Lighting affects appearance
Light emits photons
Photons travel in a straight line
When they hit an object they:
• bounce off in a new direction
• or are absorbed
• (exceptions later).

Source emits photons
And then some reach the eye/camera.
Reflectance

- Model how objects reflect light.
- Model light sources
- Algorithms for computing
  - Shading: computing intensities within polygons
  - Determine what light strikes what surfaces.

Basic fact: Light is linear

- Double intensity of sources, double photons reaching eye.
- Turn on two lights, and photons reaching eye are same as sum of number when each light is on separately.
- This means we can render lights separately
Light Model: Point Source

- Light emanates from a point
- Equal intensity in all directions

- Intensity drops off with distance.
  - With square of distance: \( \frac{1}{d^2} \)
  - To simulate effects of non-point sources: \( \frac{1}{a_0 + a_1d + a_2d^2} \)
Light model: distant point source

• All light in scene comes from same direction.
• With same intensity

Surfaces reflect light: Lambertian

• Amount of light striking surface proportional to $\cos \theta$
  • Angle between light direction and surface.
• Equal brightness in all directions
• Albedo is fraction of light reflected.
• Diffuse objects (chalk, cloth, matte paint).
• Brightness doesn’t depend on viewpoint.
Lambertian + Point Source

\[ \hat{\mathbf{i}} = \mathbf{l} \cdot \hat{n} \]

- \(\hat{\mathbf{i}}\) is direction of light
- \(\mathbf{l}\) is intensity of light

\[ i = \max(0, \lambda(\hat{\mathbf{i}} \cdot \hat{n})) \]

- \(i\) is radiance
- \(\lambda\) is albedo
- \(\hat{n}\) is surface normal

Lambertian Examples

Scene

(Oren and Nayar)

Lambertian sphere as the light moves.

(Steve Seitz)
Ambient

- Assume Lambertian surface normal receives equal light from all directions.
  
  \[ i = a\lambda \]

- Diffuse lighting, no cast shadows.
- Ambient (and point) light can be colored

Ambient + Point Source

- Needed to avoid artifacts
  - Make sure shadows aren’t black.
- Reasonable approximation to general
  - Sun + sky.
  - Lamp + light reflected by walls
  - In fact, it’s a 1st order approximation.
- But doesn’t handle many effects
  - Sources of other shapes.
  - Shadows of ambient light in concave objects.
Shadow example

Environment Map

- Environment map: \( l(\theta, \phi) \)
  - Light from all directions
  - Diffuse or point sources
  - Still distant
  - Still no cast shadows.
  - Example: outdoors (sky and sun)
Specular surfaces

- Another important class of surfaces is specular, or mirror-like.
  - radiation arriving along a direction leaves along the specular direction
  - reflect about normal
  - some fraction is absorbed, some reflected
  - color depends on color of incoming light, not of surface.

(http://graphics.cs.ucdavis.edu/GraphcsNotes/Shading/Shading.html)
Specular Direction

\[ \vec{r} + \vec{l} = 2(\vec{l} \cdot \vec{n})\vec{n} \]
\[ \vec{r} = 2(\vec{l} \cdot \vec{n})\vec{n} - \vec{l} \]

Specular surfaces

- Brightness depends on viewing direction.
- Specularity is spread out.
  - Mirror, smooth light all bounces same way.
  - Slightly rougher, direction of bounce varies.
- Diffuse, many bounces

Phong’s model

- Empirical model (e.g., hack)
- Phong’s model
  - reflected energy falls off as: \( \cos^n(\delta \theta) \)
  - \( n \) very big, this is like mirror.
  - As \( n \) gets smaller, specularity more spread out.
  - Good model for plastic
  - Specularity color of source.

(Forsyth & Ponce)

Lambertian + specular

- Two parameters: how shiny, what kind of shiny.
- Many objects combine shiny and diffuse material
  - Wood with veneer; glossy paint, plastic, greasy skin.
Lambertian+Specular+Ambient

More complex reflectances

- Physically realistic models
  - Torrance Sparrow models roughness of surfaces and shadowing of microfacets.
- Models built from observation.
  - Measurement for every lighting direction and viewing direction.
BRDF Not Always Appropriate

http://graphics.stanford.edu/papers/bssrdf/
(Jensen, Marschner, Levoy, Hanrahan)

Luminescence

- Surface shifts color of light.
- Can reflect more light of a color than is present in source.
- This is why objects can glow in “black” light.