Introduction

This lecture and the next we discuss illumination and shading models.

Illumination models express how light affects a surface's color at a given point.

Shading models use illumination models to determine the color across a surface.

- Apply the illumination model at some points.
- Interpolate the illumination at other points.

This process is sometimes called "lighting the object".

The models are only loosely physical, and emphasize:

- empirical success
- efficiency

For example, these models focus on *direct* illumination.

Later lectures will cover:

- *indirect* illumination
- shadows

Outline

1. Light sources
2. Basic Illumination Models account for

- The light source
  - ambient light
  - point light source
  - distributed light source
  - spot lights
- The surface properties
  - diffuse/rough/dull (difuse reflection)
  - specular/smooth/shiny (specular reflection, Phong)
- The geometry of souce/surface/viewer, distances.
- For more realistic appearence, the reflection from a surface is attenuated sum of ambient, diffuse and specular component s (in all primaries, and also over all ligh sources)

3. Lighting and shading in OpenGL .
   Light sources can be turned on/off:

```
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
```

OpenGL supports multiple lights, but performance suffers. Lighting model adds independent components (emmisive, ambient, diffuse, specular color "light" , also similar component description of "materials reflectance").

4. Read: HB 14.1-14.2, WND Ch 5

Illumination models

Illumination, I, at a point is modeled as the sum of several terms.

- More terms give more plausible results.
- Fewer terms give more efficient computations.

Each aditive term of I is expressed in primary colors, I_R, I_G and I_B, with each such I_λ computed independently.

- Components used to express how much light a source emits and a surface reflects.

Each I_λ is the sum of a terms, one fore each light source, computed independently.

- Overflow is possible
- There are various solutions for dealing with it.
  - One solution is to clamp I_λ to max allowable
  - Normalize individual terms

Ambient light

An *ambient* term approximates uniform, indirect illumination present everywhere.

The ambient light intensity is $I_{a\lambda}$ for primary color λ.

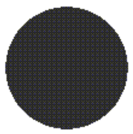
How an object reflects ambient light depends on its *material properties*.

- The overall fraction reflected is k_a.
- The fraction of primary λ reflected is $O_{d\lambda}$.
- The overall fraction of primary λ reflected is thus $k_a O_{d\lambda}$.
- This specification allows independent control of the overall intensity of reflection and of its color.

The illumination model at an object point is thus so far:

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda}$$

A resulting image:



Ambient light in OpenGL

Enable a global ambient light:

```
float globalAmbient[] = {r,g,b,1};
glLightModelfv(GL_LIGHT_MODEL_AMBIENT,
    globalAmbient);
```

OpenGL allows an ambient term in individual lights (e.g., `GL_LIGHT0`).

- What does this mean?

Specify ambient material property:

```
float ambient[] = {r,g,b,1};
glMaterialfv(GL_FRONT_AND_BACK,
    GL_AMBIENT, ambient);
```

- Note that k_a and $O_{d\lambda}$ are combined.
- Note different meaning of `{r,g,b,1}`

Nonambient light

Most light sources do not illuminate all surfaces uniformly.

Point light sources:

- radiate evenly in all directions from a position
- provide different illumination on surfaces with different orientations.
- when point light source is far, the light rays are well approximated by parallel rays

Diffuse reflection

Consider a dull, matte surface (e.g., chalk), it scaters light.

- When its orientation is *fixed* relative to a light, its illumination looks the same from all viewing angles.
- When its orientation *changes* relative to a light, its illumination changes.
  - It is brightest when the light shines directly on it.
  - It is dimmer when it makes an angle to the light.

This reflection is *diffuse* (*Lambertian*) reflection: what we see is accordinc to Lembert's law is the vertical component of the incoming light:

This vertical component at **p** is $I_{p\lambda}\cos(\theta)$ or $I_{p\lambda}(\mathbf{N} \bullet \mathbf{L})$,

where:

- The unit surface normal at a point, **p**, is **N**.
- **L** is a unit vector pointing to the light source
- θ is the angle between **N** and **L**.

The reflected light is 0 for $\theta > 90°$.

Intuition: consider a far point source shining on a plane. As the source is lowered the same amount of light is spread over larger area (vertical component decreases, surface appears dimmer)

The diffusely reflected light depends on the surface's material properties.

- The overall fraction reflected is k_d.
- The fraction of primary λ reflected is $O_{d\lambda}$.

Given point light source, the diffuse intensity at it is:

$$I_{p\lambda} k_d O_{d\lambda} (\mathbf{N} \bullet \mathbf{L})$$

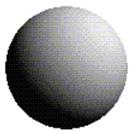
The illumination model at a point is thus so far:

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + I_{p\lambda} k_d O_{d\lambda} (\mathbf{N} \bullet \mathbf{L})$$

The dot product calculated at every point. Evaluation is more efficient assuming *directional* point light sources.

- The light's position is infinitely far away
- All rays are parallel by the time they reach the scene.
- **L** is a constant throughout the scene.

A resulting image:



Diffuse reflection in OpenGL

Specify the light that can be diffusely reflected (properties and their values), defines the " color of the light" :

```
float diffuse0[] = {r,g,b,1};
glLightfv(GL_LIGHT0, GL_DIFFUSE,
    diffuse0);
```

Specify the light's direction (from the origin to infinity):

```
float direction0[] = {dx,dy,dz,0};
glLightfv(GL_LIGHT0, GL_POSITION,
    direction0);
```

- The parameter being set is `GL_POSITION`
- The 0 in the last element of `direction0` indicates that this light is a directional light.

Specify diffuse material property:

```
float diffuse[] = {r,g,b,1};
glMaterialfv(GL_FRONT_AND_BACK,
    GL_DIFFUSE, diffuse);
```

- Must do at every frame, not just once in init. To have lights stay fixed w.r.t. scene, do after camera transformations, before object transformations.
- Note that k_d and $O_{d\lambda}$ are combined. If $k_a = k_d$, use

```
float ambDiff[] = {r,g,b,1};
glMaterialfv(GL_FRONT_AND_BACK,
    GL_AMBIENT_AND_DIFFUSE, ambDiff);
```

Specular reflection

Consider a glossy, shiny surface (e.g., plastic, metal).

- The surface reflects a bright highlight.
- The highlight changes with viewing angle.

This reflection is *specular* reflection.

More precisely:

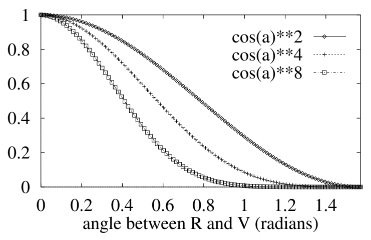
- **N** is the unit normal at point **p**.
- **L** is the unit vector pointing to the light source.
- θ is the angle between **N** and **L**.
- **R** is the vector of mirror reflection.
  - **R** also makes angle θ with **N**.
  - **R** is on the "other side" of **L**.
- **V** is a unit vector pointing to the camera.
- α is the angle between **R** and **V**.

- The highlight's visible intensity depends on α.
  - The highlight is most intense when $\alpha = 0$.
  - The highlight becomes dimmer as α grows.

Specular reflection

1. Perfect specular reflection (mirror):
2. In 1975, Phong developed and approximation to the dependency of specular reflection on α.

- A light of intensity $I_{p\lambda}$ produces a highlight intensity proportional to $I_{p\lambda}(\cos(\alpha))^n$.



- The exponent, *n* is a material property.

Other material properties affect the intensity specularly reflected.

- The overall fraction reflected is $W(\theta)$, often taken to be the constant k_s.
- The fraction of primary λ reflected is $O_{s\lambda}$.

The specular intensity is thus:

$$I_{p\lambda} k_s O_{s\lambda} (\cos(\alpha))^n$$

Specular reflection

An equivalent expression for specular reflection is:

$$I_{p\lambda} k_s O_{s\lambda} (\mathbf{R} \bullet \mathbf{V})^n$$

Deriving **R**:

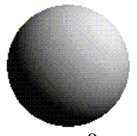
- Use the halfway vector, H =(L+V)/|L+V|, to approximate R.V by N.H.

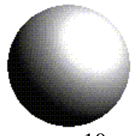
Specular reflection

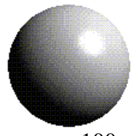
The illumination model at a point is thus so far:

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + I_{p\lambda} k_d O_{d\lambda} (\mathbf{N} \bullet \mathbf{L}) + I_{p\lambda} k_s O_{s\lambda} (\mathbf{R} \bullet \mathbf{V})^n$$

Some resulting images:


$n = 0$


$n = 10$


$n = 100$

Specular reflection in OpenGL

Specify the light that can be specularly reflected:

```
float specular0[] = {r,g,b,1};
glLightfv(GL_LIGHT0, GL_SPECULAR,
   specular0);
```

Specify specular material properties:

```
glMaterialf(GL_FRONT_AND_BACK,
   GL_SHININESS, n);
float specular[] = {r,g,b,1};
glMaterialfv(GL_FRONT_AND_BACK,
   GL_SPECULAR, specular);
```

- Note that k_s and $O_{s\lambda}$ are combined.

Other terms in illumination models

Light can attenuate with distance from the source.

Fog can affect the reflection visible at the camera.

Spotlights can produce light limited to a cone around **L**.

Shading models

Ideally, the renderer should apply the illumination model at every visible point on each surface.

This approach requires too much computation.

As an alternative, use sampling.

- Apply the illumination model at a subset of points.
- Interpolate the intensity of the other points.

Flat (constant) shading

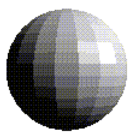
Sample illumination at one point per polygon.

Use constant interpolation: all other points on the polygon get that point's intensity.

This approach would be valid if:

- The true surface really is faceted, so **N** is constant.
- The light source is at infinity so **L** is constant.
- The viewer is at infinity so **V** is constant.

A resulting image:



Flat shading in OpenGL

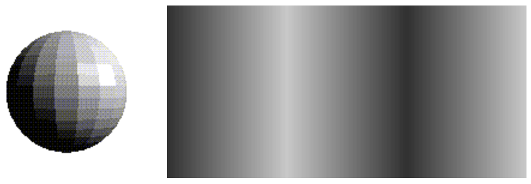
Just enable it:

```
glShadeModel(GL_FLAT);
```

Mach banding

Flat shading of more facets does not necessarily look smoother.

Imaginary dark and light lines appear at facet boundaries.



These lines appear at any discontinuity or drastic change in the rate of shading.

These lines are perceptual artifacts called *Mach bands*.

Mach bands are caused by the eye's *lateral inhibition*.

- When one receptor responds to a high intensity, it inhibits its neighboring receptors' responses.
- Receptors on the bright side of a discontinuity receive *less* inhibition from the dark side.
- Receptors on the dark side of a discontinuity receive *more* inhibition from the light side.

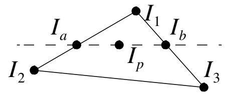
Gouraud shading

Apply the illumination model at each polygonal vertex.

- **N** is the vertex normal.
- The calculation must use **N** in world coordinates.

Interpolate intensities as part of scan conversion.

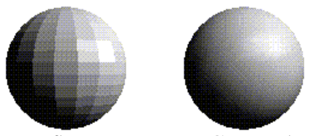
- Interpolate span endpoints from edge vertices.
- Interpolate points within a span from span endpoints.
- Perform interpolation through incremental updates.



Gouraud shading reduces Mach bands (but not entirely).

- Vertices shared between polygons will have the same vertex normal, and hence the same intensity.

Some resulting images:



fl at Gouraud

Gouraud shading in OpenGL

Just enable it:

```
glShadeModel(GL_SMOOTH);
```

Phong shading

Apply the illumination model at each pixel.

Interpolate a pixel's normal, **N**, as part of scan conversion.

- To get **N** at span endpoints, interpolate from edge vertices' normals.
- To get **N** within a span, interpolate from span endpoints.
- Perform interpolation through incremental updates.
- The vertex **N**s must be in world coordinates so the interpolated **N**s will be, too, for the illumination calculations.

This approach avoid some errors in specular illumination that appear with Gouraud shading.

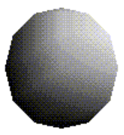
- Gouraud misses specular highlights within polygons.
- Gouraud spreads specular highlights along edges.

[FvDFH Fig. 16.21, p. 739]

OpenGL does not support Phong shading.

Problems common to Gouraud and Phong shading

Silhouette edges are not smoothed.



Interpolation ignores perspective distortion.

- Due to foreshortening, a change in scanlines does not correspond to a constant change in z in OpenGL eye coordinates.

- So the scanline halfway between two vertices does *not* correspond to z halfway between the vertices' zs.
- But pixels on that scanline get an interpolated quantity (intensity or **N**) that *does* correspond to the halfway z.