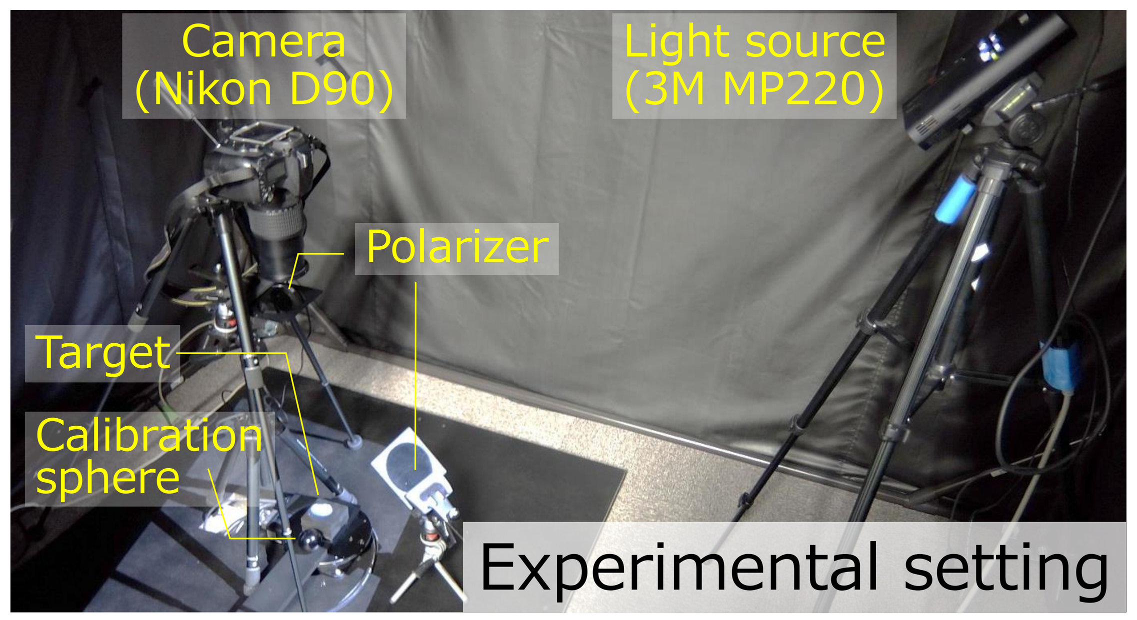
2. Deconvolution with scattering filter



$$\underset{\mathbf{N}}{\operatorname{argmin}} \left\| \text{Latent normal } \mathbf{N} * \text{Scattering filter } \mathbf{F} - \text{Blurred normal } \mathbf{N}' \right\|^2 + \lambda \left[\left\| \frac{\partial}{\partial x} \text{Latent normal } \mathbf{N} \right\|^2 + \left\| \frac{\partial}{\partial y} \text{Latent normal } \mathbf{N} \right\|^2 \right]$$



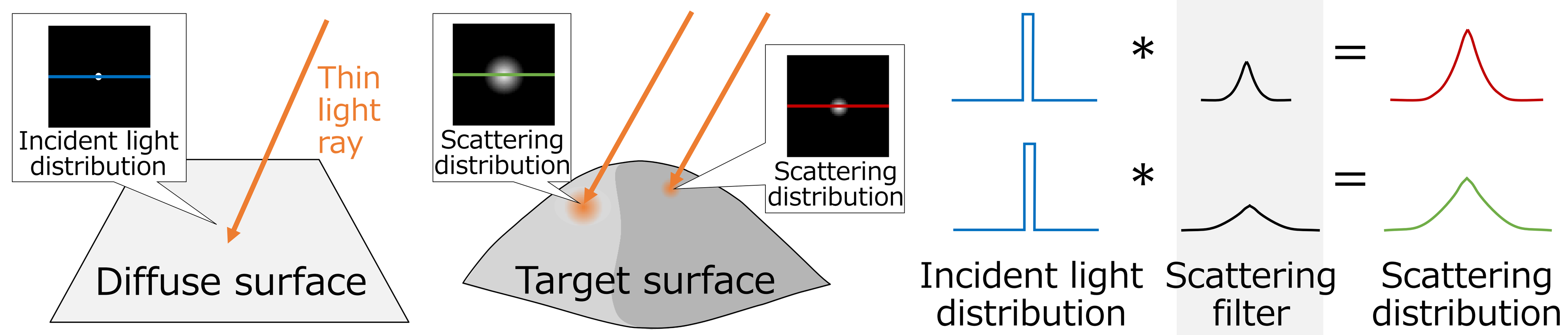
Experiments with real data



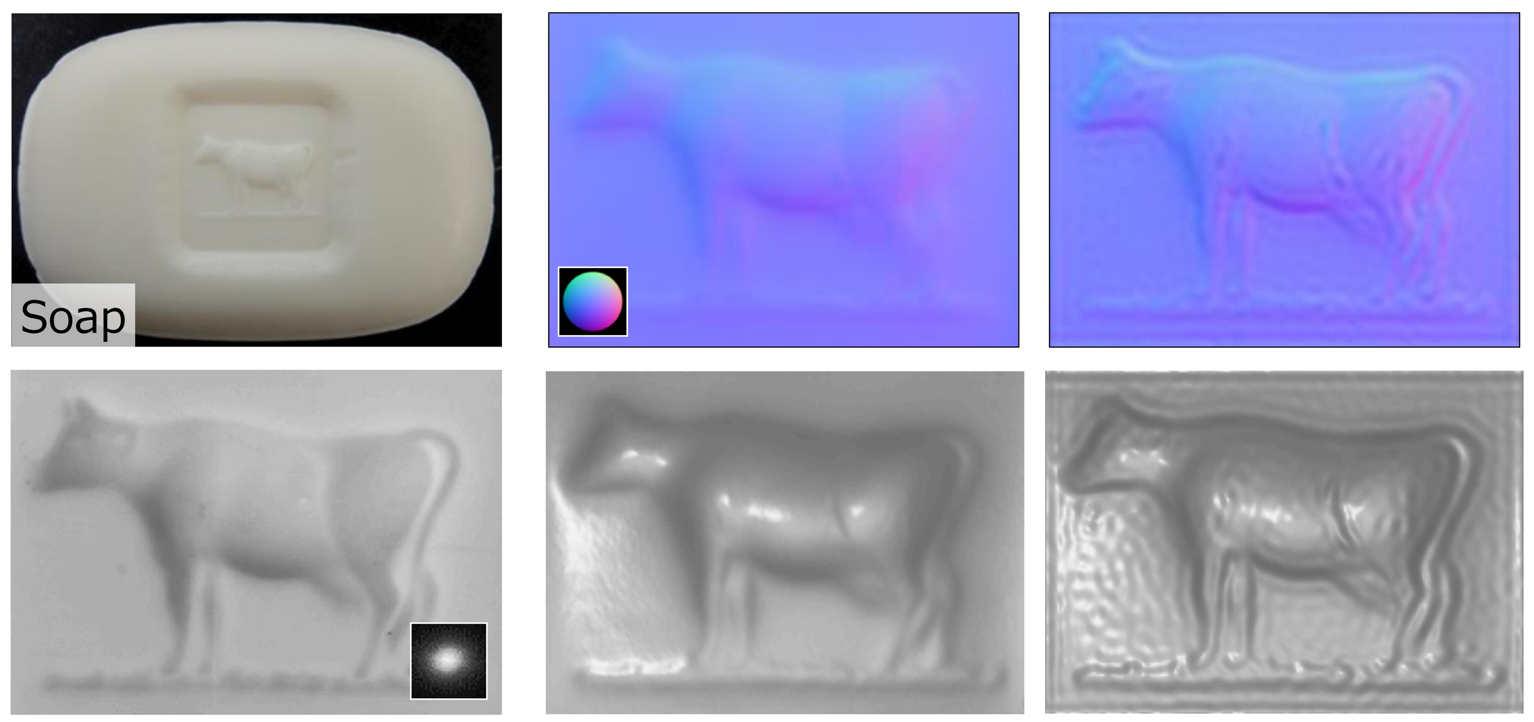
Experimental setting

Measurement of scattering filter

Estimate filter from light distribution on target object

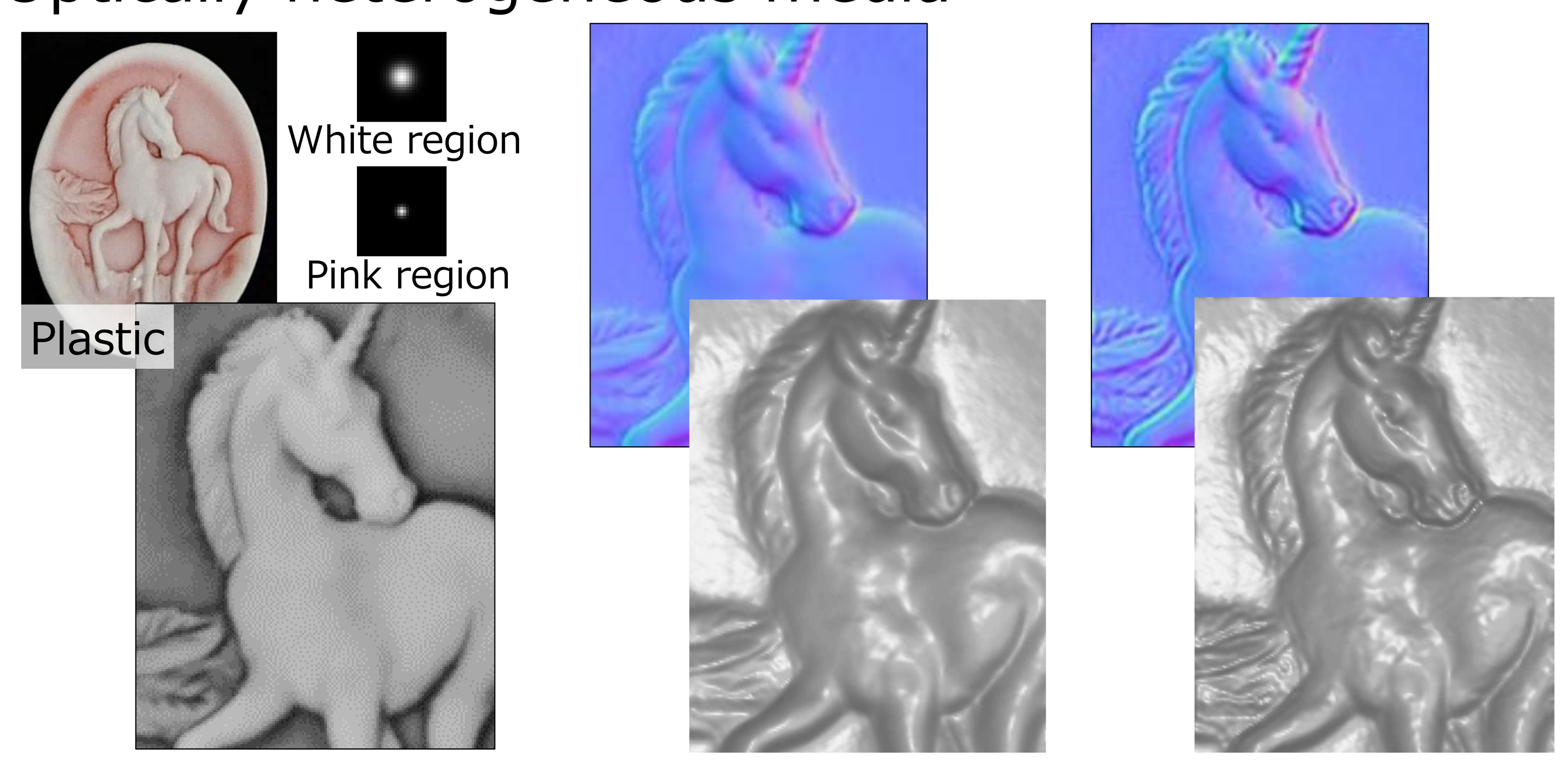


Optically homogeneous media



Observed shading image and scattering filter — Lambertian photometric stereo — Our method

Optically heterogeneous media



Observed shading image and scattering filter — Lambertian photometric stereo — Our method