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
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 ($W/m^2$)
  - Really S.E.D. per square meter ($W/m^2/nm$)
- 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 (W/m²)
  - Really S.E.D. per square meter (W/m²/nm)
  - Also called Radiosity
  - Sum over all directions $\Rightarrow$ 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

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

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

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

We left out frequency dependance here...

Also note for perfect Lambertian reflector with constant BRDF

\[ \rho = \frac{1}{\pi} \]
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 $\mathbf{L}_s$

\[
L_s(k_0) = \int_\Omega \rho(k_0, k_i) L_f(k_i) \cos(\theta_i) d\sigma
\]

\[
L_s(k_o, x) = \int_S \frac{\rho(k_o, k_i) L_s(x - x', x') \cos(\theta_i) \cos(\hat{n}'(x - x')) \delta(x, x')}{||x - x'||^2} dx'
\]

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)