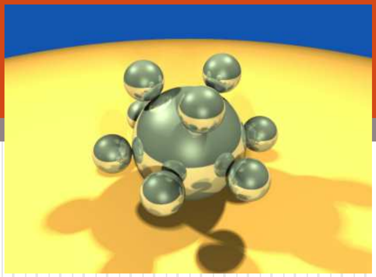


Introduction to Illumination Models

Visual Realism Requirements

- Light Sources
- Materials (e.g., plastic, metal)
- Shading Models
- Depth Buffer Hidden Surface Removal
- Textures
- Reflections
- Shadows

Rendering Objects

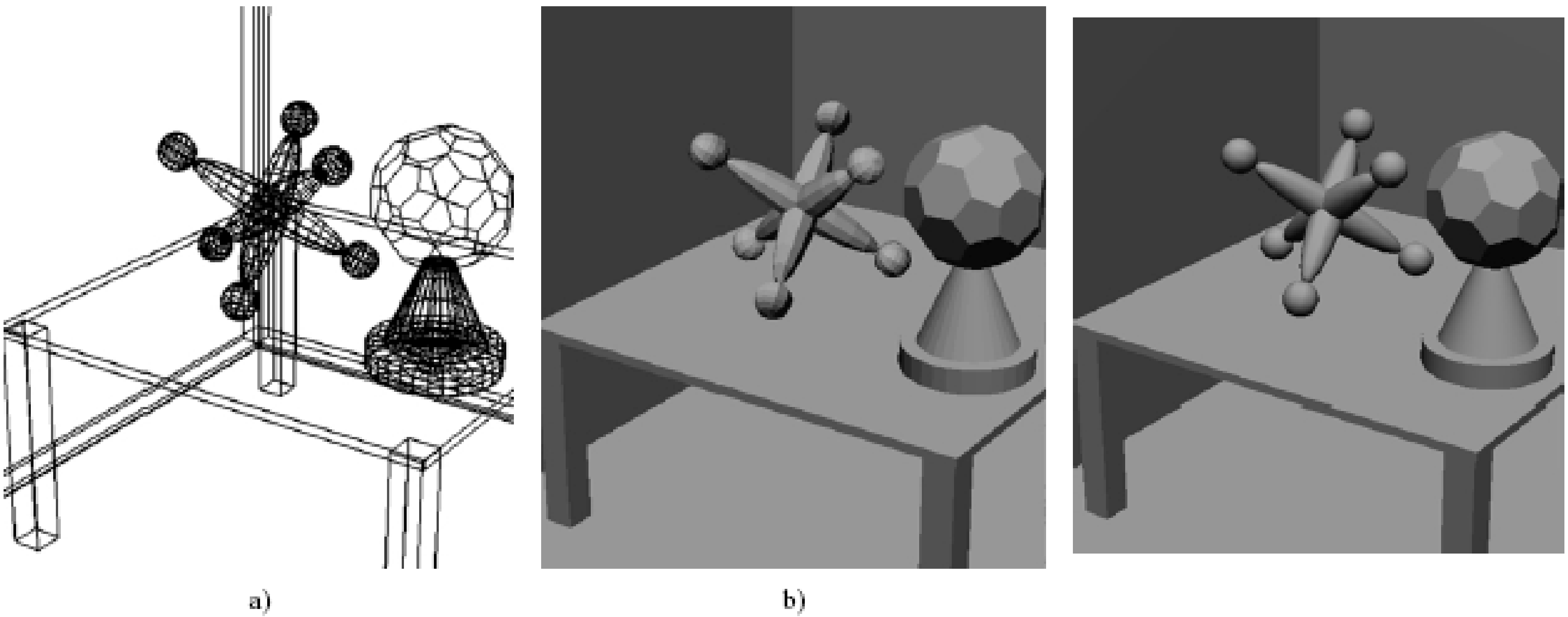
- We want to make the objects look visually interesting, realistic, or both.
- Develop methods of **rendering** for the objects of interest.
- Rendering: ***computes*** **how each pixel of a picture should look using different shading models.**

Rendering Objects (2)

- Much of rendering is based on different **shading models**,
  - describes how light from light sources interacts with objects in a scene.
- It is impractical to simulate all of the physical principles of light, scattering and reflection.
- A number of approximate models have been invented that do a good job and produce various levels of realism.

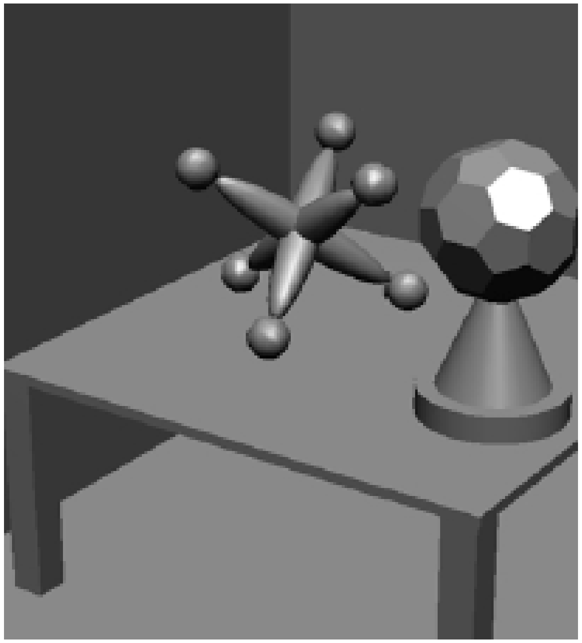
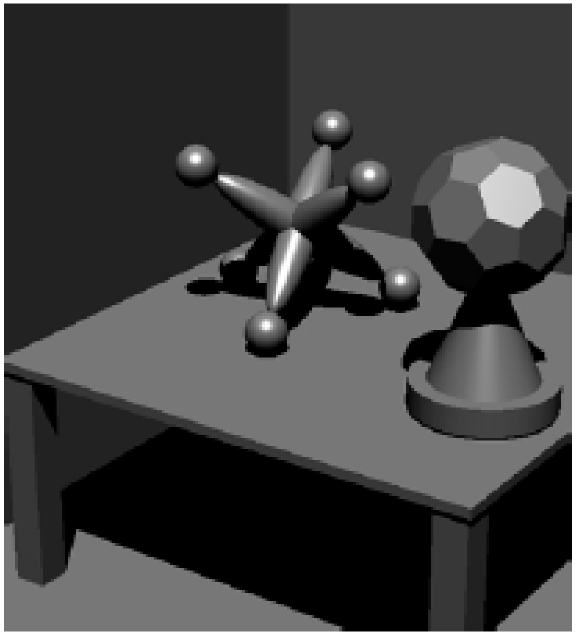
Rendering

- Example: Compare mesh objects drawn using wire-frame, flat shading, smooth (Gouraud) shading



Rendering (2)

- Compare to images with specular highlights, shadows, textures


Shading Models: Introduction

- A shading model dictates how light is scattered or reflected from a surface.
- Simple shading models focuses on achromatic light
  - It has brightness but no color
  - Only shade of gray
  - Described by single intensity value.
- Graphics uses two types of light sources
  - Ambient light - doesn't come directly from a source, but through windows or scattered by the air, comes equally from all directions.
  - Point-source light comes from a single point.

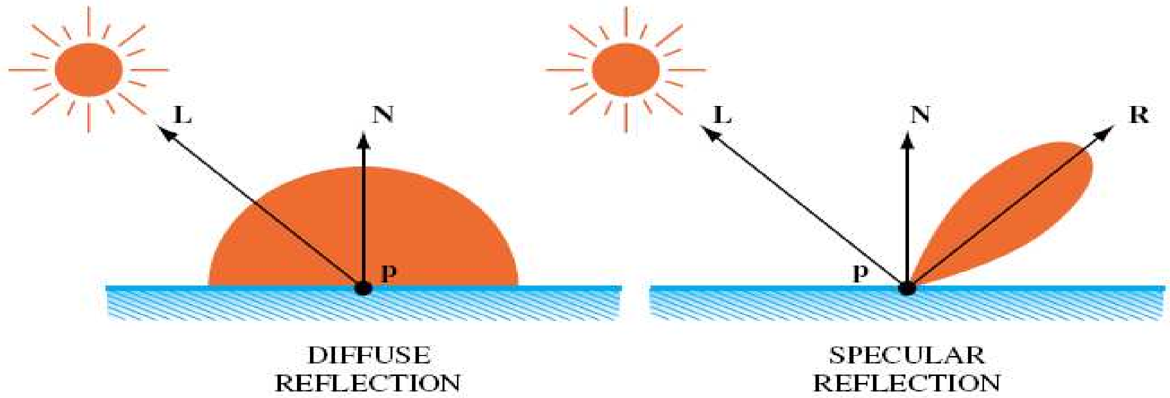
Shading Models: Introduction (2)

- When light hits an object,
  - some light is absorbed (and turns into heat),
  - some is reflected,
  - some may penetrate the interior (e.g., of a clear glass object).
- If all the light is absorbed, the object appears black and is called a blackbody.
- If all the light is transmitted, the object is visible only through reflection

Shading Models: Introduction (3)

- When light is reflected from an object, some of the reflected light reaches our eyes, and we see the object.
- The amount of light that reaches the eye depends on the
  - Orientation of the surface
  - Light sources
  - Observer
- There are two types of reflection of incident light:
  - **Diffuse Scattering**
  - **Specular Reflections**

Shading Models: Introduction (4)



- **Diffuse Scattering**:
  - some of the incident light slightly penetrates the surface
  - re-radiated uniformly in all directions.
  - The light takes on some fraction of the color of the surface.
- **Specular reflection**:
  - more mirror-like and highly directional.
  - Incident light does not penetrate.
  - Light is reflected directly from the object’s outer surface, giving rise to highlights of approximately the same color as the source.
  - The surface looks shiny.

Shading Models: Introduction (5)

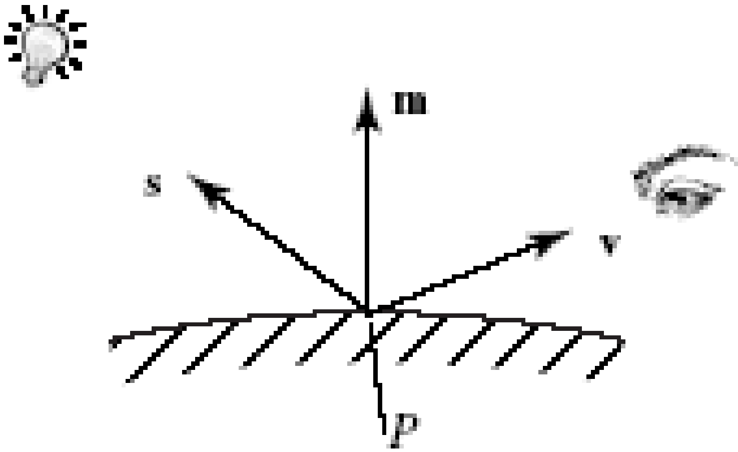
- In the simplest model, specular reflected light has the same color as the incident light. This tends to make the material look like plastic.
- In a more complex model, the color of the specular light varies over the highlight, providing a better approximation to the shininess of metal surfaces.
- Most surfaces produce some combination of diffuse and specular reflection, depending on surface characteristics such as roughness and type of material.
- The total light reflected from the surface in a certain direction is the sum of the diffuse component and the specular component.

Reflected Light Model

- Finding Reflected Light: a model
  - Model is not completely physically correct, but it provides fast and relatively good results on the screen.
  - Intensity of a light is related to its brightness. We will use I_s for intensity, where s is R or G or B.

Calculating Reflected Light

- To compute reflected light at point P, we need 3 vectors:
  - normal **m** to the surface at P
  - vectors **s** from P to the source
  - **v** from P to the eye.
  - the angles between these three vectors form the basis for computing light intensities



Calculating Diffuse Light

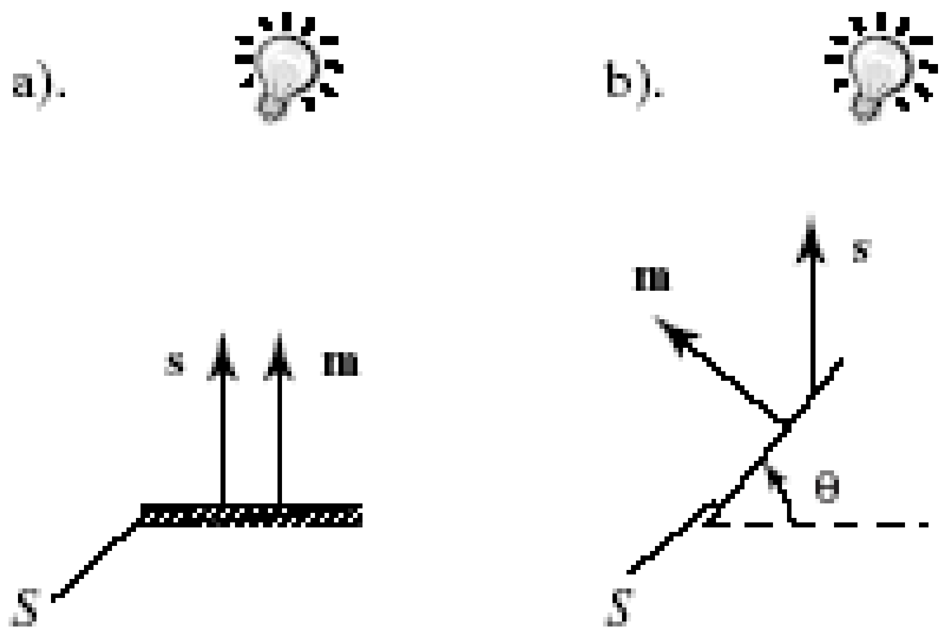
- A fraction of incident light is reradiated diffusly in all dircetions

- Diffuse scattering is assumed to be independent of the direction from the point, *P*, to the location of the viewer's eye.(omindirectional scattering)
  - I_d is independent of the angle between **m** and **v** (unless $\mathbf{v} \cdot \mathbf{m} < 0$, making $I_d = 0$.)

- The amount of light that illuminates the face *does* depend on the orientation of the face relative to the point source:
  - the amount of light is proportional to the area of the face that it sees: the area *subtended* by a face.

Calculating Diffuse Light (2)

- The relationship between brightness and surface orientation is called as Lambert's law.
- Left :I_d (normal vector m is aligned with s)
- Right: I_d cosθ (face is turned partially away from light source)



Calculating Diffuse Light (3)

- We know $\cos\theta = (\mathbf{s}\cdot\mathbf{m})/(|\mathbf{s}||\mathbf{m}|)$.
- $I_d = I_s\rho_d\,(\mathbf{s}\cdot\mathbf{m})/(|\mathbf{s}||\mathbf{m}|)$.
  - I_d – Intensity of the reradiated light that reaches eye.
  - I_s is the intensity of the source.
  - ρ_d is the diffuse reflection coefficient and depends on the material the object is made of.

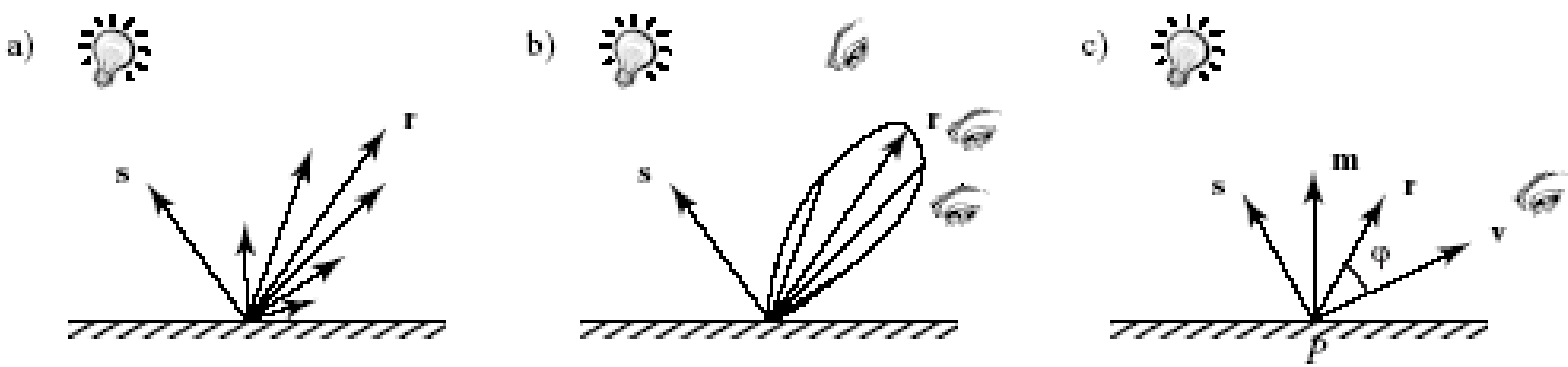
Calculating Diffuse Light (4)

- If face is aimed away from the eye this dot product is negative and we want I_d to evaluate to zero
- **If s·m** < 0 we want $I_d = 0$.
- So to take all cases into account, we use

$$I_d = I_s \rho_d \max\left[(\mathbf{s} \cdot \mathbf{m})/(|\mathbf{s}||\mathbf{m}|), 0\right].$$

Calculating the Specular Component

- Real objects do not scatter light uniformly in all directions; a specular component is added to the shading model.
- Specular reflection causes highlights, which can add significantly to realism of a picture when objects are shiny.
- Most of the light reflects at equal angles from the (smooth and/or shiny) surface, along direction **r,** the reflected direction.



Calculating the Specular Component (2)

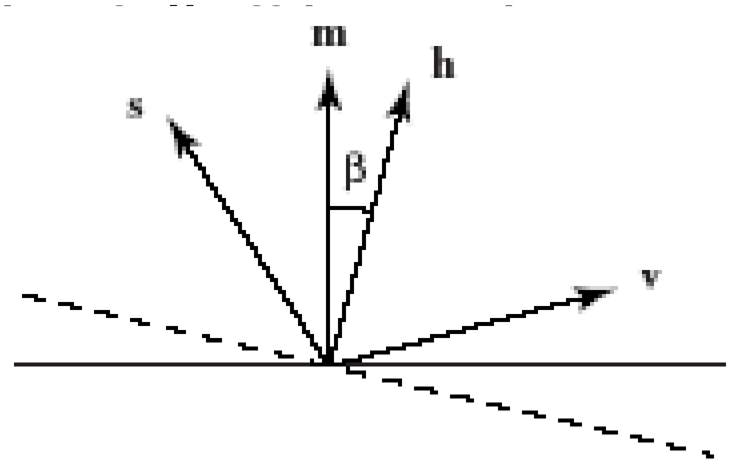
- The direction r of perfect reflection depends on both s and normal vector m
  - compute $\mathbf{r} = -\mathbf{s} + 2\,\mathbf{m}\,(\mathbf{s}\cdot\mathbf{m})/(|\mathbf{m}|^2)$ (mirror reflection direction).
- For surfaces that are not mirrors, the amount of reflected light decreases as the angle φ between **r** and **v** increases.
- For a simplified model, we say the intensity decreases as $\cos^f \varphi$,
  - where f (amount of falloff) is chosen experimentally between 1 and 200.

Calculating the Specular Component (3)

- $\cos \varphi = \mathbf{r \cdot v}/(|\mathbf{r}||\mathbf{v}|)$
- $I_{sp} = I_s \, \rho_s \, (\mathbf{r \cdot v}/(|\mathbf{r}||\mathbf{v}|))^f$.
  - ρ_s is the specular reflection coefficient, which depends on the material.
- If $\mathbf{r \cdot v} < 0$, there is no reflected specular light.
- Set $I_{sp} = 0$
- $I_{sp} = I_s \, \rho_s \, \max[(\mathbf{r \cdot v}/(|\mathbf{r}||\mathbf{v}|))^f, 0]$.

Speeding up Calculations for Specular Light

- Find the halfway vector **h** = **s** + **v**.
- Then the angle β between **h** and **m** approximately measures t
- To take care of errors, we different f value, and write



$I_{sp} = I_s \rho_s \max[(\mathbf{h}\cdot\mathbf{m}/(|\mathbf{h}||\mathbf{m}|))^f, 0]$

Ambient Light

- Our desire for a simple reflection model leaves us with far from perfect renderings of a scene.
  - E.g., shadows appear to be unrealistically deep and harsh.
- To soften these shadows, we can add a third light component called *ambient light*.
- This light arrives by multiple reflections from various objects in the surroundings and from light sources that populate the environment, such as light coming through a window, fluorescent lamps, etc.
- We assume a uniform background glow called **ambient light** exists in the environment.

Calculating Ambient Light

- The source is assigned an intensity, I_a.
- Each face in the model is assigned a value for its **ambient reflection coefficient**, ρ_a (often this is the same as the diffuse reflection coefficient, ρ_d),
- The term $I_a \rho_a$ is simply added to whatever diffuse and specular light is reaching the eye from each point P on that face.
- I_a and ρ_a are usually arrived at experimentally, by trying various values and seeing what looks best.

Combining Light Contributions and Adding Color

- I=amibent+diffuse+specular
- **$I = I_a \rho_a + I_d \rho_d$ lambert + $I_{sp} \rho_s$ x phong^f**
  - **Lambert = max[(s·m)/(|s||m|), 0]**
  - **Phong = max[(h·m/(|h||m|), 0]**
- To add color, we use 3 separate total intensities one each for Red, Green, and Blue, which combine to give any desired color of light.
- We say the light sources have three types of color:
- **$I_r = I_{ar} \rho_{ar} + I_{dr} \rho_{dr}$ lambert + $I_{spr} \rho_{sr}$ x phong^f (similarly for $I_{g,}$ $I_{d)}$**
  - ambient = (I_{ar}, I_{ag}, I_{ab})
  - diffuse = (I_{dr}, I_{dg}, I_{db})
  - specular = (I_{spr}, I_{spg}, I_{spb}).