CS184 LECTURE

RADIOMETRY

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Material HEAVILY adapted from James O'Brien, Brandon Wang, Fu-Chung Huang, and Aayush Dawra

ADMINISTRATIVE STUFF

- Project!

TODAY

- Radiometry (Abridged): Measuring light
  - Local Illumination and Raytracing were discussed in an *ad hoc* fashion
  - Proper discussion requires proper units
  - Not just pretty pictures... but correct pictures

MATCHING REALITY

Unknown

MATCHING REALITY

Cornell Box Comparison. Cornell Porgram of Computer Graphics

UNITS

Energy ($q = hf$)

- Units of Joules (J)

Light Energy ($P = \frac{dq}{dt}$)

- We actually measured power not energy
- Joules/s (J/s) = Watts (W)

Spectral Energy Density ($d\Phi = \frac{dP}{d\lambda}$)

- Intensive quantity (similar to density for mass)
- Power per unit spectrum interval
- Watts / nanometer (W/nm)
- Properly done as a function over spectrum
- Often just sampled for RGB

Often people understand S.E.D. is used and just say E

IRRADIANCE

Total light (remember, spectral energy density) striking a surface from all directions.

- Only meaningful w.r.t. a surface

$$H = \frac{dP}{dA} = \text{Power per squared meter} = \text{W/m}^2$$

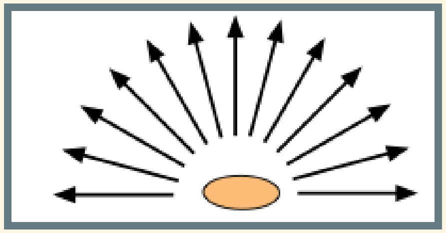
- But really spectral energy density

$$H = \frac{d\Phi}{dA} = \text{S.E.D. per squared meter} = \text{W/m}^2\text{/nm}$$

- Not all directions sum the same due to foreshortening.

RADIANCE EXITANCE

Total light ***leaving*** surface over all directions



- Only meaningful w.r.t. a surface

$$E = \frac{dP}{dA} = \text{Power per squared meter} = \text{W/m}^2$$

- But really spectral energy density

$$E = \frac{d\Phi}{dA} = \text{S.E.D. per squared meter} = \text{W/m}^2\text{/nm}$$

- Also called Radiosity
- Sum over all directions $\not\Rightarrow$ same in all directions

SUMMARY

- Energy
  $q = hf$
- Light Energy (Power)
  $P = \frac{dq}{dt}$
- Spectral Energy Density:
  $d\Phi = \frac{dP}{d\lambda}$
- Irradiance
  $H = \frac{d\Phi}{dA}$
- Radiance Exitance/Radiosity
  $E = \frac{d\Phi}{dA}$

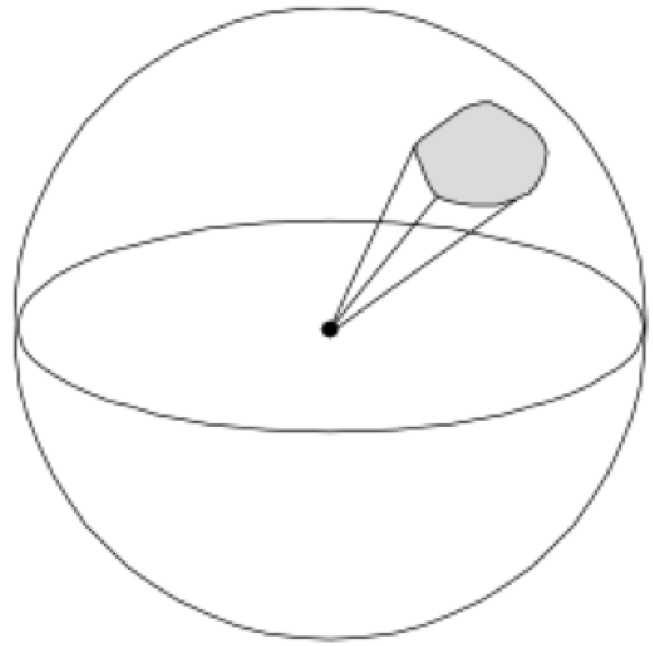
SOLID ANGLES

- Angle $\theta = \frac{l}{r}$

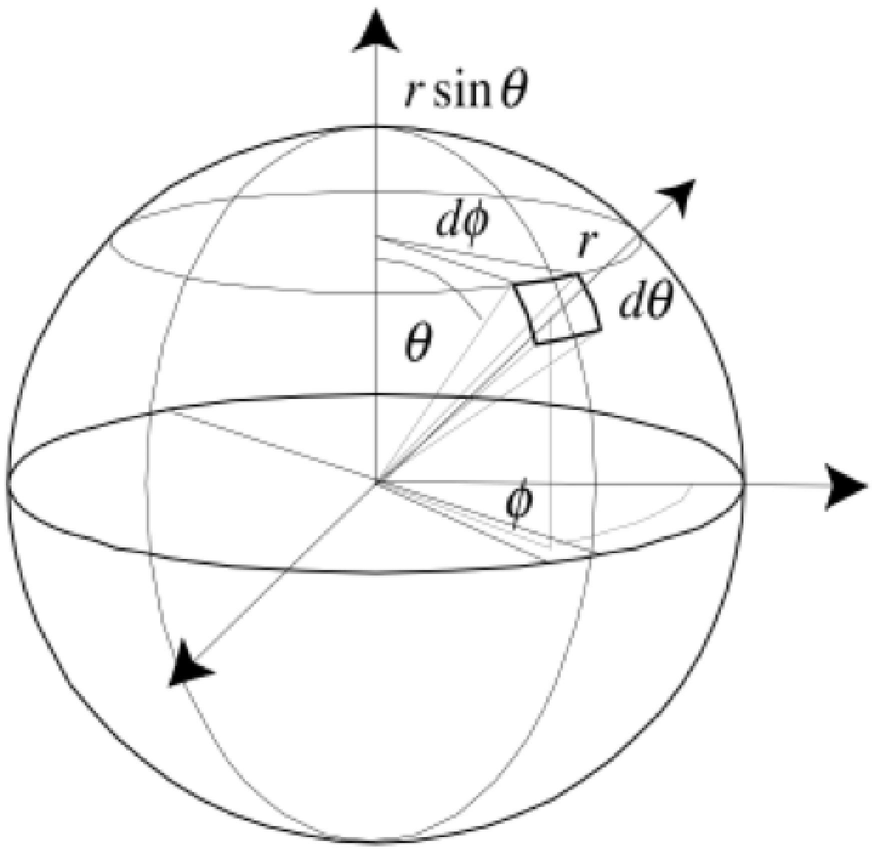
  $\Rightarrow$ circle has 2π radians

- Solid angle $\Omega = \frac{A}{R^2}$

  $\Rightarrow$ sphere has 4π steradians



DIFFERENTIAL SOLID ANGLES

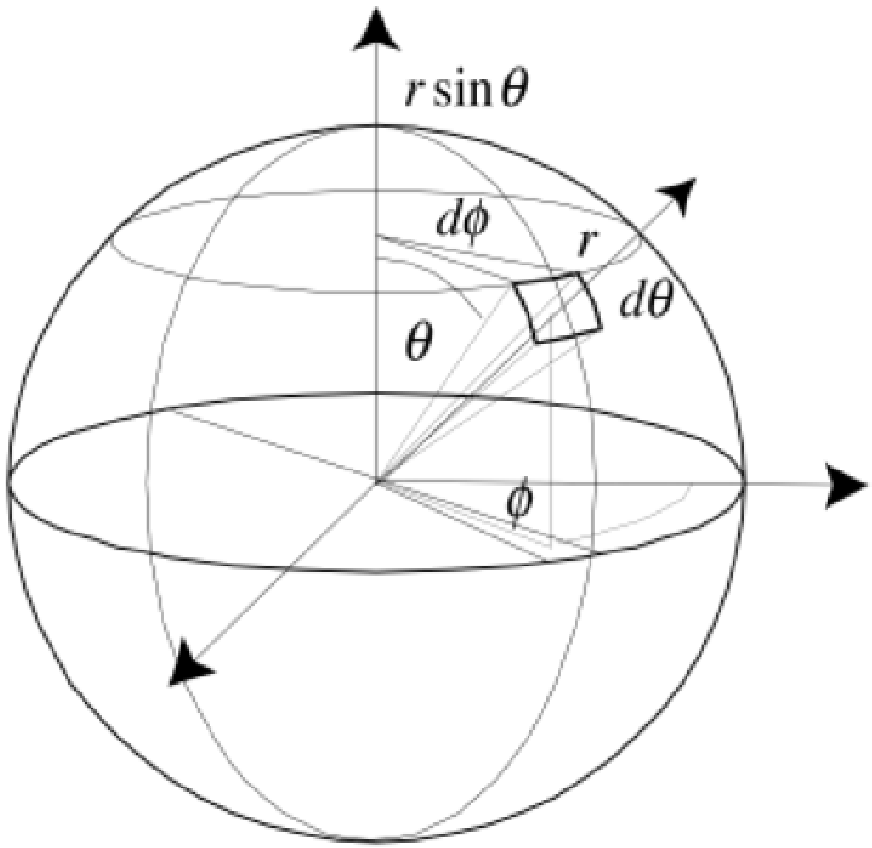


$$dA = (r\,d\theta)(r\sin\theta\,d\phi)$$
$$= r^2 \sin\theta\,d\theta\,d\phi$$

CS348B Lecture 4

Pat Hanrahan, 2009

DIFFERENTIAL SOLID ANGLES

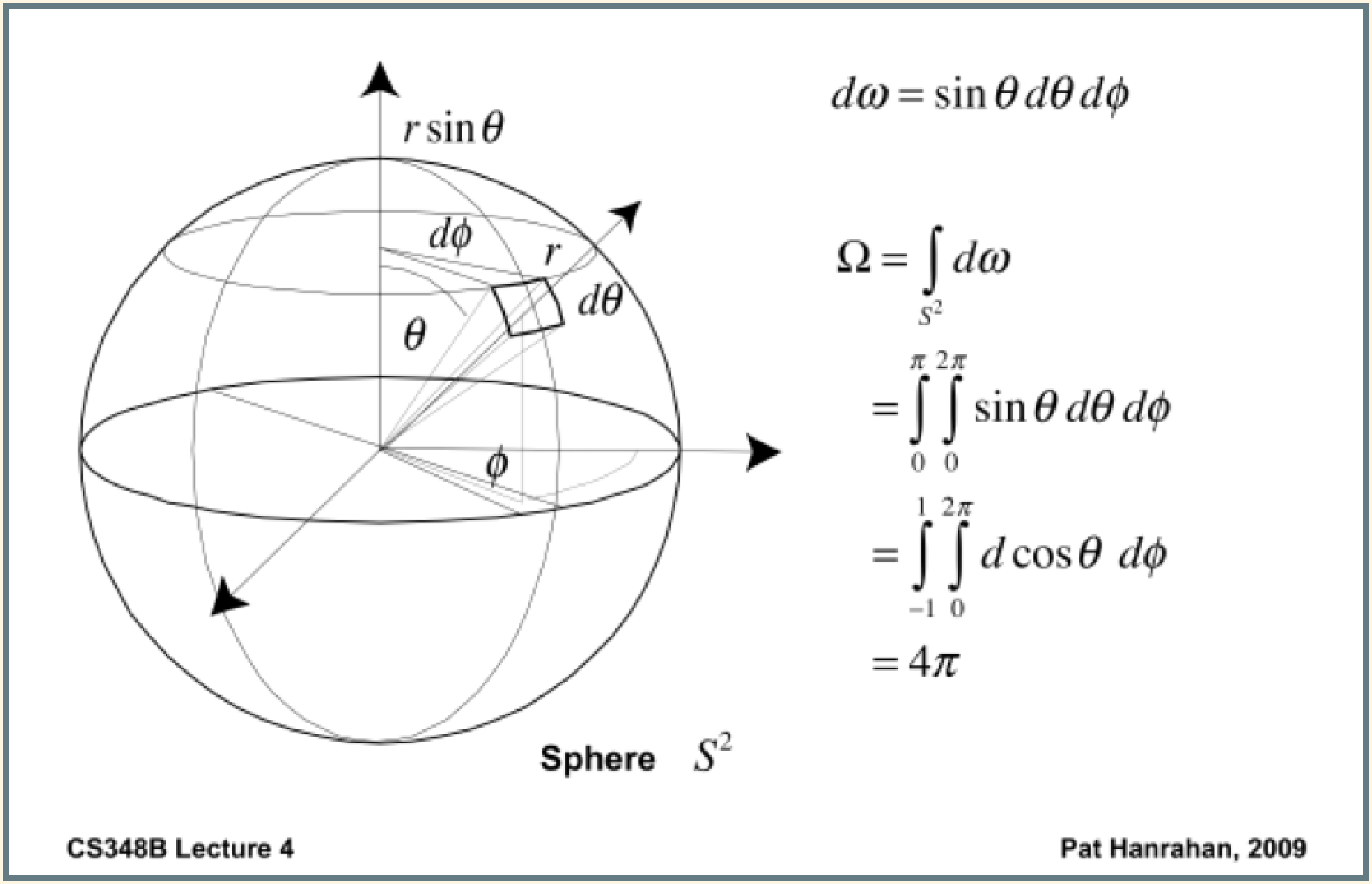


$$dA = (r\,d\theta)(r\sin\theta\,d\phi)$$
$$= r^2 \sin\theta\,d\theta\,d\phi$$

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

CS348B Lecture 4 Pat Hanrahan, 2009

DIFFERENTIAL SOLID ANGLES



A solid angle "subtends" a particular area on a sphere.

- Just like for angles in 2D, given a particular axis, defines a

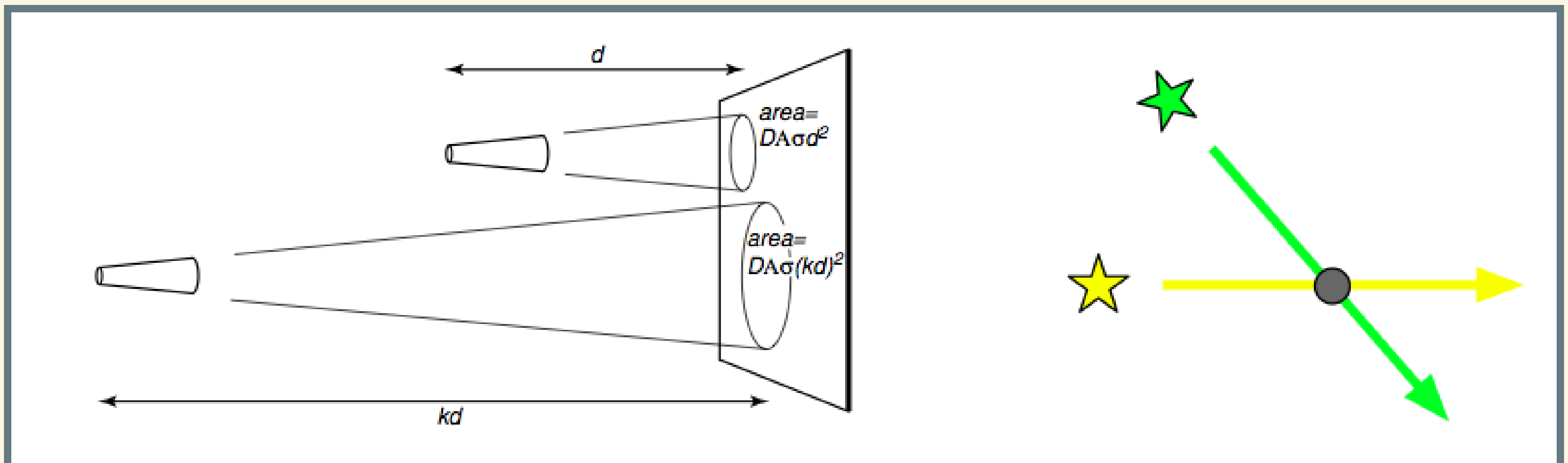
RADIANCE

Light energy passing though a point in space within a given solid angle

- Energy per steradian per square meter $(\mathrm{W/m^2/sr})$
- S.E.D. per steradian per square meter $(\mathrm{W/m^2/sr/nm})$

Constant along straight lines in free space

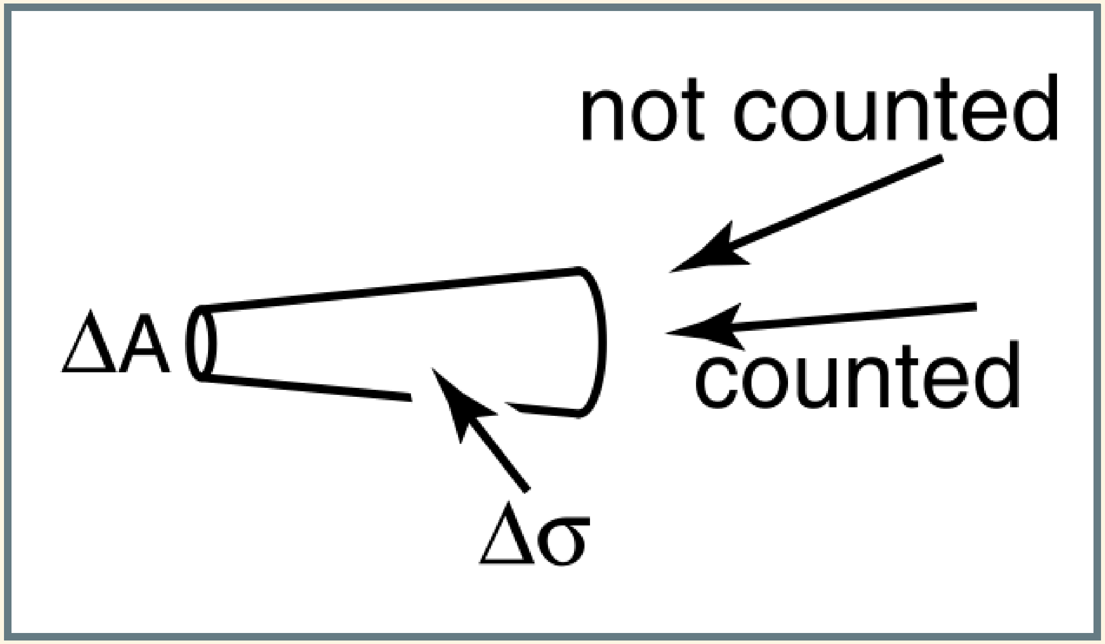
- Area of surface being sampled is proportional to distance and light inversely proportional to squared distance.



RADIANCE

Think of it as irradiance or radiosity from a specific direction (quantified by steradians.

Suppose a measuring device for this looks like:

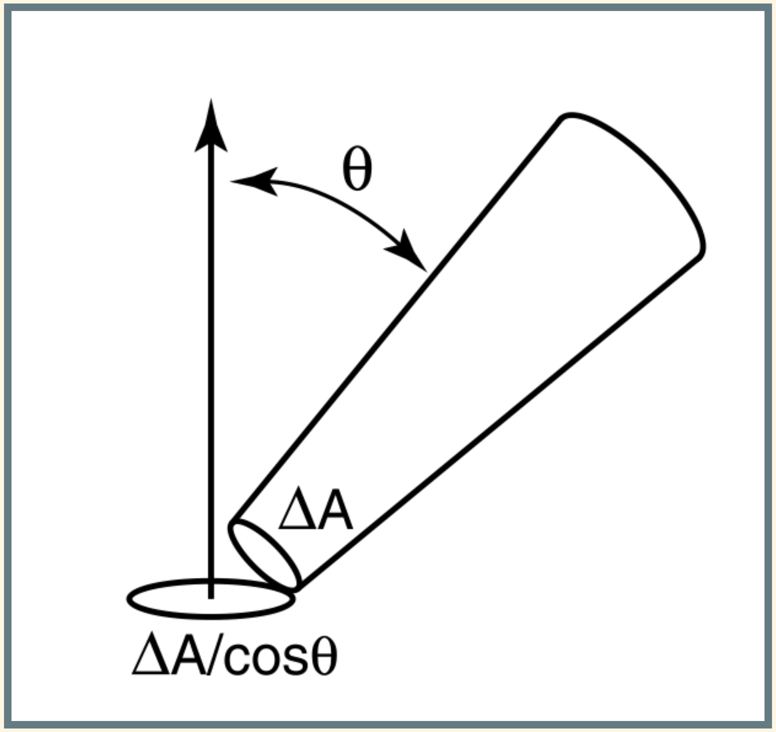


The measured radiance =

$$\frac{dH}{d\sigma} = \frac{dq}{\Delta A d\sigma dt d\lambda} = \frac{Energy}{Area \cdot Direction \cdot Time \cdot Wavelength}$$

RADIANCE

Now suppose our cone device is tilted so the area we're measuring is not flat!



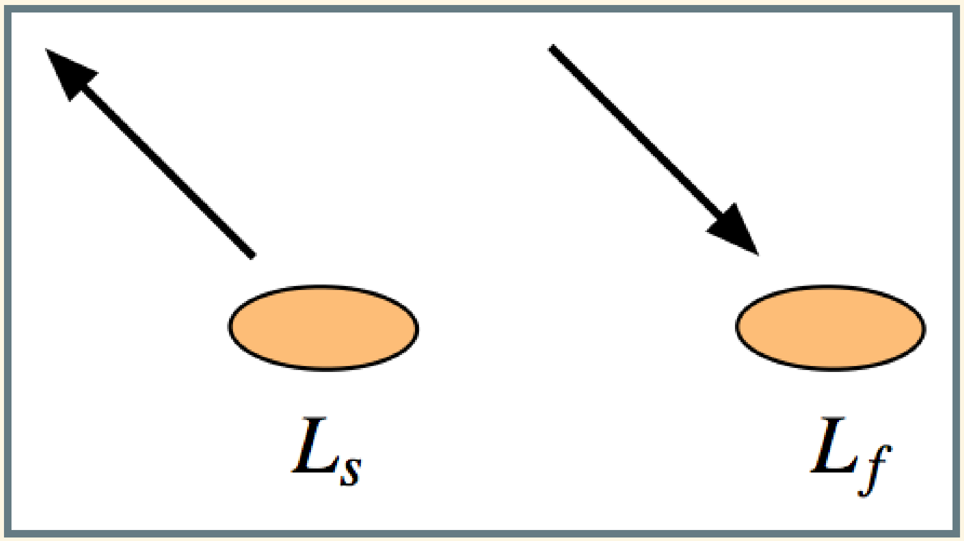
The measured radiance =

$$\frac{dH}{d\sigma} = \frac{dq}{\Delta A d\sigma dt d\lambda} = \frac{dq}{dA\cos(\theta) d\sigma dt d\lambda} = \frac{dH}{d\sigma\cos(\theta)}$$

RADIANCE

Near surfaces, differentiate between

- Radiance from the surface (surface radiance)
- Radiance from other things (field radiance)



LIGHT FIELDS

Radiance at every point in space, direction, and frequency: 6D function

Collapse frequency to RGB, and assume free space: 4D function

Sample and record it over some volume

LIGHT FIELDS

LIGHT FIELDS

Levoy and Hanrahan, SIGGRAPH 1996

LIGHT FIELDS

Michelangelo's Statue of Night. From the Digital Michelangelo Project

COMPUTING IRRADIANCE

Given a field radiance defined as:

$$L_f(\vec{k}) = \frac{\Delta H}{\Delta \sigma \cos(\theta)}$$

We can derive irradiance by integrating field radiance over all directions:

$$H = \int_{\Omega} L_f(\vec{k}) \cos(\theta) d\sigma$$

$$H = \int_0^{2\pi} \int_0^{\pi/2} L_f(\theta, \phi) \cos(\theta) \sin(\phi) d\theta d\phi$$

You can derive all other radiometric quantities from radiance! This is why it's considered the fundamental quantity.

REVISITING THE BRDF

How much light from direction k_i goes out direction k_o.

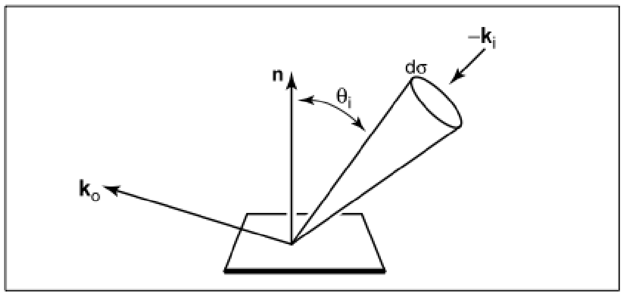
Earlier, our phong shading model approximated this quantity.

REVISITING THE BRDF

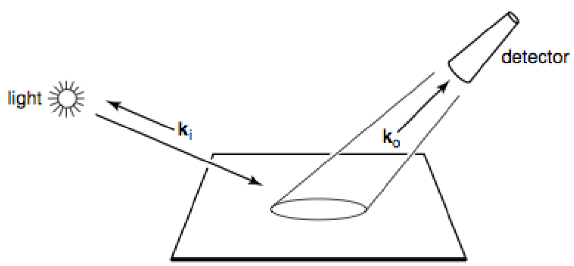
How much light from direction k_i goes out in direction k_o

Now we can talk about units:

- BRDF is ratio of surface radiance to the foreshortened field radiance



$$\rho(\mathbf{k}_i, \mathbf{k}_o) = \frac{L_s(\mathbf{k}_o)}{L_f(\mathbf{k}_i)\cos(\theta_i)}$$



We left out frequency dependance here...

Also note for perfect Lambertian reflector with constant BRDF $\rho = 1/\pi$

Note it would be more appropriate to define BRDF as:

$$\rho(k_i, k_o) = \frac{dL_s(k_o)}{L_f(k_i)\cos(\theta_i)d\sigma_i}$$

THE RENDERING EQUATION (TRANSPORT EQUATION)

Total light going out in some direction is given by an integral over all incoming directions:

$$\rho(k_i, k_o) = \frac{dL_s(k_o)}{L_f(k_i)\cos(\theta_i)d\sigma_i}$$

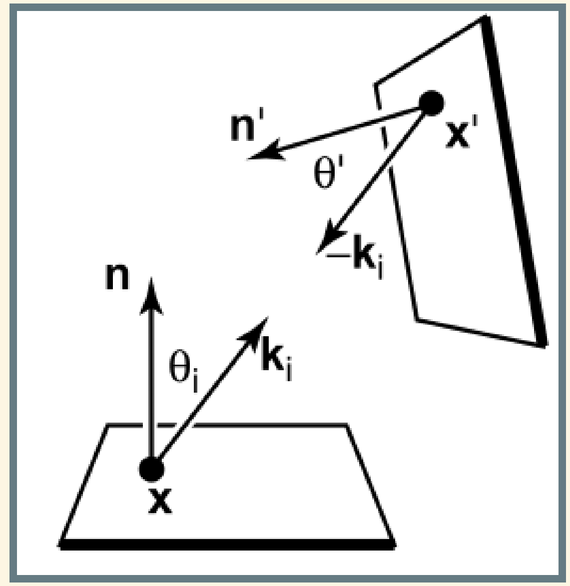
$$dL_s(k_o) = \rho(k_i, k_o)L_f(k_i)\cos(\theta_i)d\sigma_i$$

$$L_s(k_o) = \int_\Omega \rho(k_i, k_o)L_f(k_i)\cos(\theta_i)d\sigma_i$$

- Note this is recursive, L_f is another object's L_s

THE RENDERING EQUATION

$$L_s(k_o) = \int_\Omega \rho(k_i, k_o) L_f(k_i) \cos(\theta_i) d\sigma_i$$



Now, let's rewrite in terms of surface radiances **ONLY**

$$dA' \cos(\theta) = d\sigma \|\vec{x} - \vec{x}'\|^2$$

$$d\sigma = \frac{dA' \cos(\theta')}{\|\vec{x} - \vec{x}'\|^2}$$

Light Paths

Many paths from light to eye

Characterize by the types of bounces

- Begin at light
- End at eye
- “Specular” bounces
- “Diffuse” bounces

Light Paths

Describe paths using strings

- LDE, LDSE, LSE, ***etc.***

Describe types of paths with regular expressions

- L{D|S}*E ← Visible paths
- L{D|S}S*E ← Standard raytracing
- L{D|S}E ← Local illumination
- LD*E ← Radiosity method (have not talked about yet)

PROJECT SUMMARY

PROJECT SUMMARY

You're given a file with a bunch of patches

```
2
 0.00  0.00  0.00   0.33  0.00  0.00   0.66  0.00  0.00   1.00  0.00  0.00
 0.00  0.33  0.00   0.33  0.33  0.00   0.66  0.33  0.00   1.00  0.33  0.00
 0.00  0.66  0.00   0.33  0.66  0.00   0.66  0.66  0.00   1.00  0.66  0.00
 0.00  1.00  0.00   0.33  1.00  0.00   0.66  1.00  0.00   1.00  1.00  0.00

 0.00  0.00  0.00   0.33  0.00  2.00   0.66  0.00  2.00   1.00  0.00  0.00
 0.00  0.33  0.00   0.33  0.33  2.00   0.66  0.33  2.00   1.00  0.33  0.00
 0.00  0.66  0.00   0.33  0.66  2.00   0.66  0.66  2.00   1.00  0.66  0.00
 0.00  1.00  0.00   0.33  1.00  2.00   0.66  1.00  2.00   1.00  1.00  0.00
```

PROJECT SUMMARY

You render it via OpenGL