Lighting

Why Lighting?

- What light source is used and how the object response to the light makes difference
  - Ocean looks bright bluish green in sunny day but dim gray green in cloudy day
- Lighting gives you a 3D view to an object
  - A unlit sphere looks no different from a 2D disk
- To get realistic pictures, the color computation of pixels must include lighting calculations

Types of Light

- Ambient

  Light that's been scattered so much by the environment that its direction is impossible to determine - it seems to come from all directions

- Diffuse

  Light that comes from one direction, but it gets scattered equally in all directions

- Specular

  Light comes from a particular direction, and its tends to bounce off the surface in a preferred direction

Materials Colors

- A material's color depends on the percentage of the incoming different lights it reflects
- Materials have different ambient, diffuse and specular reflectances
- Material can also have an emissive color which simulates light originating from an object
  - Headlights on a automobile

OpenGL Lighting Model

- Lighting has four independent componets that are computed independently

  Emission, Ambient, Diffuse, and Specular

- OpenGL approximates lighting as if light can be borken into red, green, and blue components
  - The RGB values for lights mean different than for materials

  For light, the numbers correspond to a percentage of full intensity for each color

  For materials, the numbers correspond to the reflected proportions of those colors

- Total effect is a combination of corresponding components of incoming light and illuminated material surface

  (LR*MR, LG*MG, LB*MB)

Theory of Illumination

- Not only knowledge about light but also about what happens when light is reflected from an object into our eyes is important to obtain realistic images
- The general problem is to compute the apparent color at each pixel that corresponds to part of the object on the screen
- The color produced by lighting a vertex (or a object) has several contributions
  - Emission
  - Global ambient light
  - Contributions from light sources

Material Emission

- Emissive brightness of the material = $\boldsymbol{M_e}$
- There is no attempt to model properties of the light or its effects on the objects
- The emissive color adds intensity to the object

$$I_E = M_e$$

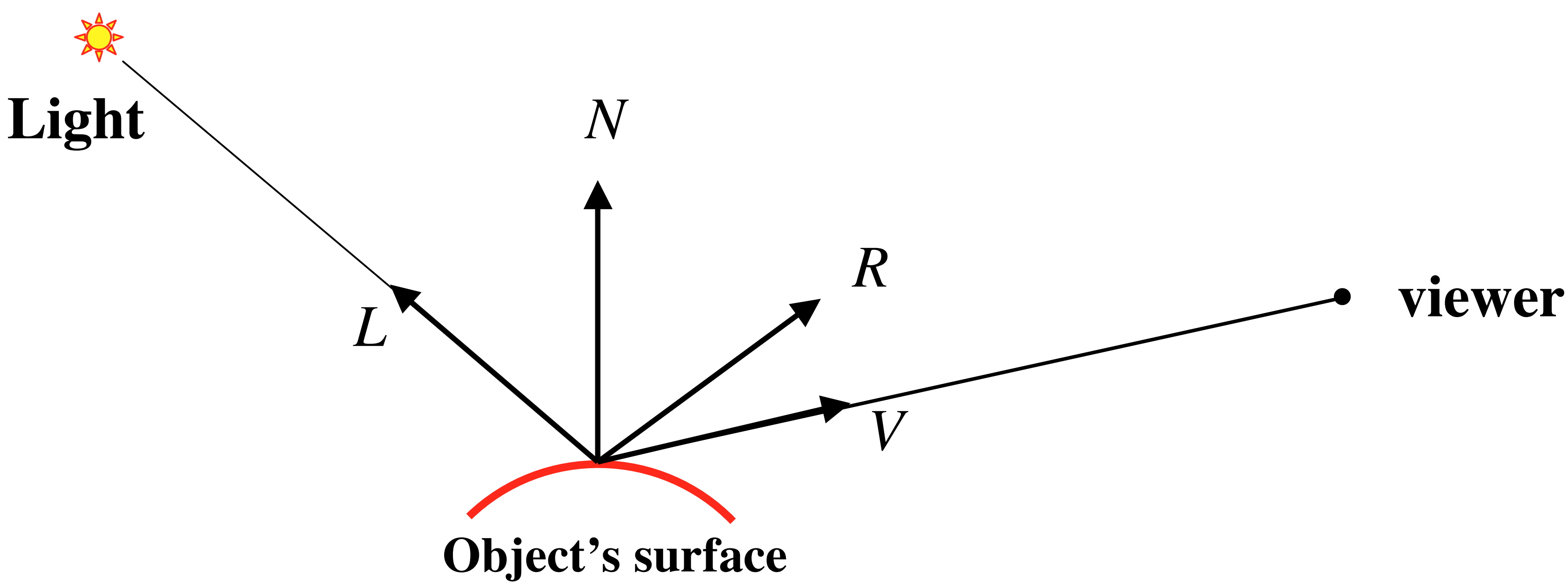
Global Ambient Light

- Light from all directions but not from any specific sources
- Ambient light intensity = G_a
- Ambient reflection coefficient of material = M_a

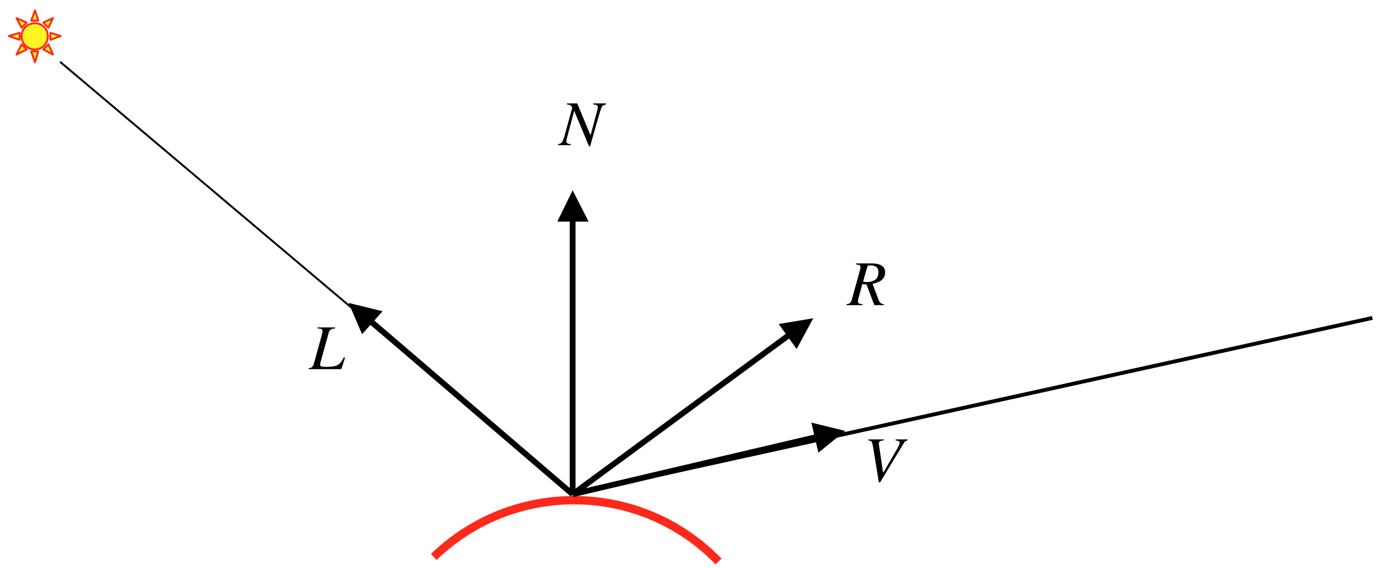
$$I_G = G_a M_a$$

A Point Source of Light

- Contribution from a point source of light include three terms
  - Light has ambient (I_a), diffuse (I_d) and specular (I_s) components
  - Material has ambient(M_a), diffuse (M_d) and specular reflection (M_s) properties



Point Light's Contribution



$$I_L^1 = I_a M_a + I_d M_d (\max\{N \bullet L, 0\}) + I_s M_s (\max\{R \bullet V, 0\})^n$$

First term = ambient

Second term = diffuse

Third term = specular

Point Light's Contribution

- Ambient term
  - ➢ The ambient component of each incoming light source is combined with a material's ambient reflectance
- Diffuse term
  - ➢ Brightness is inversely proportional to the area of the object illuminated (dot product of light vector and surface normal)

    greatest when ***N*** and ***L*** are parallel

    smallest when ***N*** and ***L*** are orthogonal
  - ➢ In calculations, **max{*N.L*, 0})** is used to avoid negative values
- Specular term
  - ➢ Brightness depends on the angle between reflection vector (***R***) and viewer vector (***V***), i.e, on direction of viewer
  - ➢ The specular reflection exponent *n* is 1 for a slightly glossy surface and infinity for a perfect mirror

Attenuation

- Attenuation factor
  - Light attenuates with distance from the source

$$f = \frac{1}{k_c + k_l d + k_q d^2}$$

where d = distance between the light and object

k_c = constant attenuation

A light source does not give an infinite amount of light

k_l = linear term

The light source is not a point

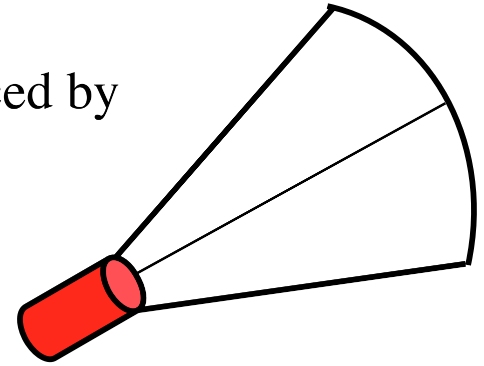
k_q = quadratic term

Models the theoretical attenuation from a point source

- The intensity becomes

$$I_L^2 = f[I_a M_a + I_d M_d (\max\{N \bullet L, 0\}) + I_s M_s (\max\{R \bullet V, 0\})^n]$$

Spotlight Effect



When the vertex lies inside the cone of illumination produced by spotlight, its contribution to the light intensity is

$$s = (\max\{D \bullet L, 0\})^m$$

Where ***D*** gives the spotlight's direction. The intensity is maximum in the center of cone and is attenuated toward the edge of the cone
s is 1 if the source is not spotlight
m is exponent determining the concentration of the light

The intensity of light source is

$$I_L = fs[I_a M_a + I_d M_d(\max\{N \bullet L, 0\}) + I_s M_s(\max\{R \bullet V, 0\})^n]$$

Putting All Together

Entire lighting calculation in RGB mode gives

$$\text{Vertex color} = M_e + G_a M_a +$$
$$\sum_{i=1}^{n-1} f_i s_i [I_a M_a + I_d M_d (\max\{N \bullet L, 0\}) + I_s M_s (\max\{R \bullet V, 0\})^n]_i$$

Adding Lighting to the Scene

- Define normal vectors for each vertex of each object
- Create, select, and position one or more light sources
- Create and select a lighting model
- Define material properties for the objects in the scene

Creating Light Sources

- Properties of light sources are color, position, and direction

- void **glLight**{if}(GLenum *light*, GLenum *pname*, *TYPE param*);

  void **glLight**{if}**v**(GLenum *light*, GLenum *pname*, *TYPE* **param*);

  - Creates the light specified by *light* that can be GL_LIGHT0, GL_LIGHT1, … or GL_LIGHT7
  - *Pname* specifies the characteristics of the light being set
  - *Param* indicates the values to which the *pname* characteristic is set

- **glEnable**(GL_LIGHT0);

Color for a Light Source

```
GLfloat light_ambient[] = {0.0,0.0,0.0,1.0};
GLfloat light_diffuse[] = {1.0,1.0,1.0,1.0};
GLfloat light_specular[] = {1.0,1.0,1.0,1.0};

glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient);
glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse);
glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular);
```

Position of Light Source

- Positional light source
  - (*x*, *y*, *z*) values specify the location of the light

    GLfloat light_position[] = {*x*, *y*, *z*, *w*};

    glLightfv(GL_LIGHT0, GL_POSITION, light_position);

- Directional light source
  - (*x*, *y*, *z*) values specify the direction of the light located at the infinity
  - No attenuation

    GLfloat light_position[] = {*x*, *y*, *z*, *0*};

    glLightfv(GL_LIGHT0, GL_POSITION, light_position);

Attenuation

- Attenuation factor for a positional light
  - Needs to specify three coefficients

    glLightf(GL_LIGHT0, GL_CONSTANT_ATTENUATION, 2.0);

    glLightf(GL_LIGHT0, GL_LINEAR_ATTENUATION, 1.0);

    glLightf(GL_LIGHT0, GL_QUADRATIC_ATTENUATION, 1.0);

- Ambient, diffuse, and specular contributions are all attenuated

Spotlights

- The shape of the light emitted is restricted to a cone
- **glLightf**(GL_LIGHT0, GL_SPOT_CUTOFF, 45.0);
  - The cutoff parameter is set to 45 degrees
- GLfloat spot_direction[] = {-1.0, -1.0, 0.0];
  glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, spot_direction);
  - specifies the spotlight's direction which determines the axis of the cone of light
- **glLightf**(GL_LIGHT0, GL_SPOT_EXPONENT, 2.0);
  - Controls how concentrated the light is

Multiple Lights

- You can define up to eight light sources
  - Need to specify all the parameters defining the position and characteristics of the light

- OpenGL performs calculations to determine how much light each vertex gets from each source

- Increasing number of lights affects performance

Controlling a Light's Position and Direction

- A light source is subject to the same matrix transformations as a geometric model
  - Position or direction is transformed by the current modelview matrix and stored in eye coordinates

- Keeping the light stationary
  - Specify the light position after modelview transformations

- Independently moving the light
  - Set the light position after the modeling transformation that you want to apply for light

- Moving the light together with the viewpoint
  - Set the light position before the viewing transformation

Selecting a Lighting Model

- How to specify a lighting model

- **glLightModel**{if}(GLenum *pname*, *TYPE param*);
  glLightModel(if}**v**(GLenum *pname*, *TYPE *param*);
  - Sets properties of the lighting model
  - *pname* defines the characteristic of the model being set
  - *param* indicates the values to which the *pname* characteristic is set

- Needs to be enabled or disabled

  glEnable(GL_LIGHTING);
  glDisable(GL_LIGHTING);

Components of Lighting Model

- Global ambient light
  - Ambient light from not any particular source

    GLfloat lmodel_ambient[] = {0.2, 0.2, 0.2, 1.0}

    glLightModelfv(GL_LIGHT_MODEL_AMBIENT, lmodel_ambient);

- Local or Infinite viewpoint
  - Whether the viewpoint position is local to the scene or whether it should be considered to be an infinite distance away

    glLightModeli(GL_LIGHT_MODEL_LOCAL_VIEWER,
    GL_TRUE);

    Default is an infinite viewpoint

- Two-sided lighting
  - Whether lighting calculations should be performed differently for both the front and bacl faces of objects

    glLightModeli(GL_LIGHT_MODEL_TWO_SIDE, GL_TRUE);

Defining Material Properties

- Specifying the ambient, diffuse, and specular colors, the shininess, and the color of any emitted light

- void **glMaterial**{if}(GLenum *face*, GLenum *pname*, *TYPE param*);

  void **glMaterial**{if}**v**(GLenum *face*, GLenum *pname*, *TYPE *param*);

  - Specifies a current material property for use in lighting calculations
  - *Face* can be GL_FRONT, GL_BACK, or GL_FRONT_AND_BACK
  - *Pname* identifies the particular material property being set
  - *Param* defines the desired values for that property

Reflectances

- Diffuse and ambient reflection
  - Gives color

```
GLfloat mat_amb_diff[] = {0.1, 0.5,0.8,1.0};
glMaterialfv(GL_FRONT_AND_BACK,
     GL_AMBIENT_AND_DIFFUSE, mat_amb_diff);
```

- Specular reflection
  - Produces highlights

```
GLfloat mat_specular[] = {1.0,1.0,1.0,1.0);
Glfloat low_shininess[] = {5.0};
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
glMaterialfv(GL_FRONT, GL_SHININESS, low_shininess);
```

- Emission
  - Make an object glow (to simulate lamps and other light sources

```
GLfloat mat_emission[] = {0.3,0.2,0.2,0.0};
glMaterialfv(GL_FRONT, GL_EMISSION, mat_emission);
```

Changing Material Properties

- Different material properties for different vertices on the same object or different objects

- **glMaterialfv**() needs to be called repeatedly to set the material property that needs to be re-specified for each case

- **glColorMaterial**(GLenum *face*, GLenum *mode*);
  - Specifies the property (properties) defined by *mode* of the selected material *face* (or faces) to track the value of the current color at all times
  - Needs enabling

Example: A lit sphere

- 2D disk in the absence of lighting
- 3D sphere
- Shinning sphere
- Emissive sphere
- Moving light source