The Perfectly Diffuse Assumption

- Standard radiosity assumes perfectly diffuse surfaces:
  - We can use radiosity instead of radiance
  - No directional energy concern
    - Doesn't matter where the energy comes from
    - Doesn't matter which direction it leaves in
- Specularities are missing:
  - No mirrors (ideal specular)
  - No highlights (directional diffuse)

Adding Specular Transfer

- Several approaches:
  - Discretize position and direction on each surface, and solve for *(x,Θ)* couples
  - Ray tracing variants (next week)
  - Simple 2-pass approaches
  - More complete 2-pass approaches

Discretizing Radiance

- Each patch stores *directional radiance* arriving from a number of discrete directions, Θ_j
  - Use a *global cube* to store values
  - A global cube is like a hemicube, but radiance values are stored at the "pixels"
- New transfer equation:

$$\forall k,l \quad L_{kl} = L_e(x_k,\Theta_l) + \sum_j \rho_{bd}(x_k,\Theta_l,-\Theta_j) L_{v(j)j} \int_{\Theta\in-\Omega_j} \cos\theta dw$$

Solving for Directional Radiance

- Use a progressive refinement algorithm
- The shooting patch, for each out direction:
  - Looks up the visible patch
  - Sums the incoming radiance, multiplied by the BRDF
  - Shoots the result to the visible patch
- Generate image using directional information providing by ray tracing

Problems with Directional Radiance

- Massive amount of data for reasonable results
- Aliases and fails to capture, or blurs, tight highlights
- Long computation times
- Solution: View dependent approaches

Two Pass Approaches

- Specularities are often highly localized in terms of both position and viewing angle
  - Few are likely to be important for any given view
- Directional radiance computes all directions, regardless of their importance
- Two pass approaches compute the non-directional component in one pass, and the strongly directional component in a second pass

Simple Two-Pass Approaches

- Radiosity first pass with ray traced second pass
  - Radiosity captures diffuse interactions
  - Ray tracing captures mirror effects and specularities due directly to sources
  - What does it get wrong?
- Radiosity first pass with Phong second pass
  - Cheap, incorrect, but can look good

Complete Two-Pass Method

- Works for ideal specularities
- First pass computes specular paths between emitters and other patches
  - Extend form factors
- Second pass computes specular paths from the eye to patches
  - Ray trace from eye into scene

Extended Form Factors

- Define the *extended form factor,* F_{ij}^{ext} to be the proportion of the total power leaving patch P_i that reaches patch P_j after any number of specular bounces
- Replace form factors in regular radiosity equation with extended form factors
- All specular bounces between emitters and receivers will be taken into account (correctly)

Computing Extended Form Factors

- Standard methods can be used to render mirror effects with a hemicube and z-buffer
  - Treat mirrors as windows into reflected world
  - Multi-pass method (can also do refraction)
- Ray tracing for form factors can be trivially extended
- Must take into account specular reflection coefficients

Second Pass

- Must account for specular reflectors seen by the eye
- Ray tracing, or multi-pass z-buffer
- For correct results, should match method used for extended form factor, so that the effects captured are consistent

Directional Diffuse BRDF

- Reflectance has a smooth variation with angle. Most real surfaces are like this.
- Use a smooth, compact representation for radiance at each patch
  - Spherical harmonics
- Take distribution into account when gathering or shooting
- Still use second pass for ideal specular effects

Participating Media

- We assumed that we were operating in a near-vacuum
  - Radiosity was not attenuated along lines
  - Radiosity was only calculated at surfaces
- Participating media (fog, smoke, clouds) are frequently important

Volumetric Effects

- Emission
  - Energy generated by the volume (flame, sun)
- Absorption
  - Energy lost to the volume
- Out-scattering
  - Energy scattered out of a volume
- In-scattering
  - Energy scattered into a volume from the neighborhood

Functions Describing a Volume

- Absorption coefficient, κ_a
  - Amount of energy absorbed per unit length
- Scattering coefficient, κ_s
  - Amount of energy scattered per unit length
- Emitted radiance, L_e
- Phase function, $f(\Theta)$
  - Function describing how much energy comes from direction Θ into another other direction

General Transfer Equation

$$\frac{dL}{ds} = -\kappa_t L + \kappa_a L_e + \kappa_s \int_\Omega L_i(\Theta) f(\Theta) d\omega$$

- With $\kappa_t = \kappa_a + \kappa_s$, *extinction coefficient*
- Describes how radiance changes along a line
- Once again, not easy to handle in its full form

Transmittance

- τ: the fraction of energy that goes straight through:

$$\frac{dL}{ds} = -\kappa_t L$$

$$L(s) = L(0) e^{-\int_0^s \kappa_t(u) du}$$

$$\tau(s) = e^{-\int_0^s \kappa_t(u) du}$$

No Scattering

$$\frac{dL}{ds} = -\kappa_a L + \kappa_a L_e$$

$$L(s) = L(0)\tau(s) + \int_0^s L_e(s)\tau(s-u)\kappa_a(u) du$$

- Can use with ray tracing
- Constant absorption and emittance (fog models):

$$L(s) = L(0)e^{-\kappa_a s} + L_e(1 - e^{-\kappa_a s})$$

Two-Pass Method

- Assume isotropic medium (scatters equally in all directions)
- Break volume into chunks
- Compute incoming radiance for all chunks and surfaces
- Render in a raytracing pass, accumulating contribution along each ray from the eye

Zonal Method Equations

For surfaces:

$$B_i A_i = E_i A_i + \rho_i \left(\sum_{j \in S} \overline{S_i S_j} B_j + \sum_{k \in V} \overline{V_k S_i} B_k \right)$$

For volumes:

$$4\kappa_t(k) B_k V_k = 4\kappa_a(k) E_k V_k + R_k \left(\sum_{j \in S} \overline{S_j V_k} B_j + \sum_{m \in V} \overline{V_m V_k} B_m \right)$$

- Need *exchange factors* (generalized from factors): Fraction of energy leaving one surface/volume that arrives at another surface/volume