Realistic Rendering

-- Shading--
Mastering 2D & 3D Graphics

- Discuss Shading Concepts
  - General Concepts
  - Illumination
  - Reflection
  - Atmospheric Effects
Before graphic objects can be shaded...

- ...points on each surface are given color & transparency
- ...light sources for illuminating the surfaces must be specified in terms of color, intensity, and propagation
- ...reflection describing the interaction of the light with a surface must be specified in terms of the properties of the surface and the nature of the incident light
- ...the position of the viewpoint must be determined
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Introduction

- Light...
  - ...leaves a light source and travels in a straight line through space...strikes, reflects, and may pass through objects ...arrives at a viewer

- A viewer...
  - ...is the viewpoint, eye, or camera looking at the scene

- Emission...
  - ...is light that pours out of a light source in a straight path until it reaches the surface of an object
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Introduction

- Reflection...
  - ...when light reaches a surface, it is partially absorbed, partially reflected, and may be partially transmitted

- Transparency and refraction...
  - ...is a measure of how opaque or translucent a surface is
  - ...light passing through an object may be refracted (with a slight change in direction)
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Introduction

- Illumination...
  - ...determines the intensity and color of light arriving at each visible point on a surface
  - ...results from light arriving from various light sources and over other surfaces

- Reflection...
  - ...simulates the interaction of the arriving light with the material making up the surface
  - ...requires calculating the intensity and color of the light from the surface toward the viewer
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Introduction

- Atmospheric effects...
  - ...modify the light's color as it travels from the object to the viewer
  - ...could be particles in the atmosphere
- In real environments, a significant amount of ambient light comes from all directions
The primary light sources for realistic images are...

- ...point light sources
- ...distant light sources (*sometimes called directional sources*)
- ...spotlight sources
- ...area light sources
Ambient light...
- ...is the easiest kind of light source to model
  ...produces constant illumination on all surfaces, regardless of their position and orientation
- ...when used as the ONLY light source, ambient light will create unrealistic images
- ...is also called flat shading! (each object appears as a flat silhouette)
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Illumination: ambient light sources

- Surfaces that are parallel to the light source, but are visible to the viewer, can be made visible using ambient light sources...
  - ...otherwise they would be drawn in black!

- Ambient light softens a harsh point light source (that is like a thin flashlight beam)
  - When only ambient light is used, each object appears as a monochromatic silhouette unless different shades were explicitly specified
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Illumination: point light sources

- Point source rays emanate from a single point which...
  - ...can be used to model a small incandescent bulb
  - ...illuminates surfaces depending on their orientation
  - If the surface is normal (perpendicular) to the incident light rays, it is brightly illuminated; the more oblique the surface is, the less it is illuminated
  - The intensity of the light falls off with the square of the distance from the light to the surface
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Illumination: distant light sources

- Distant light sources (or directional sources)
  - ...have rays that all come from the same direction
  - ...cause surfaces of like orientation to receive the same amount of light independent of their location
  - ...can be used to represent the distant sun by approximating it as an infinitely distant point source
  - Again, if the surface is normal (perpendicular) to the light rays, it is brightly illuminated; the more oblique the surface is, the less it is illuminated
  - The intensity is not affected by distance from light
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Illumination: spotlight sources

- Spotlights are sources with both position and direction
  - ...simulates a cone of light emitted from one point toward another point
  - ...the intensity of the emitted light falls off exponentially with the angle from the center of the cone
Area light sources...
- ...emit light over some area in space
- ...sometimes are called a distributed or extended source
- ...can be used to simulate frosted glass light bulbs or fluorescent tubes
- ...causes light to come from neither a single direction nor a single point
- ...this is the most complex model!
Taking all concepts into account, light reflected in a direction may be influenced by light striking the surface from anywhere inside the incident hemisphere.
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Reflection

- Is the process of simulating the interaction
  - of the light arriving at a surface with surface material
- Light emerging from a surface uses information:
  - ...the direction, color, intensity of the arriving light
  - ...the color of the surface
  - ...the opacity of the surface -- which is the extent to which the surface absorbs light coming from behind
  - ...the orientation of the surface, using a surface normal
  - ...the direction in which the surface is viewed
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Reflection

Reflection may simulate sharp reflections of a mirror reflecting another object.

Reflection may also simulate diffuse reflections of less highly polished surfaces.
The three primary types of reflection are...
- ...ambient reflection
- ...diffuse reflection
- ...specular reflection

Ambient reflection...
- ...is the surface reflection of ambient light sources
- ...has a reflection intensity independent of both the surface location and orientation
- ...has a reflection intensity dependent on both the color of the light source and the reflectivity of the surface
Without ambient reflection,
- if a surface is parallel to the light source it is therefore invisible to it, it would be drawn in black!
- Ambient light makes it possible to see this surface!

Most objects do not emit light of their own...
- ...instead they absorb light and reflect part of it
- ...for example a green object absorbs white light and reflects a green component in the light
- ...this is called diffuse reflection
Diffuse reflection...
  - ...causes a surface to reflect colored light when illuminated by white light

A surface that is uniform scatters light equally in all directions
  - ...which means that the amount of reflected light seen does not depend on the viewer's position
Such surfaces are dull or matt and the intensity of diffuse reflected light is given by Lambert's law:

- Intensity = (Intensity of the light) * (diffuse reflectivity) * cos(angle between the surface normal and the line from the light source)

A better way to think of this is as a dot product:

\[ I = I \times \text{Reflec} \times (L \cdot N) \]
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Diffuse Reflection

- Please note:
  - (1) The angle must be between 0 degrees and 90 degrees if the light source is to have any direct effect on the point being shaded
  - (2) When the angle is not within this range, ambient reflection should be used to make the surface visible
As we have already learned today...

- ...with diffuse reflection, light is not reflected in a single direction but is scattered almost randomly in all possible directions
- ...and the light is influenced by the surface...part will be reflected and part will be absorbed by the surface
- ...the part not absorbed will be reflected randomly in all directions
- ...which is why the direction from which the incoming light comes is unimportant
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Lighting of Objects: diffuse reflection

- Three parameters are usually used to specify the diffuse reflectivity of a surface:
  - ...coefficients for red, green, and blue all ranging from 0 to 1 ($K_{dr}, K_{dg}, K_{db}$)
  - ...for example, a dark green surface might have a diffuse reflectivity of (0,0.5,0)
The incoming light...

- ...whether ambient, point light, or diffuse light...
- ...will also consist of three components which describe its intensity in terms of RGB \((I_r, I_g, I_b)\)
- ...to be system independent we will assume they range from 0 to 1
- ...but in reality they may range from 0 to the maximum intensity available on your system!
With ambient light...

- ...which comes from all possible directions
- ...and reflects randomly in all possible directions
- ...there is no angle from which the light comes
- ...and there is no angle from which light goes
- ...which means it is reflected equally in all directions
- ...which also means that the angle in which the reflecting surface is tilted in space is insignificant
With ambient light...
  - ...and the light coming from it will always be the same, producing a uniform illumination of the surface at any viewing position
  - ...even if the surface is curved, the illumination will be the same

Ambient light that hits a surface is described by three components \((I_{ar}, I_{ag}, I_{ab})\)
  - The resulting reflected light is also described by three components \((I_r, I_g, I_b)\)
For ambient light...
  ...we can compute the intensity of the light reflected by:
  \[ I_{ar} = K_{dr} \cdot I_{ar} \]
  \[ I_{ag} = K_{dg} \cdot I_{ag} \]
  \[ I_{ab} = K_{db} \cdot I_{ab} \]

The resulting values represent the contribution from ambient light to the total illumination of the surface.
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Lighting of Objects: diffuse reflection

- With point light sources...
  - ...light comes in at an angle
  - ...where the incident angle is the angle $\phi$ between the vector that points to the light source (L) and the surface normal at this point (N)
  - ...and the intensity of the light is proportional to the number of light rays that hit an area, where the proportion is the cosine of the incident angle $\phi$
  - ...where $0 \leq \phi \leq \pi/2$ ...called Lambert's cosine law
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Lighting of Objects: diffuse reflection

- With point light sources...
  What this means is...
  - ...we must multiply all intensities of the incoming light by the \( \cos \theta \) to get the actual intensity with which light hits the surface...
  - ...it is the actual intensity at the surface that is reflected through diffuse reflection
With point light sources...

- ...the distance of the point light source from the surface is another factor that influences the intensity of the light striking a surface
- ...however, usually the distances involved are so large in comparison to the size of the illuminated surface that the differences due to distance for different points on the surface of an object are negligible
- ...we will include this distance as $D$
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Lighting of Objects: diffuse reflection

- So, if the intensity of light coming from a point light source is $I_{pr}$, $I_{pg}$, $I_{pb}$...
  - ...then the contribution of the point light to the overall illumination is:
    - $I_{r} = I_{pr} \times \cos \phi \times K_{dr}/D^2$
    - $I_{g} = I_{pg} \times \cos \phi \times K_{dg}/D^2$
    - $I_{b} = I_{pb} \times \cos \phi \times K_{db}/D^2$
As a result...

- ...the incident angle $\phi$ can be computed as the dot product of the vector $L$ and the vector $N$: $\cos \phi = N \cdot L$

Therefore, diffuse reflection of both ambient light and point light sources is:

- $I_r = K_{dr} \cdot I_{ar} + I_{pr} \cdot \cos \phi \cdot K_{dr}/D^2$
- $I_g = K_{dg} \cdot I_{ag} + I_{pg} \cdot \cos \phi \cdot K_{dg}/D^2$
- $I_b = K_{db} \cdot I_{ab} + I_{pb} \cdot \cos \phi \cdot K_{db}/D^2$

Note: For surfaces that are illuminated by the sun or by a far light sources, the division by $D$ is ignored.
Specular reflection...
- ...is useful for surfaces that have some degree of glossiness (for example a mirror is a perfect glossy surface)
- ...causes light reflected from glossy surfaces to leave the surface at an angle
- ...which is an angle that the light source beam makes with the surface
- ...means that the degree of specular reflection seen by a viewer depends on the viewing direction
Specular reflection...

- ...for example, with a perfect mirror surface, the angle of reflection is equal to the angle generated from the light source.
Specular reflection...

- ...in practice is not perfect and reflected light can be seen from viewing directions close to the direction of the reflected beam (called the highlight area)
- ...these highlights allow specularly reflected light to be different than diffuse reflected light
- for example, if a green surface is illuminated with white light then the reflected diffuse light is green but the highlight is white
- ...the amount of highlight depends on the glossiness
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Specular Reflection

With perfect mirror reflection, the angle between the viewer and the reflected beam must be 0° in order for the surface to be viewed.

With other types of surfaces, specular reflection is concentrated around the "mirror direction" and does not require the viewer to be exactly aligned with a single reflected beam.

As a surface becomes more and more dull, the highlight becomes more spread out and intensity diminishes.

The angle between the viewer and the mirror direction is useful to determine the reflectivity.
The reflectivity of specular reflecting surfaces...

- ...falls off sharply with the larger angles away from the mirror direction
- ...falls off at the rate:

\[ \text{Specular reflection} = (\text{Surface Normal } \cdot \text{Halfway})^{\frac{1}{\text{roughness}}} \]
This means that the rougher the surface, the less specular light will be reflected to the viewer

- For a perfect mirror -- the roughness factor would be 1; the less perfect the surface, the larger the roughness factor

- Think of this equation as spreading the highlight over a greater area

- Specular reflections are like blurred images of the light source being reflected on a surface
The Phong model...

- combines ambient, diffuse, and specular reflection
  - calculates the intensity at a point on a surface by taking a linear combination of these three components
- Light incident at a surface = light reflected + light scattered + light absorbed + light transmitted
- ...takes into account that the intensity of light reflected is dependent on the incident intensity, the angle of incidence, & the nature of the material (e.g., how rough it is)
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Phong Model

- The Phong model...
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*Phong Model*

- The Phong model...
  - ...assumes that all light sources are point sources
  - ...ignores any intensity distribution of the light source
  - ...ignores all geometry of the object except for the surface normal
  - ...assumes that the light sources and viewer are located at infinity
  - ...simulates the decrease of specular light around the mirror direction to model the glossiness of a surface
The Phong model...

- assumes the color of the specular reflection to be that of the light source (this means that highlights are rendered white regardless of the material)
- ambient light is modeled as a constant
- The Phong model is a popular and simple method...
- ...which provides a degree of realism sufficient for many applications
- ...but creates objects that appear plastic like
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Lighting of Objects: specular reflection

- As we have already learned today...
  - ...with specular reflection, light is reflected in a fixed direction without affecting its quality

- As we look at specular reflection...
  - ...we will follow the Phong model
  - ...which simplifies the complex physical characteristics of specularly reflected light
  - ...where wavelengths of RGB of the incoming light are all reflected equally
First, let's look at specular reflection of ambient light...

- ...guess what!
- ...there is no such thing!
- ...since ambient light comes from all possible angles, specular reflection must have the same effect on ambient light as diffuse reflection has - it reflects in all possible directions
With point light sources...
  - ...light comes in at an angle
  - ...where the specular reflection depends on this angle of incoming light
  - ...the quality of specular reflection is dependent on the shininess of the surface
  - ...where a very shiny surface will reflect almost all of the incoming light precisely in the direction of the reflection vector and
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Lighting of Objects: specular reflection

- With point light sources...
  - ...a less shiny surface will reflect much of the incoming light along that same vector - but also scatter a little around the reflection vector
  - ...where Phong characterizes the surfaces shininess by $SH$
With point light sources, let's make the following assumptions...

- ...the incoming light as an intensity: $I$
- ...the light is coming from direction: $L$
- ...the reflection vector is: $R$
- ...and light is reflected at an intensity of: $I \cdot \cos^{SH} \phi$
- ...where $\phi$ is the angle of deviation of the reflected light from the precise direction of reflection
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Lighting of Objects: specular reflection

- Using these concepts...
  - ...if the light is reflected precisely in the direction of the reflection vector, then the angle of deviation would be zero and
  - ...the reflected intensity would be \( I \cdot \cos^{SH0} \Rightarrow I \)
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Lighting of Objects: specular reflection

- When light is not reflected in precisely the direction of the reflection vector...
  - ...the angle of deviation will be greater than zero
  - ...so that the light is reflected with the intensity $I \cdot \cos^{SH} \phi$
  - ...which is a very small amount of light when $SH$ is large (i.e., when $SH$ is large, little of the light is reflected in directions that deviate from the reflection vector)
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Lighting of Objects: specular reflection

- When light is not reflected in precisely the direction of the reflection vector...
  - ...surfaces that are very shiny - like polished silver - will have a very large value of $SH$ (like 150 or more!)
  - ...less shiny surfaces will have values of $SH$ as small as 1 (e.g., cardboard or paper will have such small parameters)
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Lighting of Objects: specular reflection

- Using the Phong specular reflectance model...
  - ...with a constant $k_s$ for the specular reflection coefficient of the surface
  - ...the intensity of the light reflected is...
  - $I_r = I_{pr} \times k_s \times I*cos^{SH} \varphi$
  - $I_g = I_{pg} \times k_s \times I*cos^{SH} \varphi$
  - $I_b = I_{pb} \times k_s \times I*cos^{SH} \varphi$
So, combining the results for diffuse ambient light, diffuse reflected light, and specularly reflected point light gives us:

- \[ I_{r} = K_{dr}I_{ar} + I_{pr} \left( k_{s} * I * \cos^{SH} \varphi + \cos \varphi * \frac{K_{dr}}{D^{2}} \right) \]
- \[ I_{g} = K_{dg}I_{ag} + I_{pg} \left( k_{s} * I * \cos^{SH} \varphi + \cos \varphi * \frac{K_{dg}}{D^{2}} \right) \]
- \[ I_{b} = K_{db}I_{ab} + I_{pb} \left( k_{s} * I * \cos^{SH} \varphi + \cos \varphi * \frac{K_{db}}{D^{2}} \right) \]
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Lighting of Objects: example

- Let's compute the contribution of one or more point light sources to the overall illumination of each pixel...using...
  - ...the incoming light as an intensity: $I$
  - ...the light is coming from direction(s): $L1, L2, \text{ etc.}$
  - ...the reflection vector(s): $R1, R2, \text{ etc.}$
  - ...the surface normal: $N$
  - ...the viewing direction: $V$
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Lighting of Objects: example

- And...using...
  - ...the point on the surface which corresponds to a pixel on the screen: \((x,y,z)\)
  - ...the location of the point light source: \((S_x,S_y,S_z)\)
    ...the position of the eye: \((E_x,E_y,E_z)\)...which will coincide with the center of projection \((0,0,d)\)

- So, we can compute...
  - ...\(L \rightarrow L_x = S_x-x; L_y = S_y-y; L_z=S_z-z\) and normalize
  - ...\(V \rightarrow V_x = E_x-x; V_y = E_y-y; V_z = E_z-z\) and normalize
Now let's review the method used for computing the reflection vector...

- ...using a geometric approach using vector algebra
- ...notice the incident angle and the reflection angle are both the same
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Lighting of Objects: reflection vector

- The vector $A$ is parallel to $-L$...
  - ...and forms an isosceles triangle:
Atmosphere effects...
- ...are caused when any light ray traveling between surfaces passes through the atmosphere
- ...are introduced by materials like dust, smoke, haze, fog
- ...cause the light to seems whiter with haze and fog
- ...are important to create reality
- ...provide depth cues to the relative distances of objects
Depth cuing simulates atmospheric effects...

- causing more distant objects to be rendered with a lower intensity than closer ones
- with front and back depth-cue reference planes defined in NPC space with associated scale factors (between 0 and 1) that determine the blending of the original intensity with that of a depth-cue color
- Some depth cue shaders mix the background color into the reflected light according to the distance between the surface and the viewpoint