

5. Shading

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Reading

Required:

- ♦ Watt, sections 6.2-6.3

Optional:

- ♦ Watt, chapter 7.

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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

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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

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Our problem

We're going to build up to an *approximation* of reality called the **Phong illumination model**.

It has the following characteristics:

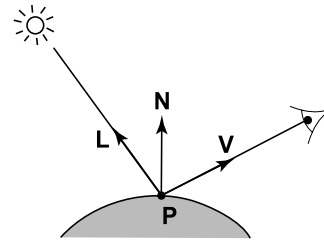
- ♦ *not* physically based
- ♦ gives a first-order *approximation* to physical light reflection
- ♦ very fast
- ♦ widely used

In addition, we will assume **local illumination**, i.e., light goes: light source → surface → viewer.

No interreflections, no shadows.

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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 at **P**

Compute the color, I , of pixel p .

Assume that the direction vectors are normalized:

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

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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.]

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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?

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Wavelength dependence

Really, k_r , k_a , and I_a are functions over all wavelengths λ .

Ideally, we would do the calculation on these functions. For the ambient shading equation, we would start with:

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

then we would find good RGB values to represent the spectrum $I(\lambda)$.

Traditionally, though, k_a and I_a are represented as RGB triples, and the computation is performed on each color channel separately:

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

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

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

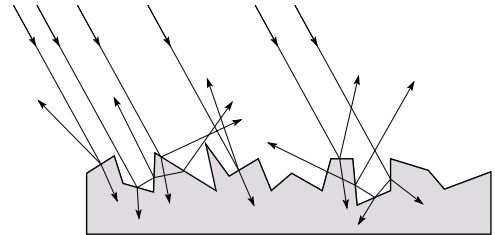
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Diffuse reflectors

Diffuse reflection occurs from dull, matte surfaces, like latex paint, or chalk.

These **diffuse** or **Lambertian** reflectors reradiate light equally in all directions.

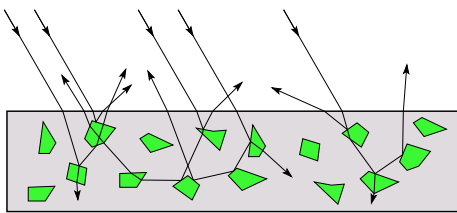
Picture a rough surface with lots of tiny **microfacets**.



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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.

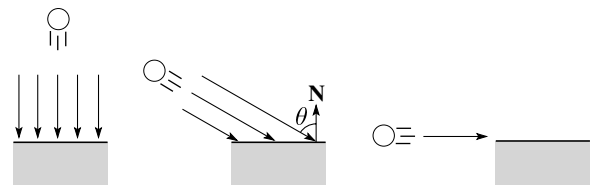
Embedded pigments are responsible for the coloration of diffusely reflected light in plastics and paints.

Note: the figures above are intuitive, but not strictly (physically) correct.

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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:



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Iteration two

The incoming energy is proportional to _____, giving the diffuse reflection equations:

$$I = k_e + k_a I_a + k_d I_\ell \text{ _____}$$

$$= k_e + k_a I_a + k_d I_\ell (\quad)$$

where:

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

[Note: Watt uses I_i instead of I_ℓ .]

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Specular reflection

Specular reflection accounts for the highlight that you see on some objects.

It is particularly important for *smooth, shiny* surfaces, such as:

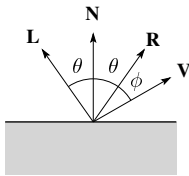
- ◆ metal
- ◆ polished stone
- ◆ plastics
- ◆ apples
- ◆ skin

Properties:

- ◆ Specular reflection depends on the viewing direction \mathbf{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)

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Specular reflection "derivation"



For a perfect mirror reflector, light is reflected about \mathbf{N} , so

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

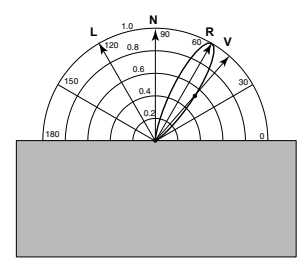
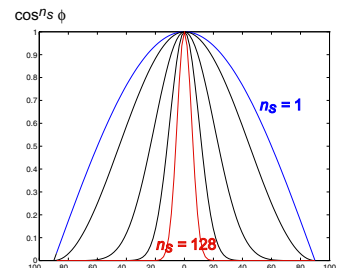
For a near-perfect reflector, you might expect the highlight to fall off quickly with increasing angle ϕ .

Also known as:

- ◆ "rough specular" reflection
- ◆ "directional diffuse" reflection
- ◆ "glossy" reflection

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Derivation, cont.



One way to get this effect is to take $(\mathbf{R} \cdot \mathbf{V})$, 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

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Iteration three

The next update to the Phong shading model is then:

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

where:

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

[Note: Watt uses n instead of n_s .]

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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 I_l by $1/d^2$.

Sometimes, this distance-squared dropoff is considered too "harsh." A common alternative is:

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

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

[Note: not discussed in Watt.]

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Iteration four

Since light is additive, we can handle multiple lights by taking the sum over every light.

Our equation is now:

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

This is the Phong illumination model.

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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

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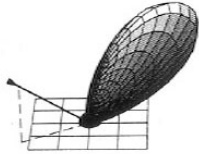
BRDF

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:

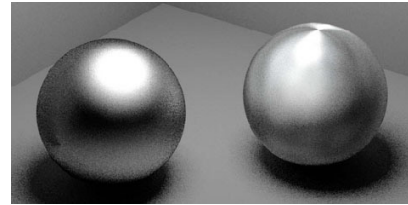
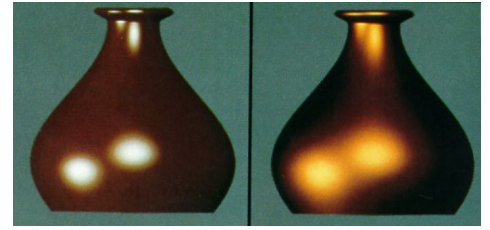
$$f_r(\omega_{in}, \omega_{out}) = f_r(\omega_{out}, \omega_{in})$$

and should conserve energy (no light amplification).

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More sophisticated BRDF's

Cook and
Torrance, 1982



Westin, Arvo, Torrance 1992



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Summary

The most important thing to take away from this lecture is the final equation for the Phong model.

- ♦ What is the physical meaning of each variable?
- ♦ How are the terms computed?
- ♦ What effect does each term contribute to the image?
- ♦ What does varying the parameters do?

You should also understand the differences between faceted, Gouraud, and Phong interpolated shading.

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