# Lighting and Shading

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CMPT370
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# Review last time

- Modelling: vertex lists, face lists, edge lists
  - OpenGL vertex arrays
  - OpenGL display lists (see RedBook ch7)
- Viewing: (see RedBook ch3)
  - Positioning the camera: model-view matrix
  - Selecting a lens: projection matrix
  - Clipping: setting the view volume

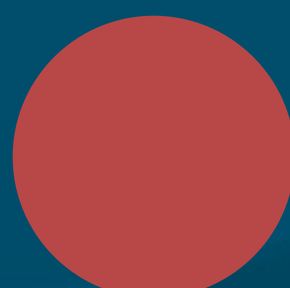
    - See UC-Davis ECS175 graphics course

# What's on for today

- Lighting and shading
  - The global rendering equation
  - Light-material interaction
  - Kinds of light sources
- The OpenGL local illumination model
  - Ambient term
  - Diffuse term
  - Specular term
  - Specifying in OpenGL
- See RedBook ch5

# Shading for realism

- Colour is part of the OpenGL state
  - Specify glColor (glColor3f, glColor4b, etc.) before adding vertex
- Red ball:
  - glColor3f(1.0, 0.0, 0.0);
  - glVertex3f( ... ); ...
- Flat-shaded:

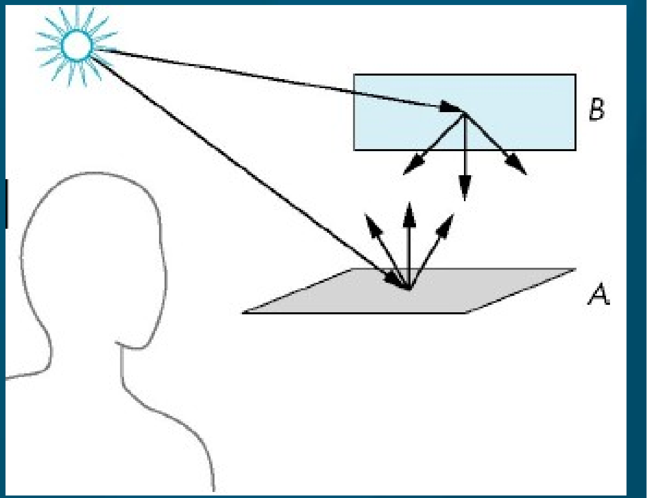


- Not realistic!

# Factors involved in shading

- What makes the real sphere look like this?
- Interactions between light and material:
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation

# The rendering equation




- Light originates from light sources
- Each time light strikes a surface:
  - Some absorbed, some scattered

$$I(x,x') = g(x,x')\left[\epsilon(x,x') + \int \rho(x,x',x'')\, I(x',x'')\, dx''\right]$$

$I(x,x')$: *intensity from x to x'*

$g(x,x')$: *visibility between x, x'*

$\epsilon(x,x')$: *transfer emittance from x to x'*

$\rho(x,x',x'')$: *scattering from x to x' via x''*

- Cannot be solved analytically in general
- Global illumination: all objects, all light sources
- OpenGL pipeline is local: one polygon at a time

# Light – material interaction

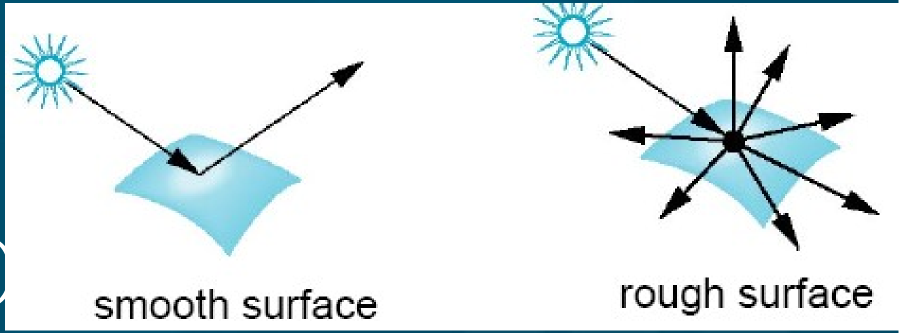
- Light striking a material is
  - Partially absorbed
  - Partially scattered (reflected):
    - Depends on smoothness, orientation of surface
- A surface looks red because it absorbs everything else and reflects the red component of light

# Light sources

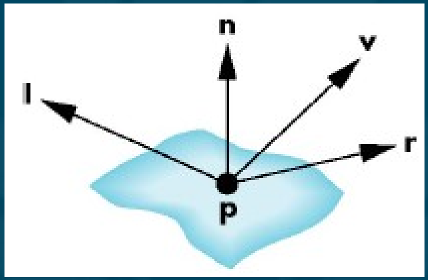
- General (area) light sources: must integrate light from all points of light source: hard!
- Simple kinds of light sources:
  - Ambient light: uniform light everywhere
    - Models contribution of many sources
  - Point source: has position and colour
    - Directional light: position is infinitely far away
  - Spotlight: restrict light to a cone
    - Can have falloff at edges of cone

# OpenGL local illumination model

- Smooth: reflect concentrated in one direction
  - Rough surfaces scatter light in all directions
- The OpenGL illumination model has 3 parts:
  - Ambient light
  - Diffuse scattering (rough)
  - Specular reflection (smooth)




- Uses four vectors:
  - To source (l), To viewer (v)
  - Surface normal (n), Ideal reflection (r)

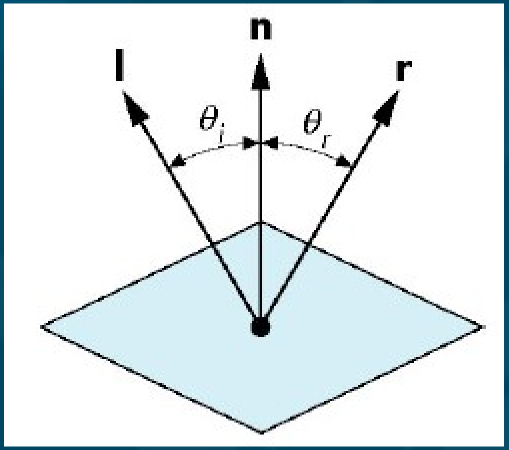


# Ambient light

- Easy way to model multiple interactions between large area light sources and many objects
  - Shadowless
- Intensity and colour depends on:
  - Colour of ambient light: $k_a$
  - Reflectivity of surface material with respect to ambient light: $I_a$
- Ambient term is $k_a I_a$

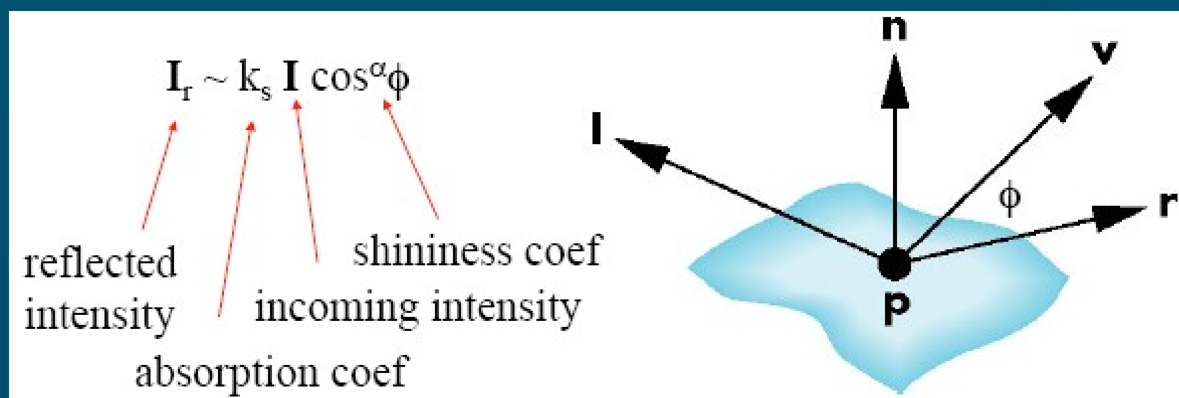
# Lambertian surfaces

- An perfectly specular surface reflects all incident light in the direction of reflection
  - Angle of incidence equals angle of reflection
- A perfectly diffuse (Lambertian) surface scatters all incident light equally in all directions
  - Light reflected is proportional to $\cos(\theta_l) = l * n$
  - Diffuse colour of surface $k_d$ also modulates reflected light
- Diffuse term is $k_d I_d (l * n)$

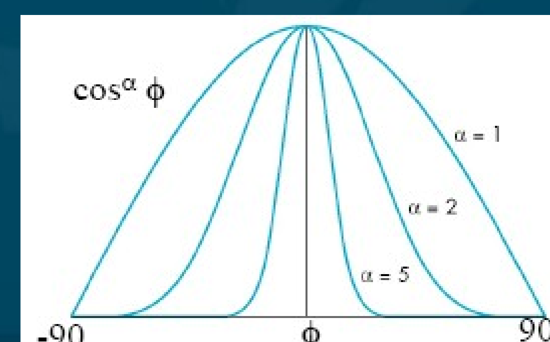


# Shininess

- If viewer is looking along the reflection vector, we see the specular highlight
- Phong added falloff if viewer is slightly off from ideal reflection vector: shininess coefficient




- $\cos(\phi)$ is dotproduct of view vector $v$ and reflection $r$
- Specular term is: $k_s \, I_s \, ( v * r )^{\alpha}$



# Putting it together

- Intensity of a surface patch from our view is
  $$I = k_a I_a + k_d I_d (l * n) + k_s I_s (v * r)^{\alpha}$$
  - Light properties (9):
    - Ambient colour $I_a$
    - Diffuse colour $I_d$
    - Specular colour $I_s$
  - Material properties (10):
    - Absorption coefficients:
      - Ambient $k_a$, diffuse $k_d$, specular $k_s$
    - Shininess coefficient $\alpha$

# Doing this in OpenGL

- Enable shading and select shading model
- Specify lights
- Specify material properties
- Specify geometry and normals

# Selecting lighting model

- Enable lighting (otherwise only flat-shading):
    - glEnable( GL_LIGHTING );
  - Also have to enable each light source:
    - glEnable( GL_LIGHT0 );
    - glEnable( GL_LIGHT1 );
    - Have at least 8 lights (GL_MAX_LIGHTS)
- Set lighting model parameters:
  - Set global ambient light colour
    - glLightModelif( GL_LIGHT_MODEL_AMBIENT, r, g, b )
    - Other params: GL_LIGHT_MODEL_LOCAL_VIEWER, GL_LIGHT_MODEL_TWO_SIDED

# Defining lights

- Point source: position, colours (amb, diff, spec)
  - GL float diffuse0[] = {1.0, 0.0, 0.0, 1.0}; // RGBA
  - GL float ambient0[] = {1.0, 0.0, 0.0, 1.0};
  - GL float specular0[] = {1.0, 0.0, 0.0, 1.0};
  - Glfloat light0_pos[] = {1.0, 2.0, 3,0, 1.0}; // homogeneous

  - glEnable( GL_LIGHTING);
  - glEnable( GL_LIGHT0);

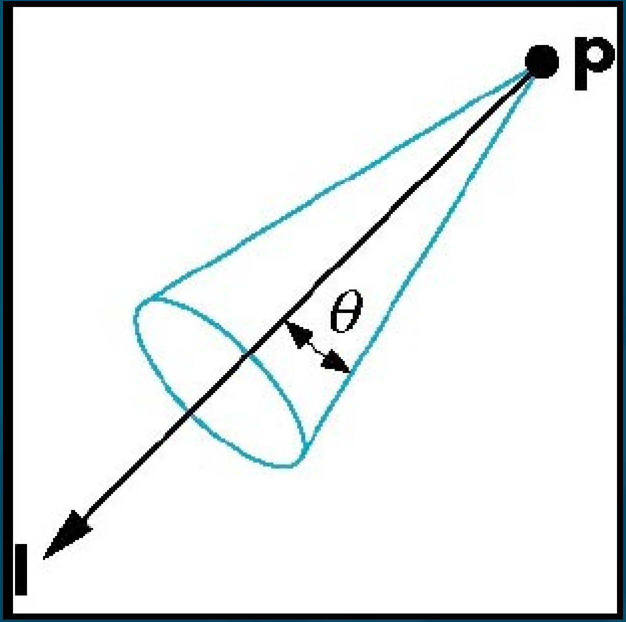
  - glLightv( GL_LIGHT0, GL_POSITION, light0_pos );
  - glLightv( GL_LIGHT0, GL_AMBIENT, ambient0 );
  - glLightv( GL_LIGHT0, GL_DIFFUSE, diffuse0 );
  - glLightv( GL_LIGHT0, GL_SPECULAR, specular0 );

# Directional light source

- The position of a point source is specified in homogeneous coordinates:
  - w=1.0: light is a point source
    - (x,y,z) give coordinates of position
  - w=0.0: light is a directional source
    - (x,y,z) give vector
    - **Glfloat light0_pos[] = {1.0, 2.0, 3,0, 1.0}; // homogeneous**
    - **glLightv( GL_LIGHT0, GL_POSITION, light0_pos );**
- Note that light sources are geometric objects, too
  - Affected by current model-view matrix

# Spotlights

- Spotlights have:
  - RGBA colour (amb, diff, spec)
  - Position
  - Direction
  - Cutoff distance
  - Attenuation exponent $\alpha$
    - Falloff is proportional to $\cos^{\alpha}\phi$

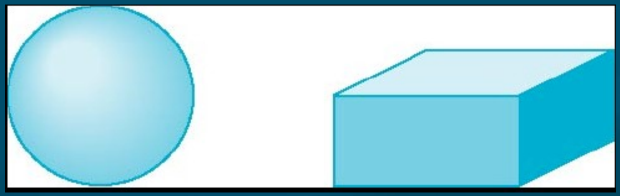


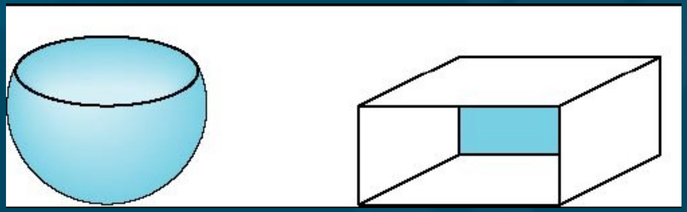
# Material properties

- Part of the OpenGL state: specify before the vertices/polygon to which they apply
  - GLfloat ambient[] = {0.2, 0.2, 0.2, 1.0};
  - GLfloat diffuse[] = {1.0, 0.8, 0.0, 1.0};
  - GLfloat specular[] = {1.0, 1.0, 1.0, 1.0};
  - GLfloat shine = 100.0;
  - glMaterialfv( GL_FRONT, GL_AMBIENT, ambient );
  - glMaterialfv( GL_FRONT, GL_DIFFUSE, diffuse );
  - glMaterialfv( GL_FRONT, GL_SPECULAR, specular );
  - glMaterialfv( GL_FRONT, GL_SHININESS, shine );

# Front and back face materials

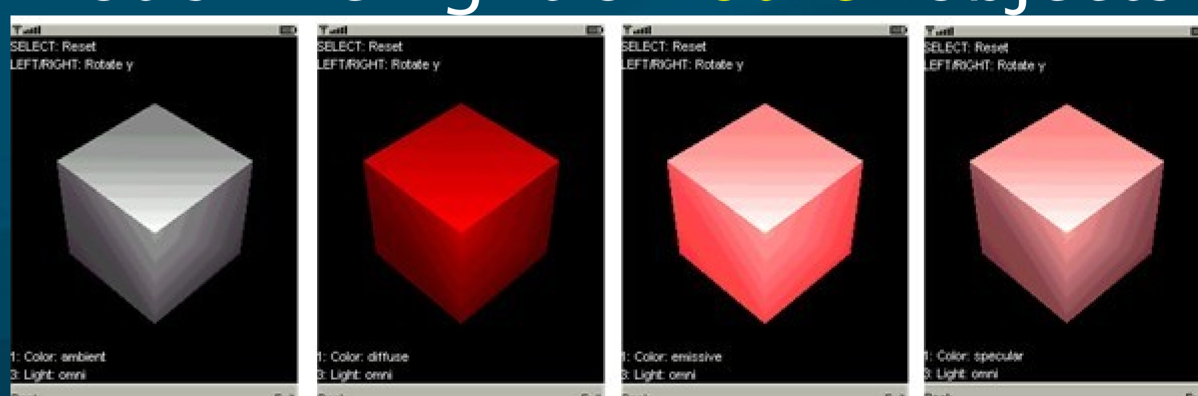
- Recall back-face culling: don't render faces which point away from camera (v * n > 0)
- Two-sided lighting disables back-face culling
  - Front and back faces can get different material properties
  - Use GL_FRONT, GL_BACK, or GL_FRONT_AND_BACK in glMaterialf()





# Emissive light

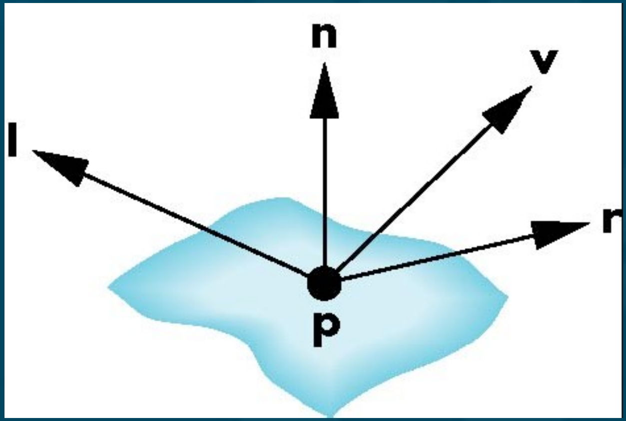
- An extra feature OpenGL throws in is the **emissive** term:
    - GLfloat emission[] = 0.0, 0.3, 0.3, 1.0);
    - glMaterialf( GL_FRONT, GL_EMISSION, emission );
  - Extra light added to the shading equation:
    - I = (ambient) + (diffuse) + (specular) + (emissive)
  - Simulates glowing object
  - Does not shine light on other objects




*(a) ambient*
*(b) diffuse*
*(c) emissive*
*(d) specular*

# Computing the local illumination

- The illumination model relies on four vectors:
  - To light (l): specified by the model/scene
  - To viewer (v): specified by model-view matrix
  - Surface normal (n)
  - Reflection (r): compute from l, n
- Computing normals is not always easy
  - Depends on how we represent the surface
  - OpenGL leaves this up to us (in our application)



# TODO

- Lab4: due this Thu 15Mar
  - Add a virtual trackball using quaternions