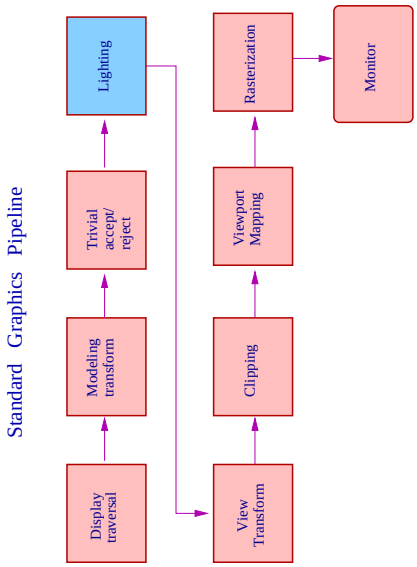
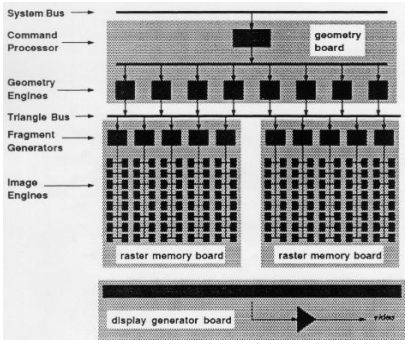
Viewing Pipeline



Slide 1

Graphics Architecture



Slide 2

Illumination Models

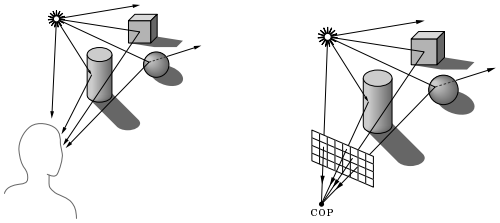
Photorealism

- ☆ Accurate representation of objects.
- ☆ Good lighting effects:
  - reflections, transparency
  - shading
  - surface details
  - shadows
- ☆ Computing the color/intensity at each pixel.
- ☆ Interaction of electromagnetic energy and object surfaces.

Slide 3

Light Sources

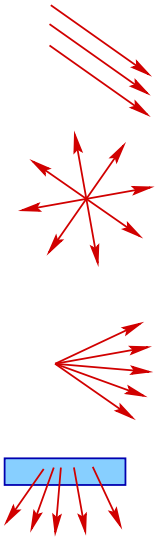
- ☆ Light emitting sources
- ☆ Light reflecting sources



Slide 4

Different Light Sources

- ☆ Directional sources
- ☆ Point sources
  - Same energy emitted in each direction.
  - Good approximation for small, distant light sources.
- ☆ Spot light: Light emitted along a cone.
- ☆ Distributed light sources
  - Fluorescent light
  - Intensity varies with direction.

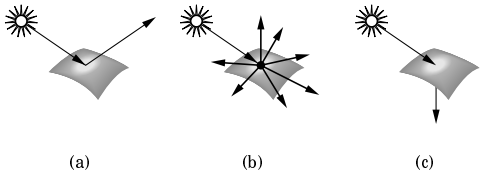


Slide 5

Illumination Models

Components of a simple illumination model:

- ☆ Ambient reflection
- ☆ Diffuse reflection
- ☆ Specular reflection



Slide 6

Ambient Reflection

- ☆ No spatial & directional characterization.
- ☆ Light incident on each object is the same.
- ☆ Reflection for each surface is independent of spatial orientation or viewing direction.
- ☆ A way of approximating global illumination.
- ☆ Reflection depends on optical properties of the surface.
- ☆ I_a: Intensity of the ambient light.
- ☆ k_a: Ambient reflection coefficient.

$$I = I_a \cdot k_a.$$

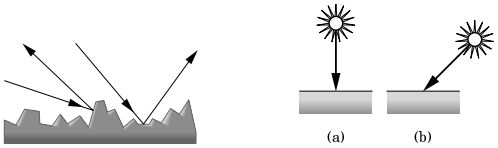
Produces flat shading!

Slide 7

Diffuse Reflection

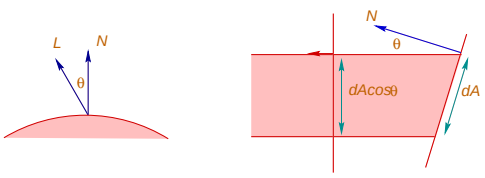
Lambertian Reflection:

- ☆ Point light source.
- ☆ Equal light is reflected in all directions.
- ☆ Equally bright from all view directions.
- ☆ Light incident to a surface depends on spatial orientation.
- ☆ Typical of dull, matte surfaces.
- ☆ Determines the color of the object.



Slide 8

Lambertian Model



- ☆ **N**: Surface normal.
- ☆ **L**: Direction of the light source.
- ☆ Energy falling on a small area dA: $I_L dA \cos\theta$
  $\cos\theta = \mathbf{N} \cdot \mathbf{L}$.
- ☆ k_d: Diffuse reflection coefficient.

$$I_{diff} = k_d \cdot I_L(\mathbf{N} \cdot \mathbf{L})$$

After adding ambient light:

$$I = k_a I_a + k_d \cdot I_L(\mathbf{N} \cdot \mathbf{L})$$

Slide 9

Light Source Attenuation

- ☆ Intensity reduces with distance.
- ☆ f_{att}: Attenuation factor.

$$I = k_a I_a + f_{att} k_d \cdot I_L(\mathbf{N} \cdot \mathbf{L})$$

- ☆ Makes surface with equal $k_d(\mathbf{N} \cdot \mathbf{L})$ differ in apperance.
- ☆ Important for overlapping objects.

Ideally, $f_{att} = 1/d_L^2$.

- ☆ Intensity doesn't vary much for large values of d_L.
- ☆ Varies a lot for small values of d_L.

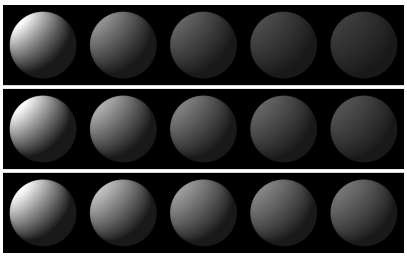
In practice,

$$f_{att} = \min\left(1, \frac{1}{k_c + k_l d_L + k_q d_L^2}\right).$$

- ☆ k_c, k_l, k_d are constants.
- ☆ Taylor series approximation of an arbitrary function.

Slide 10

Light Source Attenuation



- ☆ For all spheres $I_a = I_L = 1.0$.
- ☆ From left to right:
  $d_L = 1.0, 1.375, 1.75, 2.125, 2.5$.
- ☆ Top row: $k_c = k_l = 0.0, k_q = 1.0$ $(1/d_L^2)$.
- ☆ Middle row: $k_c = k_l = 0.25, k_q = 0.5$.
- ☆ Bottom row: $k_c = k_q = 0.0, k_L = 1.0$ $(1/d_L)$.

Slide 11

Colored Light Sources

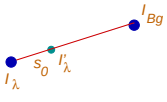
- ☆ Write equations for each basic color (e.g., RGB) separately.
- ☆ Object diffuse color: (O_{dR}, O_{dG}, O_{dB}).

$$I_R = k_{aR} I_{aR} O_{dR} + f_{att} k_{dR} \cdot I_{LR} \cdot O_{dR}(\mathbf{N} \cdot \mathbf{L}).$$

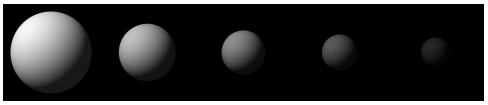
- ☆ Assumes that RGB colors model the interaction of light and objects accurately.
- ☆ Not true in general
  - Reflectance and transmittance of light depends on the actual frequency of the color.

Atmospheric attenuations

- ☆ Depth cueing
- ☆ Fog



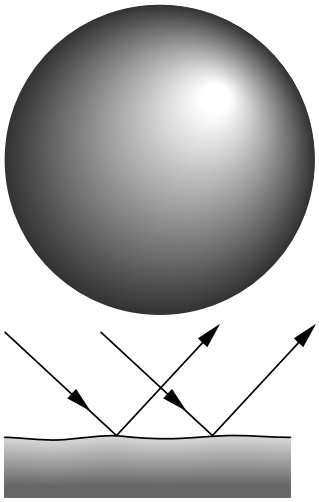
$$I'_\lambda = s_0 I_\lambda + (1 - s_0) I_{Bg,\lambda}$$



Slide 12

Specular Reflection

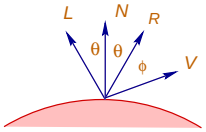
- ☆ Bright spot in certain directions.
- ☆ Around specular reflection angle.

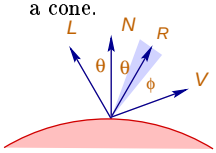


Slide 13

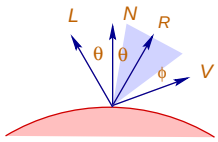
Specular Reflection

- ☆ Shiny surfaces
- ☆ Ideal reflector: Only in direction R.
- ☆ Non-ideal reflector: Specular reflection in a cone.





shiny



rough

- ☆ Angle of the cone depends on material properties.
- ☆ Color also depends on the material.

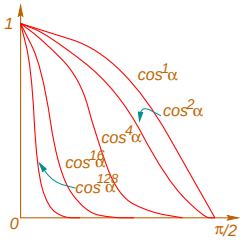
Slide 14

Phong Model

- ☆ Neglects the effect of object color in specular reflection.
- ☆ I_θ: Light in direction θ.

$$I = I_\theta \cos^n \phi \quad I_\theta = I_L \cdot W(\theta) \quad \cos\phi = \mathbf{R}.\mathbf{V}.$$

$$I_{spec} = I_L W(\theta)(\mathbf{R} \cdot \mathbf{V})^n$$



Typically, $W(\theta) = k_{s\lambda}$.

$$I_\lambda = k_a I_{a\lambda} O_{d\lambda} + f_{att} I_{L\lambda} [k_d \cdot O_{d\lambda}(\mathbf{N} \cdot \mathbf{L}) + k_{s\lambda}(\mathbf{R} \cdot \mathbf{V})^n]$$

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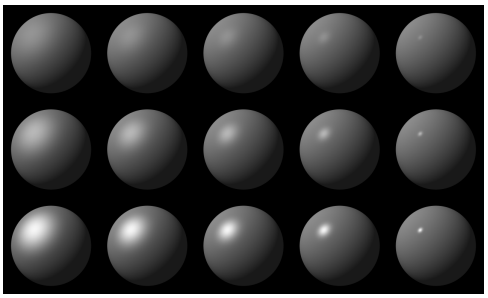
Phong Model



- ☆ For all spheres $I_1 = I_p = 1.0$,
- ☆ From left to right: $n = 3.0, 5.0, 10.0, 27.0, 200.0$.
- ☆ Top row: $k_s = 0.1$.
- ☆ Middle row: $k_s = 0.25$.
- ☆ Bottom row: $k_s = 0.5$.

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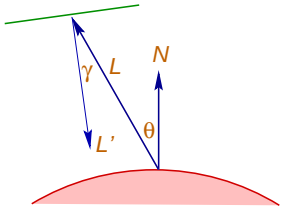
Warn Model

- ☆ Generalization of Phong model.
- ☆ Models directional effects to point sources.
- ☆ L is modeled by a point on a hypothetical reflecting surface.



$$I_L = I_{L'} \cdot \cos^p \gamma$$
$$= I_{L'} (-\mathbf{L} \cdot \mathbf{L}')^p$$

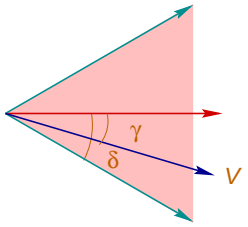
Slide 17

Warn Model

Flaps:

- ☆ Restricts the area of light in world coordinates.
- ☆ Six flaps: $x_{\min}, x_{\max}, y_{\min}, \ldots$.

Cones: (Spot lights)



Slide 18

Lighting in OpenGL

- ☆ RGB values of lights and materials.
- ☆ Positions of light sources.
- ☆ Lighting models.
- ☆ *Need to specify normals.*

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Lighting in OpenGL

`glLight{if} (light, pname, para);`

`glLight{if}v (light, pname, para);`

light: GL_LIGHT0, GL_LIGHT1, ..., GL_LIGHT7

pname: GL_AMBIENT, GL_DIFFUSE, GL_SPECULAR, GL_POSITION

```
GLfloat amb[] = { 0.0, 0.0, 1.0, 1.0};
GLfloat diffuse[] = { 1.0, 1.0, 1.0, 1.0};
GLfloat spec[] = { 1.0, 0.0, 1.0, 1.0};
GLfloat pos[] = { 1.0, 1.0, 1.0, 0.0};
glLightfv (GL_LIGHT0, GL_AMBIENT, amb);
glLightfv (GL_LIGHT0, GL_DIFFUSE, diffuse);
glLightfv (GL_LIGHT0, GL_SPECULAR, spec);
glLightfv (GL_LIGHT0, GL_POSITION, pos);
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
```

Slide 20

Lighting in OpenGL

Distance Attenuation:

$$f_{att} = \frac{1}{k_c + k_l d_L + k_q d_L^2}$$

- ☆ GL_CONST_ATTENUATION $= k_c$
- ☆ GL_LINEAR_ATTENUATION $= k_l$
- ☆ GL_QUADRATIC_ATTENUATION $= k_q$

Spot light: **V**: Viewing direction

$$\max\{\mathbf{V} \cdot \mathbf{D}, 0\}^p$$

- ☆ GL_SPOT_DIRECTION $= \mathbf{D}$
- ☆ GL_SPOT_CUTOFF $= \delta$
- ☆ GL_SPOT_EXPONENT $= p$

Slide 21

Lighting Models in OpenGL

`glLightModel`{if} (pname, para);

`glLightModel`{if}`v` (pname, para);

pname:

- ☆ GL_LIGHT_MODEL_AMBIENT
  Ambient RGB value of the entire scene .
- ☆ GL_LIGHT_LOCAL_VIEWER
  Viewer at finite distance or at infinity.
- ☆ GL_LIGHT_TWO_SIDE
  Lighting for both front and back faces.

Slide 22

Material Properties

`glMaterial`{if} (face, pname, para);

`glMaterial`{if}`v` (face, pname, para);

face: GL_FRONT, GL_BACK, GL_FRONT_AND_BACK

pname:

- ☆ GL_AMBIENT, GL_DIFFUSE,
- ☆ GL_AMBIENT_AND_DIFFUSE
- ☆ GL_SPECULAR
- ☆ GL_SHININESS

`glColorMaterial`(face, mode);

- ☆ mode: GL_AMBIENT, GL_DIFFUSE, ...
- ☆ Only one mode is active.
- ☆ `glColor` will set the color.

Slide 23