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
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 (W/m²)
  - Really S.E.D. per square meter (W/m²/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 (W/m²)
  - Really S.E.D. per square meter (W/m²/nm)
  - Also called Radiosity
  - Sum over all directions ⇒ same in all directions

Solid Angles

- Regular angles measured in *radians*
  - Measured by arc-length on unit circle [0..2π]
- Solid angles measured in *steradians*
  - Measured by area on unit sphere [0..4π]
  - 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/m² /sr)
  - S.E.D. per steradian per square meter (W/m² /sr /nm)
- Constant along straight lines in free space

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

Michelangelo's Statue of Night
From the Digital Michelangelo Project
Computing Irradiance

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

\[
H = \int_{\Omega} L_f(k) \cos(\theta) d\sigma
\]

\[
H = \int_{0}^{2\pi} \int_{0}^{\pi/2} L_f(\theta, \phi) \cos(\theta) \sin(\theta) d\theta d\phi
\]

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

\[
\rho(\theta_i, \theta_o) = \frac{L_s(\theta_o)}{L_f(\theta_i) \cos(\theta_o)}
\]

We left out frequency dependence 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:

\[ L_s(k_o) = \int_{\Omega} \rho(k_o, k_i) L_f(k_i) \cos(\theta) \, d\sigma \]

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

The Rendering Equation

- We can rewrite explicitly in terms of \( L_s \)

\[ L_s(k_o) = \int_{\Omega} \rho(k_o, k_i) L_f(k_i) \cos(\theta) \, d\sigma \]

\[ L_s(k_o, x) = \int_{S} \rho(k_o, k_i) L_s(x - x', x') \cos(\theta_i \cos(\hat{n}'(x - x')) \delta(x, x') \, d\sigma \]

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