CSE 167:
Introduction to Computer Graphics
Lecture #5: Illumination Model

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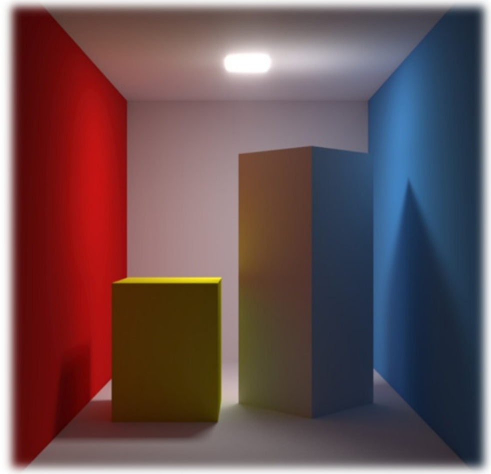
Announcements

- Project 2 due next Friday at 2pm

Shading

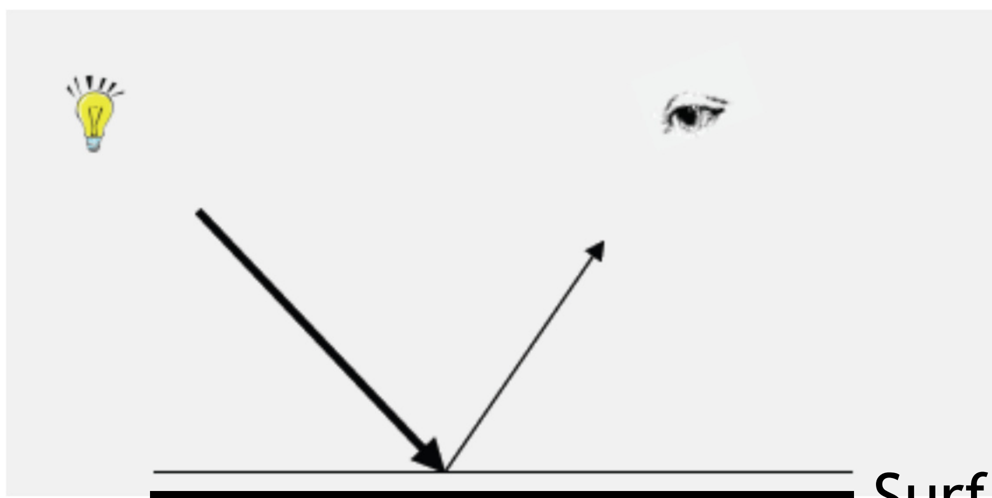
- Compute interaction of light with surfaces
- Requires simulation of physics
- "Global illumination"
  - Multiple bounces of light
  - Computationally expensive, minutes per image
  - Used in movies, architectural design, etc.

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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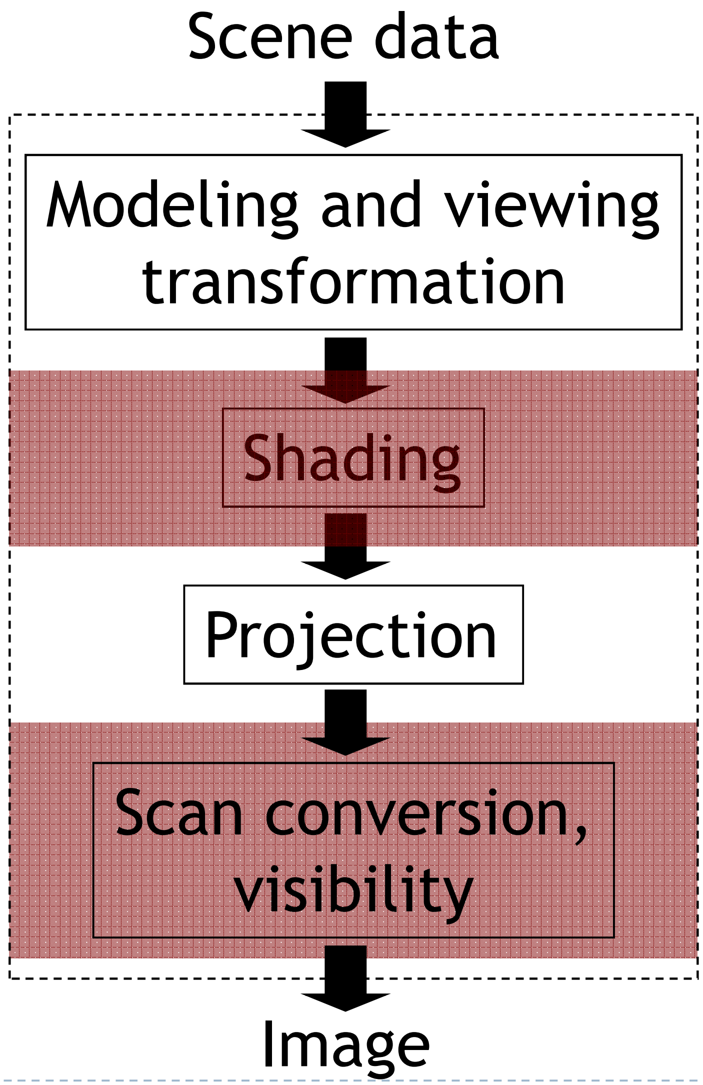
Rendering Pipeline



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

Lecture Overview

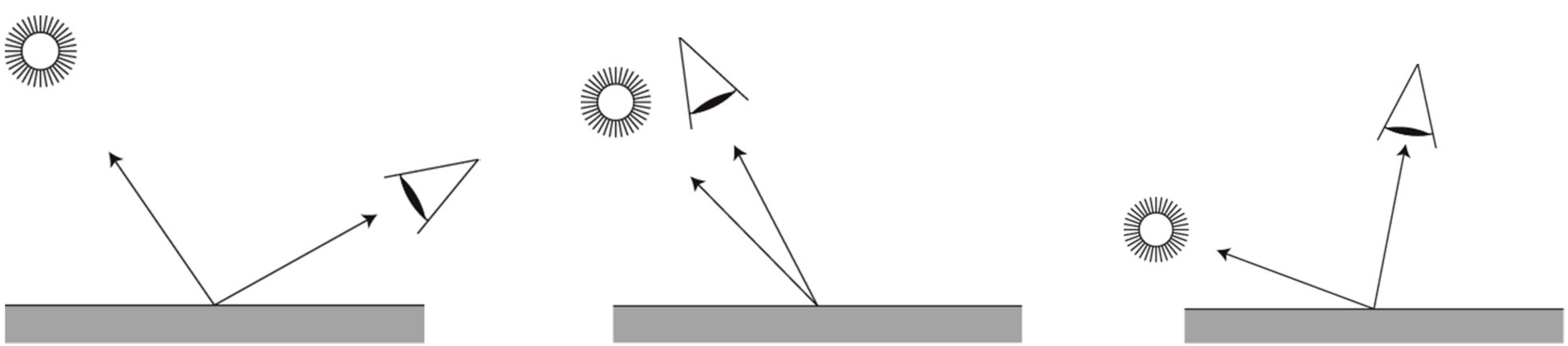
- OpenGL's local shading model

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

Local Illumination

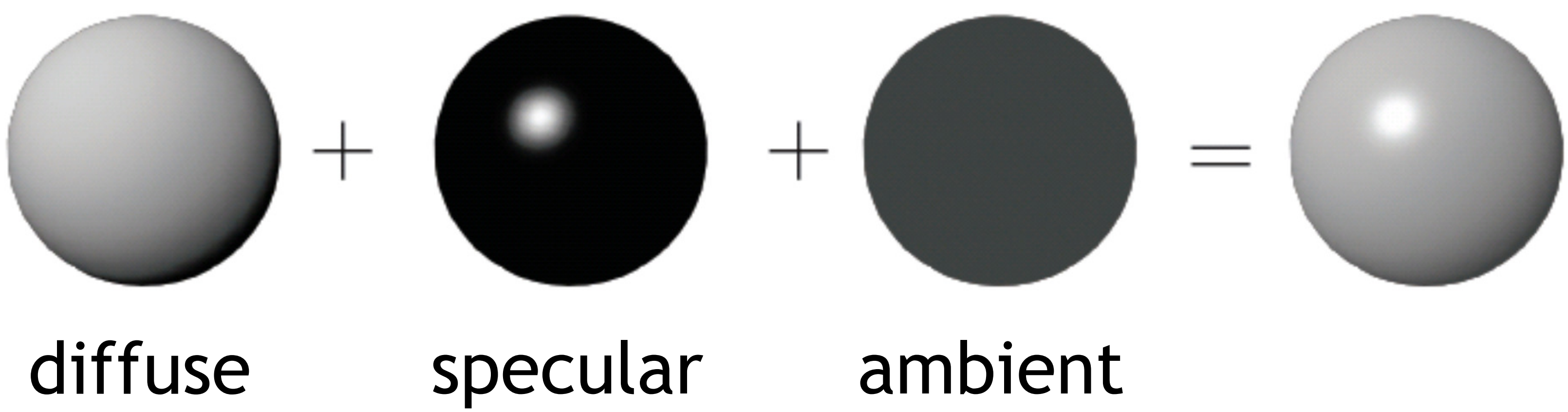
- Model reflection of light at surfaces
  - Assumption: no subsurface scattering
- Bidirectional reflectance distribution function (BRDF)
  - Given light direction, viewing direction, how much light is reflected towards the viewer
  - For any pair of light/viewing directions!



Local Illumination

Simplified model

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



Local Illumination

Simplified model

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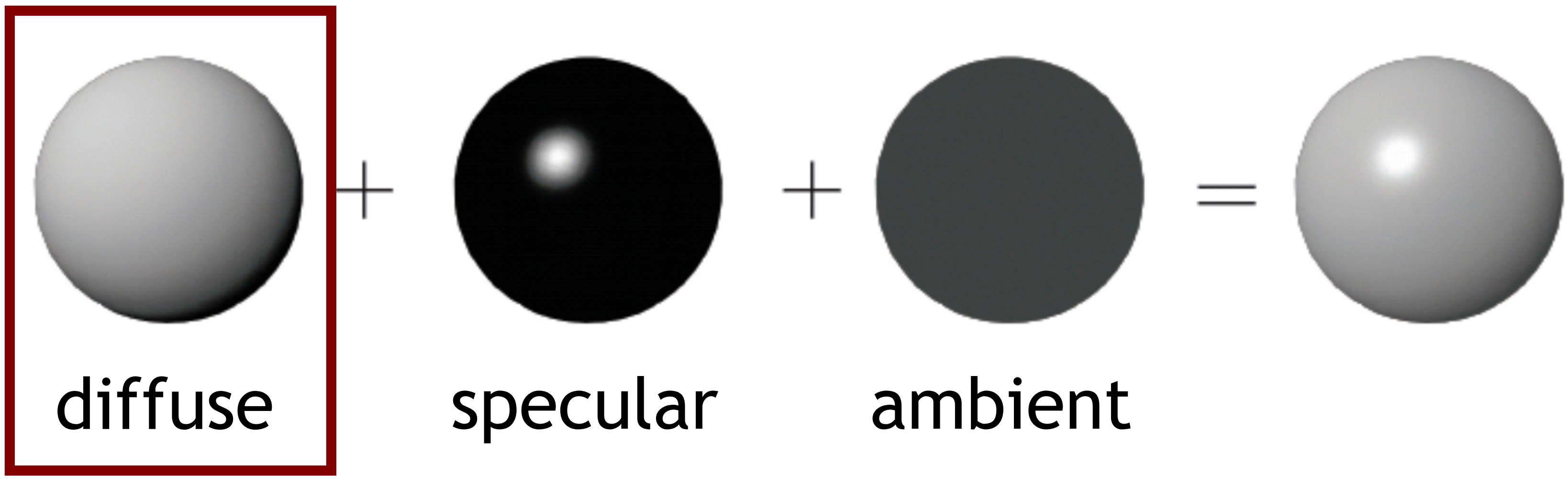
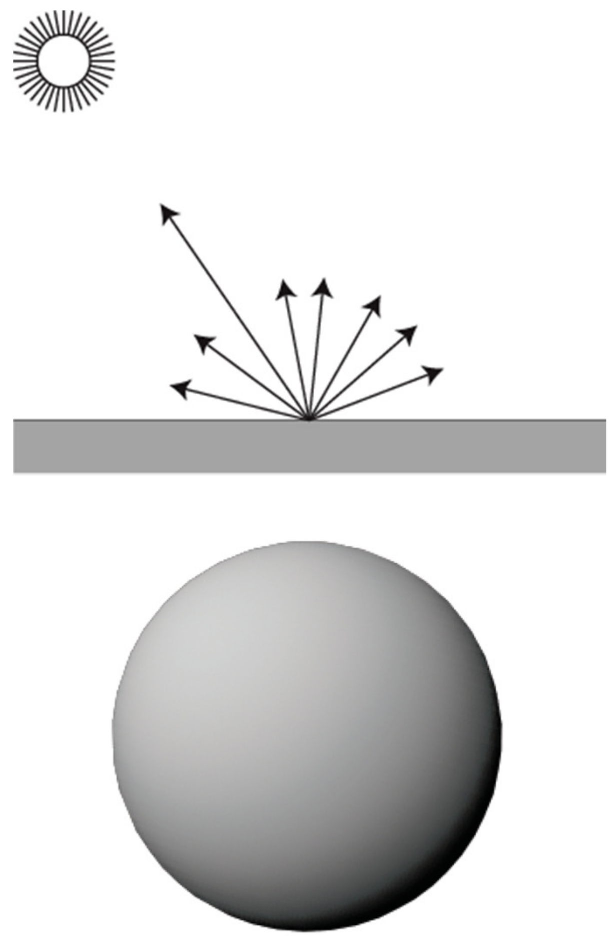


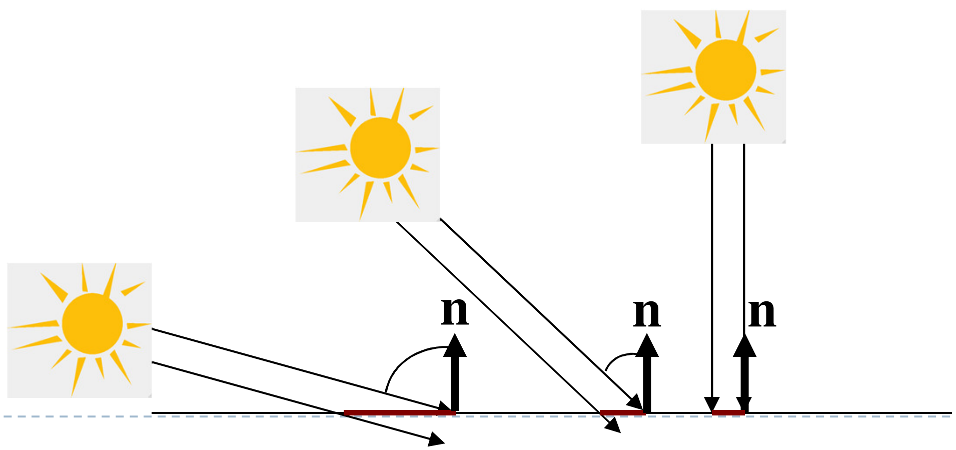
Diffuse Reflection

- 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

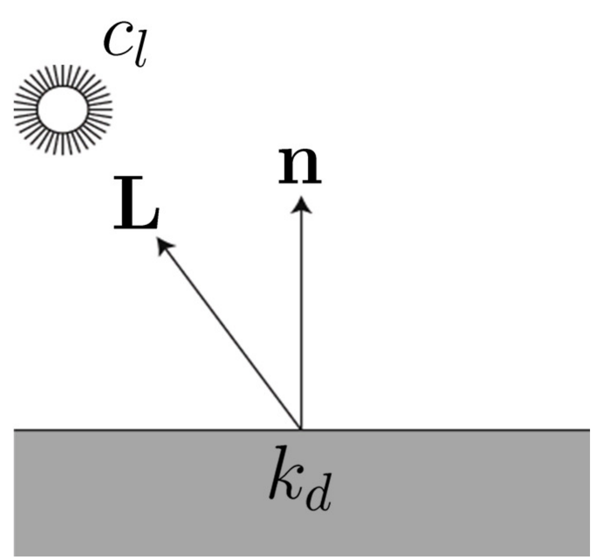


Diffuse Reflection

- 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



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

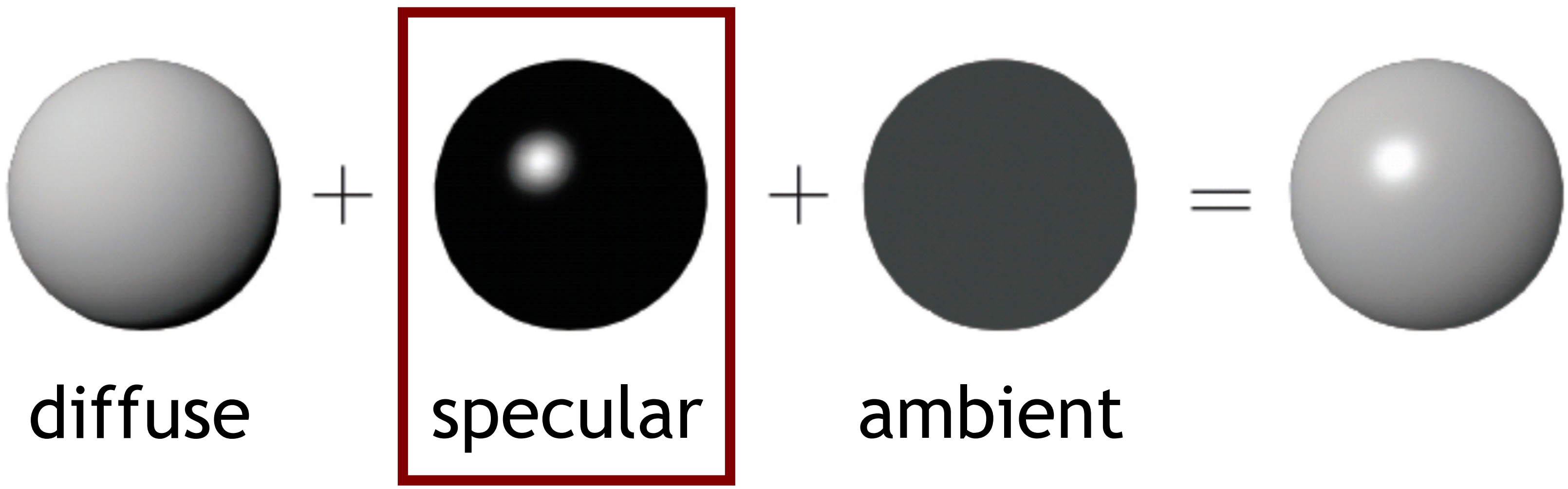
OpenGL

- 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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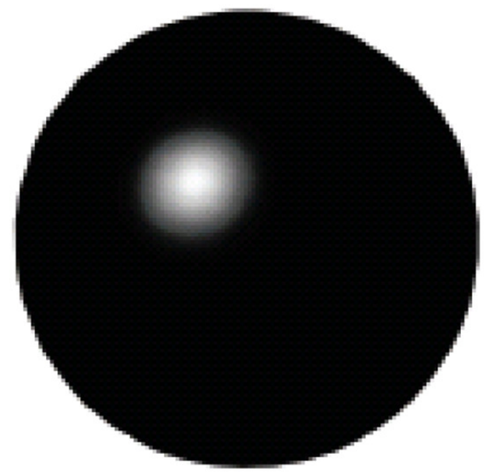
Specular Reflection

- 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

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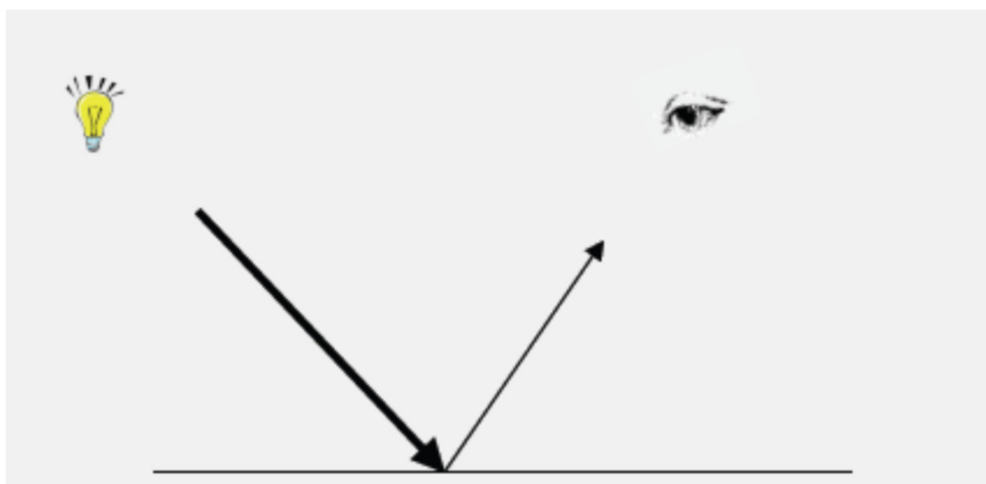
Specular Reflection

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

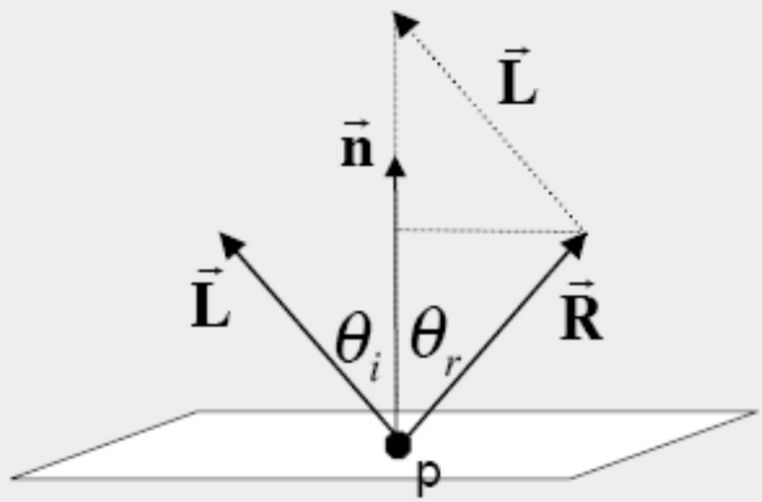


Law of Reflection

- Angle of incidence equals angle of reflection

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

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



$$\theta_r = \theta_i$$

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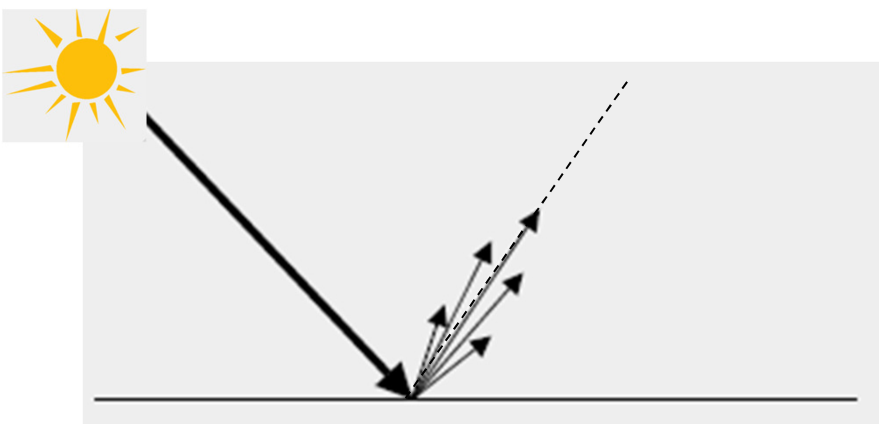
Specular Reflection

- Many materials are not perfect mirrors
  - Glossy materials



Glossy teapot

Glossy Materials

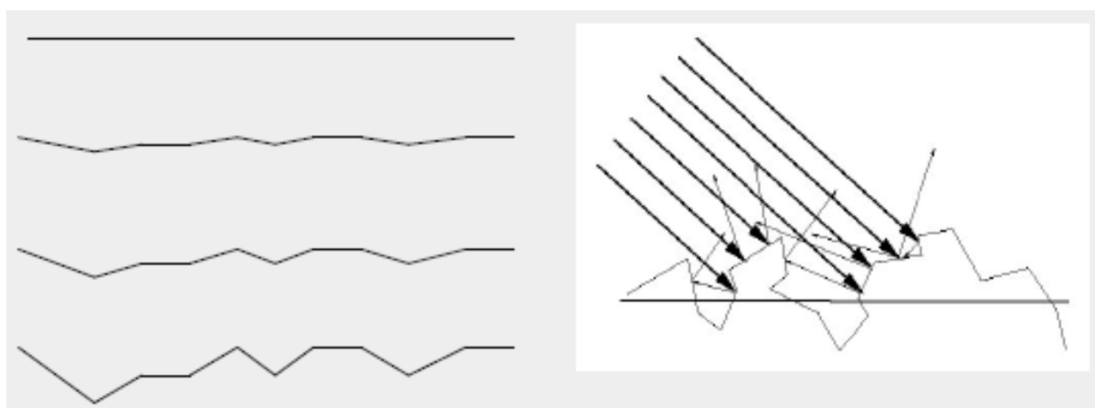
- Assume surface composed of small mirrors with random orientation (micro-facets)
- Smooth surfaces
  - Micro-facet normals close to surface normal
  - Sharp highlights
- Rough surfaces
  - Micro-facet normals vary strongly
  - Blurry highlight

Polished

Smooth

Rough

Very rough

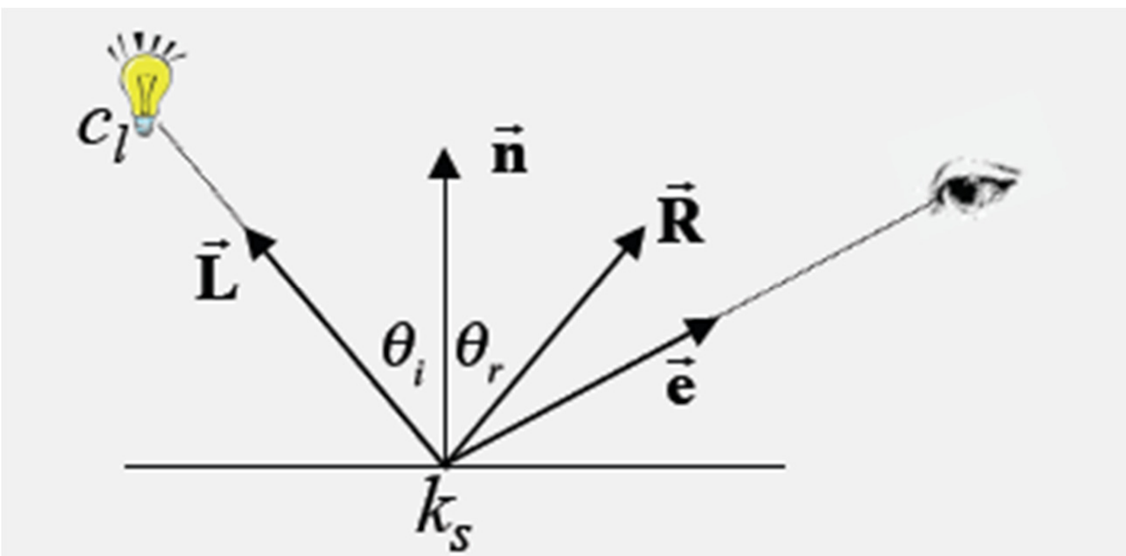


Glossy Surfaces

- 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 in1973
- Specular reflectance coefficient k_s
- Phong exponent p
  - Greater p means smaller (sharper) highlight



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

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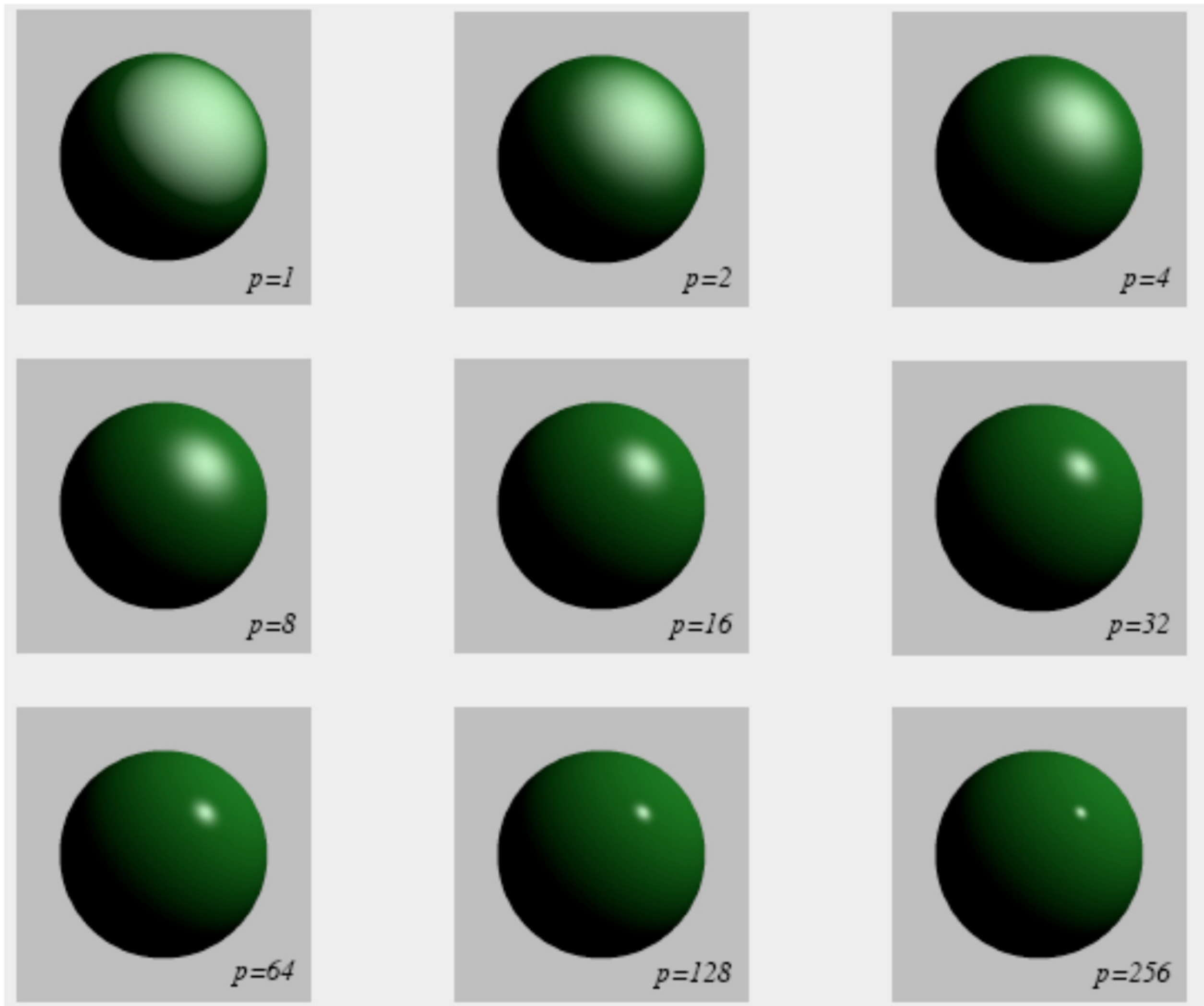
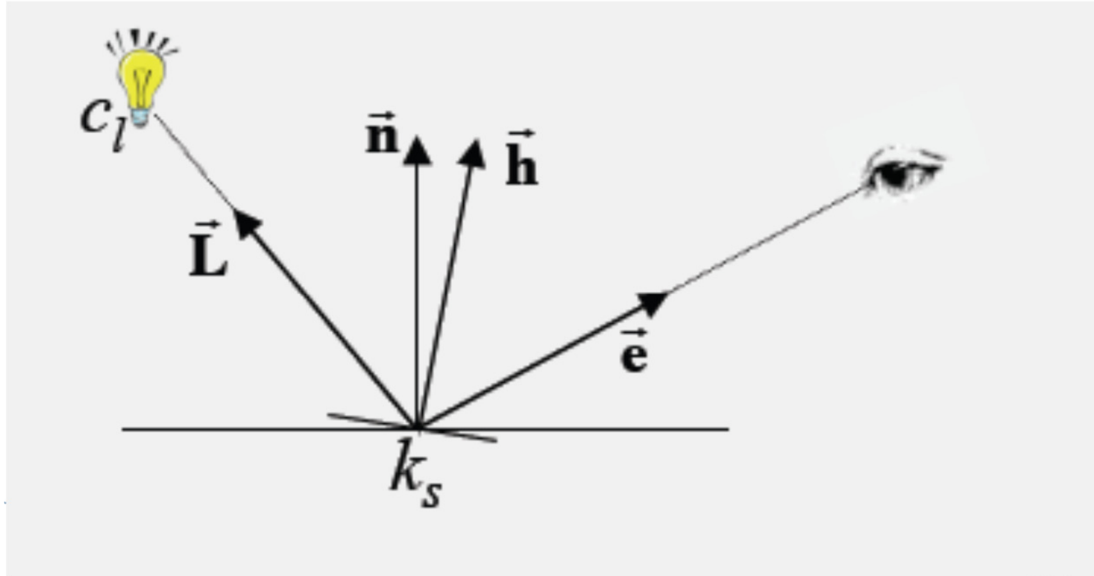
Phong Shading Model



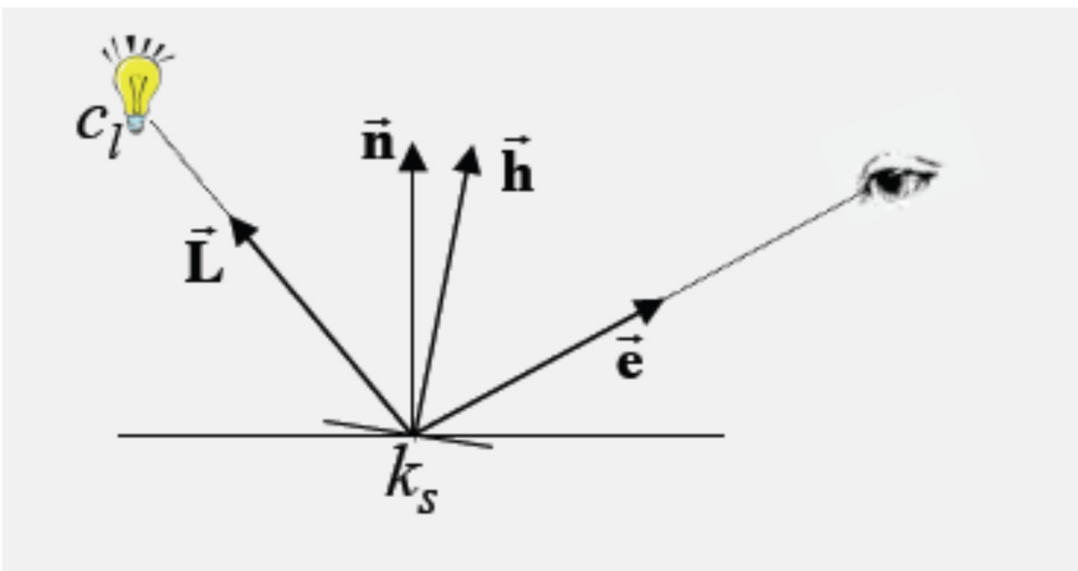
Blinn Shading Model (Jim Blinn, 1977)

- 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



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

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Local Illumination

Simplified model

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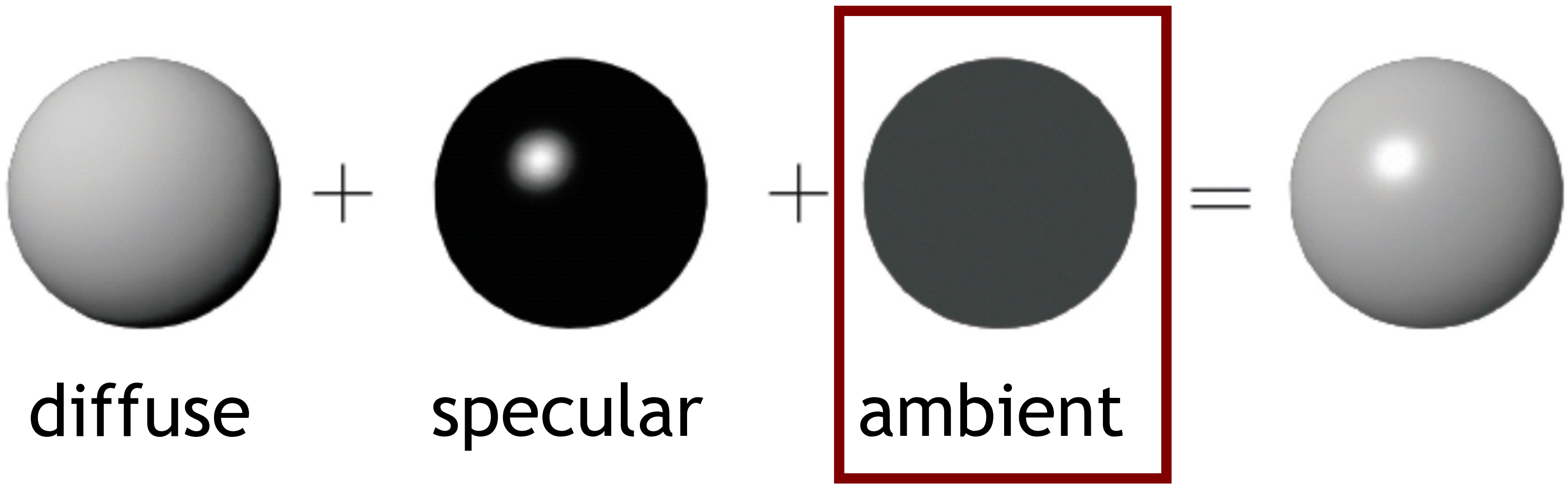


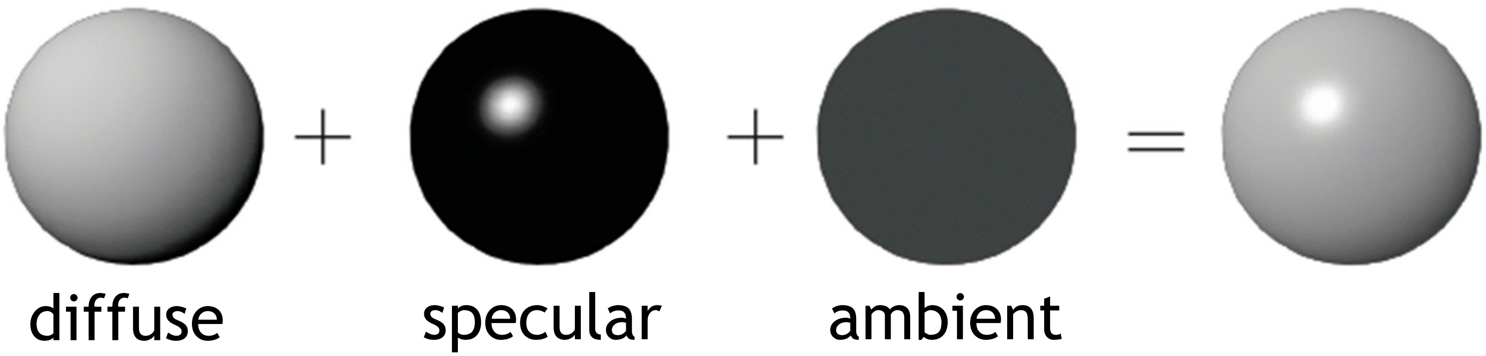
Ambient Light

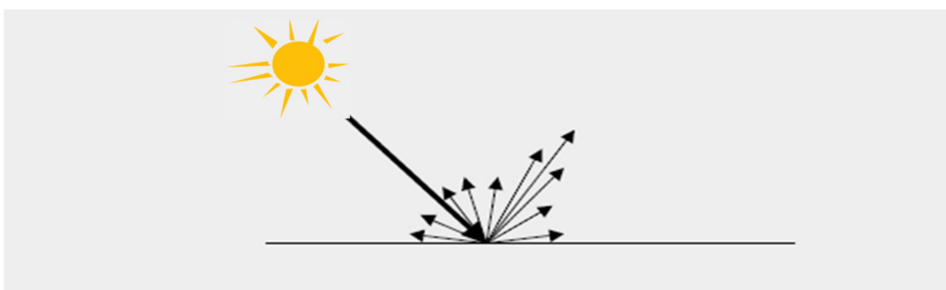
- In real world, light is bounced all around scene
- Could use global illumination techniques to simulate
- Simple approximation
  - Add constant ambient light at each point: $k_a c_a$
  - Ambient light color: c_a
  - Ambient reflection coefficient: k_a
- Areas with no direct illumination are not completely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

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





Lecture Overview

- OpenGL Light Sources
  - Directional Lights
  - Point Lights
  - Spot Lights

Light Sources

- Real light sources can have complex properties
  - Geometric area over which light is produced
  - Anisotropy (directionally dependent)
  - Reflective surfaces act as light sources (indirect light)







- OpenGL uses a drastically simplified model to allow real-time rendering

OpenGL Light Sources

- At each point on surfaces we need to know
  - Direction of incoming light (the $\mathbf{L}$ vector)
  - Intensity of incoming light (the c_l values)
- Standard light sources in OpenGL
  - Directional: from a specific direction
  - Point light source: from a specific point
  - Spotlight: from a specific point with intensity that depends on direction

Lecture Overview

- OpenGL Light Sources
  - Directional Lights
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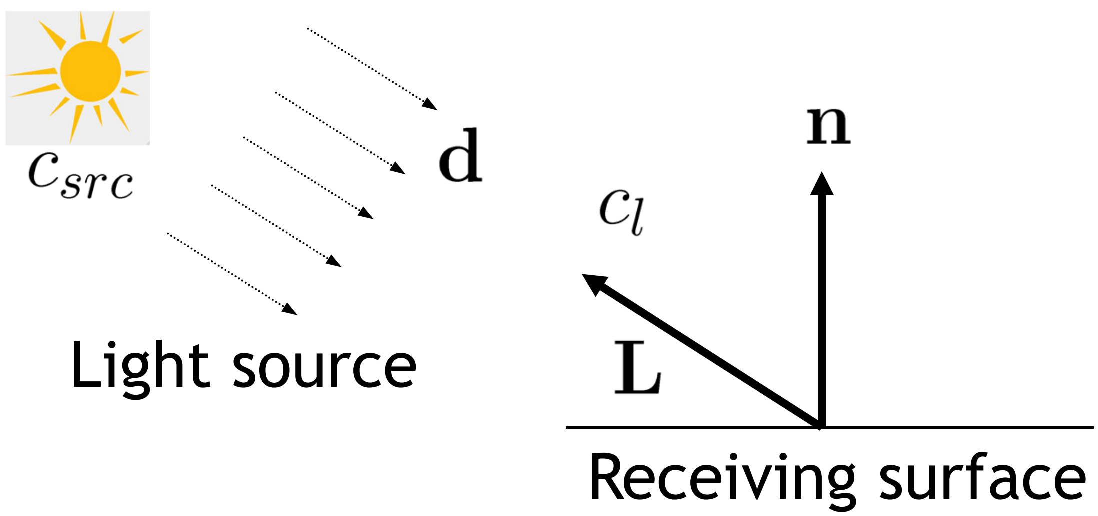
Directional Light

- Light from a distant source
  - Light rays are parallel
  - Direction and intensity are the same everywhere
  - As if the source were infinitely far away
  - Good approximation of sunlight
- Specified by a unit length direction vector, and a color



$$\mathbf{L} = -\mathbf{d}$$

$$c_l = c_{src}$$

Lecture Overview

- OpenGL Light Sources
  - Directional Lights
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Point Lights

- Similar to light bulbs
- Infinitely small point radiates light equally in all directions
  - Light vector varies across receiving surface
  - What is light intensity over distance proportional to?
  - Intensity drops off proportionally to the inverse square of the distance from the light
    - Reason for inverse square falloff:
      Surface area A of sphere:
      $A = 4 \pi r^2$

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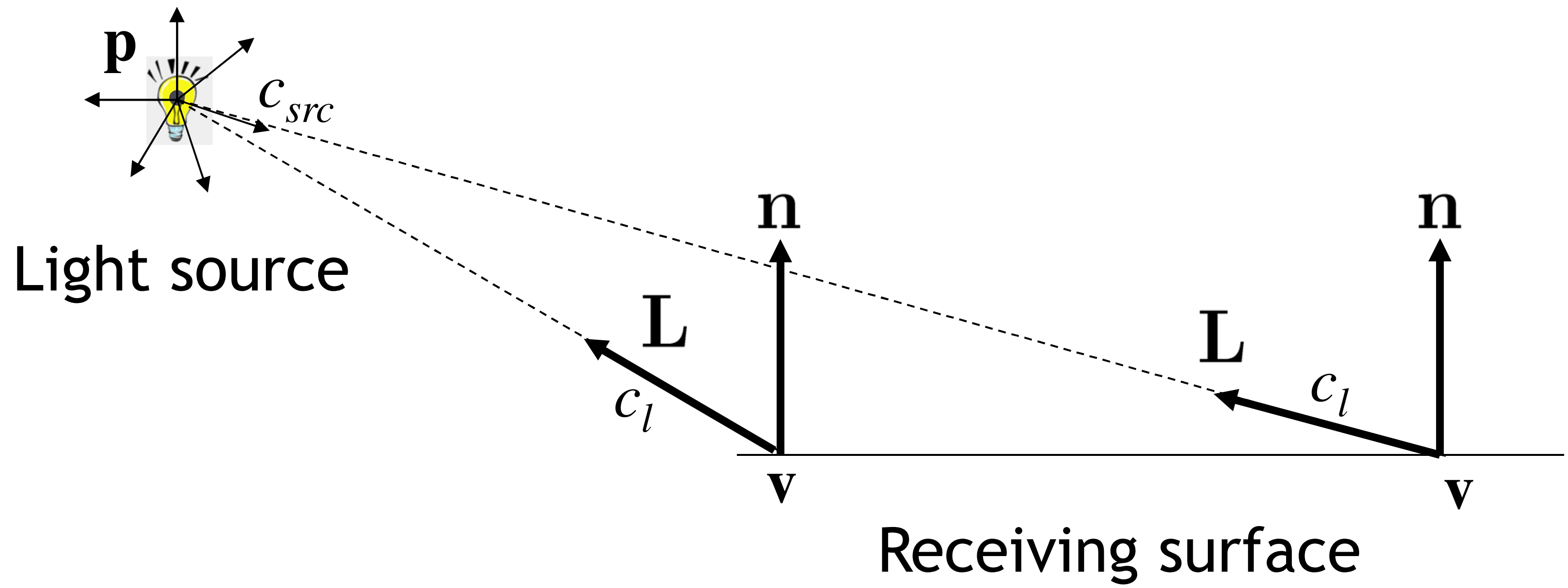
Point Lights in Theory



At any point v on the surface:

$$\mathbf{L} = \frac{\mathbf{p} - \mathbf{v}}{\|\mathbf{p} - \mathbf{v}\|}$$

$$c_l = \frac{c_{src}}{\|\mathbf{p} - \mathbf{v}\|^2}$$

Point Lights in OpenGL

- OpenGL model for distance attenuation:

$$c_l = \frac{c_{src}}{k_c + k_l |\mathbf{p} - \mathbf{v}| + k_q |\mathbf{p} - \mathbf{v}|^2}$$

- Attenuation parameters:
  - k_c = constant attenuation, default: 1
  - k_l = linear attenuation, default: 0
  - k_q = quadratic attenuation, default: 0
- Default: no attenuation: $c_l = c_{src}$
- Change attenuation parameters with:
  - GL_CONSTANT_ATTENUATION
  - GL_LINEAR_ATTENUATION
  - GL_QUADRATIC_ATTENUATION

Lecture Overview

- OpenGL Light Sources
  - Directional Lights
  - Point Lights
  - Spot Lights

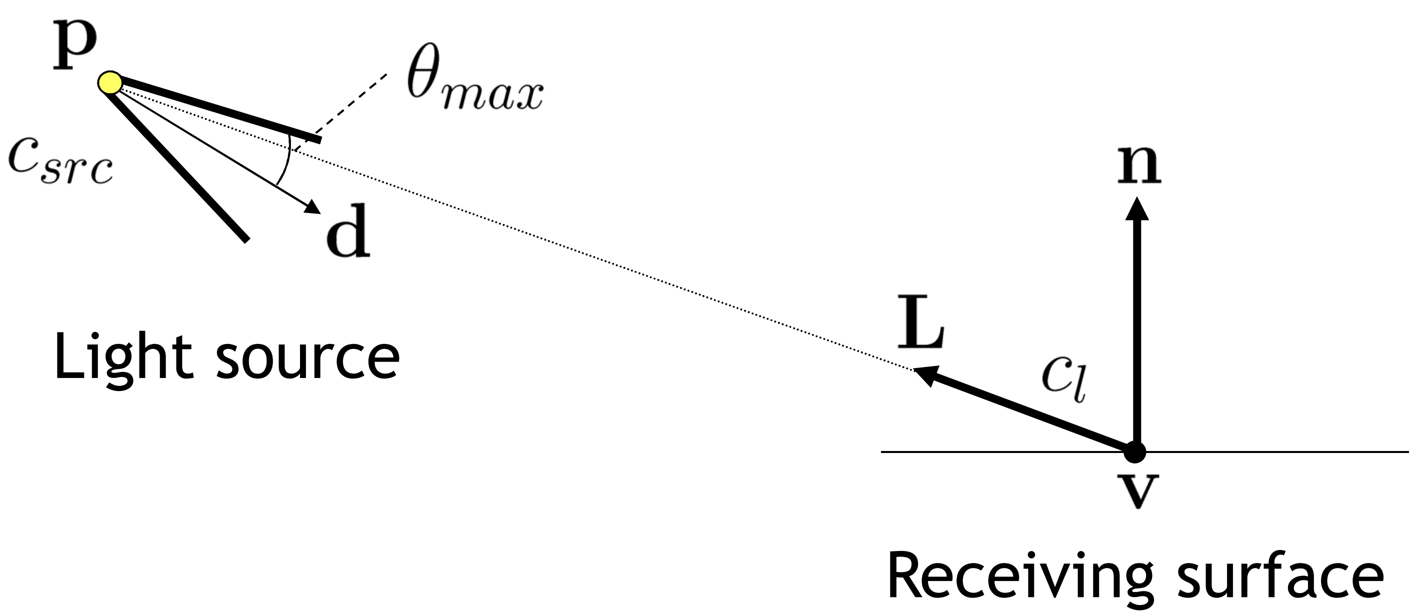
Spotlights

- Like point source, but intensity depends on direction

Parameters

- Position: location of light source
- Spot direction: center axis of light source
- Falloff parameters:
  - Beam width (cone angle)
  - The way the light tapers off at the edges of the beam (cosine exponent)

Spotlights



$$\mathbf{L} = \frac{\mathbf{p}-\mathbf{v}}{\|\mathbf{p}-\mathbf{v}\|}$$

$$c_l = \begin{cases} 0 & \text{if} \quad -\mathbf{L}\cdot\mathbf{d} \leq \cos(\theta_{max}) \\ c_{src}\,(-\mathbf{L}\cdot\mathbf{d})^f & \text{otherwise} \end{cases}$$

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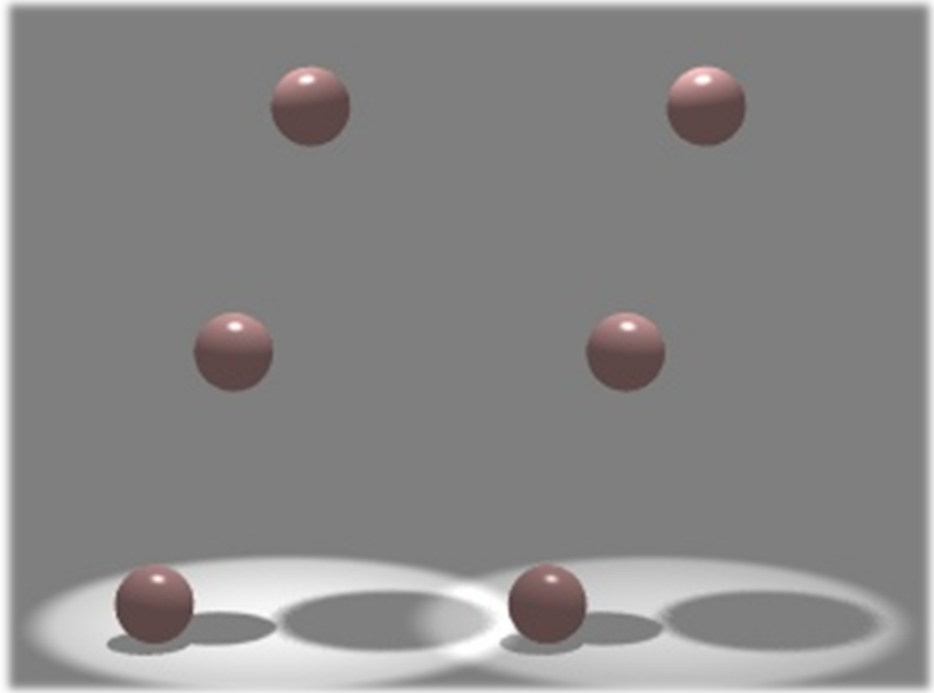
Spotlights

Photograph of real spotlight



Spotlights in OpenGL