CS-184: Computer Graphics

Lecture #15: Radiometry

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Today

- Radiometry: 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

Photo

Rendered

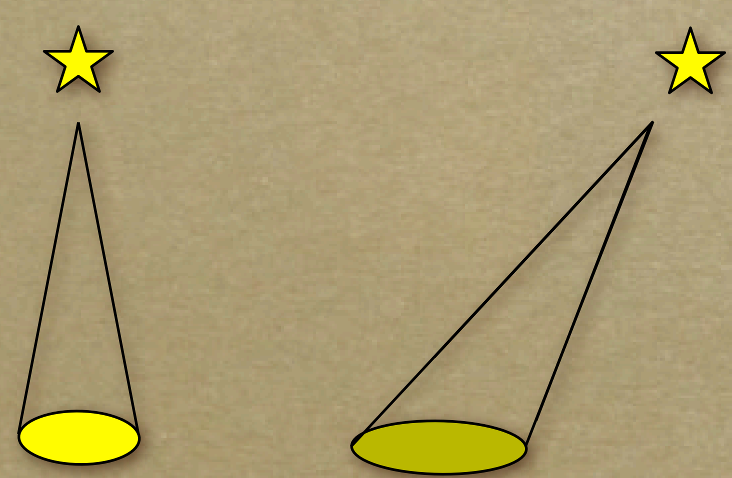
Cornell Box Comparison
Cornell Program of Computer Graphics

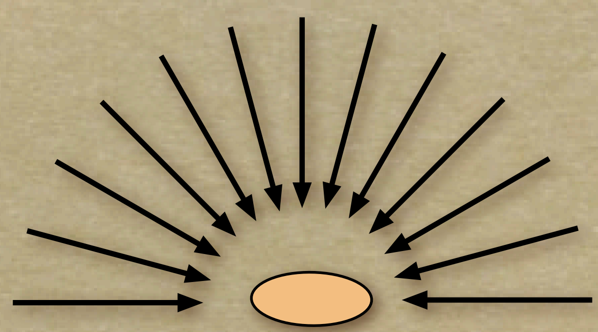
Units

- Light energy
  - Really power not energy is what we measure
  - Joules / second (J/s) = Watts (W)
- Spectral energy density
  - power per unit spectrum interval
  - Watts / nano-meter (W/nm)
  - Properly done as function over spectrum
  - Often just sampled for RGB
- Often we assume people know we're talking about S.E.D. and just say E...

Irradiance

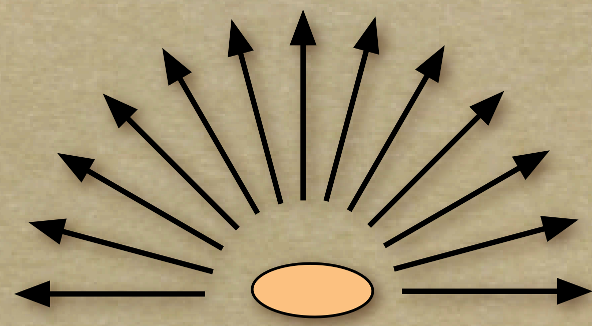
- Total light striking surface from all directions
  - Only meaningful w.r.t. a surface
  - Power per square meter ($\mathrm{W/m^2}$)
  - Really S.E.D. per square meter ($\mathrm{W/m^2/nm}$)
  - Not all directions sum the same because of foreshortening





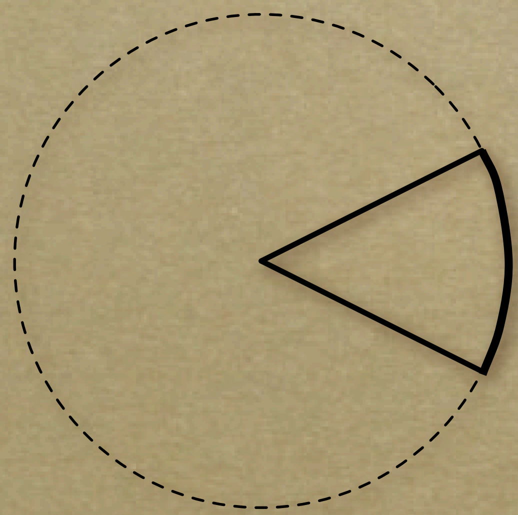
Radiant Exitance

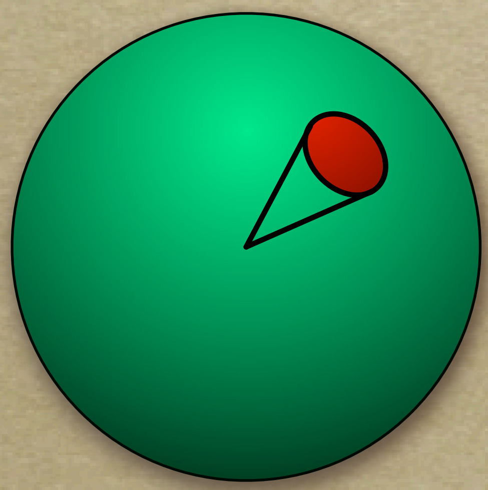
- Total light *leaving* surface over all directions
  - Only meaningful w.r.t. a surface
  - Power per square meter ($\mathrm{W/m^2}$)
  - Really S.E.D. per square meter ($\mathrm{W/m^2/nm}$)
  - Also called Radiosity
  - Sum over all directions $\nRightarrow$ same in all directions



Solid Angles

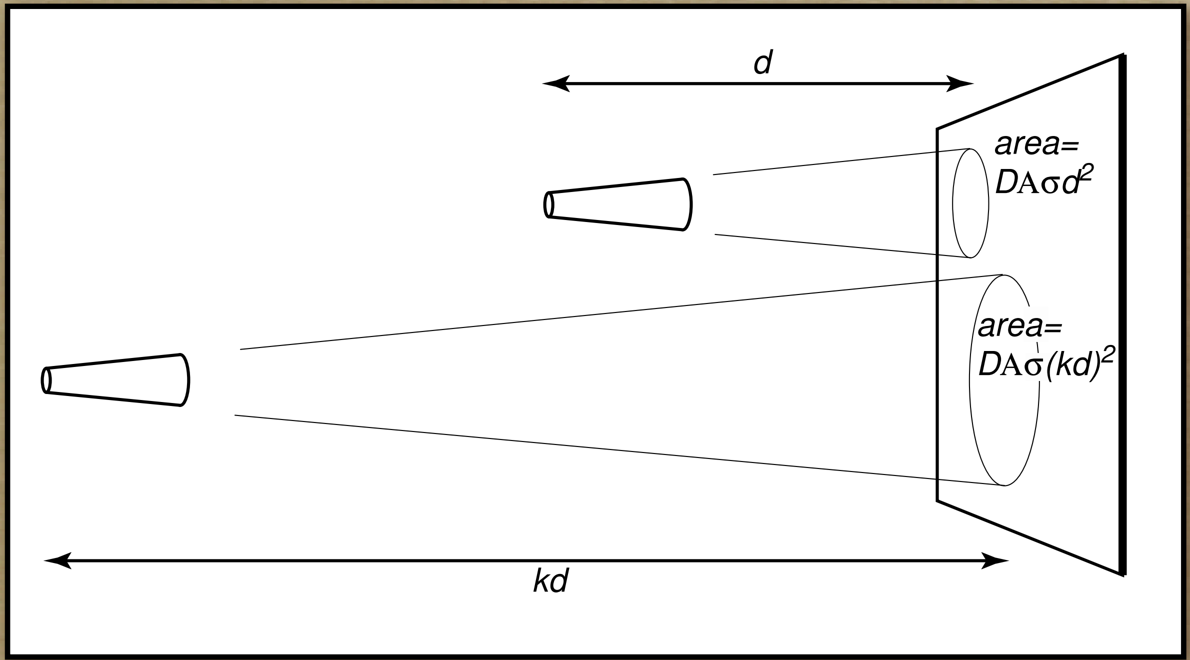
- Regular angles measured in *radians*
  - Measured by arc-length on unit circle $[0..2\pi]$
- Solid angles measured in *steradians*
  - Measured by area on unit sphere $[0..4\pi]$
  - Not necessarily little round pieces...

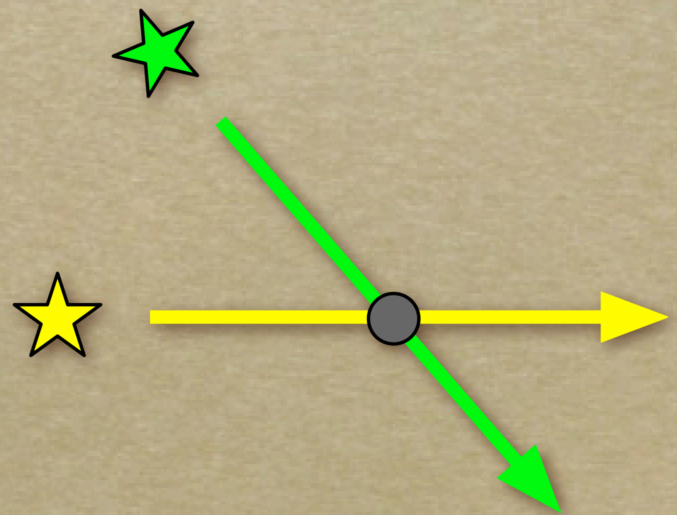




Radiance

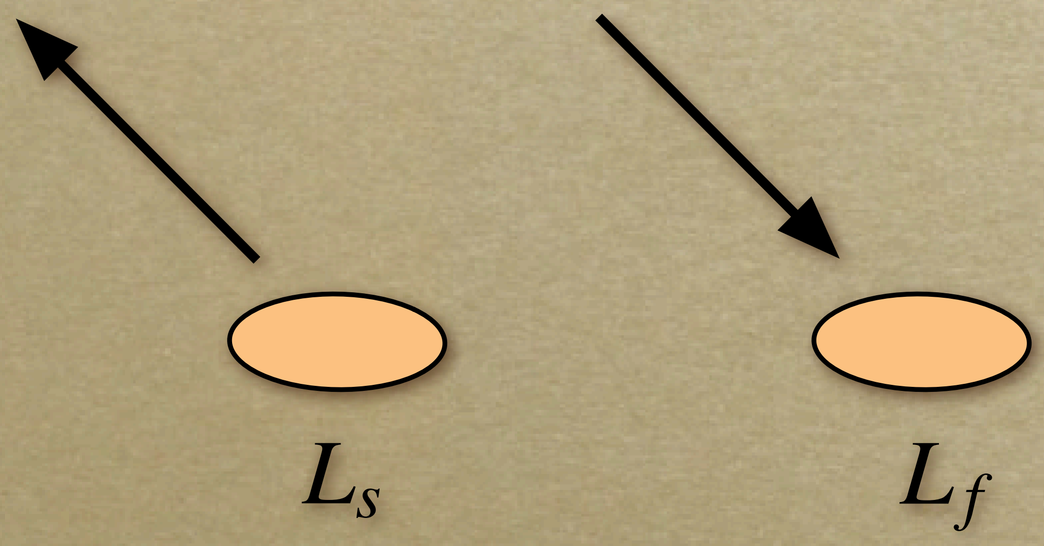
- Light energy passing though a point in space in a given direction
  - Energy per steradian per square meter ($W/m^2/sr$)
  - S.E.D. per steradian per square meter ($W/m^2/sr/nm$)
- Constant along straight lines in free space





Radiance

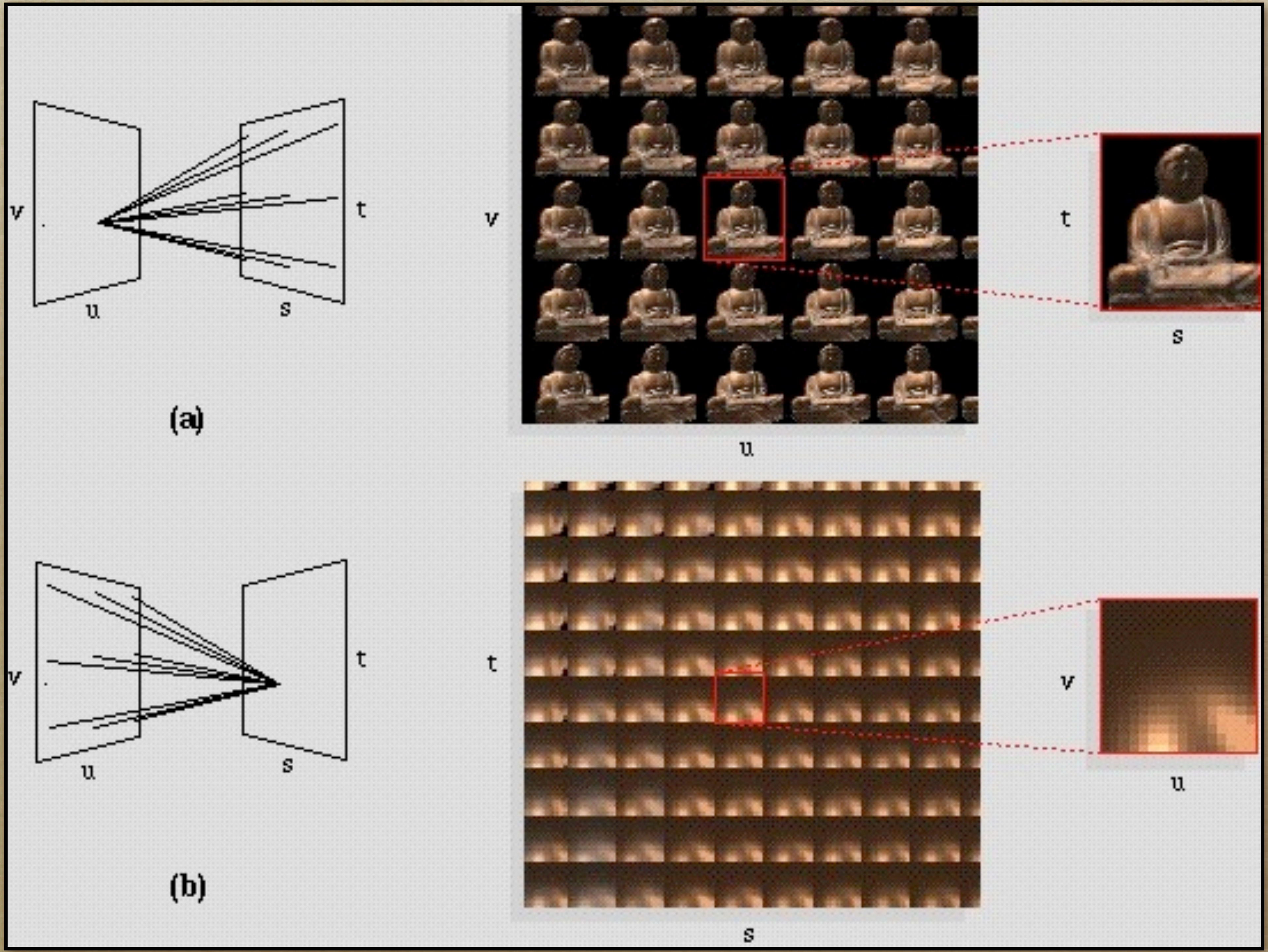
- Near surfaces, differentiate between
  - Radiance from the surface (surface radiance)
  - Radiance from other things (field radiance)



Light Fields

- The 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

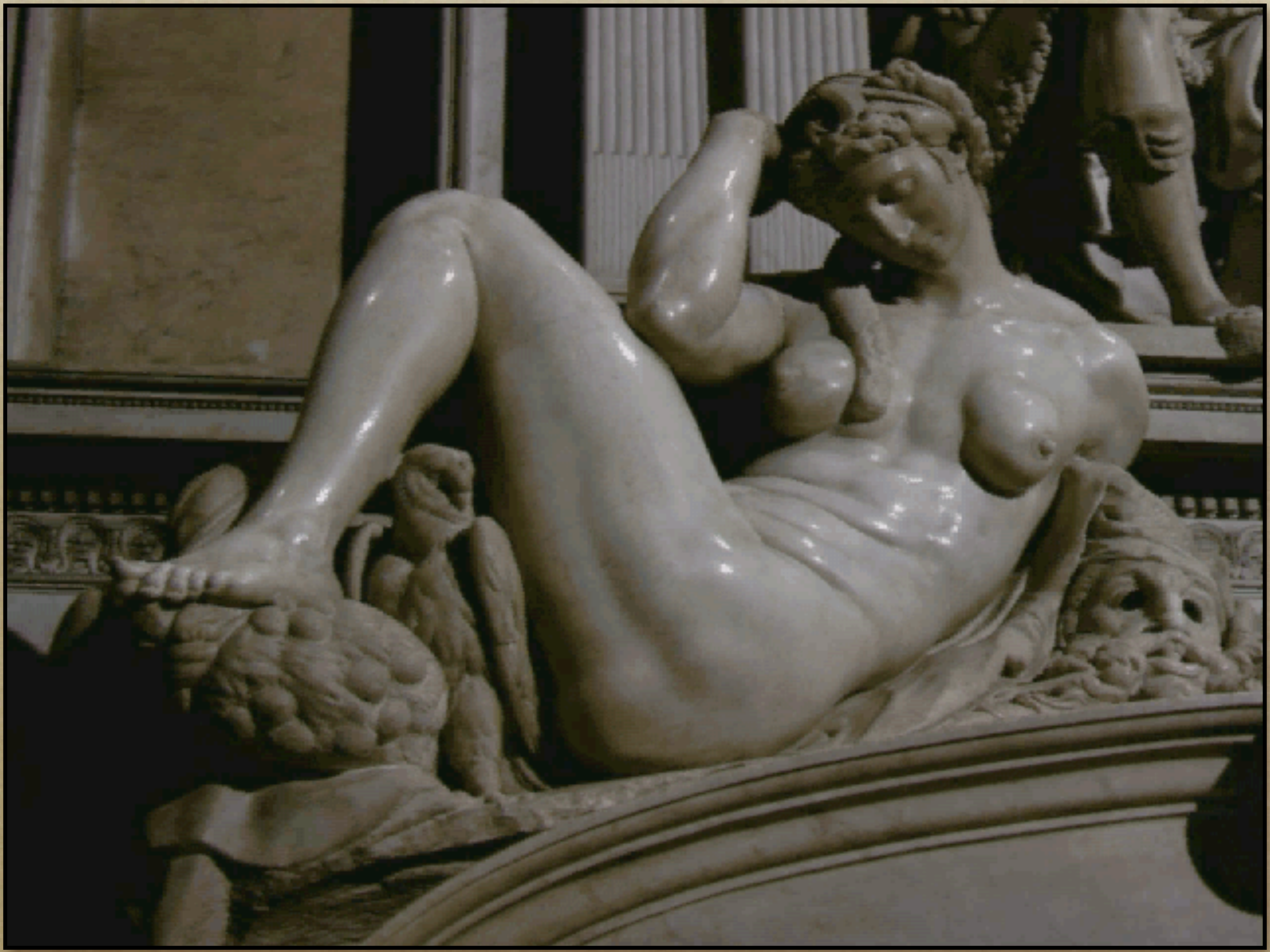


Levoy and Hanrahan, SIGGRAPH 1996

Light Fields

Levoy and Hanrahan, SIGGRAPH 1996

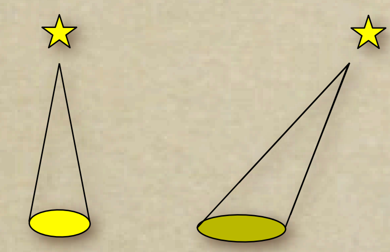
Light Fields



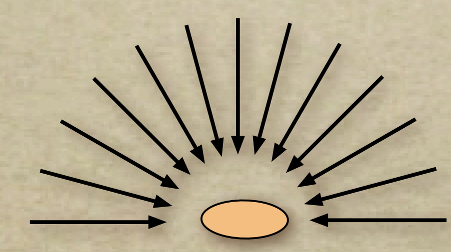
Michelangelo's *Statue of Night*
From the Digital Michelangelo Project

Computing Irradiance

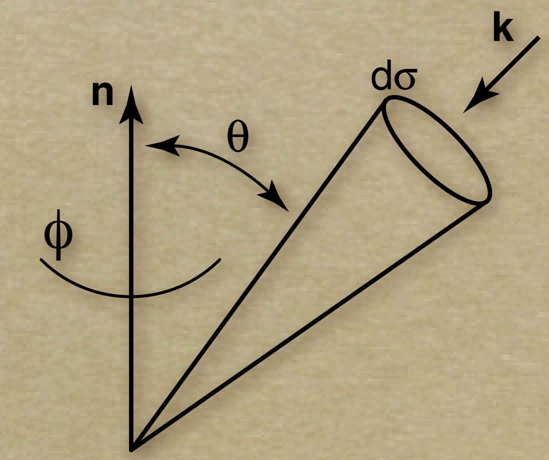
- Integrate incoming radiance (field radiance) over all direction
  - Take into account foreshortening



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



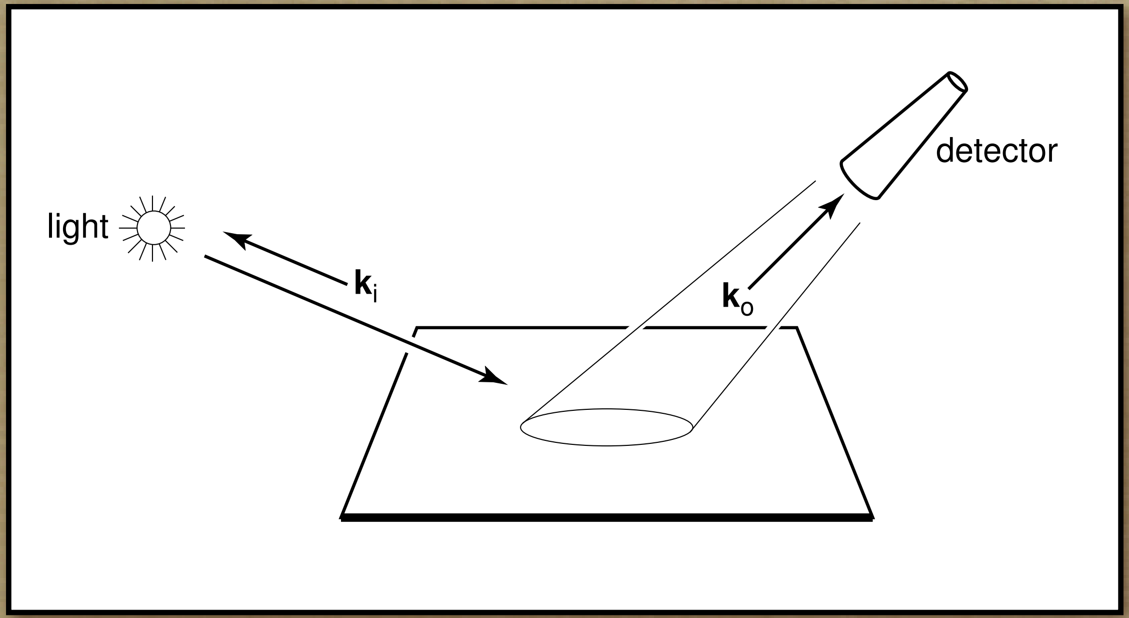
$$H = \int_0^{2\pi} \int_0^{\pi/2} L_f(\theta, \phi) \cos(\theta) \sin(\theta) \, d\theta \, d\phi$$



Revisiting The BRDF

- How much light from direction A goes out in direction B
- Now we can talk about units:
  - BRDF is ratio of foreshortened field radiance to surface radiance

$$\rho(\theta_i, \theta_o) = \frac{L_s(\theta_o)}{L_f(\theta_i)\cos(\angle \hat{\mathbf{n}}\theta)}$$



We left out frequency dependance here...

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

The Rendering Equation

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

$$L_s(\mathbf{k}_o) = \int_\Omega \rho(\mathbf{k}_o, \mathbf{k}_i) L_f(\mathbf{k}_i) \cos(\theta) d\sigma$$

  - Note, this is recursive (my L_f is another's L_s)

The Rendering Equation

- We can rewrite explicitly in terms of L_s

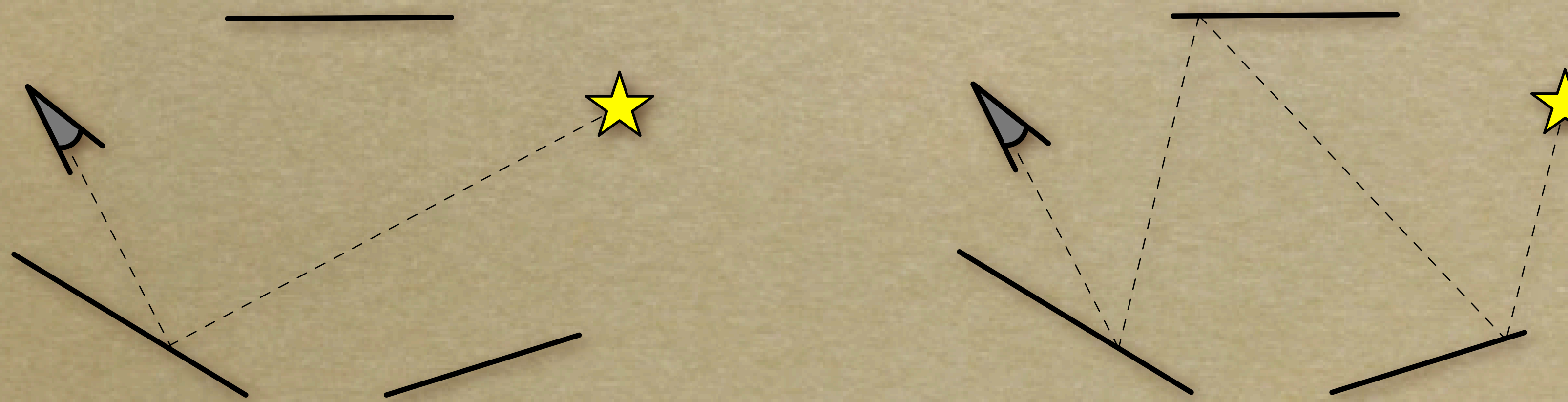
$$L_s(\mathbf{k}_o) = \int_\Omega \rho(\mathbf{k}_o, \mathbf{k}_i) L_f(\mathbf{k}_i) \cos(\theta_i) d\sigma$$

$$L_s(\mathbf{k}_o, \mathbf{x}) = \int_S \frac{\rho(\mathbf{k}_o, \mathbf{k}_i) L_s(\mathbf{x} - \mathbf{x}', \mathbf{x}') \cos(\theta_i) \cos(\angle \hat{\mathbf{n}}'(\mathbf{x} - \mathbf{x}')) \delta(\mathbf{x}, \mathbf{x}')}{||\mathbf{x} - \mathbf{x}'||^2} d\mathbf{x}'$$

Consider what ray tracing was doing....

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)