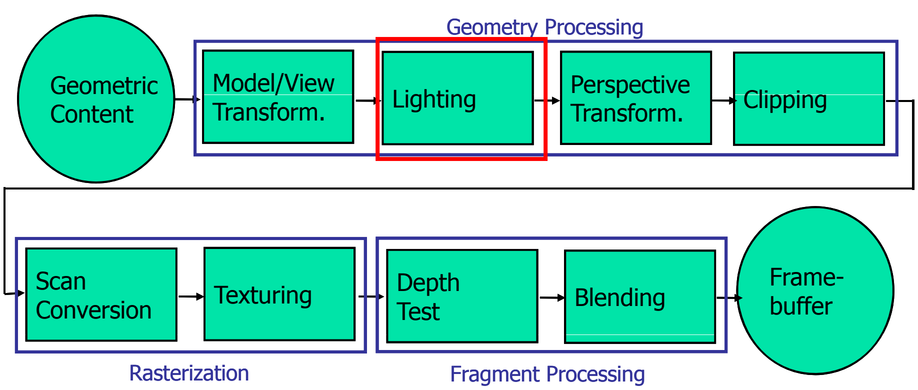
Chapter 6

Lighting

Rendering Pipeline

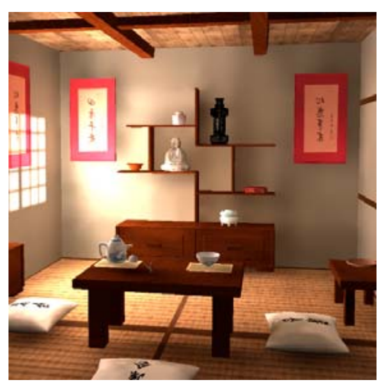


Lighting/Shading

- Goal
  - Model the interaction of light with surfaces to render realistic images
  - Generate per (pixel/vertex) color

Factors

- Light sources
  - Location, type & color
- Surface materials
  - How surfaces reflect light
- Transport of light
  - How light moves in a scene
- Viewer position

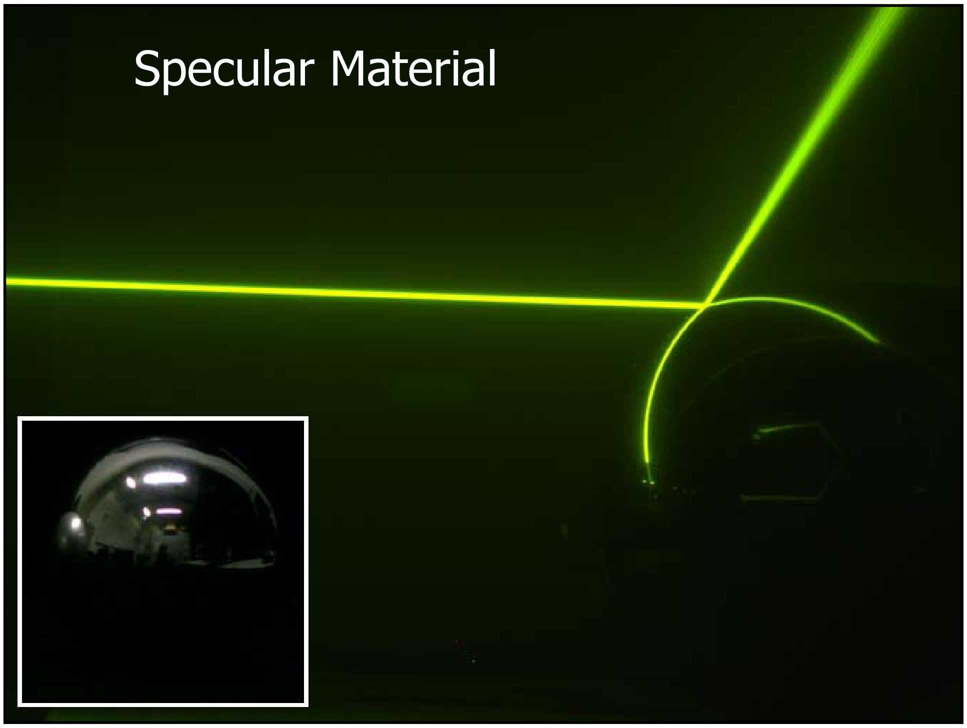


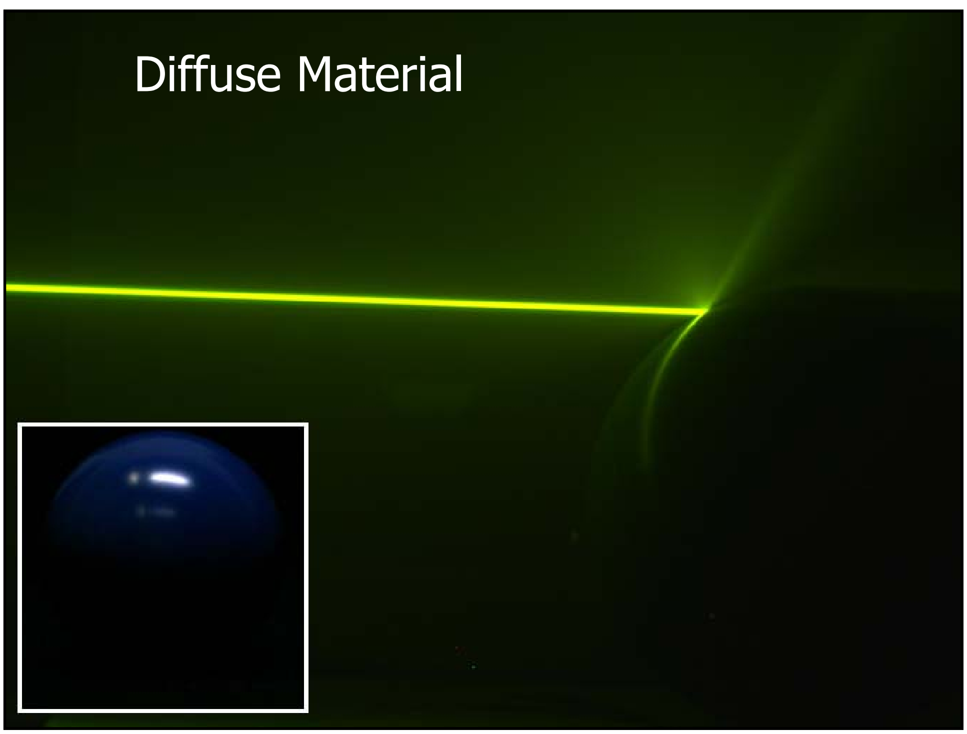
Illumination Models/Algorithms

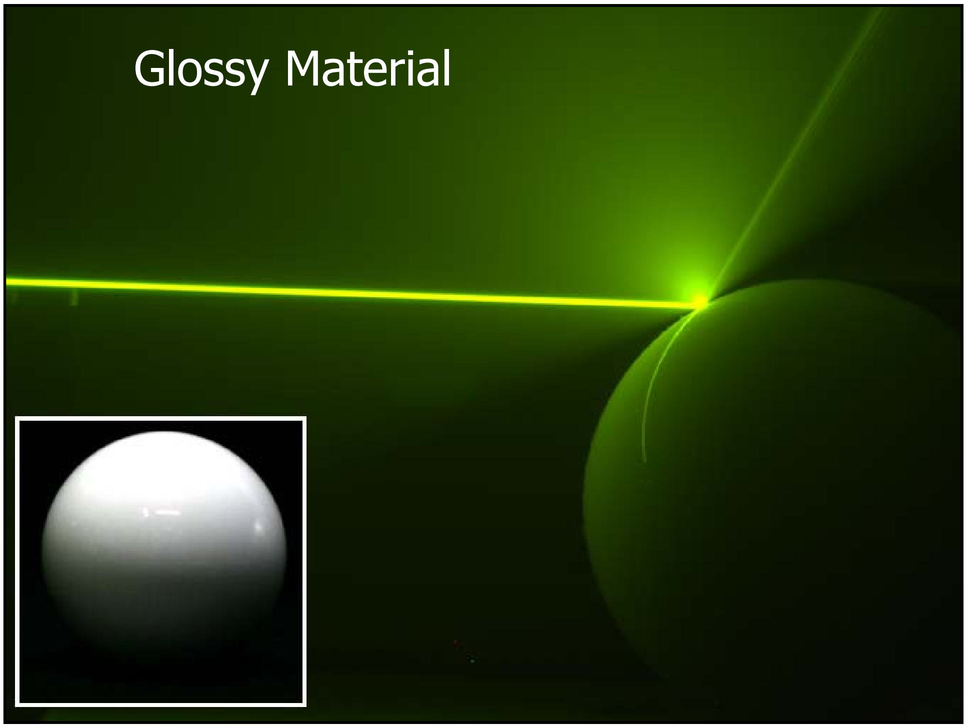
- Local illumination - Fast
  - Ignore real physics, approximate the look
  - Interaction of each object with light
    - Compute on surface (light to viewer)
- Global illumination – Slow
  - Physically based
  - Interactions between objects

Materials

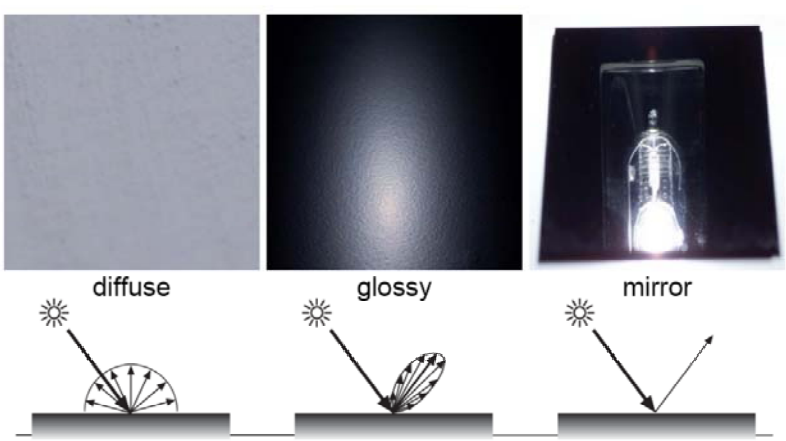
- Surface reflectance:
  - Illuminate surface point with a ray of light from different directions
  - How much light is reflected in each direction?


Specular Material


Diffuse Material

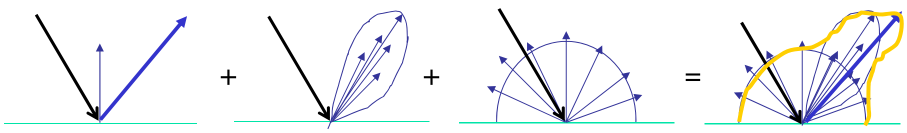


Basic Types



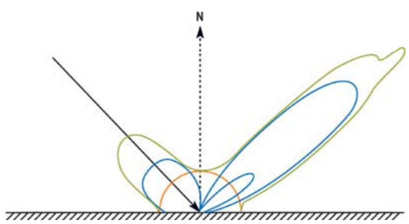
Reflectance Distribution Model

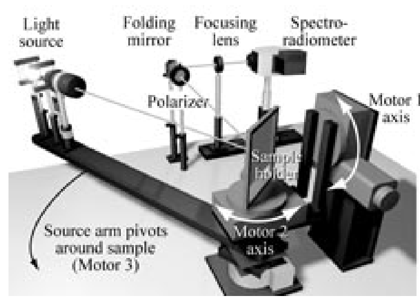
- Most surfaces exhibit complex reflectances
  - Vary with incident and reflected directions.
  - Model with combination – known as BRDF
    - BRDF: *Bidirectional Reflectance Distribution Function*



BRDF measurements/plots

- 2D slice



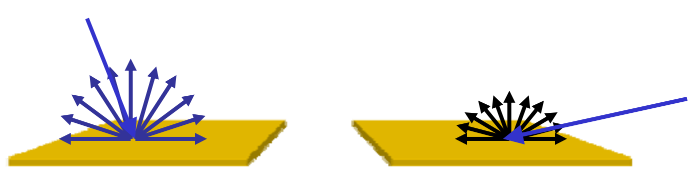


Practical Considerations

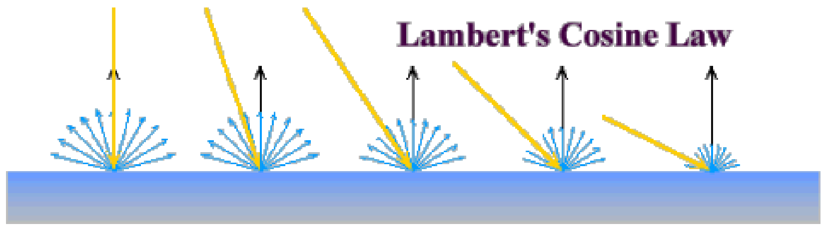
- In practice, often simplify (computational efficiency)
- Derive specific formulas that describe basic reflectance behaviors
  - diffuse, glossy, specular
  - OpenGL choice

Physics of Diffuse Reflection

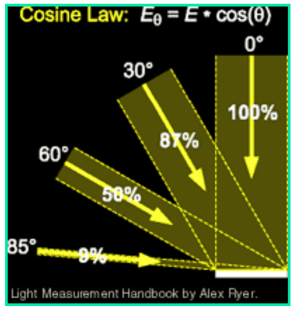
- Ideal diffuse reflection
  - Very rough surface at the microscopic level
    - Real-world example: chalk
    - Microscopic variations mean incoming ray of light equally likely to be reflected in any direction over the hemisphere
  - Reflected intensity only depends on light direction!



Lambert's "Law"

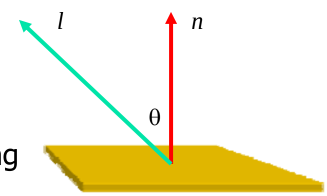


Intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- Depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \cos\theta$
- In practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\mathbf{n} \cdot \mathbf{l})$
- Always normalize vectors used in lighting
  - $\mathbf{n}$, $\mathbf{l}$ should be unit vectors
- Scalar (B/W intensity) or 3-tuple or 4-tuple (color)
  - k_d: diffuse coefficient, surface color
  - I_{light}: incoming light intensity
  - $I_{diffuse}$: outgoing light intensity (for diffuse reflection)



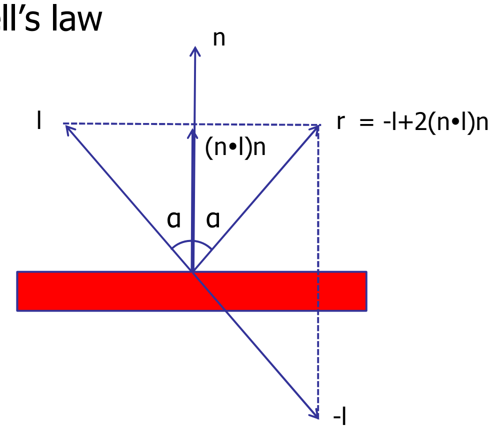
Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°
  - *Why?*

Physics of Specular Reflection

- Geometry of specular (perfect mirror) reflection
  - Snell's law

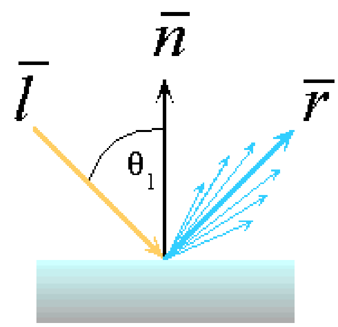


Empirical Approximation

- Snell's law = perfect mirror-like surfaces
  - But ..
    - few surfaces exhibit perfect specularity
    - Gaze and reflection directions never EXACTLY coincide
- Expect **most** reflected light to travel in direction predicted by Snell's Law
- But some light may be reflected in a direction slightly off the ideal reflected ray
- As angle from ideal reflected ray increases, we expect less light to be reflected

Empirical Approximation

- Angular falloff

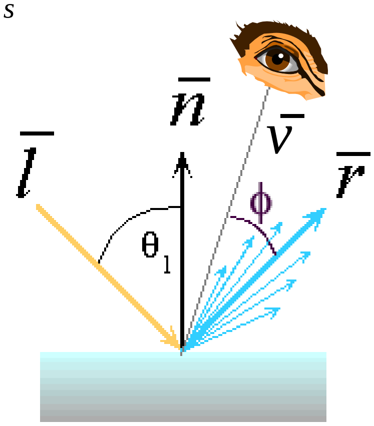


- How to model this falloff?

Phong Lighting

- Most common lighting model in computer graphics
  - (Phong Bui-Tuong, 1975)

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\cos\phi)^{n_s}$$



ϕ: angle between r and view direction v

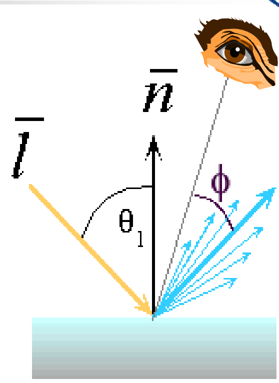
n_s : purely empirical constant, varies rate of falloff

k_s: specular coefficient, highlight color

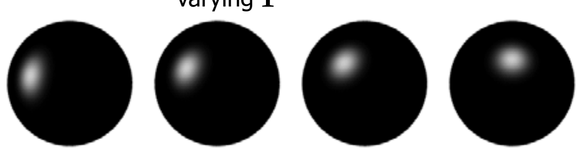
no physical basis, works ok in practice

Phong Examples

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\cos\phi)^{n_s}$$



varying l



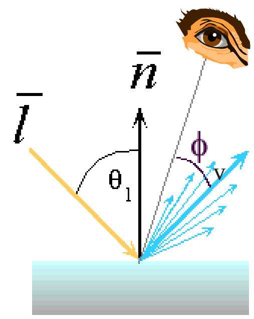
varying n_s

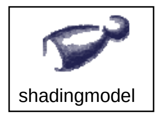
Calculating Phong Lighting

- compute cosine term of Phong lighting with vectors

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\mathbf{v} \bullet \mathbf{r})^{n_s}$$

- v: unit vector towards viewer/eye
- r: ideal reflectance direction (unit vector)
- k_s: specular component = highlight color
- I_{light}: incoming light intensity





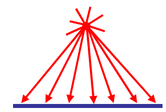
Materials (last bit)

- Light is **linear**
  - If multiple rays illuminate the surface point the result is just the sum of the individual reflections for each ray

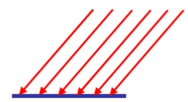
$$\sum_p I_p (k_d (n \cdot l_p) + k_s (r_p \cdot v)^n)$$

Light Sources

- Point source
  - light originates at a point
  - Rays hit planar surface at different angles

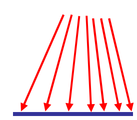


- Parallel source
  - light rays are parallel
  - Rays hit a planar surface at identical angles
  - Can model as point source at infinity
  - *Directional light*

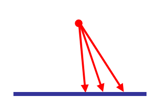


Light Sources

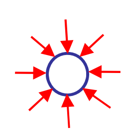
- Area source
  - Light originates at finite area in space.
  - In-between point and parallel sources



- Spotlights
  - position, direction, angle



- Ambient light (environment light)
  - Hack for replacing true global illumination
    - (light bouncing off from other objects)

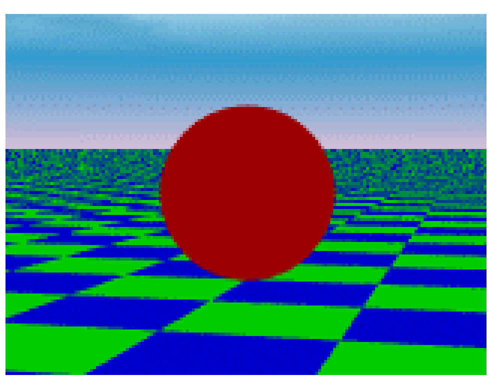


Ambient Light

- Non-directional light – environment light
- Object illuminated with same light everywhere
  - Looks like silhouette
- Illumination equation $I = I_a k_a$
  - I_a - ambient light intensity
  - k_a - fraction of this light reflected from surface

Ambient Light Sources

- Scene lit only with an ambient light source



Light Position Not Important

Viewer Position Not Important

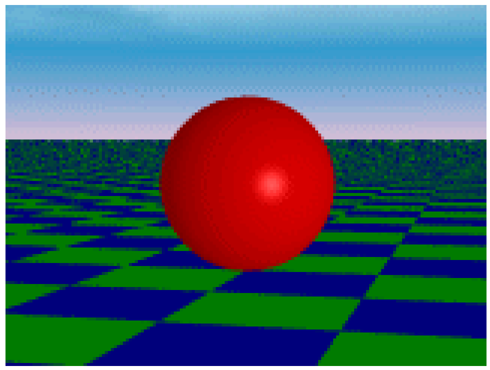
Surface Angle Not Important

Directional Light Sources

- Scene lit with directional and ambient light

Surface Angle Important

Viewer Position Important



Light Position Not Important

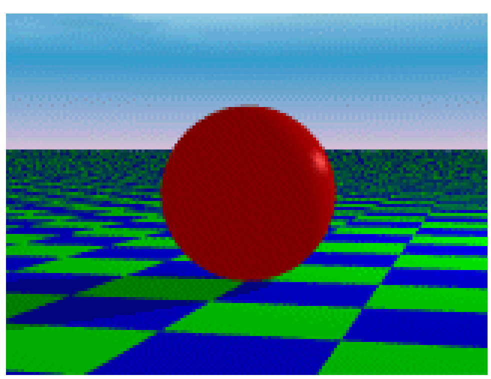
Point Light Sources

- Scene lit with ambient and point light source

Light Position Important

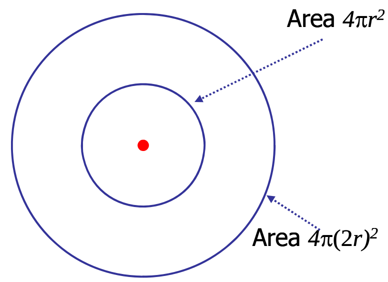
Viewer Position Important

Surface Angle Important



Light Source Falloff

- Quadratic falloff (point- and spot lights)
  - Brightness of objects depends on power per unit area that hits the object
  - The power per unit area for a point or spot light decreases quadratically with distance



Light Source Falloff

- Non-quadratic falloff
  - Many systems allow for other falloffs
  - Allows for faking effect of area light sources
  - OpenGL / graphics hardware
    - I_o: intensity of light source
    - $\mathbf{x}$: object point
    - r: distance of light from $\mathbf{x}$

$$I_{in}(\mathbf{x}) = \frac{1}{ar^2 + br + c} \cdot I_0$$

Illumination Equation

- For multiple light sources:

$$I = I_a k_a + \sum_p \frac{I_p}{A(d_p)} (k_d (n \cdot l_p) + k_s (r_p \cdot v)^n)$$

- d_p - distance between surface and light source + distance between surface and viewer, A – attenuation function

Light

- Light has color
- Interacts with object color (r,g,b)

$$I = I_a k_a$$
$$I_a = (I_{ar}, I_{ag}, I_{ab})$$
$$k_a = (k_{ar}, k_{ag}, k_{ab})$$
$$I = (I_r, I_g, I_b) = (I_{ar} k_{ar}, I_{ag} k_{ag}, I_{ab} k_{ab})$$

- Blue light on white surface?
- Blue light on red surface?

Lighting in OpenGL

- Light source: amount of RGB light emitted
  - value = percentage of full intensity, e.g., (1.0,0.5,0.5)
  - every light source emits ambient, diffuse, and specular light
- Materials: amount of RGB light reflected
  - value represents percentage reflected e.g., (0.0,1.0,0.5)
- Interaction: multiply components
  - Red light (1,0,0) x green surface (0,1,0) = black (0,0,0)

In OpenGL

- k_a, k_d, k_s - surface color (RGB)
- Modify by glMaterialfv(GL_FRONT_AND_BACK , *pname*, RGB[])
- *pname* - GL_AMBIENT, GL_DIFFUSE, GL_SPECULAR
- Light source properties (also RGB) glLightfv(GL_LIGHTi,*pname*,light[])

Lighting in OpenGL

```
glLightfv(GL_LIGHT0, GL_AMBIENT, amb_light_rgba );
glLightfv(GL_LIGHT0, GL_DIFFUSE, dif_light_rgba );
glLightfv(GL_LIGHT0, GL_SPECULAR, spec_light_rgba );
glLightfv(GL_LIGHT0, GL_POSITION, position);
glEnable(GL_LIGHT0);

glMaterialfv( GL_FRONT, GL_AMBIENT, ambient_rgba );
glMaterialfv( GL_FRONT, GL_DIFFUSE, diffuse_rgba );
glMaterialfv( GL_FRONT, GL_SPECULAR, specular_rgba );
glMaterialfv( GL_FRONT, GL_SHININESS, n );
```

Light Sources - OpenGL

- Specify parameters
  glLightfv(GL_LIGHTi,GL_POSITION,light[])
  i – between 0 & 8 (or more)
- Directional $[x \quad y \quad z \quad 0]$
- Point source $[x \quad y \quad z \quad 1]$
- Spotlight has extra parameters:
  - GL_SPOT_DIRECTION, GL_SPOT_EXPONENT, GL_SPOT_CUTOFF
- Area source – too complex for projective pipeline (e.g. OpenGL)

Lighting in Rendering Pipeline

- Notes:
  - Lighting is applied to every **vertex**
    - i.e. the three vertices in a triangle
    - Per-vertex lighting
  - Will later see how the interior points of the triangle obtain their color
    - This process is called **shading**
    - Will discuss in the context of scan conversion