CSE 167:
Introduction to Computer Graphics
Lecture #6: Shading

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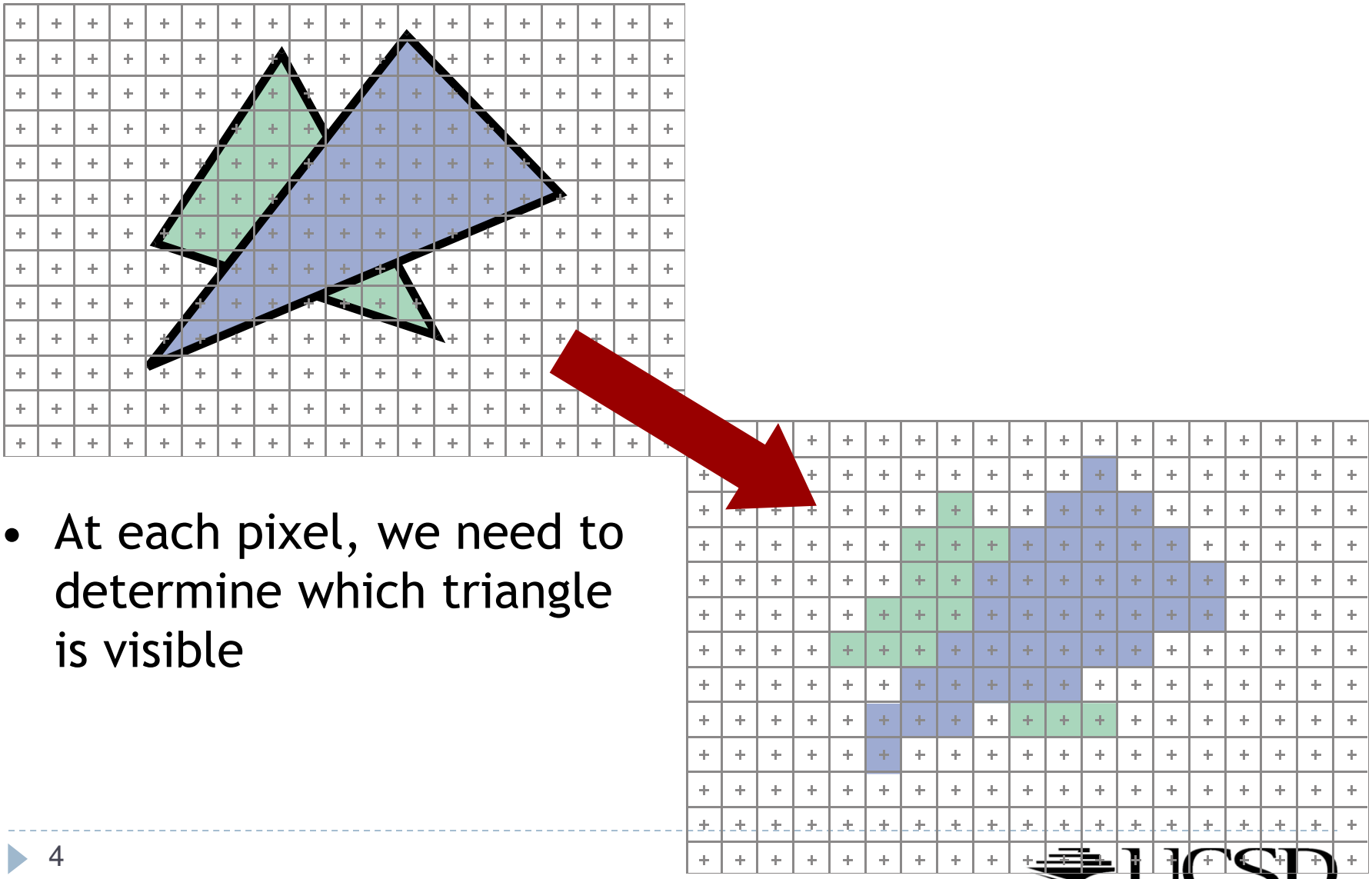
Announcements

- Project 3 due this Friday at 1pm
- Grading starts at 12:15 in CSE labs 260+270
- Next Thursday: Midterm
  - Midterm discussion on Monday at 4pm

Lecture Overview

- Visibility
- Shading

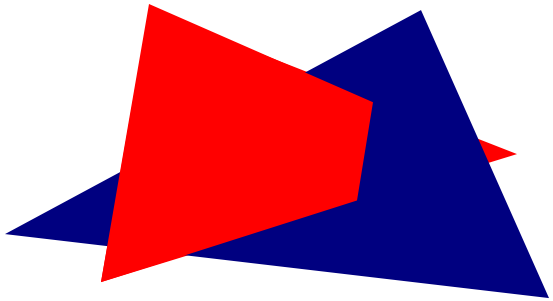
Visibility



- At each pixel, we need to determine which triangle is visible

Painter's Algorithm

- Paint from back to front
- Every new pixel always paints over previous pixel in frame buffer
- Need to sort geometry according to depth
- May need to split triangles if they intersect



- Outdated algorithm, created when memory was expensive

Z-Buffering

- Store z-value for each pixel
- Depth test
  - During rasterization, compare stored value to new value
  - Update pixel only if new value is smaller

```
setpixel(int x, int y, color c, float z)
if(z<zbuffer(x,y)) then
  zbuffer(x,y) = z
  color(x,y) = c
```

- z-buffer is dedicated memory reserved for GPU (graphics memory)
- Depth test is performed by GPU

Z-Buffering in OpenGL

- In your application:
  - Ask for a depth buffer when you create your window.
  - Place a call to glEnable (GL_DEPTH_TEST) in your program's initialization routine.
  - Ensure that your *zNear* and *zFar* clipping planes are set correctly (in glOrtho, glFrustum or gluPerspective) and in a way that provides adequate depth buffer precision.
  - Pass GL_DEPTH_BUFFER_BIT as a parameter to glClear.

Z-Buffering

- Problem: translucent geometry
  - Storage of multiple depth and color values per pixel (not practical in real-time graphics)
  - Or back to front rendering of translucent geometry, after rendering opaque geometry
    - Does not always work correctly: programmer has to weight rendering correctness against computational effort

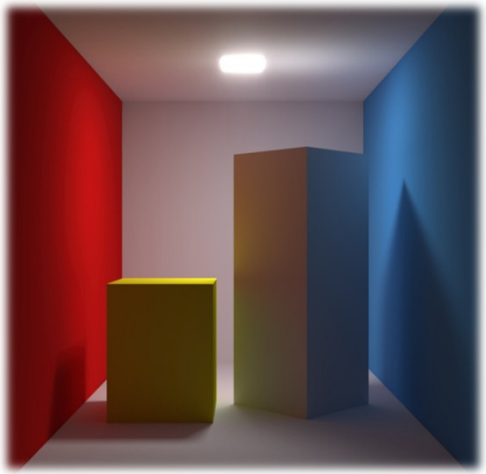
Lecture Overview

- Visibility
- Shading

Shading

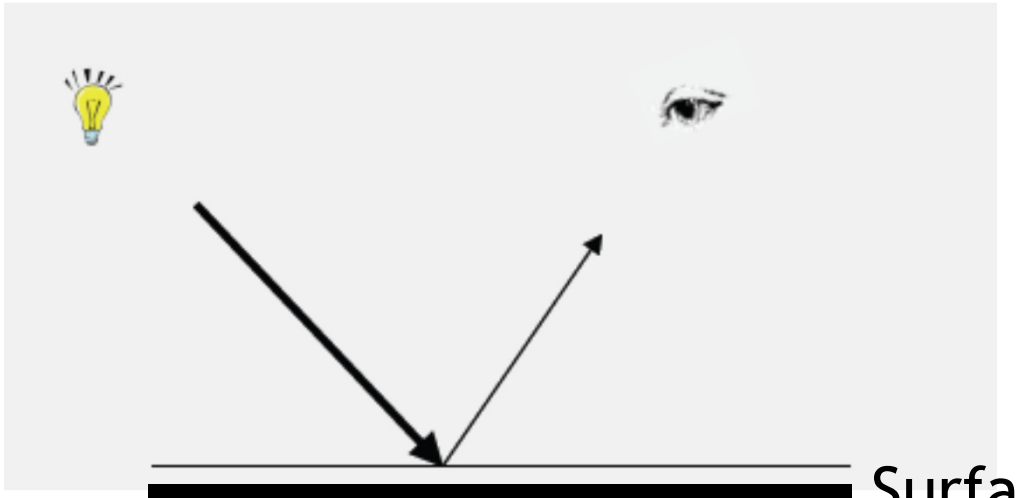
- Compute interaction of light with surfaces
- Requires simulation of physics
- "Global illumination"
  - Multiple bounces of light
  - Computationally expensive, minutes per image
  - Used in movies, architectural design, etc.

Global Illumination



Interactive Applications

- No physics-based simulation
- Simplified models
- Reproduce perceptually most important effects
- Local illumination
  - Only one bounce of light between light source and viewer



One bounce of light

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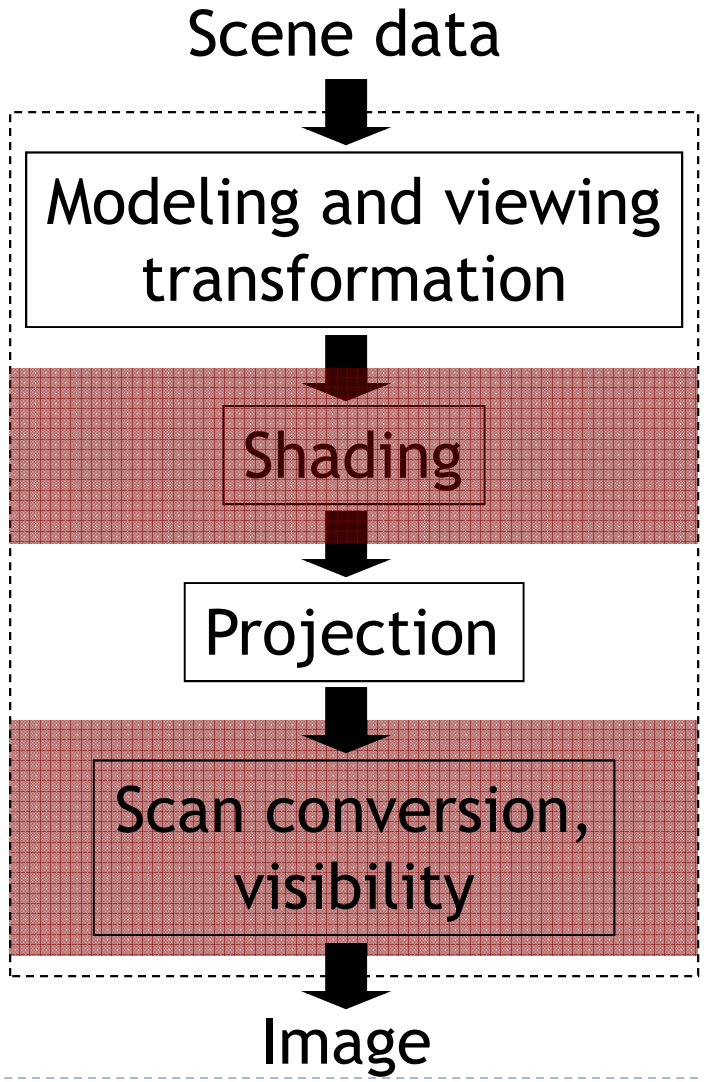
Rendering Pipeline



- Position object in 3D
- Determine colors of vertices
  - Per vertex shading
- Map triangles to 2D
- Draw triangles
  - Per pixel shading

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Lecture Overview

- OpenGL's local shading model

Local Illumination

- What gives a material its color?
- How is light reflected by a
  - Mirror
  - White sheet of paper
  - Blue sheet of paper
  - Glossy metal

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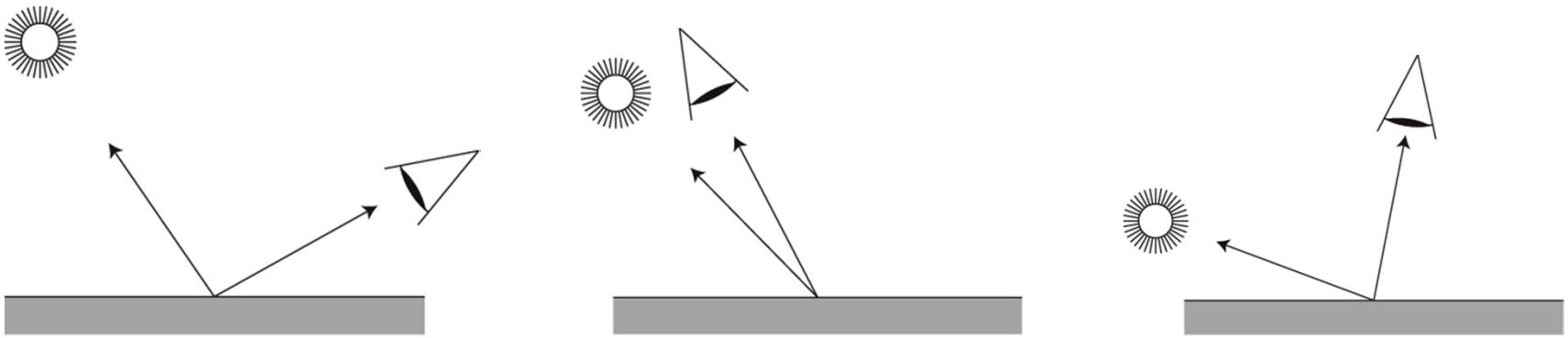
Local Illumination

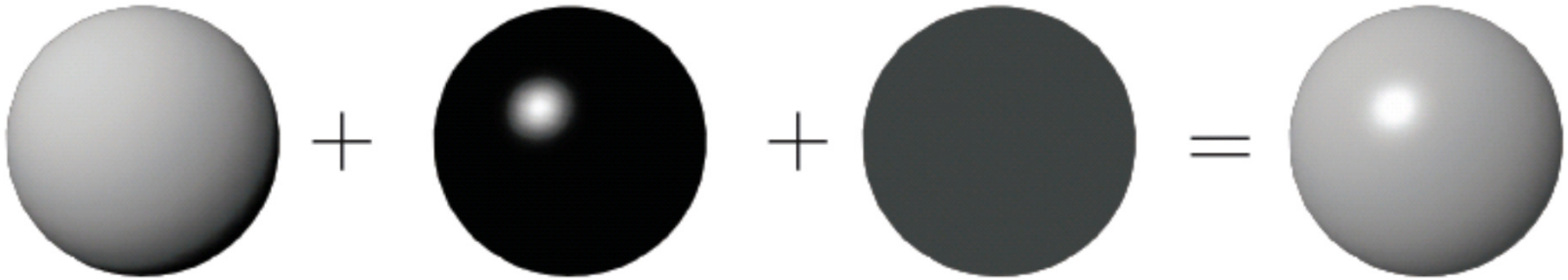
- Model reflection of light at surfaces
  - Assumption: no subsurface scattering
- Bidirectional reflectance distribution function (BRDF)
  - Given light direction, viewing direction, how much light is reflected towards the viewer
  - For any pair of light/viewing directions!



Local Illumination

Simplified model

- Sum of 3 components
- Covers a large class of real surfaces



Local Illumination

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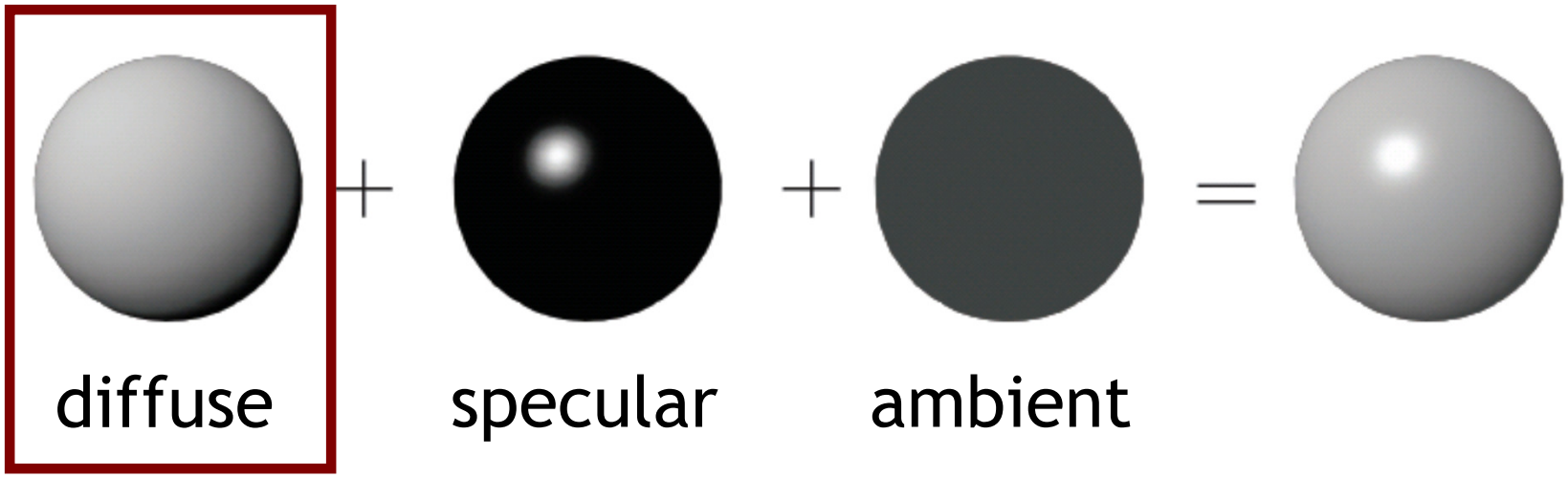
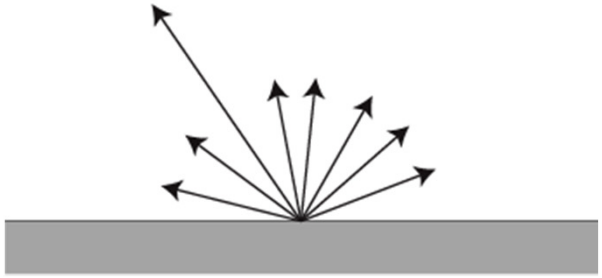


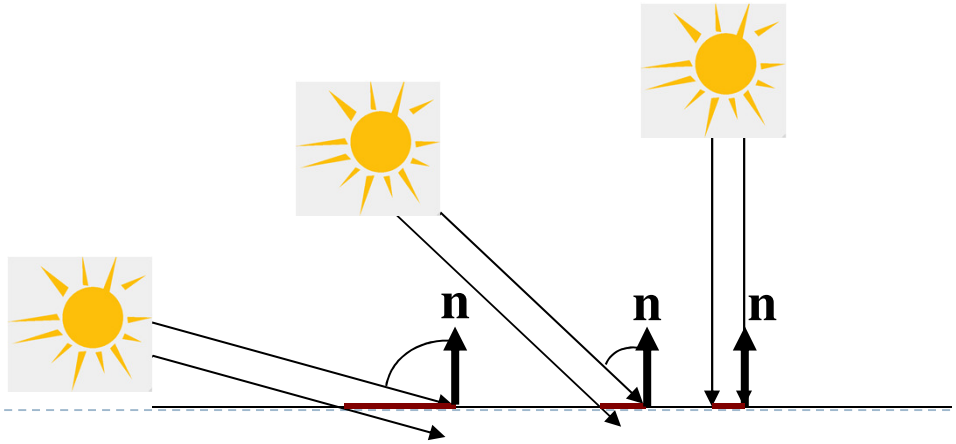
Diffuse Reflection

- Ideal diffuse material reflects light equally in all directions
- View-independent
- Matte, not shiny materials
  - Paper
  - Unfinished wood
  - Unpolished stone



Diffuse Reflection

- Beam of parallel rays shining on a surface
  - Area covered by beam varies with the angle between the beam and the normal
  - The larger the area, the less incident light per area
  - Incident light per unit area is proportional to the cosine of the angle between the normal and the light rays
- Object darkens as normal turns away from light
- Lambert's cosine law (Johann Heinrich Lambert, 1760)
- Diffuse surfaces are also called Lambertian surfaces



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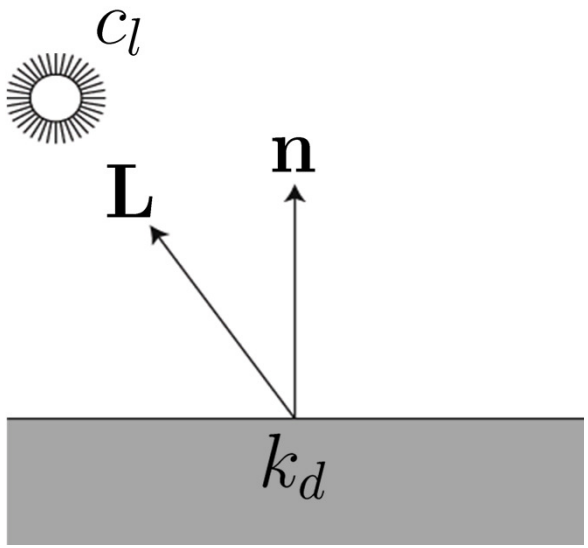
Diffuse Reflection

- Given
  - Unit surface normal **n**
  - Unit light direction **L**
  - Material diffuse reflectance (material color) k_d
  - Light color (intensity) c_l

- Diffuse color c_d is:

$$c_d = c_l k_d \underbrace{(\mathbf{n} \cdot \mathbf{L})}$$

Proportional to cosine between normal and light



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Diffuse Reflection

Notes

- Parameters k_d, c_l are r,g,b vectors
- Need to compute r,g,b values of diffuse color c_d separately
- Parameters in this model have no precise physical meaning
  - c_l: strength, color of light source
  - k_d: fraction of reflected light, material color

Diffuse Reflection

- Provides visual cues
  - Surface curvature
  - Depth variation

Lambertian (diffuse) sphere under different lighting directions

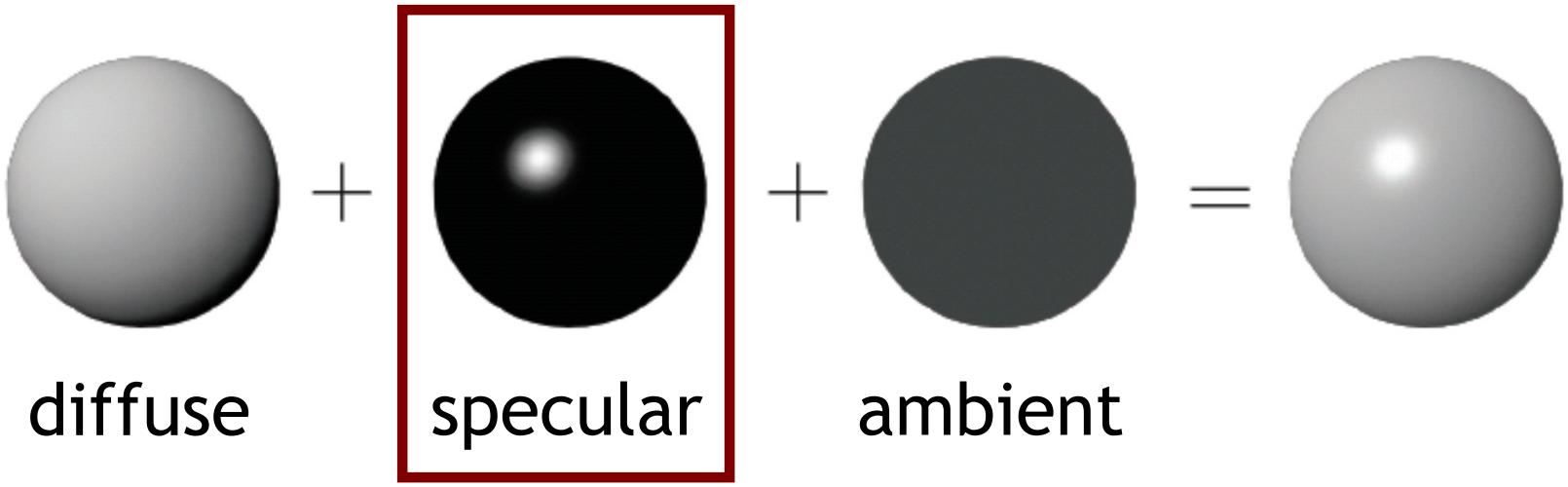
OpenGL

- Lights (glLight*)
  - Values for light: $(0,0,0) \leq c_l \leq (1,1,1)$
  - Definition: $(0,0,0)$ is black, $(1,1,1)$ is white
- OpenGL
  - Values for diffuse reflection
  - Fraction of reflected light: $(0,0,0) \leq k_d \leq (1,1,1)$
- Consult OpenGL Programming Guide (Red Book)
  - See course web site

Local Illumination

Simplified model

- Sum of 3 components
- Covers a large class of real surfaces



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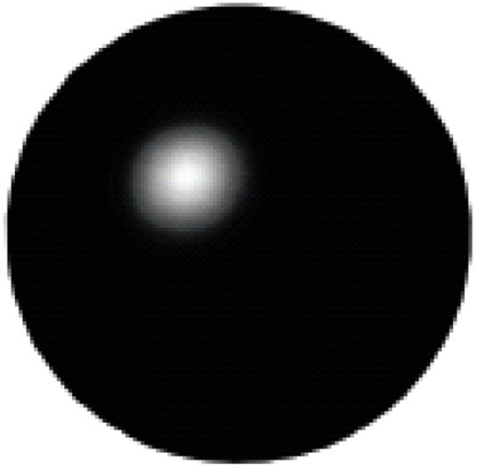
Specular Reflection

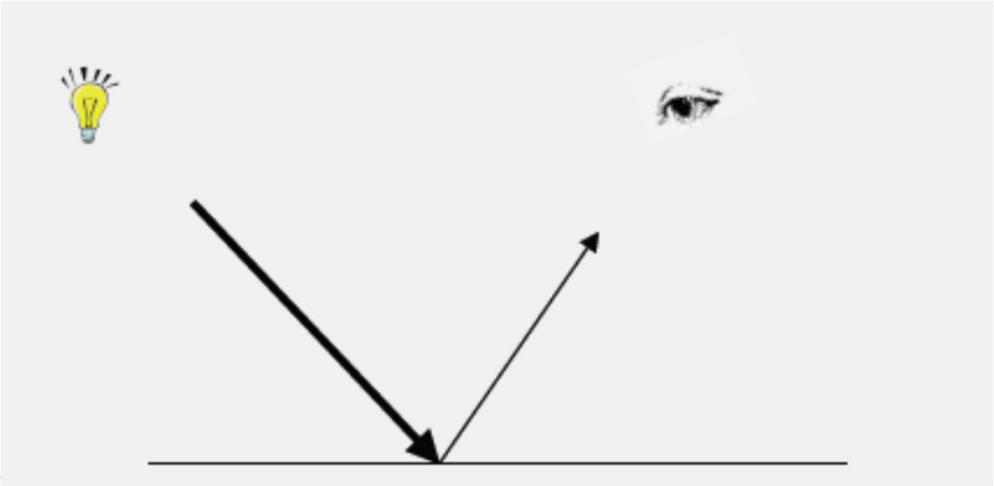
- Shiny surfaces
  - Polished metal
  - Glossy car finish
  - Plastics
- Specular highlight
  - Blurred reflection of the light source
  - Position of highlight depends on viewing direction



Specular highlight

Specular Reflection

- Ideal specular reflection is mirror reflection
  - Perfectly smooth surface
  - Incoming light ray is bounced in single direction
  - Angle of incidence equals angle of reflection

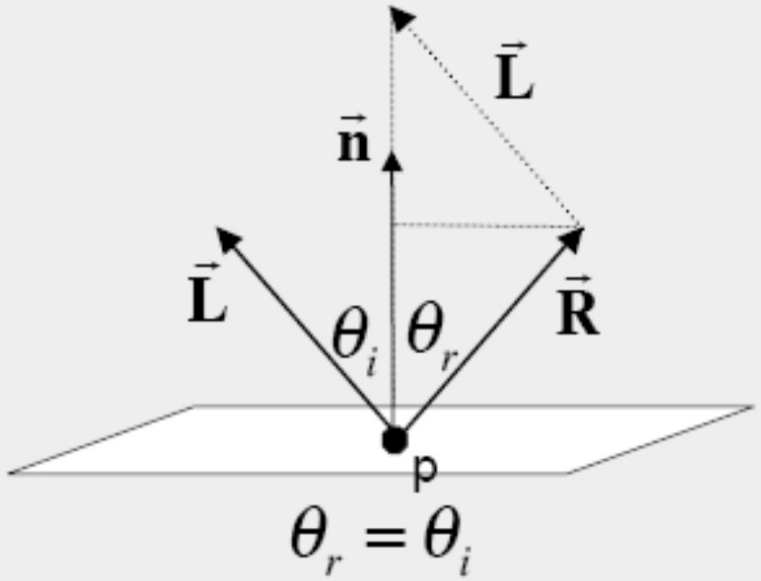


Law of Reflection

- Angle of incidence equals angle of reflection

$$\vec{\mathbf{R}} + \vec{\mathbf{L}} = 2\cos\theta\ \vec{\mathbf{n}} = 2\left(\vec{\mathbf{L}} \cdot \vec{\mathbf{n}}\right)\vec{\mathbf{n}}$$

$$\vec{\mathbf{R}} = 2\left(\vec{\mathbf{L}} \cdot \vec{\mathbf{n}}\right)\vec{\mathbf{n}} - \vec{\mathbf{L}}$$



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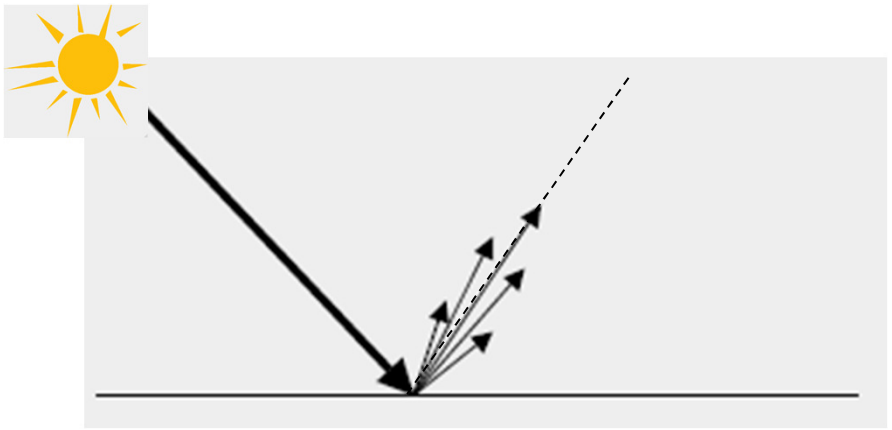
Specular Reflection

- Many materials are not perfect mirrors
  - Glossy materials



Glossy teapot

Glossy Materials

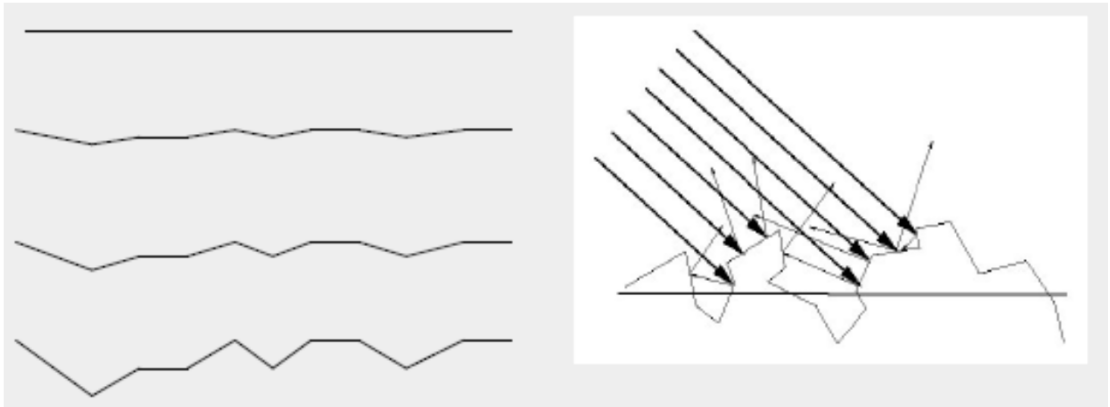
- Assume surface composed of small mirrors with random orientation (micro-facets)
- Smooth surfaces
  - Micro-facet normals close to surface normal
  - Sharp highlights
- Rough surfaces
  - Micro-facet normals vary strongly
  - Blurry highlight

Polished

Smooth

Rough

Very rough

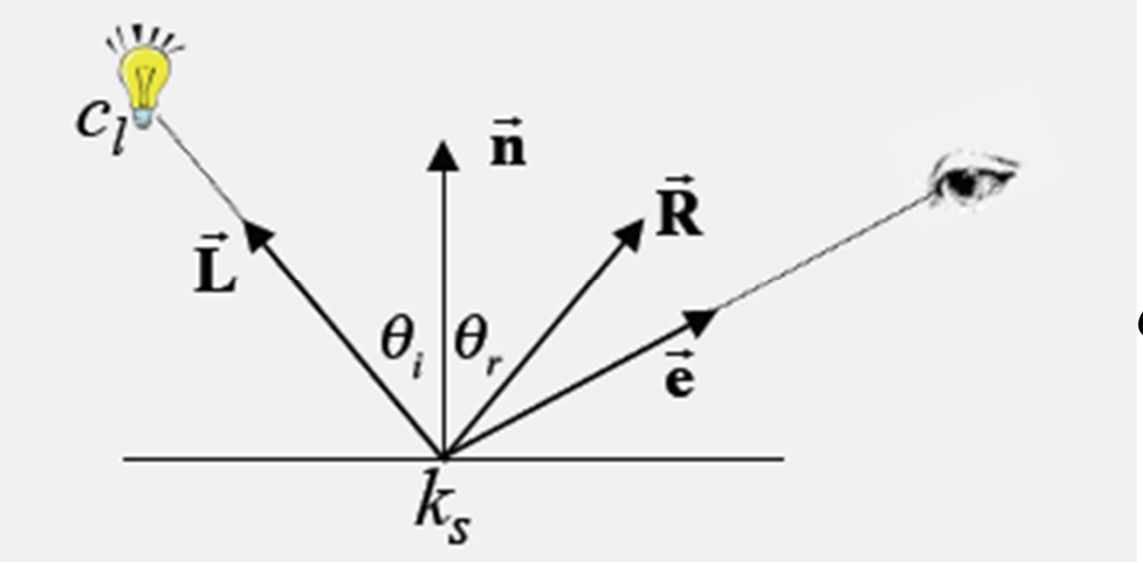


Glossy Surfaces

- Expect most light to be reflected in mirror direction
- Because of micro-facets, some light is reflected slightly off ideal reflection direction
- Reflection
  - Brightest when view vector is aligned with reflection
  - Decreases as angle between view vector and reflection direction increases

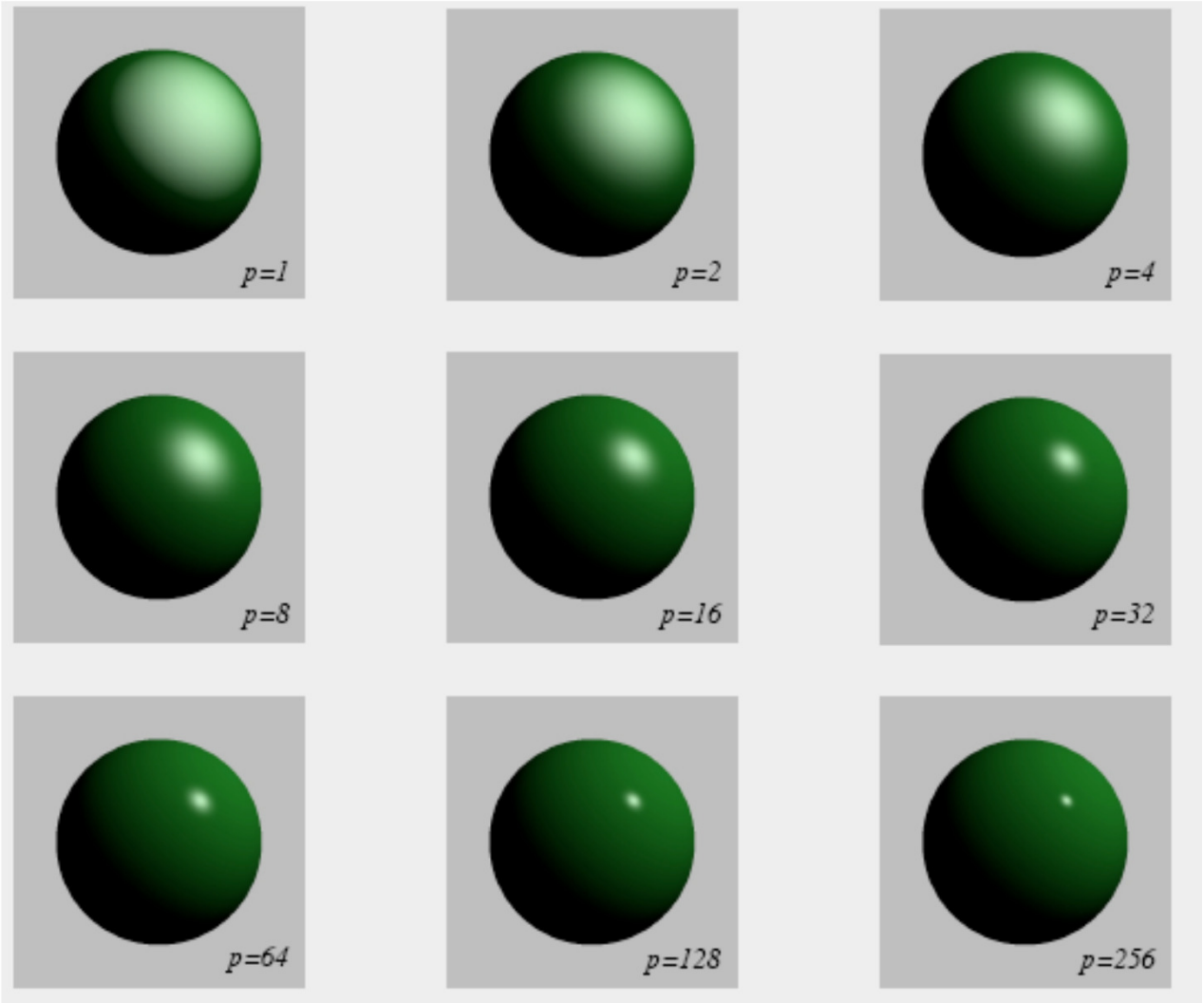
Phong Shading Model

- Developed by Bui Tuong Phong in 1973
- Specular reflectance coefficient k_s
- Phong exponent p
  - Greater p means smaller (sharper) highlight



$$c = k_s c_l \left(\mathbf{R} \cdot \mathbf{e}\right)^p$$

Phong Shading Model



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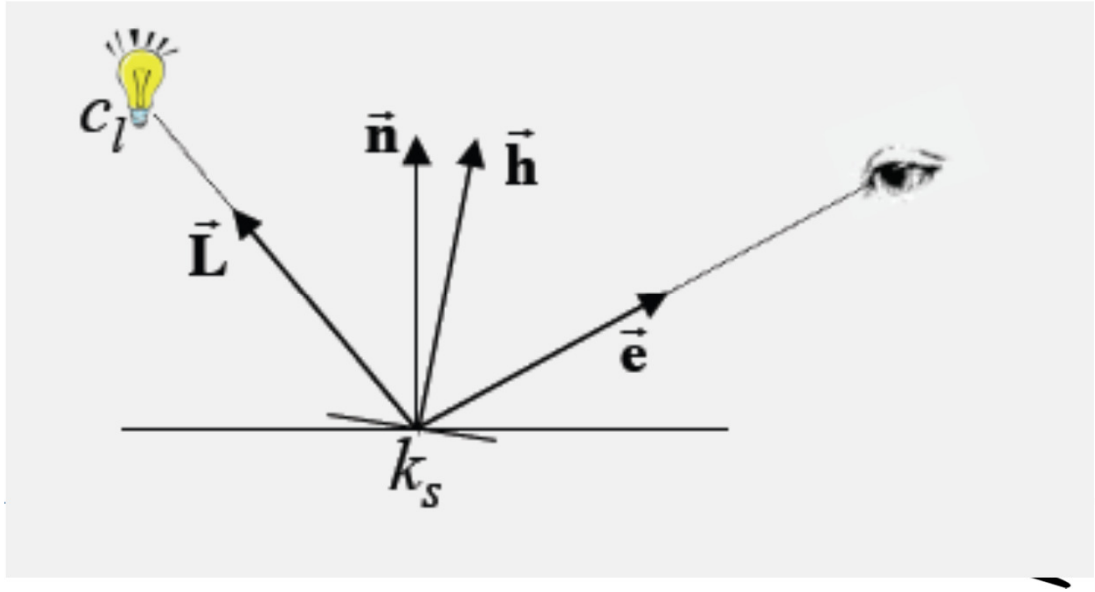
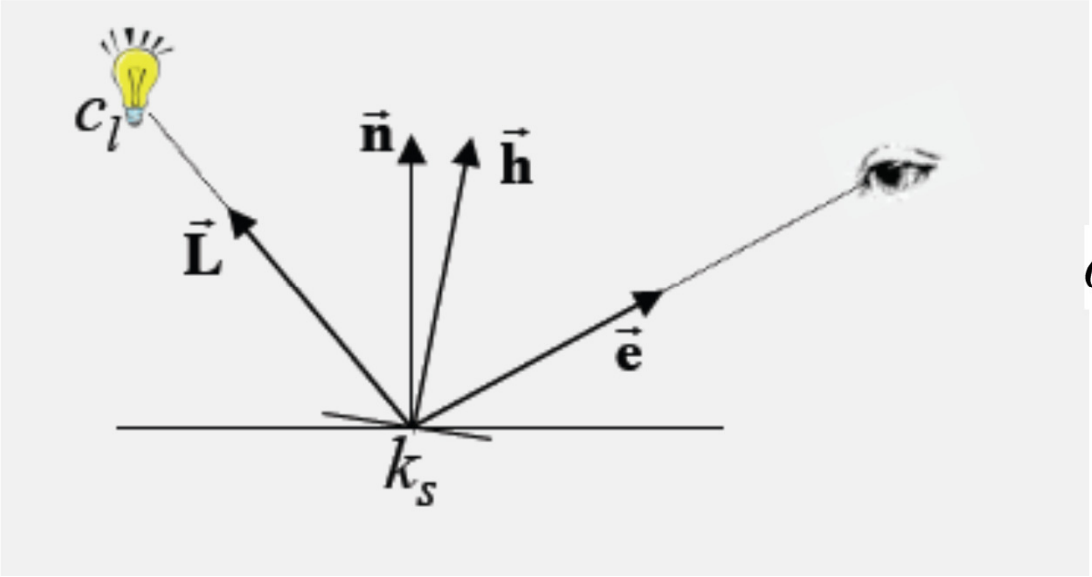
Blinn Shading Model (Jim Blinn, 1977)

- Modification of Phong Shading Model
- Defines unit halfway vector $$\mathbf{h} = \frac{\mathbf{L} + \mathbf{e}}{\|\mathbf{L} + \mathbf{e}\|}$$
- Halfway vector represents normal of micro-facet that would lead to mirror reflection to the eye



Blinn Shading Model

- The larger the angle between micro-facet orientation and normal, the less likely
- Use cosine of angle between them
- Shininess parameter *s*
- Very similar to Phong Model

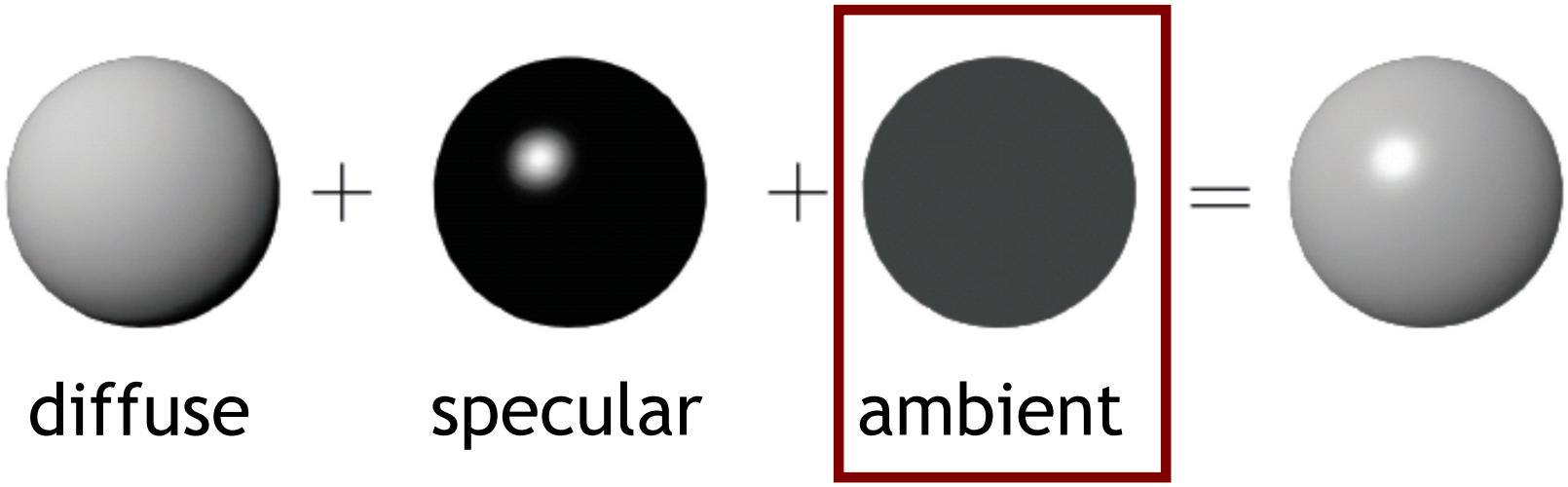


$$c = k_s c_l \left(\mathbf{h} \cdot \mathbf{n}\right)^s$$

Local Illumination

Simplified model

- Sum of 3 components
- Covers a large class of real surfaces



Ambient Light

- In real world, light is bounced all around scene
- Could use global illumination techniques to simulate
- Simple approximation
  - Add constant ambient light at each point: $k_a c_a$
  - Ambient light color: c_a
  - Ambient reflection coefficient: k_a
- Areas with no direct illumination are not completely dark

Complete Blinn-Phong Shading Model

- Blinn-Phong model with several light sources I
- All colors and reflection coefficients are vectors with 3 components for red, green, blue

$$c = \sum_i c_{l_i} \left(k_d \left(\mathbf{L}_i \cdot \mathbf{n} \right) + k_s \left(\mathbf{h}_i \cdot \mathbf{n} \right)^s \right) + k_a c_a$$

diffuse specular ambient