Surface shading

Computer Graphics

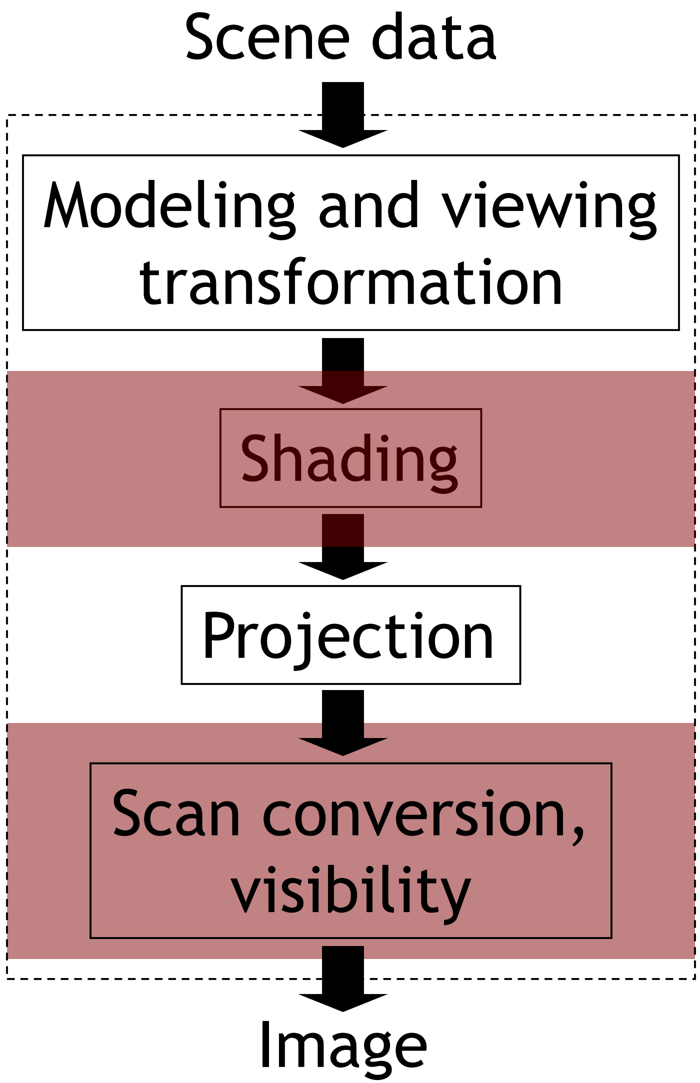
CSE 167

Lecture 6

CSE 167: Computer Graphics

- Global illumination
- Local illumination
- Surface shading
  - Materials
  - Lights

Rendering Pipeline



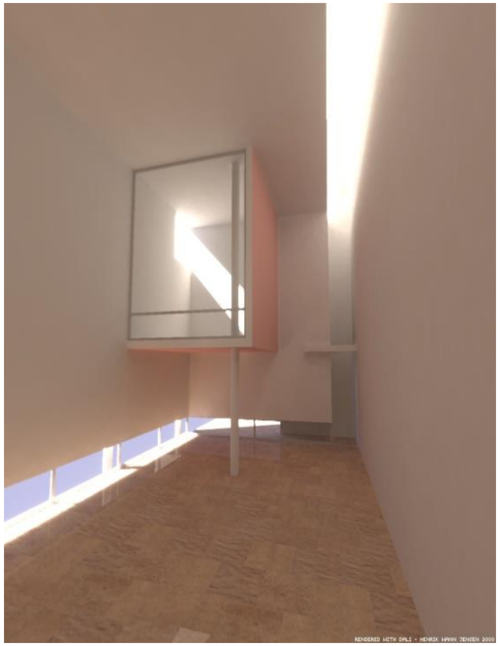
- Position object in 3D
- Determine colors of vertices
  - Per vertex shading
- Map triangles to 2D
- Draw triangles
  - Per pixel shading

Appearance: lighting, surface reflectance, and shading

Global illumination

- Photorealistic rendering using physics-based simulation
  - Multiple bounces of light
    - Direct (from light source) and indirect (from light reflected by other surfaces) illumination
- Computationally expensive (minutes per image)
- Used in movies, architectural design, etc.

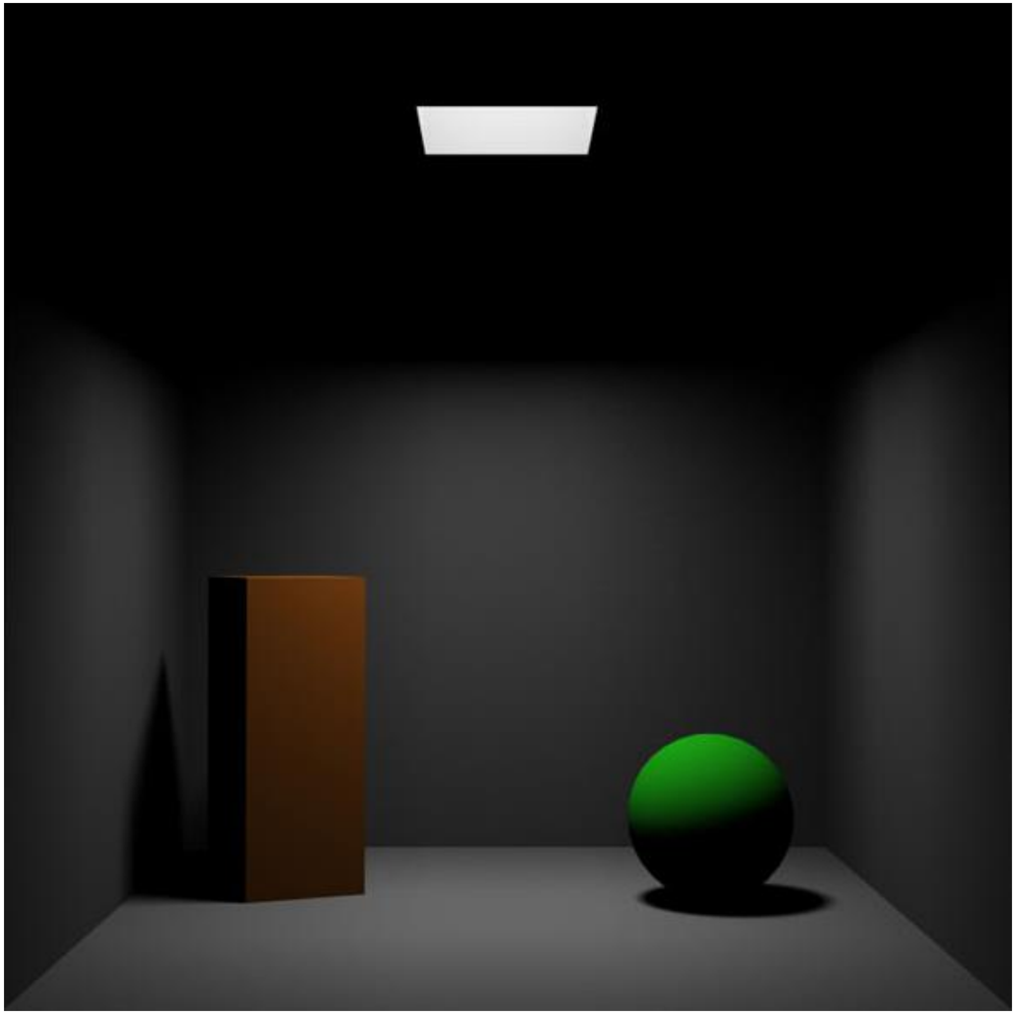
Global illumination

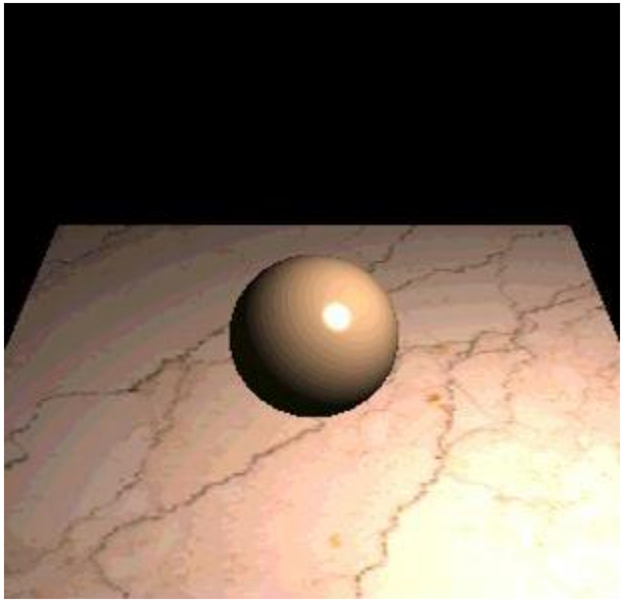


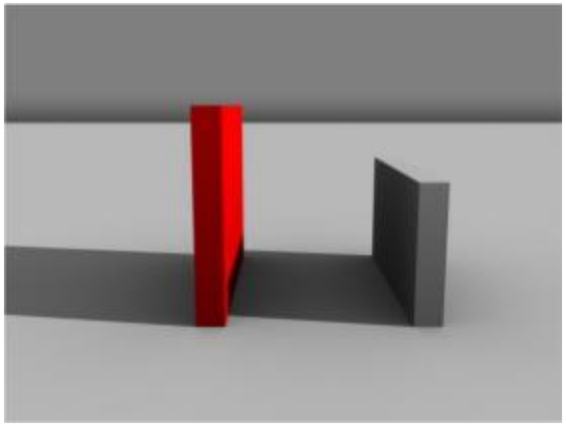
Local illumination

- Not a physics-based simulation
- Uses simplified models that reproduce perceptually most important effects
  - One bounce of light
    - Direct (from light source) illumination
  - Indirect illumination with an “ambient” term
- Computationally very fast
- Used in interactive applications

Local illumination

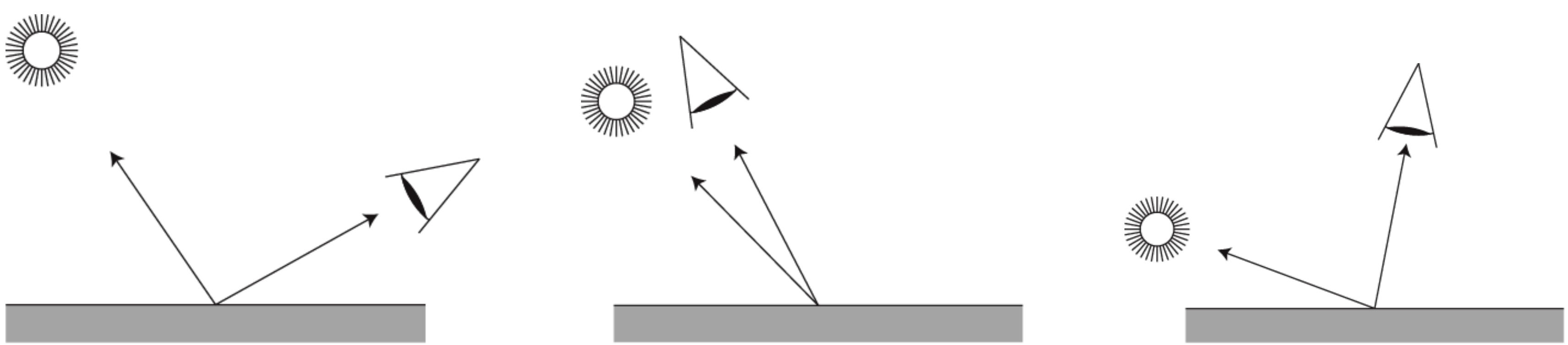






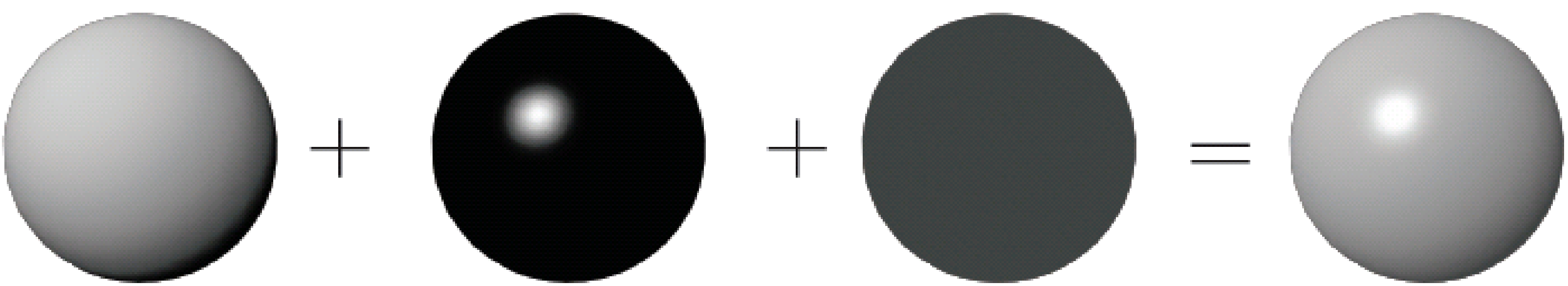
Local illumination

- 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



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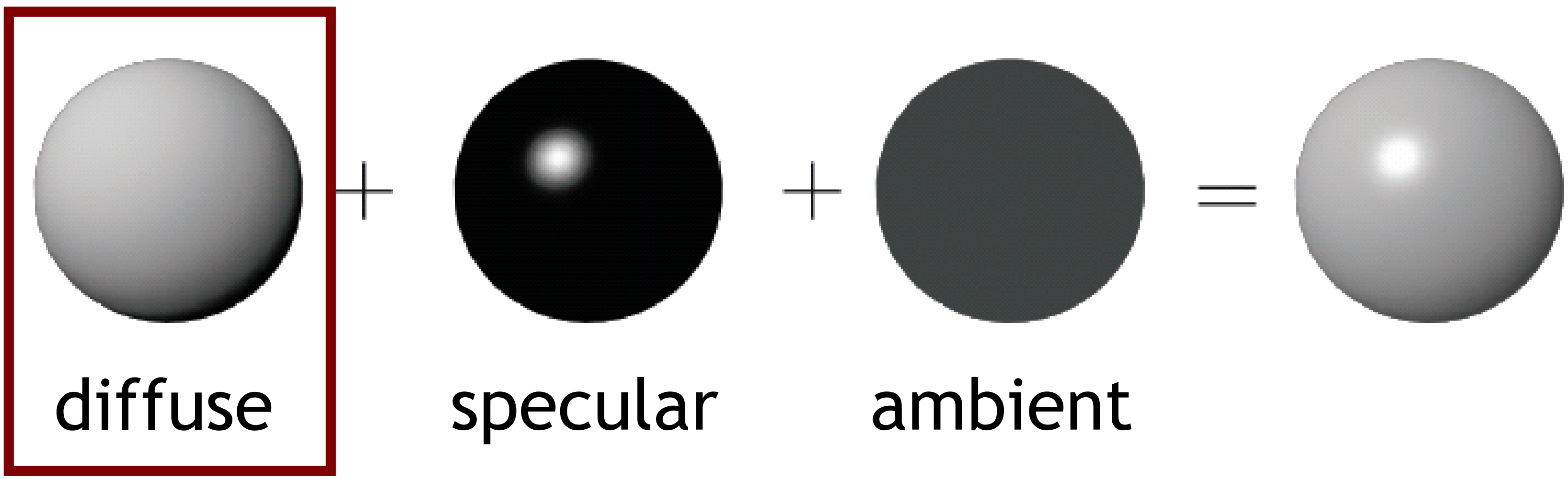
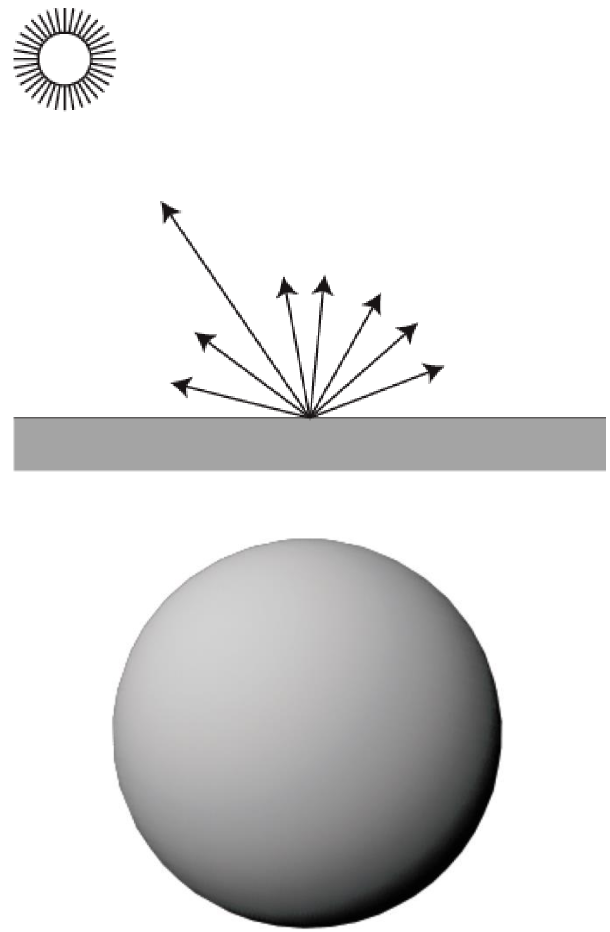


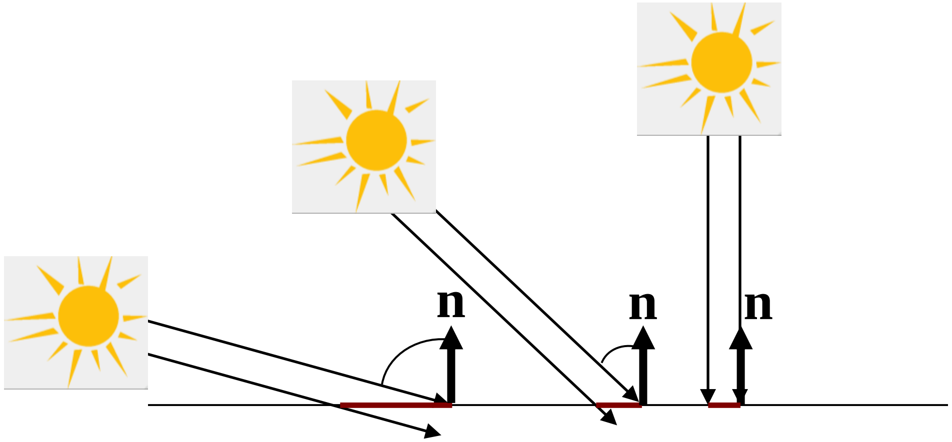
Diffuse reflection

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

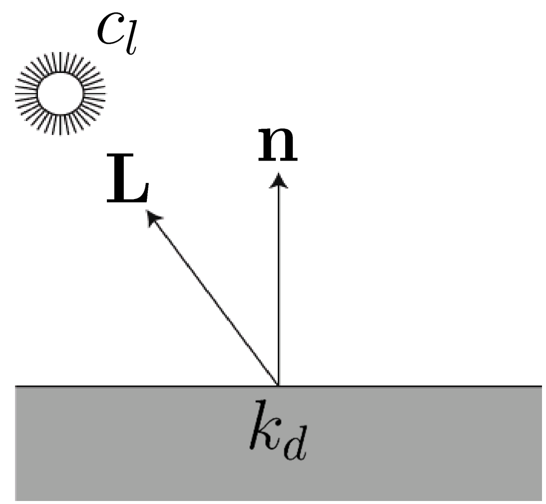


Diffuse reflection

- 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 color (albedo) k_d
  - Light color c_l
- Reflected color c_d is given by $c_d = c_l k_d \mathbf{n}^\top \mathbf{L}$

$$\cos(\theta) = \mathbf{n}^\top \mathbf{L}$$

Do not allow angles less than 0 (light is behind surface)

$$\cos^+(\theta) = \max(0, \mathbf{n}^\top \mathbf{L})$$

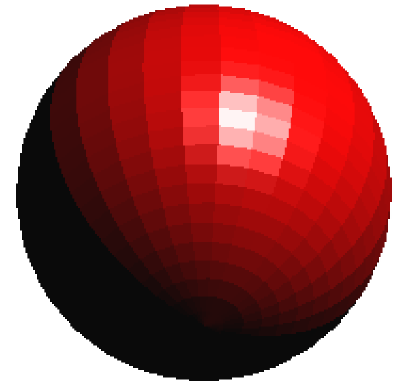
$$c_d = c_l k_d \max(0, \mathbf{n}^\top \mathbf{L})$$

Diffuse reflection

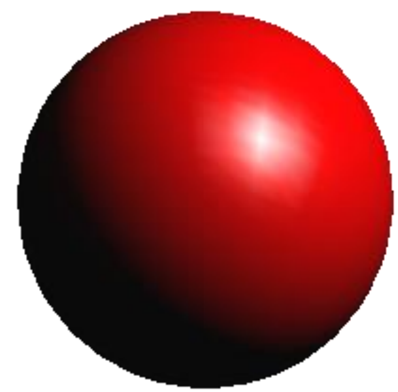
- Notes
  - Material color (albedo) k_d and light color c_l are r,g,b vectors
  - Need to compute r,g,b values of reflected color c_d separately

Surface normals

- Important to bring out 3D appearance
- Important for correct shading under lights
- The way shading is done also important
  - Flat: Each facet has single normal
  - Smooth: Each vertex has a single normal, interpolate normal vectors to determine normal at point on facet



Flat



Smooth

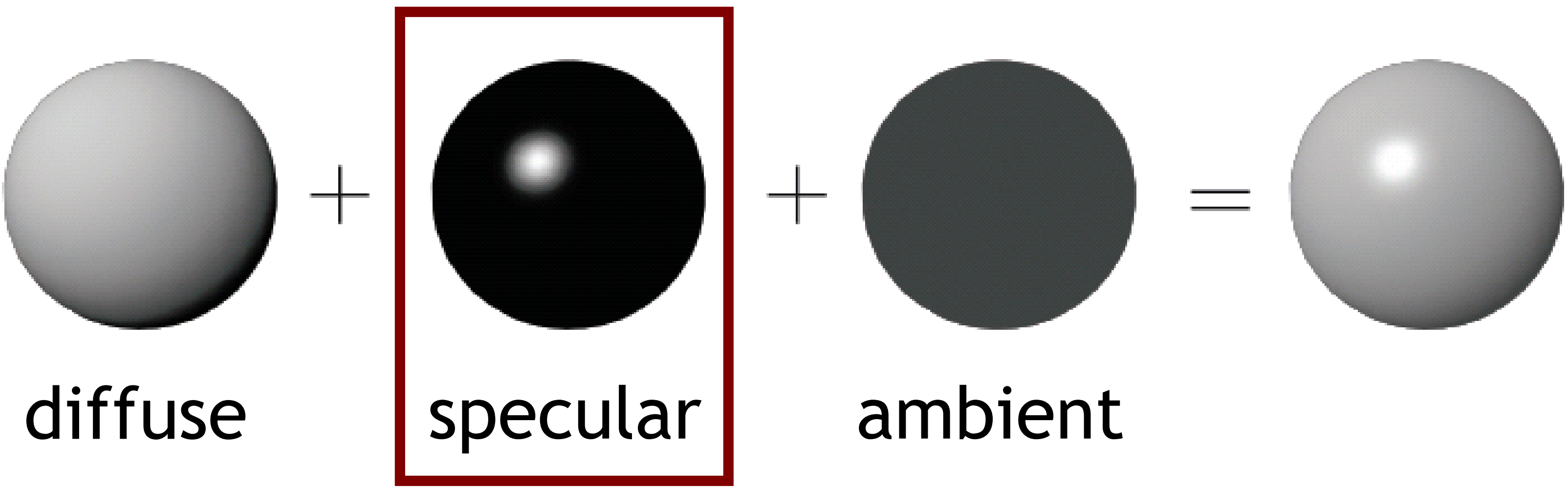
Diffuse reflection

- Provides visual cues
  - Surface curvature
  - Depth variation

Lambertian (diffuse) sphere under different lighting directions

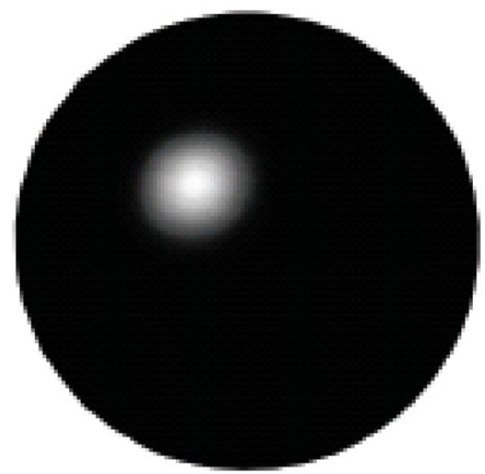
Local illumination

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



Specular reflection

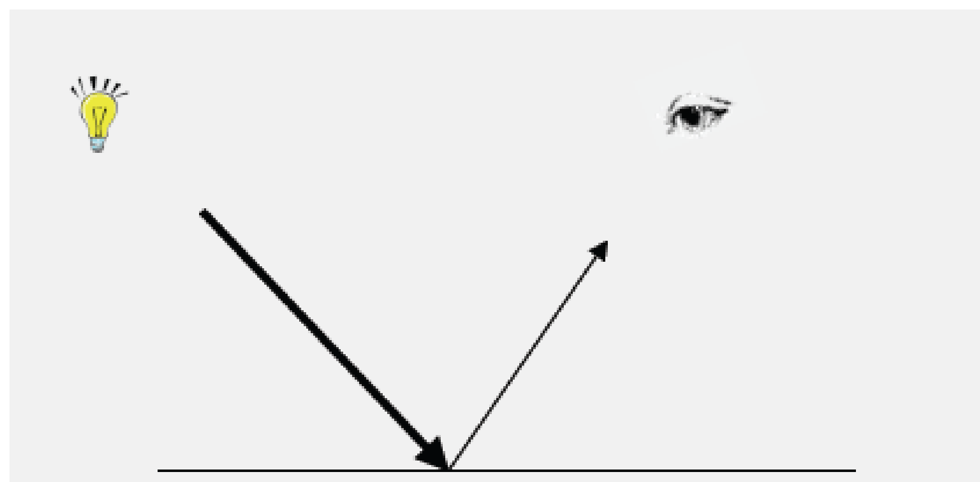
- Shiny surfaces
  - Polished metal
  - Glossy car finish
  - Plastics
- Specular highlight
  - Blurred reflection of the light source
  - Position of highlight depends on viewing direction



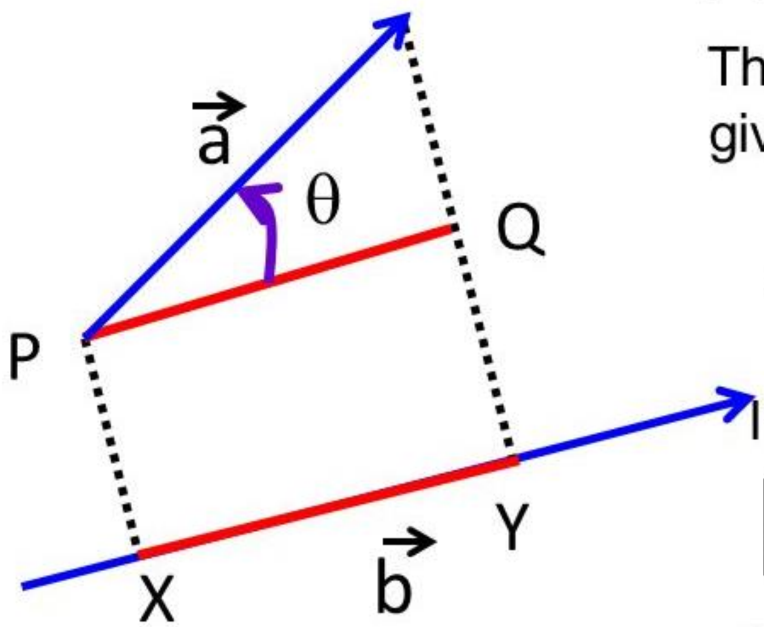
Specular highlight

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



Projection of vector on another vector



Projection of $\vec{a}$ on $\vec{b}$ is XY

The projection of **a** onto **b** will be given by:

$$proj_b a = |a| \cos\theta \, \frac{\mathrm{b}}{|\mathrm{b}|}$$

In summary, the $proj_a$ b has length $|a|\cos\theta$, and direction $\frac{b}{|b|}$

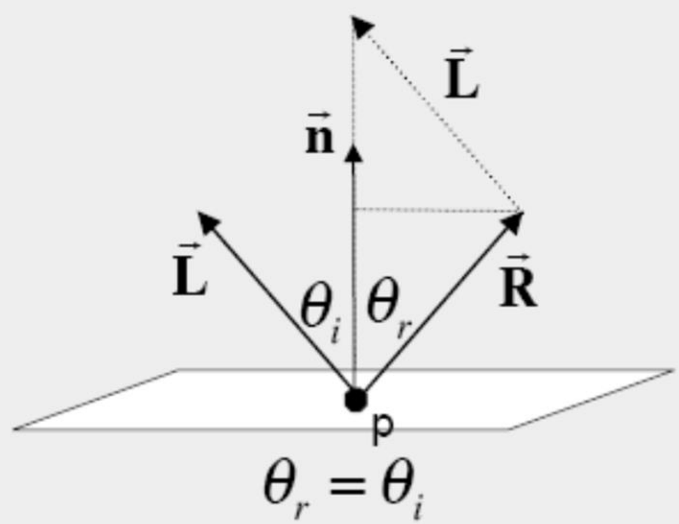
It is called the scalar component of **a** in the direction of **b**

Law of reflection

- Angle of incidence equals angle of reflection

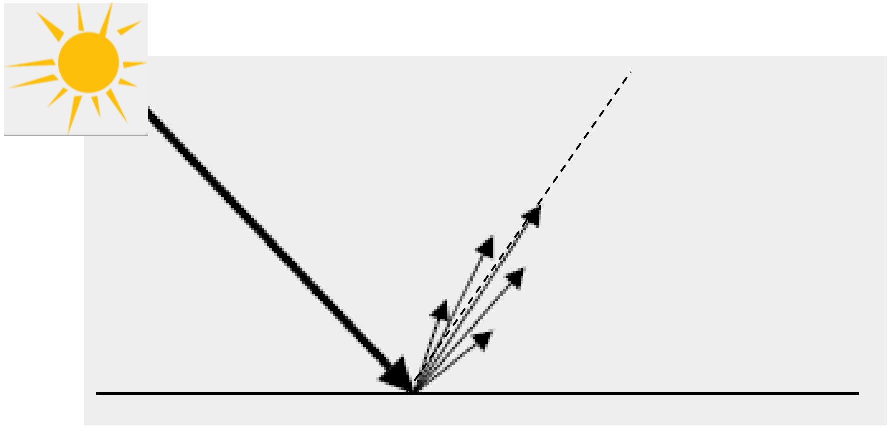
$$\vec{\mathbf{R}} + \vec{\mathbf{L}} = 2\cos\theta\ \vec{\mathbf{n}} = 2\left(\vec{\mathbf{L}} \cdot \vec{\mathbf{n}}\right)\vec{\mathbf{n}}$$

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



Specular reflection

- Many materials are not perfect mirrors
  - Glossy materials



Glossy teapot

Glossy materials

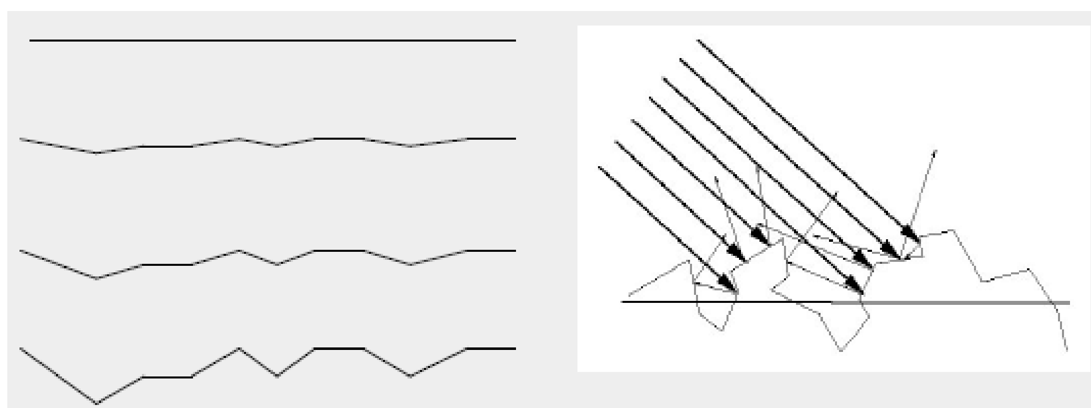
- Assume surface composed of small mirrors with random orientation (micro-facets)
- Smooth surfaces
  - Micro-facet normals close to surface normal
  - Sharp highlights
- Rough surfaces
  - Micro-facet normals vary strongly
  - Blurry highlight

Polished

Smooth

Rough

Very rough

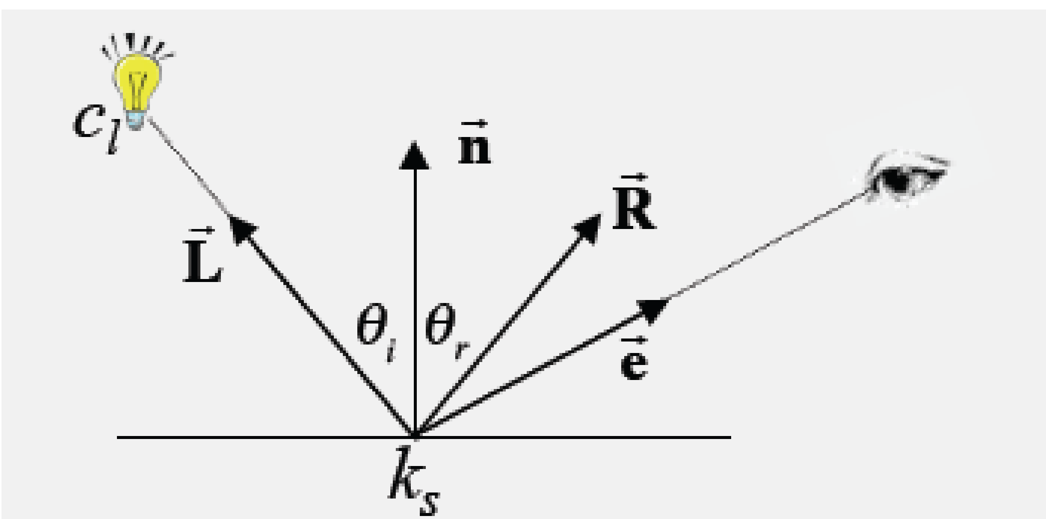


Glossy surfaces

- 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

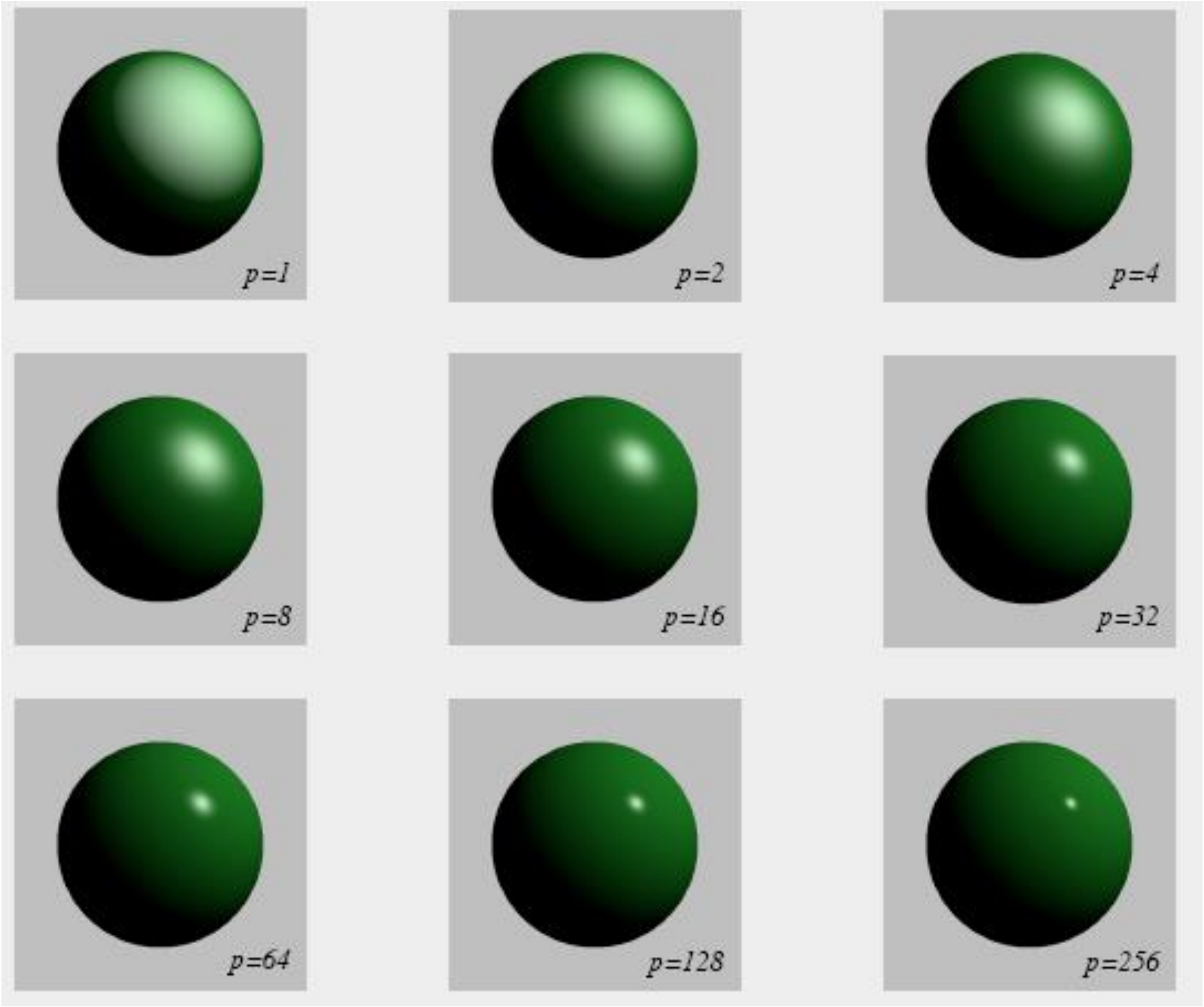
Phong shading model

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



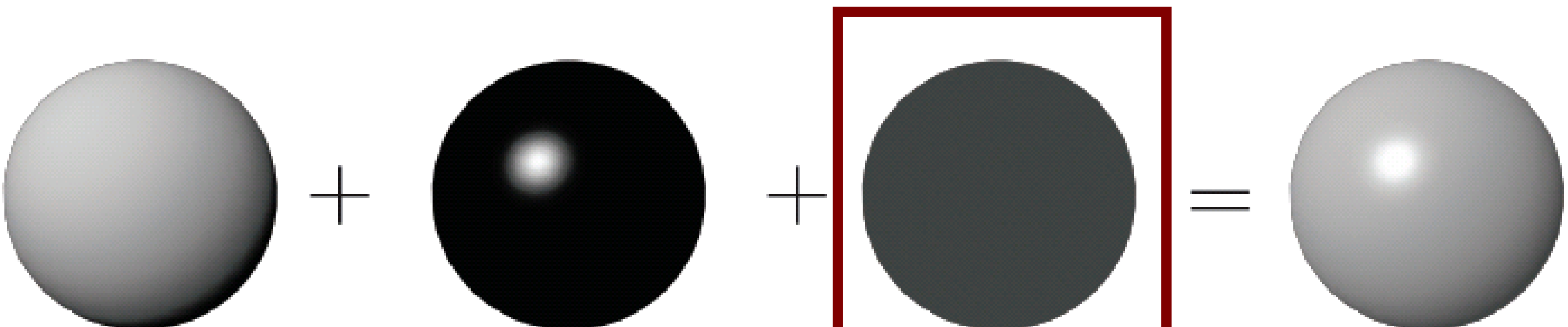
$$c = k_s c_l \left(\mathbf{R} \cdot \mathbf{e}\right)^p$$

Phong shading model



Local Illumination

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



diffuse specular ambient

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 Phong shading model

- Phong model supports multiple light sources
- All light colors *c* and material coefficients *k* are 3-component vectors for red, green, blue

$$c = \sum_i c_{l_i}(k_d(L_i \cdot n) + k_s(R \cdot e)^p + k_a)$$

Sum over all light sources

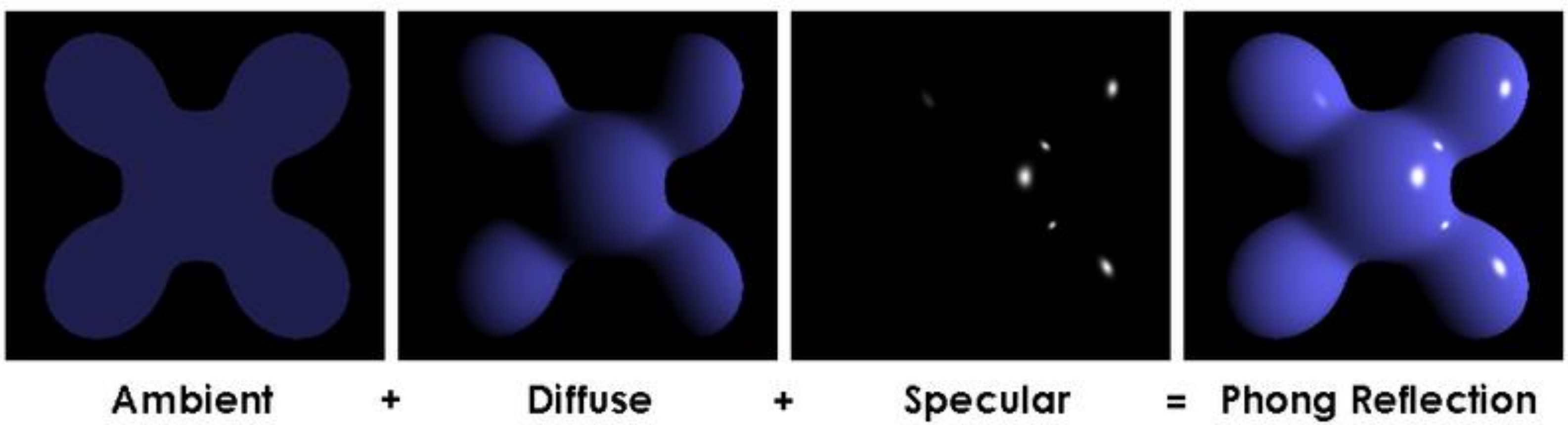


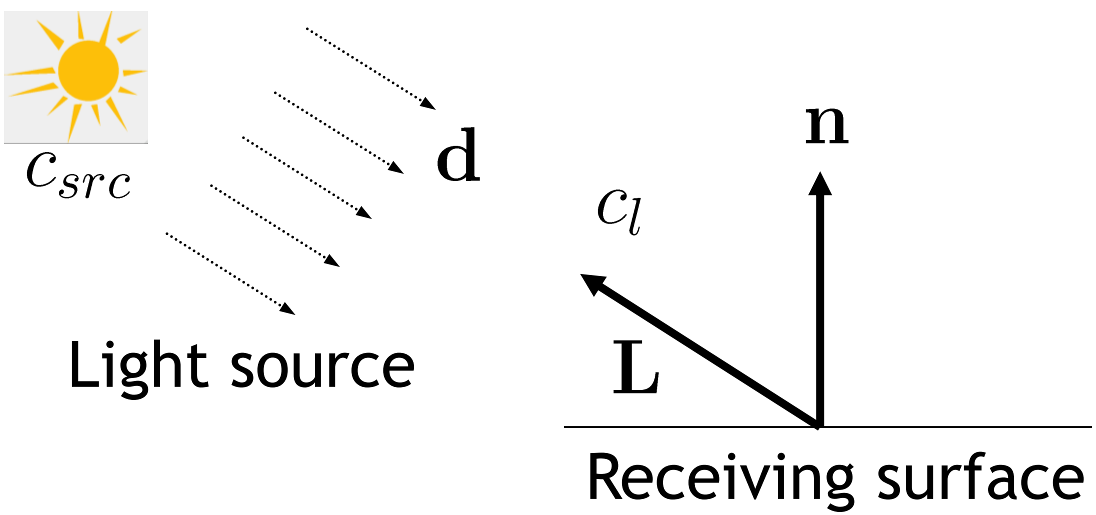
Image by Brad Smith

Types of light sources

- At each point on surfaces we need to know
  - Direction of incoming light (the **L** vector)
  - Intensity of incoming light (the c_l values)
- Three light types:
  - Directional: from a specific direction
  - Point light: from a specific point
  - Spotlight: from a specific point with intensity that depends on direction

Directional light source

- 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



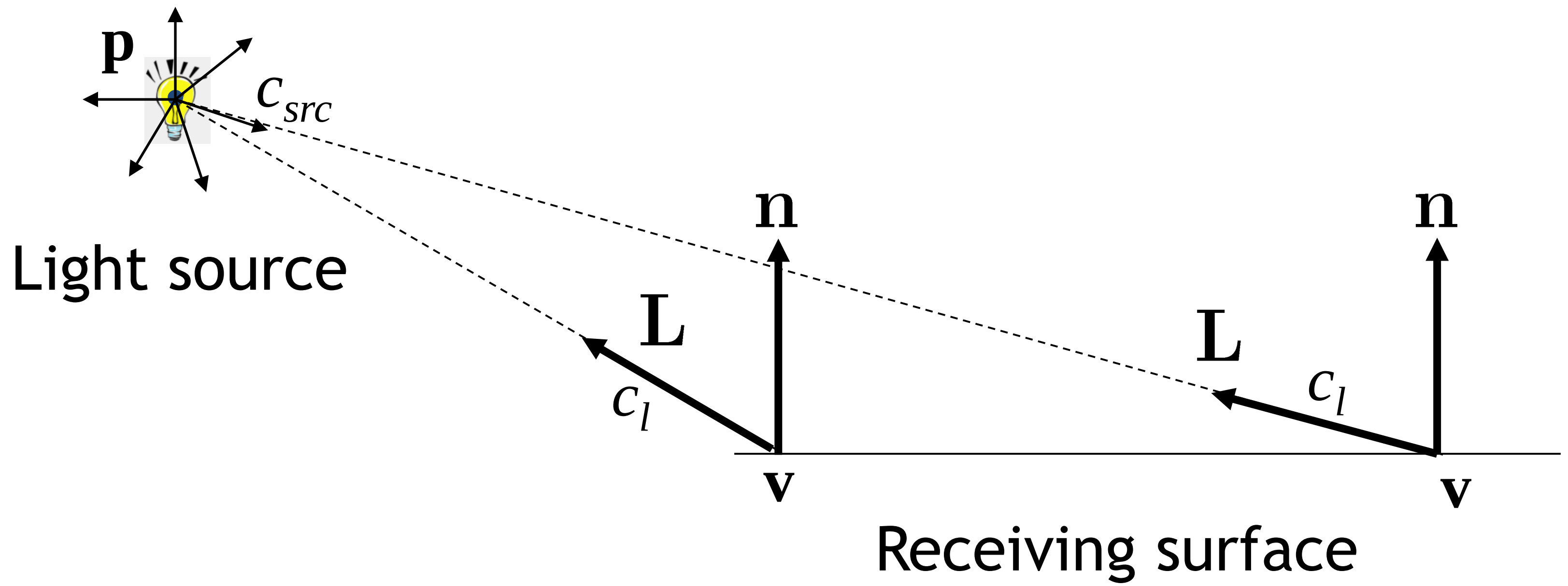
$$\mathbf{L} = -\mathbf{d}$$

$$c_l = c_{src}$$

Point light source

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

Point light source



At any point v on the surface:

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

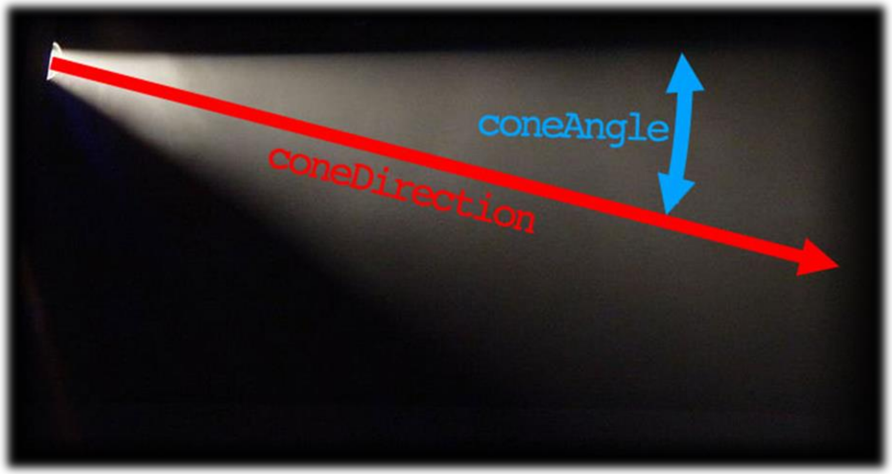
Attenuation: $$c_l = \frac{c_{src}}{\|\mathbf{p} - \mathbf{v}\|^2}$$

Point light source, attenuation

- Adding constant factor k to denominator for better control
- Quadratic attenuation $k\|\mathbf{p}-\mathbf{v}\|^2$
  – Most computationally expensive, most physically accurate
- Linear attenuation $k\|\mathbf{p}-\mathbf{v}\|$
  – Less expensive, less accurate
- Constant attenuation k
  – Least expensive, least accurate

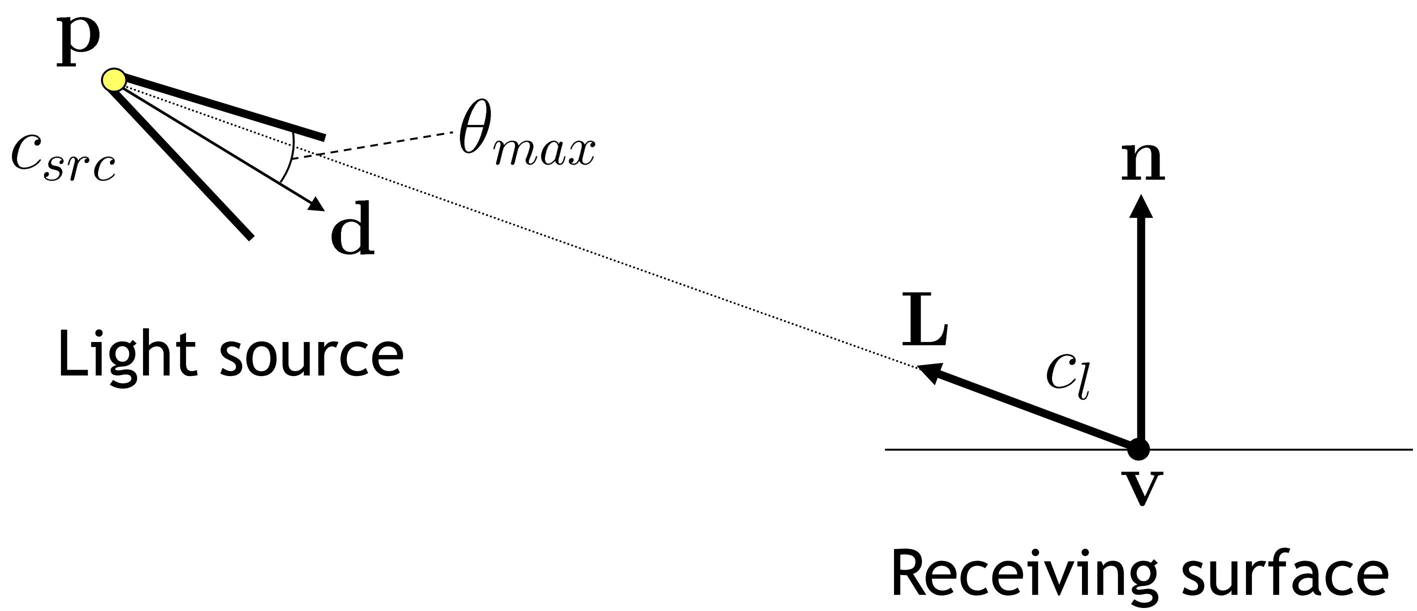
Spotlight source

- Like point light source, but intensity depends on direction



- Parameters
  - Position **p**: location of light source
  - Cone direction **d**: center axis of light source
  - Intensity falloff:
    - Beam width (cone angle θ_{max})
    - The way the light tapers off at the edges of the beam (cosine exponent *f*)

Spotlight source



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

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