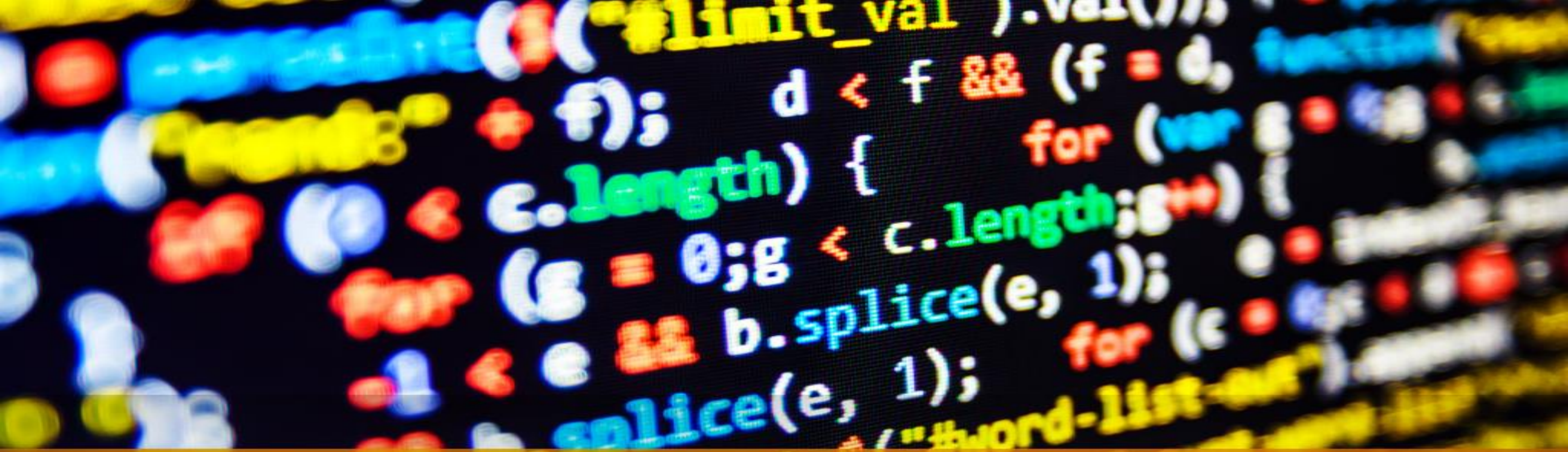


Lecture 08

Lighting, Shading, & Texture Mapping (Part 1)

Prepared by Ban Kar Weng (William)

Motivations

- Models of 3D objects should have proper **geometrical shape** and desired **visual appearance**.

- Realistic visual appearance can be achieved through **lighting**, **shading**, and **texture mapping**.

Definitions

Lighting

- How to compute the outgoing luminous intensity (i.e. outgoing light) at a particular point.

Shading

- How to assign colours to pixels.

Texture Mapping

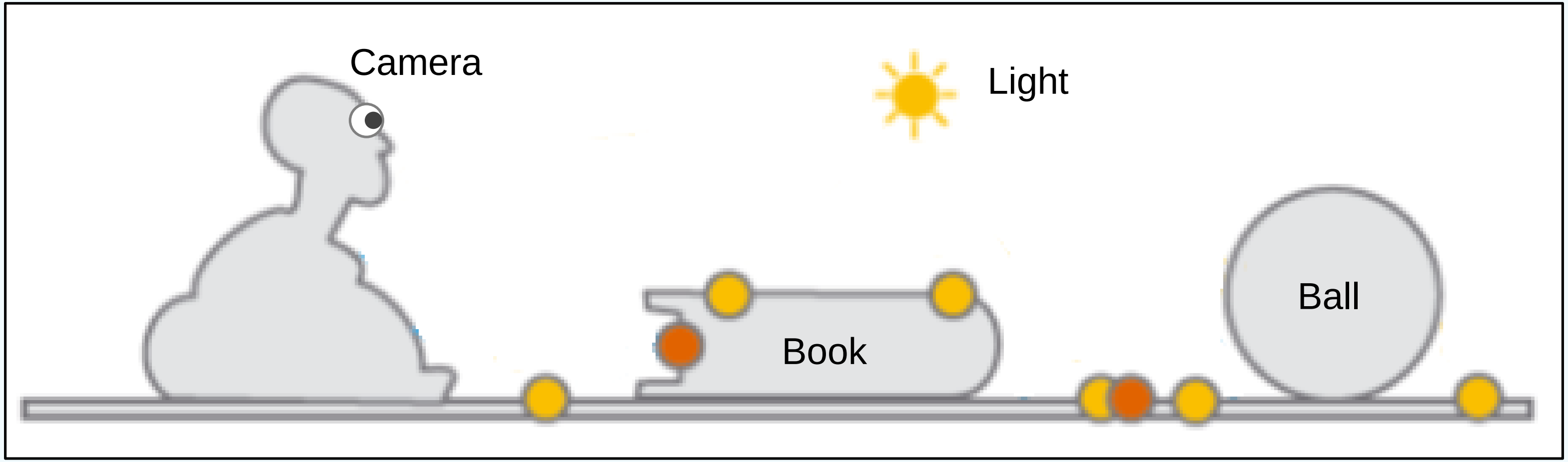
- How to use images to enhance realism of surfaces in 3D.

Lighting

Intuition + Lighting Model

Lighting | Intuition

Consider a scene with light, camera, and some objects.

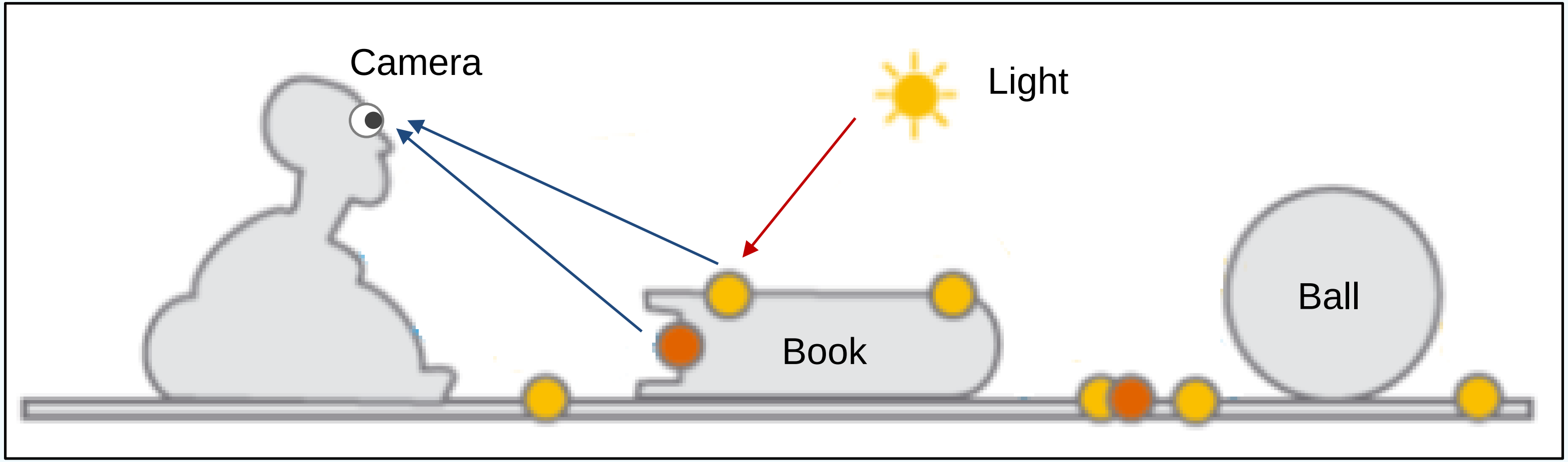


To determine the outgoing light intensity, we need to know

What affects the colour of an object as seen by the camera?

Lighting | Intuition

Hints #1:

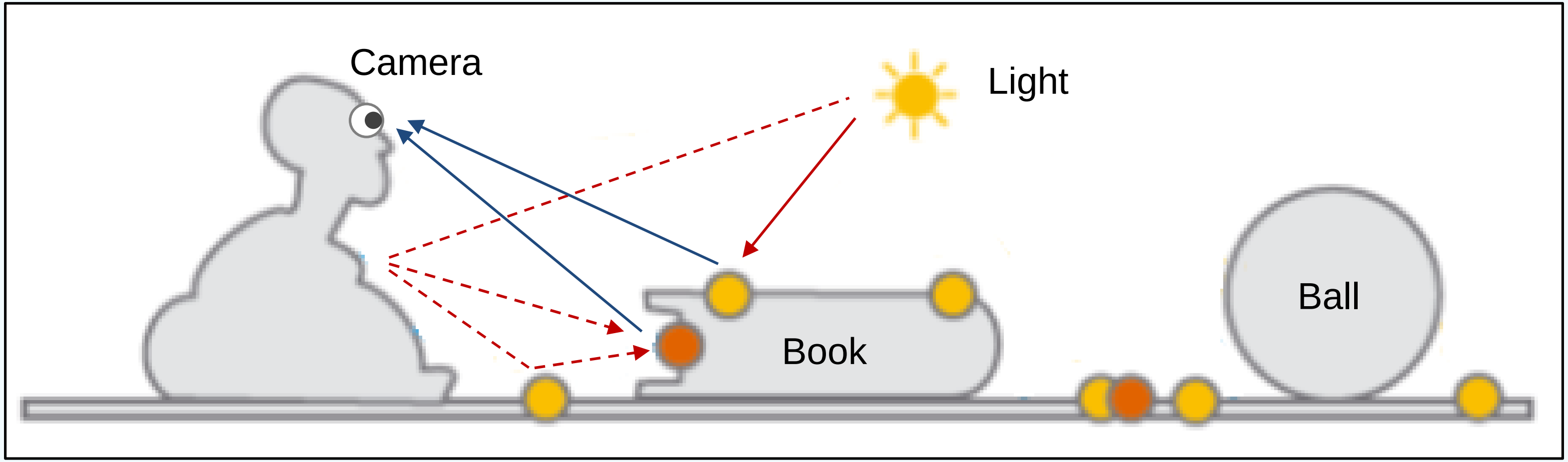


What happens if the <u>ball</u> is coated with **metallic paint**?

What happens if the <u>ball</u> is coated with **non-metallic paint**?

Lighting | Intuition

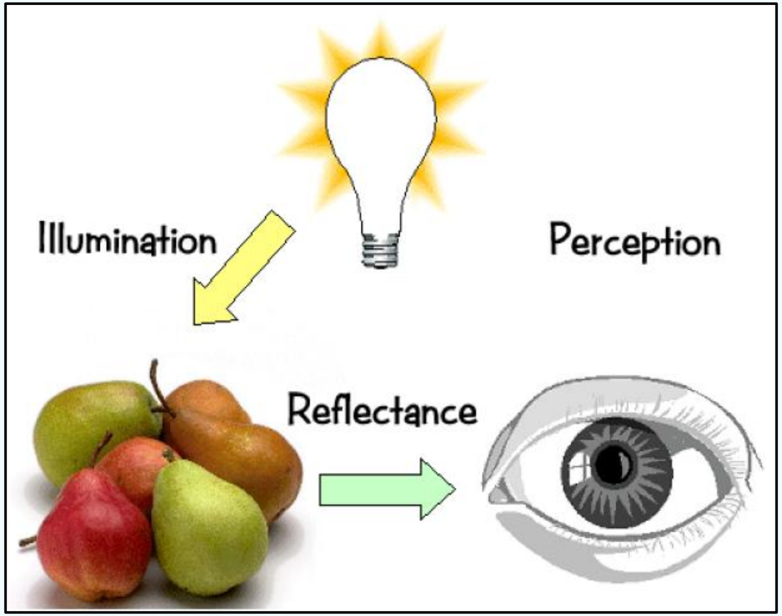
Hints #2:



What happens if the light source is the **sun**?

What happens if the light source is a **spot light**?

Lighting | Intuition



In a nutshell ……

What affects the colour of a point on an object?

1. Object surface properties (Hint #1)
2. Light sources (Hint #2)

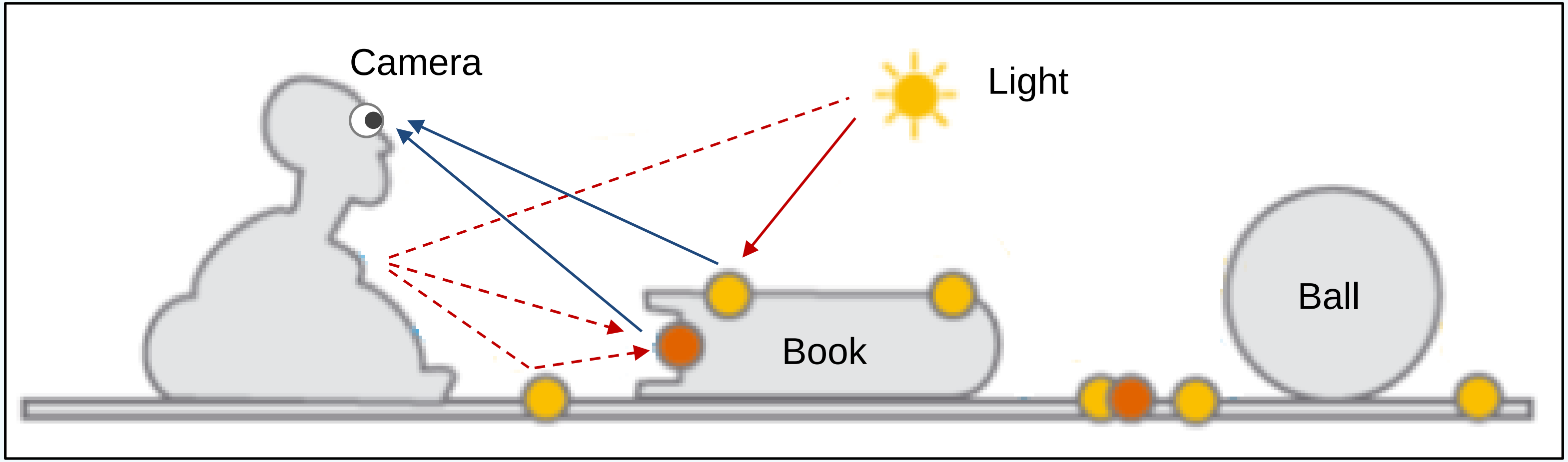
Lighting | Lighting Model

A mathematical model that:

- Formulates the interactions between light and surface.
- Calculates the intensity of light observed at a given on the surface of an object.
- Requires information about the light sources and object surface properties.

Lighting | Lighting Model

A phenomenon of interactions between light and surfaces.



Direct Illumination

Indirect Illumination

Light ray
from point to camera

Lighting | Lighting Model

Goal:

Given light source(s) and object surface properties, the goal of lighting model is to find:

$$I = I_{indirect} + I_{direct}$$

Where:

$I \rightarrow$ total outgoing intensity
$I_{indirect} \rightarrow$ outgoing intensity from indirect illumination
$I_{direct} \rightarrow$ outgoing intensity from direct illumination

Lighting | Lighting Model

Two categories:

- **Empirical**
  - Simple formulations that approximated observed phenomenon.
  - Only **direct illuminations** is considered.
  - **Indirect illuminations** is highly **approximated**.

- **Physically-based**
  - Models based on the actual physics of light interacting with matter.

Lighting | Lighting Model

Application in real-time graphics:

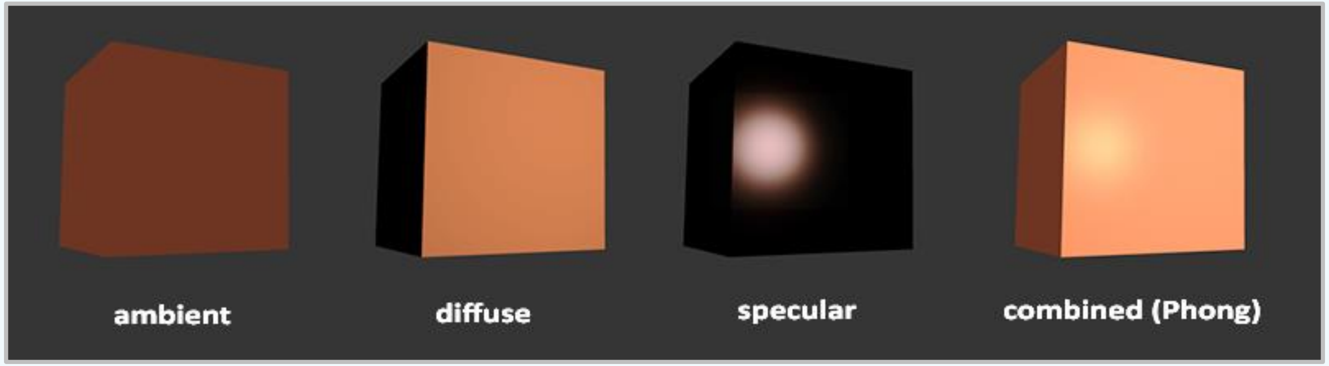
- Mostly use empirical models, but physically-based models have been used increasingly due to improved graphics hardware.

This lecture covers an empirical model know as <u>Phong Lighting Model</u>

Phong Lighting Model

Introduction

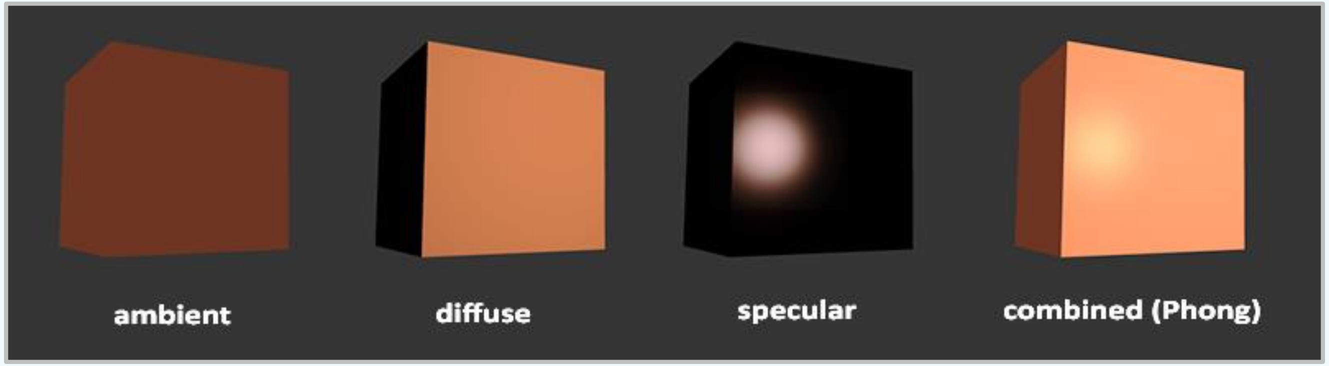
Phong Lighting Model



3 components:

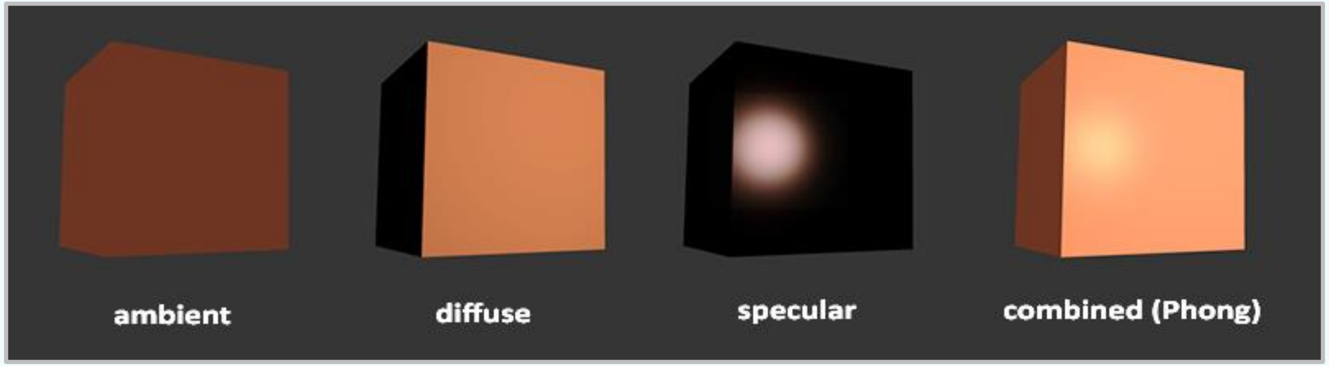
- **Ambient lighting**: approximates indirect illumination.
- **Diffuse lighting**: simulates directional impact of a light on a matte surface.
- **Specular lighting**: simulates bright spot (i.e. specular highlight) of a light on shinny objects.

Phong Lighting Model



$$
\begin{aligned}
I &= I_{indirect} + I_{direct} \\
&= I_{ambient} + I_{diffuse} + I_{specular}
\end{aligned}
$$

Phong Lighting Model



For any component c, computing I_c exhibits a common pattern:

$$I_c = \text{object surface properties for } c \;\; \text{X} \;\; \text{incoming light intensity for } c$$

Object Surface Properties

- When light hits an opaque surface, some is absorbed, the rest is reflected.
- The reflected light is what we see.
- The amount of reflection varies with material
    - ❖ The surface micro structure define the details of reflection
    - ❖ Varies between bright specular reflection (e.g. mirrors) to dull matte finish (e.g. chalk)

Phong Lighting Model

Part 1 - Ambient Lighting

Ambient Lighting

- An **approximation** to the results of **indirect illumination** from light bouncing off intermediate surfaces.
- Illuminate all surfaces equally due to **no spatial** and **directional** characteristics.
- Makes objects not directly lit visible.

Ambient Lighting

How to compute:

$$I_{ambient} = k_a I_a$$

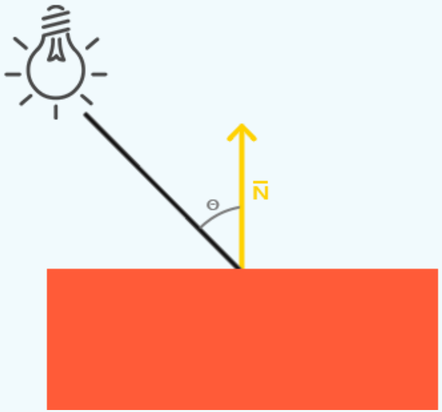
$k_a \rightarrow$ reflection properties for indirect illumination
$I_a \rightarrow$ light intensity from indirect illumination / **ambient light**.

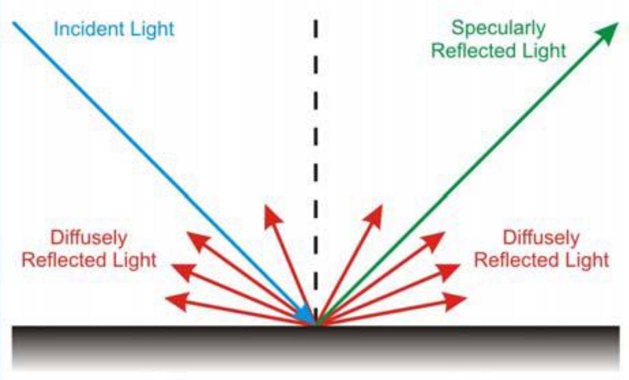
Phong Lighting Model

Part 2 - Diffuse Lighting

Diffuse Lighting

- Models a very rough surface at the microscopic level.
- Incoming light is reflected in any direction over the hemisphere.
- Depends only on direction of incoming light.



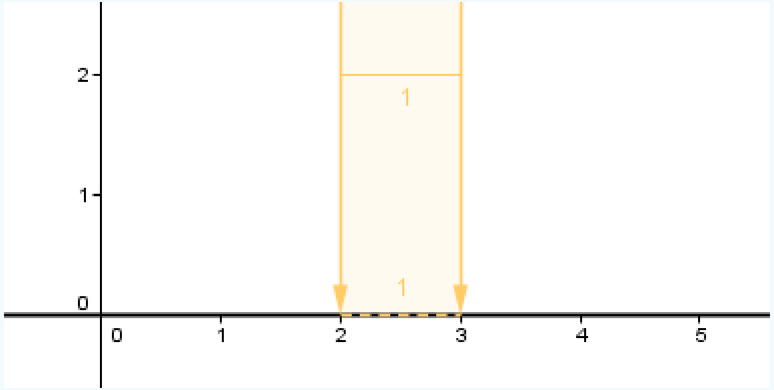


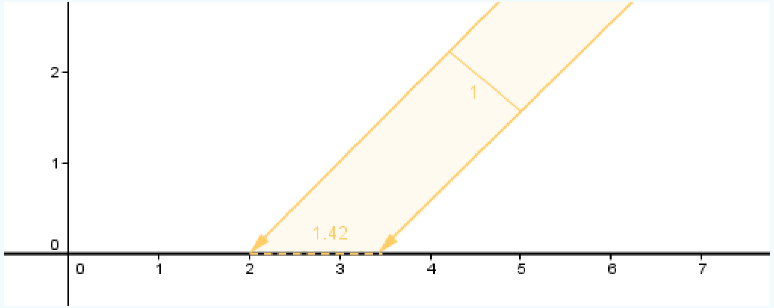
Diffuse Lighting

Lambert's Cosine Law

- The reflection of light source in a given direction is proportional to the **cosine of the angle between that direction and the surface normal**.

- Reflected light is independent of the viewing direction, but does depend on the surface normal.





Surface Reflection | Ideal Diffuse Reflection

How to compute:

$$\boldsymbol{I_{diffuse} = k_d I_{light} \cos\theta}$$

In practice, we use this formula:

$$\boldsymbol{I_{diffuse} = k_d I_{light}\, max(N \cdot L, 0)}$$

Inherently, this assumes N and L be normal vectors.

Phong Lighting Model

Part 3 - Specular Lighting

Specular Lighting

- Models a smooth surface at the microscopic level.
- Incoming lights are likely reflected in a mirror-like fashion.
- Exhibited by shiny surfaces (e.g. metallic paint).
- Specular surface causes **specular highlight** (i.e. bright spot), which appears when the light shining the surface is reflected directly to the camera.

Specular Lighting

- In reality, few surfaces exhibit perfect specular reflection like mirrors, as some light may be reflected slightly off the ideal reflection direction.

- The Phong Lighting Model account for such imperfection.

Specular Lighting

How to compute:

$$\boldsymbol{I_{specular} = k_s I_{light} (\cos \phi)^s}$$

$k_s \rightarrow$ specular reflection properties.
$\phi \rightarrow$ angle between perfect reflection direction and camera direction from the point
$s \rightarrow$ specular exponent that varies the rate of falloff.

Specular Lighting

In practice, the cos term is replaced by the following dot product for efficiency:

$$\boldsymbol{I_{specular} = k_s I_{light}(V \cdot R)^s}$$

- $V \rightarrow$ unit vector towards the camera.
- $R \rightarrow$ ideal reflectance direction, which can be calculated as:

Specular Lighting

How to compute R:

$$\boldsymbol{R} = \boldsymbol{2(N \cdot L)N - L}$$

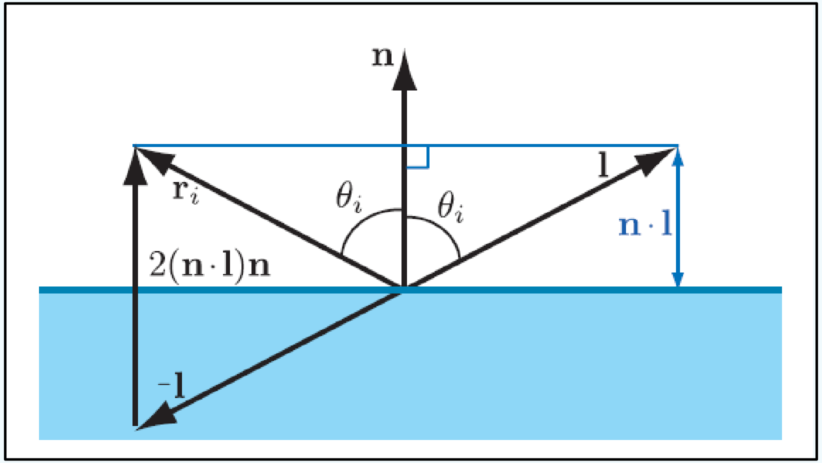


Image taken from Figure 9.19, Real-time Rendering (4th Edition)

Phong Lighting Model

Part 4 – Putting All Together

Phong Lighting Model

Combining ambient, diffuse, and specular lighting leads to:

$$I = I_{ambient} + \left(I_{diffuse} + I_{specular}\right)$$

$$= k_a I_a + k_d I_{light} \max(N \cdot L, 0) + k_s I_{light} \max(V \cdot R, 0)^s$$

$$\boldsymbol{I = k_a I_a + I_{light}\left[k_d \max(N \cdot L, 0) + k_s \max(V \cdot R, 0)^s\right]}$$

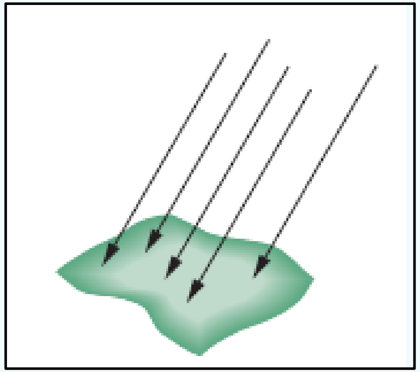
Phong Lighting Model

What if there are multiple light sources?

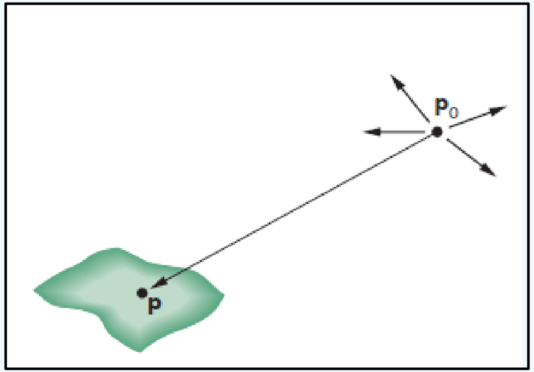
$$\boldsymbol{I = k_a I_a + \sum_{i=0}^{\#lights} I_{light}[k_d \max(N \cdot L, 0) + k_s \max(V \cdot R, 0)^s]}$$

Light Sources

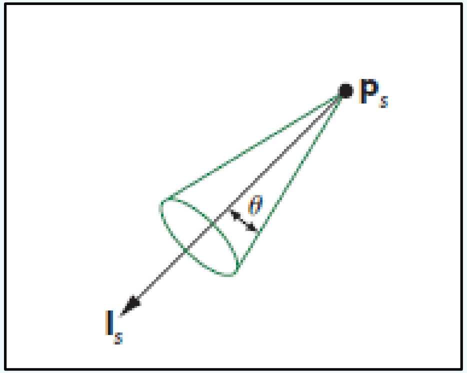
Light Sources | Common Types



Distant Light



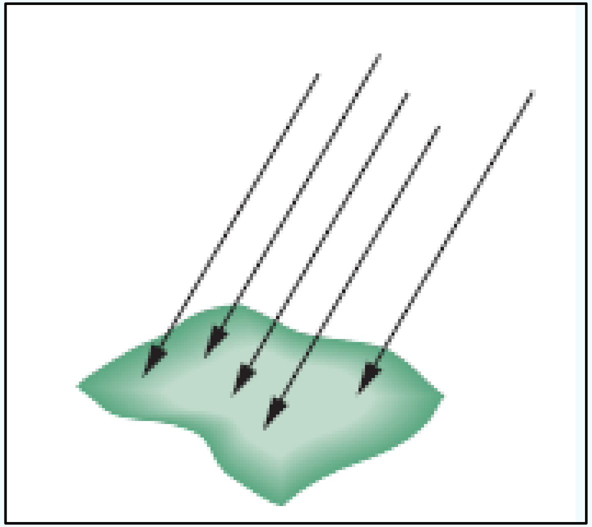
Point Light



Spotlight

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

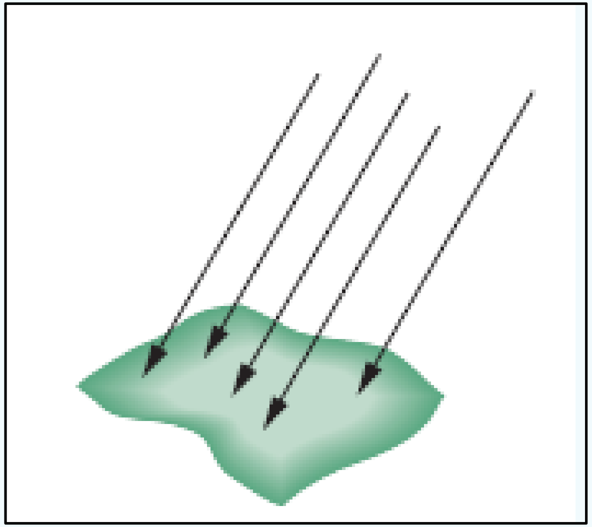
Lighting | Distant Light



- All rays from the light are parallel, as if the light source is infinitely far away from the surfaces.
- This direction is constant for all surface in the scene.
- Example: Sunlight

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Distant Light

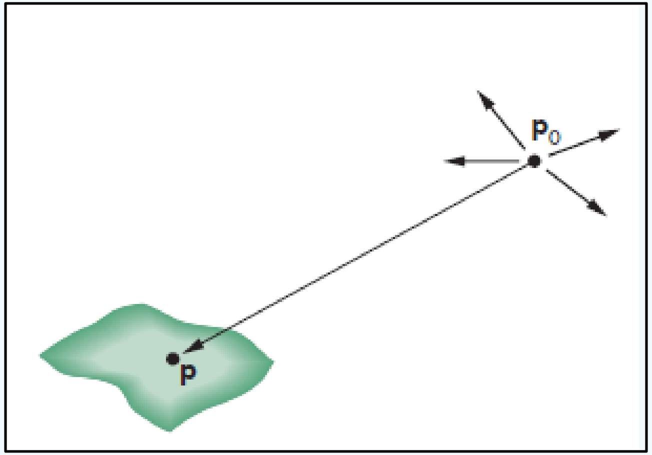


Application on Phong Lighting Model

- L = direction of the distant light at any surface.
- I_{light} = constant across all surfaces

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

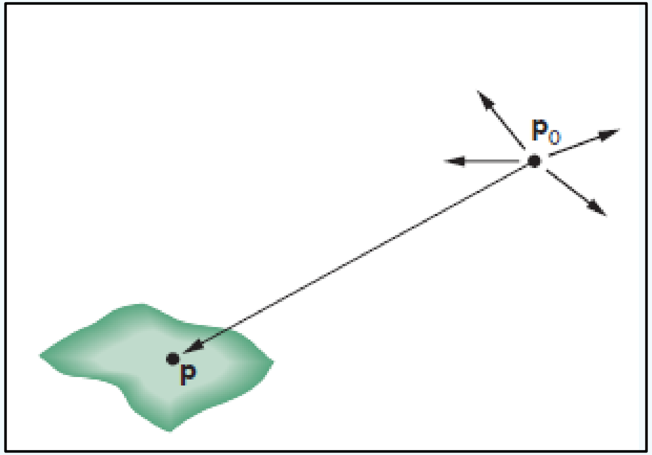
Lighting | Point Light



- Emits light equally in all directions from a single point.
- The direction from the light to a point on a surface differs for different points.

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Point Light



Attenuation

- The farther the light source, the lesser the intensity received at the surface point.

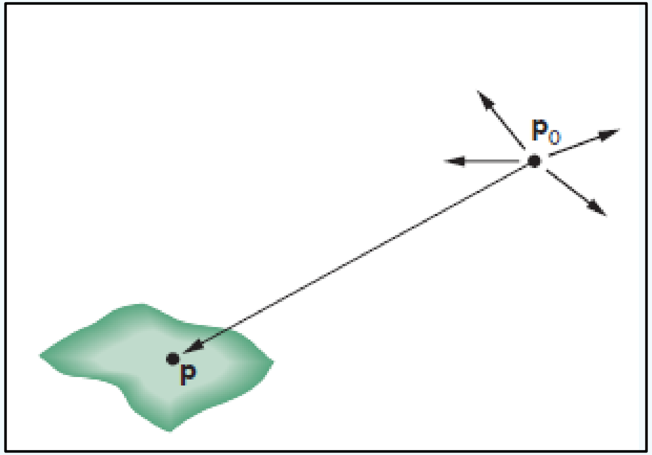
- One way of incorporating attenuation:

$$I_{light} = \frac{1}{(a + bd + d^2)} I_{p_0}$$

I_{p_0} → light intensity at p_o
d → distance between p and p_0

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Point Light

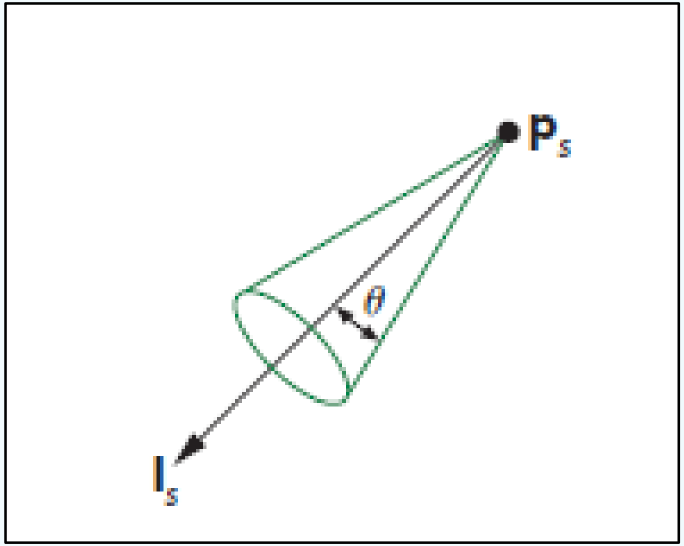


Application on Phong Lighting Model

- $L = p_0 - p$
- $I_{light} = \frac{1}{(a+bd+d^2)} I_{p_0}$

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Spotlight

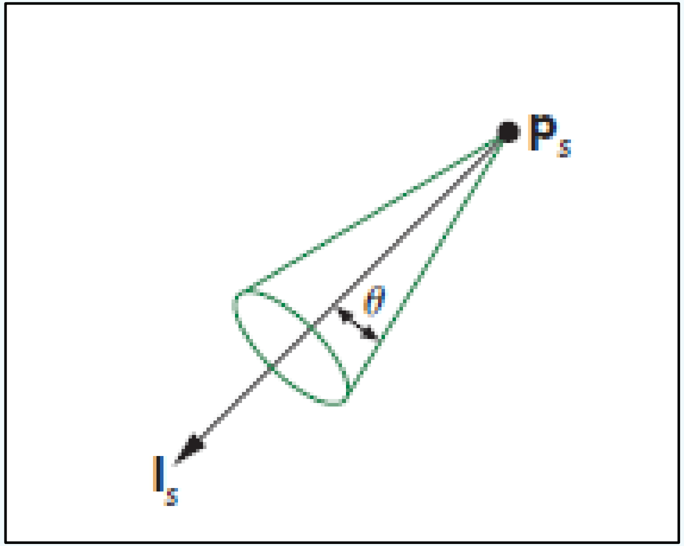


- A point light with limited angles at which the light from the source can be seen.

- Can be represented as a cone with **apex at $\boldsymbol{p_s}$**, which **points in the direction $\boldsymbol{l_s}$**, and whose width is determined by a **cut-off angle $\boldsymbol{\theta}$**.

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Spotlight



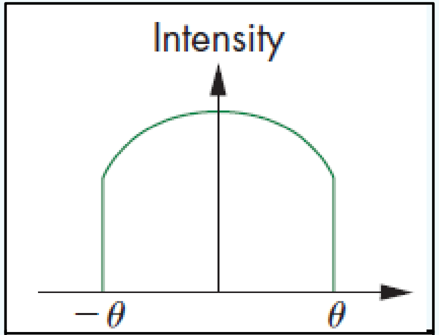
Attenuation:

- If L deviates more than θ from l_s, there is no light intensity contributed by the spotlight.
- If L deviates less than θ from l_s,

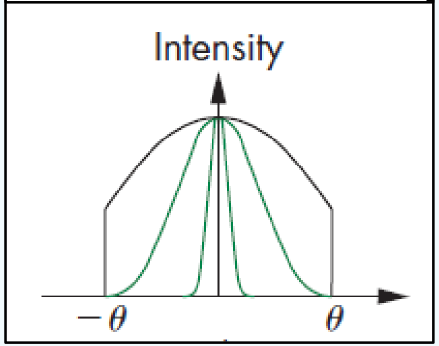
$$I_{light} = \begin{cases} (-L \cdot l_s) I_s, & (-L \cdot l_s) \geq \cos\theta \\ 0, & otherwise \end{cases}$$

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Spotlight



Without exponent e



With exponent e

Attenuation:

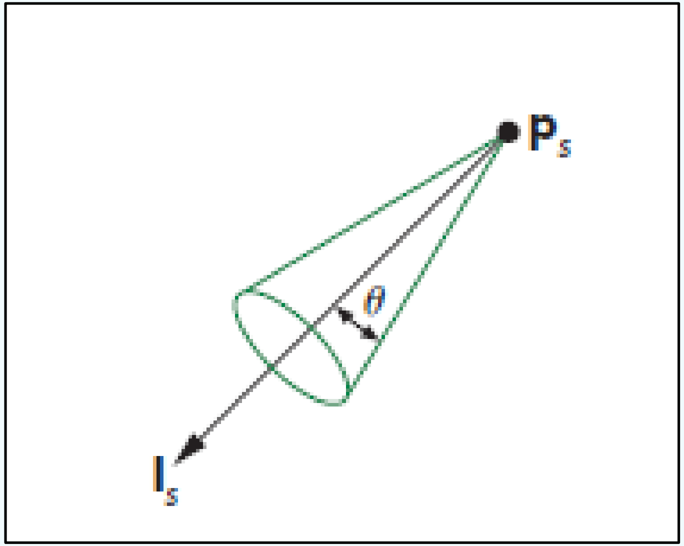
- In practice, an exponent e is used to determine how rapidly the light intensity drops off.

$$I_{light} = \begin{cases} (-L \cdot l_s)^{e} I_s, & (-L \cdot l_s) \geq \cos\theta \\ 0, & otherwise \end{cases}$$

- Attenuation by distance (i.e. from Point light) can be used if necessary.

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Lighting | Spotlight



Application on Phong Lighting Model

- $L = p_s - p$
- $I_{light} = \begin{cases} (-L \cdot l_s)^{e} I_s, & (-L \cdot l_s) \geq \cos\theta \\ 0, & otherwise \end{cases}$

Image taken from pages 281 and 282, Interactive Computer Graphics, A Top Down Approach using WebGL (7th Edition)

Q & A

Acknowledgement

- This presentation has been designed using resources from PoweredTemplate.com