

## Objectives

- Learn to shade objects so their images appear three-dimensional
- Introduce the types of light-material interactions
- Build a simple reflection model---the Phong model--- that can be used with real time graphics hardware



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## Why we need shading

- Suppose we build a model of a sphere using many polygons and color it with `glColor`. We get something like



- But we want



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## Shading

- Why does the image of a real sphere look like



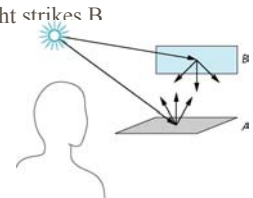
- Light-material interactions cause each point to have a different color or shade
- Need to consider
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation



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## Scattering

- Light strikes A
  - Some scattered
  - Some absorbed
- Some of scattered light strikes B
  - Some scattered
  - Some absorbed
- Some of this scattered light strikes A and so on



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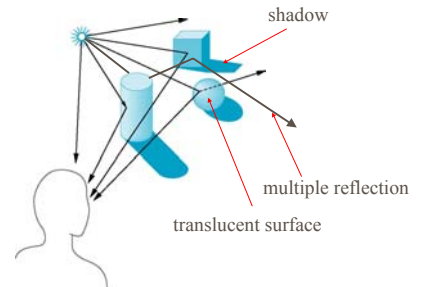
## Rendering Equation

- The infinite scattering and absorption of light can be described by the *rendering equation*
$$i(p, p') = v(p, p')\epsilon(p, p') + \int \rho(p, p', p'')(p', p'')dp''$$
  - Cannot be solved in general
  - Ray tracing is a special case for perfectly reflecting surfaces
- Rendering equation is global and includes
  - Shadows
  - Multiple scattering from object to object



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## Global Effects



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## Local vs Global Rendering

- Correct shading requires a global calculation involving all objects and light sources
  - Incompatible with pipeline model which shades each polygon independently (local rendering)
- However, in computer graphics, especially real time graphics, we are happy if things “look right”
  - Exist many techniques for approximating global effects



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## Light-Material Interaction

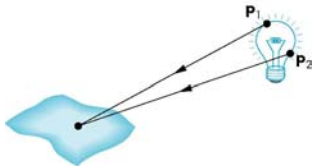
- Light that strikes an object is partially absorbed and partially scattered (reflected)
- The amount reflected determines the color and brightness of the object
  - A surface appears red under white light because the red component of the light is reflected and the rest is absorbed
- The reflected light is scattered in a manner that depends on the smoothness and orientation of the surface



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## Light Sources

General light sources are difficult to work with because we must integrate light coming from all points on the source



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## Simple Light Sources

- Point source
  - Model with position and color
  - Distant source = infinite distance away (parallel)
- Spotlight
  - Restrict light from ideal point source
- Ambient light
  - Same amount of light everywhere in scene
  - Can model contribution of many sources and reflecting surfaces



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## Surface Types

- The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror would reflected the light
- A very rough surface scatters light in all directions



smooth surface



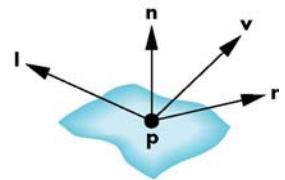
rough surface



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## Phong Model

- A simple model that can be computed rapidly
- Has three components
  - Diffuse
  - Specular
  - Ambient
- Uses four vectors
  - To source
  - To viewer
  - Normal
  - Perfect reflector

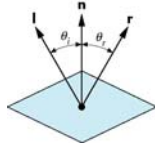


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## Ideal Reflector

- Normal is determined by local orientation
- Angle of incidence = angle of reflection
- The three vectors must be coplanar

$$r = 2(I \cdot n)n - I$$



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## Lambertian Surface

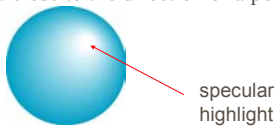
- Perfectly diffuse reflector
- Light scattered equally in all directions
- Amount of light reflected is proportional to the vertical component of incoming light
  - reflected light  $\sim \cos \theta_i$
  - $\cos \theta_i = I \cdot n$  if vectors normalized
  - There are also three coefficients,  $k_r$ ,  $k_b$ ,  $k_g$  that show how much of each color component is reflected



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## Specular Surfaces

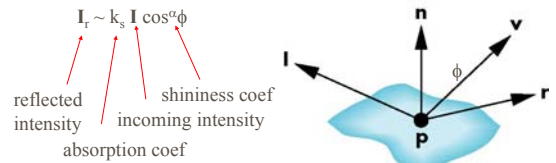
- Most surfaces are neither ideal diffusers nor perfectly specular (ideal reflectors)
- Smooth surfaces show specular highlights due to incoming light being reflected in directions concentrated close to the direction of a perfect reflection



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## Modeling Specular Reflections

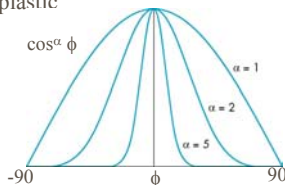
- Phong proposed using a term that dropped off as the angle between the viewer and the ideal reflection increased



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## The Shininess Coefficient

- Values of  $\alpha$  between 100 and 200 correspond to metals
- Values between 5 and 10 give surface that look like plastic



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## Ambient Light

- Ambient light is the result of multiple interactions between (large) light sources and the objects in the environment
- Amount and color depend on both the color of the light(s) and the material properties of the object
- Add  $k_a I_a$  to diffuse and specular terms

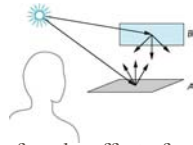


reflection coef      intensity of ambient light

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## Distance Terms

- The light from a point source that reaches a surface is inversely proportional to the square of the distance between them
- We can add a factor of the form  $1/(ad + bd + cd^2)$  to the diffuse and specular terms
- The constant and linear terms soften the effect of the point source



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## Light Sources

- In the Phong Model, we add the results from each light source
- Each light source has separate diffuse, specular, and ambient terms to allow for maximum flexibility even though this form does not have a physical justification
- Separate red, green and blue components
- Hence, 9 coefficients for each point source
  - $I_{dr}, I_{dg}, I_{db}, I_{sr}, I_{sg}, I_{sb}, I_{ar}, I_{ag}, I_{ab}$



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## Material Properties

- Material properties match light source properties
  - Nine absorption coefficients
    - $k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb}, k_{ar}, k_{ag}, k_{ab}$
  - Shininess coefficient  $\alpha$



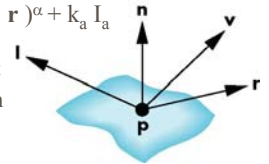
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## Adding up the Components

For each light source and each color component, the Phong model can be written (without the distance terms) as

$$I = k_d I_d \mathbf{l} \cdot \mathbf{n} + k_s I_s (\mathbf{v} \cdot \mathbf{r})^\alpha + k_a I_a$$

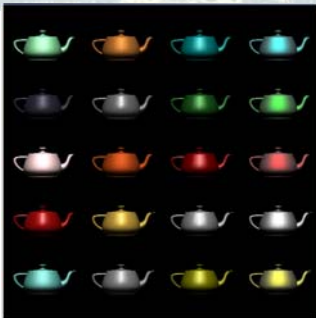
For each color component we add contributions from all sources



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## Example

Only differences in these teapots are the parameters in the Phong model



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