Semi-calibrated Photometric Stereo

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From Photometric Stereo under Non-uniform Light Intensities and Exposures, ECCV 2016

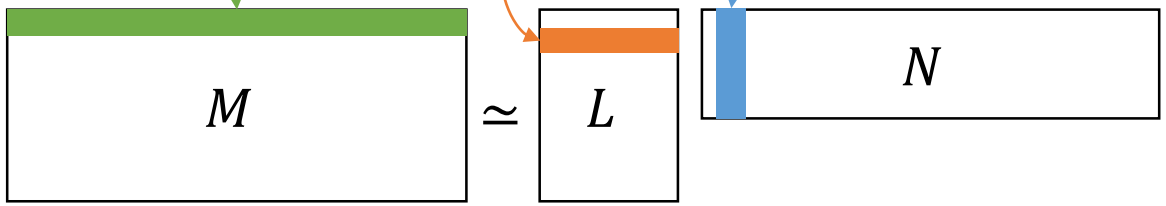
Photometric Stereo

Photometric Stereo

Dense (per-pixel) surface normal

(Calibrated) Photometric Stereo

Light vector Normal of a pixel



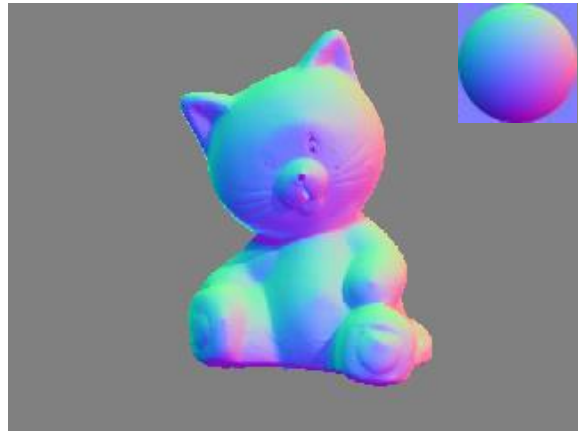
Observations $M \in \mathbb{R}^{f \times p}$

Intensity-scaled Light $L \in \mathbb{R}^{f \times 3}$

Albedo-scaled Normal $N \in \mathbb{R}^{3 \times p}$

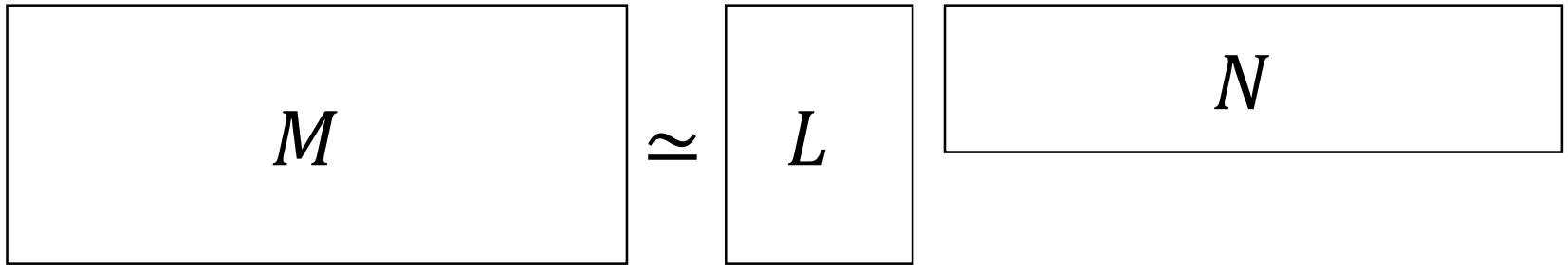
f: # of images, p: # of pixels

$N = L^{\dagger} M$ [Woodham'80]



Surface Normal

(Calibrated) Photometric Stereo



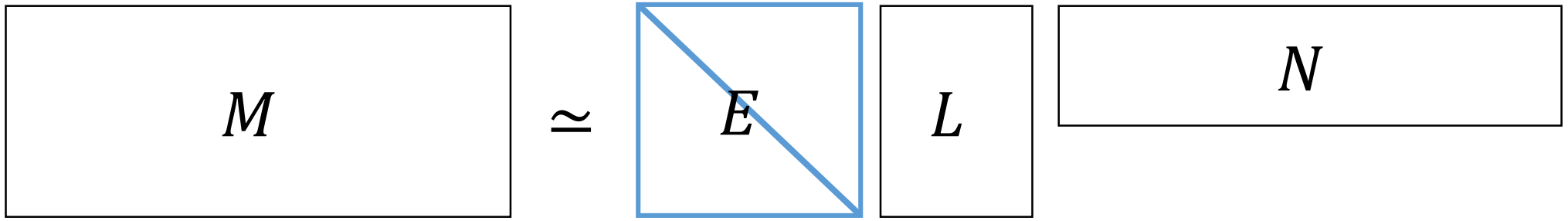
Observations | Intensity-scaled Light | Albedo-scaled Normal

$M \in \mathbb{R}^{f \times p}$ $L \in \mathbb{R}^{f \times 3}$ $N \in \mathbb{R}^{3 \times p}$

f: # of images, p: # of pixels

(Calibrated) Photometric Stereo

Diagonal light intensity matrix E



Observations

Unit Light

Albedo-scaled Normal

$M \in \mathbb{R}^{f \times p}$

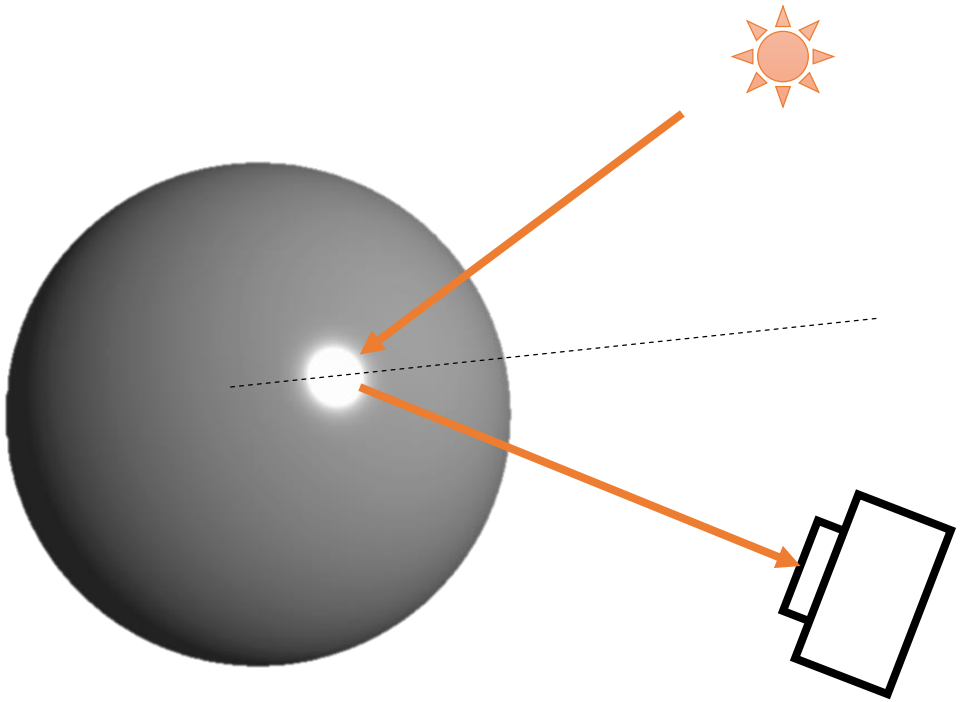
$L \in \mathbb{R}^{f \times 3}$

$N \in \mathbb{R}^{3 \times p}$

f: # of images, p: # of pixels

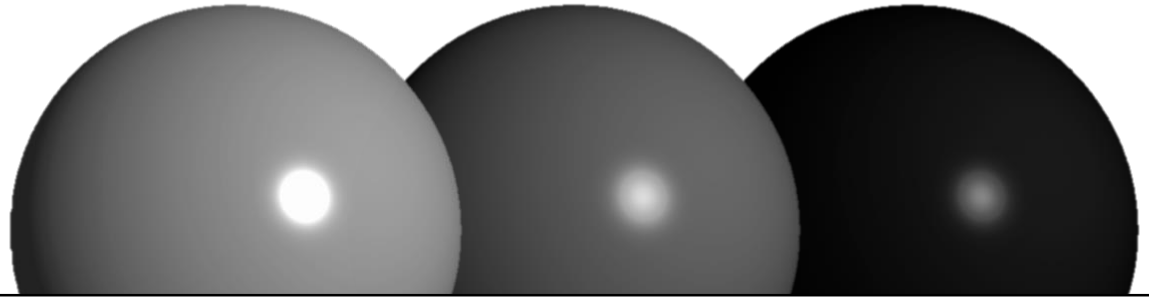
Calibration of light – Direction and Intensity

- Direction - Easier



Observation of specular reflections

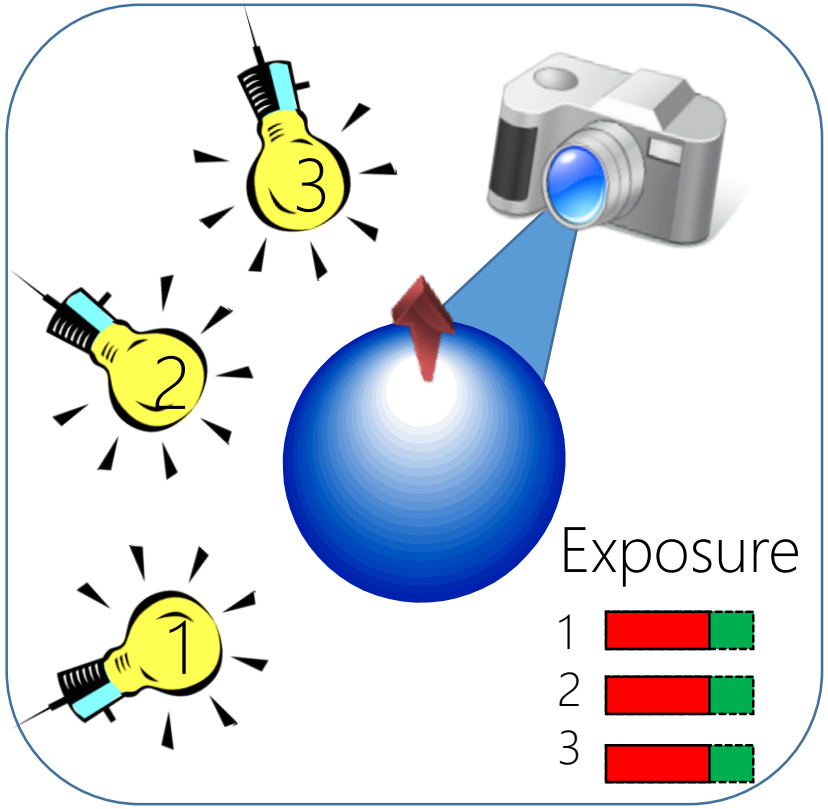
- Intensity - Harder



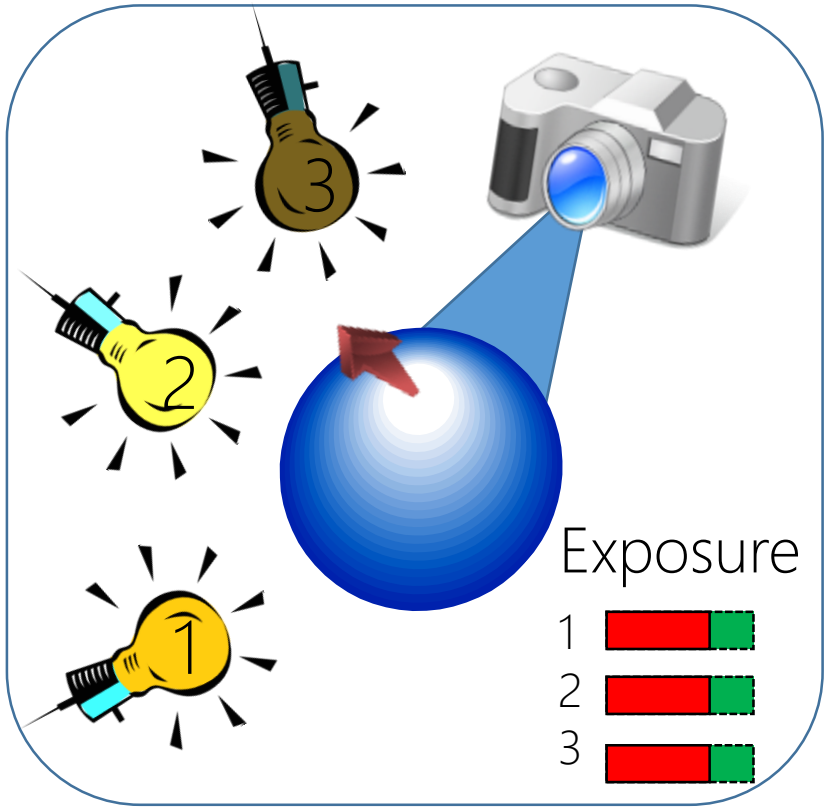
Quantization, power fluctuations, anisotropy

High-dynamic range imaging

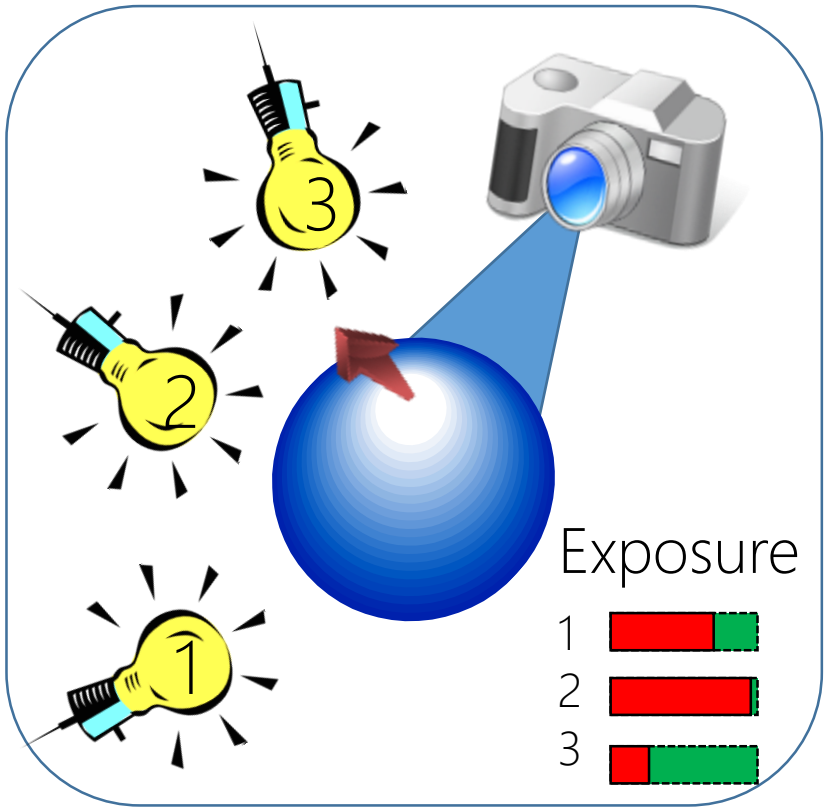
Light source intensities and exposures



Same light brightness
Same exposure time

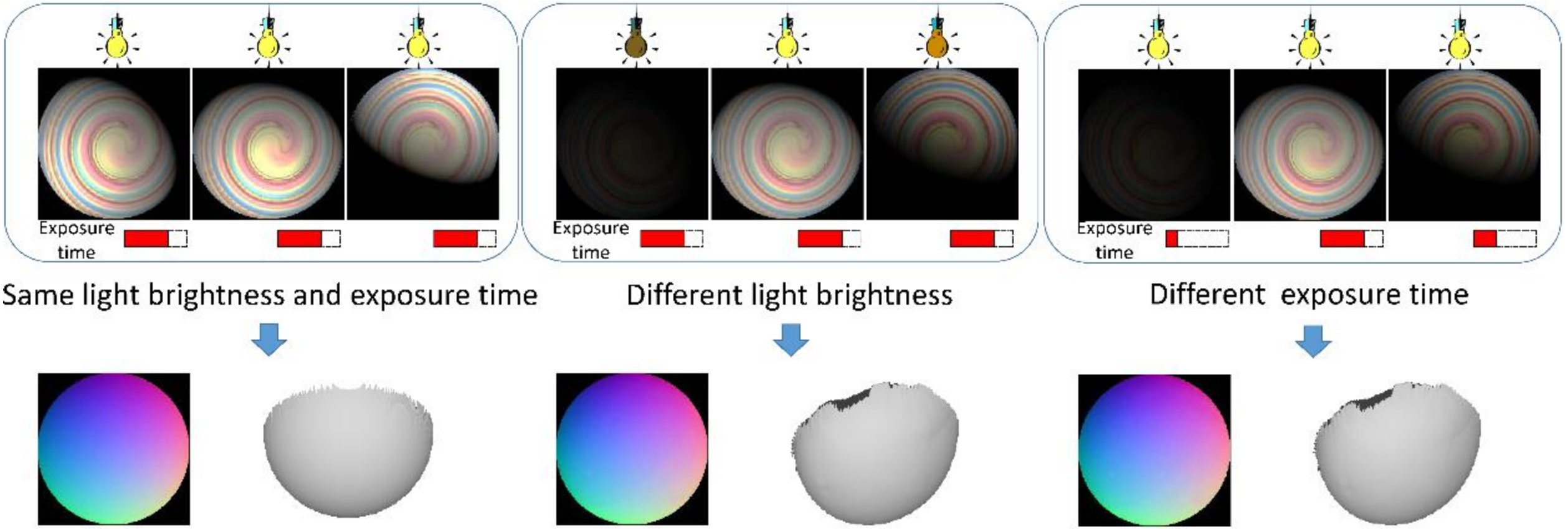


Different light brightness
Same exposure time



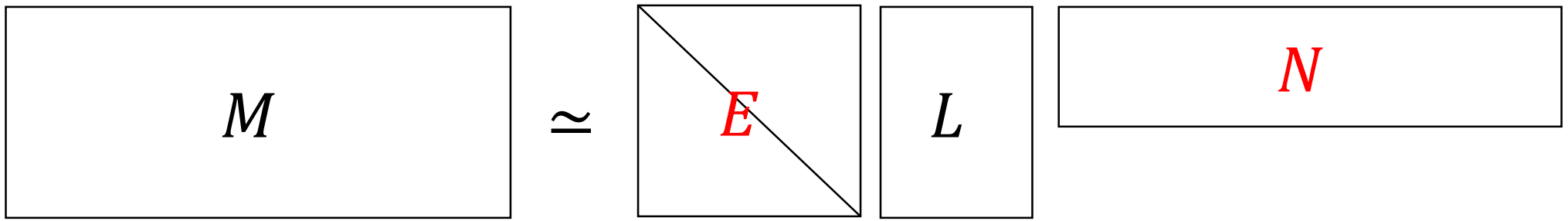
Same light brightness
Varying exposure time

Light source intensities and exposures



Semi-Calibrated Photometric Stereo

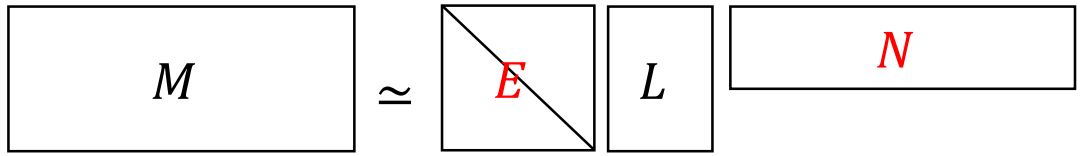
Problem: Find E and N that best satisfies $M \simeq ELN$



Merits:

- Unknown and varying light source intensities
- Unknown and varying exposure times
- Compatible to conventional photometric stereo

Linear solution method

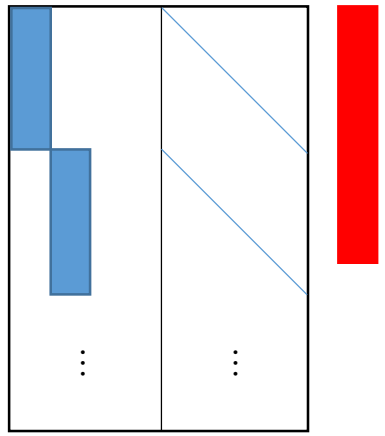


Problem: Find E and N that best satisfies $M \simeq ELN$

⇨ E invertible: $E^{-1}M - LN \simeq \mathbf{0}$

⇨ Turn it into $Ax = \mathbf{0}$ form

$$\left[-I_p \otimes L \mid \left[\mathrm{diag}(m_1) \mid \ldots \mid \mathrm{diag}(m_p)\right]^T\right] \begin{bmatrix} \mathrm{vec}(N) \\ E^{-1}\mathbf{1} \end{bmatrix} \simeq \mathbf{0}$$

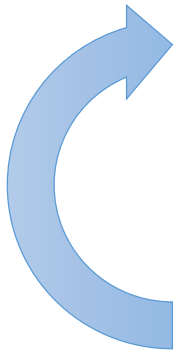


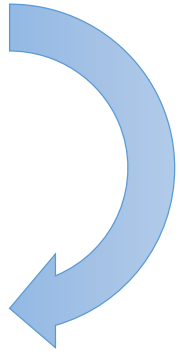
$\simeq \mathbf{0}$

Alternating minimization method

Fix E and solve for N

$$\{N^{(t+1)}\} = \arg\min_{N} \|M - E^{(t)}LN\|_F^2$$

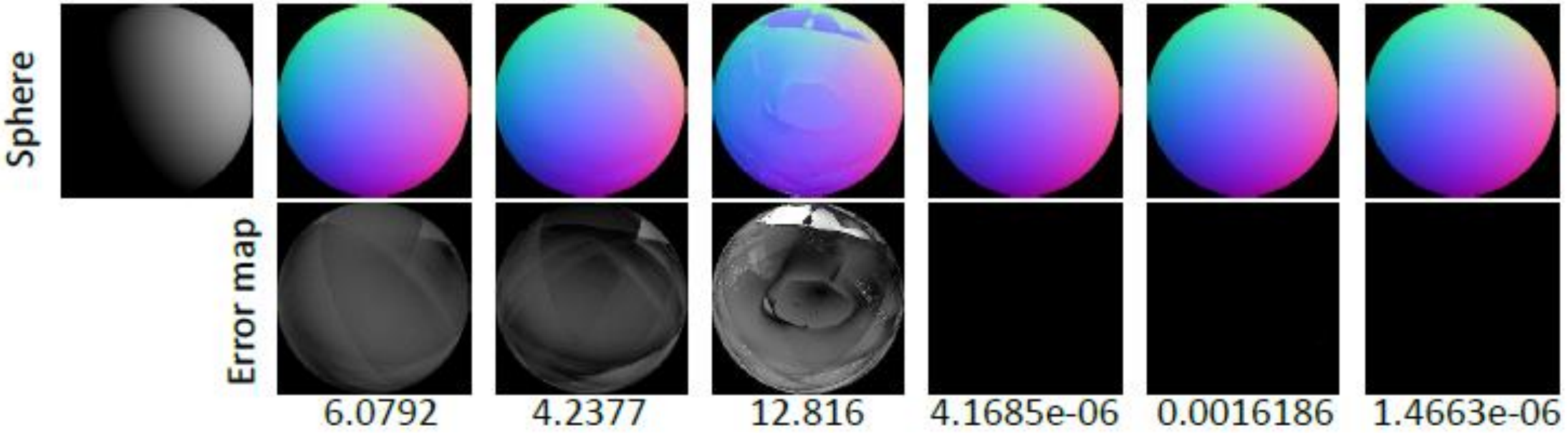


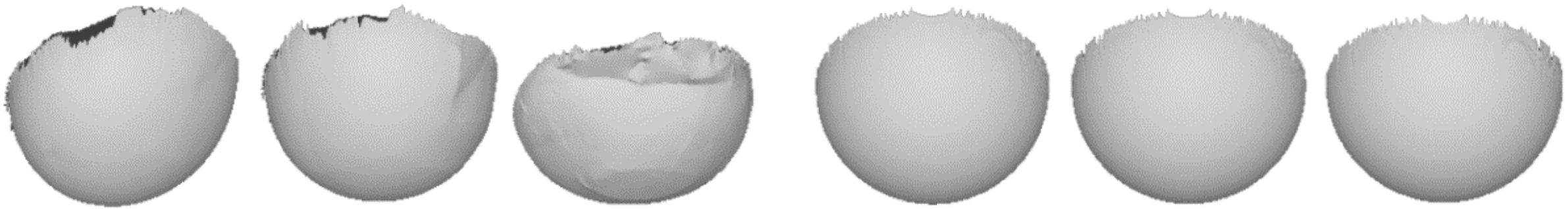


Fix N and solve for E

$$\{E^{(t+1)}\} = \arg\min_{E} \|M - ELN^{(t)}\|_F^2$$

Experiment – synthetic scene





Conventional L2

L1

CBR
[Ikehata et al.]

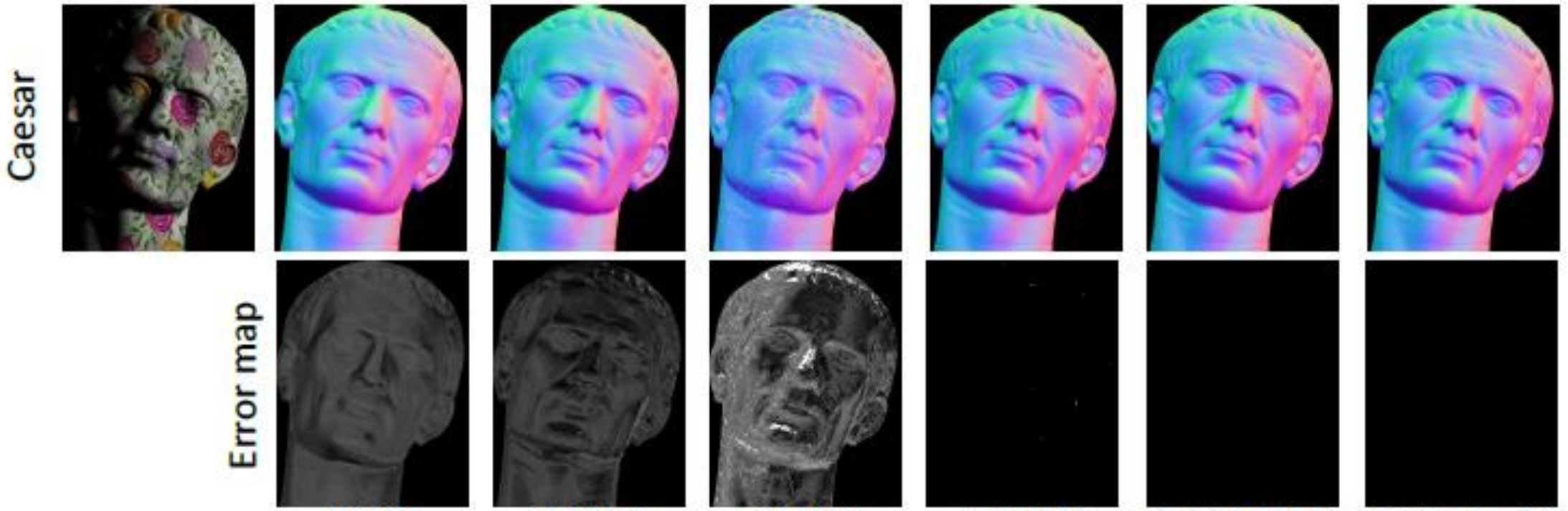
Linear

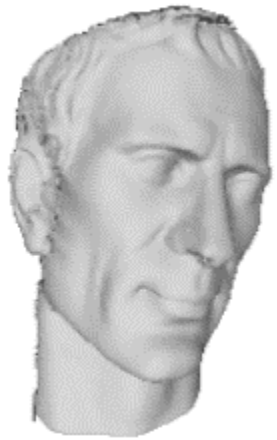
Factorization

Alternating
Minimization

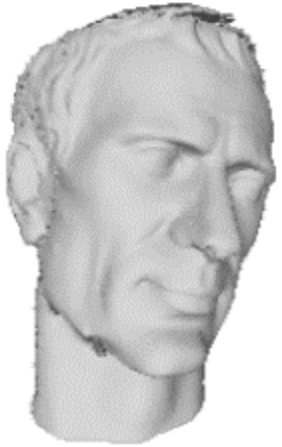
Proposed method

Experiment – synthetic scene



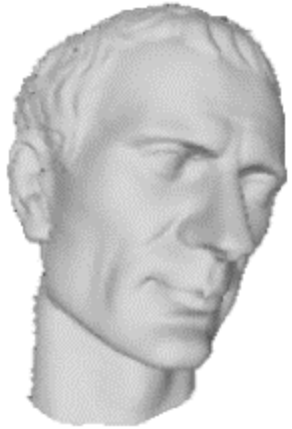


Conventional L2



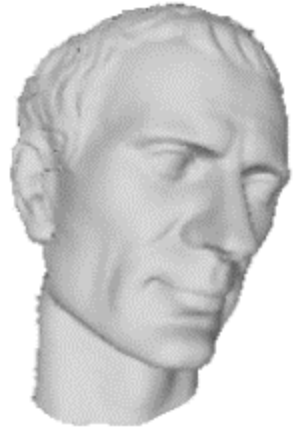
L1

CBR
[Ikehata et al.]



Linear

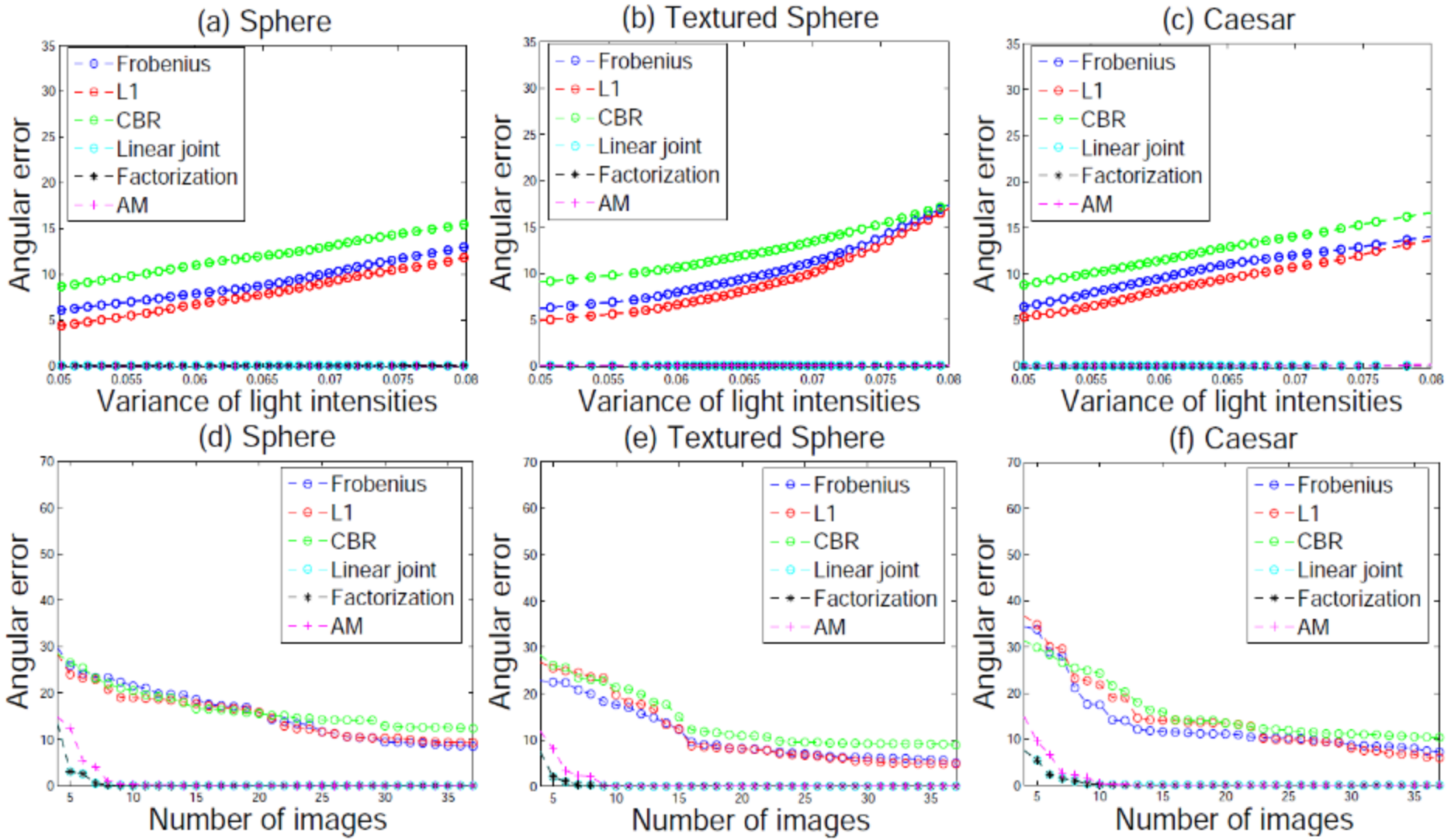
Factorization



Alternating
Minimization

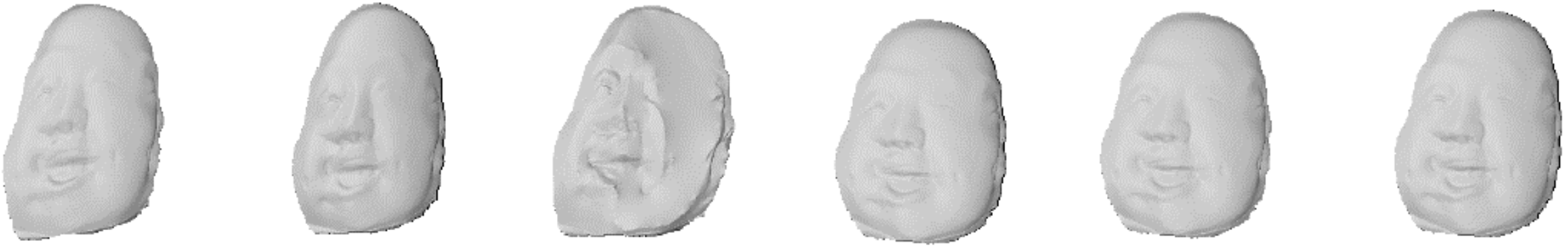
Proposed method

Quantitative evaluation



Experiment – real data

Input



Conventional L2 | L1 | CBR [Ikehata et al.] | Linear | Factorization | Alternating Minimization

Proposed method

Experiment – real data

Input

Conventional L2 | L1 | CBR [Ikehata et al.] | Linear | Factorization | Alternating Minimization

Proposed method

Summary – Semi-calibrated photometric stereo

- Light ``intensity'' calibration is not easy, while ``direction'' calibration is manageable

- Applicable to conventional photometric stereo settings
  - Without careful intensity calibration
  - With auto-exposure → reduced noise