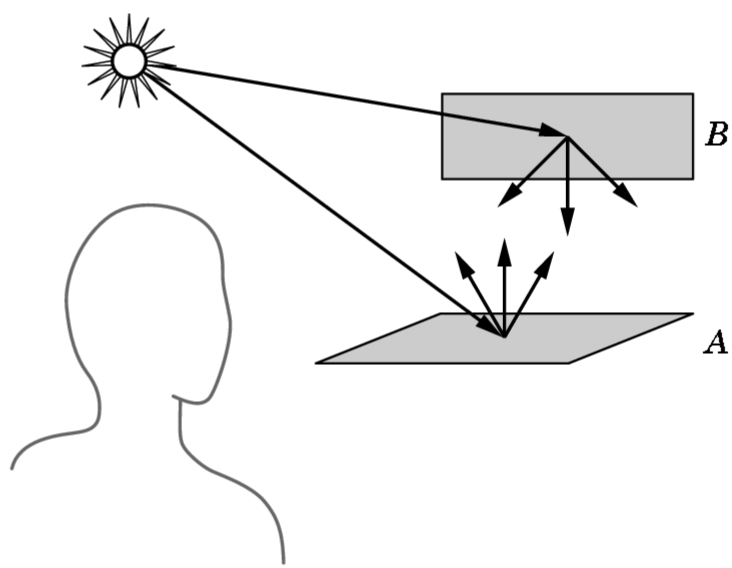
CS312

OpenGL

Lights and Materials

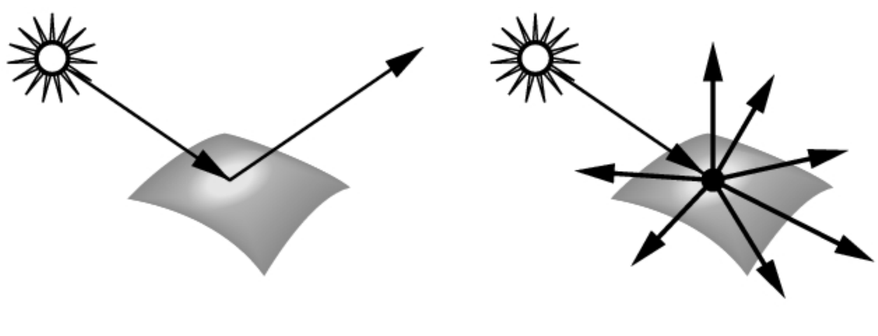
Light and Matter

- From a physical perspective, a surface can either
  - emit light by self-emission (as a light bulb)
  - reflect light from other sources that illuminate it.



Interaction Between Light and Surfaces

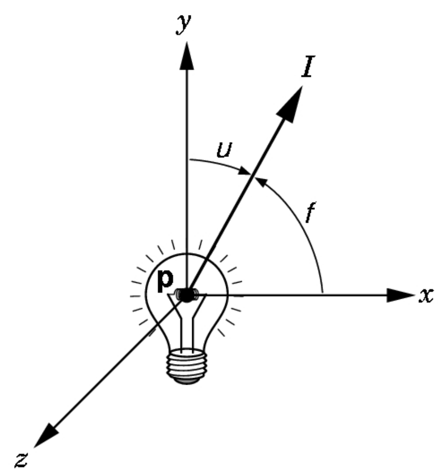
- (a) specular
- (b) diffuse
- (c) translucent



(a) (b) (c)

Light Sources

- Light can leave a surface through
  - self-emission and reflection.
- What specifies a light source
  - position
  - direction
  - intensity



Color Sources

- Not only do light sources emit different amounts of light at different frequencies, but also their directional properties vary with frequency.
- Our visual system is based upon three primaries
    - For most applications, it is sufficient to reduce each light to a 3-component frequency:

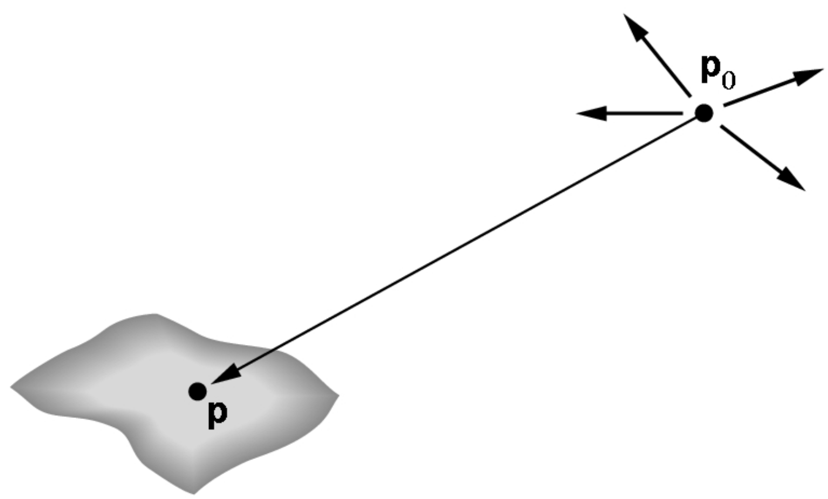
$$I = aI_r + \beta I_g + gI_b$$

Ambient Lights

- Lights that are designed and positioned to provide uniform illumination throughout the room (kitchens, classrooms).
- Achieved with light sources that have diffusers whose purpose is to scatter light in all directions.
  - Florescent lights have covers designed to do this.
- To the lit surface, ambient light has no apparent direction.

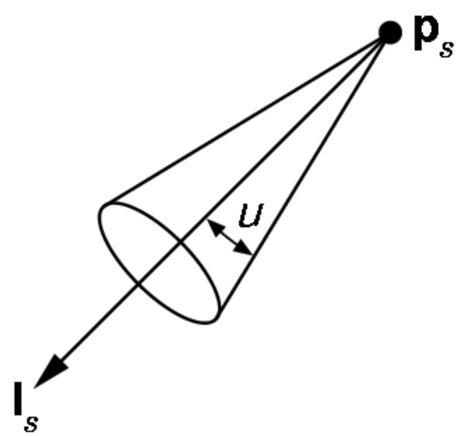
Point Sources (Diffuse)

- An ideal point source emits light equally in all directions.
- To the lit surface, diffuse light is directional.
- The intensity of illumination proportional to the distance, and also depends on the angle of impact.



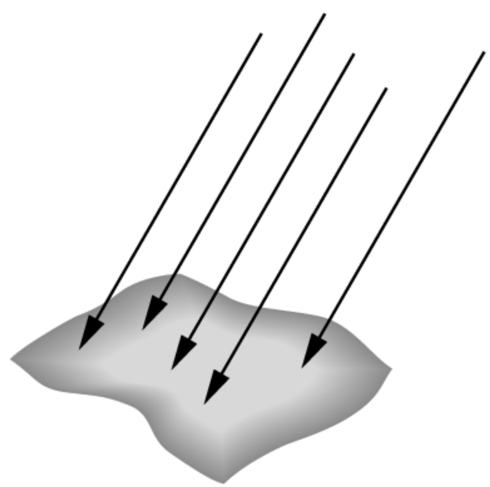
Spotlights

- Spotlights are characterized by a narrow range of angles through which light is emitted.
  - A spotlight can be constructed from a point source by limiting the angles



Distant Light Sources

- If the light source is far from the surface, the direction of light is uniform across the entire surface (the sun).



Parallel Light Rays

- Equivalent to a source that illuminates objects with parallel rays of light.
- Graphics systems can carry out rendering calculations more efficiently for distant light sources than for near ones.
  - OpenGL allows both

Material Properties

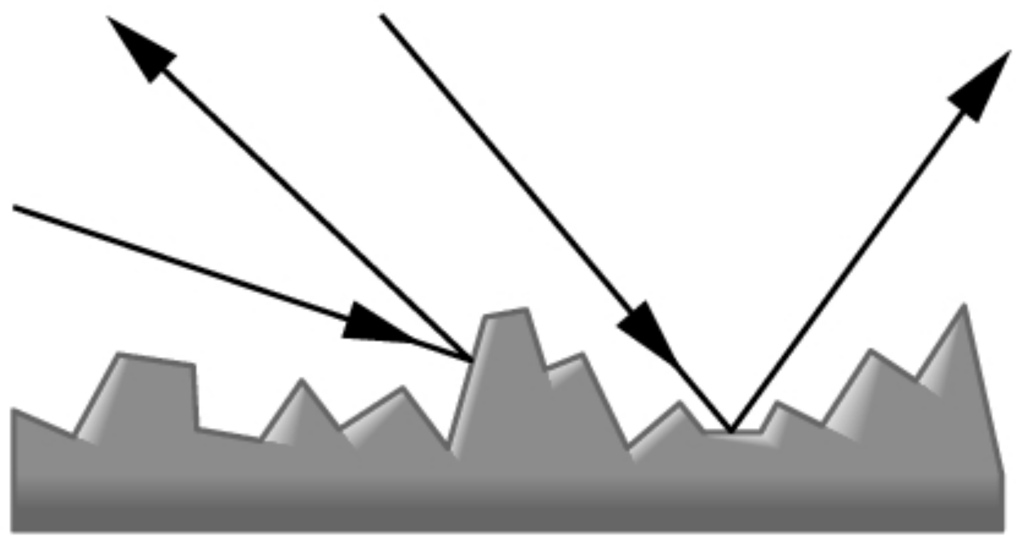
- Three different reflections
  - ambient
  - diffuse
  - specular

Ambient Reflection

- The intensity of ambient light is the same at every point on the surface.
  - Some light is absorbed and some is reflected.
  - A surface has of course, three ambient coefficients and they can be different.
  - Hence, a sphere appears yellow under white ambient light if its blue ambient coefficient is small and its red and green coefficients are large.

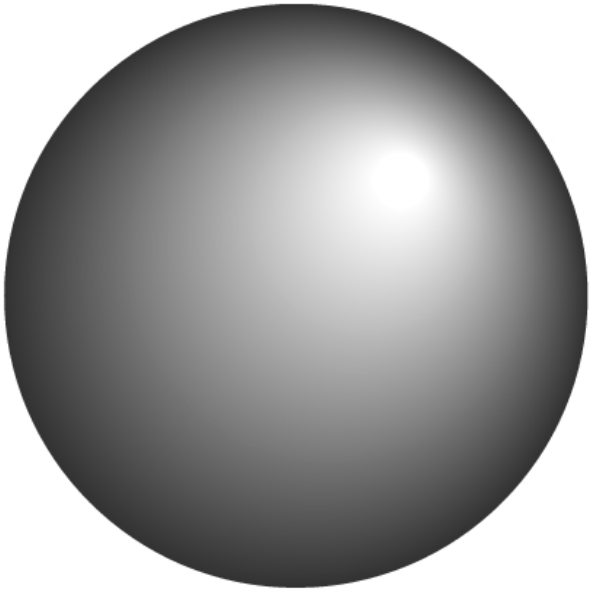
Diffuse Reflection

- A perfectly diffuse reflector scatters the light that it reflects equally in all directions.
- Perfectly diffuse surfaces are so rough that there is no preferred angle of reflection



Specular Reflection

- Only ambient and diffuse reflections result in shaded but dull, somewhat chalk-like surfaces.
- The highlights



Normal Vectors

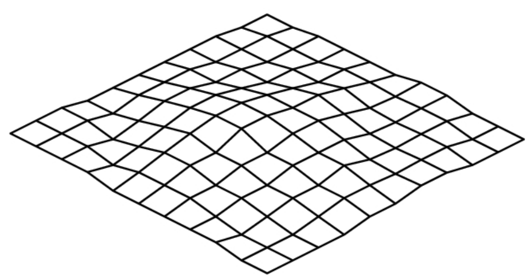
- The surface normal gives the orientation.
- Given 3 noncollinear points, normal is
  - n = (p2-p0) x (p1-p0)
  - Be careful about the order of the vectors. Reversing the order changes the surface from outward pointing to inward pointing.

GL Normals

- Associate a normal with a vertex through functions such as
  - `glNormal3f(nx, ny, nz);`
  - `glNormal3fv(ptr_to_array);`
  - Normals are modal: if we define a normal before a sequence of vertices, this normal is associated with all the vertices
- Set the normal to have unit length so cosine calculations are correct
  - Length can be affected by transformations
  - `glEnable(GL_NORMALIZE)` allows for autonormalization at a performance penalty

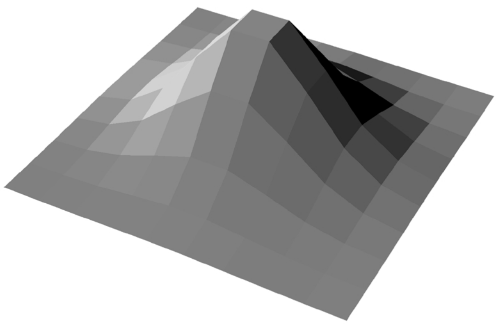
Polygonal Shading

- Consider the polygon mesh shown here. We will consider three ways to shade the polygons: flat, interpolative or Gourand, and Phong shading



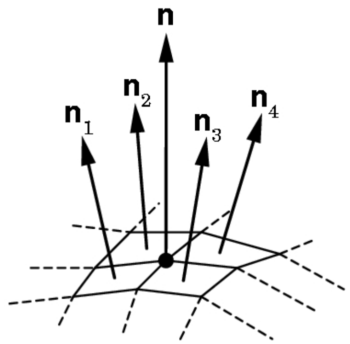
Flat Shading

- For a flat polygon, the normal is constant
- The shading calculations only need to be carried out once for each polygon.
  - `glShadeModel(GL_FLAT);`



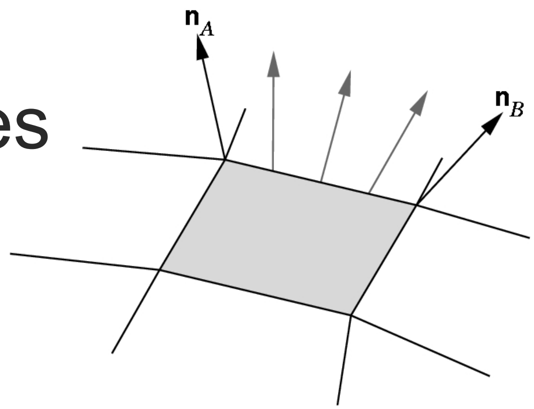
Interpolative and Gourand Shading

- The normals are computed at each vertex. Colors and intensities of interior points are interpolated between vertices.
  - **`glShadeModel(GL_SMOOTH);`**



Phong Shading

- Instead of interpolating the intensities, interpolate the normals
- Then do calculation of intensities using the interpolated normal (typically at scan conversion)



- Interpolating normals is much more expensive than interpolating colors in Gourand Shading
- Phong shading (e.g., per pixel shading) can be implemented using shaders in OpenGL
- Usually done off-line (not supported in OpenGL)

Light Sources in OpenGL

- OpenGL supports the four types of light sources that we just described, and allows at least 8 light sources per program.
- Each light source must be individually specified and enabled.
  - `glLightfv(source, parameter, pointer_to_array);`
  - `glLightf(source, parameter, value);`

Light Parameters

- The position (or direction) of the light, the amount of ambient, diffuse, and specular light associated with a source.

```
GL float diffuse0[]={1.0, 0.0, 0.0, 1.0};
...
glLightfv(GL_LIGHT0, GL_POSITION, light0_pos);
glLightfv(GL_LIGHT0, GL_AMBIENT, ambient0);
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffuse0);
glLightfv(GL_LIGHT0, GL_SPECULAR, specular0);
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
```

- Note that we must enable both lighting and all the particular source lights.

Direction and Position

- When specifying a light position, a light may either be directional (rays parallel), or positional.

```
float light0_pos[] = {1.0,1.0,1.0,0.0};
glLightfv(GL_LIGHT0, GL_POSITION, light0_pos);
```

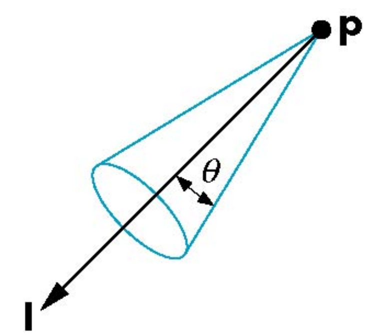
- If the 4th value is `0` then the light is directional. Otherwise it is positional.

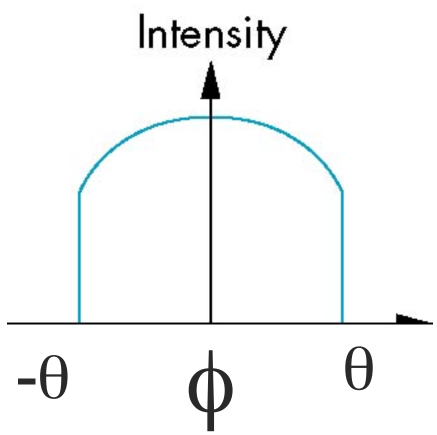
Other Lighting Functions

- Change lighting model
  - **`glLightModel*(Param, value);`**
  - **`GL_LIGHT_MODEL_AMIENT, (0.2, 0.2, 0.2)`**
  - **`GL_LIGHT_MODEL_LOCAL_VIEWER, GL_FALSE`**
  - **`GL_LIGHT_MODEL_TWO_SIDED, GL_FALSE`**

Spotlights

- Use `glLightf` to set
  - Direction `GL_SPOT_DIRECTION`
  - Cutoff `GL_SPOT_CUTOFF`
  - Exponent `GL_SPOT_EXPONENT`
    - Shininess controlled by $\cos^{\alpha}\phi$





Moving Light Sources

- Light sources are geometric objects whose positions or directions are affected by the model-view matrix
- Depending on where we place the position (direction) setting function, we can
  - Move the light source(s) with the object(s)
  - Fix the object(s) and move the light source(s)
  - Fix the light source(s) and move the object(s)
  - Move the light source(s) and object(s) independently

Materials Specifications

- Material reflective parameters are specified through the functions:
  - `glMaterialfv(face, type, pointer_to_array);`
  - `glMaterialf(face, value);`
- For Example:
  - `glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, ambient);`

Material Properties

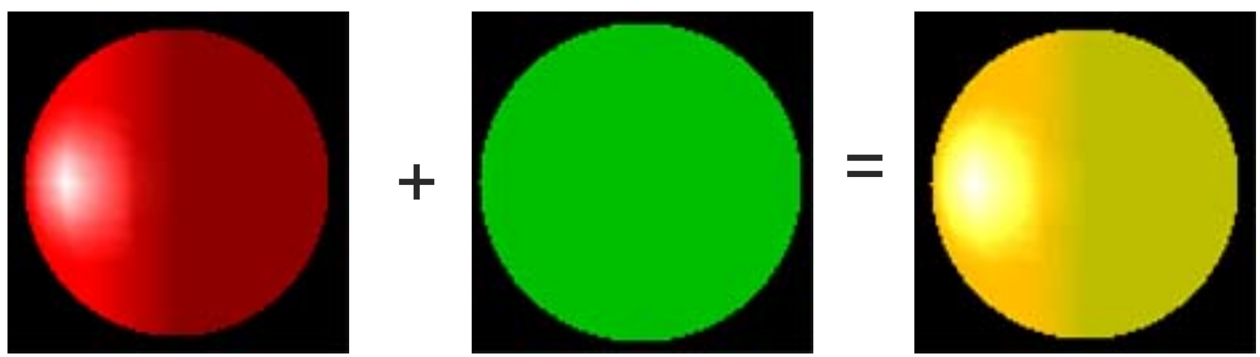
- To specify different front- and back-face properties
  - Use **`GL_FRONT`** or **`GL_BACK`**
- The shininess of a surface (specular-reflection term) is specified as follows:
  - **`glMatrialg(GL_FRONT, GL_SHININESS, 100.0);`**

Material Properties

```
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
glMaterialf(GL_FRONT, GL_AMBIENT, ambient);
glMaterialf(GL_FRONT, GL_DIFFUSE, diffuse);
glMaterialf(GL_FRONT, GL_SPECULAR, specular);
glMaterialf(GL_FRONT, GL_SHININESS, shine);
```

Emissive Term

- We can simulate a light source in OpenGL by giving a material an emissive component
- This color is unaffected by other light sources.



Red light Green Emissive

```
GLfloat emission[] = 0.0, 0.8, 0.1, 1.0);
glMaterialf(GL_FRONT, GL_EMISSION, emission);
```

Steps in OpenGL shading

1. Enable shading and select model
2. Specify normals
3. Specify material properties
4. Specify lights

Efficiency

- Because material properties are part of the state, if we change materials for many surfaces, we can affect performance
- We can make the code cleaner by defining a material structure and setting all materials during initialization

```
typedef struct materialStruct {
   GLfloat ambient[4];
   GLfloat diffuse[4];
   GLfloat specular[4];
   GLfloat shineness;
} MaterialStruct;
```

- We can then select a material by a pointer

Smooth Shading

- We can set a new normal at each vertex
- Easy for sphere model
  - If centered at origin $\mathbf{n} = \mathbf{p}$
- Now smooth shading works
- Note *silhouette edge*

Gouraud and Phong Shading

- Gouraud Shading
  - Find average normal at each vertex (vertex normals)
  - Apply Phong model at each vertex
  - Interpolate vertex shades across each polygon
- Phong shading
  - Find vertex normals
  - Interpolate vertex normals across edges
  - Find shades along edges
  - Interpolate edge shades across polygons

Comparison

- If the polygon mesh approximates surfaces with a high curvatures, Phong shading may look smooth while Gouraud shading may show edges
- Phong shading requires much more work than Gouraud shading
  - Usually not available in real time systems
- Both need data structures to represent meshes so we can obtain vertex normals