Announcements

- **Assignment 1**
  - Programming (**due Friday**)
  - Theory is **graded**
- **Assignment 2**
- **Midterm**
- **No class or tutorial on Monday (Thanksgiving)**
- **Office Hours**
  - Alex will have office hours on **Thursday 11-12**
  - I will also have office hours on **Tuesday 4-5pm**

Introduction

- **So far we have only considered in our rendering pipeline**
  - Geometry of the scene
  - Camera modeling
- **We did not consider**
  - **Lighting**
  - Shading of polygons (must account for properties of the surface)
  - Shadows

Lighting and Reflections

Computer Graphics, CSCD18

Fall 2008

Instructor: Leonid Sigal

Introduction

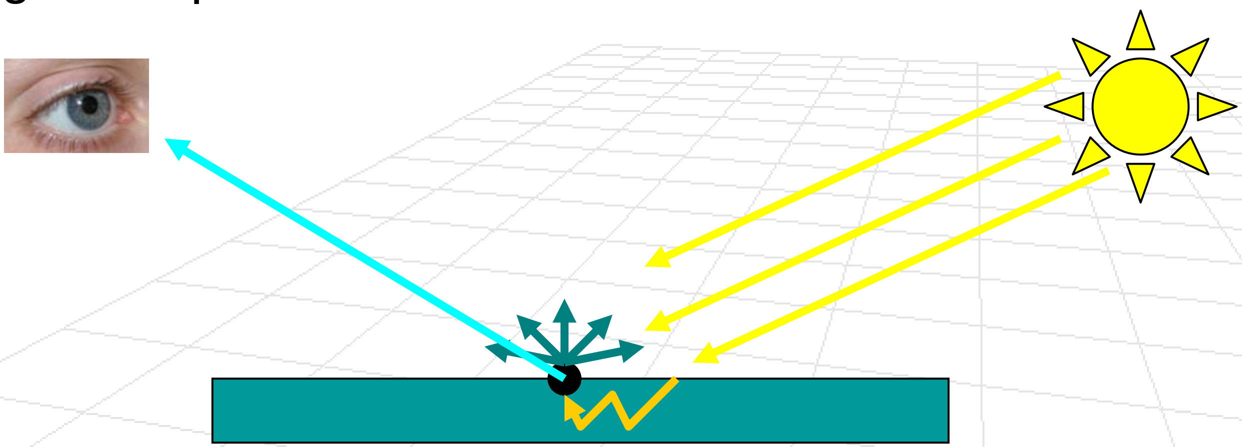
- In general, to reason about shading, lighting and shadows
  - We must consider every light ray that hits every surface in the scene
    - Rays that come directly from the light source
    - Rays that are reflected from different object surfaces
  - This is impractical for most scenes
  - We need to make simplifications

Lighting Basics

- Light sources
  - Point sources (e.g. sun)
    - Light is reflected in all directions from the small light source far away
  - Extended light sources (e.g. day lights)
    - Light is reflected in all directions but from many points
  - Directional lighting
  - Secondary lighting
    - Light reflected from other objects

Reflection Basics

- Reflectance (different objects reflect light in different ways)
  - Diffuse surfaces (e.g. egg)
    - Appear the same from all directions
  - Secular surfaces (e.g. mirrors)
    - Reflected light is a function of the viewing direction
  - Transmission (e.g. skin, glass, water)
    - Light can penetrate the surface



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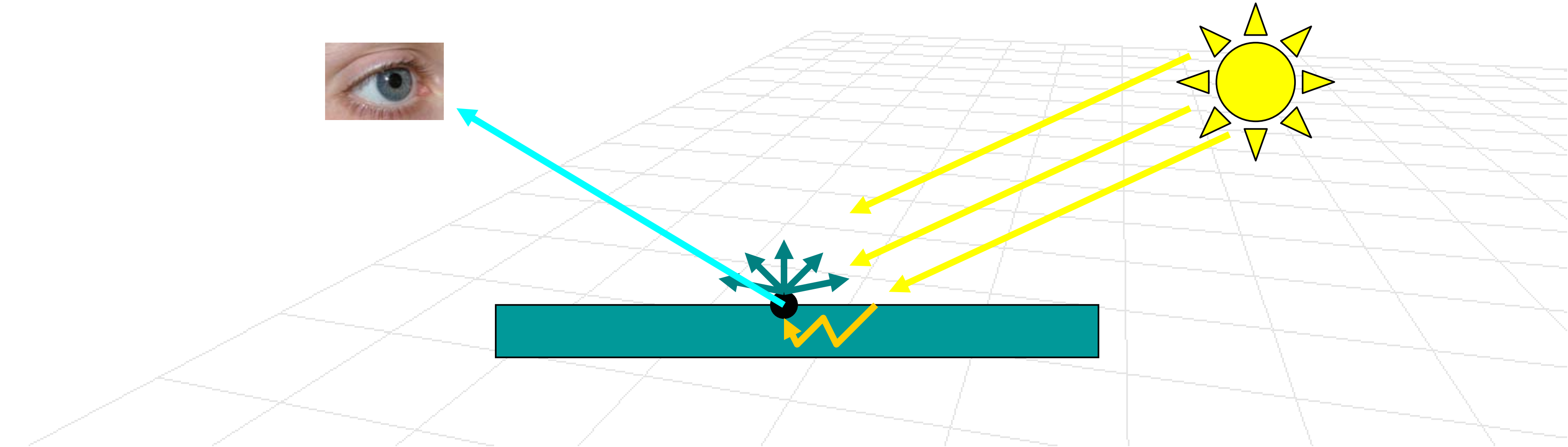


Diffuse Reflection

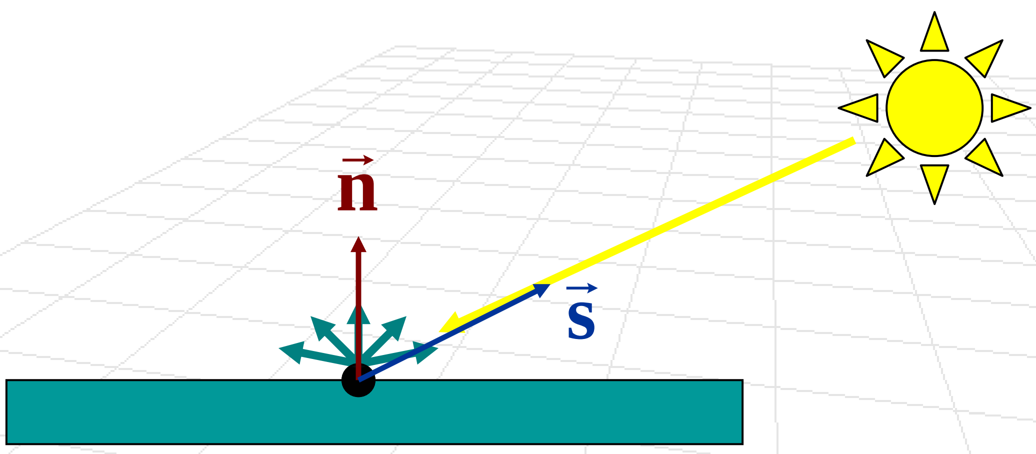
- **Idea:** reflected light is the same in all directions
- **Assumptions:** point light source
- Simplest model: $\mathbf{L_d}(\overline{\mathbf{p}}) = \mathbf{r_d}\ \mathbf{I}\ \max(0, \vec{\mathbf{s}} \cdot \vec{\mathbf{n}})$

  $\mathbf{I}$ - intensity of the light source

  $\mathbf{r_d}$ - fraction of the light being reflected

  $\vec{\mathbf{s}}$ - direction of the light source

  $\vec{\mathbf{n}}$ - surface normal



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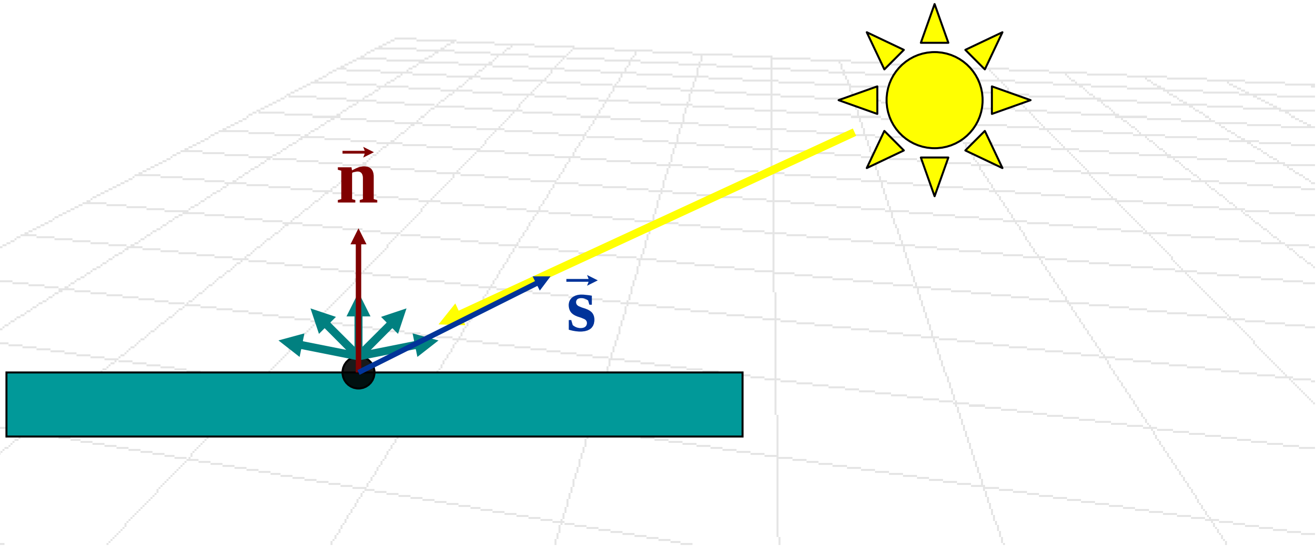
  $\mathbf{I}$ - intensity of the light source

  $\mathbf{r_d}$ - fraction of the light being reflected

  $\vec{\mathbf{s}}$ - direction of the light source (normalized)

  $\vec{\mathbf{n}}$ - surface normal (normalized)



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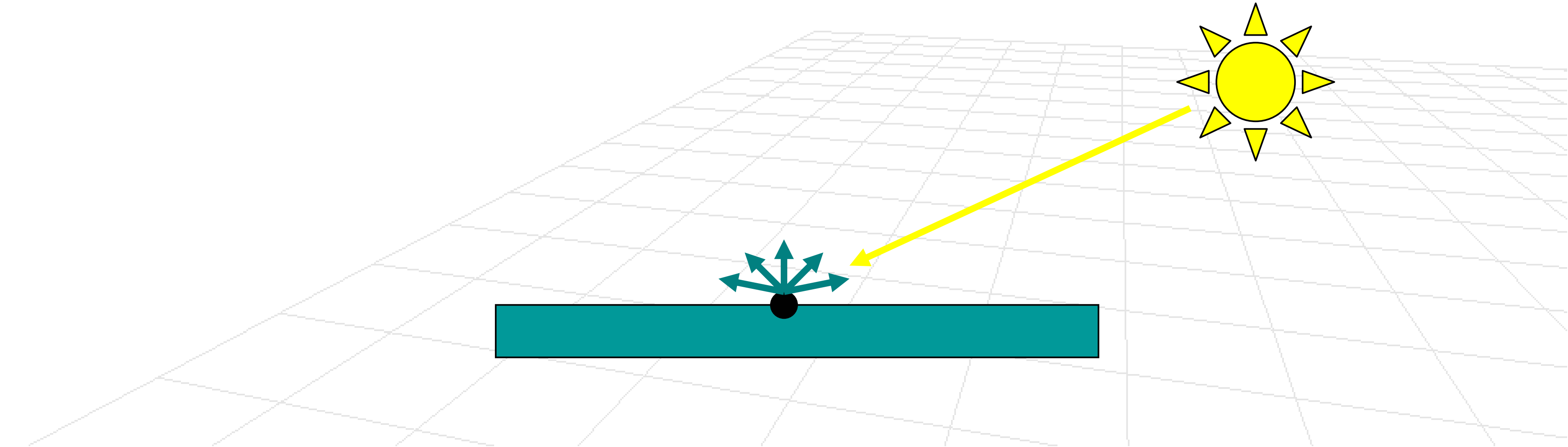
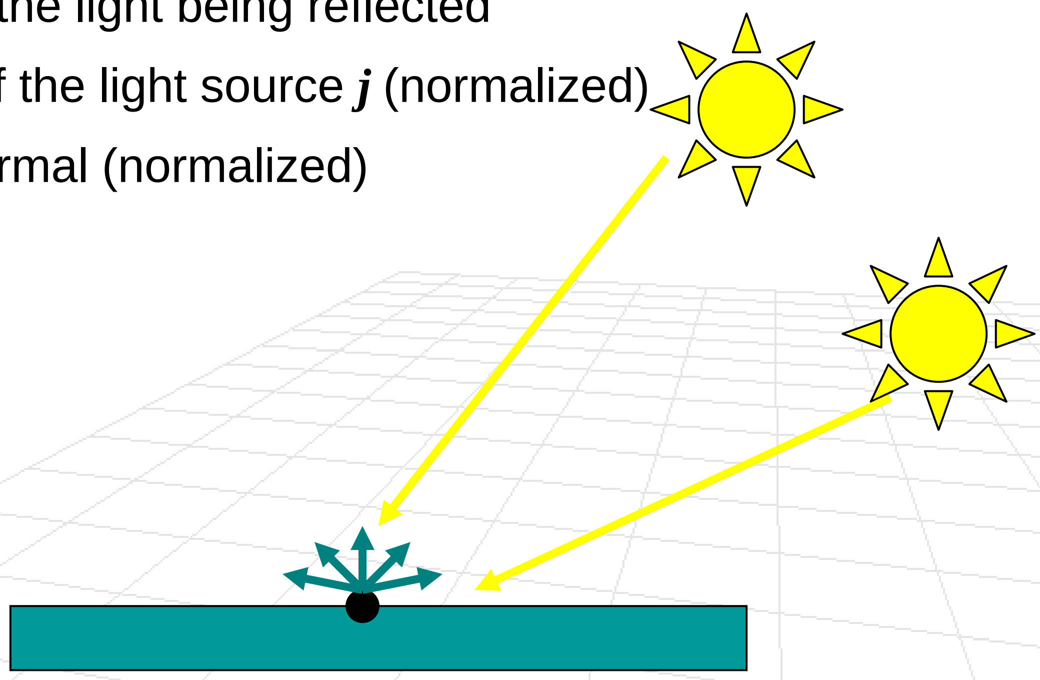


Diffuse Reflection with Multiple Lights

- **Idea:** reflected light is the same in all directions
- **Assumptions:** point light source
- Light is additive, so $\mathbf{L_d}(\overline{\mathbf{p}}) = \sum_{\mathbf{j}} \mathbf{r_d} \, \mathbf{I_j} \max(0, \vec{\mathbf{s}}_{\mathbf{j}} \cdot \vec{\mathbf{n}})$

  - $\mathbf{I_j}$ - intensity of the light source ***j***
  - $\mathbf{r_d}$ - fraction of the light being reflected
  - $\vec{\mathbf{s}}_{\mathbf{j}}$ - direction of the light source ***j*** (normalized)
  - $\vec{\mathbf{n}}$ - surface normal (normalized)



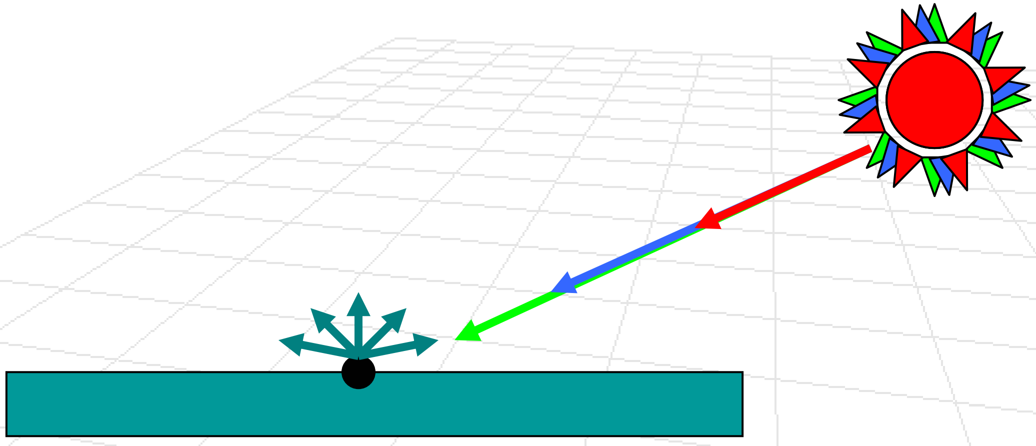
What about color?

- **Idea:** reflected light is the same in all directions
- **Assumptions:** point light source
- We can specify reflectance and light intensity in terms of color components

$$\mathbf{L}_{\mathbf{d},\mathbf{R}}(\bar{\mathbf{p}}) = \mathbf{r}_{\mathbf{d},\mathbf{R}}\ \mathbf{I}_{\mathbf{j},\mathbf{R}}\ \max(0, \vec{\mathbf{s}} \cdot \vec{\mathbf{n}})$$

$$\mathbf{L}_{\mathbf{d},\mathbf{G}}(\bar{\mathbf{p}}) = \mathbf{r}_{\mathbf{d},\mathbf{G}}\ \mathbf{I}_{\mathbf{j},\mathbf{G}}\ \max(0, \vec{\mathbf{s}} \cdot \vec{\mathbf{n}})$$

$$\mathbf{L}_{\mathbf{d},\mathbf{B}}(\bar{\mathbf{p}}) = \mathbf{r}_{\mathbf{d},\mathbf{B}}\ \mathbf{I}_{\mathbf{j},\mathbf{B}}\ \max(0, \vec{\mathbf{s}} \cdot \vec{\mathbf{n}})$$



Ambient Illumination

- Diffuse reflection with point light source produce strong shadows
- Surface patches that point away from the light source, $\vec{\mathbf{s}} \cdot \vec{\mathbf{n}} < 0$, end up being black. This looks unnatural. **Why?**

- Solutions
  - Have many light sources to approximate an extended light source
  - Use ambient reflectance
    - Approximates the average amount of light in the scene

Ambient Illumination

- Simple **ambient reflectance**

$$\mathbf{L_a}(\overline{\mathbf{p}}) = \mathbf{r_a I_a}$$

$\mathbf{I_a}$ - amount of ambient illumination

$\mathbf{r_a}$ - ambient reflection coefficient (how much light is reflected)

(often people set $\mathbf{r_a} = \mathbf{r_d}$)

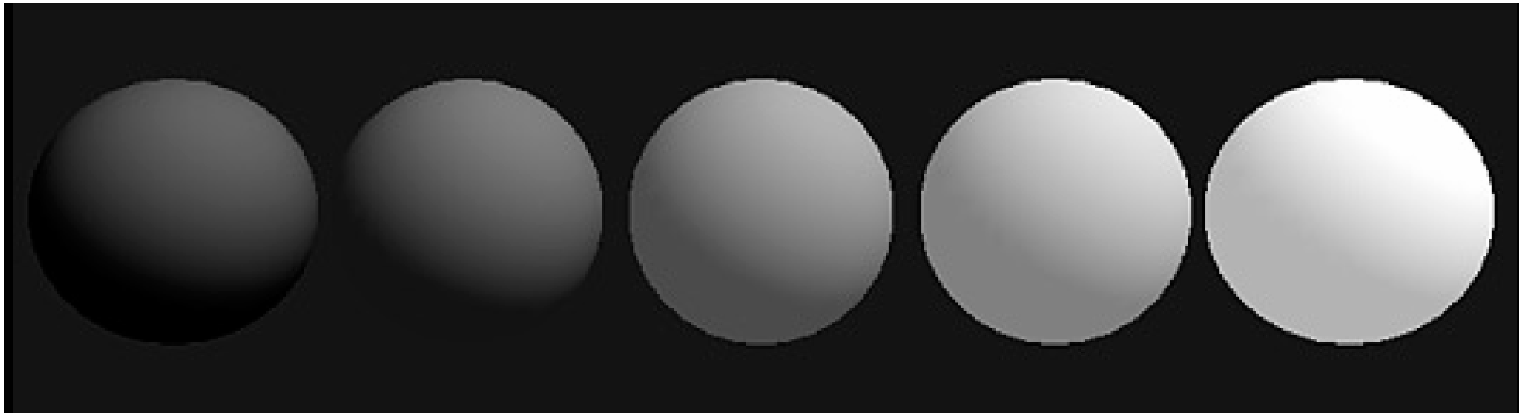
- **Color ambient reflectance**

$$\mathbf{L_{a,R}}(\overline{\mathbf{p}}) = \mathbf{r_{a,R} I_{a,R}}$$

$$\mathbf{L_{a,G}}(\overline{\mathbf{p}}) = \mathbf{r_{a,G} I_{a,G}}$$

$$\mathbf{L_{a,B}}(\overline{\mathbf{p}}) = \mathbf{r_{a,B} I_{a,B}}$$

Diffuse Reflectance Model



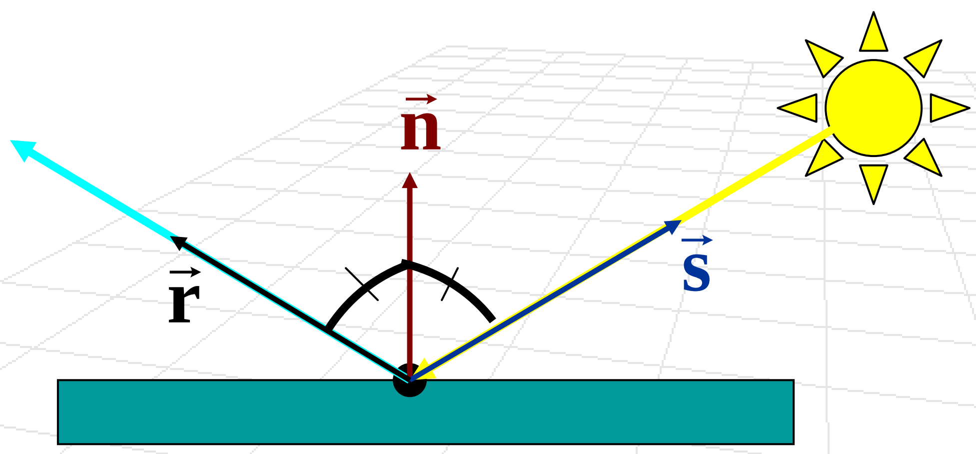
Increasing ratio of ambient to diffuse reflection: →

Specular Reflectance

- **Idealization:** a mirror
- Models plastics, metals, and polished surfaces

- **Property:** Angle of reflection equal to the angle of incident with respect to the normal

$\vec{\mathbf{r}}$ - is unit vector corresponding to emitting direction (it is determined by the normal and the light source)

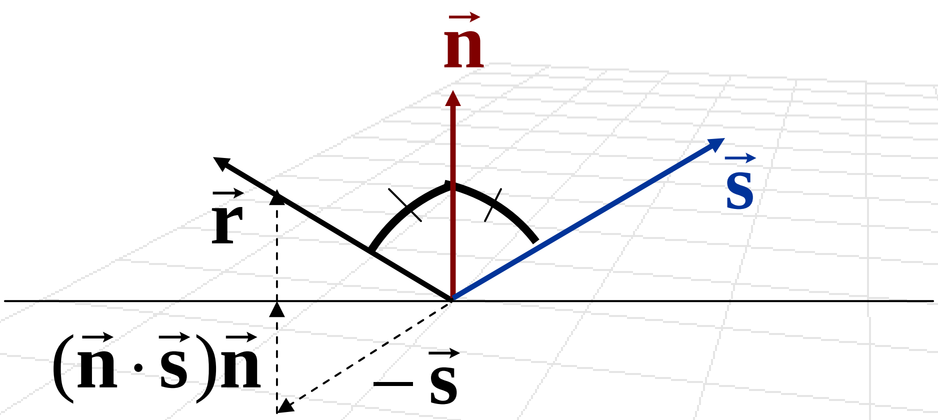


Specular Reflectance

- **Idealization:** a mirror
- Models plastics, metals, and polished surfaces

- **Property:** Angle of reflection equal to the angle of incident with respect to the normal

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



In practice most specular surfaces reflect light close to this direction

Specular Reflectance

- Common **specular model**

$$\mathbf{L}_s(\bar{\mathbf{p}}, \vec{\mathbf{c}}) = \mathbf{r}_s \mathbf{I}_s \max(0, \vec{\mathbf{r}} \cdot \vec{\mathbf{c}})^{\alpha}$$

where

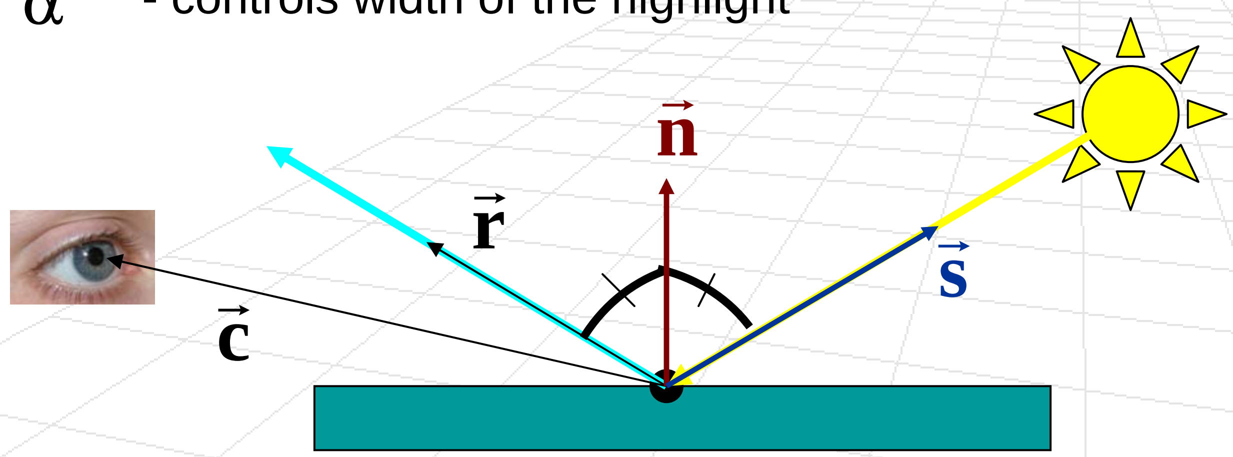
$\mathbf{r}_s$ - specular reflectance coefficient (how much light is reflected)

$\mathbf{I}_s$ - “specular light source” (often = I_d)

$\vec{\mathbf{r}}$ - direction of emission (normalized)

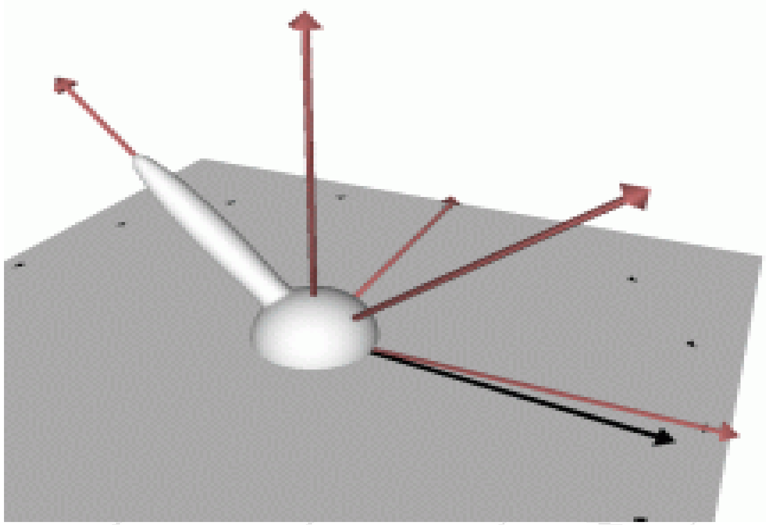
$\vec{\mathbf{c}}$ - direction from the point to camera (normalized)

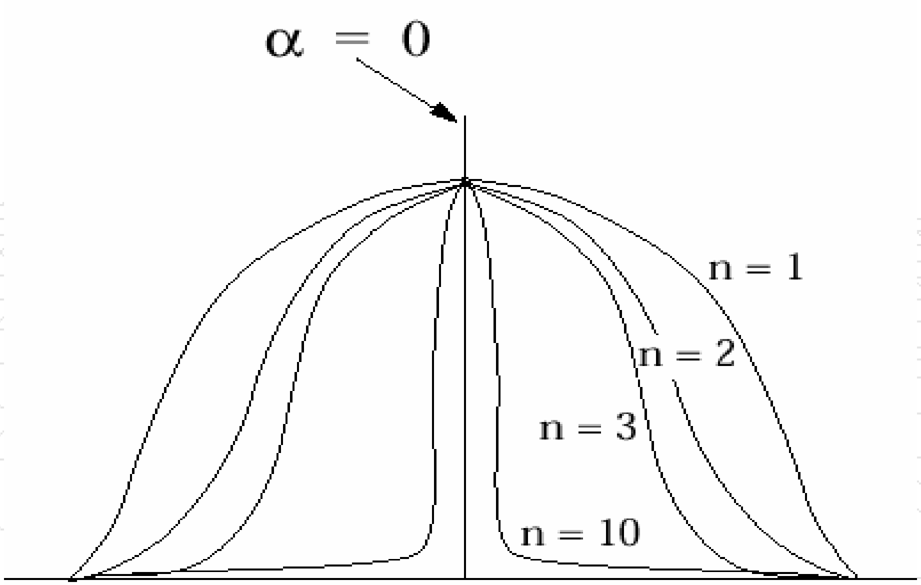
α - controls width of the highlight



Specular Reflectance

- As we decrease alpha the reflection becomes more peaked (more like a mirror)





Phong Reflectance Model

- Lets put all the peaces together
- **Remember:** light is additive

$$\mathbf{L}(\overline{\mathbf{p}}, \vec{\mathbf{c}}) = \mathbf{r_d I_d} \max(0, \vec{\mathbf{s}} \cdot \vec{\mathbf{n}}) + \mathbf{r_a I_a} + \mathbf{r_s I_s} \max(0, \vec{\mathbf{r}} \cdot \vec{\mathbf{c}})^{\alpha}$$

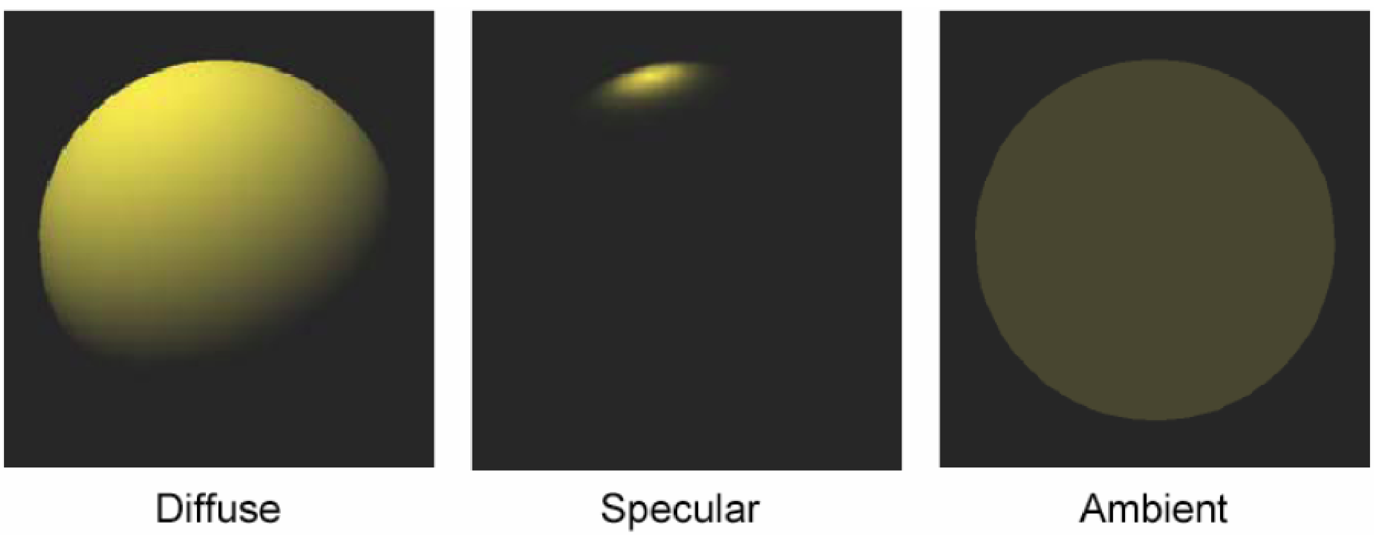


Image from lecture slides of David Breen

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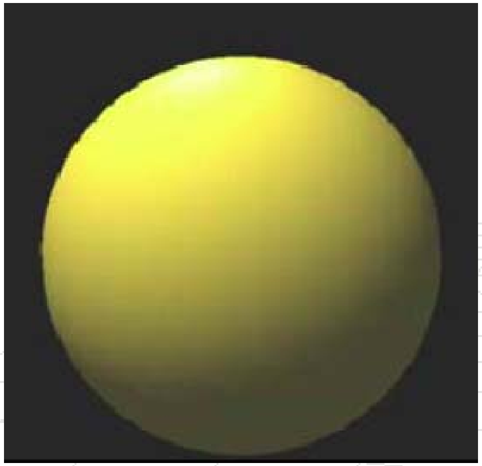

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Phong Reflectance Model

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- for color

$$\mathbf{L_R}(\overline{\mathbf{p}},\vec{\mathbf{c}}) = \mathbf{r_{d,R} I_{d,R}}\max(0,\vec{\mathbf{s}}\cdot\vec{\mathbf{n}}) + \mathbf{r_{a,R} I_{a,R}} + \mathbf{r_{s,R} I_{s,R}}\max(0,\vec{\mathbf{r}}\cdot\vec{\mathbf{c}})^{\alpha}$$

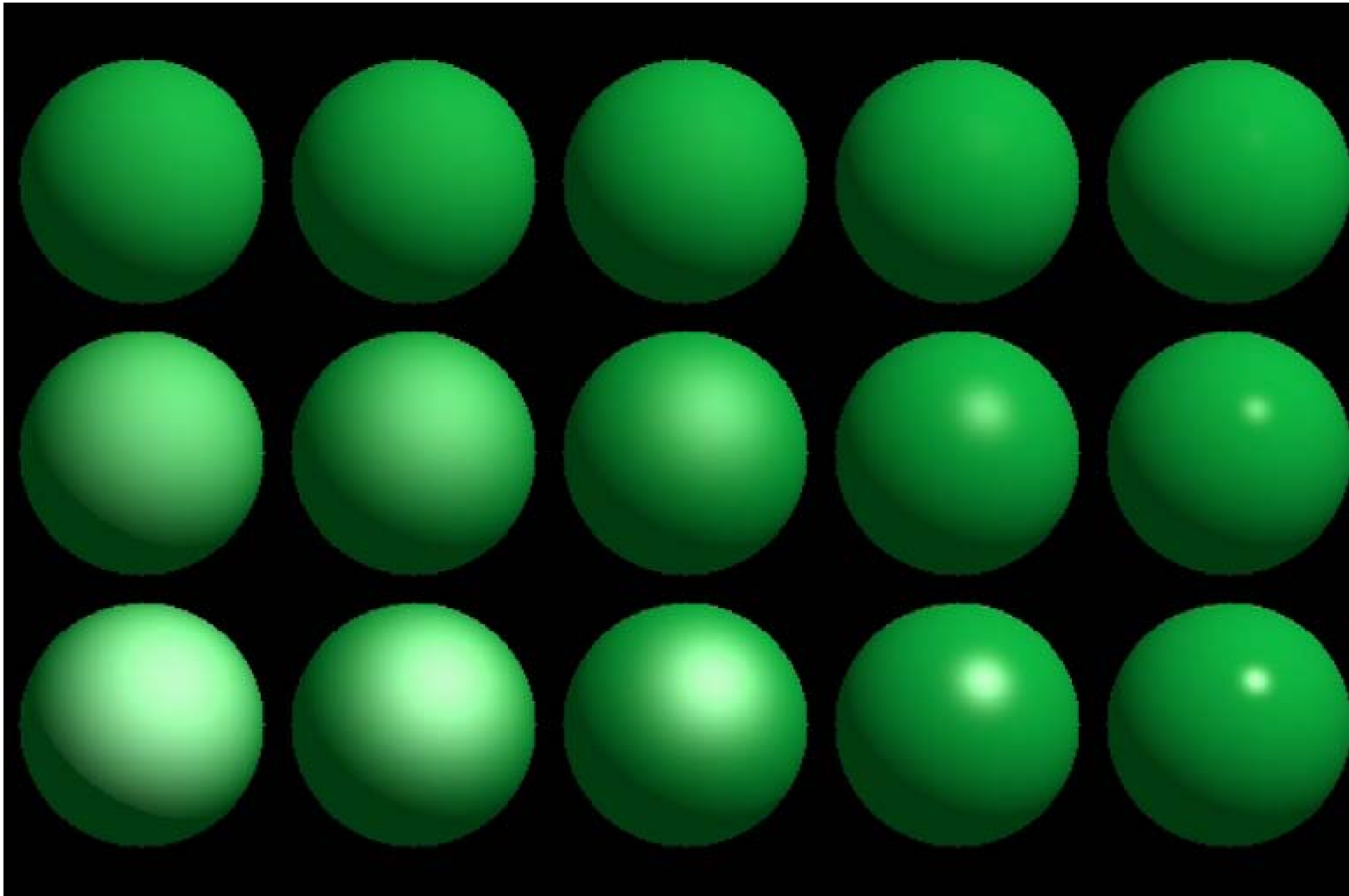
$$\mathbf{L_G}(\overline{\mathbf{p}},\vec{\mathbf{c}}) = \mathbf{r_{d,G} I_{d,G}}\max(0,\vec{\mathbf{s}}\cdot\vec{\mathbf{n}}) + \mathbf{r_{a,G} I_{a,G}} + \mathbf{r_{s,G} I_{s,G}}\max(0,\vec{\mathbf{r}}\cdot\vec{\mathbf{c}})^{\alpha}$$

$$\mathbf{L_B}(\overline{\mathbf{p}},\vec{\mathbf{c}}) = \mathbf{r_{d,B} I_{d,B}}\max(0,\vec{\mathbf{s}}\cdot\vec{\mathbf{n}}) + \mathbf{r_{a,B} I_{a,B}} + \mathbf{r_{s,B} I_{s,B}}\max(0,\vec{\mathbf{r}}\cdot\vec{\mathbf{c}})^{\alpha}$$

- Notice we are still only considering point light source and are not considering secondary reflectance from surfaces

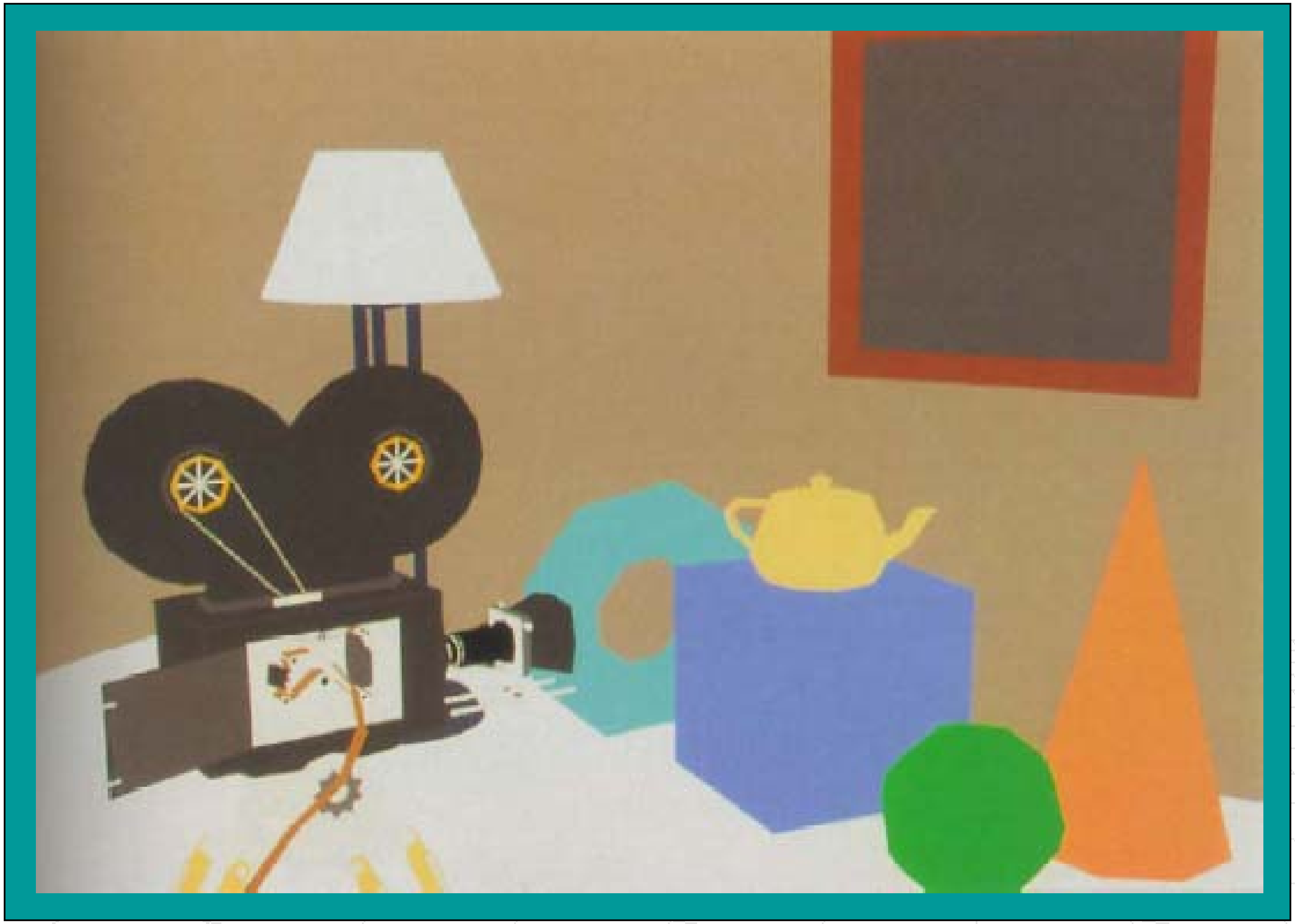
Phong Reflectance Model

Increasing ratio of diffuse to specular reflection coefficients →



Increasing exponent in specular term →

Ambient only



Foley, van Dam, Feiner, Hughes, Plate II.28

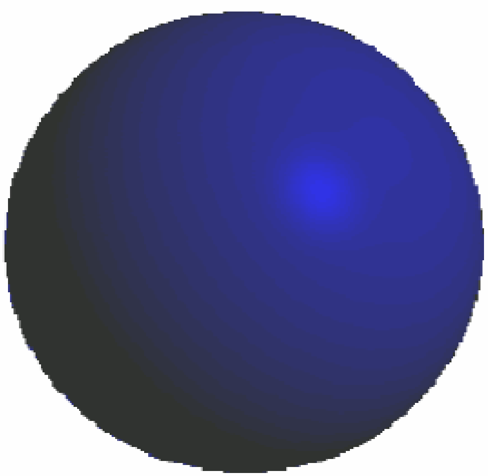
Diffuse only

Foley, van Dam, Feiner, Hughes, Plate II.29

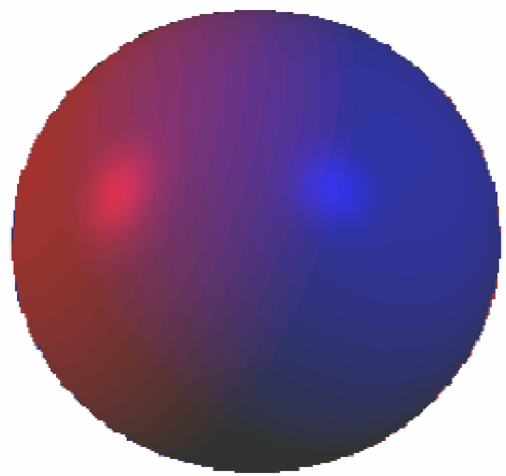
Full Phong Model

Foley, van Dam, Feiner, Hughes, Plate II.32

Multiple Light Sources



Blue Light Source



Blue+Red Light Sources

Blue+Red+Green Light Sources

Image from lecture slides of Giovanni Motta