Shading Models
Consider the process of looking at (or photographing) a scene through a window.

At every point on the window the light from the scene has a certain intensity $I(x, y)$.

Intensity is a measure of the brightness of the light.

Generally there will be a mixture of light of different wavelengths at each point on the window: $I = I(x, y, \lambda)$ where $\lambda$ is the wavelength.

We don't discuss the wavelength dependency in these notes.
Types of illumination

Direct illumination

Light striking the objects comes directly from the light sources
Indirect illumination

Light striking the objects has been reflected off at least one other object since leaving the light source.

The light could also have been refracted through transparent objects.
Reflection Models

There exists a number of reflection models that model the real world to varying degrees of realism.

In general, the more realistic a model is, the more physics and computation is involved.

Most reflection models incorporate direct illumination.

The indirect illumination is very expensive to calculate.

Only the most advanced rendering techniques incorporate indirect illumination.

Examples are ray tracing and radiosity.
Some more terminology

Direct illumination is referred to as *local* illumination.

Indirect illumination is referred to as *global* illumination.
Determining an Object’s Appearance

Ultimately, we’re interested in modeling **light transport** in scene
- Light is emitted from light sources and interacts with surfaces
- on impact with an object, some is reflected and some is absorbed
- distribution of reflected light determines “finish” (matte, glossy, ...)
- composition of light arriving at eye determines what we see

Let’s focus on the local interaction of light with single surface point
Interaction of light and objects.

We must also model the way that light interacts with the surfaces of objects.

When light hits the surface of an object, it can be:

- Reflected
- Absorbed
- Transmitted (for transparent objects)

We see opaque objects by the light they reflect.
The way in which light interacts with real objects is very complicated.

The interaction depends on:

- the material properties of the object
- the wavelength of the incident light
- the angle of incidence of the light and the surface

The *polarisation* of the light is also involved, but rarely modelled in computer graphics.
Basic Local Illumination Model

We’re only interested in light that finally arrives at view point
  • a function of the light & viewing positions
  • and local surface reflectance

Characterize light using RGB triples
  • can operate on each channel separately

Given a point, compute intensity of reflected light
Phong Illumination

Empirically divides reflection into 3 components

- Ambient
- Diffuse (Lambertian)
- Specular
Diffuse Reflection

This is the simplest kind of reflection
- also called Lambertian reflection
- models dull, matte surfaces — materials like chalk

Ideal diffuse reflection
- scatters incoming light equally in all directions
- identical appearance from all viewing directions
- reflected intensity depends only on direction of light source

Light is reflected according to Lambert’s Law
**Diffuse reflection**

The incident light is scattered equally in all directions.

This is characteristic of dull, matt surfaces such as paper, bricks, carpet, etc.
Lambert’s Law for Diffuse Reflection

Purely diffuse object

\[ I = I_L k_d \cos \theta \]
\[ = I_L k_d (n \cdot L) \]

\( I \): resulting intensity
\( I_L \): light source intensity
\( k_d \): (diffuse) surface reflectance coefficient

\( k_d \in [0,1] \)

\( \theta \): angle between normal & light direction
Specular Reflection

Diffuse reflection is nice, but many surfaces are shiny
- their appearance changes as the viewpoint moves
- they have glossy specular highlights (or specularities)
- because they reflect light coherently, in a preferred direction

A mirror is a perfect specular reflector
- incoming ray reflected about normal direction
- nothing reflected in any other direction

Most surfaces are imperfect specular reflectors
- reflect rays in cone about perfect reflection direction
Specular reflection

The reflected light is concentrated around the direction of mirror reflection, and is spread out.

This can be used to model shiny surfaces.
**Phong Illumination Model**

\[ I = I_L k_d \cos \theta + I_L k_s \cos^n \phi \]

\[ = I_L k_d (n \cdot L) + I_L k_s (r \cdot v)^n \]

One particular specular reflection model
- quite common in practice
- it is purely empirical
- there's *no physical basis* for it

**Variables:**
- \( I \): resulting intensity
- \( I_L \): light source intensity
- \( k_s \): (specular) surface reflectance coefficient
  \( k_s \in [0,1] \)
- \( \phi \): angle between viewing & reflection direction
- \( n \): "shininess" factor
Calculating the Reflected Ray

\[ r = (2 \times (n \cdot L) \times n) - L \]

- Derivation left for the students
- Clamp all dot products to zero. They shouldn’t be negative, but they can be
  - \[ \text{MAX} (0, n \cdot L) \]
\[ \cos \theta \]

\[ \cos^2 \theta \]

\[ \cos^{10} \theta \]

\[ \cos^{25} \theta \]

\[ 1.0 \]

\[ -90^\circ \]

\[ 90^\circ \]
Diffuse + specular reflection
Examples of Phong Specular Model

Diffuse only  Diffuse + Specular (shininess 5)  Diffuse + Specular (shininess 50)
The Ambient Glow

So far, areas not directly illuminated by any light appear black
  • this tends to look rather unnatural
  • in the real world, there’s lots of ambient light

To compensate, we invent new light source
  • assume there is a constant ambient “glow”
  • this ambient glow is purely fictitious

Just add in another term to our illumination equation

\[ I = I_L k_d \cos \theta + I_L k_s \cos^n \phi + I_a k_a \]

\( I_a \) : ambient light intensity
\( k_a \) : (ambient) surface reflectance coefficient
Our Three Basic Components of Illumination

Diffuse
Specular
Ambient
Combined for the Final Result