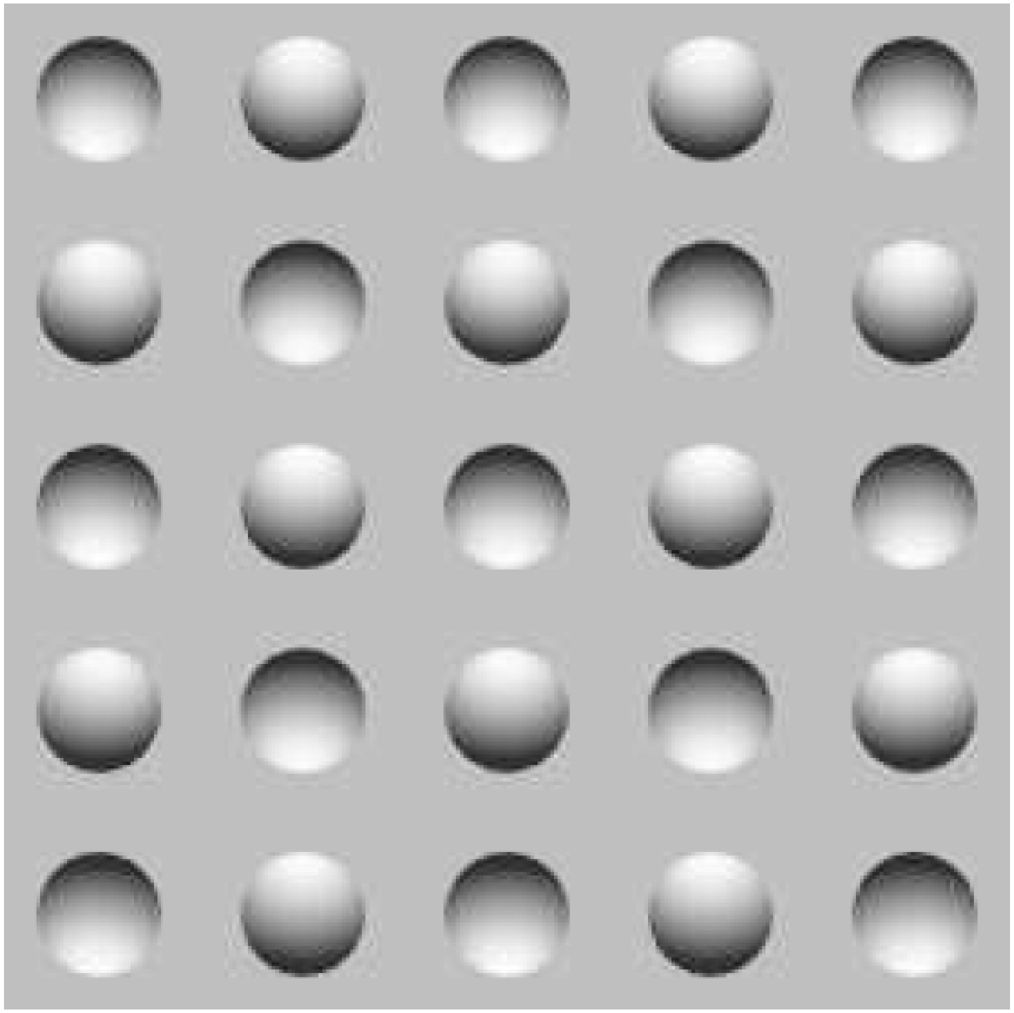
# Sources, shading and photometric stereo
# F&P Ch 5 (old), Ch 2 (new)

Guido Gerig

CS 6643, Spring 2017

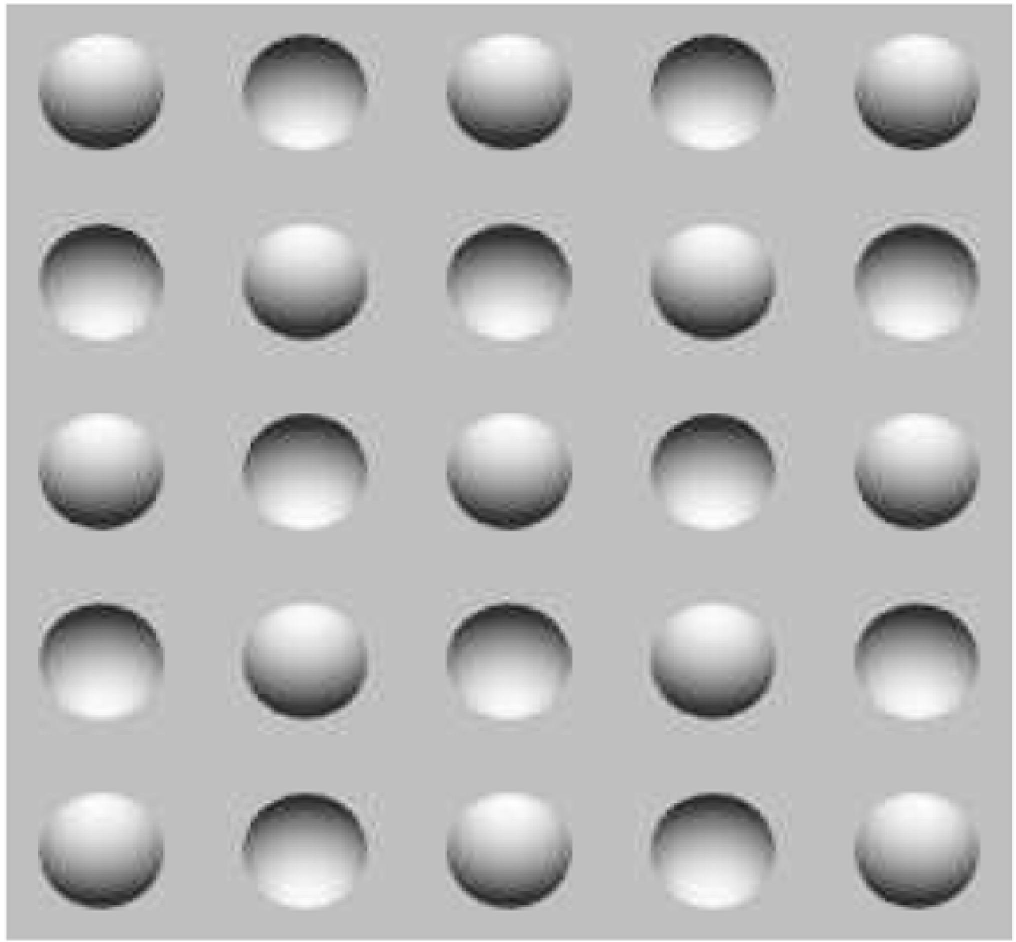
Credits: modified from original slides by David A. Forsyth plus modifications by Marc Pollefeys,
Materials from Ohad Ben-Shahar, CS 202-1-5261, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading



Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading



Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Inverting the image formation process**

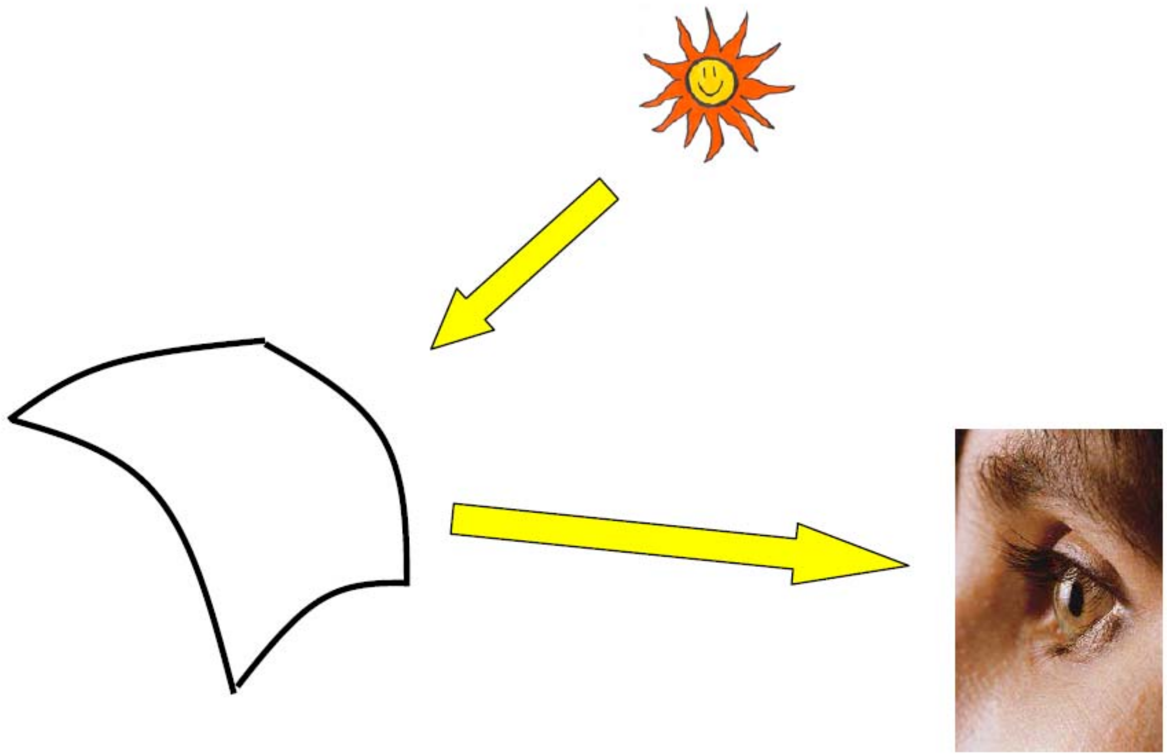
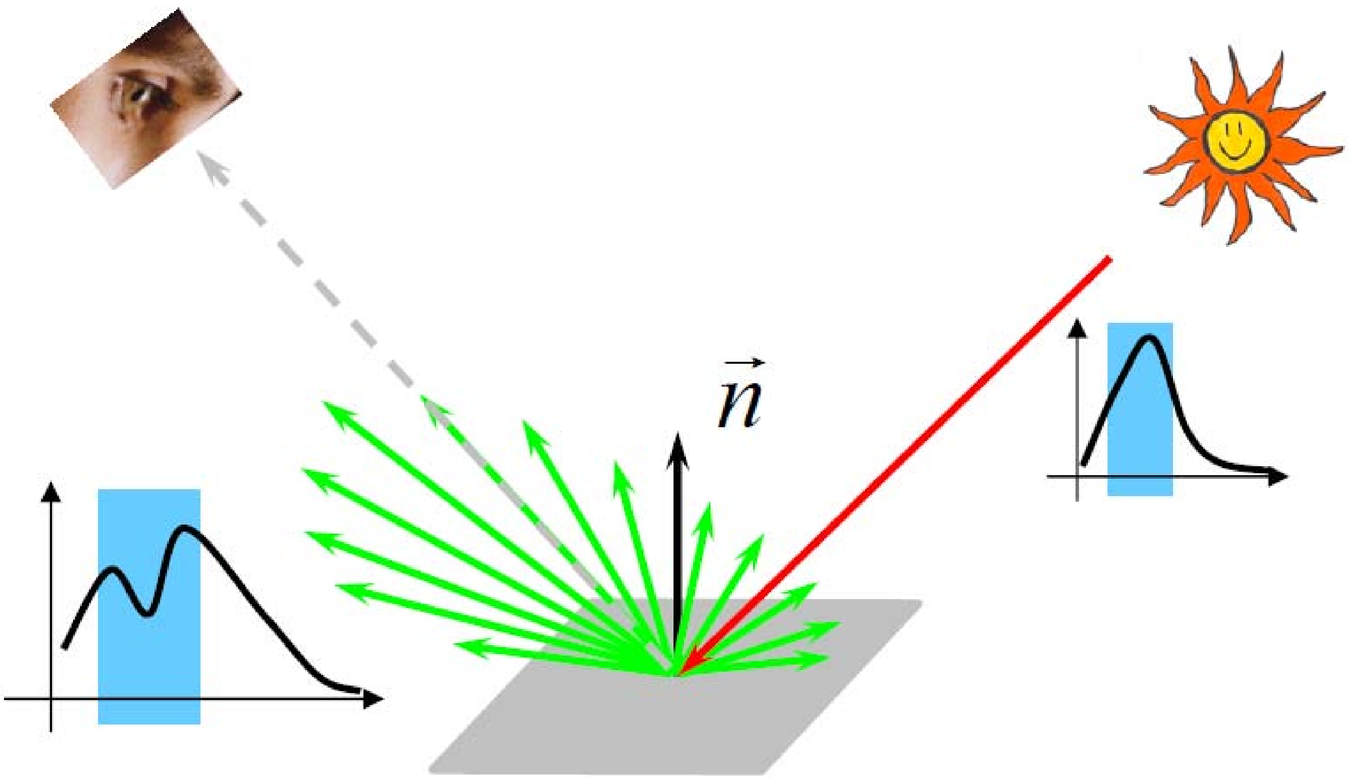


**Image formation = "Shading from shape" (and light sources)**

Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

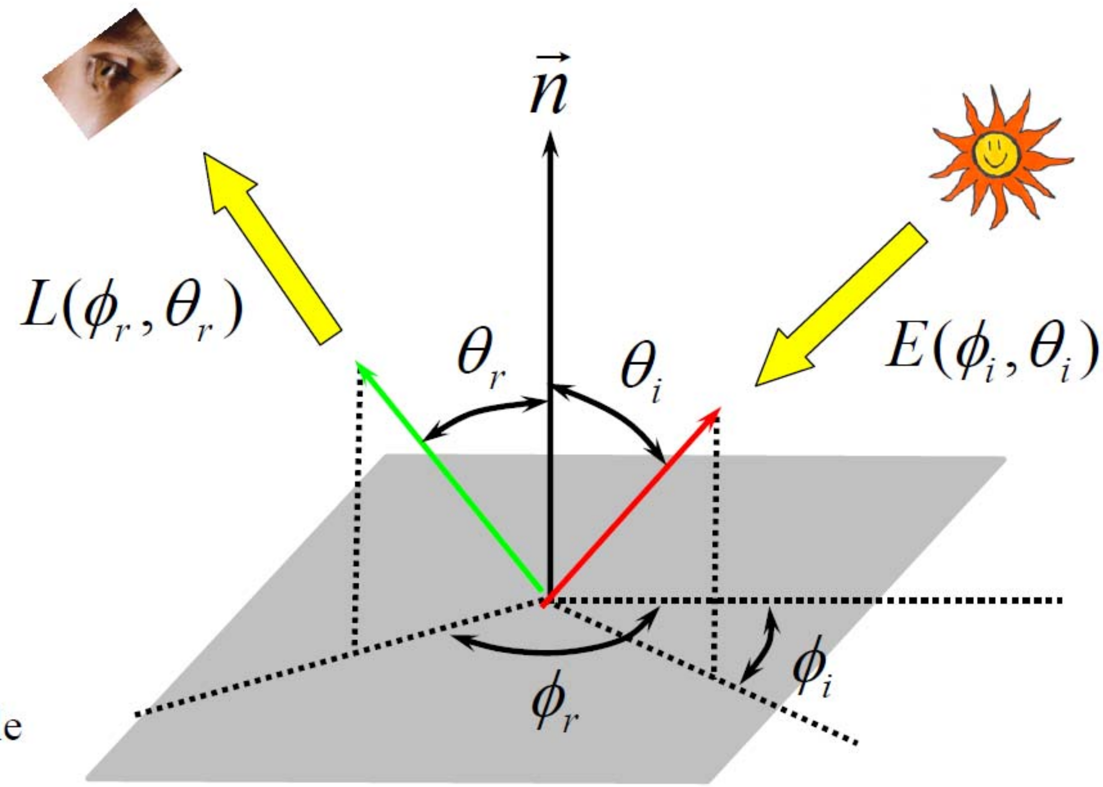
## Image formation




Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Polar representation of directions**




$\phi$ - Azimuth angle

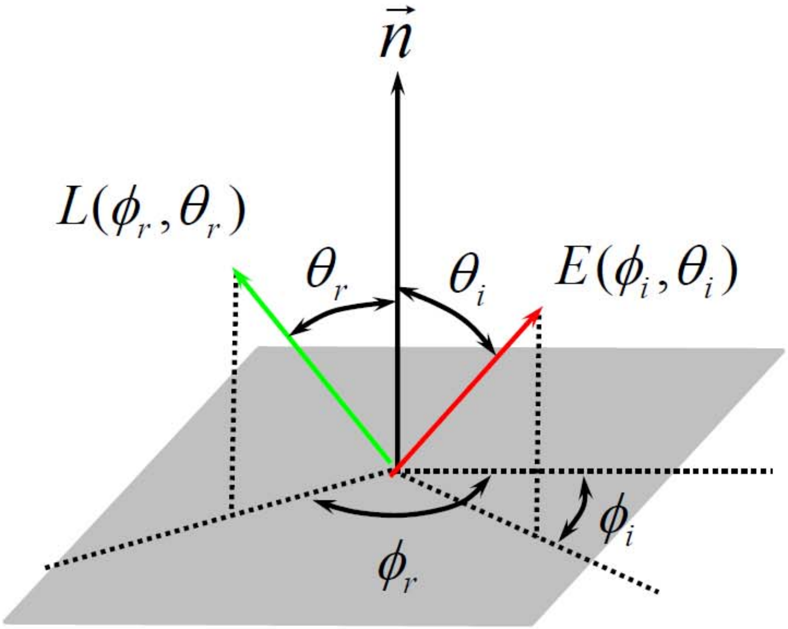
$\theta$ - Zenith angle

Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**The Bidirectional Reflectance Distribution Function (BRDF)**

$$f_\lambda(\phi_i,\theta_i;\phi_r,\theta_r)=\frac{L_\lambda(\phi_r,\theta_r)}{E_\lambda(\phi_i,\theta_i)}$$




Helmholtz's reciprocity

$$f(\phi_i,\theta_i;\phi_r,\theta_r)=f(\phi_r,\theta_r;\phi_i,\theta_i)$$

Isotropic materials:

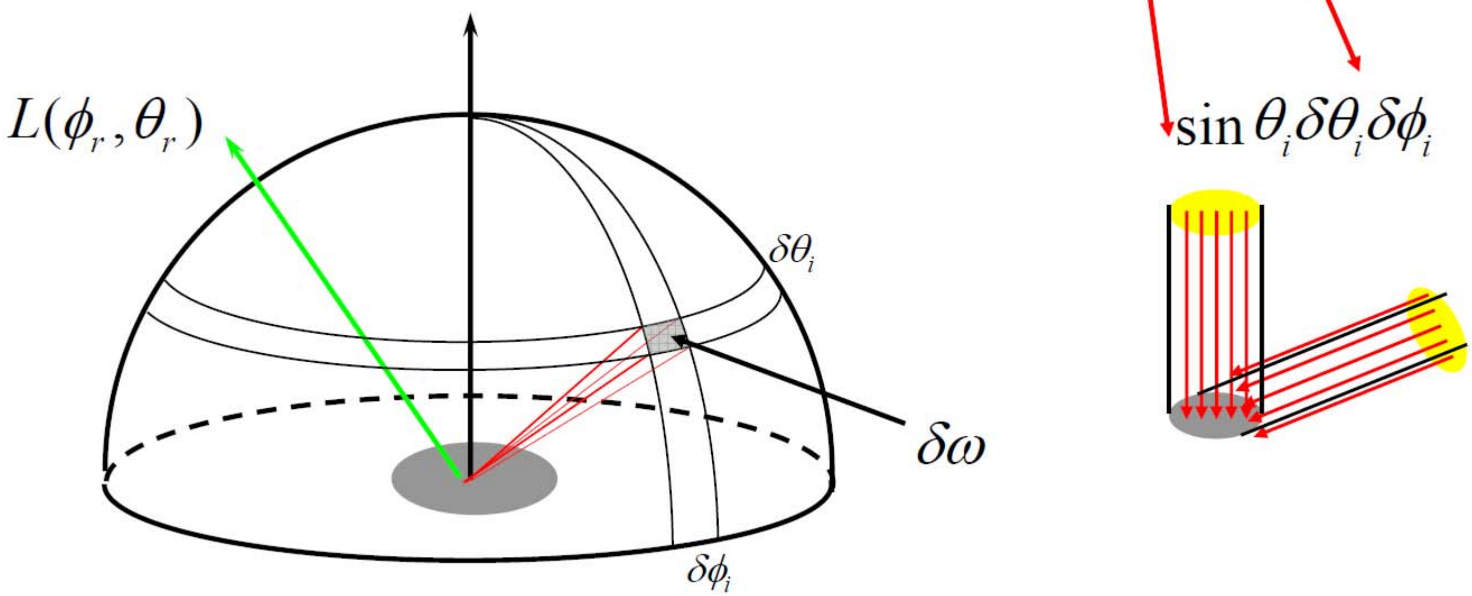
$$f(\phi_i,\theta_i;\phi_r,\theta_r)=f(\phi_i-\phi_r,\theta_i,\theta_r)$$

Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Total surface reflection**

$$L(\phi_r,\theta_r)=\int_{\omega} f(\phi_i,\theta_i;\phi_r,\theta_r)\cdot E(\phi_i,\theta_i)\cdot \cos\theta_i\, d\omega$$

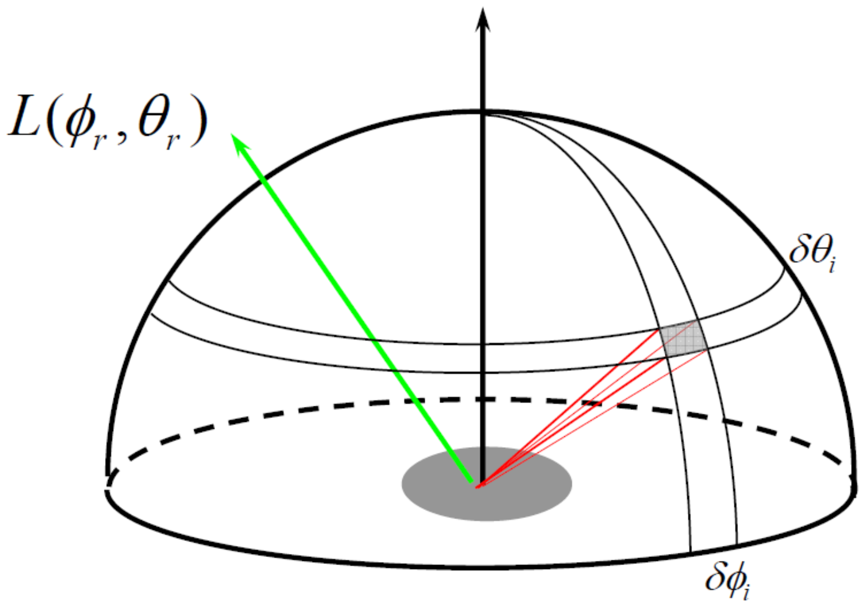



Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Total surface reflection**

$$L(\phi_r,\theta_r)=\int_{-\pi}^{\pi}\int_{0}^{\pi/2} f(\phi_i,\theta_i;\phi_r,\theta_r)\cdot E(\phi_i,\theta_i)\cdot\sin\theta_i\cdot\cos\theta_i\cdot\delta\theta_i\delta\phi_i$$



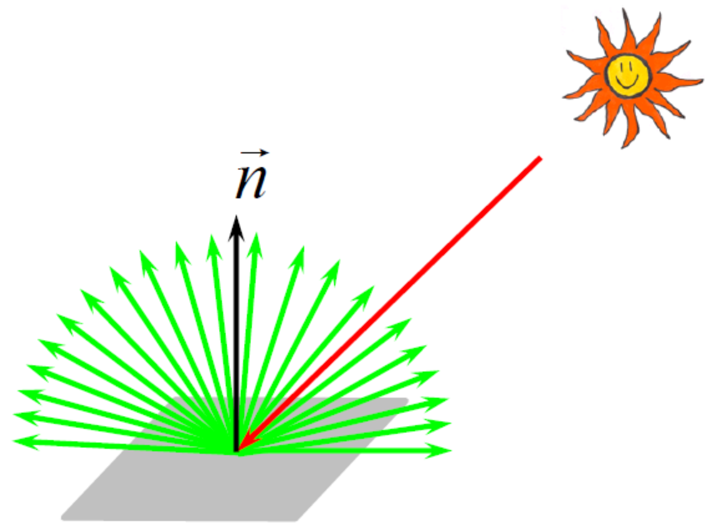

Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Lambertian (perfectly diffused) surfaces**

$$f_L(\phi_i, \theta_i; \phi_r, \theta_r) = const = \bar{f} = \rho \frac{1}{\pi}$$

Albedo

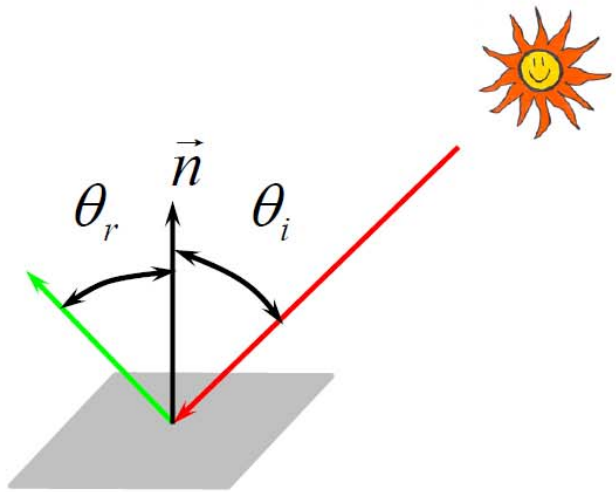



Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Mirrored (perfectly secular) surfaces**

$$f_S(\phi_i,\theta_i;\phi_r,\theta_r)=\frac{\delta(\theta_r-\theta_i)\delta(\phi_r-\phi_i-\pi)}{\sin\theta_i\cos\theta_i}$$



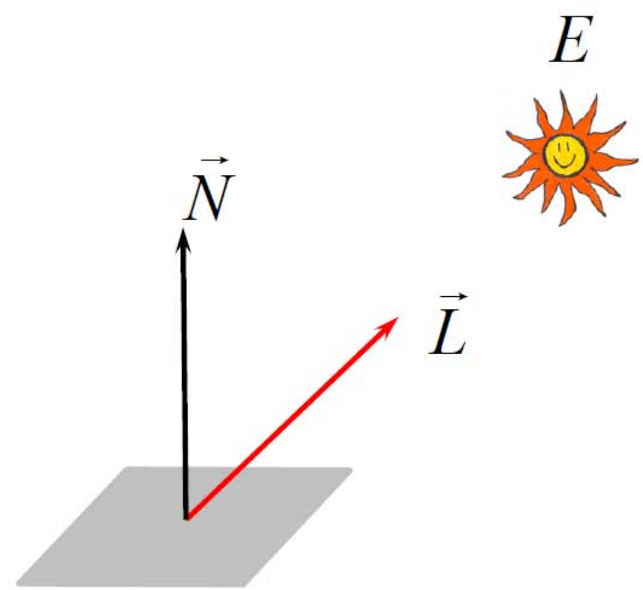

Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Point light source from direction** $(\phi_L, \theta_L)$

$$E(\phi_i, \theta_i) = E \cdot \frac{\delta(\theta_L - \theta_i) \cdot \delta(\phi_L - \phi_i)}{\sin \theta_L}$$

$$\int_{-\pi}^{\pi} \int_{0}^{\pi/2} E(\phi_i, \theta_i) \cdot \sin \theta_i \cdot \delta\theta_i \delta\phi_i = E$$




Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

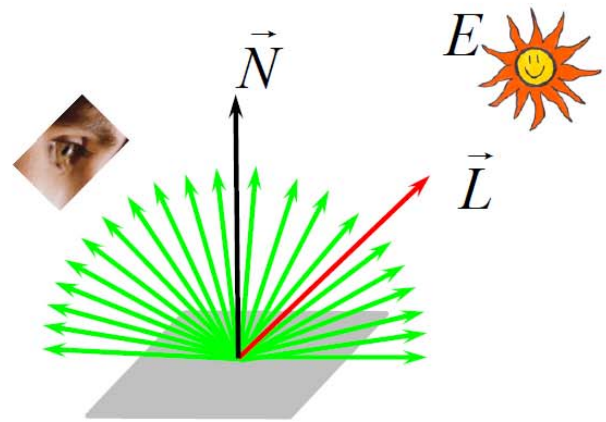
**Surface brightness – appearance in the Lambertian case and point light source**

$$f_L(\phi_i,\theta_i;\phi_r,\theta_r) = \rho\frac{1}{\pi}$$

$$E(\phi_i,\theta_i) = \frac{\delta(\theta_L-\theta_i)\delta(\phi_L-\phi_i)}{\sin\theta_L}$$

$$I(x,y) \propto L(\phi_r,\theta_r) = \int_{-\pi}^{\pi}\int_{0}^{\pi/2} f(\phi_i,\theta_i;\phi_r,\theta_r)\cdot E(\phi_i,\theta_i)\cdot\sin\theta_i\cdot\cos\theta_i\cdot\delta\theta_i\delta\phi_i$$

$$L = \rho\frac{1}{\pi}E\cos\theta_L \propto \rho(\hat{N}\cdot\hat{L})$$

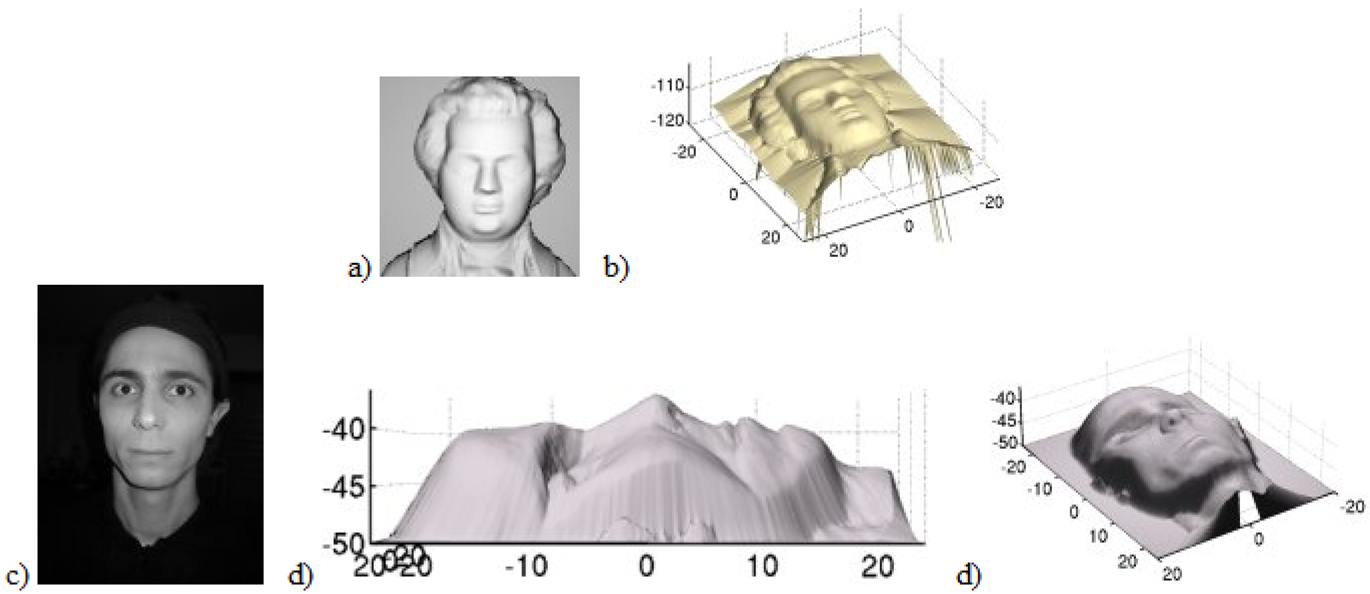



Courtesy Ohad Ben-Shahar, BGU, http://www.cs.bgu.ac.il/~ben-shahar/

# Shape from Shading

**Authors: Emmanuel Prados and Olivier Faugeras**

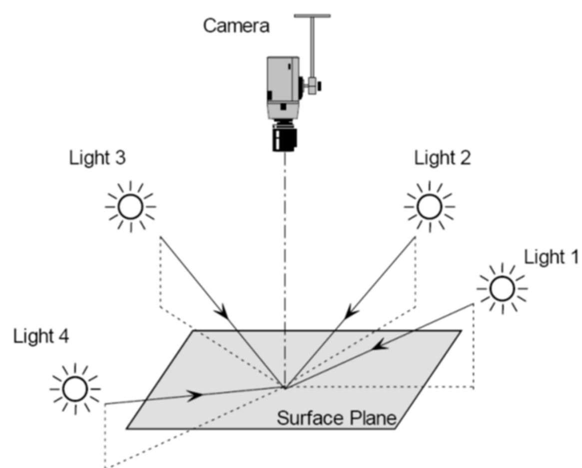
CVPR'2005, International Conference on Computer Vision and Pattern Recognition, San Diego, CA, USA, June 2005.




a) Synthetic image generated from the classical Mozart's face [Zhang-Tsai-etal:99]; b) reconstructed surface from a) by new algorithm; c) real image of a face; d)-e) reconstructed surface from c) by new algorithm.

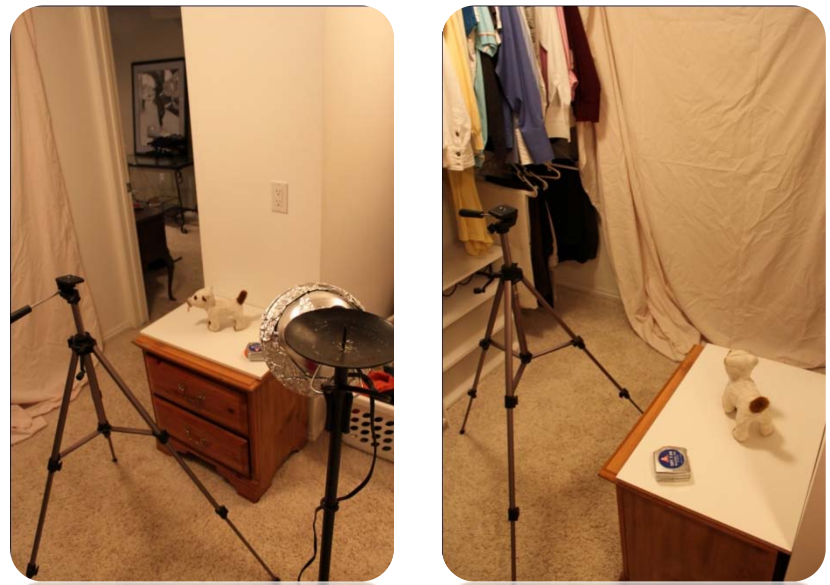
# Photometric stereo

- Assume:
  - a local shading model
  - a set of point sources that are infinitely distant
  - a set of pictures of an object, obtained in exactly the same camera/object configuration but using different sources
  - A Lambertian object (or the specular component has been identified and removed)



# Photometric Stereo
# Christopher Bireley

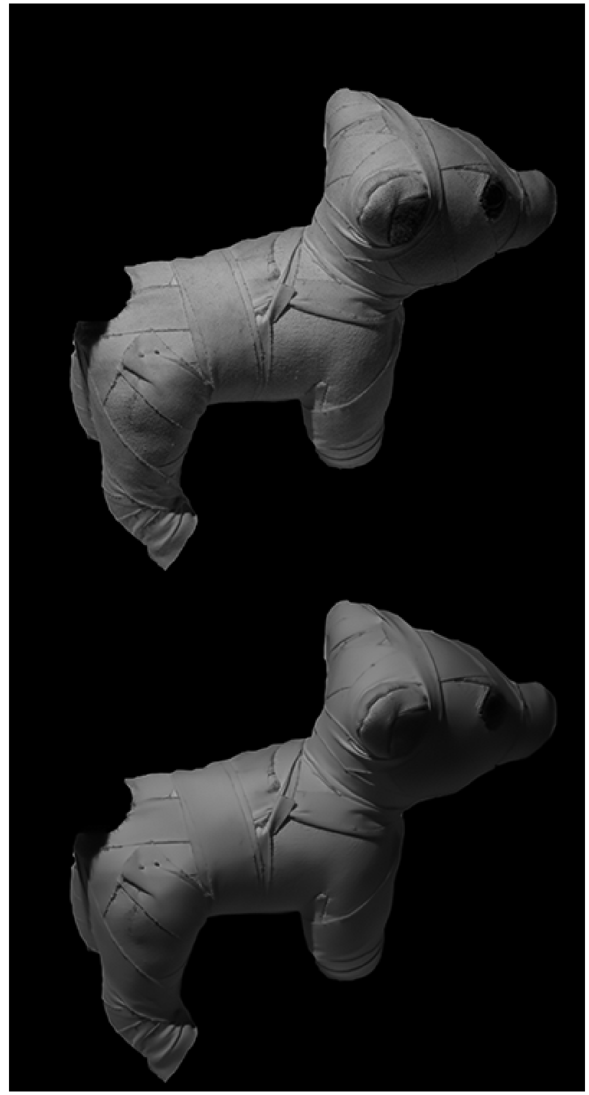
Bandage Dog



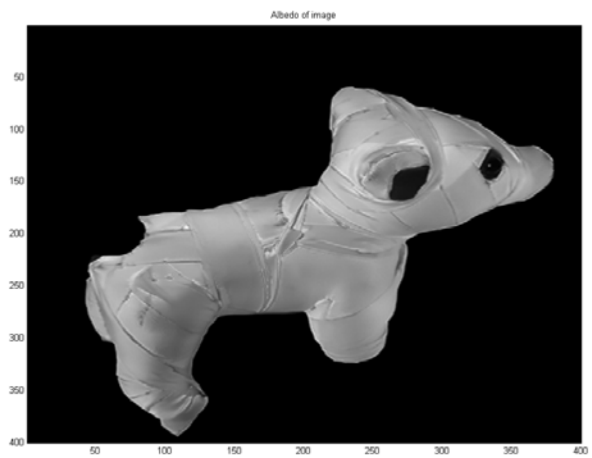
Imaging Setup

# Preprocessing

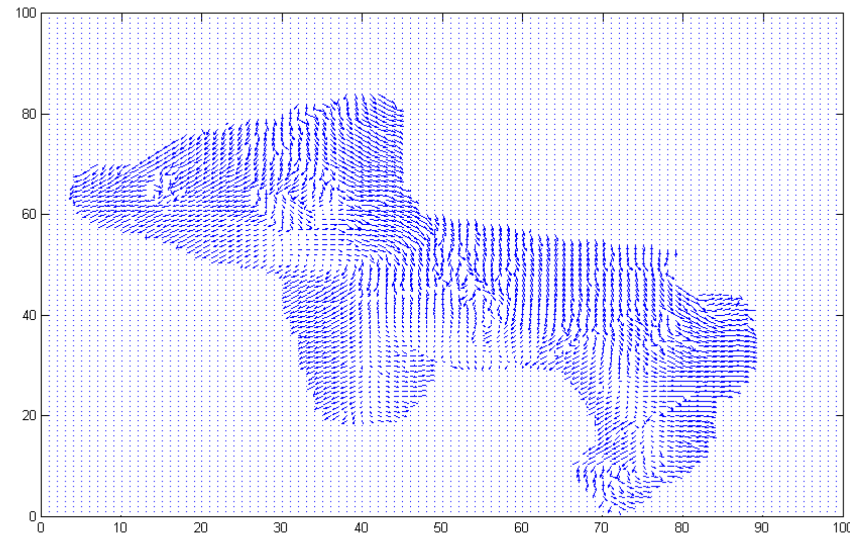
- Remove background isolate dog
- Filter with NL Means



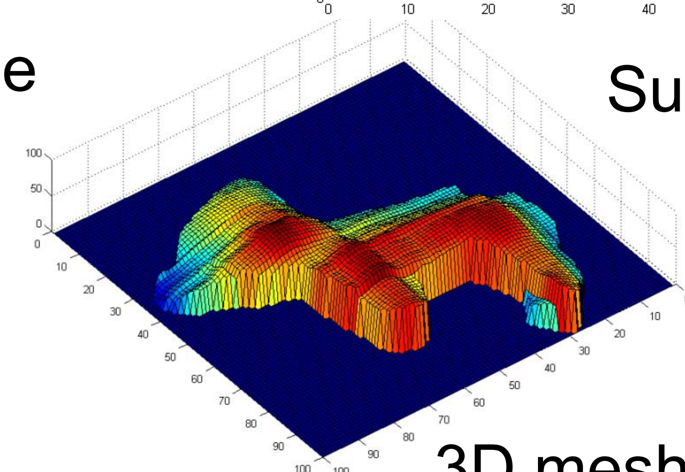
# Photometric Stereo
# Christopher Bireley




Albedo image




Surface Normals




3D mesh