Shading

Reading

- Required:
  - Watt, sections 6.2-6.3
- Optional:
  - Watt, chapter 7.

Introduction

- Affine transformations help us to place objects into a scene.
- Before creating images of these objects, we'll look at models for how light interacts with their surfaces.
- Such a model is called a **shading model**.
- Other names:
  - Lighting model
  - Light reflection model
  - Local illumination model
  - Reflectance model
  - BRDF

An abundance of photons

- Properly determining the right color is *really hard.*
- Look around the room. Each light source has different characteristics. Trillions of photons are pouring out every second.
- These photons can:
  - interact with the atmosphere, or with things in the atmosphere
  - strike a surface and
    - be absorbed
    - be reflected (scattered)
    - cause fluorescence or phosphorescence.
  - interact in a wavelength-dependent manner
  - generally bounce around and around

Break problem into two parts

- Part 1:
  What happens when photons interact with a particular point on a surface?
- "Local illumination model"
- Part 2:
  How do photons bounce between surfaces? And, what is the final result of all of this bouncing?
- "Global illumination model"

- Today we're going to focus on Part 1.

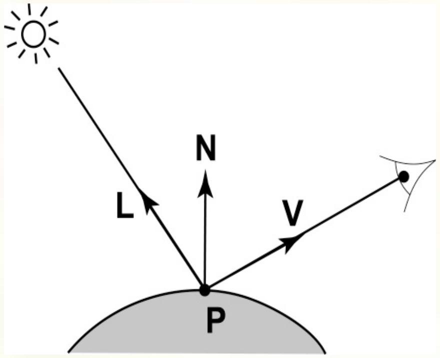
Strategy for today

- We're going to build up to an *approximation* of reality called the **Phong illumination model**.
- It has the following characteristics:
  - *not* physically based
  - gives a first-order *approximation* to physical light reflection
  - very fast
  - widely used

- We will assume **local illumination**, i.e., light goes: light source -> surface -> viewer.
- No interreflections, no shadows.

Setup…

- Given:
  - a point **P** on a surface visible through pixel *p*
  - The normal **N** at **P**
  - The lighting direction, **L**, and intensity, I_ℓ ,at **P**
  - The viewing direction, **V**, at **P**
  - The shading coefficients (material properties) at **P**



- Compute the color, *I*, of pixel *p*.
- Assume that the direction vectors are normalized:

$$\|\mathbf{N}\| = \|\mathbf{L}\| = \|\mathbf{V}\| = 1$$

Iteration zero

- The simplest thing you can do is…
- Assign each polygon a single color: $I = k_e$

  where
  - I is the resulting intensity
  - k_e is the **emissivity** or intrinsic shade associated with the object

- This has some special-purpose uses, but not really good for drawing a scene.
- [Note: k_e is omitted in Watt.]

Iteration one

- Let's make the color at least dependent on the overall quantity of light available in the scene:

$$I = k_e + k_a I_a$$

  - k_a is the **ambient reflection coefficient.**
    - really the reflectance of ambient light
    - "ambient" light is assumed to be equal in all directions
  - I_a is the **ambient intensity**.

- Physically, what is "ambient" light?

Wavelength dependence

- Really, k_e, k_a, and I_a are functions over all wavelengths λ.
- Ideally, we would do the calculation on these functions. We would start with:

$$I(\lambda) = k_e(\lambda) + k_a(\lambda) I_a(\lambda)$$

- then we would find good RGB values to represent the spectrum $I(\lambda)$.
- Traditionally, though, k_e, k_a and I_a are represented as RGB triples, and the computation is performed on each color channel separately:

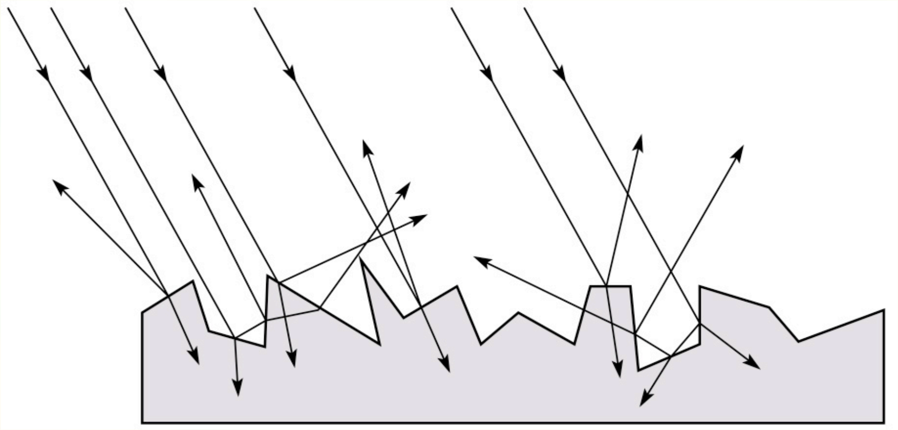
$$I_R = k_{e,R} + k_{a,R} I_{a,R}$$

$$I_G = k_{e,G} + k_{a,G} I_{a,G}$$

$$I_B = k_{e,B} + k_{a,B} I_{a,B}$$

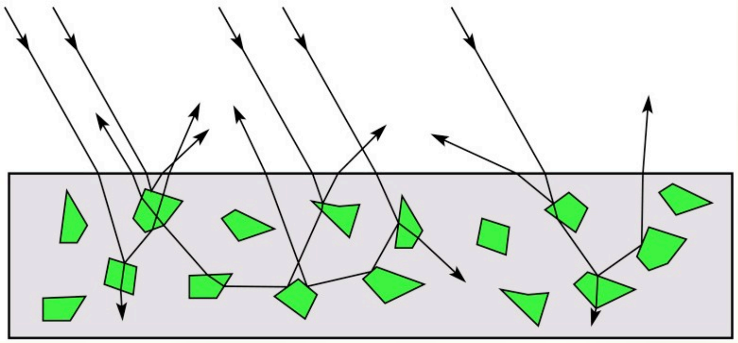
Diffuse reflectors

- Diffuse reflection occurs from dull, matte surfaces, like latex paint, or chalk.
- These **diffuse** or **Lambertian** reflectors reradiate light equally in all directions.
- Picture a rough surface with lots of tiny **microfacets**.



Diffuse reflectors

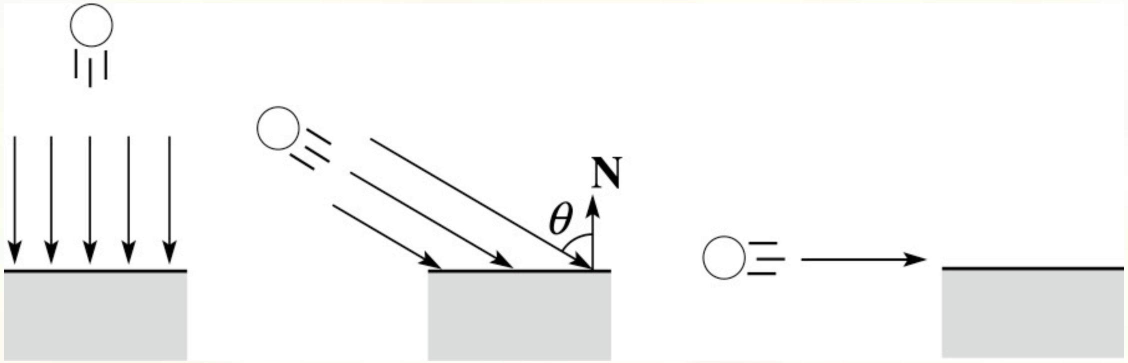
- …or picture a surface with little pigment particles embedded beneath the surface (neglect reflection at the surface for the moment):



- The microfacets and pigments distribute light rays in all directions.
- Embedded pigments are responsible for the coloration of diffusely reflected light in plastics and paints.
- Note: the figures above are intuitive, but not strictly (physically) correct.

Diffuse reflectors, cont.

- The reflected intensity from a diffuse surface does not depend on the direction of the viewer. The incoming light, though, does depend on the direction of the light source:



Iteration two

- The incoming energy is proportional to $\cos(\theta)$, giving the diffuse reflection equations:

$$\begin{aligned} I &= k_e + k_a I_a + k_d I_\ell \cos(\theta)_+ \\ &= k_e + k_a I_a + k_d I_\ell (\mathbf{N} \bullet \mathbf{L})_+ \end{aligned}$$

where:

  - k_d is the **diffuse reflection coefficient**
  - I_ℓ is the intensity of the light source
  - **N** is the normal to the surface (unit vector)
  - **L** is the direction to the light source (unit vector)
  - $(x)_+$ means max $\{0, x\}$

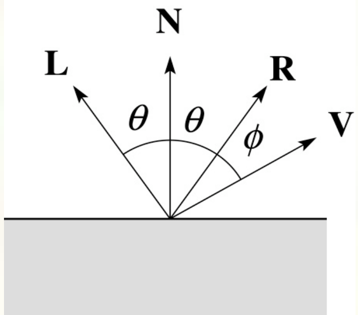
[Note: Watt uses I_i instead of I_ℓ .]

Specular reflection

- **Specular reflection** accounts for the highlight that you see on some objects.
- It is particularly important for *smooth, shiny* surfaces, such as:
    - metal
    - polished stone
    - plastics
    - apples
    - skin

- Properties:
    - Specular reflection depends on the viewing direction V.
    - For non-metals, the color is determined solely by the color of the light.
    - For metals, the color may be altered (e.g., brass)

Specular reflection "derivation"

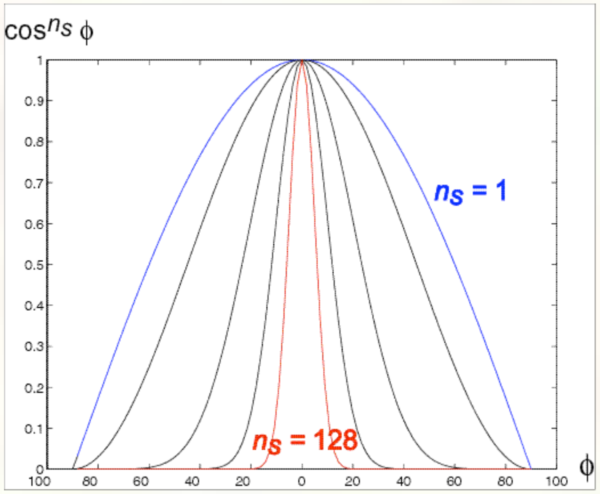


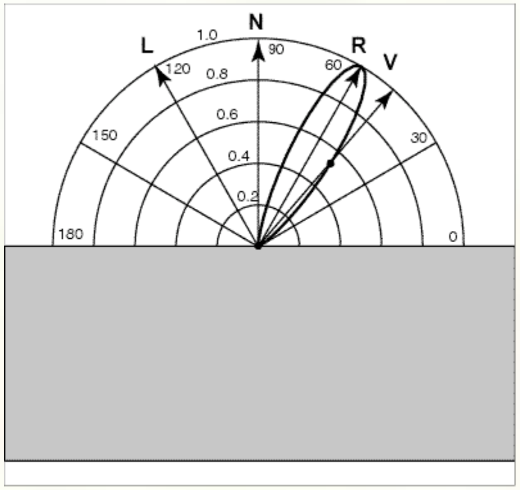
- For a perfect mirror reflector, light is reflected about **N**, so

$$I = \begin{cases} I_\ell & \text{if } \mathbf{V} = \mathbf{R} \\ 0 & \text{otherwise} \end{cases}$$

- For a near-perfect reflector, you might expect the highlight to fall off quickly with increasing angle ϕ.
- Also known as:
  - **"rough specular" reflection**
  - **"directional diffuse" reflection**
  - **"glossy" reflection**

Derivation, cont.





- One way to get this effect is to take (**R·V**), raised to a power n_s.
- As n_s gets larger,
  - the dropoff becomes {more,less} gradual
  - gives a {larger,smaller} highlight
  - simulates a {more,less} mirror-like surface

Iteration three

- The next update to the Phong shading model is then:

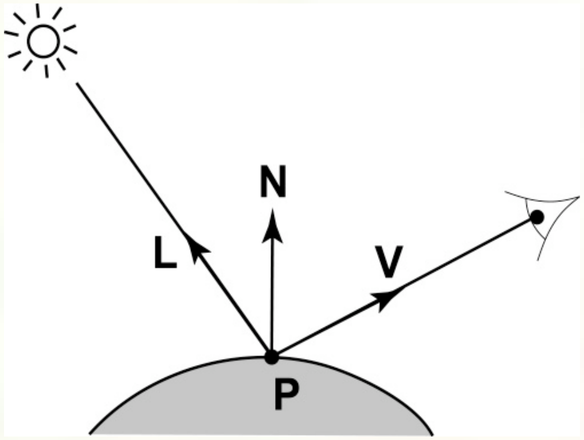
$$I = k_e + k_a I_a + k_d I_\ell (\mathbf{N} \bullet \mathbf{L})_+ + k_s I_\ell (\mathbf{R} \bullet \mathbf{V})_+^{n_s}$$

where:

  - k_s is the **specular reflection coefficient**
  - n_s is the **specular exponent** or **shininess**
  - **R** is the reflection of the light about the normal (unit vector)
  - **V** is viewing direction (unit vector)

[Note: Watt uses n instead of n_s.]

What is incoming light intensity?



So far we've just been considering what happens at the surface itself.

How does incoming light intensity change as light moves further away?

Intensity drop-off with distance

- OpenGL supports different kinds of lights: point, directional, and spot.
- For point light sources, the laws of physics state that the intensity of a point light source must drop off inversely with the square of the distance.
- We can incorporate this effect by multiplying $\boldsymbol{I}_\ell$ by $1/d^2$.
- Sometimes, this distance-squared dropoff is considered too "harsh." A common alternative is:

$$f_{atten}(d) = \frac{1}{a + bd + cd^2}$$

with user-supplied constants for a, b, and c.

[Note: not discussed in Watt.]

Iteration four

- Since light is additive, we can handle multiple lights by taking the sum over every light.
- Our equation is now:

$$I = k_e + k_a I_a + \sum_j f_{atten}(d_j) I_{\ell_j} \left[k_d (\mathbf{N} \bullet \mathbf{L}_j)_+ + k_s (\mathbf{R}_j \bullet \mathbf{V})_+^{n_s} \right]$$

- This is the Phong illumination model.

Choosing the parameters

- Experiment with different parameter settings. To get you started, here are a few suggestions:
  - Try n_s in the range [0,100]
  - Try $k_a + k_d + k_s < 1$
  - Use a small k_a (~0.1)

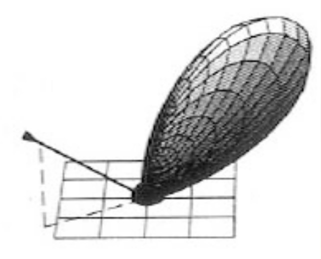
	n_s	k_d	k_s
Metal	large	Small, color of metal	Large, color of metal
Plastic	medium	Medium, color of plastic	Medium, white
Planet	0	varying	0

BRDF

- The Phong illumination model is really a function that maps light from incoming (light) directions to outgoing (viewing) directions:

$$f_r(\omega_{in},\omega_{out})$$

- This function is called the **Bi-directional Reflectance Distribution Function (BRDF)**.
- Here’s a plot with ω_{in} held constant:

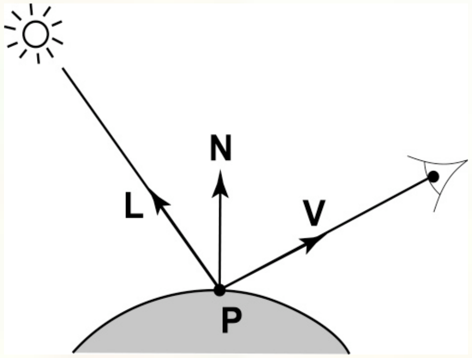


- Physically valid BRDF’s obey Helmholtz reciprocity:

$$f_r(\omega_{in},\omega_{out}) = f_r(\omega_{out},\omega_{in})$$

and should conserve energy (no light amplification).

Phong BRDF



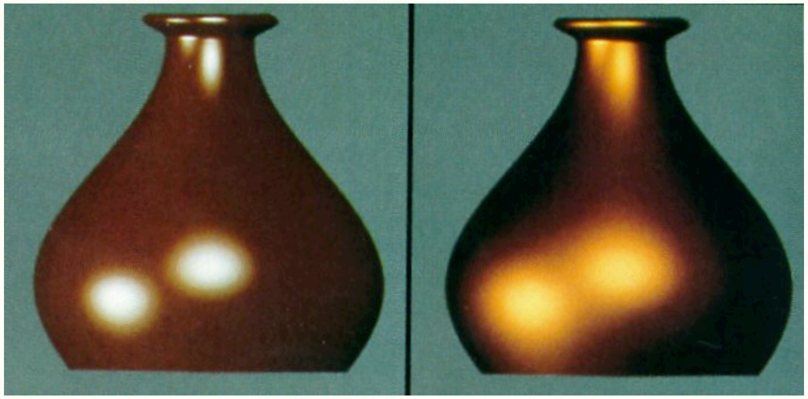
$$f_r(\omega_{in}, \omega_{out}) = f_r(\mathbf{L}, \mathbf{V})$$

How do we express Phong model using explicit BRDF?

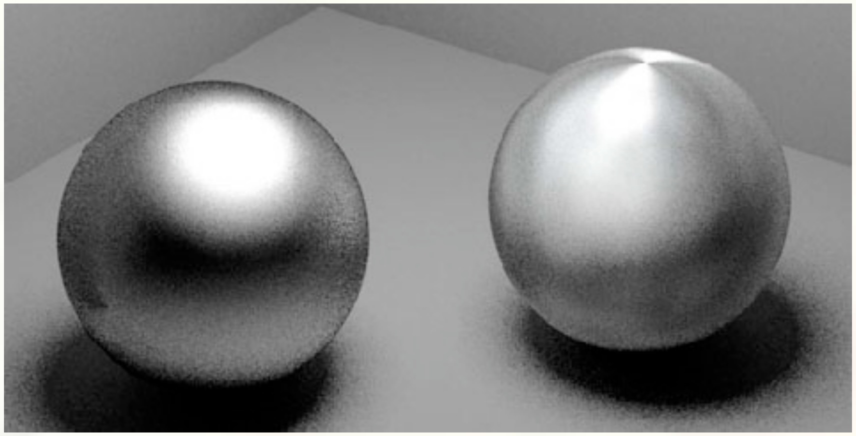
$$I = k_e + k_a I_a + \sum_j f_{atten}(d_j) I_{\ell_j} \left[k_d (\mathbf{N} \bullet \mathbf{L}_j)_+ + k_s (\mathbf{R}_j \bullet \mathbf{V})_+^{n_s} \right]$$

More sophisticated BRDF's

Cook and Torrance, 1982



Westin, Arvo, Torrance 1992



Summary

- Local vs. Global Illumination Models
- Local Illumination Models:
  - Phong – Physically inspired, but not truly physically correct.
  - Arbitrary BRDFs

- In applying the Phong model, we assumed unshadowed "point" light sources.

Next time: Ray tracing

- Topics:

  How do we model the transport of light within the scene?

  How do we determine which surfaces are visible from the eye, or shadowed from a light?
- Read:
  - Watt, sections 1.3-1.4, 12.1-12.5.1.
  - T. Whitted. An improved illumination model for shaded display. Communications of the ACM 23(6), 343-349, 1980.
    [Course reader, pp. 211-217]
- Optional:
  - A. Glassner. An Introduction to Ray Tracing. Academic Press, 1989.
    [In the graphics research lab, ACES 2.102]
  - K. Turkowski, “Properties of Surface Normal Transformations,” Graphics Gems, 1990, pp. 539-547. [Course reader pp. 218-226]