Computer Graphics Lighting

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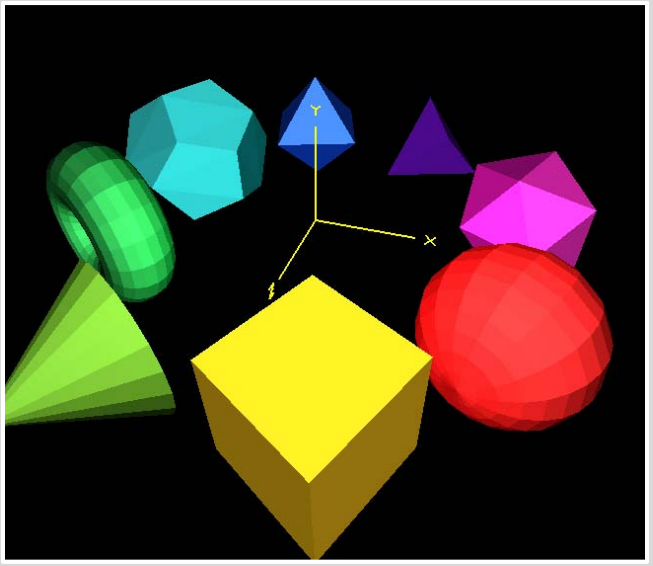
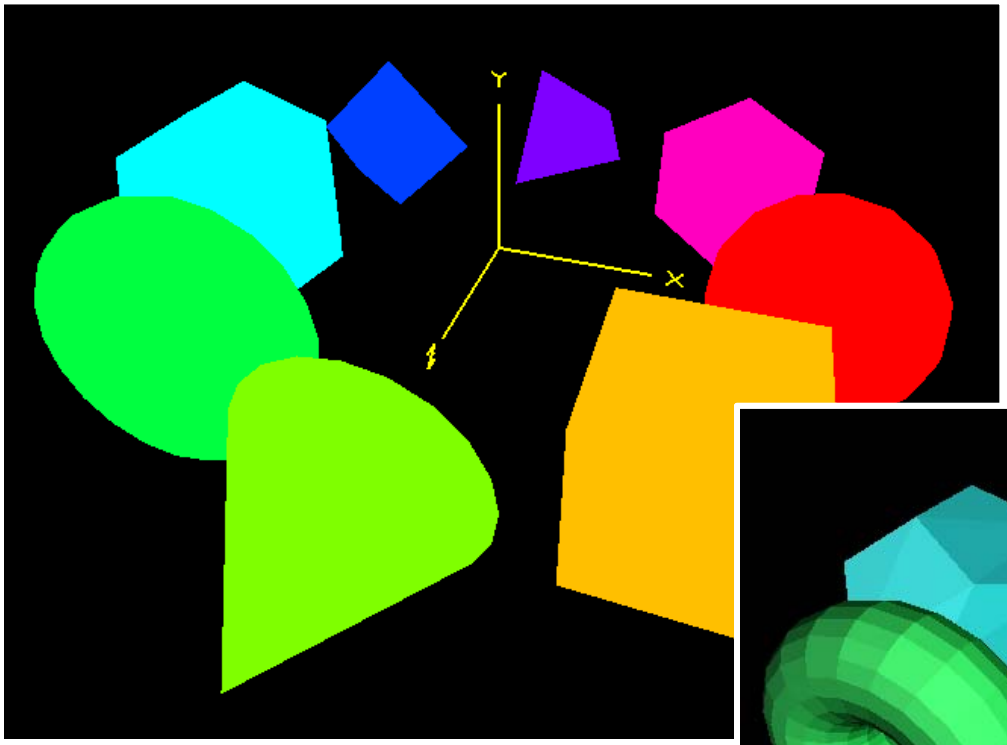
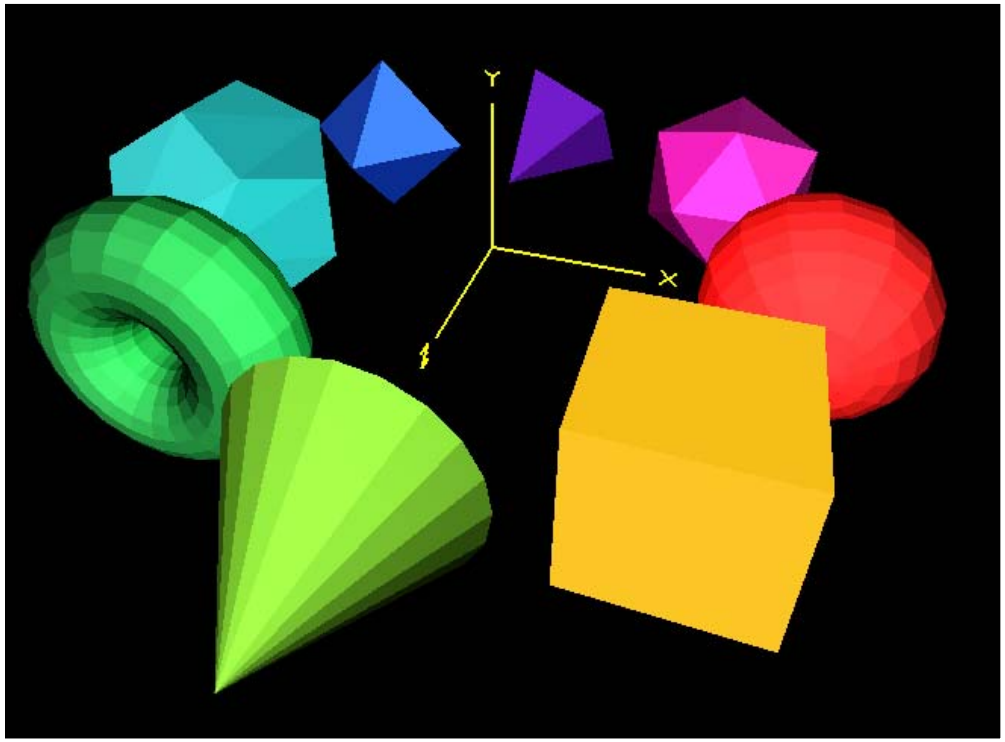


Why Do We Care About Lighting?

Lighting “dis-ambiguates” 3D scenes



Without lighting



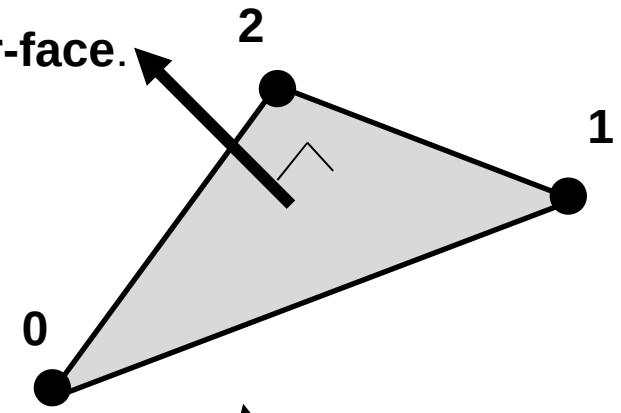
With lighting

The Surface Normal

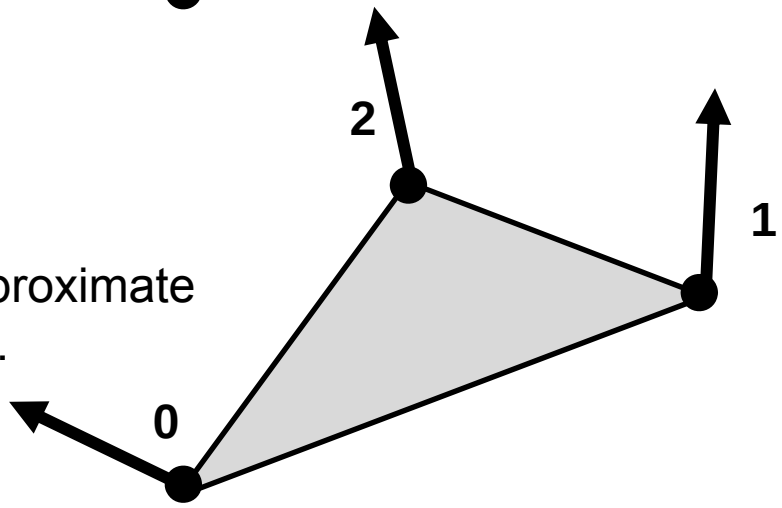
A surface normal is a vector perpendicular to the surface.

Sometimes surface normals are defined or computed **per-face**.

$$n = (P1 - P0) \times (P2 - P0)$$



Sometimes they are defined **per-vertex** to best approximate the underlying surface that the face is representing.



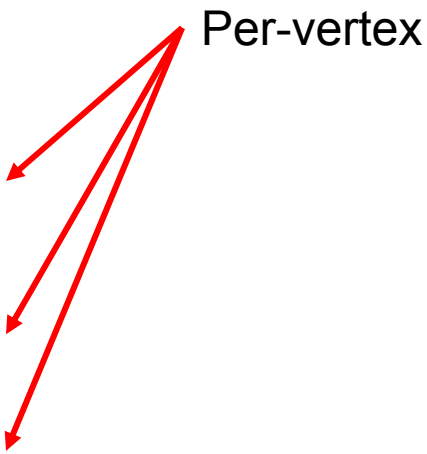
Setting a Surface Normal in OpenGL

```
glMatrixMode( GL_MODELVIEW );

glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glNormal3f( nx, ny, nz );

glColor3f( r, g, b );
glBegin( GL_TRIANGLES );
        glVertex3f( x0, y0, z0 );
        glVertex3f( x1, y1, z1 );
        glVertex3f( x2, y2, z2 );
glEnd( );
```

Per-face

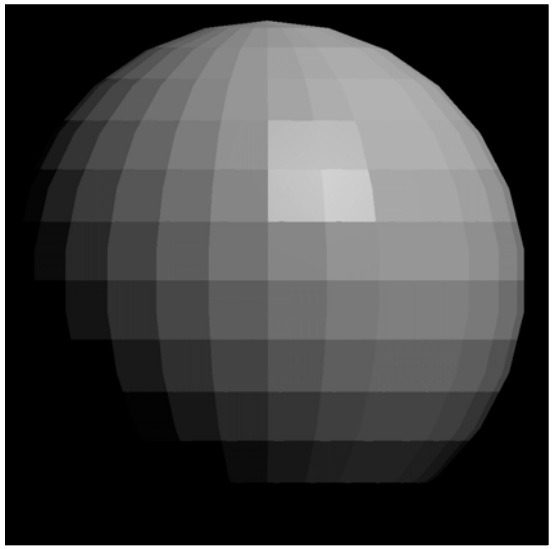
Setting a Surface Normal in OpenGL

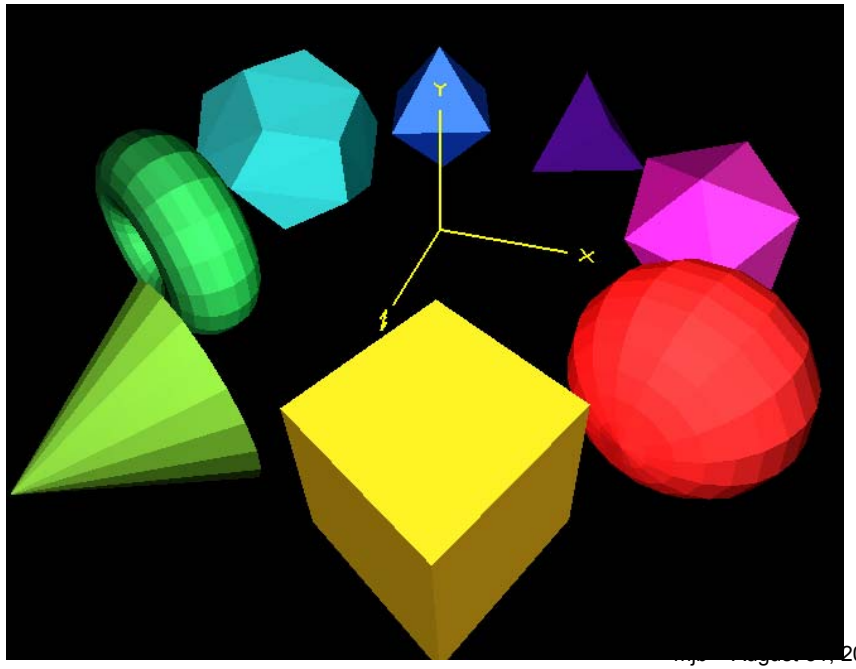
```
glMatrixMode( GL_MODELVIEW );

glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glColor3f( r, g, b );
glBegin(GL_TRIANGLES );
        glNormal3f( nx0, ny0, nz0 );
        glVertex3f( x0, y0, z0 );
        glNormal3f( nx1, ny1, nz1 );
        glVertex3f( x1, y1, z1 );
        glNormal3f( nx2, ny2, nz2 );
        glVertex3f( x2, y2, z2 );
glEnd( );
```



Flat Shading (Per-face)

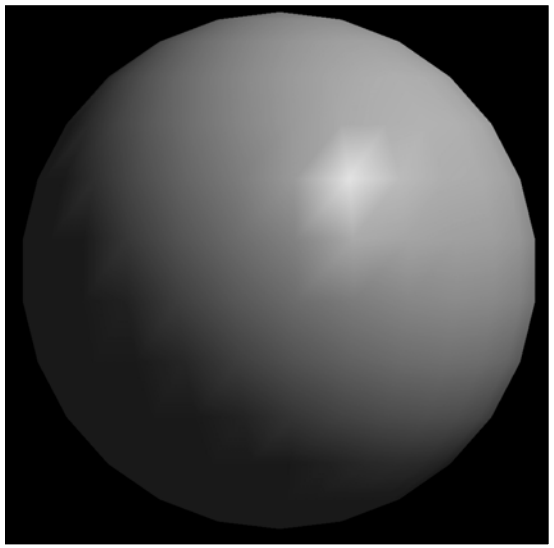

```
glMatrixMode( GL_MODELVIEW );

glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glShadeModel( GL_FLAT );
glNormal3f( nx, ny, nz );

glColor3f( r, g, b );
glBegin(GL_TRIANGLES );
        glVertex3f( x0, y0, z0 );
        glVertex3f( x1, y1, z1 );
        glVertex3f( x2, y2, z2 );
glEnd( );
```

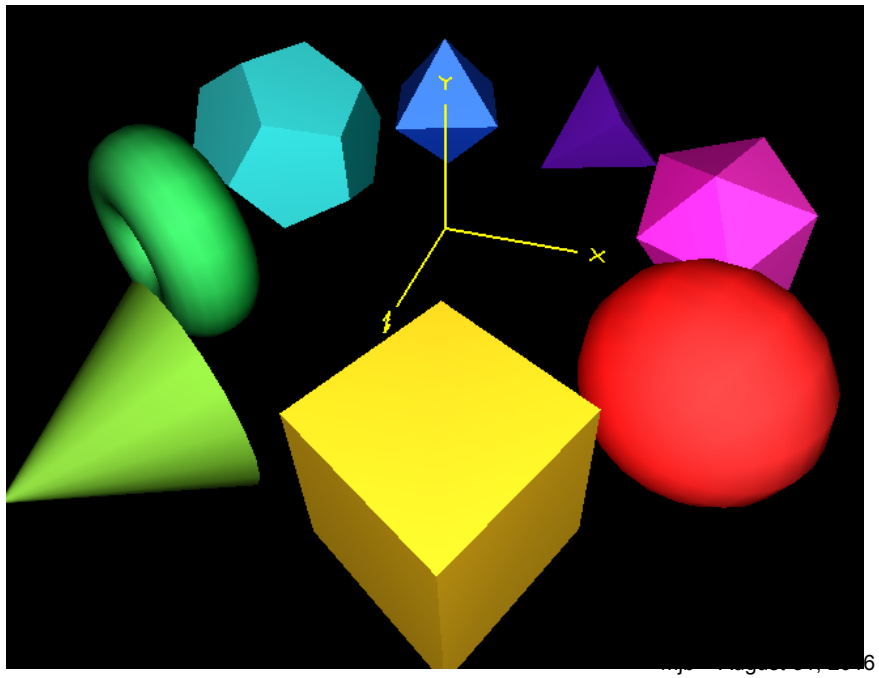


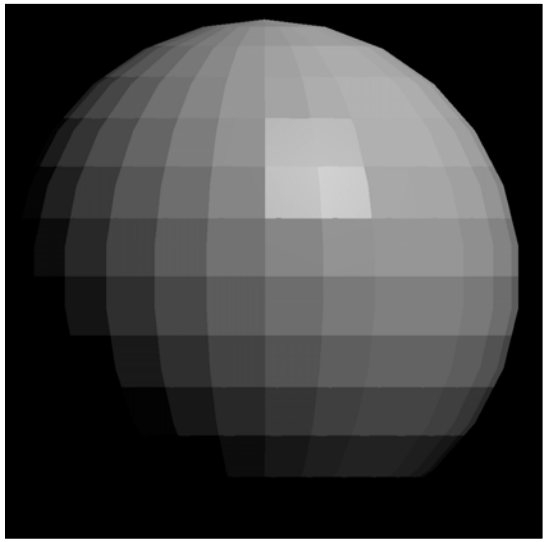


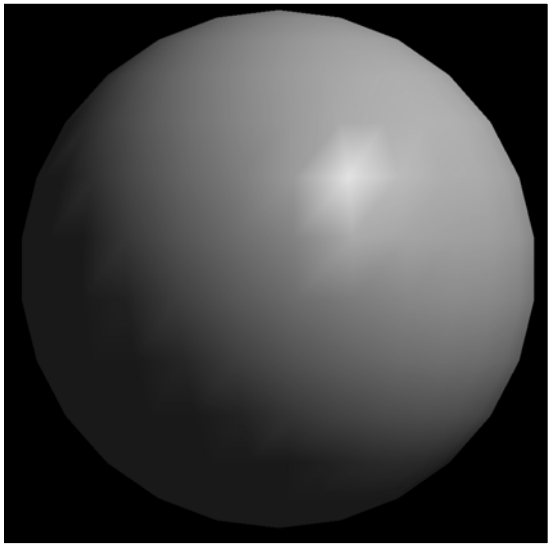
Smooth Shading (Per-vertex)

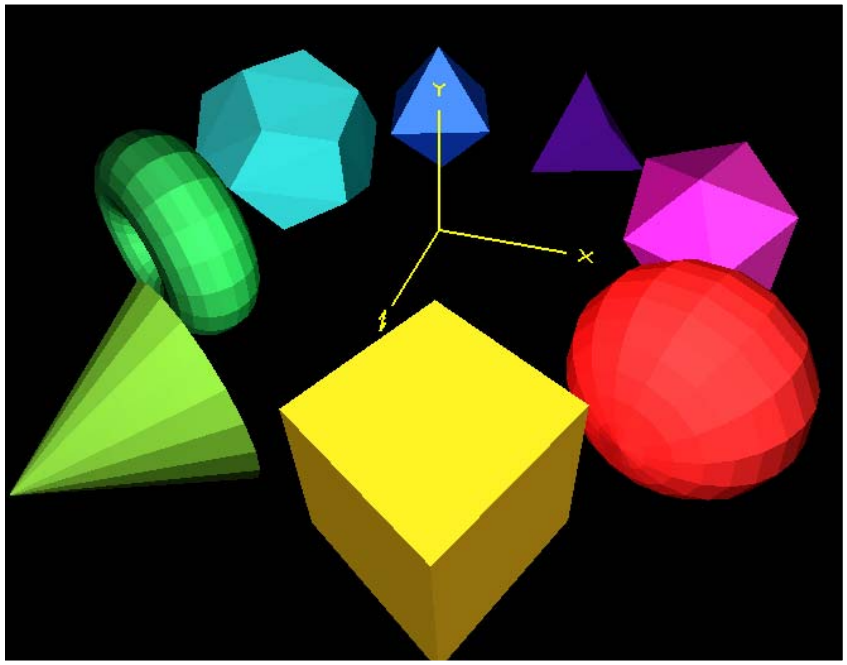
```
glMatrixMode( GL_MODELVIEW );

glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glShadeModel( GL_SMOOTH );

glColor3f( r, g, b );
glBegin(GL_TRIANGLES );
        glNormal3f( nx0, ny0, nz0 );
        glVertex3f( x0, y0, z0 );
        glNormal3f( nx1, ny1, nz1 );
        glVertex3f( x1, y1, z1 );
        glNormal3f( nx2, ny2, nz2 );
        glVertex3f( x2, y2, z2 );
glEnd( );
```

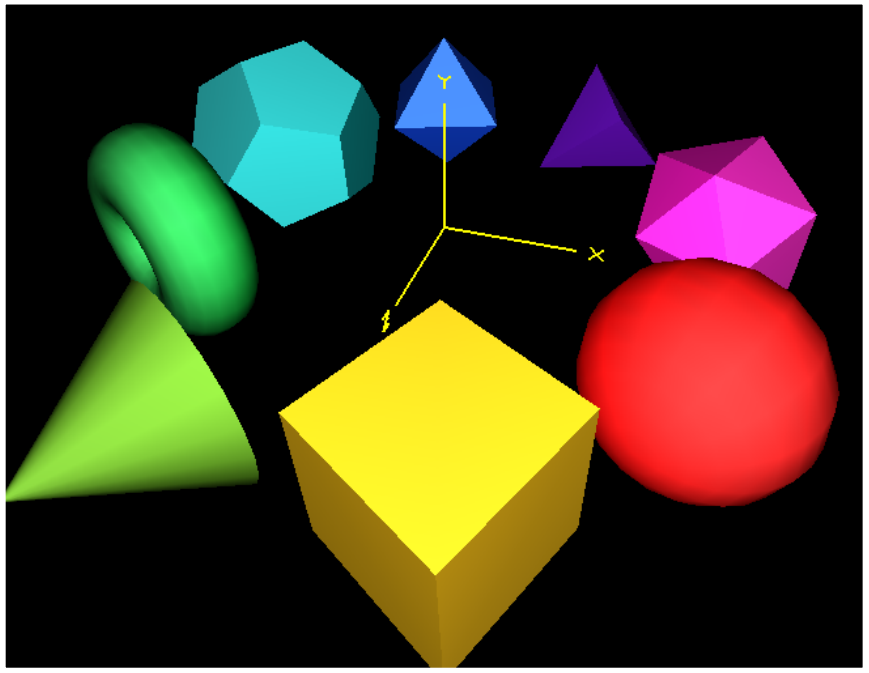









Y
X
Z


Y
X
Z

OpenGL Surface Normals Need to be Unitized by Someone

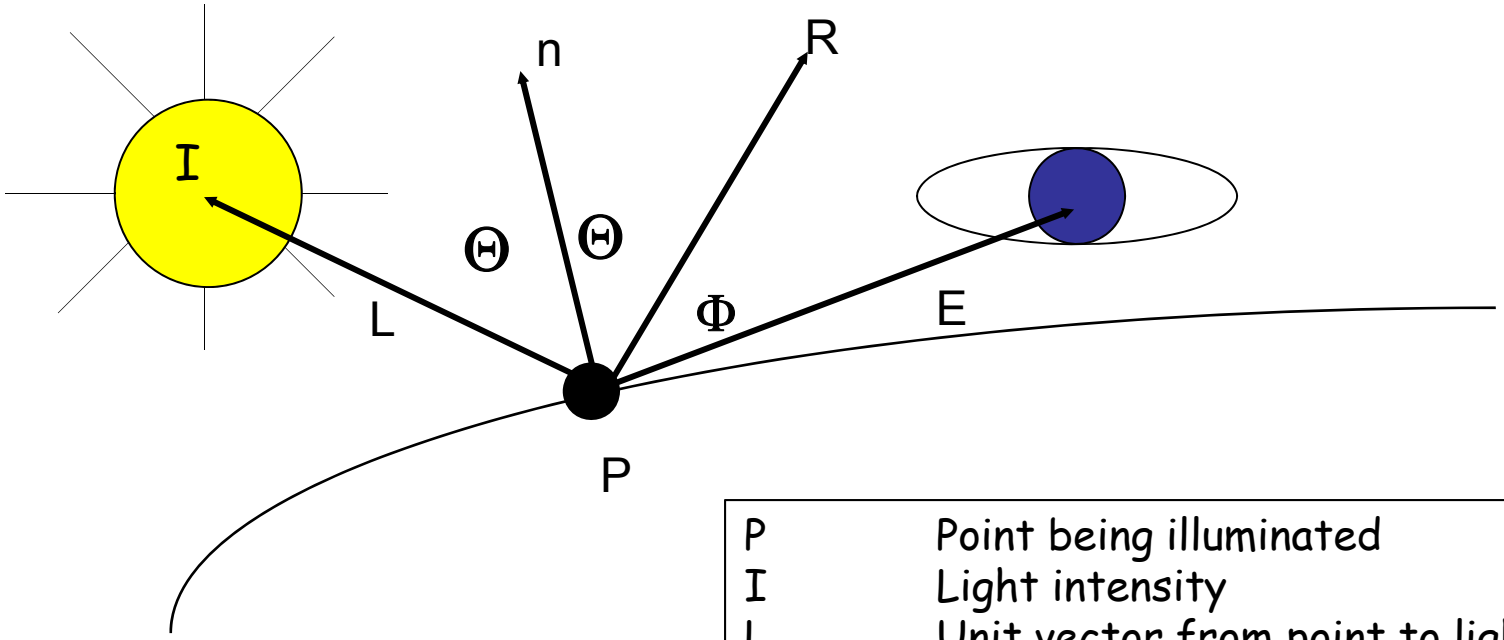
```
glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glNormal3f( nx, ny, nz );
```

OpenGL expects the normal vector to be a unit vector, that is:
$nx^2 + ny^2 + nz^2 = 1$

If it is not, or if you are using scaling transformations, you can force OpenGL to do the unitizing for you with:

glEnable(GL_NORMALIZE);

The OpenGL "built-in" Lighting Model



P	Point being illuminated
I	Light intensity
L	Unit vector from point to light
n	Unit vector surface normal
R	Perfect reflection unit vector
E	Unit vector to eye position

The OpenGL "built-in" Lighting Model

1. **Ambient** = a constant

Accounts for light bouncing "everywhere"

2. **Diffuse** = $I^*\cos\Theta$

Accounts for the angle between the incoming light and the surface normal

3. **Specular** = $I^*\cos^S\phi$

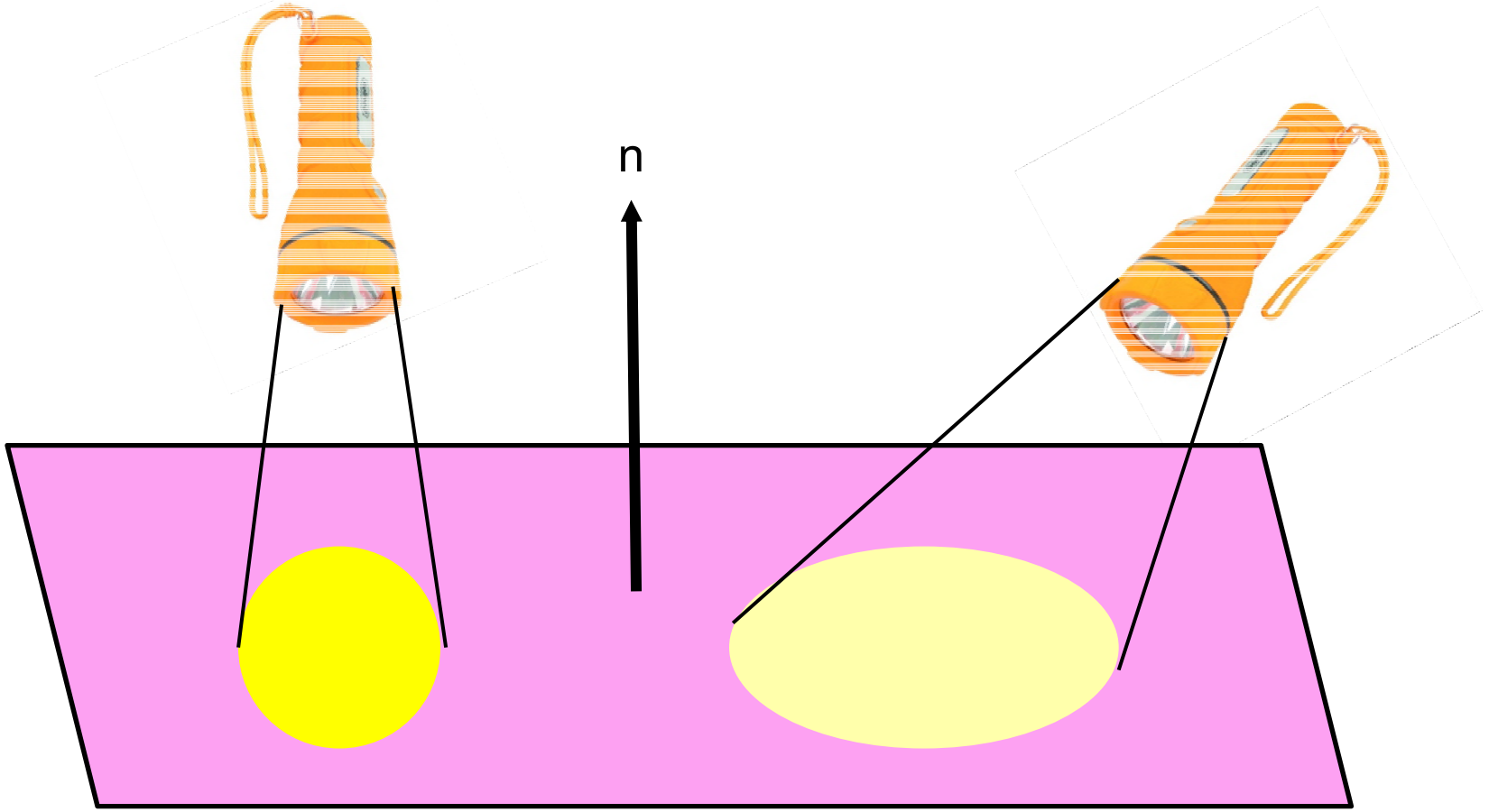
Accounts for the angle between the "perfect reflector" and the eye. The exponent, S, accounts for surface shininess

Note that $\cos\Theta$ is just the dot product between unit vectors L and n

Note that $\cos\phi$ is just the dot product between unit vectors R and E

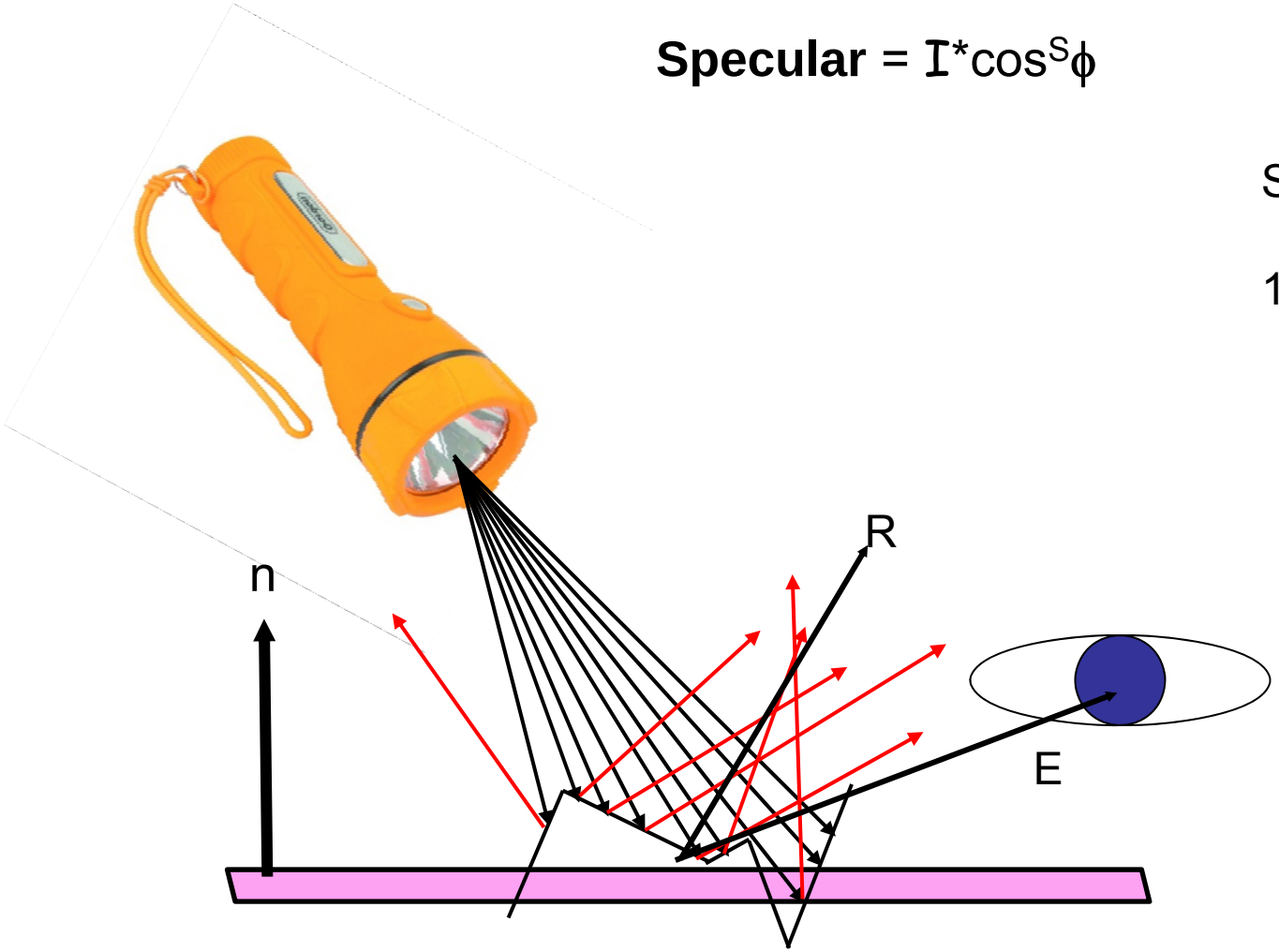
Diffuse Lighting works because of spreading out the same amount of light energy across more surface area

Diffuse = I*cosΘ



The Specular Lighting equation is a heuristic that approximates reflection from a rough surface

Specular = $I^*\cos^S\phi$



S ≈ “shininess”

1/S ≈ “roughness”

The Three Elements of Computer Graphics Lighting

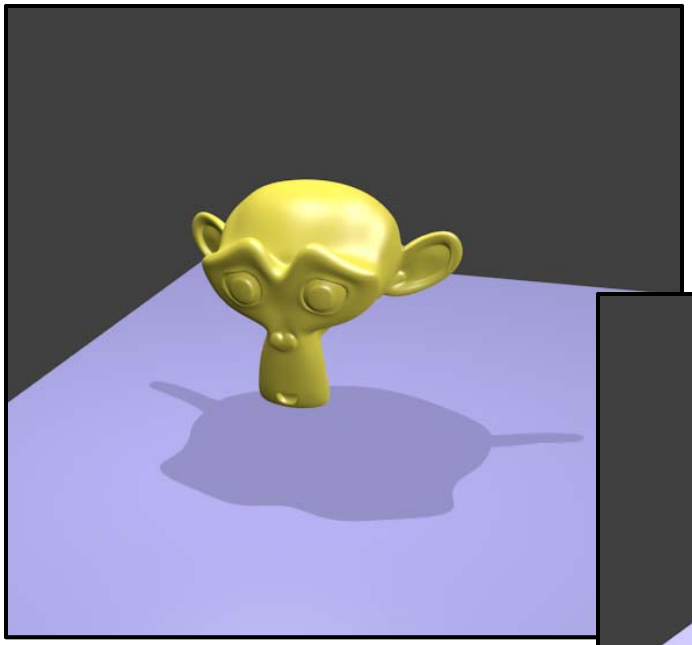
+

+

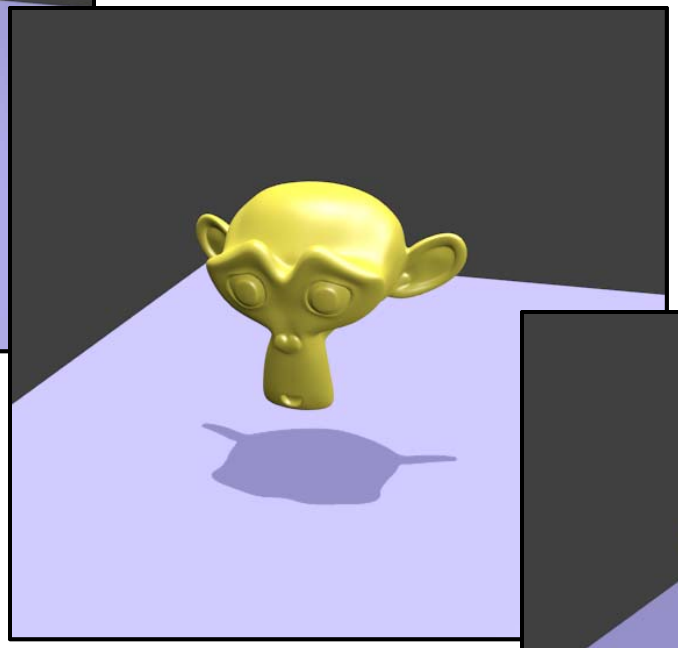
=

Types of Light Sources

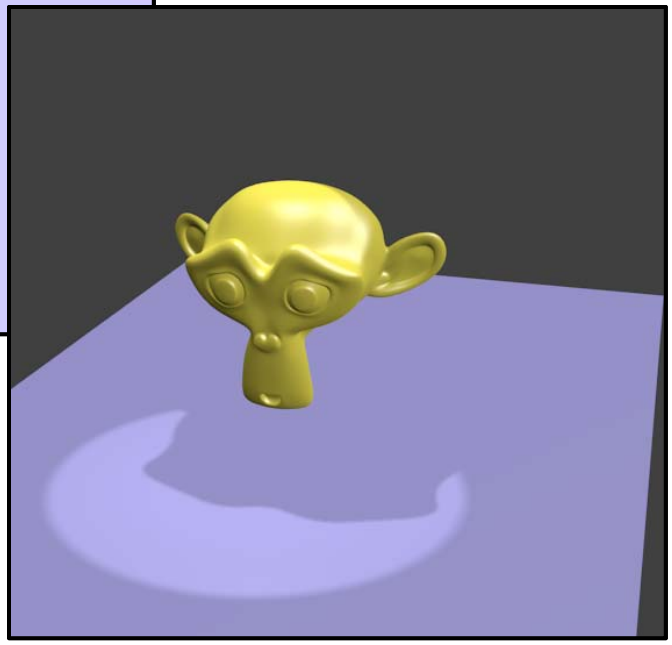
Point



Directional (Parallel, Sun)

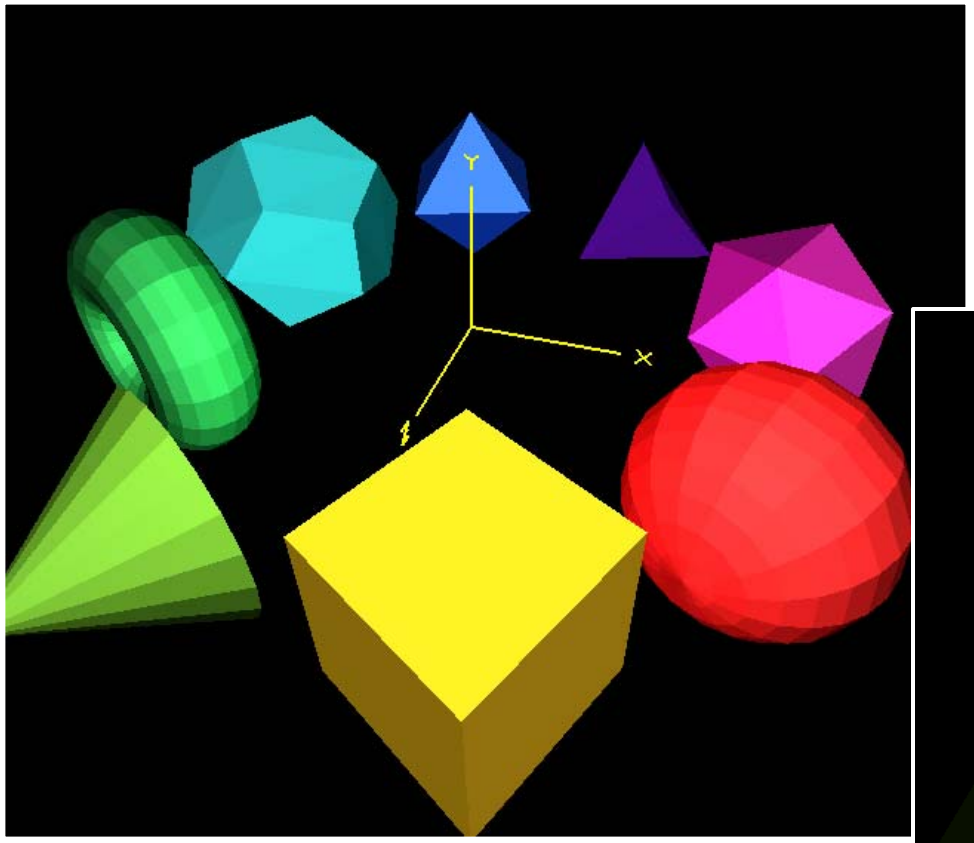


Spotlight

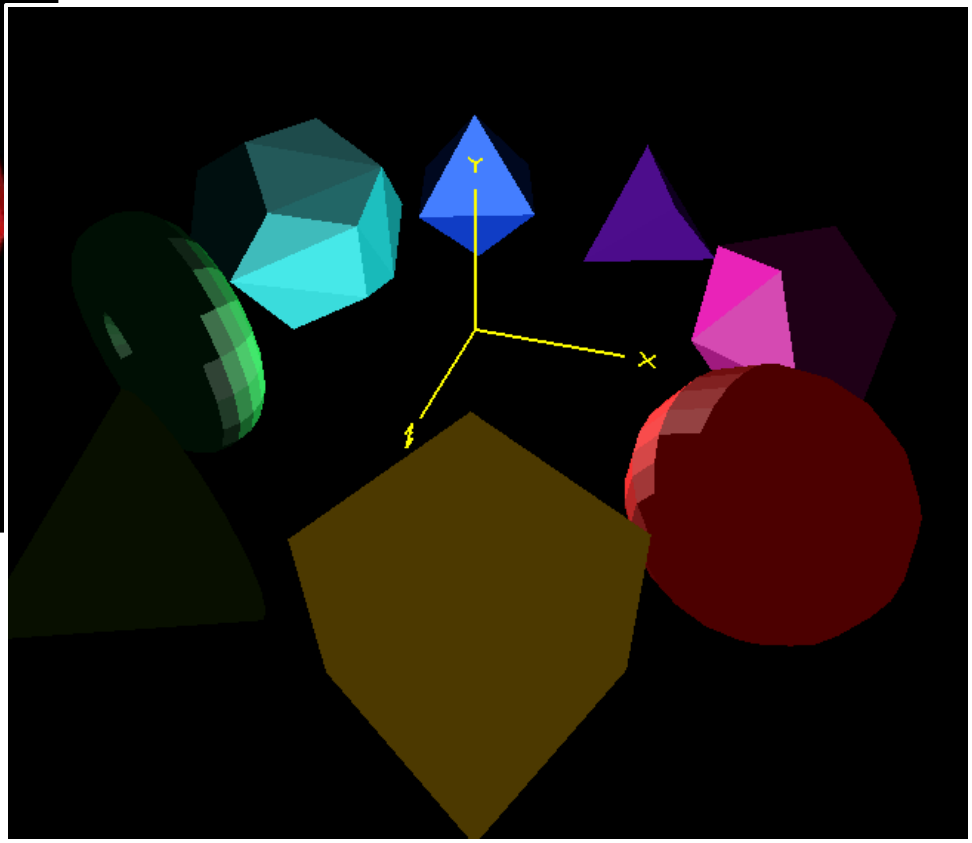


Lighting Examples

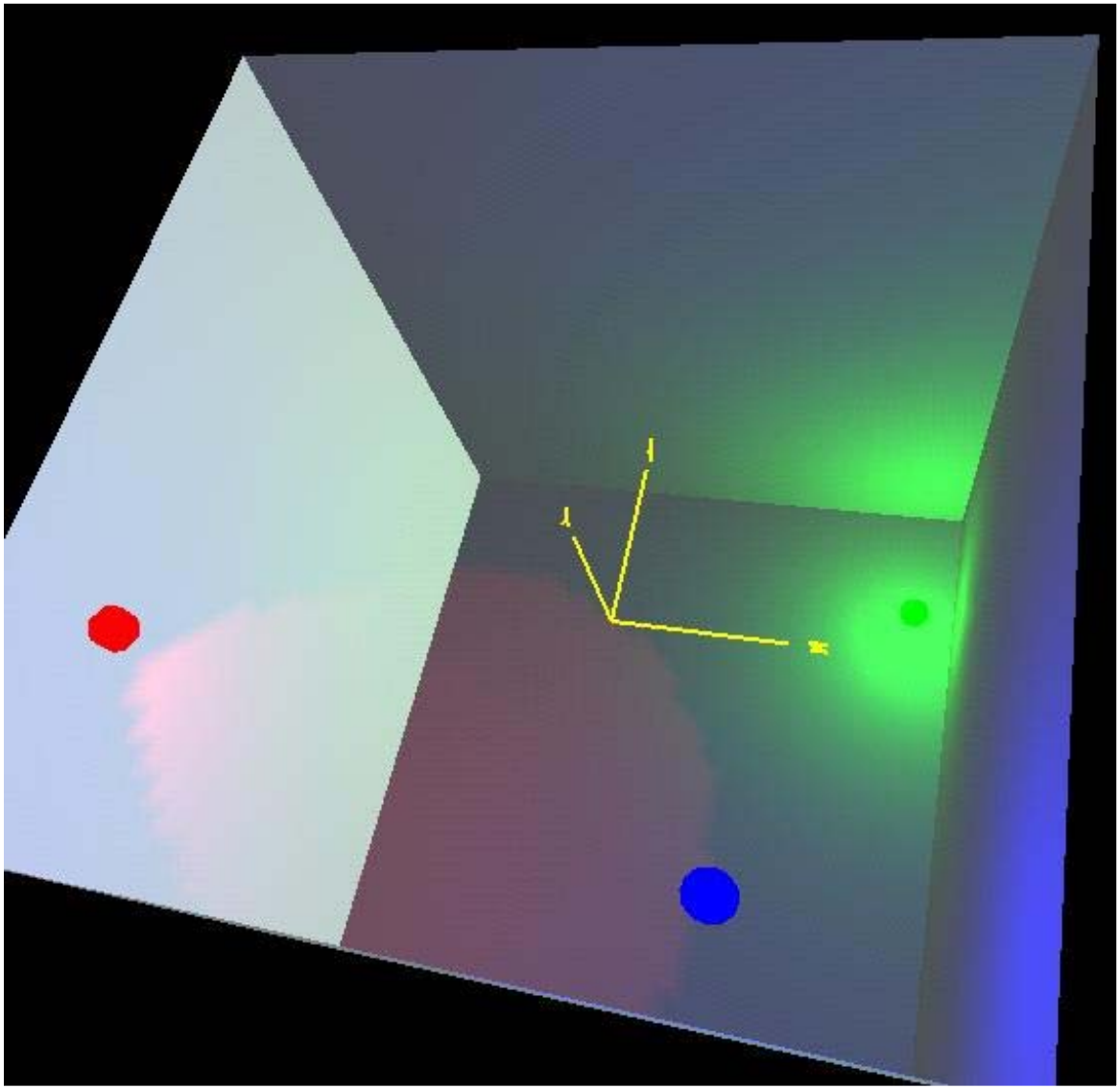
Point Light at the Eye



Point Light at the Origin

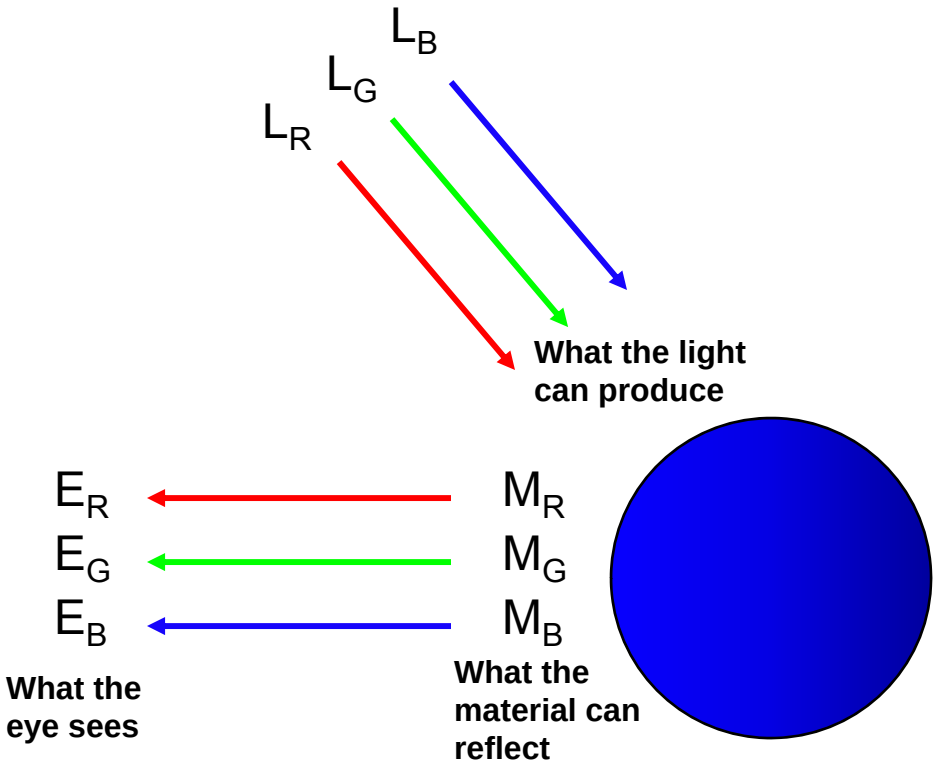


Lighting Examples



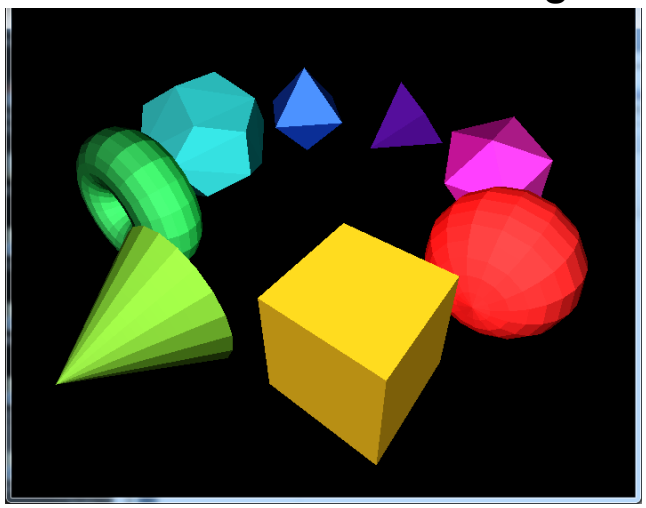
Spot Lights

Colored Lights Shining on Colored Objects

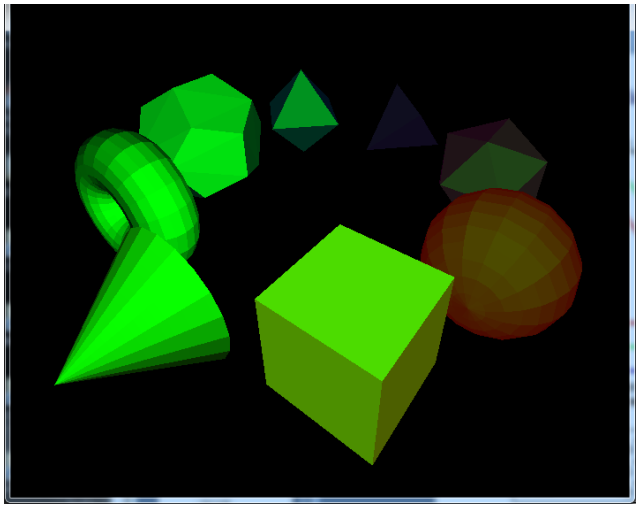


$$E_R = L_R * M_R$$
$$E_G = L_G * M_G$$
$$E_B = L_B * M_B$$

White Light



Green Light



Too Many Lighting Options

If there is one light and one material, the following things can be set independently:

- Global scene ambient red, green, blue
- Light position: x, y, z
- Light ambient red, green, blue
- Light diffuse red, green, blue
- Light specular red, green, blue
- Material reaction to ambient red, green, blue
- Material reaction to diffuse red, green, blue
- Material reaction to specular red, green, blue
- Material specular shininess

This makes for ***25*** things that can be set for just one light and one material! While many combinations are possible, some make more sense than others.

Ways to Simplify Too Many Lighting Options

1. Set the ambient light globally using, for example,
   glLightModelfv(GL_LIGHT_MODEL_AMBIENT, MulArray3(.3f, White))
   I.e., set it to some low intensity of white.

2. Set the light's ambient component to zero.

3. Set the light's diffuse and specular components to the full color of the light.

4. Set each material's ambient and diffuse to the full color of the object.

5. Set each material's specular component to some fraction of white.

```
float		White[ ] = { 1.,1.,1.,1. };

// utility to create an array from 3 separate values:

float *
Array3( float a, float b, float c )
{
		static float array[4];

		array[0] = a;
		array[1] = b;
		array[2] = c;
		array[3] = 1.;
		return array;
}

// utility to create an array from a multiplier and an array:

float *
MulArray3( float factor, float array0[3] )
{
		static float array[4];

		array[0] = factor * array0[0];
		array[1] = factor * array0[1];
		array[2] = factor * array0[2];
		array[3] = 1.;
		return array;
}
```

Setting the Material Characteristics

```
glMaterialfv( GL_BACK,  GL_AMBIENT,    MulArray3( .4, White ) );
glMaterialfv( GL_BACK,  GL_DIFFUSE,    MulArray3( 1., White ) );
glMaterialfv( GL_BACK,  GL_SPECULAR, Array3( 0., 0., 0. ) );
glMaterialf (  GL_BACK,  GL_SHININESS, 5. );
glMaterialfv( GL_BACK,  GL_EMISSION,   Array3( 0., 0., 0. ) );
```

```
glMaterialfv( GL_FRONT, GL_AMBIENT,    MulArray3( 1., rgb ) );
glMaterialfv( GL_FRONT, GL_DIFFUSE,    MulArray3( 1., rgb ) );
glMaterialfv( GL_FRONT, GL_SPECULAR, MulArray3( .7, White ) );
glMaterialf (  GL_FRONT, GL_SHININESS, 8. );
glMaterialfv( GL_FRONT, GL_EMISSION,   Array3( 0., 0., 0. ) );
```

Setting the Light Characteristics

```
glLightModelfv( GL_LIGHT_MODEL_AMBIENT, MulArray3( .2, White ) );
glLightModeli (  GL_LIGHT_MODEL_TWO_SIDE, GL_TRUE );

glLightfv( GL_LIGHT0, GL_AMBIENT,   Array3( 0., 0., 0. ) );
glLightfv( GL_LIGHT0, GL_DIFFUSE,     LightColor );
glLightfv( GL_LIGHT0, GL_SPECULAR,  LightColor );

glLightf ( GL_LIGHT0, GL_CONSTANT_ATTENUATION,  1. );
glLightf ( GL_LIGHT0, GL_LINEAR_ATTENUATION,       0. );
glLightf ( GL_LIGHT0, GL_QUADRATIC_ATTENUATION, 0. );

// this is here because we are going to do object (and thus normal) scaling:

glEnable( GL_NORMALIZE );
```

You can have multiple lights

Attenuation = $\frac{1}{C + Ld + Qd^2}$ where *d* is the distance from the light to the point being lit

Setting the Light Position

```
glMatrixMode( GL_MODELVIEW );
glLoadIdentity( );
```

The light position gets transformed by the value of the ModelView matrix at the moment the light position is set.

```
// if we do this, then the light will be wrt the scene at XLIGHT, YLIGHT, ZLIGHT:

glLightfv( GL_LIGHT0, GL_POSITION,  Array3(XLIGHT, YLIGHT, ZLIGHT) );


// translate the object into the viewing volume:

gluLookAt(  XEYE, YEYE, ZEYE,  0., 0., 0.,  0., 1., 0. );


// if we do this, then the light will be wrt the eye at XLIGHT, YLIGHT, ZLIGHT:

// glLightfv( GL_LIGHT0, GL_POSITION,  Array3(XLIGHT, YLIGHT, ZLIGHT) );
```

```
// perform the rotations and scaling about the origin:

glRotatef( Xrot, 1., 0., 0. );
glRotatef( Yrot, 0., 1., 0. );
glScalef( Scale, Scale, Scale );


// if we do this, then the light will be wrt to the object at XLIGHT, YLIGHT, ZLIGHT:

// glLightfv( GL_LIGHT0, GL_POSITION,  Array3(XLIGHT, YLIGHT, ZLIGHT) );


// specify the shading model:

glShadeModel( GL_SMOOTH );


// enable lighting:
glEnable( GL_LIGHTING );

glEnable( GL_LIGHT0 );


// draw the objects:
    . . .
```

You can enable and disable lighting “at all”. (This toggles between using the lighting equations say and what glColor3f( ) says

You can enable and disable each light independently

It is usually good form to disable the lighting after you are done using it

Sidebar: Why are Light Positions 4-element arrays where the 4th element is 1.0? Homogeneous Coordinates!

```
float *
Array3( float a, float b, float c )
{
        static float array[4];

        array[0] = a;
        array[1] = b;
        array[2] = c;
        array[3] = 1.;
        return array;
}
```

We usually think of a 3D point as being represented by a triple: (x,y,z).

Using homogeneous coordinates, we add a 4th number: (x,y,z,w)

Graphics systems take (x,y,z,w) and then divide x, y, and z by w before using them.

$$X = \frac{x}{w}, Y = \frac{y}{w}, Z = \frac{z}{w}$$

Thus (1,2,3,1) , (2,4,6,2) , (-1,-2,-3,-1) all represent the same 3D point.

This Lets us Represent Points at Infinity

This is useful to be able specify a parallel light source by placing the light source location at infinity.

The point (1,2,3,1) represents the 3D point (1,2,3)

The point (1,2,3,.5) represents the 3D point (2,4,6)

The point (1,2,3,.01) represents the point (100,200,300)

So, (1,2,3,0) represents a point at infinity, but along the ray from the origin through (1,2,3).

Points-at-infinity are used for parallel light sources and some shadow algorithms

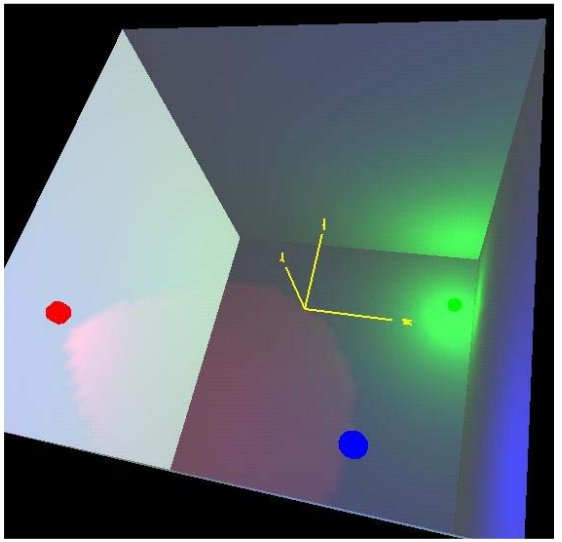
Additional Parameters for Spotlights

glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, Array3(xdir,ydir,zdir))

Specifies the spotlight-pointing direction. This gets transformed by the current value of the ModelView matrix.

glLightf(GL_LIGHT0, GL_SPOT_EXPONENT, e)

Specifies the spotlight directional intensity. This acts very much like the exponent in the specular lighting equation.



glLightf(GL_LIGHT0, GL_SPOT_CUTOFF, deg)

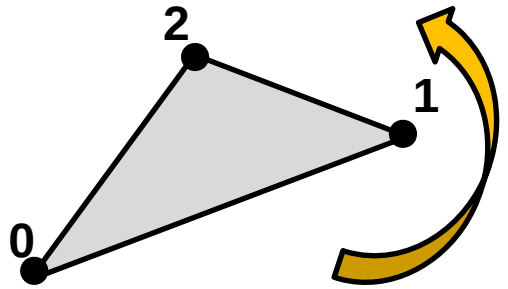
Specifies the spotlight maximum spread angle.

Shortcuts I Like

```
void
SetMaterial( float r, float g, float b,  float shininess )
{
        glMaterialfv( GL_BACK, GL_EMISSION, Array3( 0., 0., 0. ) );
        glMaterialfv( GL_BACK, GL_AMBIENT, MulArray3( .4f, White ) );
        glMaterialfv( GL_BACK, GL_DIFFUSE, MulArray3( 1., White ) );
        glMaterialfv( GL_BACK, GL_SPECULAR, Array3( 0., 0., 0. ) );
        glMaterialf (  GL_BACK, GL_SHININESS, 2.f );

        glMaterialfv( GL_FRONT, GL_EMISSION, Array3( 0., 0., 0. ) );
        glMaterialfv( GL_FRONT, GL_AMBIENT, Array3( r, g, b ) );
        glMaterialfv( GL_FRONT, GL_DIFFUSE, Array3( r, g, b ) );
        glMaterialfv( GL_FRONT, GL_SPECULAR, MulArray3( .8f, White ) );
        glMaterialf ( GL_FRONT, GL_SHININESS, shininess );
}
```

Definition of GL_FRONT and GL_BACK:

GL_FRONT side Vertices are CCW when viewed from the outside



GL_BACK side Vertices are CW when viewed from the outside

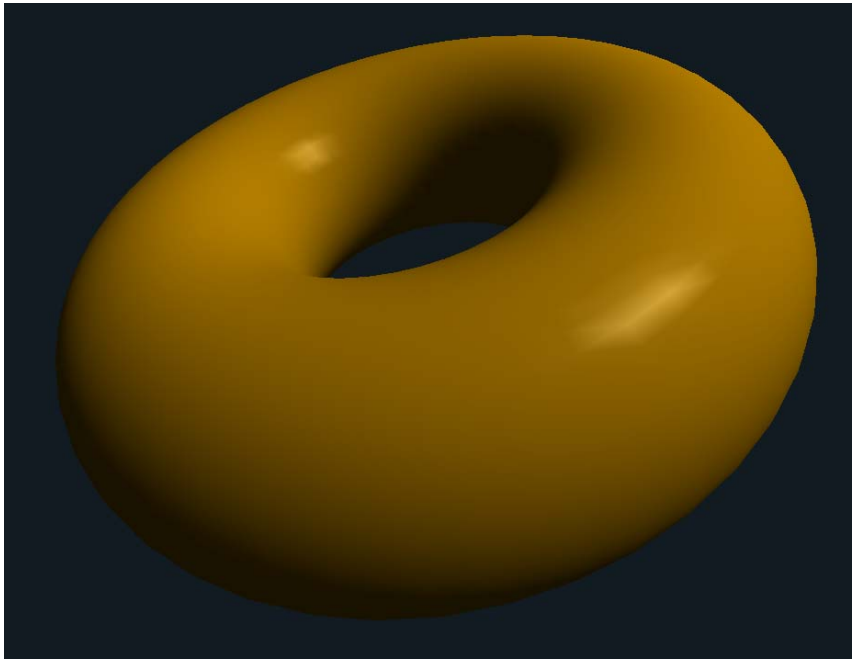
Shortcuts I Like

```
void
SetPointLight( int ilight, float x, float y, float z,  float r, float g, float b )
{
	glLightfv( ilight, GL_POSITION,  Array3( x, y, z ) );
	glLightfv( ilight, GL_AMBIENT,   Array3( 0., 0., 0. ) );
	glLightfv( ilight, GL_DIFFUSE,   Array3( r, g, b ) );
	glLightfv( ilight, GL_SPECULAR,  Array3( r, g, b ) );
	glLightf ( ilight, GL_CONSTANT_ATTENUATION, 1. );
	glLightf ( ilight, GL_LINEAR_ATTENUATION, 0. );
	glLightf ( ilight, GL_QUADRATIC_ATTENUATION, 0. );
	glEnable( ilight );
}

void
SetSpotLight( int ilight, float x, float y, float z,  float xdir, float ydir, float zdir, float r, float g, float b )
{
	glLightfv( ilight, GL_POSITION,  Array3( x, y, z ) );
	glLightfv( ilight, GL_SPOT_DIRECTION,  Array3(xdir,ydir,zdir) );
	glLightf(  ilight, GL_SPOT_EXPONENT, 1. );
	glLightf(  ilight, GL_SPOT_CUTOFF, 45. );
	glLightfv( ilight, GL_AMBIENT,   Array3( 0., 0., 0. ) );
	glLightfv( ilight, GL_DIFFUSE,   Array3( r, g, b ) );
	glLightfv( ilight, GL_SPECULAR,  Array3( r, g, b ) );
	glLightf ( ilight, GL_CONSTANT_ATTENUATION, 1. );
	glLightf ( ilight, GL_LINEAR_ATTENUATION, 0. );
	glLightf ( ilight, GL_QUADRATIC_ATTENUATION, 0. );
	glEnable( ilight );
}
```

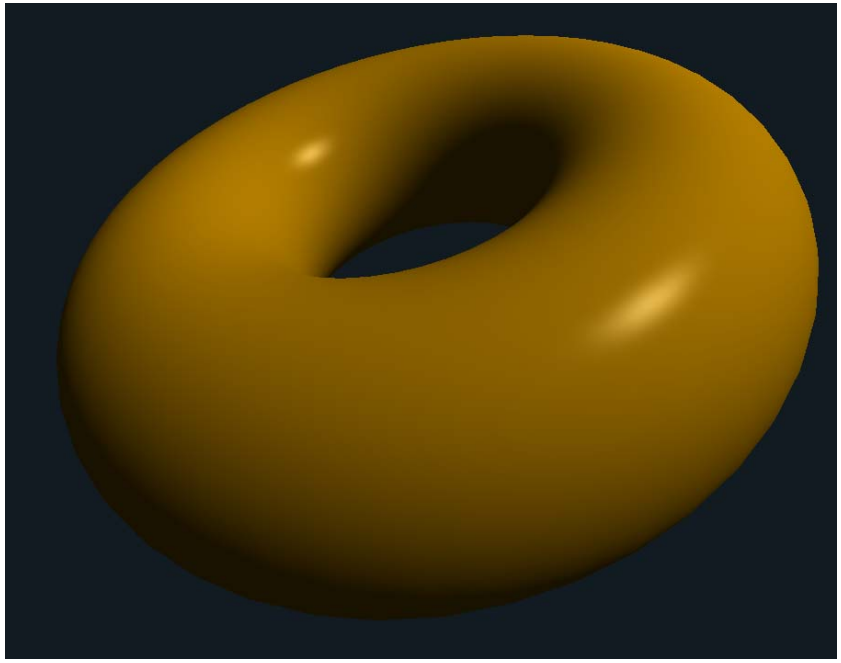
OSU

Sidebar: Note that we are computing the light intensity at each vertex first, and then interpolating that intensity across the polygon second

That is, you are only using the lighting model *at each vertex*.
You can do an even better job if you interpolate the normal across the polygon first, and then compute the light intensity with the lighting model at each fragment second:



Per-vertex



Per-fragment

But, for that you will need the Shaders course (CS 457/557)

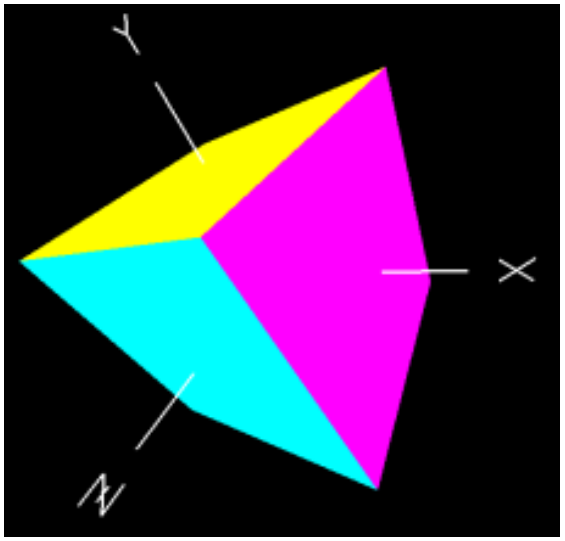
Per-vertex

Per-fragment

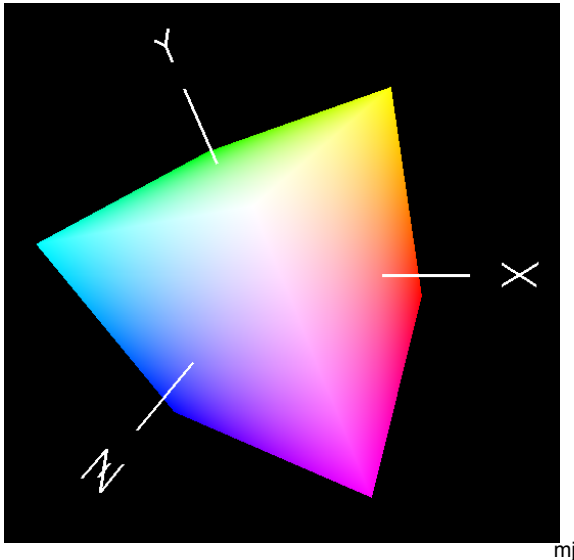
Sidebar: Smooth Shading can also interpolate vertex colors, not just the results of the lighting model

```
glMatrixMode( GL_MODELVIEW );

glTranslatef( tx, ty, tz );
glRotatef( degrees,  ax, ay, az );
glScalef( sx, sy, sz );

glShadeModel( GL_SMOOTH );

glBegin(GL_TRIANGLES );
        glColor3f( r0, g0, b0 );
        glVertex3f( x0, y0, z0 );
        glColor3f( r1, g1, b1 );
        glVertex3f( x1, y1, z1 );
        glColor3f( r2, g2, b2 );
glEnd( );
```

Flat

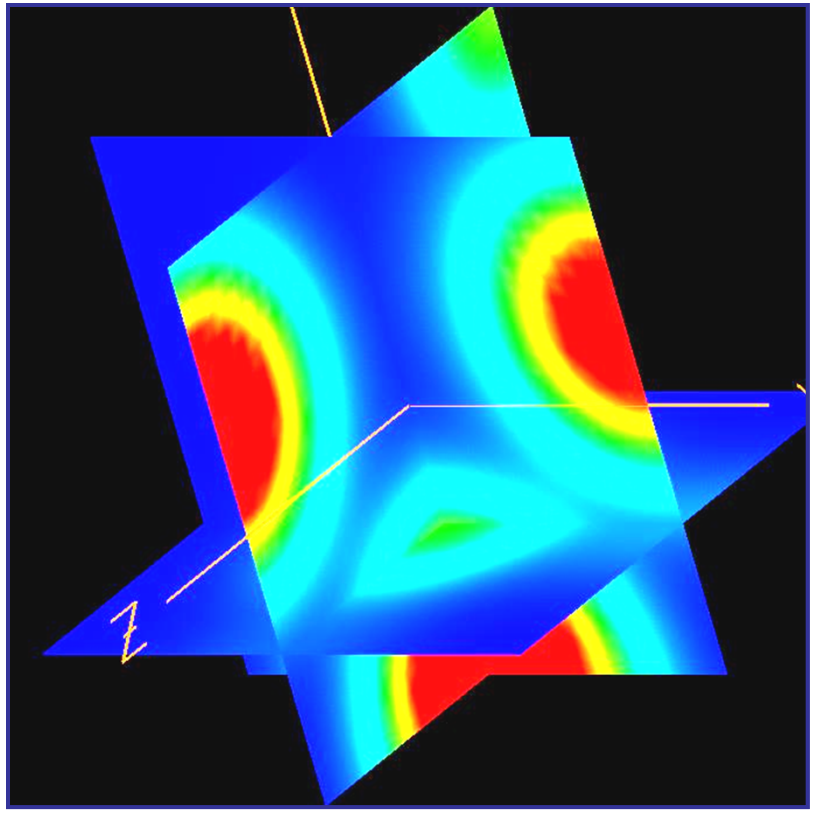


Smooth



Smooth Shading can also interpolate vertex colors, not just the results of the lighting model

This is especially useful when using colors for scientific visualization:



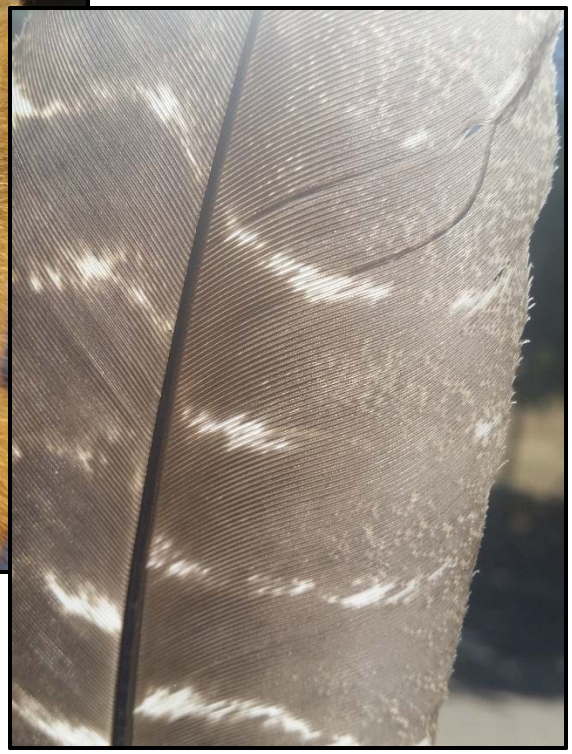
Tricky Lighting Situations

Hair

Watch for these in movies!

Fur

Feathers



Tricky Lighting Situations

Watch for these in movies!
Oh, wait, you probably just saw one.

Disney