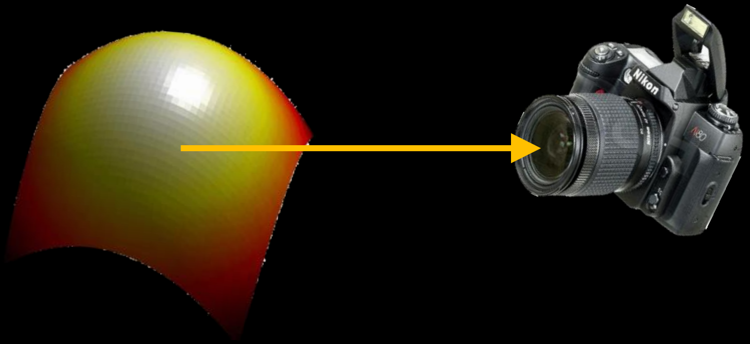
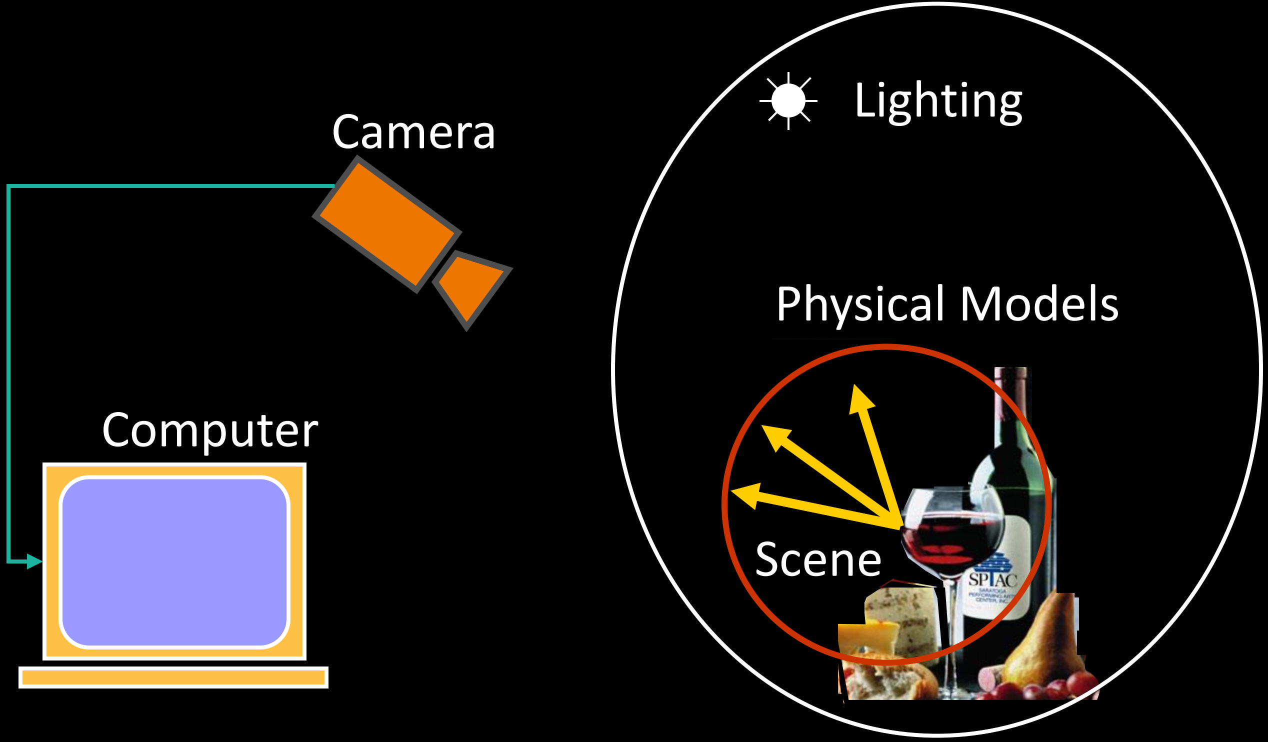
CS4495/6495
Introduction to Computer Vision

5A-L1 *Photometry*



Slides by Yin Li
Thanks to Srinivasa Narasimhan, Shree Nayar, David Kreigman, Marc Pollefeys

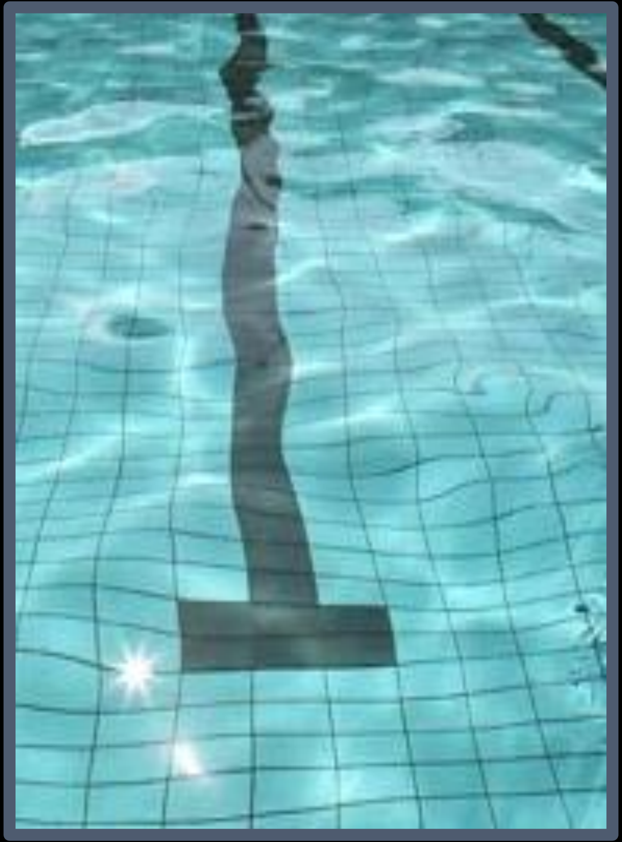
Photometry: Measuring light



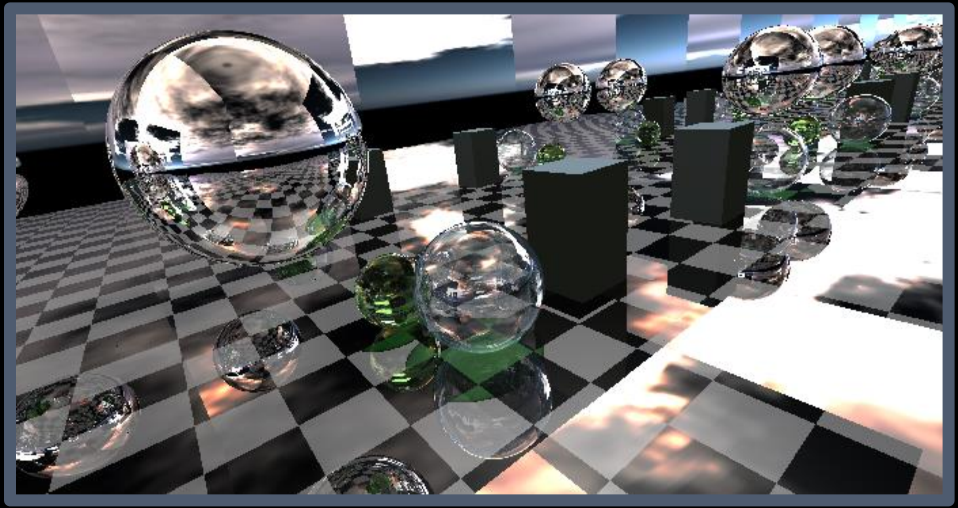
Lights, surfaces ,and shadows

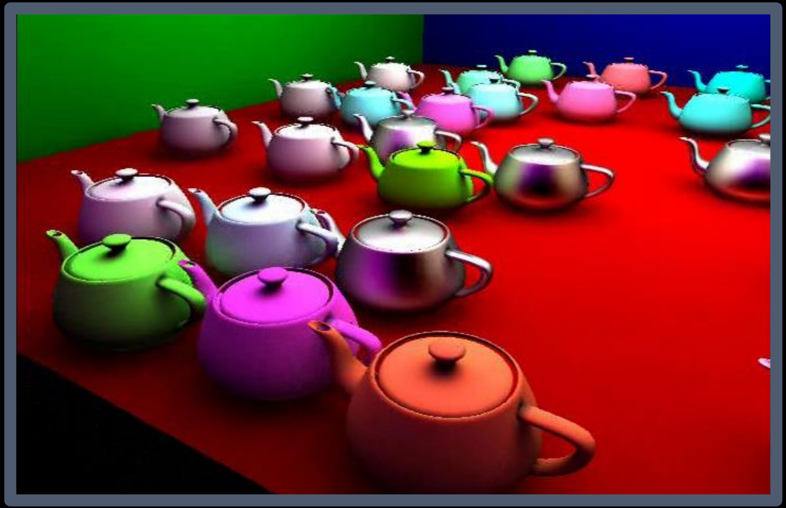
Reflections

Refractions



Interreflections





Scattering

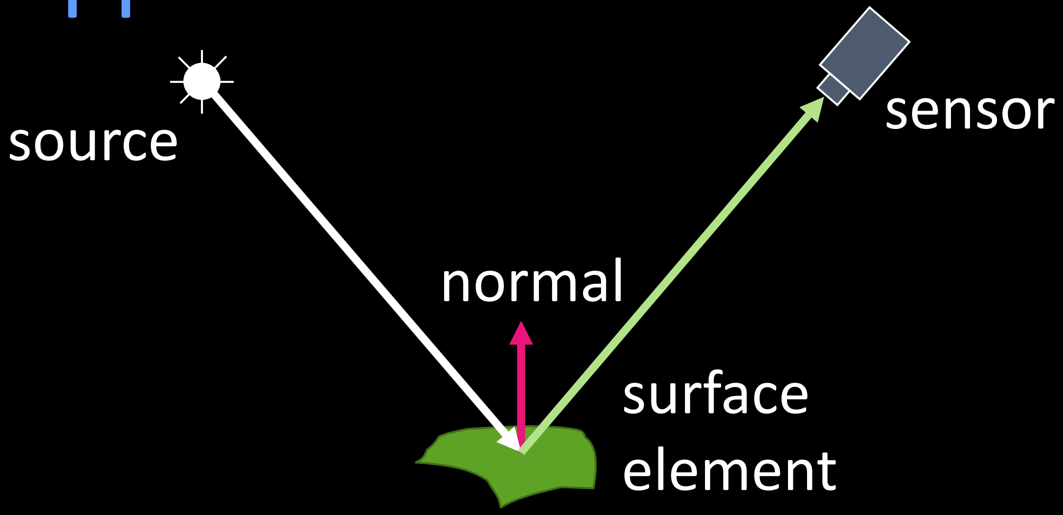








Surface appearance

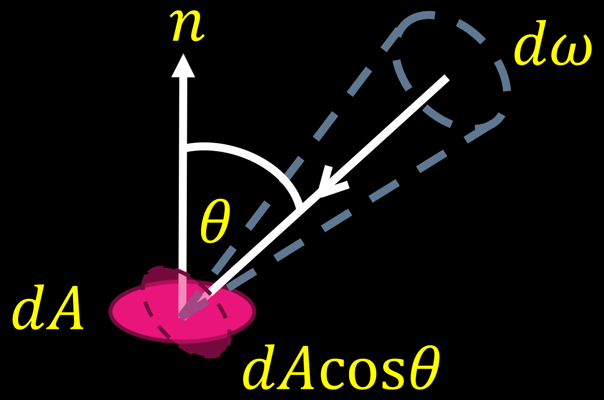


- Image intensity = f (normal, surface reflectance, illumination)
- Surface reflection depends on both the viewing and illumination directions

Radiometry

Radiance (L): Energy carried by a ray

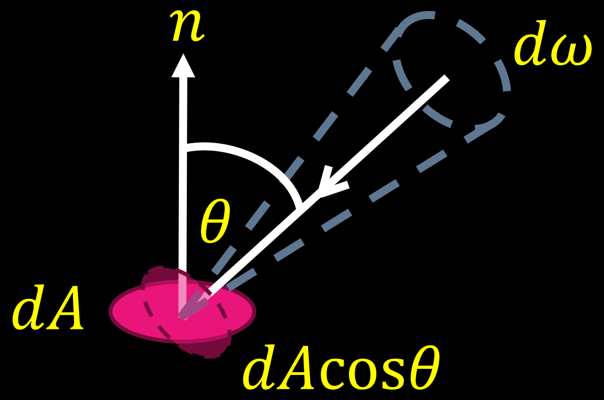
- Power per unit area *perpendicular to direction of travel*, per unit solid angle
- Units: Watts per square meter per steradian ($Wm^{-2}sr^{-1}$)



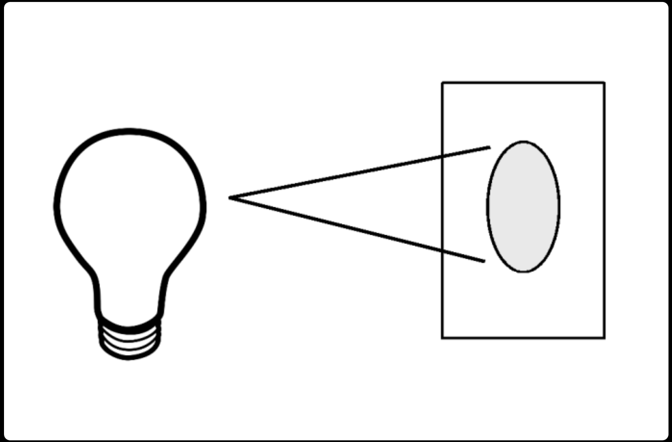
Radiometry

Irradiance (E): Energy arriving at a surface

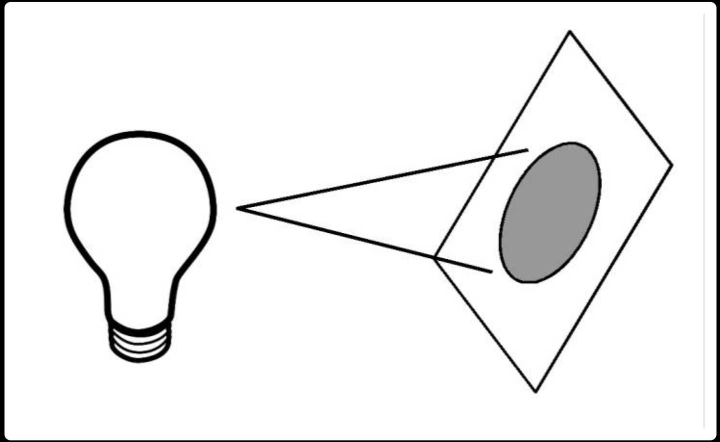
- Incident power in a given direction, per unit area
- Units: Wm^{-2}



Foreshortening: A simple observation



"Perpendicular light"

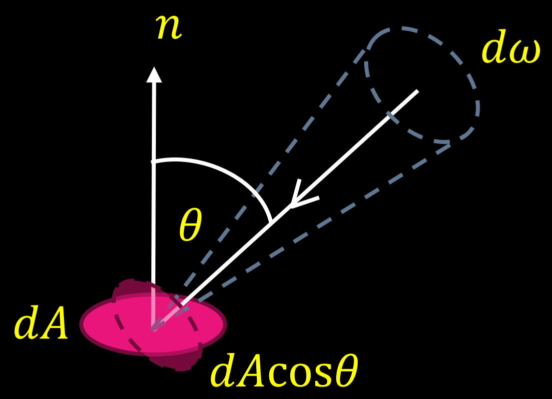


"Foreshortened light"

Radiometry

Irradiance (E): Energy arriving at a surface

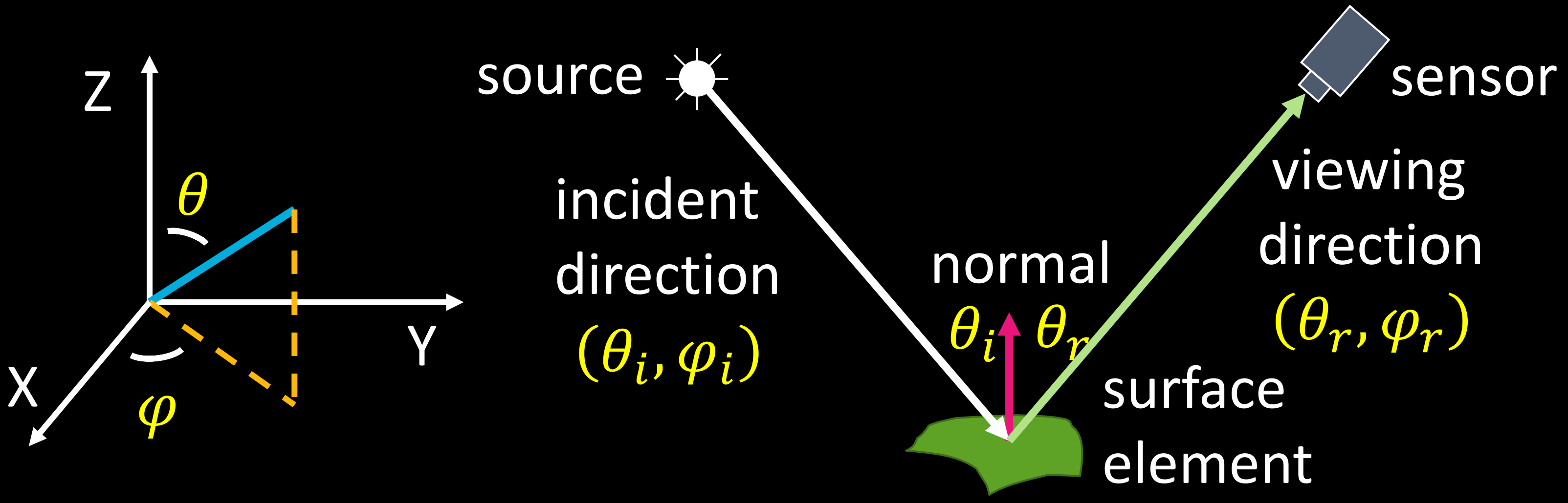
- Incident power in a given direction, per unit area
- Units: Wm^{-2}



For a surface receiving radiance $L(\theta, \varphi)$ coming in from $d\omega$ the corresponding irradiance is

$$E(\theta, \varphi) = L(\theta, \varphi)\cos\theta\, d\omega$$

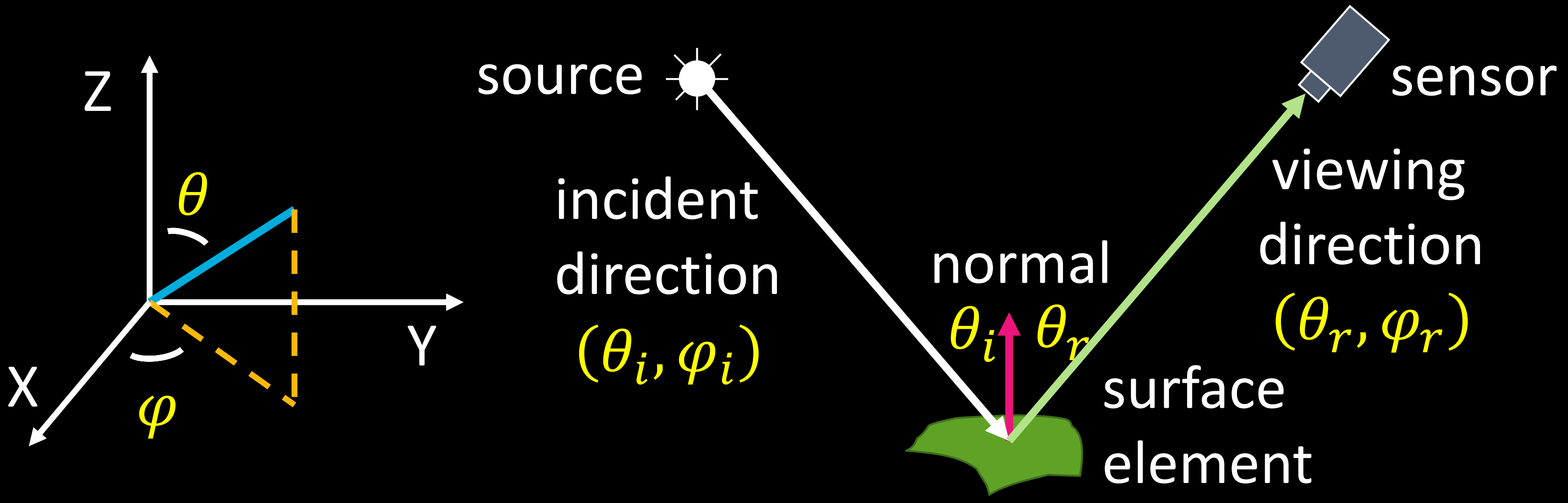
BRDF: Bidirectional Reflectance Distribution Function



Irradiance: Light per unit area incident on a surface

Radiance: Light from the surface reflected in a given direction, within a given solid angle

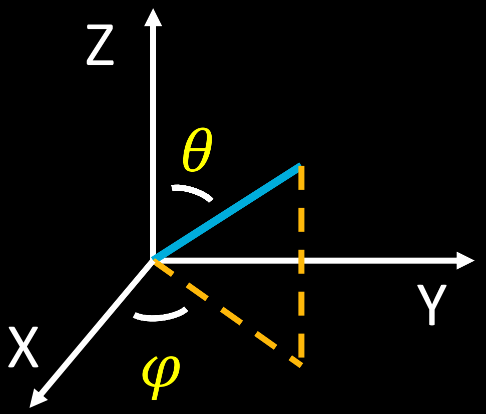
BRDF: Bidirectional Reflectance Distribution Function

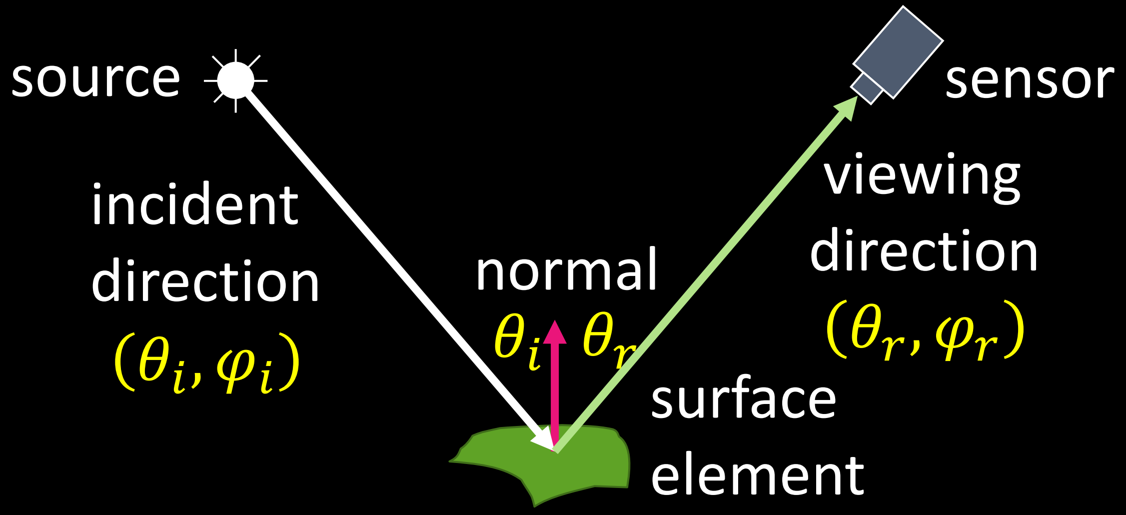


$E^{surface}(\theta_i, \varphi_i)$: Irradiance at surface from direction (θ_i, φ_i)

$L^{surface}(\theta_r, \varphi_r)$: Radiance from surface in direction (θ_r, φ_r)

BRDF: Bidirectional Reflectance Distribution Function



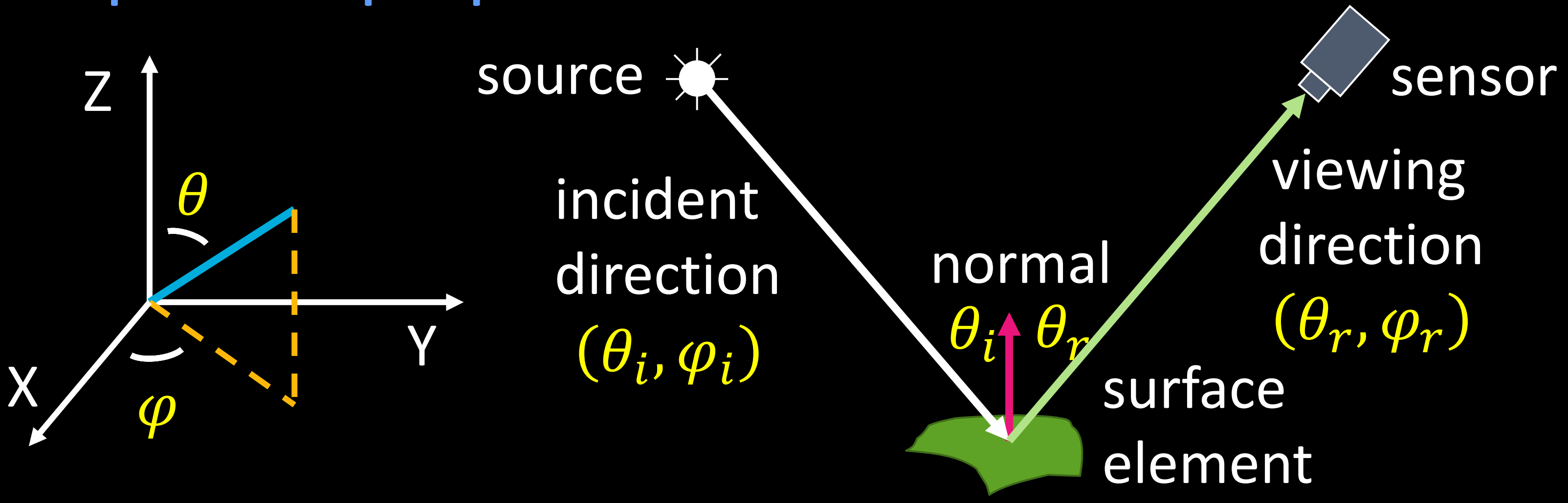


$E^{surface}(\theta_i, \varphi_i)$: Irradiance at surface from direction (θ_i, φ_i)

$L^{surface}(\theta_r, \varphi_r)$: Radiance from surface in direction (θ_r, φ_r)

$$\text{BRDF: } f(\theta_i, \varphi_i;\ \theta_r, \varphi_r) = \frac{L^{surface}(\theta_r, \varphi_r)}{E^{surface}(\theta_i, \varphi_i)}$$

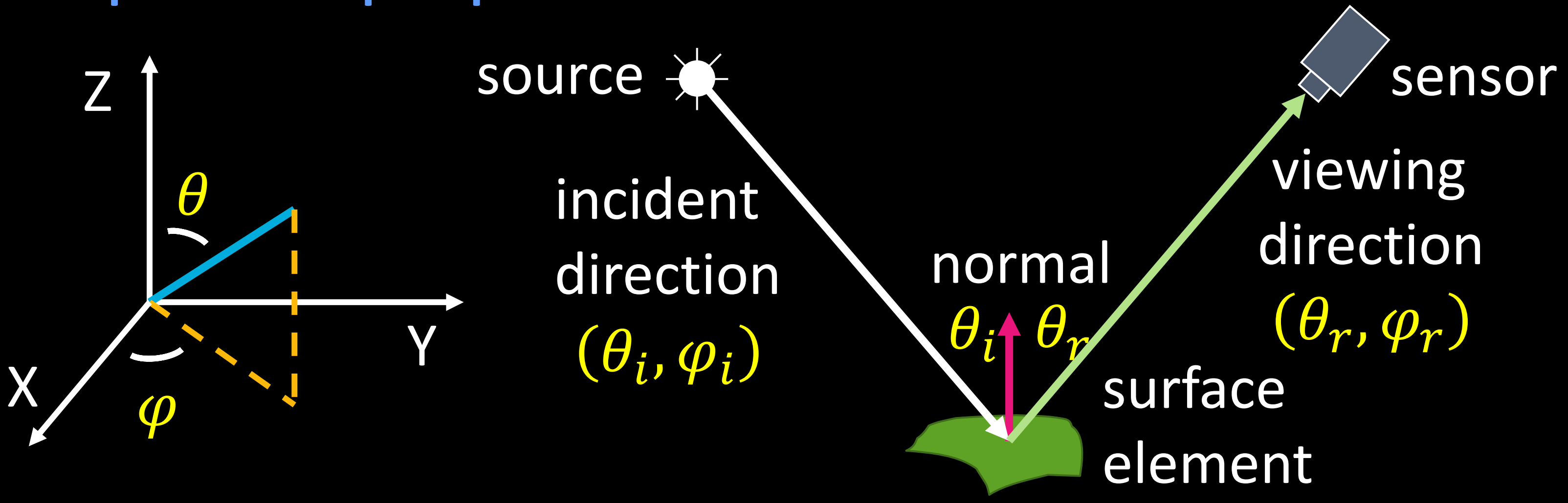
Important properties of BRDFs



Helmholtz Reciprocity:

$$f(\theta_i, \varphi_i; \theta_r, \varphi_r) = f(\theta_r, \varphi_r; \theta_i, \varphi_i)$$

Important properties of BRDFs



Rotational Symmetry (Isotropy):

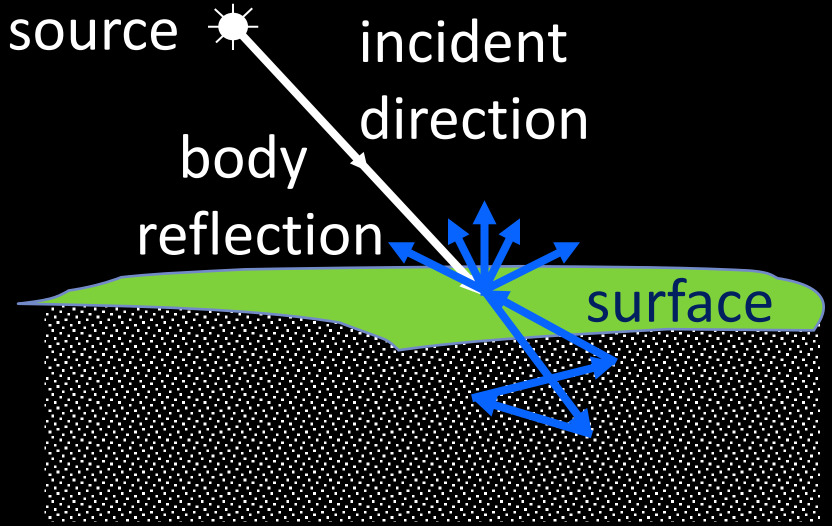
$$f(\theta_i, \varphi_i; \theta_r, \varphi_r) = f(\theta_i, \theta_r, \varphi_i - \varphi_r)$$

BRDF’s can be incredibly complicated…

Reflection Models

Body (diffuse) Reflection:

- Diffuse Reflection
- Matte Appearance
- Non-Homogeneous medium
- Clay, paper, etc.



Reflection Models

Body (diffuse) Reflection:

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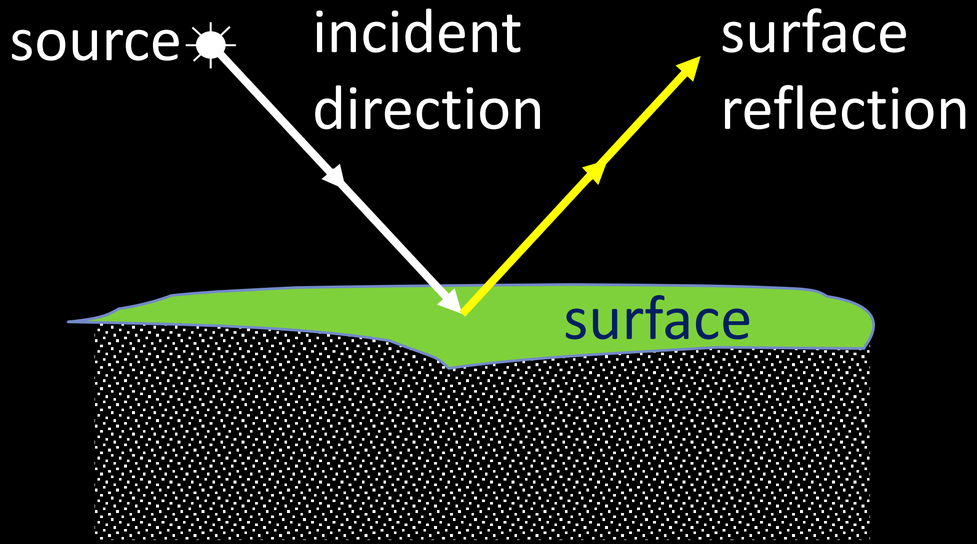
Reflection Models

Surface Reflection:

- Specular Reflection
- Glossy Appearance
- Highlights
- Dominant for Metals



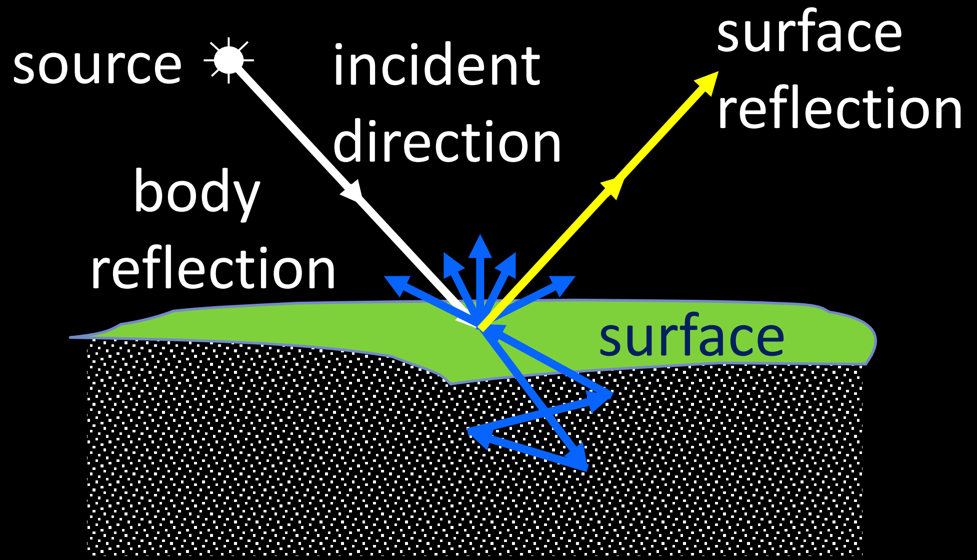
Reflection Models

Surface Reflection:

- Specular Reflection
- Glossy Appearance
- Highlights
- Dominant for Metals

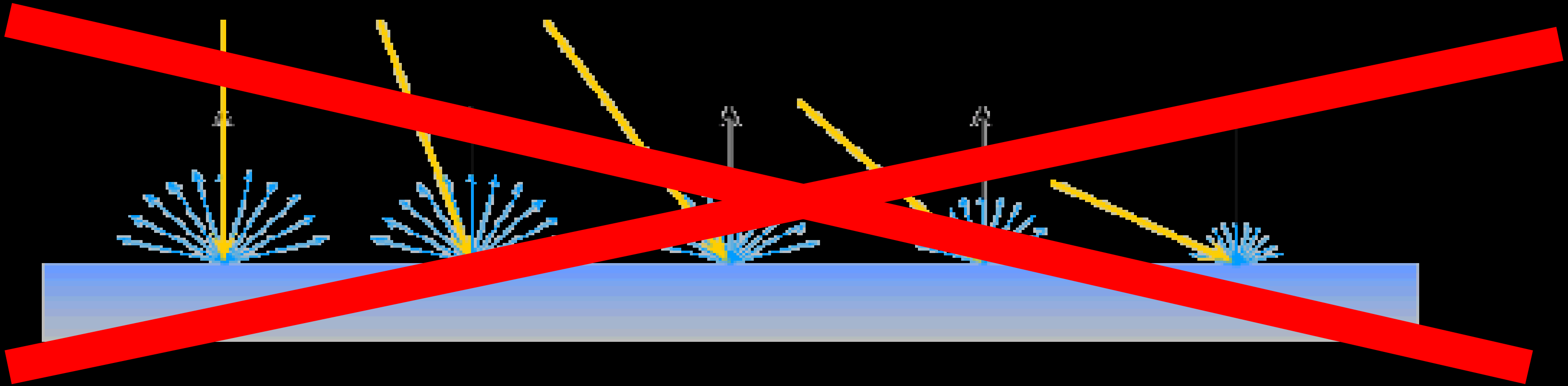
Reflection Models

Image Intensity =
Body Reflection +
Surface Reflection

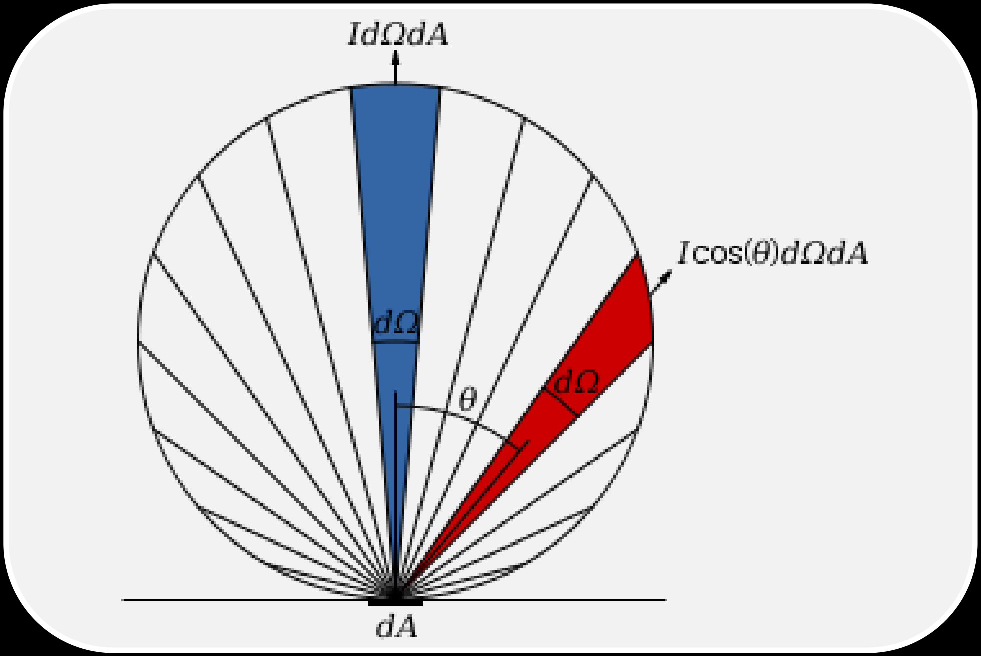


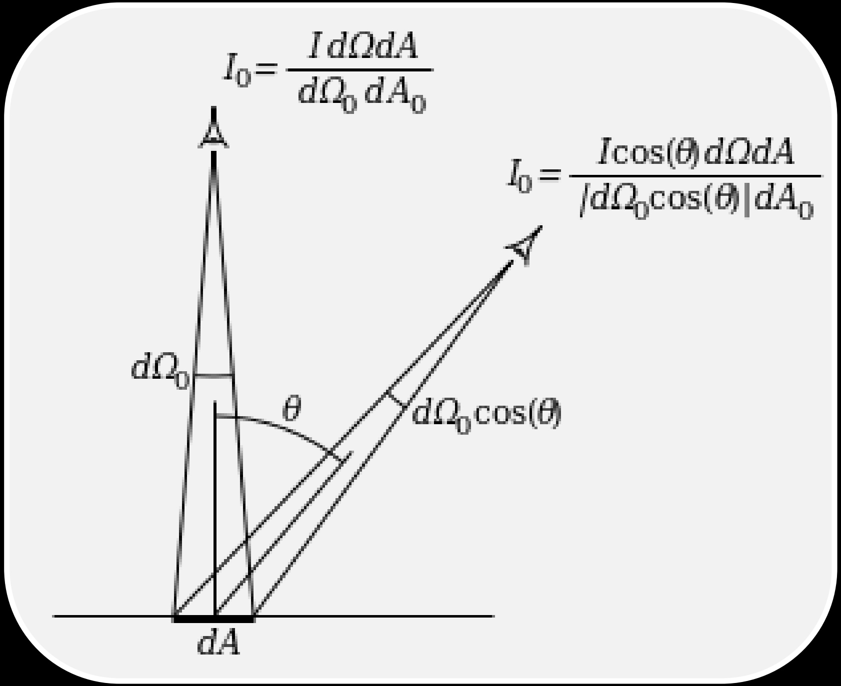
Diffuse Reflection and Lambertian BRDF

- Only body reflection, and no specular reflection
- *Lamberts* law – essentially a patch looks equally bright from every direction.

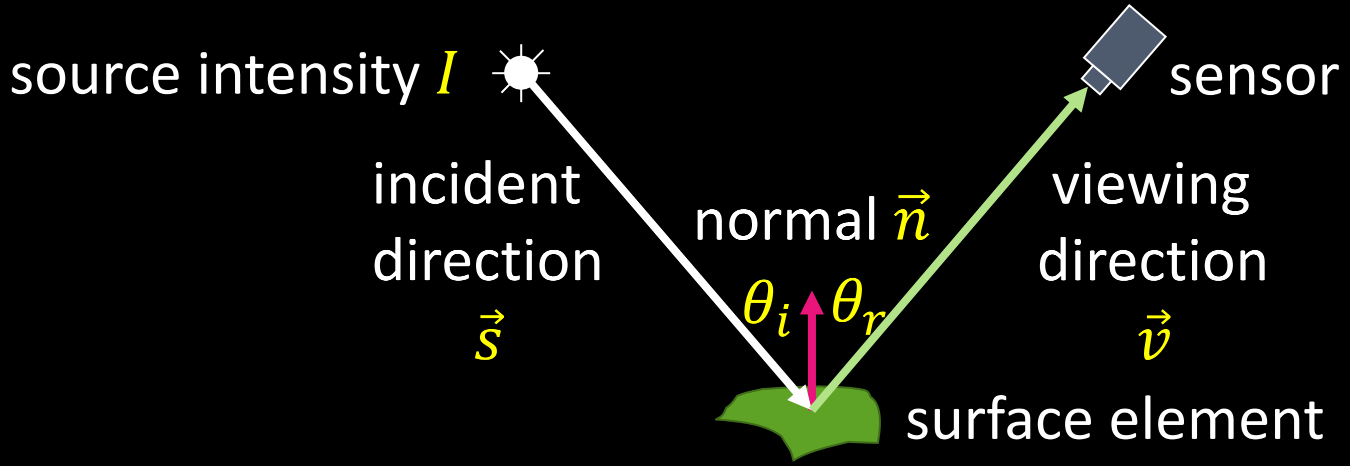


Diffuse Reflection and Lambertian BRDF



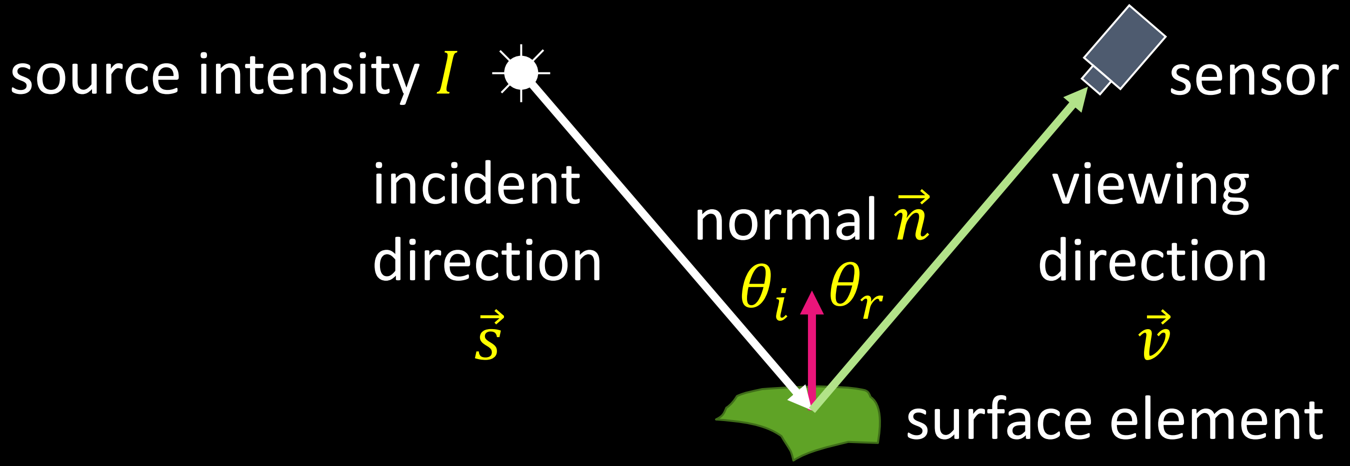


Diffuse Reflection and Lambertian BRDF



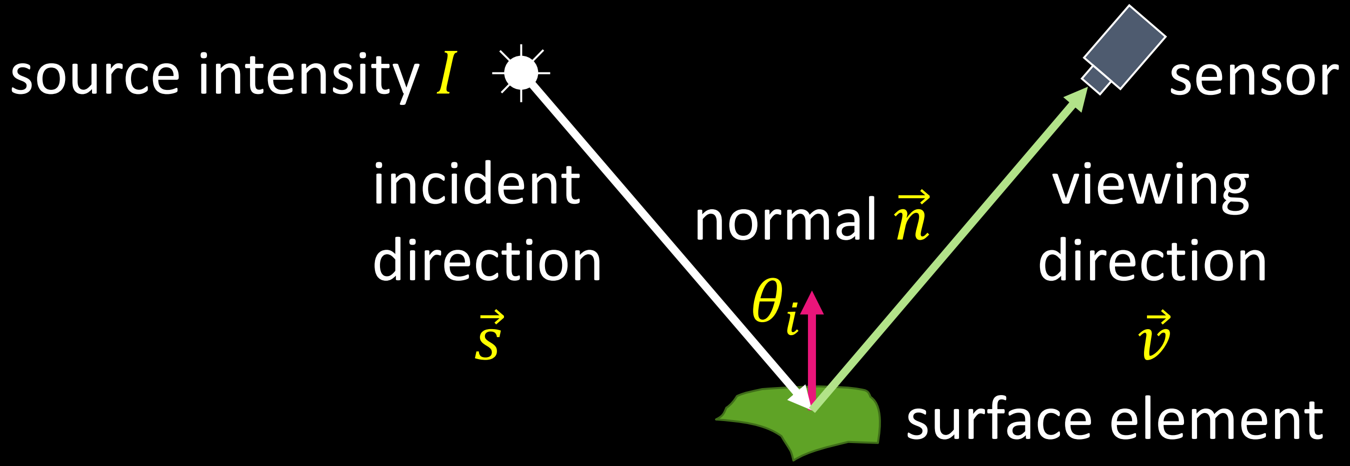
- Surface appears equally bright from *all* directions! (independent of $\vec{v}$)

Diffuse Reflection and Lambertian BRDF



- Lambertian BRDF is simply a constant – the *albedo*:
  $f(\theta_i, \varphi_i; \theta_r, \varphi_r) = \rho_d$

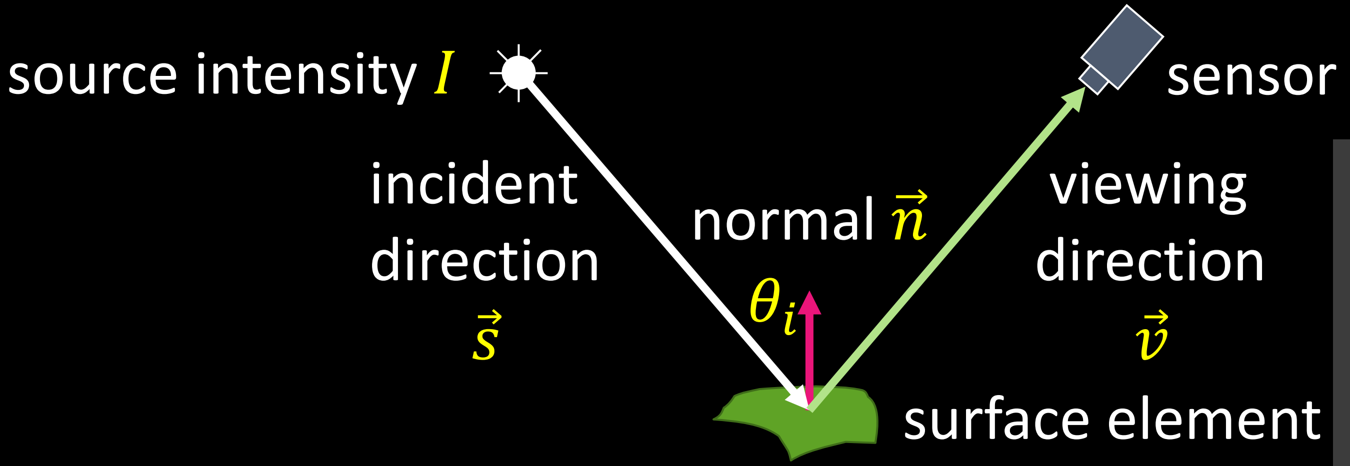
Diffuse Reflection and Lambertian BRDF

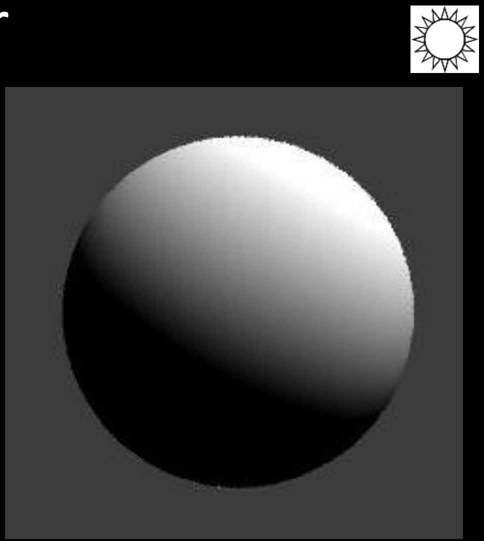


- Surface Radiance: $L = \rho_d \, I \cos\theta_i = \rho_d \, I \, (\vec{n} \cdot \vec{s})$

source intensity

Diffuse Reflection and Lambertian BRDF

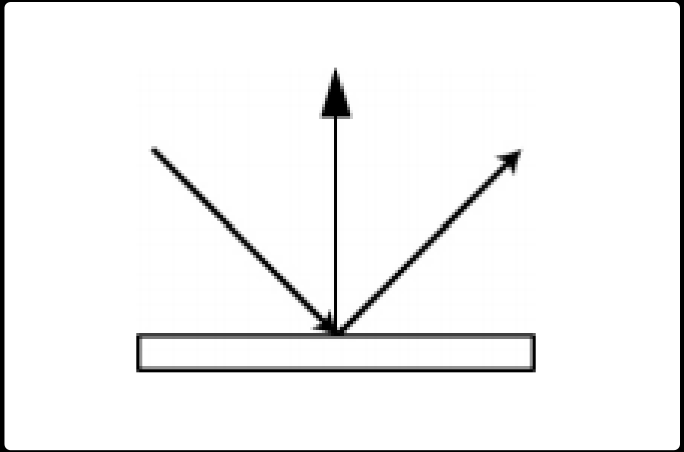




- Surface Radiance: $L = \rho_d \, I \cos\theta_i = \rho_d \, I \, (\vec{n} \cdot \vec{s})$

source intensity

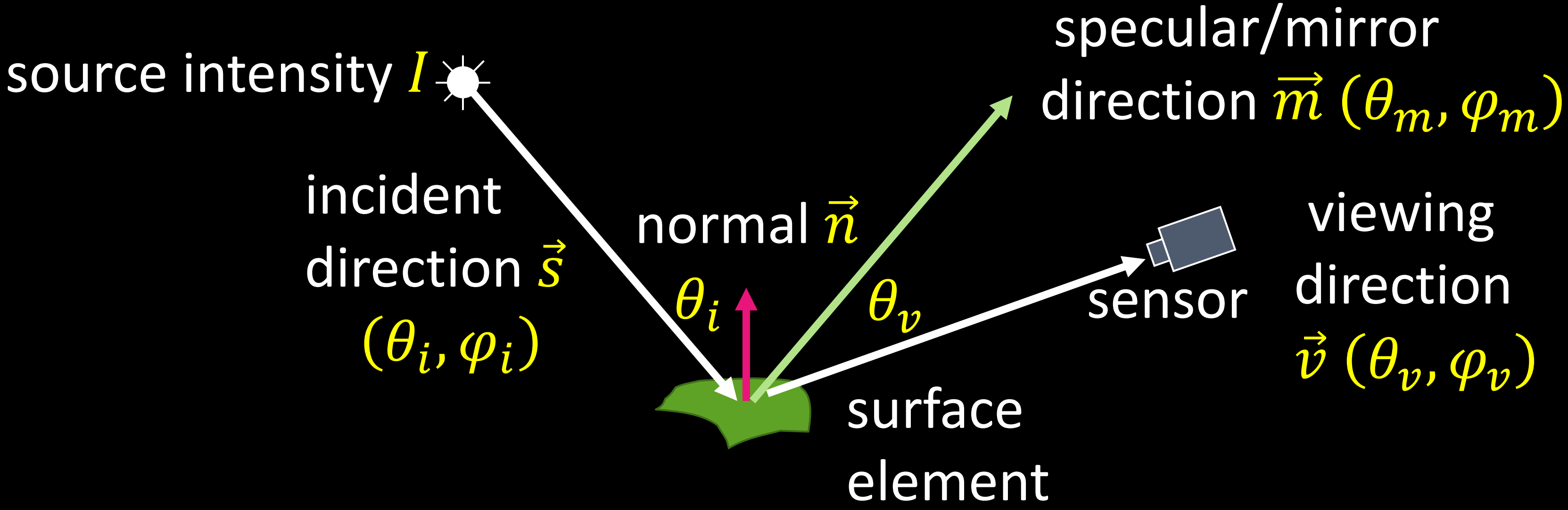
Specular Reflection and Mirror BRDF



How about a mirror?

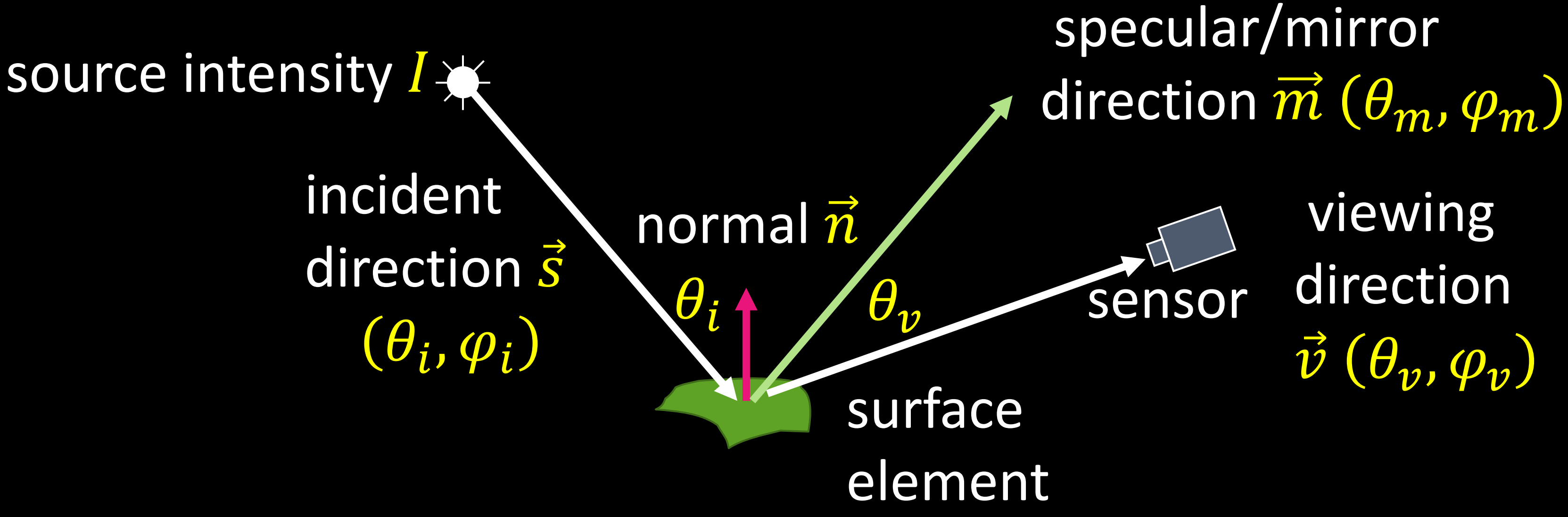
Reflection *only* at mirror angle

Specular Reflection and Mirror BRDF



- All incident light reflected in a *single* direction (visible when $\vec{v} = \vec{m}$)

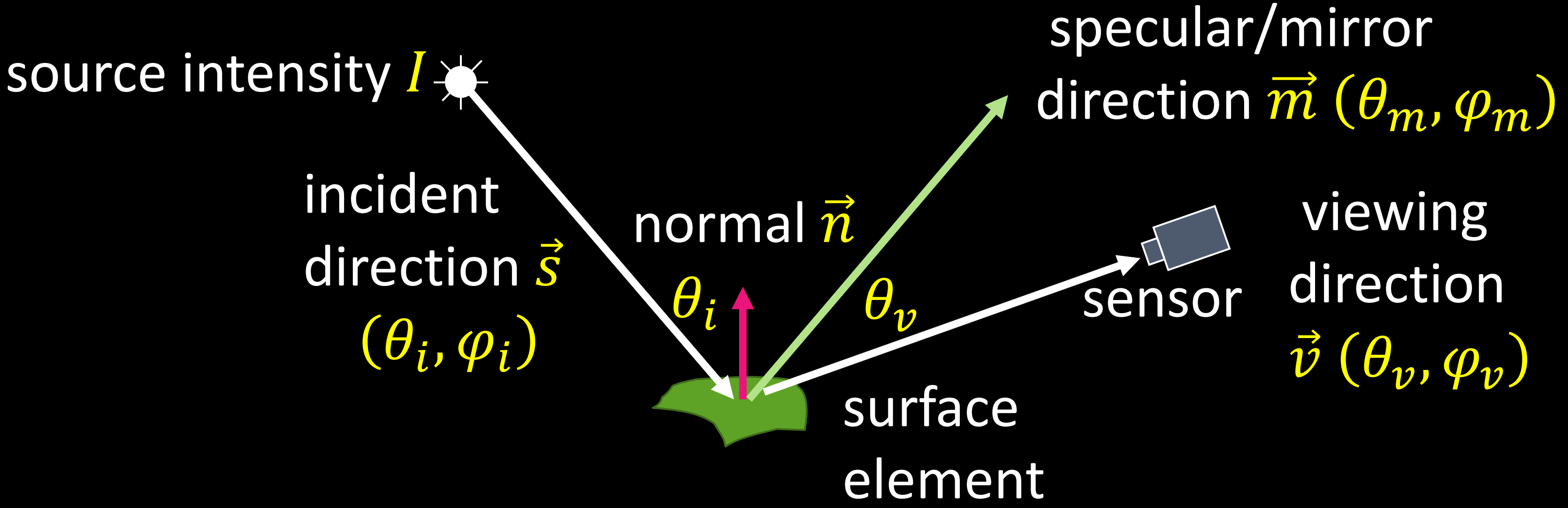
Specular Reflection and Mirror BRDF



- Mirror BRDF is simply a double-delta function:

$$f(\theta_i, \phi_i; \theta_v, \phi_v) = \rho_s \delta(\theta_i - \theta_v)\, \delta(\phi_i + \pi - \phi_v)$$

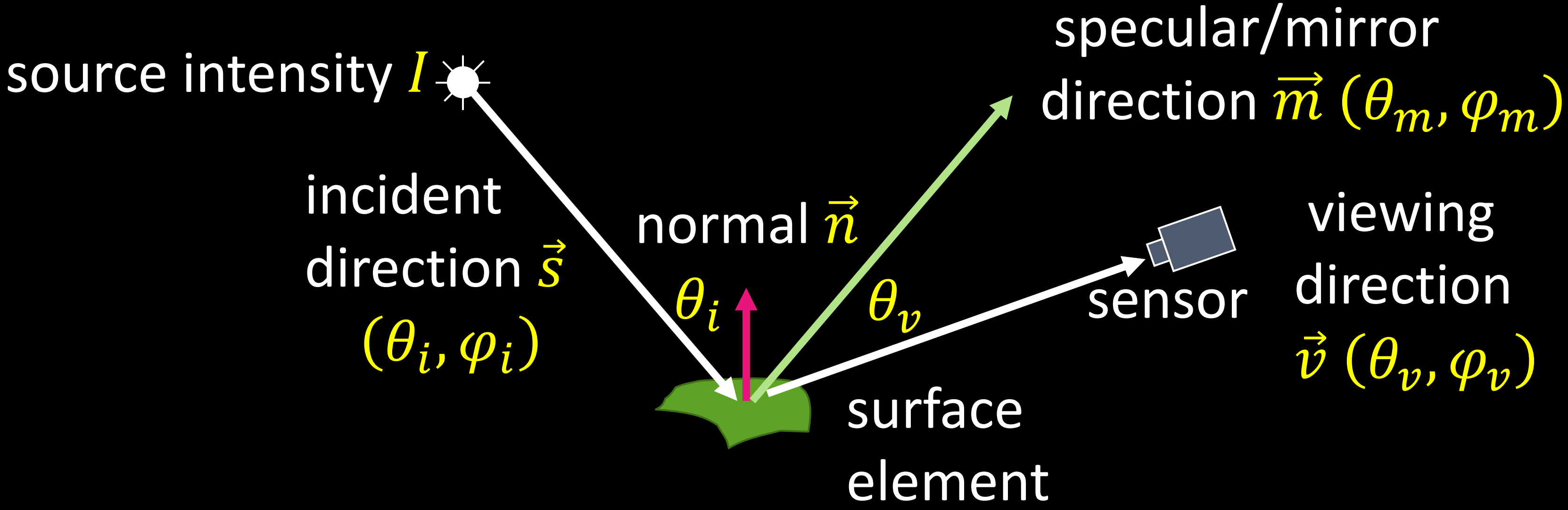
Specular Reflection and Mirror BRDF



- Surface Radiance:

$$L = I\,\rho_s\,\delta(\theta_i - \theta_v)\,\delta(\varphi_i + \pi - \varphi_v)$$

Specular Reflection and Mirror BRDF



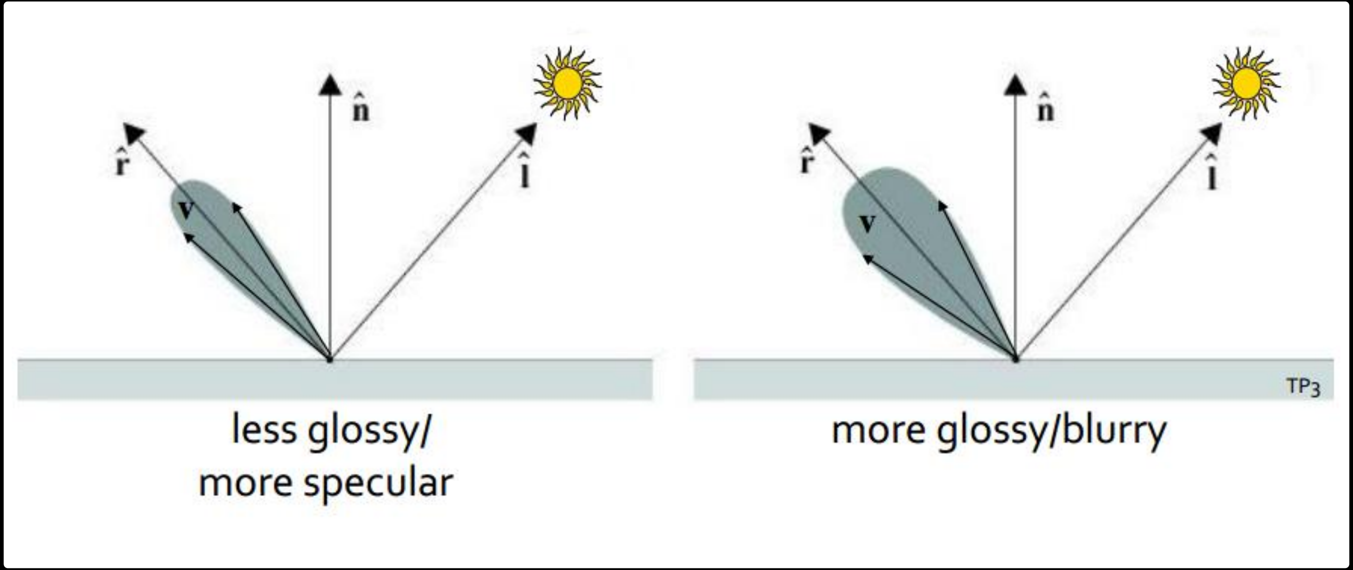
- Surface Radiance:

$$L = I\rho_s\delta(\vec{m} - \vec{v}) \text{ or } I\,\rho_s\,\delta\left(\vec{n} - \vec{h}\right)$$

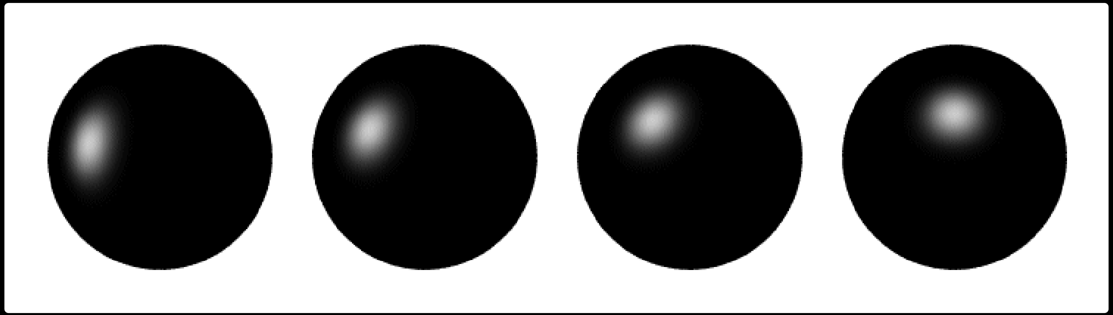
($\vec{h}$ is the “half angle”)

Specular Reflection and *Glossy* BRDF

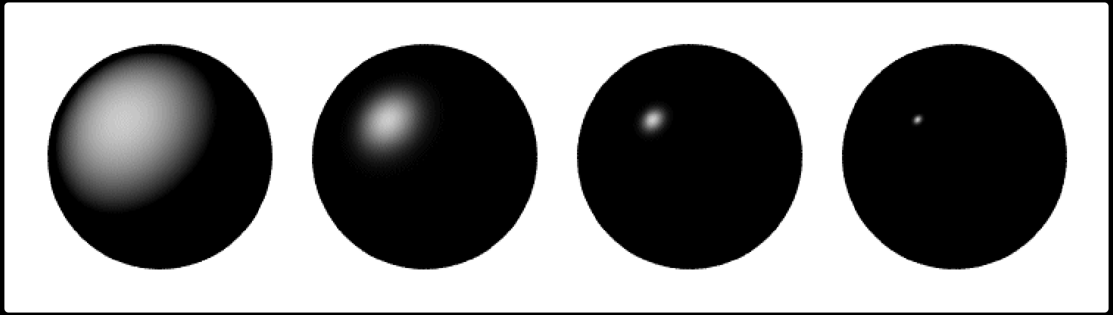
$$L = I \rho_s (\overrightarrow{m} \cdot \vec{v})^k$$



Specular reflection



Moving the light source



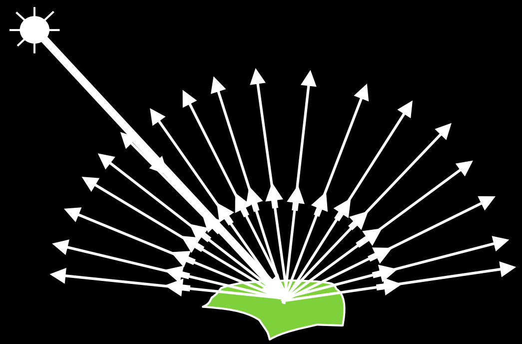
Changing the exponent

Phong Reflection Model

The BRDF of many surfaces can be approximated by:

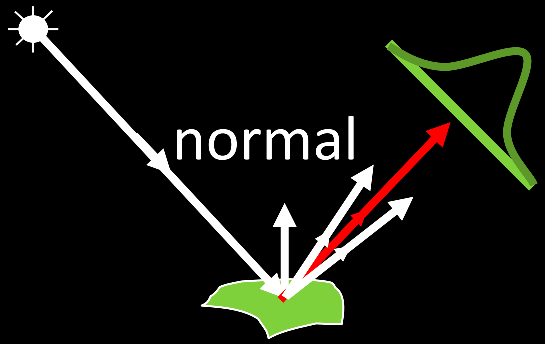
Lambertian + Specular Model

source



Lambertian

source



Specular Model

Diffuse + Specular Reflection

diffuse specular diffuse + specular