CS580:
Radiometry

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(윤성의)

Course URL:
http://sglab.kaist.ac.kr/~sungeui/GCG

Announcements

- **Final project**
  - **Make a team of two or three members**
  - **Think about which papers you want to implement**
  - **Present papers related to it**
  - **Declare your members at the Noah board by Apr.-4**

- **Scope of papers for presentation**
  - **Papers published since 2011**
  - **ACM SIGGRAPH, SIG. Asia, or**
  - **Any top-tier conf./journal (e.g., CVPR); get a permission from the instructor**

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Announcements

- **Declare two papers at the Noah board by Apr-11**
  - **First come, first served**
- **Present a single talk covering those two papers**
  - **Give a intro and related work**
  - **Discuss main methods and results of those two papers**
  - **Discuss their pros/cons**

- **Talk time: 35 min**
  - **25 min for the talk and 10 min for Q&A**

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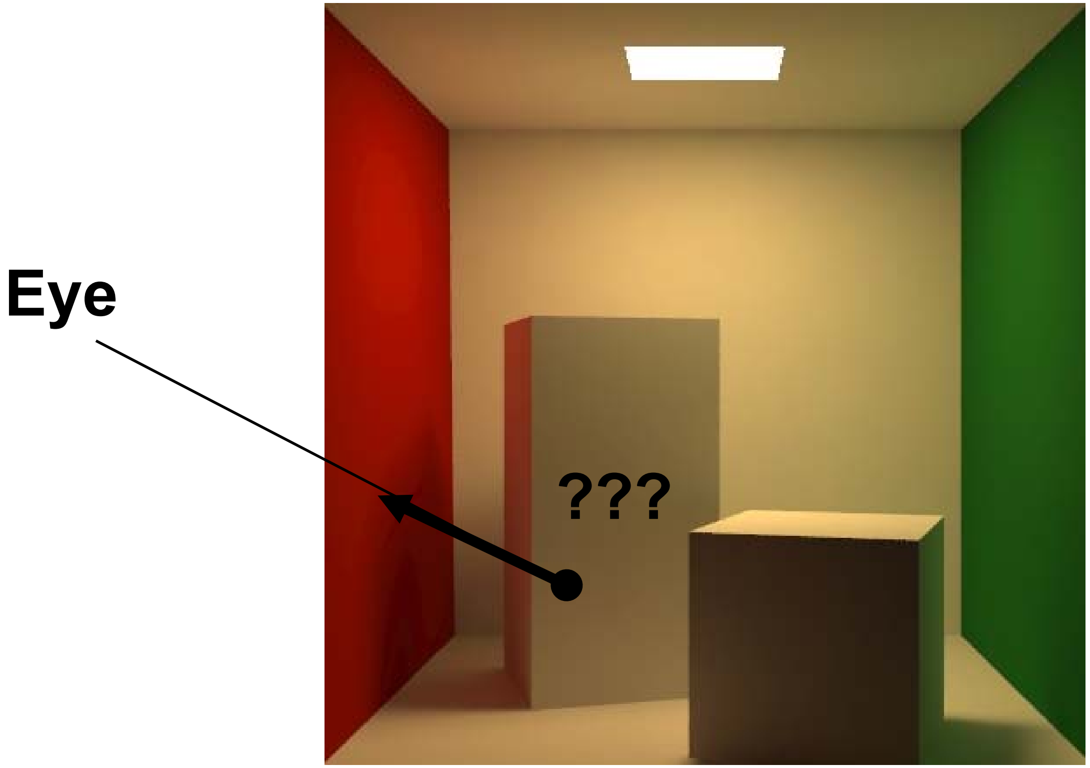
Tentative schedule

- 4/26: mid-term exam
- 4/28: student presentations (SP) 1
- 5/3: SP 2
- 5/10: SP 3
- 5/12: SP 4
- 5/24: mid-project presentation I
- 5/26: II
- 5/31: SP 5
- 6/2: SP 6
- 6/7: SP 7
- 6/9: SP 8
- 6/14: Final project I
- 6/16: II

Class Objectives

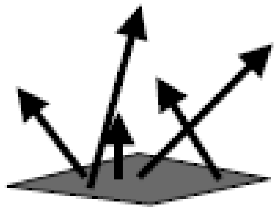
- **Know terms of:**
  - **Hemispherical coordinates and integration**
  - **Various radiometric quantities (e.g., radiance)**
  - **Basic material function, BRDF**

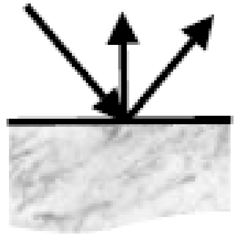
Motivation



Light and Material Interactions

- **Physics of light**





- **Radiometry**
- **Material properties**

From kavita's slides

- **Rendering equation**

Models of Light

- Quantum optics
  - Fundamental model of the light
  - Explain the dual wave-particle nature of light
- Wave model
  - Simplified quantum optics
  - Explains diffraction, interference, and polarization

- Geometric optics
  - Most commonly used model in CG
  - Size of objects >> wavelength of light
  - Light is emitted, reflected, and transmitted

Radiometry and Photometry

- **Photometry**
  - **Quantify the perception of light energy**
- **Radiometry**
  - **Measurement of light energy: critical component for photo-realistic rendering**
  - **Light energy flows through space, and varies with time, position, and direction**
  - **Radiometric quantities: densities of energy at particular places in time, space, and direction**

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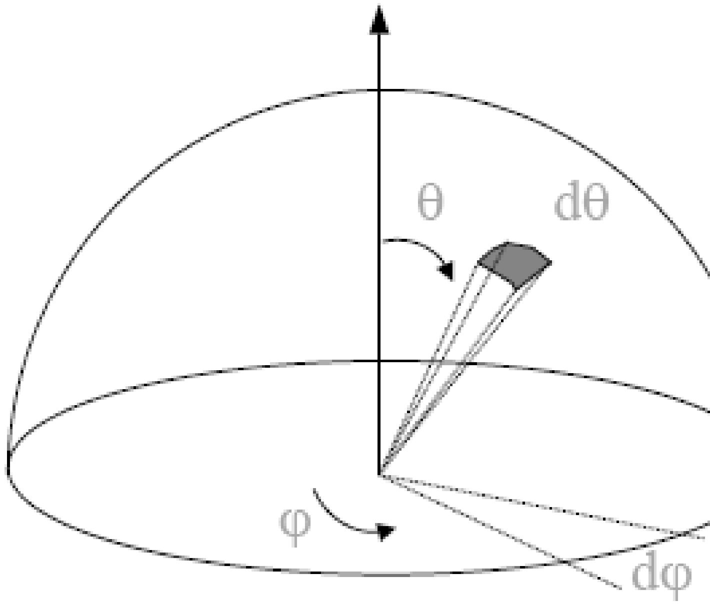
Hemispheres

- **Hemisphere**
  - **Two-dimensional surfaces**
- **Direction**
  - **Point on (unit) sphere**



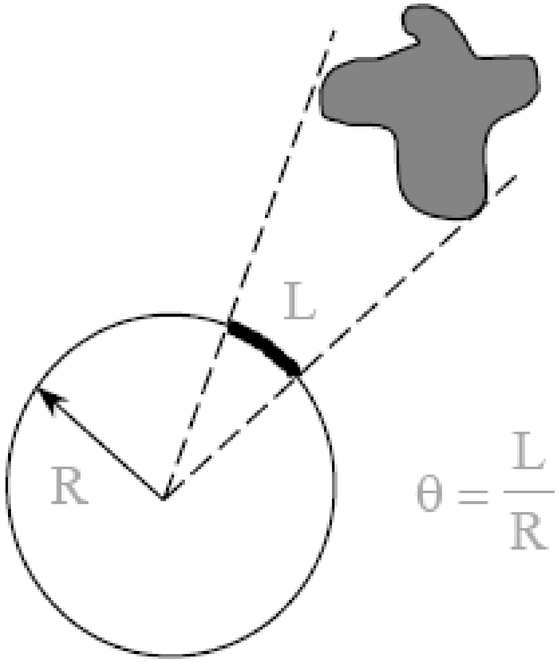
$$\theta \in [0, \frac{\pi}{2}]$$

$$\varphi \in [0, 2\pi]$$

From kavita's slides

Solid Angles

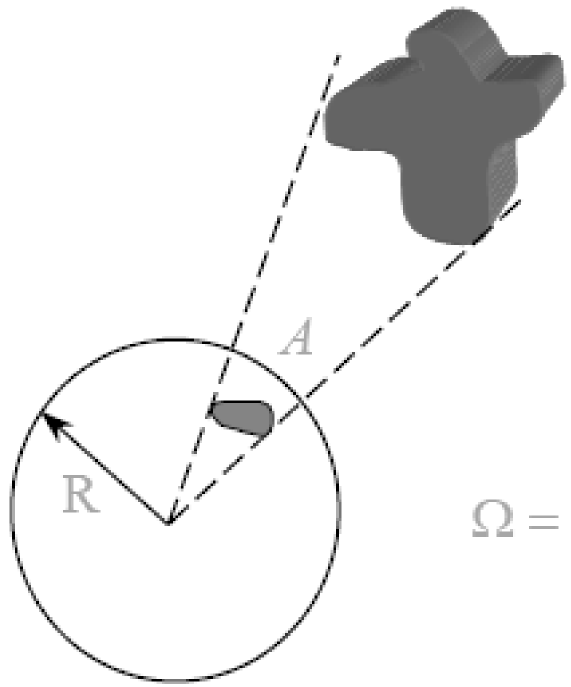
2D



$$\theta = \frac{L}{R}$$

Full circle = 2pi radians

3D

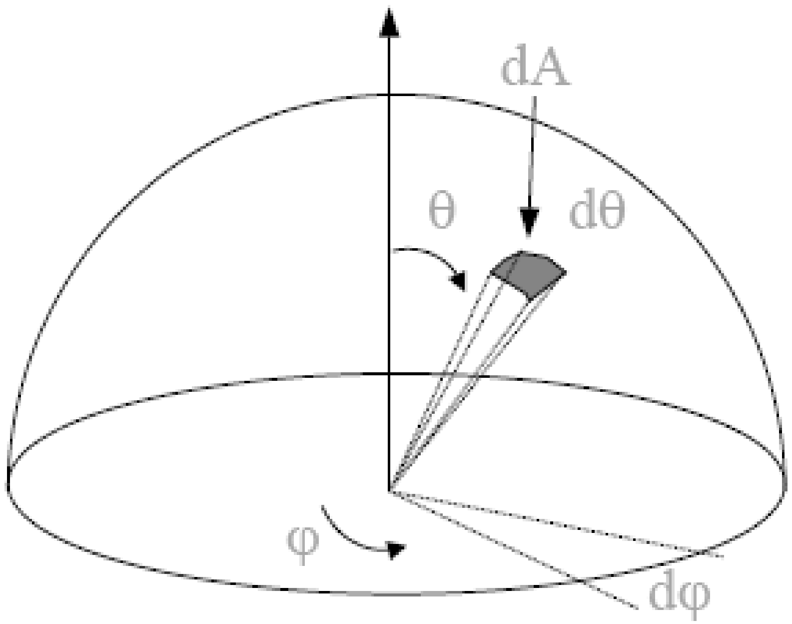


$$\Omega = \frac{A}{R^2}$$

Full sphere = 4pi steradians

Hemispherical Coordinates

- **Direction, Θ**
  - **Point on (unit) sphere**

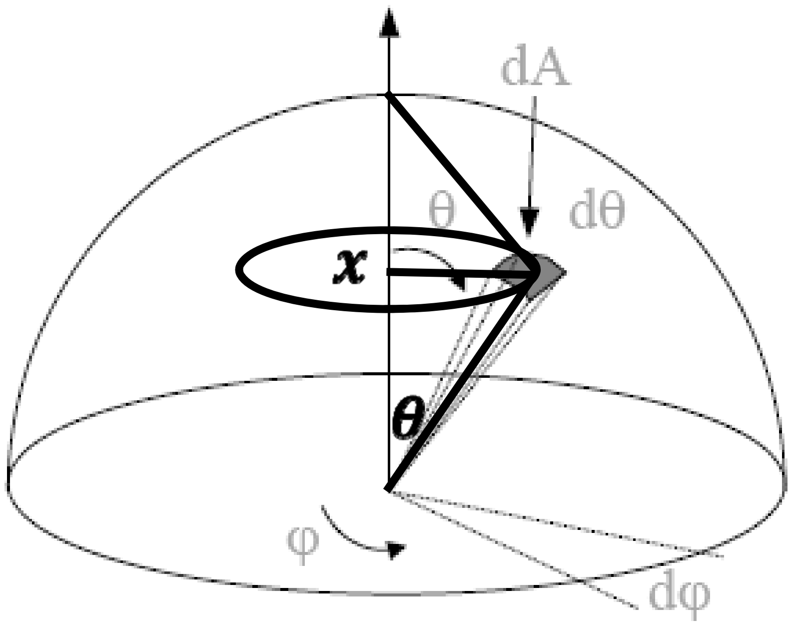


$$dA = (r \sin\theta d\varphi)(r d\theta)$$

From kavita's slides

Hemispherical Coordinates

- **Direction, Θ**
  - **Point on (unit) sphere**



$$\sin\theta = \frac{x}{r},$$
$$x = r\sin\theta$$

$$dA = (r\sin\theta d\varphi)(rd\theta)$$

From kavita's slides

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Hemispherical Coordinates

- **Differential solid angle**

$$d\omega = \frac{dA}{r^2} = \sin\theta d\theta d\varphi$$

Hemispherical Integration

- **Area of hemispehre:**

$$\int_{\Omega_x} d\omega = \int_0^{2\pi} d\varphi \int_0^{\pi/2} \sin\theta d\theta$$

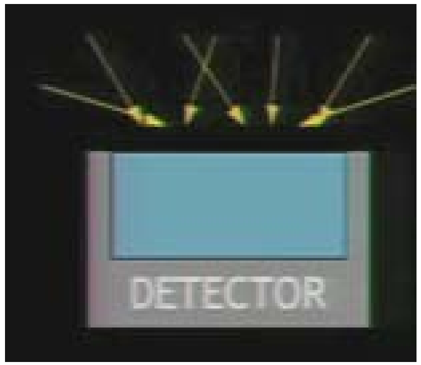
$$= \int_0^{2\pi} d\varphi \left[-\cos\theta\right]_0^{\pi/2}$$

$$= \int_0^{2\pi} d\varphi$$

$$= 2\pi$$

Energy

- Symbol: Q
  - # of photons in this context
  - Unit: Joules

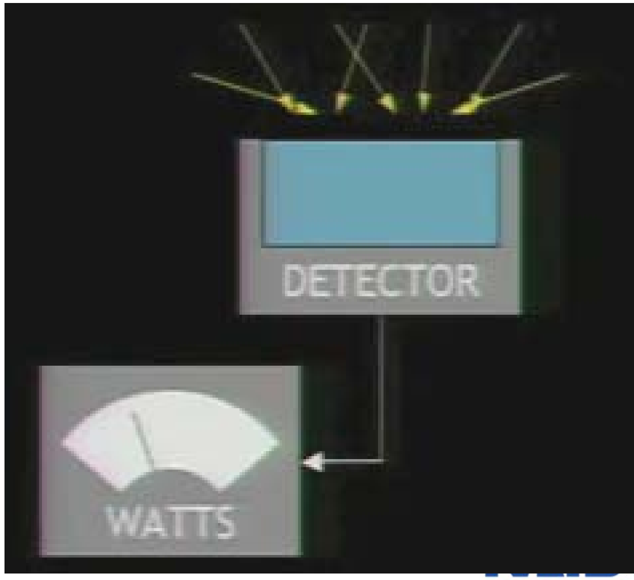


From Steve Marschner's talk

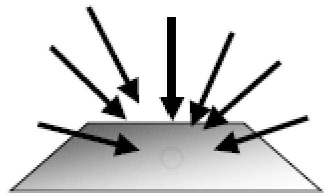
Power (or Flux)

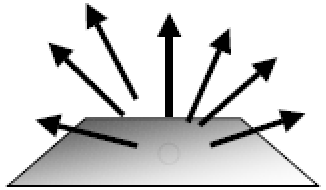
- Symbol, P or Φ
  - Total amount of energy through a surface per unit time, dQ/dt
  - Radiant flux in this context
  - Unit: Watts (=Joules / sec.)
  - Other quantities are derivatives of P

- Example
  - A light source emits 50 watts of radiant power
  - 20 watts of radiant power is incident on a table

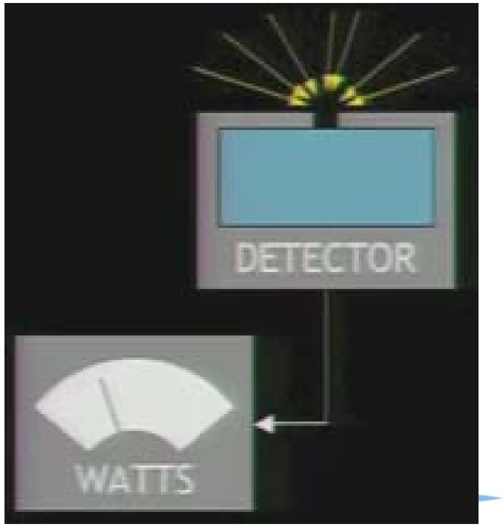


Irradiance





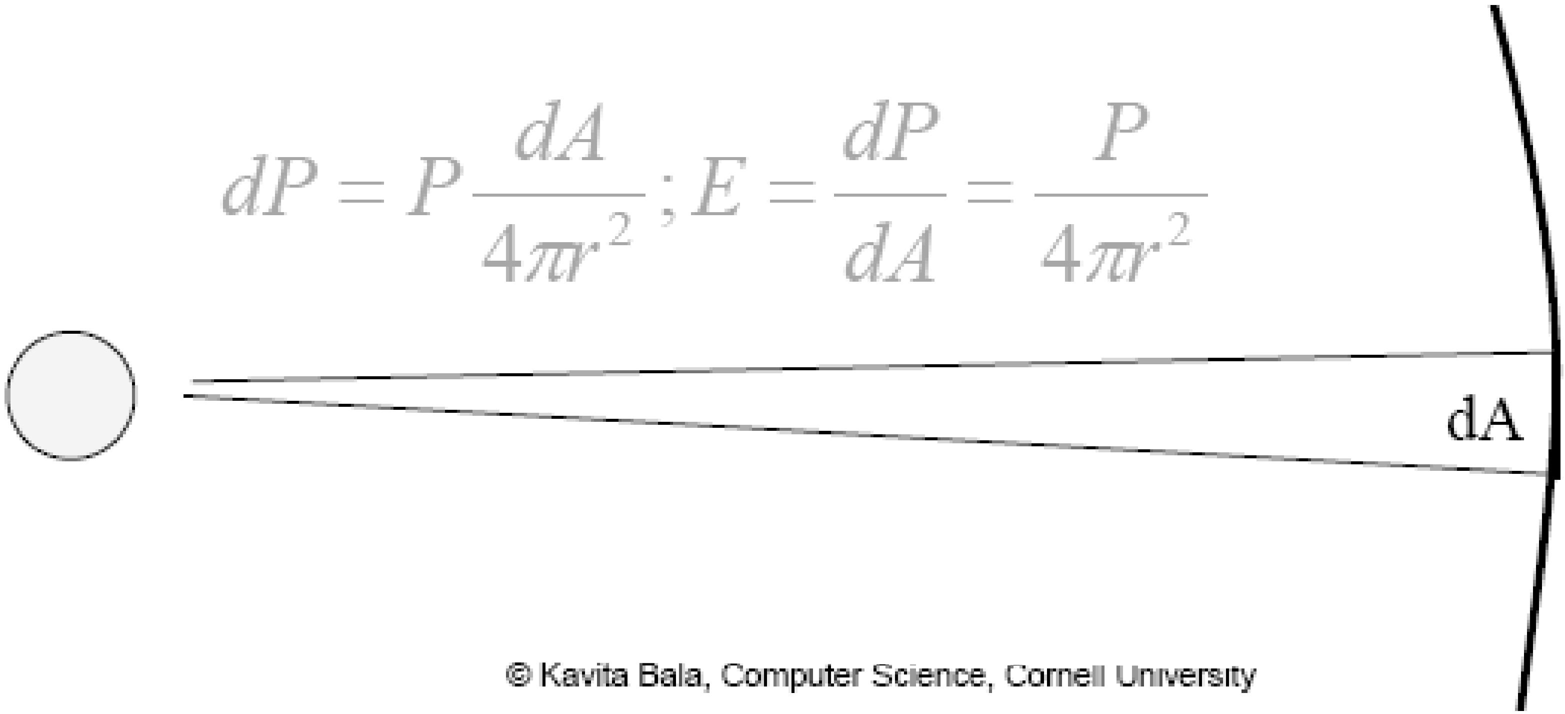
- Incident radiant power per unit area (dP/dA)
  - Area density of power
- Symbol: E, unit: W/ m^2
  - Area power density existing a surface is called radiance exitance (M) or radiosity (B)
- For example
  - A light source emitting 100 W of area 0.1 m^2
  - Its radiant exitance is 1000 W/ m^2



Irradiance Example

- **Uniform point source illuminates a small surface dA from a distance r**
  - **Power P is uniformly spread over the area of the sphere**

$$dP = P\frac{dA}{4\pi r^2}; E = \frac{dP}{dA} = \frac{P}{4\pi r^2}$$



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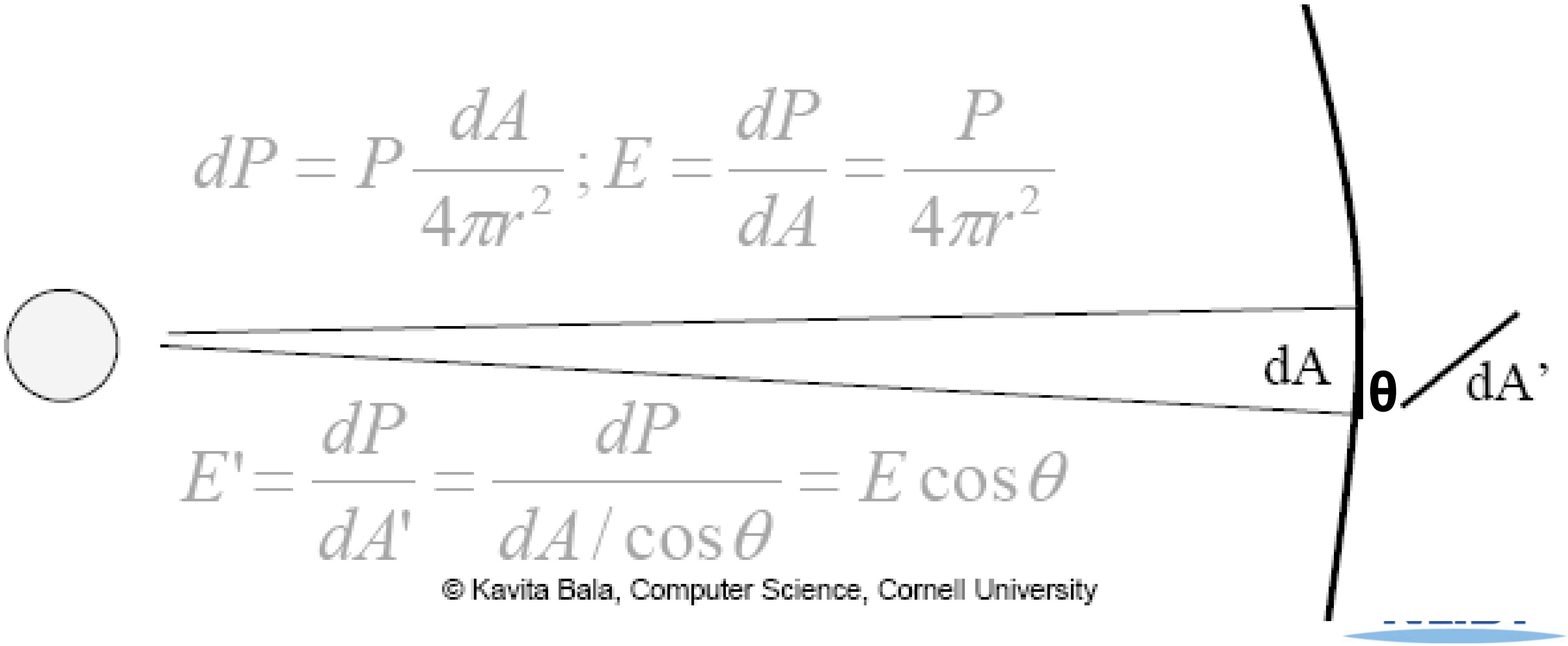
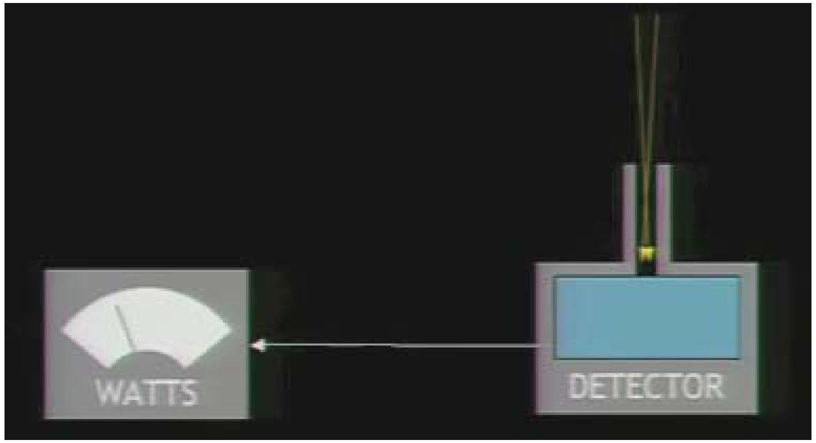


$$E' = \frac{dP}{dA'} = \frac{dP}{dA/\cos\theta} = E\cos\theta$$

Radiance

- **Radiant power at x in direction θ**
  - $L(x \rightarrow \Theta)$ **: 5D function**
    - **Per unit area**
    - **Per unit solid angle**

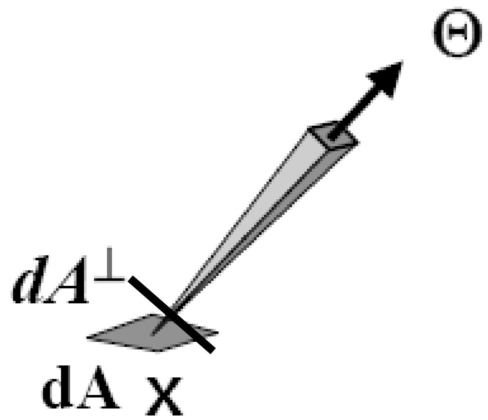


- **Important quantity for rendering**

Radiance

- **Radiant power at x in direction θ**
  - $L(x \rightarrow \Theta)$ **: 5D function**
    - **Per unit area**
    - **Per unit solid angle**

$$L(x \rightarrow \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_{\Theta}}$$

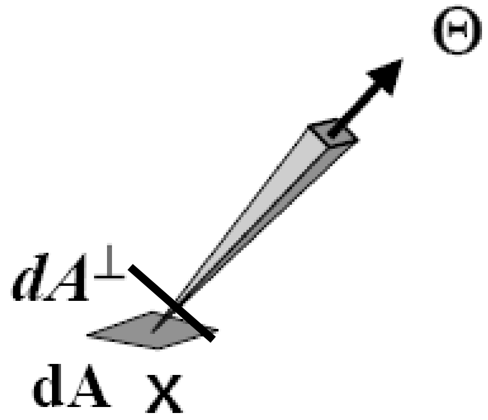


  - **Units: Watt / (m^2 sr)**
  - **Irradiance per unit solid angle**
  - **2^{nd} derivative of P**
  - **Most commonly used term**

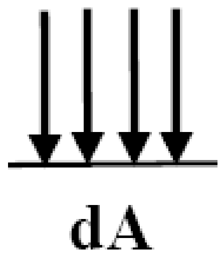
Radiance: Projected Area

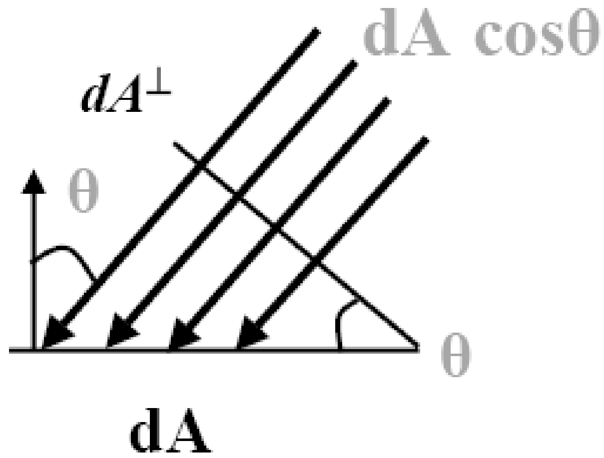
$$L(x \to \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_{\Theta}}$$

$$= \frac{d^2 P}{d\omega_{\Theta} \, dA \cos\theta}$$



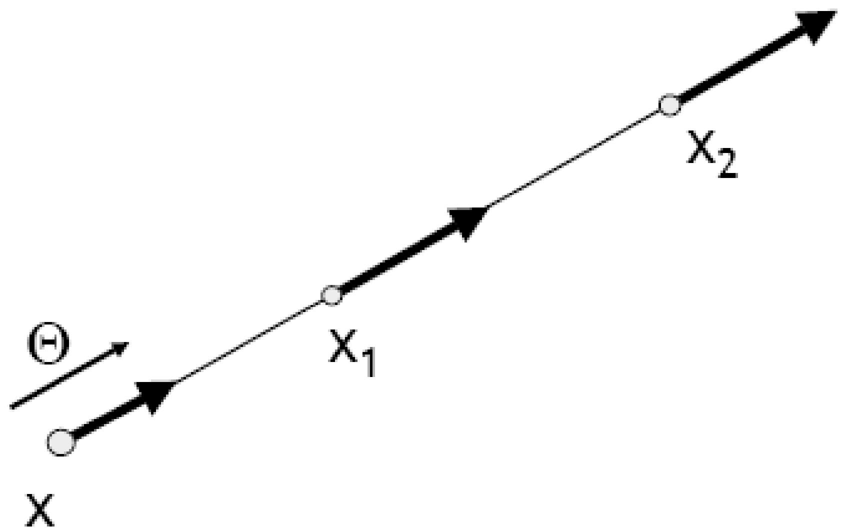
- **Why per unit projected surface area**





Properties of Radiance

- **Invariant along a straight line (in vacuum)**



From kavita's slides

Invariance of Radiance

We can prove it based on the assumption the conservation of energy.

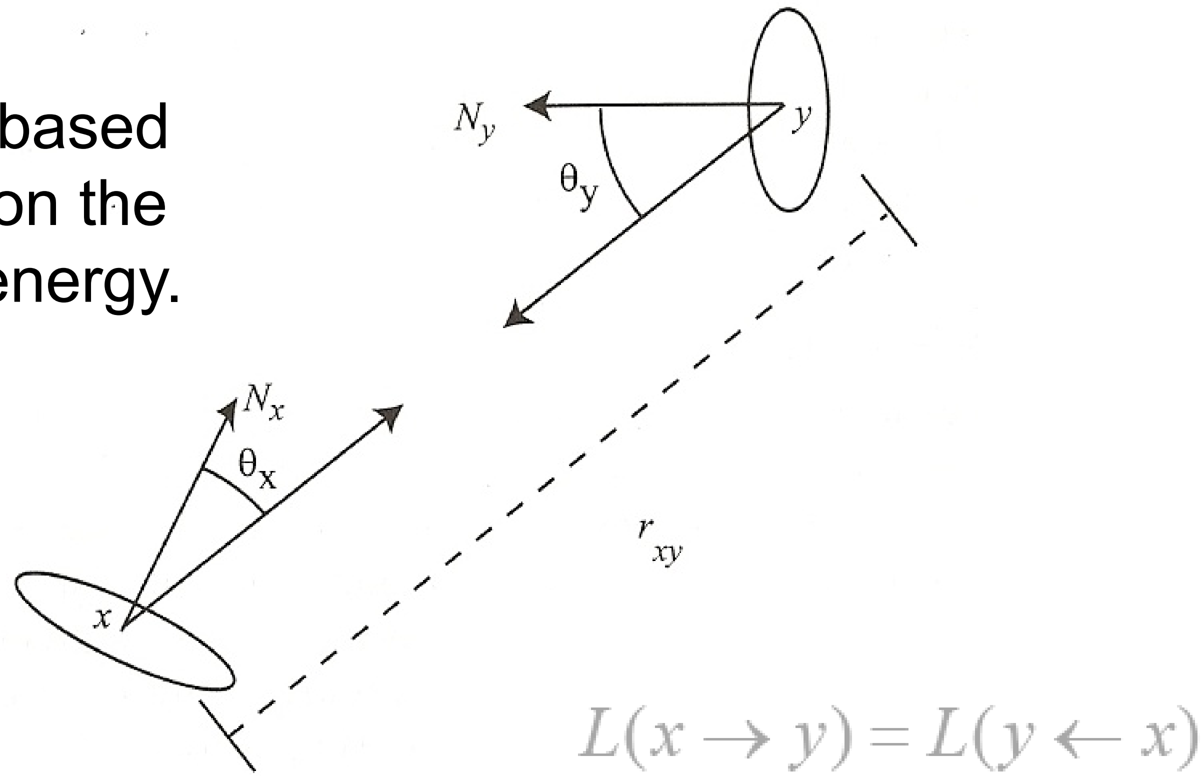
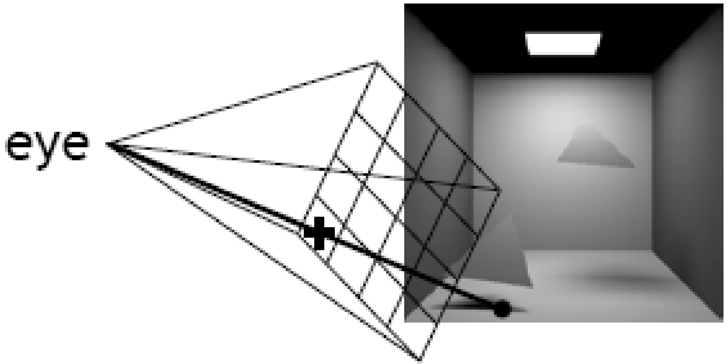


Figure 2.3. Invariance of radiance.

Sensitivity to Radiance

- **Responses of sensors (camera, human eye) is proportional to radiance**



From kavita's slides

- **Pixel values in image proportional to radiance received from that direction**

Relationships

- **Radiance is the fundamental quantity**

$$L(x \to \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_\Theta}$$

- **Power:**

$$P = \int_{Area} \int_{\substack{Solid \\ Angle}} L(x \to \Theta) \cdot \cos\theta \cdot d\omega_\Theta \cdot dA$$

- **Radiosity:**

$$B = \int_{\substack{Solid \\ Angle}} L(x \to \Theta) \cdot \cos\theta \cdot d\omega_\Theta$$

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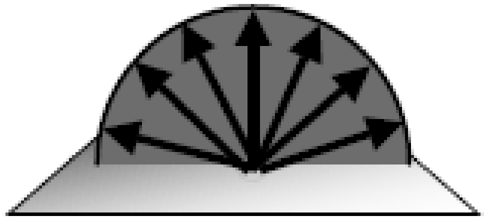
Example: Diffuse emitter

- Diffuse emitter: light source with equal radiance everywhere

$$L(x \to \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_{\Theta}}$$



Example: Diffuse emitter

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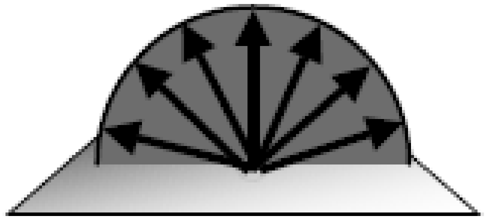

$$L(x \to \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_\Theta}$$

$$P = \int_{Area} \int_{\substack{Solid\\Angle}} L(x \to \Theta) \cdot \cos\theta \cdot d\omega_\Theta \cdot dA$$

Example: Diffuse emitter

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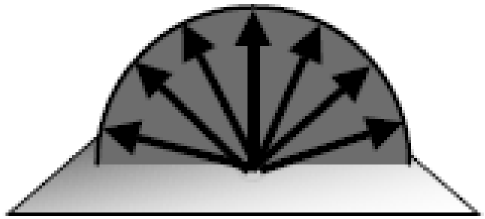


$$L(x \to \Theta) = \frac{d^2 P}{dA^{\perp} d\omega_{\Theta}}$$

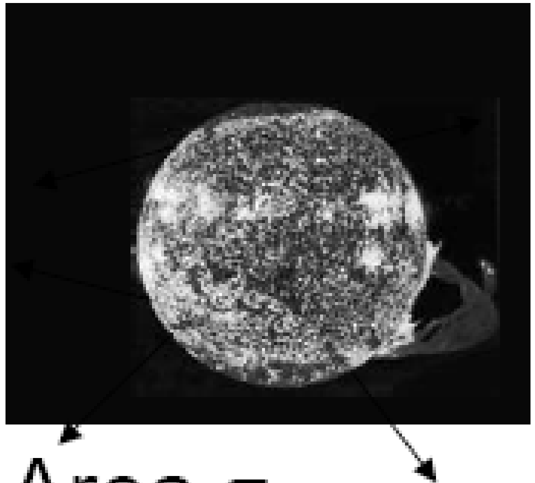
$$P = \int_{Area} \int_{\substack{Solid \\ Angle}} L(x \to \Theta) \cdot \cos\theta \cdot d\omega_{\Theta} \cdot dA$$

$$= L \int_{Area} dA \int_{\substack{Solid \\ Angle}} \cos\theta \cdot d\omega_{\Theta}$$

$$= L \cdot Area \cdot \pi$$

Sun Example: radiance

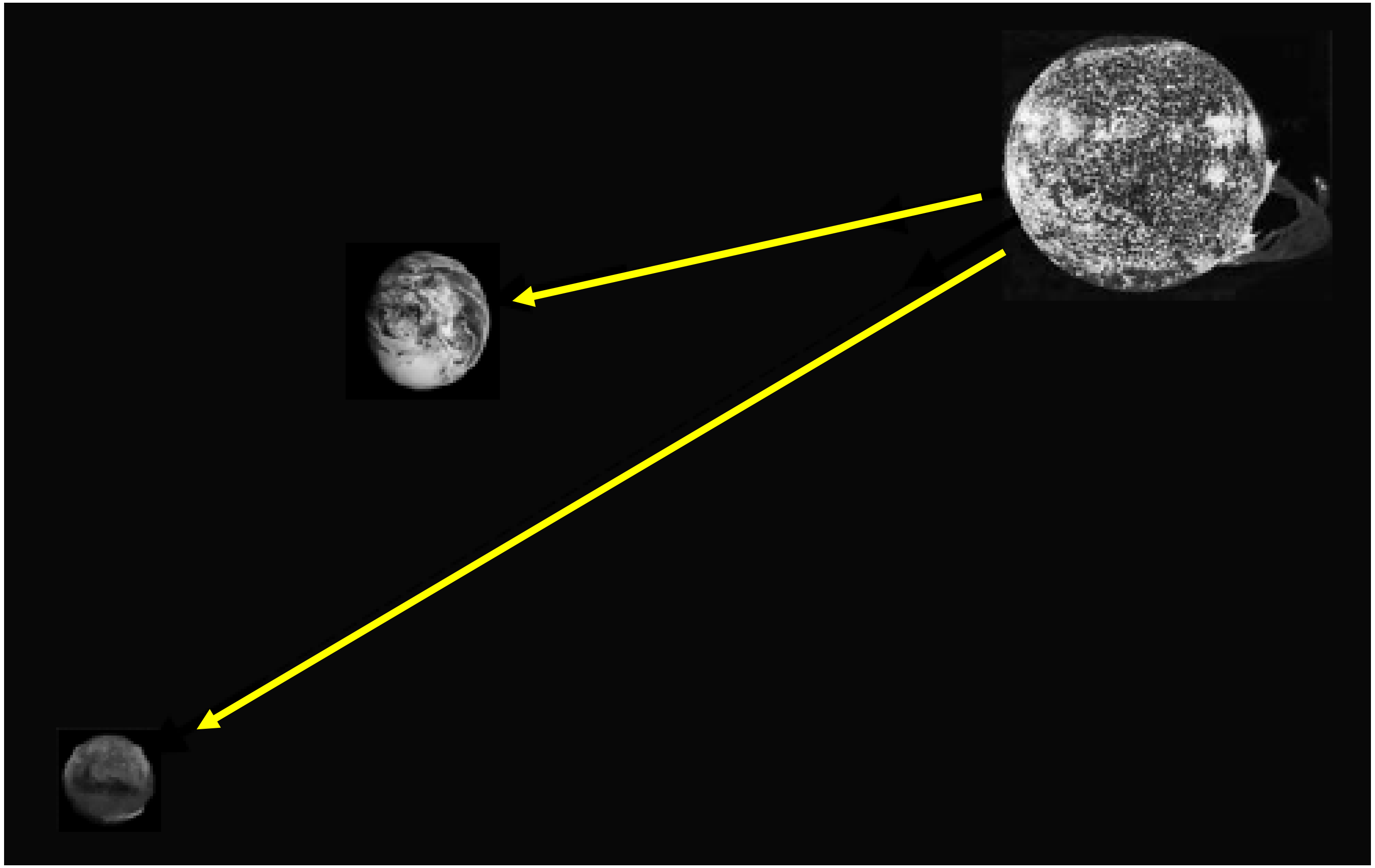
- Power: 3.91×10^{26} W
- Surface Area: 6.07×10^{18} m^2



- Power = Radiance.Surface Area.π
- Radiance = Power/(Surface Area.π)

- Radiance = 2.05×10^7 W/ m^2.sr

Sun Example

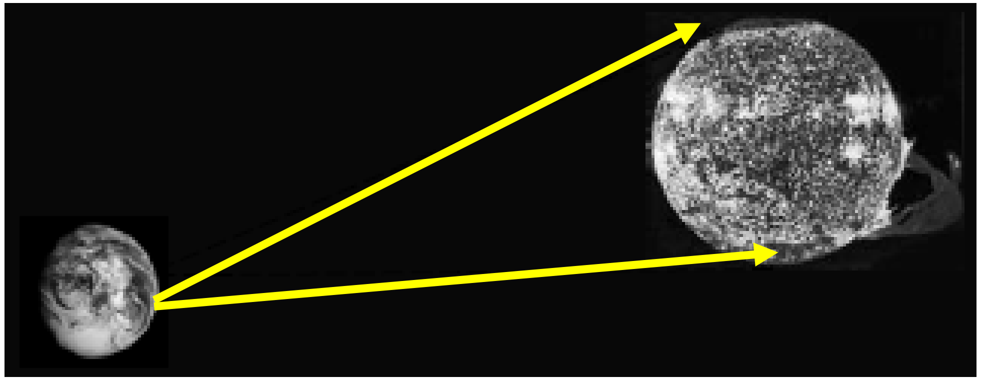


Same radiance on Earth and Mars?

Sun Example: Power on Earth

- Power reaching earth on a $1m^2$ square:

$$P = L \int_{Area} dA \int_{Solid\ Angle} \cos\theta \cdot d\omega_{\Theta}$$

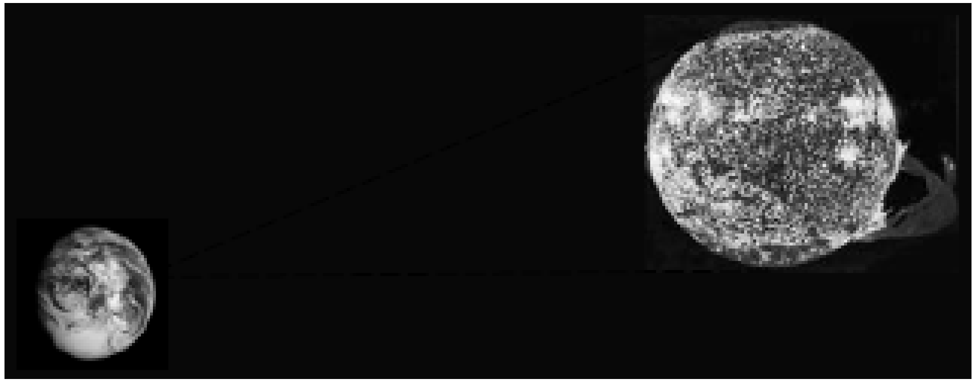


- Assume $\cos\theta = 1$ (sun in zenith)

$$P = L \int_{Area} dA \int_{Solid\ Angle} d\omega_{\Theta}$$

Sun Example: Power on Earth

Power = Radiance.Area.Solid Angle



Solid Angle = Projected $Area_{Sun}/(distance_{earth\_sun})^2$
= $6.7\ 10^{-5}$ sr

P = $(2.05 \times 10^7\ W/\ m^2.sr) \times (1\ m^2) \times (6.7\ 10^{-5}\ sr)$
= 1373.5 Watt

Sun Example: Power on Mars

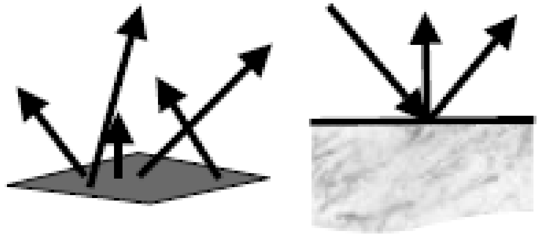
Power = Radiance.Area.Solid Angle

Solid Angle = Projected $\text{Area}_{Sun}/(\text{distance}_{mars\_sun})^2$
= $2.92\ 10^{-5}$ sr

P = $(2.05 \times 10^7$ W/ $m^2.sr) \times (1\ m^2) \times (2.92\ 10^{-5}$ sr)
= 598.6 Watt

Light and Material Interactions

- Physics of light

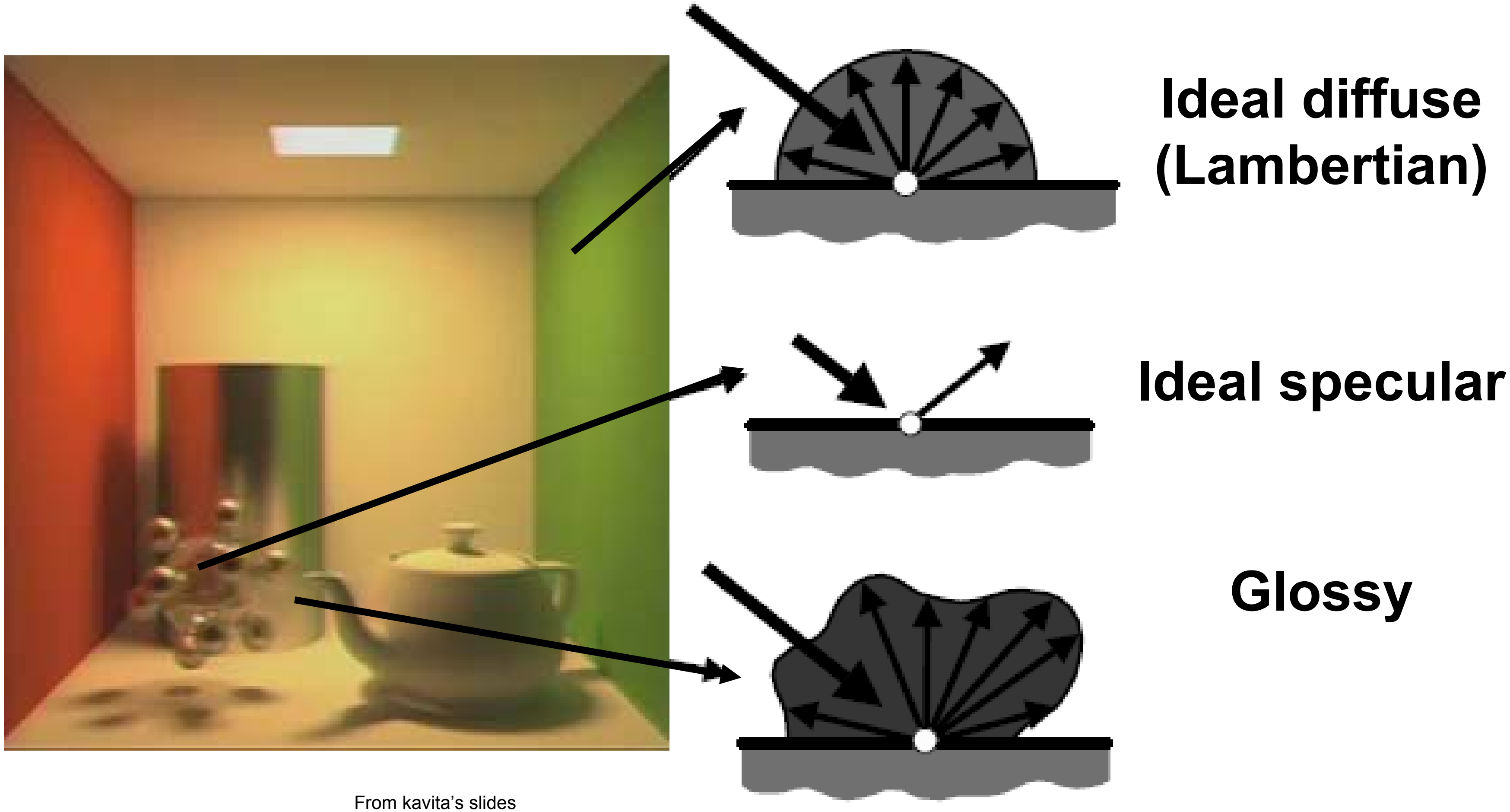


- Radiometry
- Material properties

From kavita's slides

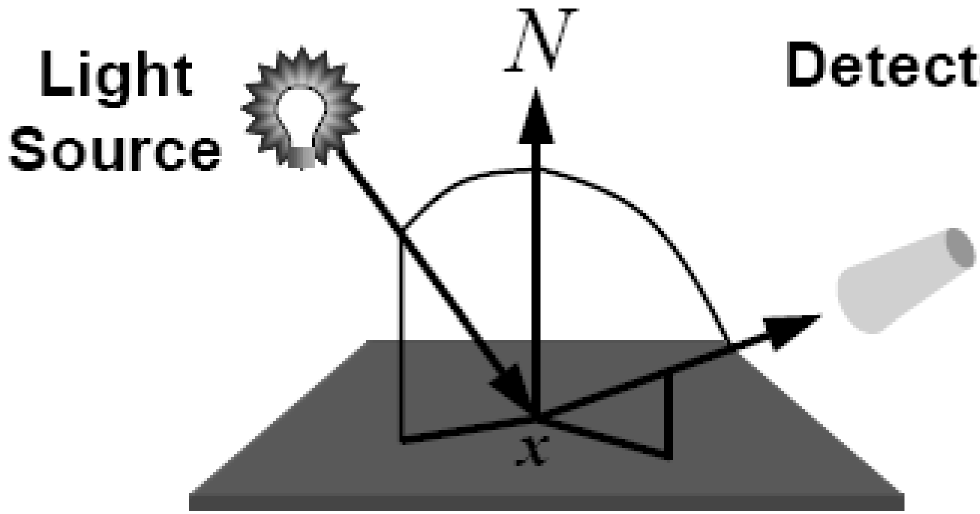
- Rendering equation

Materials



From kavita's slides

Bidirectional Reflectance Distribution Function (BRDF)

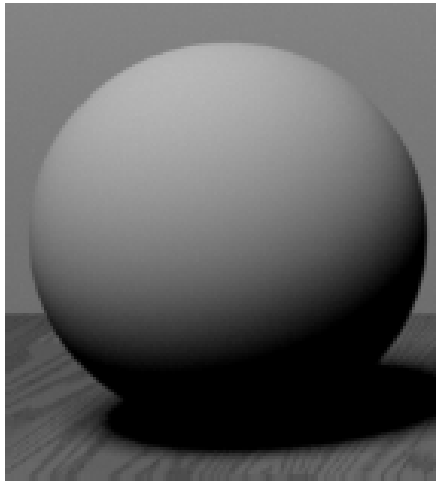


$$f_r(x, \Psi \rightarrow \Theta) = \frac{dL(x \rightarrow \Theta)}{dE(x \leftarrow \Psi)} = \frac{dL(x \rightarrow \Theta)}{L(x \leftarrow \Psi)\cos(N_x, \Psi)d\omega_\Psi}$$

BRDF special case: ideal diffuse

Pure Lambertian

$$f_r(x, \Psi \rightarrow \Theta) = \frac{\rho_d}{\pi}$$



$$\rho_d = \frac{Energy_{out}}{Energy_{in}} \qquad 0 \leq \rho_d \leq 1$$

Properties of the BRDF

- Reciprocity:

$$f_r(x, \Psi \rightarrow \Theta) = f_r(x, \Theta \rightarrow \Psi)$$

- Therefore, notation: $f_r(x, \Psi \leftrightarrow \Theta)$

- Important for bidirectional tracing

Properties of the BRDF

- Bounds:

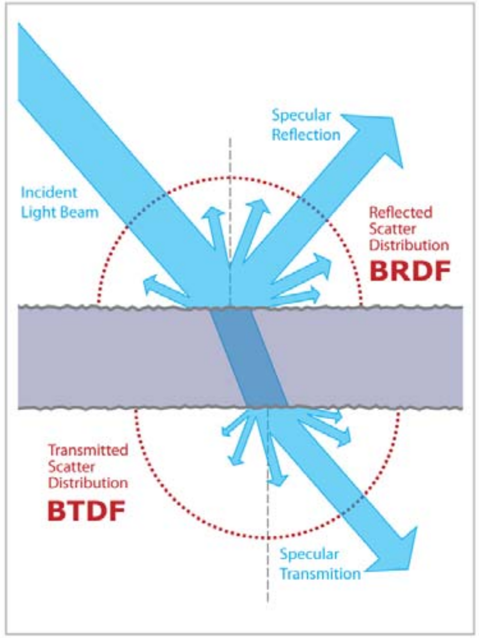
$$0 \leq f_r(x, \Psi \leftrightarrow \Theta) \leq \infty$$

- Energy conservation:

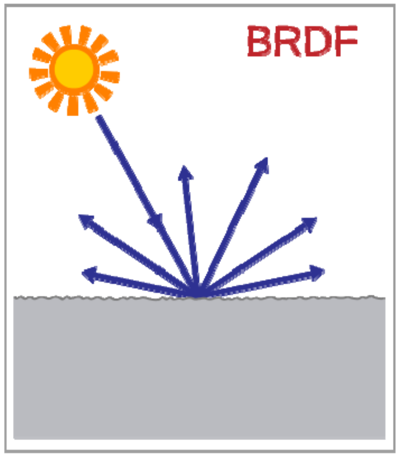
$$\forall \Psi \quad \int_{\Theta} f_r(x, \Psi \leftrightarrow \Theta) \cos(N_x, \Theta) d\omega_{\Theta} \leq 1$$

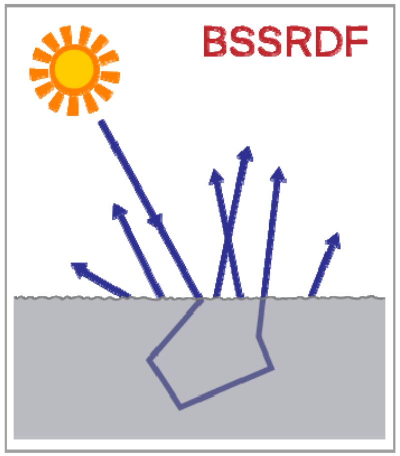
Other Distribution Functions: BxDF

- **BSDF (S: Scattering)**
  - **The general form combining BRDF + BTDF (T: Transmittance)**



- **BSSRDF (SS: Surface Scattering)**
  - **Handle subsurface scattering**





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Homework 1

- **Prove the invariance**
  - **Utilize the energy conservation**

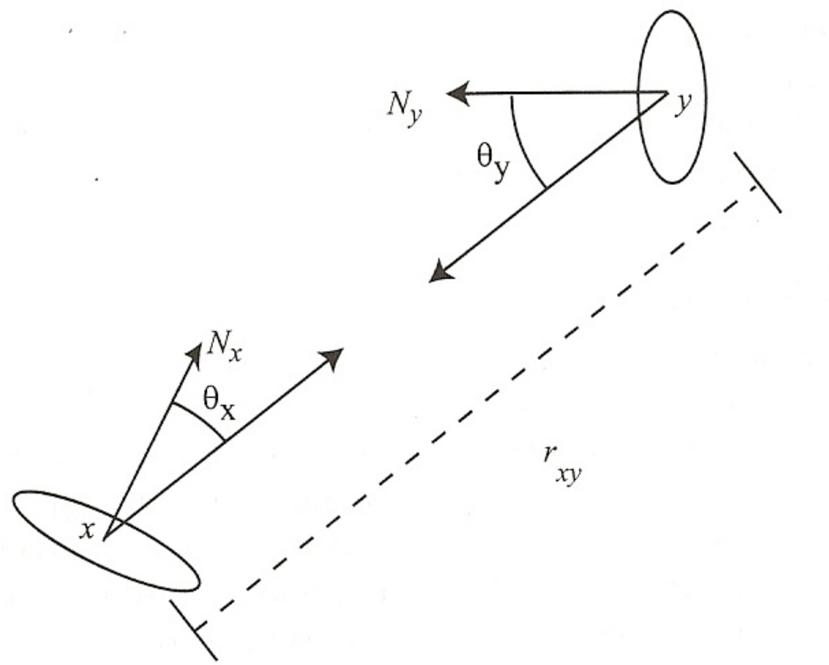

Figure 2.3. Invariance of radiance.

$$L(x \rightarrow y) = L(y \leftarrow x)$$

Class Objectives were:

- Know terms of:
  - Hemispherical coordinates and integration
  - Various radiometric quantities (e.g., radiance)
  - Basic material function, BRDF

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Homework

- **Go over the next lecture slides before the class**
- **Watch 2 SIGGRAPH videos and submit your summaries every Tue. class**
  - **Just one paragraph for each summary**

Example:

Title: XXX XXXX XXXX
Abstract: this video is about accelerating the performance of ray tracing. To achieve its goal, they design a new technique for reordering rays, since by doing so, they can improve the ray coherence and thus improve the overall performance.

Any Questions?

- **Come up with one question on what we have discussed in the class and submit at the end of the class**
  - **1 for already answered questions**
  - **2 for typical questions**
  - **3 for questions with thoughts**

- **Submit questions at least four times before the mid-term exam**
  - **Multiple questions for the class is counted as only a single time**

Next Time

- **Rendering equation**