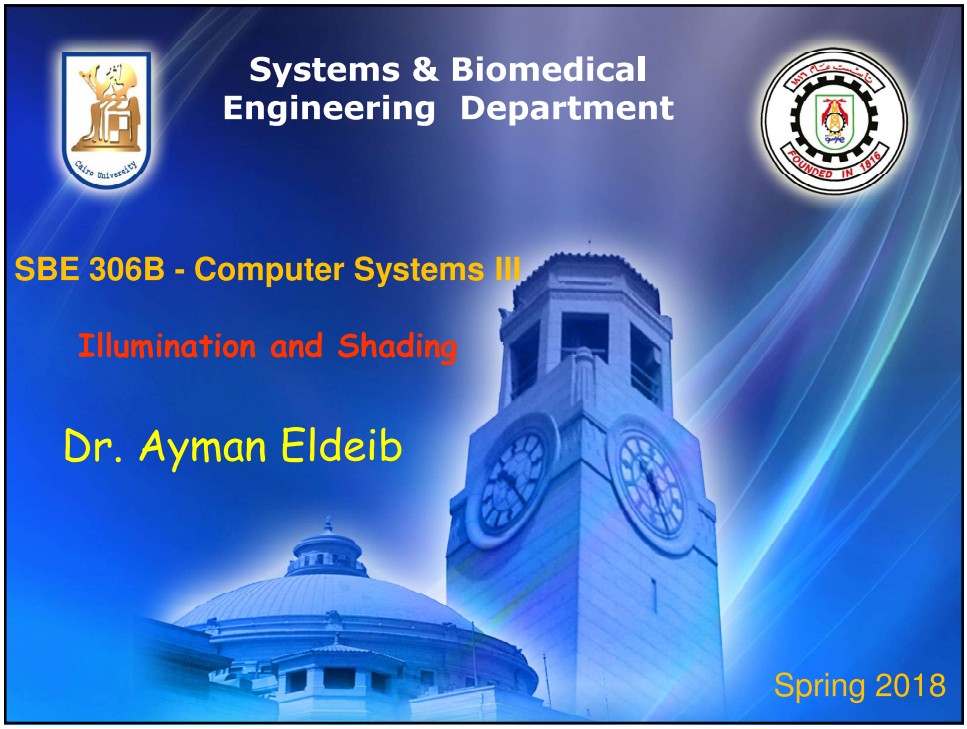


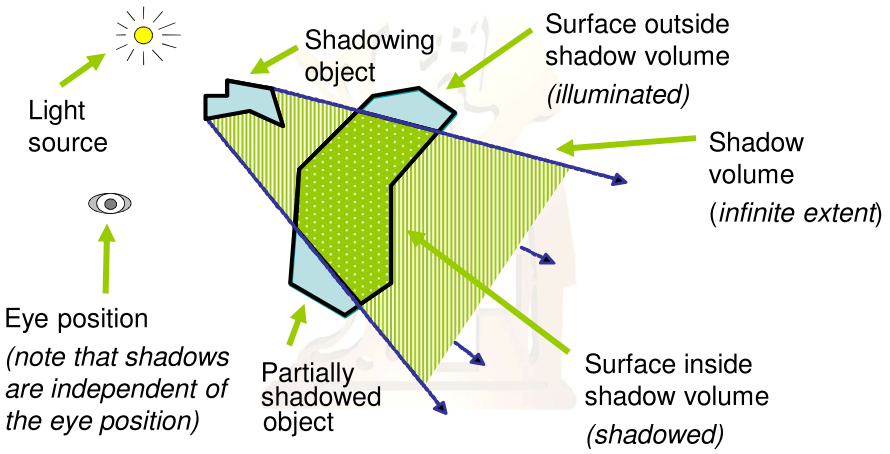

## Computer Graphics Illumination & Shading

### Lighting

- So…given a 3-D triangle and a 3-D viewpoint, we can set the right pixels
- But what color should those pixels be?
- If we're attempting to create a realistic image, we need to simulate the *lighting* of the surfaces in the scene
  - Fundamentally simulation of *physics* and *optics*
  - As you'll see, we use a lot of approximations (a.k.a hacks) to do this simulation fast enough

## Computer Graphics Illumination & Shading

### Illumination and Shading

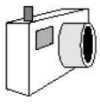


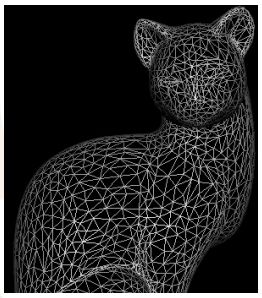

## Computer Graphics Illumination & Shading

### Illumination and Shading
### Mesh Surfaces

**What is the problem?**

Must determine the color of each vertex.





## Computer Graphics Illumination & Shading

### Definitions

- **Illumination**: the transport of energy (in particular, the luminous flux of visible light) from light sources to surfaces & points
  - Note: includes *direct* and *indirect illumination*
- **Lighting**: the process of computing the luminous intensity (i.e., outgoing light) at a particular 3-D point, usually on a surface
- **Shading**: the process of assigning colors to pixels

## Computer Graphics Illumination & Shading

### Definitions

Cont.

- Illumination models fall into two categories:
  - **Empirical**: simple formulations that approximate observed phenomenon
  - **Physically-based**: models based on the actual physics of light interacting with matter
- We mostly use empirical models in interactive graphics for simplicity
- Increasingly, realistic graphics are using physically-based models

## Computer Graphics Illumination & Shading

### Components of Illumination

- Two components of illumination: light sources and surface properties
- Light sources (or *emitters*)
  - Spectrum of emittance (i.e, color of the light)
  - Geometric attributes
    - Position
    - Direction
    - Shape
  - Directional attenuation

## Computer Graphics Illumination & Shading

### Components of Illumination

Cont.

- Surface properties
  - Reflectance spectrum (i.e., color of the surface)
  - Geometric attributes
    - Position
    - Orientation
    - Micro-structure
- Common simplifications in interactive graphics
  - Only *direct illumination* from emitters to surfaces
  - Simplify geometry of emitters to trivial cases

## Computer Graphics Illumination & Shading

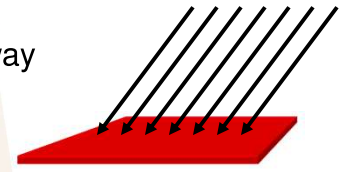
### Ambient Light Source

- Objects not directly lit are typically still visible
  - E.g., the ceiling in this room, undersides of desks
- This is the result of *indirect illumination* from emitters, bouncing off intermediate surfaces
- Images without ambient light have too much contrast
- Very rough approximation of global illumination
- Too expensive to calculate (in real time), so we use a hack called an *ambient light source*
  - No directional characteristics; illuminates all surfaces equally
  - Amount reflected depends on surface properties
  - Independent of object, light and viewer position

## Computer Graphics Illumination & Shading

### Directional Light Source

- For a *directional light source* we make the simplifying assumption that all rays of light from the source are parallel
  - As if the source is infinitely far away from the surfaces in the scene
  - A good approximation to sunlight

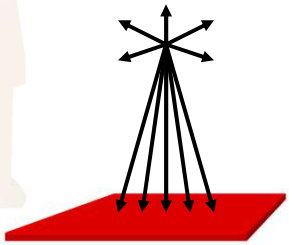


- The direction from a surface to the light source is important in lighting the surface
- With a directional light source, this direction is constant for all surfaces in the scene

## Computer Graphics Illumination & Shading

### Point Light Source

- A *point light source* emits light equally in all directions from a single point
- The direction to the light from a point on a surface thus differs for different points:
  - So we need to calculate a normalized vector to the light source for every point we light.



## Computer Graphics Illumination & Shading

### Other Light Sources

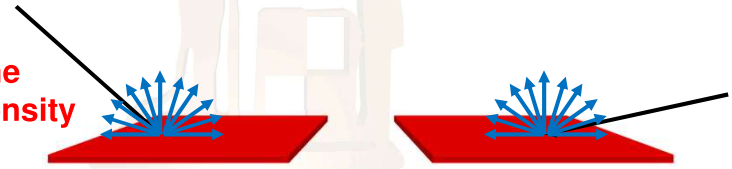
- *Spotlights* are point sources whose intensity falls off directionally.
  - Supported by OpenGL
- *Area light sources* define a 2-D emissive surface (usually a disc or polygon)
  - Good example: fluorescent light panels

## Computer Graphics Illumination & Shading

### Physics of Reflection

- Ideal diffuse reflection
  - An *ideal diffuse reflector*, at the microscopic level, is a very rough surface (real-world example: chalk)
  - Because of these microscopic variations, an incoming ray of light is equally likely to be reflected in any direction over the hemisphere

**What does the reflected intensity depend on?**



## Computer Graphics Illumination & Shading

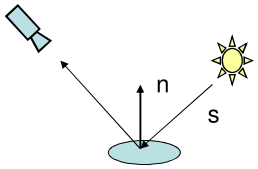
### Lambert's Cosine Law

- Ideal diffuse surfaces reflect according to *Lambert's cosine law*:
  - The energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal
- These are often called *Lambertian surfaces*
- Note that the reflected intensity is independent of the viewing direction, but does depend on the surface orientation with regard to the light source

## Computer Graphics Illumination & Shading

### Computing Diffuse Reflection

- The amount of light falling on a surface is proportional to the angle between the surface normal and the light source direction

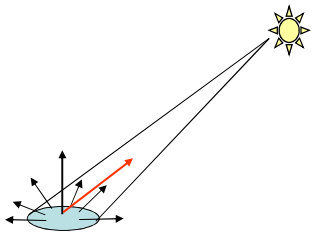



n=Surface normal
s=Direction of illumination
Θ= angle between s and n

$$I = \rho \cos\theta$$

$$I = \rho(\mathbf{n} \cdot \mathbf{s})$$

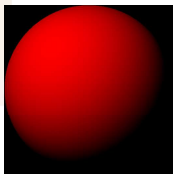
The amount of light that is reflected



$$I \propto \cos\theta$$

$$I = \max(\cos\theta, 0)$$

Can not have negative light



A Lambertian sphere. NOTE: independent of location of camera

## Computer Graphics Illumination & Shading

### Specular Reflection

- Shiny surfaces exhibit *specular reflection*
  - Polished metal
  - Glossy car finish
- A light shining on a specular surface causes a bright spot known as a *specular highlight*
- Where these highlights appear is a function of the viewer's position, so specular reflectance is view-dependent

## Computer Graphics Illumination & Shading

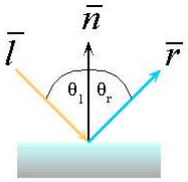
### Physics of Reflection

- At the microscopic level a specular reflecting surface is very smooth
- Thus rays of light are likely to bounce off the microgeometry in a mirror-like fashion
- The smoother the surface, the closer it becomes to a perfect mirror

## Computer Graphics Illumination & Shading

### Optics of Reflection

- Reflection follows *Snell's Laws:*
  - The incoming ray and reflected ray lie in a plane with the surface normal
  - The angle that the reflected ray forms with the surface normal equals the angle formed by the incoming ray and the surface normal:

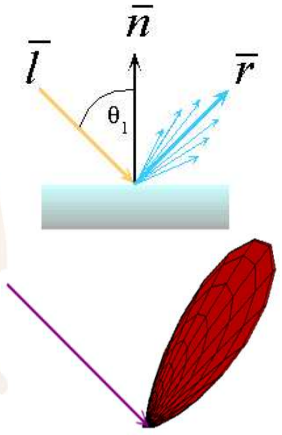



$$\theta_l = \theta_r$$

## Computer Graphics Illumination & Shading

### Non-Ideal Specular Reflection
### An Empirical Approximation

- In general, we expect most reflected light to travel in direction predicted by Snell's Law
- But because of microscopic surface variations, some light may be reflected in a direction slightly off the ideal reflected ray
- As the angle from the ideal reflected ray increases, we expect less light to be reflected



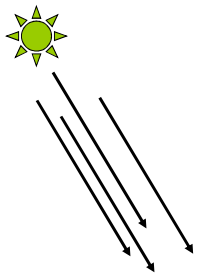

## Computer Graphics Illumination & Shading

### Illumination and Shading
### Models

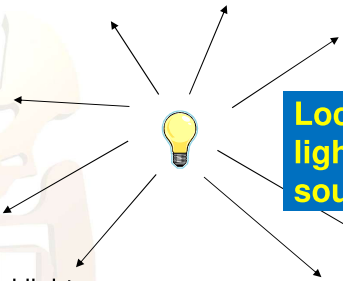
- How do we model light sources?
  - Point
  - Area
- How do we model the reflectance of light off a surface?
  - Direct illumination
  - Global illumination
- How do we model of the material properties of a surface?
  - Plastic, metallic, shiny, etc…

## Computer Graphics Illumination & Shading

### Light Sources



**Distant light source**



**Local light source**

- Distant light source
  - No attenuation
  - Described by a direction
- Local light source
  - Attenuation with distance
  - Point light sourced described by a position (x,y,z)
  - Area light sources more complicated

## Computer Graphics Illumination & Shading

### Local Light Source Attenuation

- Radial intensity attenuation function for a point light source for distance *d*

$$\frac{1}{d^2}$$

- Radial intensity attenuation function used in practice

$$\frac{1}{a_0 + a_1 d + a_2 d^2}$$

## Computer Graphics Illumination & Shading

### OpenGL Lighting

- **glLight* (name, property, value)**
- Name specifies which light
- multiple lights, starting with **GL_LIGHT0**
  - **glGetIntegerv( *GL_MAX_LIGHTS, &n );***
- Properties
  - Position and type
  - Ambient (**GL_AMBIENT**), diffuse, (**GL_DIFFUSE**) and specular (**GL_SPECULAR**) colors
  - Attenuation coefficients

## Computer Graphics Illumination & Shading

### OpenGL Lighting

Cont.

**Types of Lights**

- OpenGL supports two types of Lights
  - Local (Point) light sources
  - Infinite (Directional) light sources
- Type of light controlled by w coordinate
  - *w = 0 Infinite Light directed along (x y z)*
  - *w ≠ 0 Local Light positioned at (x/w  y/w  z/w)*

## Computer Graphics Illumination & Shading

### OpenGL Lighting

Cont.

```
void InitLights (void)
{
        glEnable(GL_LIGHTING);          // Turn on the power
        glEnable(GL_LIGHT0);            // Flip each light's switch
        glEnable(GL_LIGHT1);

        GLfloat lightpos0[] = {.5, 1, .5, 0};
        glLightfv(GL_LIGHT0, GL_POSITION, lightpos0);

        GLfloat lightpos1[] = {4,4,4,0};
        glLightfv(GL_LIGHT1, GL_POSITION, lightpos1);
}
```

## Computer Graphics Illumination & Shading

### OpenGL Moving Light Source

- Light sources transform like geometry
- Only modelview transform is applied

- Stationary light
  - Set transform to identity before specifying location

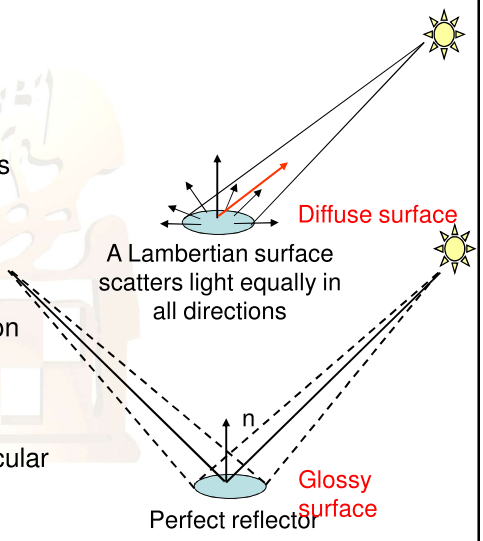
- Moving light
  - push matrix, move light, pop matrix to uniquely control a light's position

- Light source attached to camera

## Computer Graphics Illumination & Shading

### Simple Models in CG

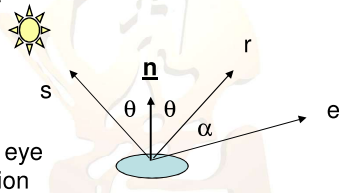
- Lambertian (diffuse)
  - Irradiance from any direction is equally scattered in all directions
- Specular (Perfect) reflection
  - Irradiance from a direction is reflected in only a single direction
- Phong
  - Combines Lambertian with specular




## Computer Graphics Illumination & Shading

### Phong Reflectance Model

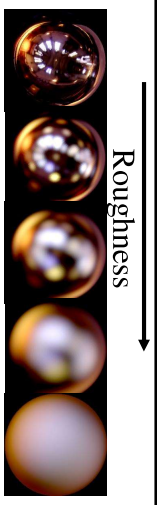
- Find a simple way to create highlights that are **view-dependent** and happen at about the right place
- Not physically based
- Use dot product (cosine) of eye and reflection of light direction about surface normal (**n**)
- Raise cosine lobe to some power (*n*) to control roughness
- Note: vectors should be normalized to unit length
- r : direction of specula reflection




$$\mathbf{r} = -\mathbf{s} + 2(\mathbf{s}\cdot\underline{\mathbf{n}})\underline{\mathbf{n}}$$

$$I = a\cos\theta + b\cos^{n}(\alpha)$$

diffuse specular



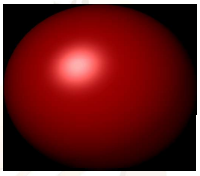
## Computer Graphics Illumination & Shading

### Phong Reflectance Model

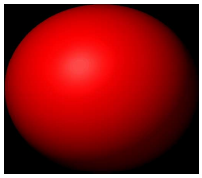
Cont.

$$I = a\cos\theta + b\cos^{n}(\alpha)$$

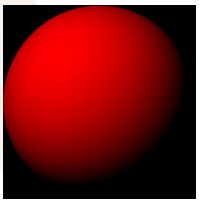
diffuse specular



a=0.3, b=0.7, n=2



a=0.7, b=0.3, n=0.5



A Lambertian sphere.

## Computer Graphics Illumination & Shading

### Color

- Light sources have color
- Objects have color
- Typically each color component (R,G,B) is treated separately
- For plastics the color of the specular highlight is the color of the light. For metals the color of the highlight is the color of the metal.
- Typically a separate color is assigned for the diffuse and specular components

## Computer Graphics Illumination & Shading

### Applying Illumination

- We now have an illumination model for a point on a surface
- Assuming that our surface is defined as a mesh of polygonal facets, *which points should we use?*
- Keep in mind:
  - It's a fairly expensive calculation
  - Several possible answers, each with different implications for the visual quality of the result

## Computer Graphics Illumination & Shading

### Flat Shading

- The simplest approach, *flat shading*, calculates illumination at a single point for each polygon:
  - If an object really is faceted, is this accurate?
  - No:
    - For point sources, the direction to light varies across the facet
    - For specular reflectance, direction to eye varies across the facet

## Computer Graphics Illumination & Shading

### Flat Shading

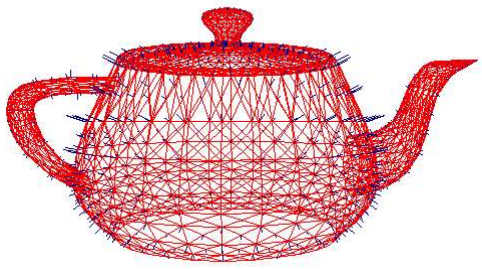
Cont.

- We can refine it a bit by evaluating the Phong lighting model at each pixel of each polygon, but the result is still clearly faceted:
- To get smoother-looking surfaces we introduce *vertex normals* at each vertex
  - Usually different from facet normal

## Computer Graphics Illumination & Shading

### Vertex Normal

- Vertex normal may be
  - Provided with the model
  - Computed from first principles
  - Approximated by averaging the normals of the facets that share the vertex



## Computer Graphics Illumination & Shading

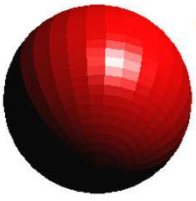
### Goaraud Shading

- This is the most common approach
  - Perform Phong lighting at the vertices
  - Linearly interpolate the resulting colors over faces
  - This is what OpenGL does
- *Does this eliminate the facets?*
  - No

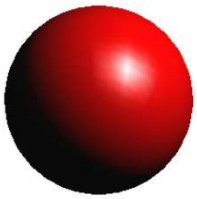
## Computer Graphics Illumination & Shading

### Goaraud Shading

Cont.



glShadeModel(GL_FLAT)



glShadeModel(GL_SMOOTH)

## Computer Graphics Illumination & Shading

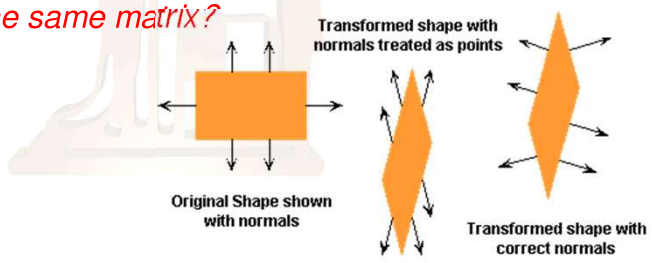
### Phong Shading

- *Phong shading* is <u>not</u> the same as Phong lighting, though they are sometimes mixed up
  - Phong lighting: the empirical model we've been discussing to calculate illumination at a point on a surface
  - Phong shading: linearly interpolating the surface normal across the facet, applying the Phong lighting model at every pixel
    - Same input as Gouraud shading
    - Usually very smooth-looking results
    - But, considerably more expensive

## Computer Graphics Illumination & Shading

### Transforming Normals

- Irritatingly, the matrix for transforming a normal vector is not the same as the matrix for the corresponding transformation on points
  - In other words, don't just treat normals as points:
- Some not-too-complicated affine analysis shows:
  - If **A** is a matrix for transforming points, then $(\mathbf{A}^T)^{-1}$ is the matrix for transforming normals
- *When is this the same matrix?*



## Computer Graphics Illumination & Shading

### Shading Polygons

- Flat shading
  - Use one surface normal for each polygon
  - Calculate one color for each polygon
  - glShadeModel(GL_FLAT)
- Gouraud shading
  - Calculate a surface normal at each vertex
  - Calculate color at each vertex
  - Interpolate color inside polygon
  - glShadeModel(GL_SMOOTH)
- Phong normal interpolation
  - Calculate a surface normal at each vertex
  - Interpolate surface normals across polygon
  - Use interpolated normals to calculate color at each pixel
  - OpenGL doesn't do this, but you can with programmable shaders

## Computer Graphics Illumination & Shading

### OpenGL Specifying Material Properties

- **glMaterialfv (face, property, value)**
- Separate materials for front and back
- Properties

| | |
|---|---|
| **GL_DIFFUSE** | Base color |
| **GL_SPECULAR** | Highlight Color |
| **GL_AMBIENT** | Low-light Color |
| **GL_EMISSION** | Glow Color |
| **GL_SHININESS** | Surface Smoothness |

## Computer Graphics Illumination & Shading

### OpenGL Specifying Normal

- Use the function **glNormal3f**( *x, y, z)*
- Normals define how a surface reflects light
- Specifying a normal sets the *current* normal
  - Remains unchanged until user alters it
  - Usual sequence: **glNormal, glVertex……., glNormal, glVertex……., glNormal, glVertex…**
- Usually, we want unit normals for shading
  - **glEnable( GL_NORMALIZE )**
  - This is slow – either normalize them yourself or don't use glScale
  - scaling affects a normal's length
- You should generate normals for curved surfaces
  - GLUT does it automatically for teapot, cylinder,…