Lecture slides (CT4201/EC4215 – Computer Graphics)

Illumination and Shading

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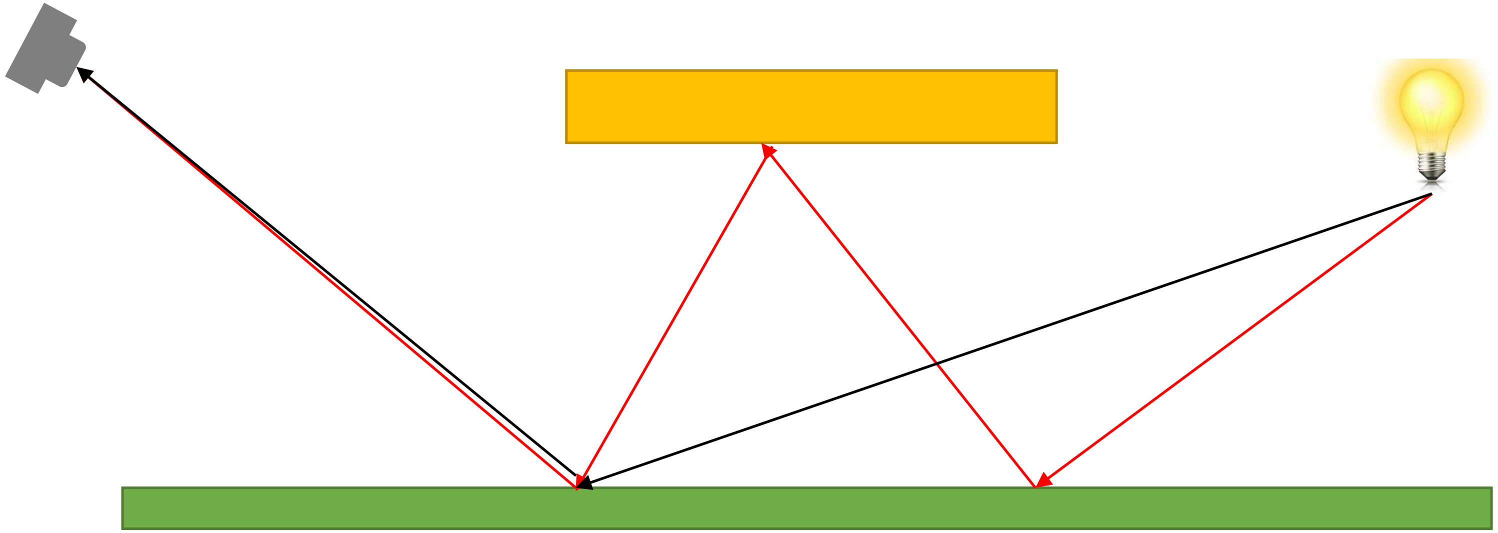
GIST
Computer Graphics Laboratory

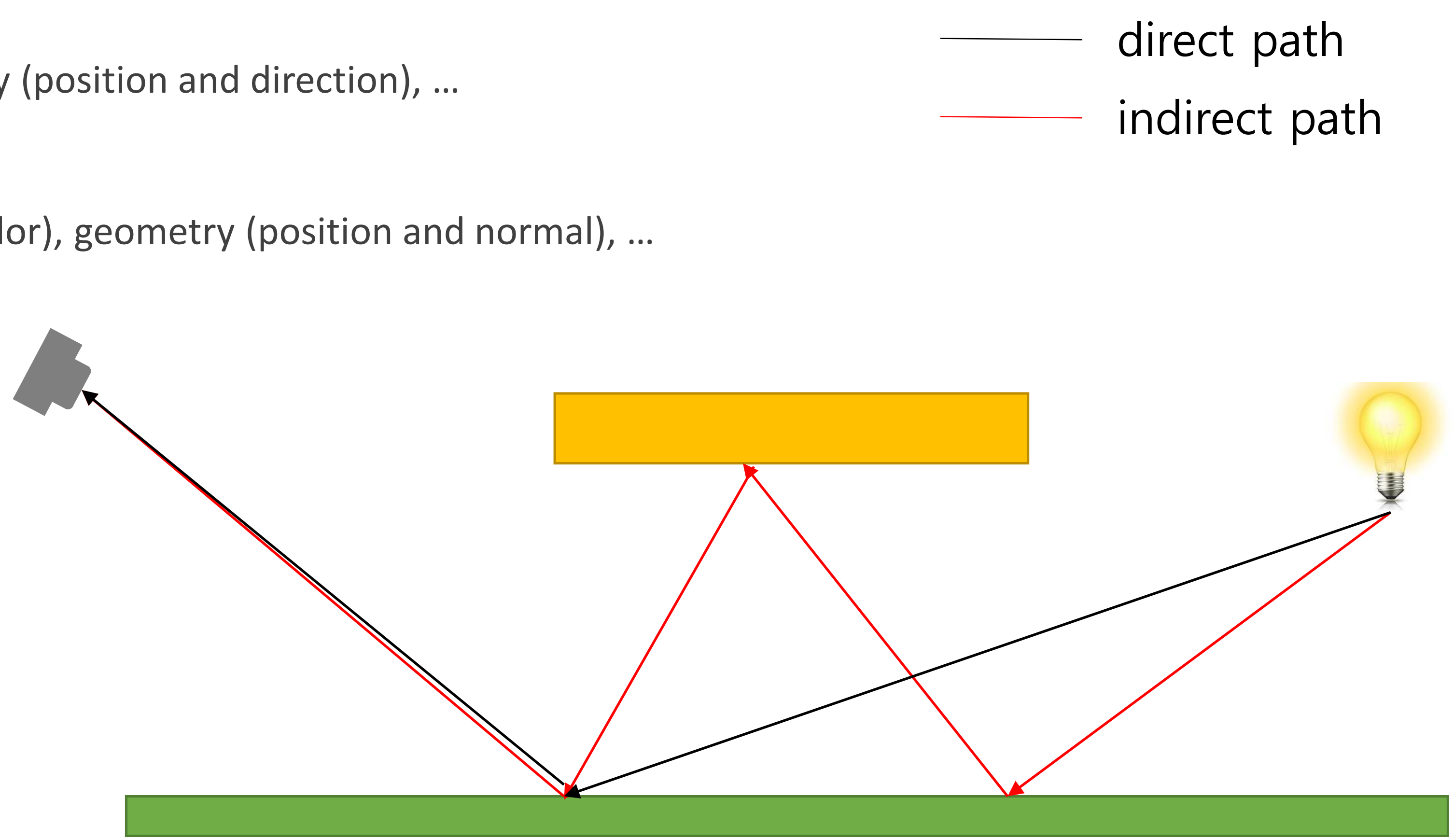
Photorealism

- The ultimate goal of rendering is to produce photo realistic images.
  - i.e., rendered images should be indistinguishable from photographs



Illumination (Lighting) Model

- A technique (or a model) that computes the color of a surface, by considering the following:
  - Lights
    - color, geometry (position and direction), …
  - Surfaces
    - reflectance (color), geometry (position and normal), …



Phong Illumination Model

- A simple model that considers the three terms below:
  - Ambient:
    - Assume that each surface receives a constant amount of light
    - Ignore the following:
      - Position and orientation of a surface
      - Position of a viewer
      - Direction of a light

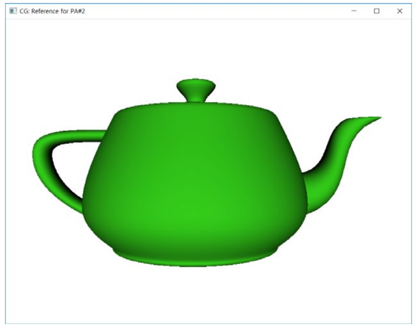
ambient

$$I = L_a k_a$$

L_a: intensity of an ambient light
k_a: coefficient of ambient reflection

Phong Illumination Model

- A simple model that considers the three terms below:
  - Diffuse:
    - Surfaces can have different colors based on distance and orientation with respect to the light source



diffuse

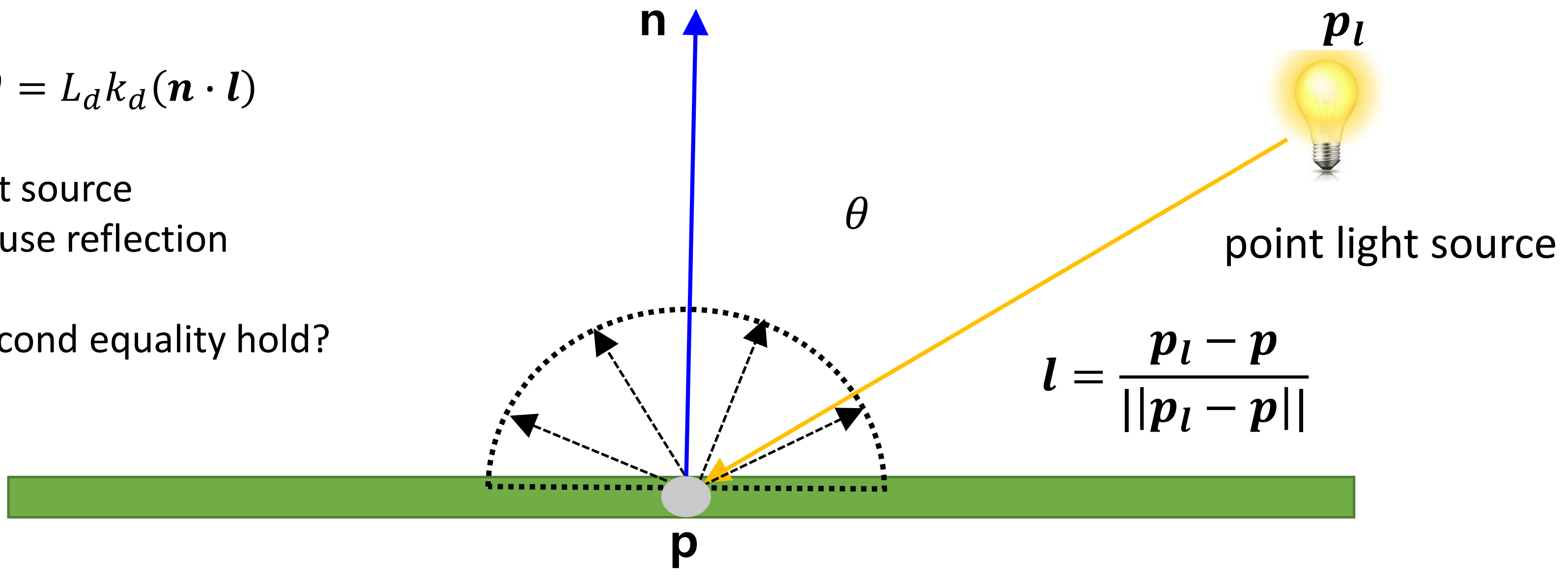
Diffuse Reflection

- A simple model that considers the three terms below:
  - Diffuse:
    - When light intersects with an “ideal” diffuse surface, the surface reflects light equally in all directions.
      - Lambertian reflection
    - Outgoing light intensity is independent from the position of the viewer.

$$I = L_d k_d cos\theta = L_d k_d(\boldsymbol{n} \cdot \boldsymbol{l})$$

L_d: intensity of a light source
k_d: coefficient of diffuse reflection

Q. When does the second equality hold?
Q. $k_d > 1$?



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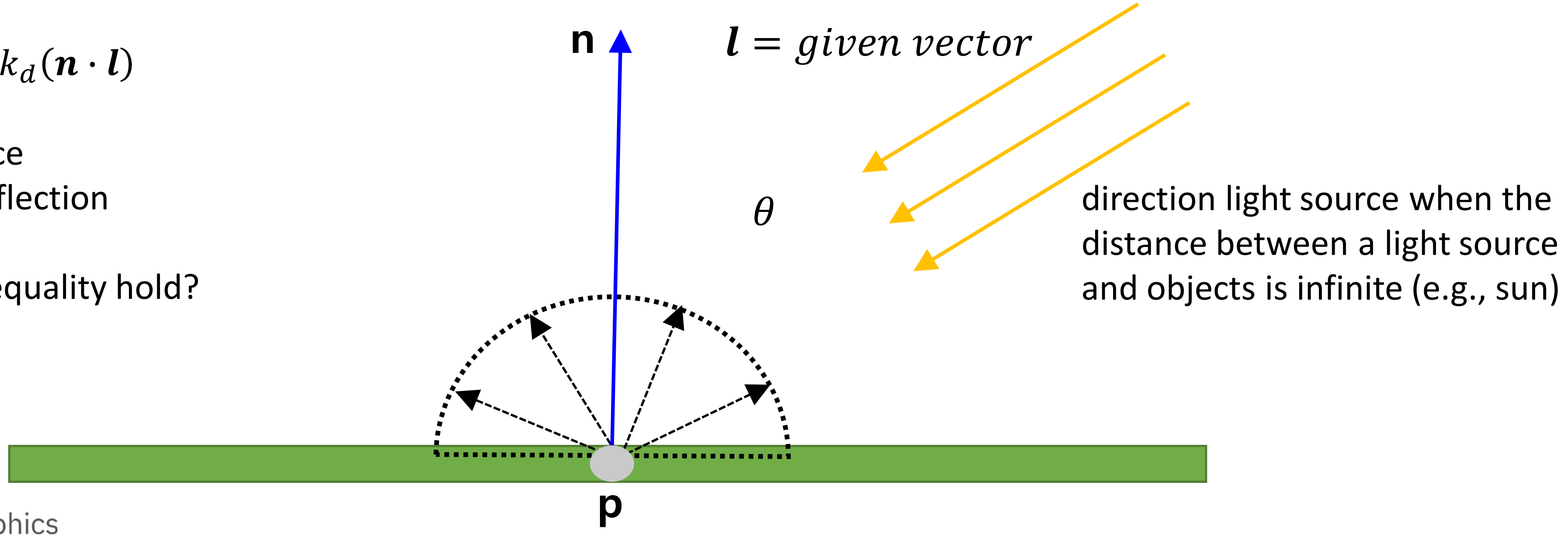
$$I = L_d k_d cos\theta = L_d k_d (\boldsymbol{n} \cdot \boldsymbol{l})$$

L_d: intensity of a light source
k_d: coefficient of diffuse reflection

Q. When does the second equality hold?
Q. $k_d > 1$?

Q. $\boldsymbol{n} \cdot \boldsymbol{l} < 0$?



Light Source Attenuation (optional)

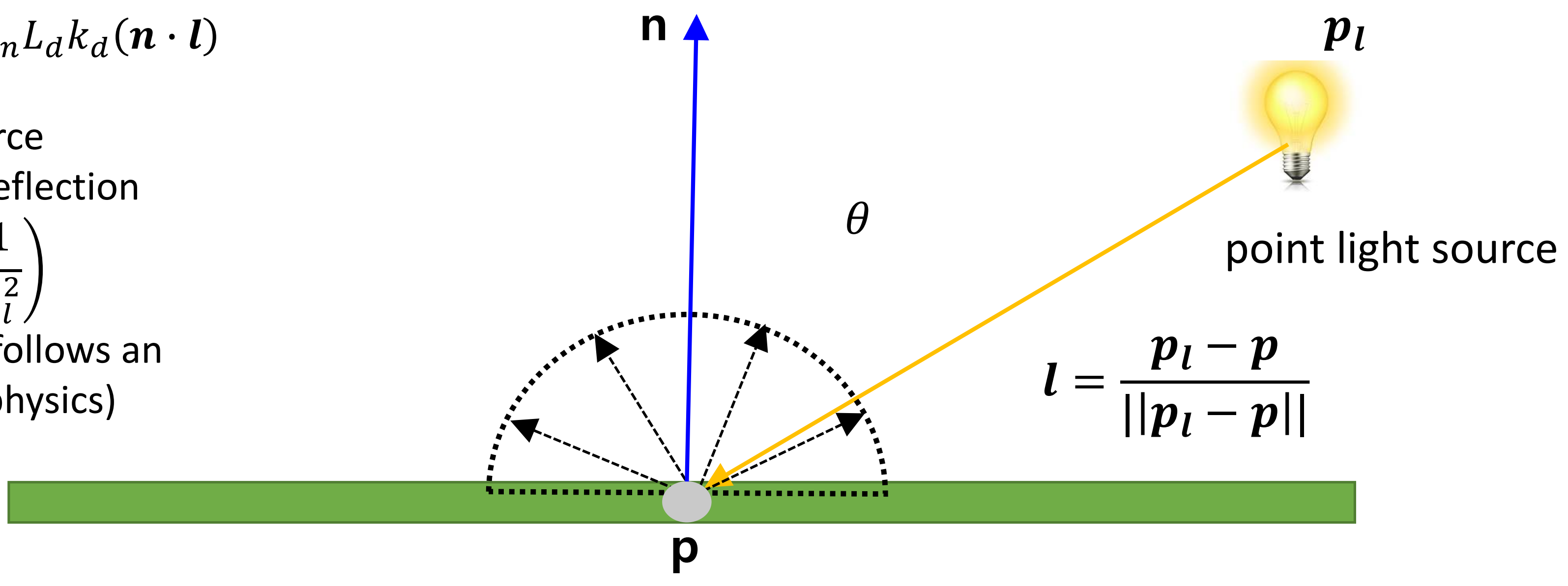
- A simple model that considers the three terms below:
  - Diffuse:
    - When light intersects with an “ideal” diffuse surface, the surface reflects light equally in all directions.
      - Lambertian reflection
    - Outgoing light intensity is independent from the position of the viewer.

$$I = L_d k_d \cos\theta = f_{atten} L_d k_d (\boldsymbol{n} \cdot \boldsymbol{l})$$

L_d: intensity of a light source
k_d: coefficient of diffuse reflection

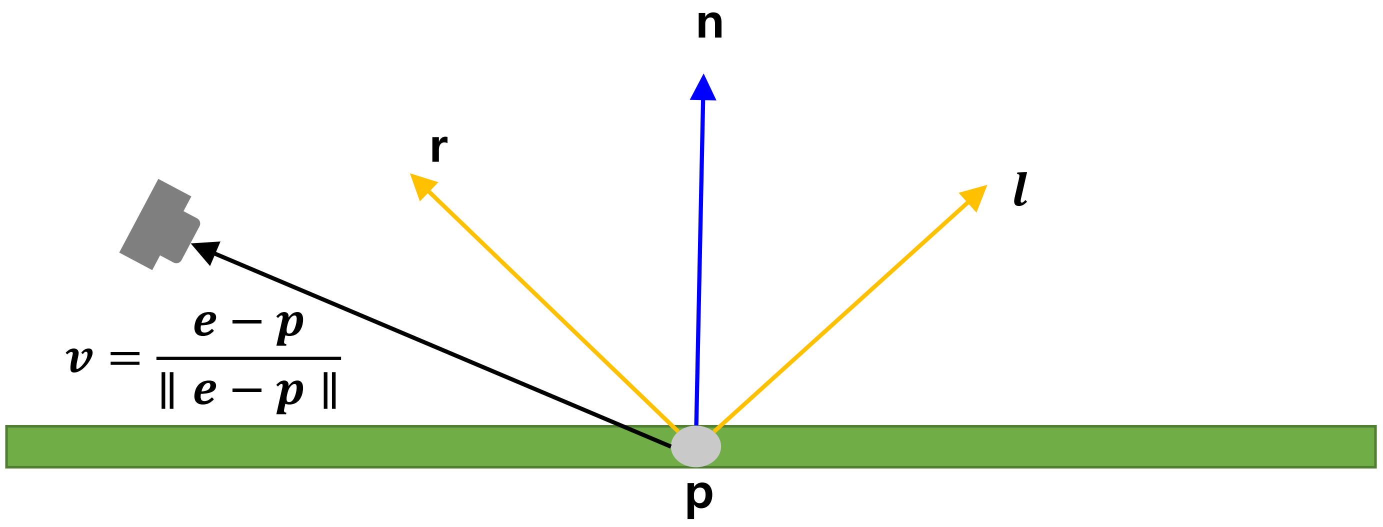
$$f_{atten} = \frac{1}{d_l^2} \; or \; \min\left(C_1, \frac{1}{d_l^2}\right)$$

Intensity of a light source follows an inverse square law (from physics)



Specular Reflection

- A simple model that considers the three terms below:
  - specular:
    - When light intersects with a shiny surface, it can be seen as highlights (directional)
    - It also depends on how much the surface is shiny (shininess).
    - The viewing direction is also important.



Specular Reflection

- The reflection vector r is determined by Snell's law.
- Snell's law
  - $n_i sin\theta_i = n_o sin\theta_o$
  - n_i, n_o: indices of refraction
    - Determined by the relative speeds of light
  - Reflection is a special case
    - $\theta_l = \theta_r$
    - The medium of the incoming light and reflected ray is the same.

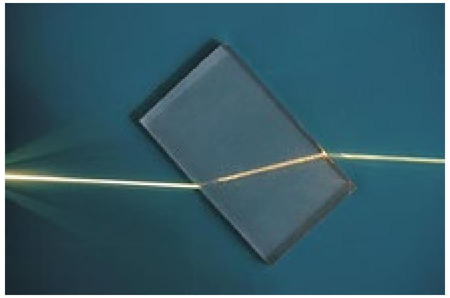
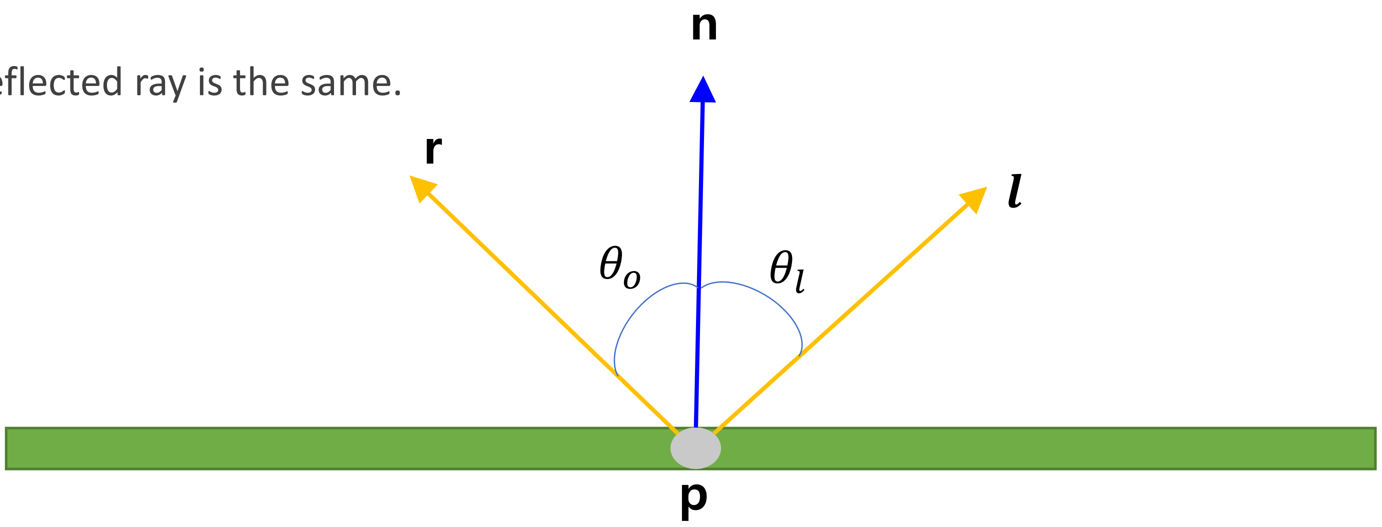


Image from wikipedia

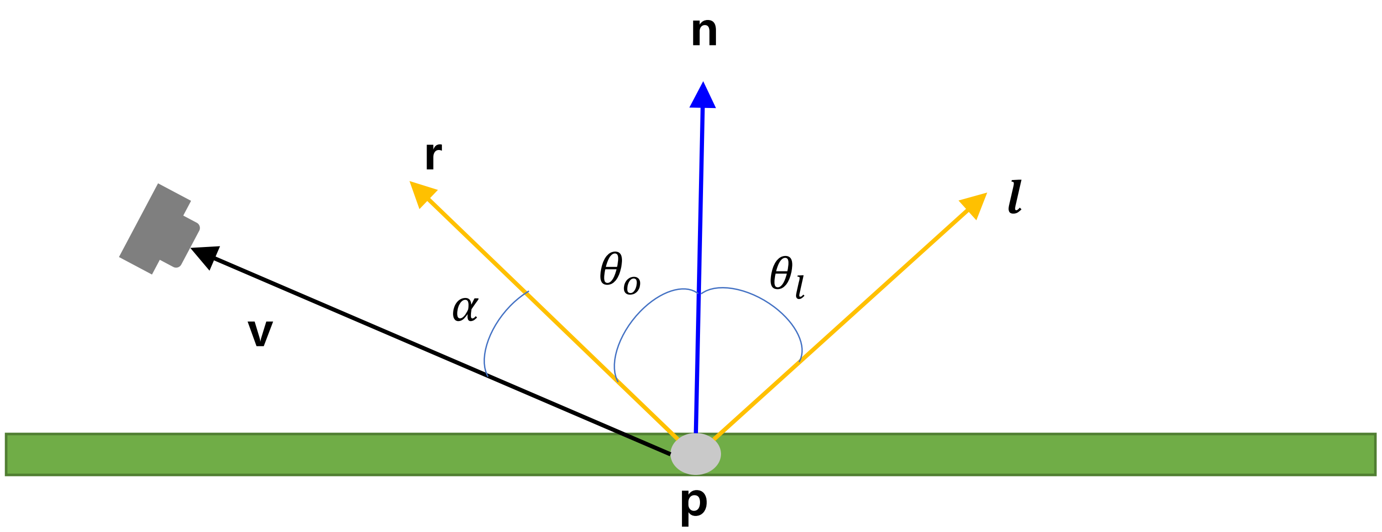


Specular Reflection

- A simple model that considers the three terms below:
  - specular:

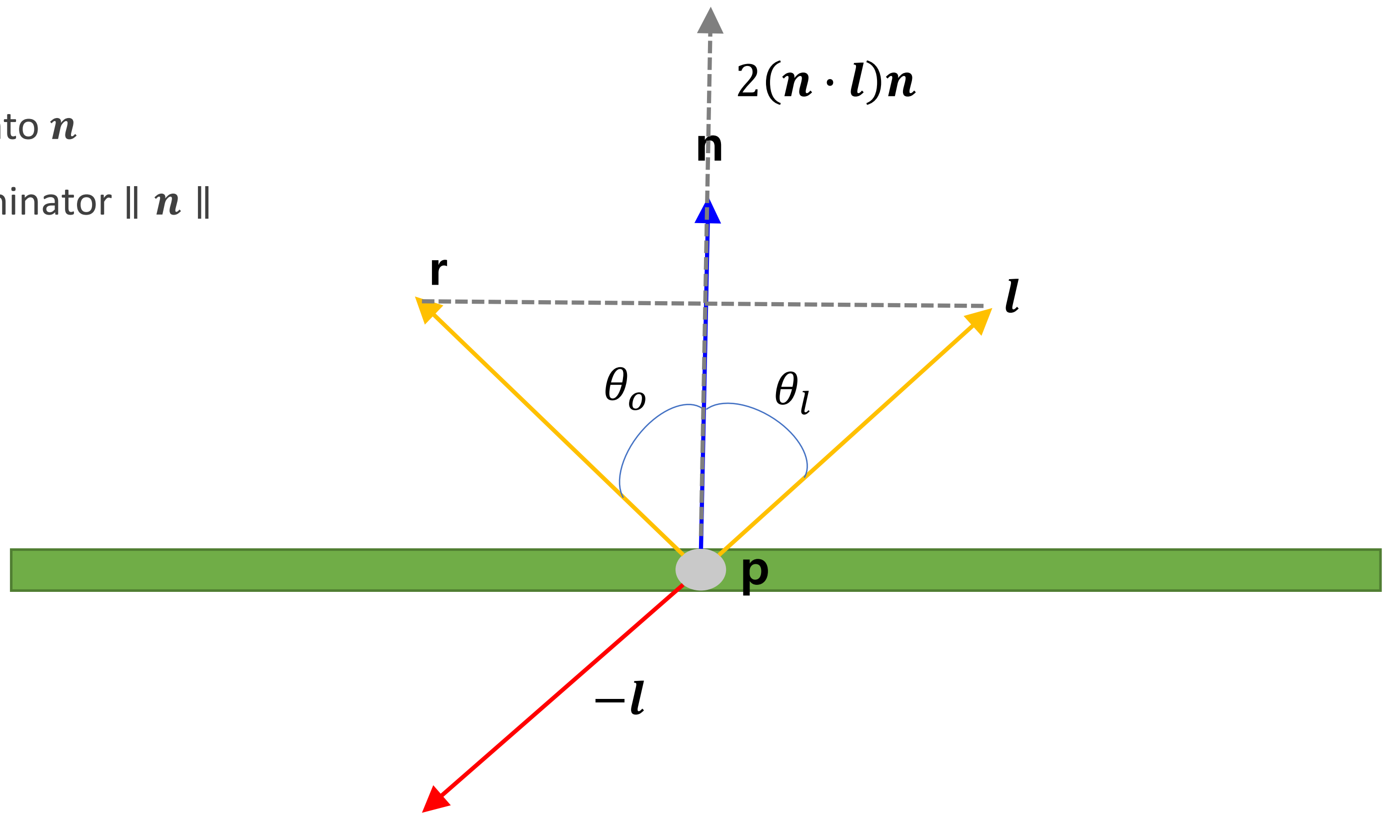
$$I = L_s k_s \cos^s \alpha = L_s k_s (\boldsymbol{r} \cdot \boldsymbol{v})^s$$

L_s: intensity of a light source
k_s: coefficient of specular reflection
s: shininess of a surface



Specular Reflection

- The reflection vector, r, can be computed as the following:
  - $\boldsymbol{r} = 2(\boldsymbol{n} \cdot \boldsymbol{l})\boldsymbol{n} - \boldsymbol{l}$
  - $\boldsymbol{n} \cdot \boldsymbol{l}$: length of the projected vector onto $\boldsymbol{n}$
  - Note: we don't need to use the denominator $\| \boldsymbol{n} \|$



Non-ideal Specular Reflection

- A simple model that considers the three terms below:
  - specular:

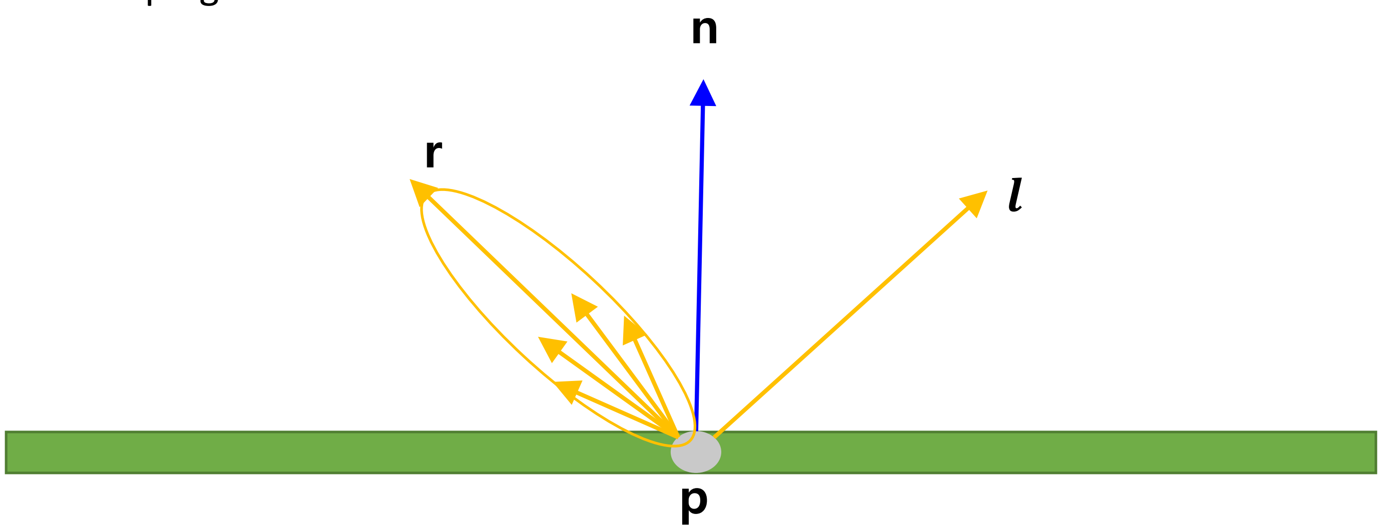
$$I = L_s k_s \cos^s \alpha = L_s k_s (\boldsymbol{r} \cdot \boldsymbol{v})^s$$

L_s: intensity of a light source
k_s: coefficient of specular reflection
s: shininess of a surface

In practice, we should use a clamping function, $max(r \cdot v, 0)$

Note:

- Snell's law does not explain this case. i.e., it is only for ideal reflection (e.g., reflection on mirror)
- Approaches
  - Simulate all the reflected rays
  - Empirically capture this effect (highlights) with simple parameters (i.e., s)

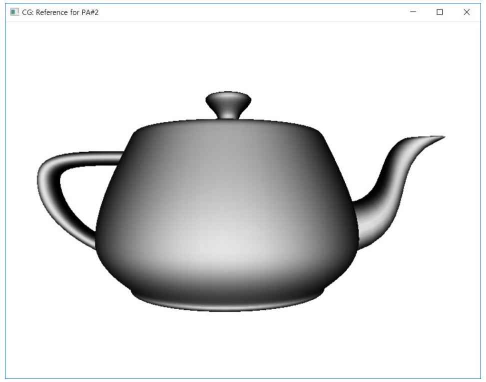


Non-ideal Specular Reflection

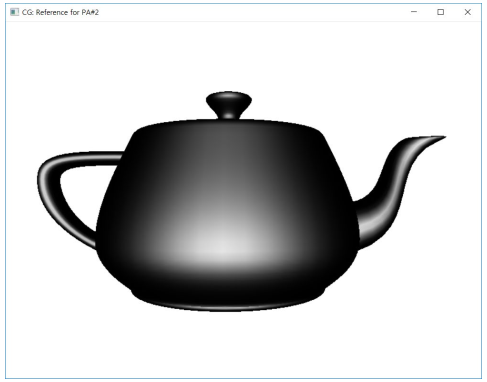
- A simple model that considers the three terms below:
  - specular:

$$I = L_s k_s \cos^s \alpha = L_s k_s (\boldsymbol{r} \cdot \boldsymbol{v})^s$$

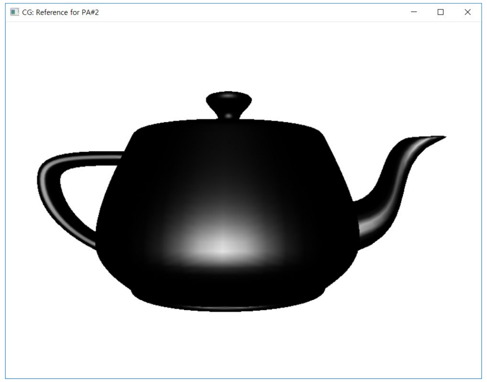
L_s: intensity of a light source
k_s: coefficient of specular reflection
s: shininess of a surface – control the shape of the highlights



s = 3



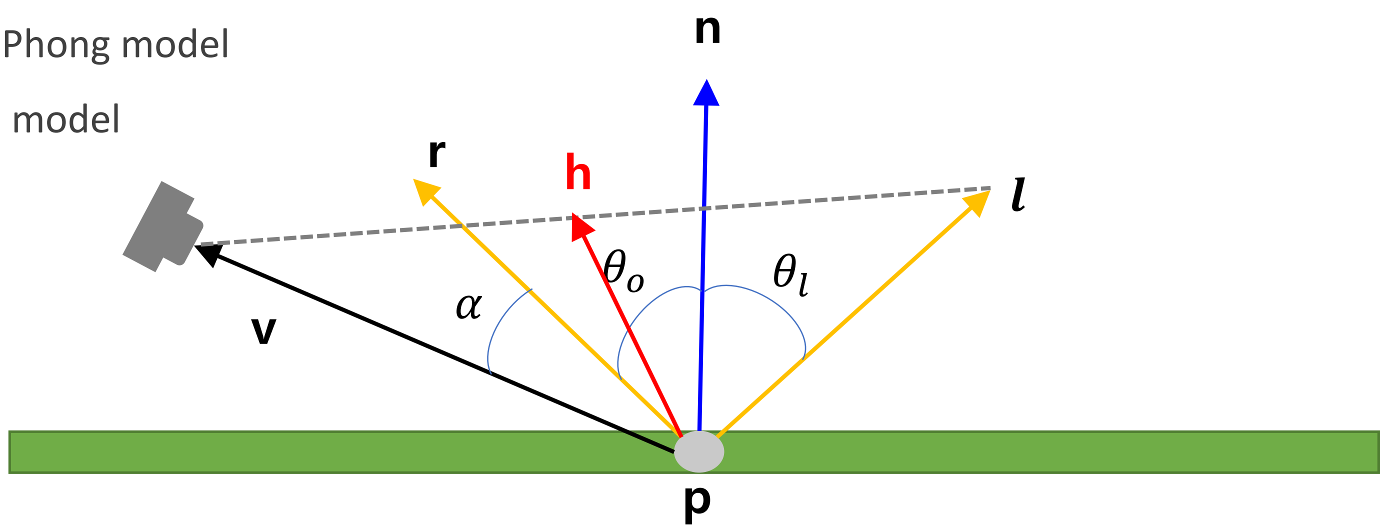
s = 10



s = 30

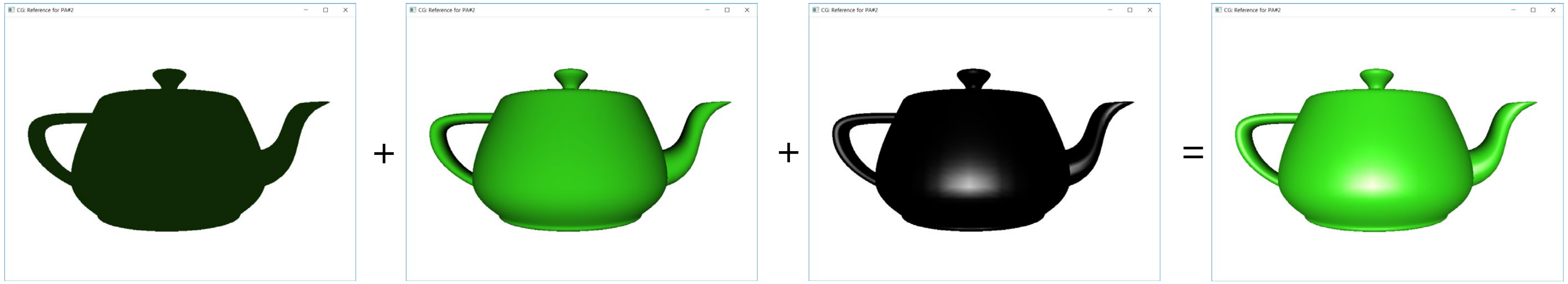
Blinn-Phong Model

- A modification to the Phong specular model is to replace the reflection vector with the halfway vector.
  - $h = \frac{l+v}{\|l+v\|}$
  - $I = L_s k_s \cos^s \alpha = L_s k_s (\boldsymbol{n} \cdot \boldsymbol{h})^s$
  - Note
    - Cheaper than the Phong model
    - Another empirical model



Phong Illumination Model

- A simple model that considers the three terms below:
  - $I = I_a + I_d + I_s = L_a k_a + L_d k_d \max(0, \boldsymbol{n} \cdot \boldsymbol{l}) + L_s k_s \max(0, \boldsymbol{r} \cdot \boldsymbol{v})^s$

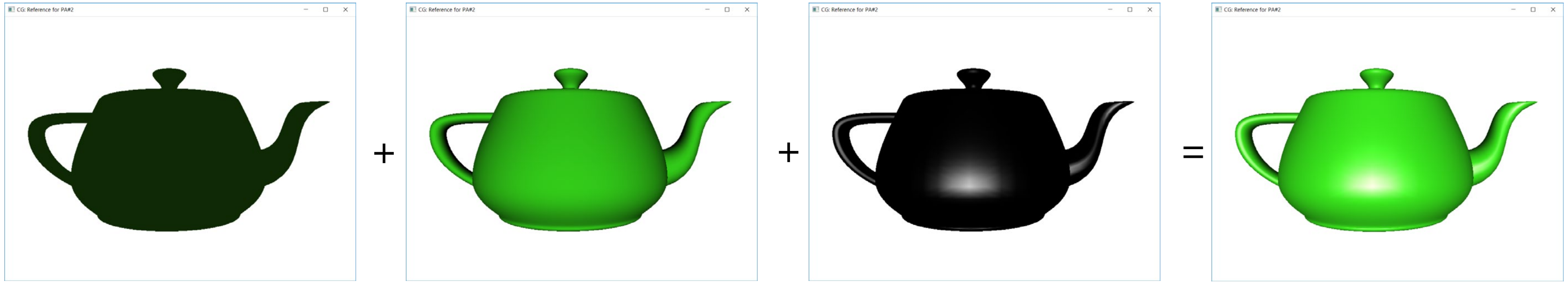


ambient diffuse specular

Multiple Light Sources

- $I = \sum_{i=1}^{\#\,of\,lights} L_a^i k_a + L_d^i k_d \max\left(0, \boldsymbol{n} \cdot \boldsymbol{l^i}\right) + L_s^i k_s \max\left(0, \boldsymbol{r^i} \cdot \boldsymbol{v}\right)^s$

- OpenGL uses this empirical model.
  - Need to specify L_a, L_d, L_s for each light
  - Need to assign material properties k_a, k_d, k_s, s to each object (or each triangle)



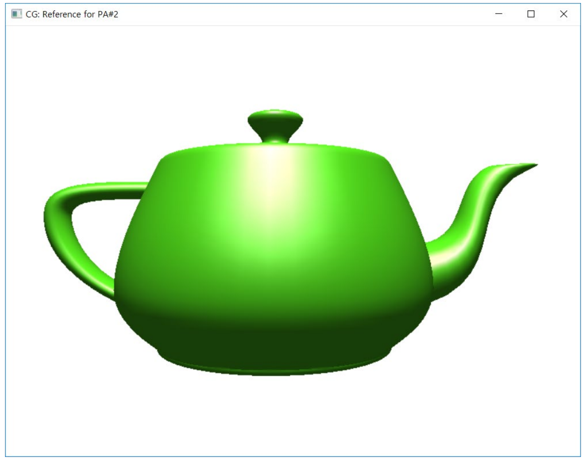
ambient diffuse specular

Example Code in OpenGL

- // build a point light on the position & set parameters for the light
- float pointLight [] = { 0.0, 10.0, 0.0, 1.0 };
- float La[] = { 0.1, 0.1, 0.1, 1.0 };
- float Ld[] = { 1.0, 1.0, 1.0, 1.0 };
- float Ls[] = { 1.0, 1.0, 1.0, 1.0 };
- glLightfv(GL_LIGHT0, GL_POSITION, pointLight);
- glLightfv(GL_LIGHT0, GL_AMBIENT, La);
- glLightfv(GL_LIGHT0, GL_DIFFUSE, Ld);
- glLightfv(GL_LIGHT0, GL_SPECULAR, Ls);
- glEnable(GL_LIGHT0);

Example Code in OpenGL

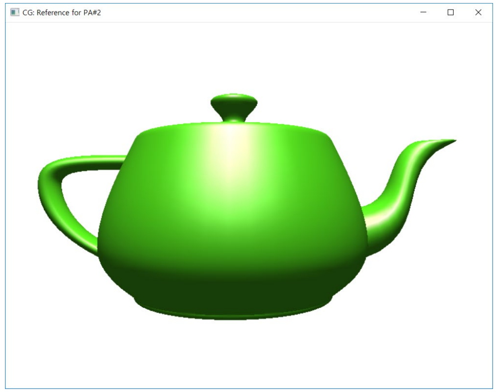
- // assign a material to an object
- float ka[] = { 0.3, 0.8, 0.1, 1.0 };
- float kd[] = { 0.3, 0.8, 0.1, 1.0 };
- float ks[] = { 0.9, 0.9, 0.9, 1.0 };
- float shininess[] = { 30.0 };
- glMaterialfv(GL_FRONT, GL_AMBIENT, ka);
- glMaterialfv(GL_FRONT, GL_DIFFUSE, kd);
- glMaterialfv(GL_FRONT, GL_SPECULAR, ks);
- glMaterialfv(GL_FRONT, GL_SHININESS, shininess);



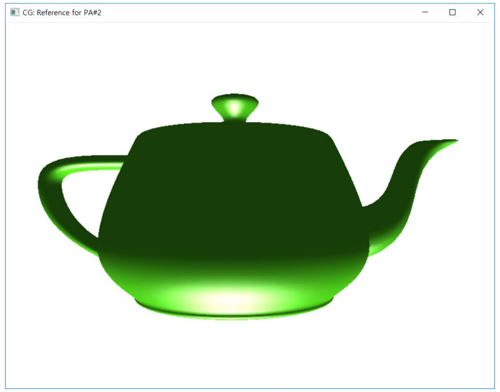
Illuminated by light0

Example Code in OpenGL

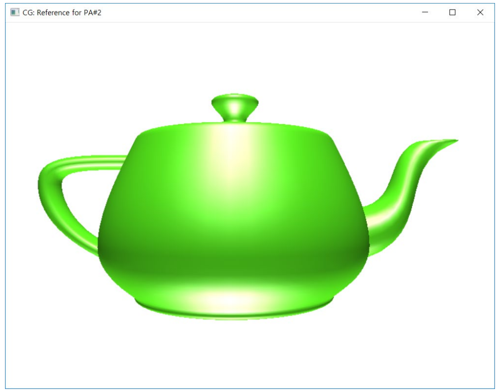
- // build a directional light (w = 0.0)
- float directionalLight[] = { 0.0, -10.0, 0.0, 0.0 };
- glLightfv(GL_LIGHT1, GL_POSITION, directionalLight);
- glLightfv(GL_LIGHT1, GL_AMBIENT, La);
- glLightfv(GL_LIGHT1, GL_DIFFUSE, Ld);
- glLightfv(GL_LIGHT1, GL_SPECULAR, Ls);
- glEnable(GL_LIGHT1);



Illuminated by light0



Illuminated by light1



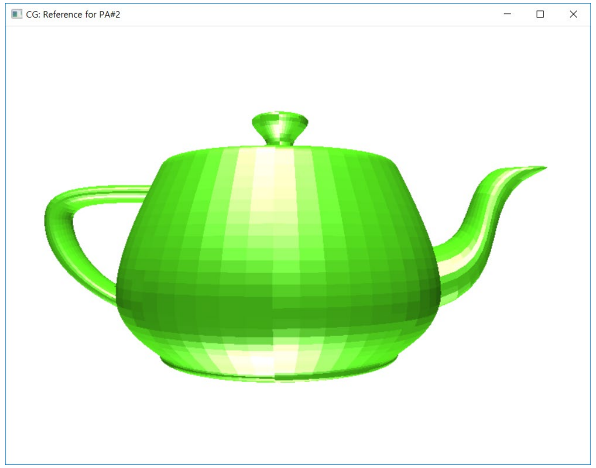
Illuminated by both lights

Shading

- An illumination model defines how to compute the color of a point on surfaces.
- A shading model defines where we should use the illumination model.
    - Flat (constant)
    - Gouraud
    - Phong

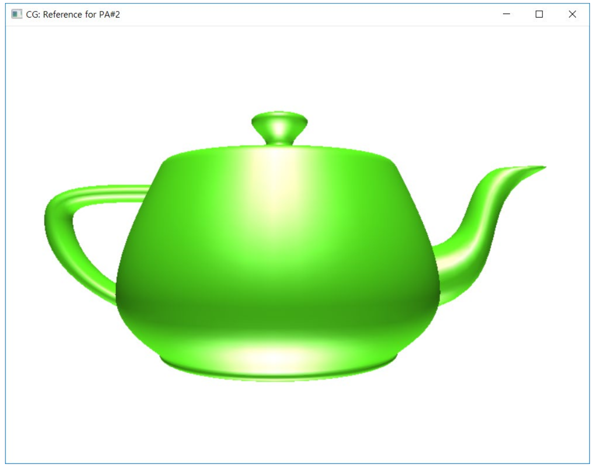
Flat (Constant) Shading

- The illumination model is applied only once to a polygon
  - All points within the polygon have the same color
- Properties
  - Very simple & cheap
  - Very low rendering quality (not smooth)
- OpenGL code
  - glShadeModel(GL_FLAT);



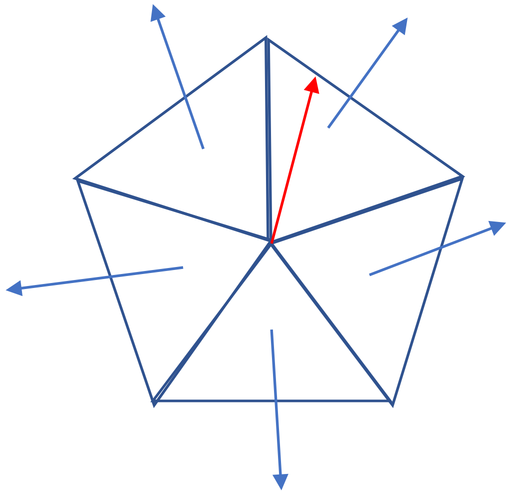
Gouraud Shading

- The illumination model is applied to each vertex of a polygon
  - The inside points' colors of the polygon are interpolated ones of the vertex colors
- Properties
  - More expensive than the flat shading
  - Higher quality than the constant
  - Relatively good but still not very smooth
- OpenGL code
  - glShadeModel(GL_SMOOTH);



Vertex Normal

- The normal at a vertex is generally an averaged one of the normals of neighboring polygons



Phong Shading

- The illumination model is applied for each point of a polygon
  - Should compute the normal at a point by interpolating the vertex normals

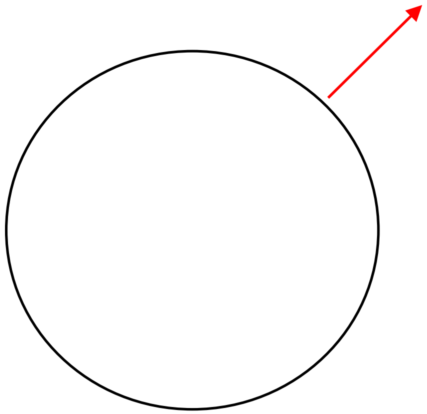
- Properties
  - Much more expensive than the flat and Gouraud shading methods
  - Produce very smooth appearance

- OpenGL code
  - Not supported as a simple function call
  - You should implement it (e.g., per-fragment shading)
    - Further reading: search fragment shader (c/c++ like language)
  - You can make your own shading

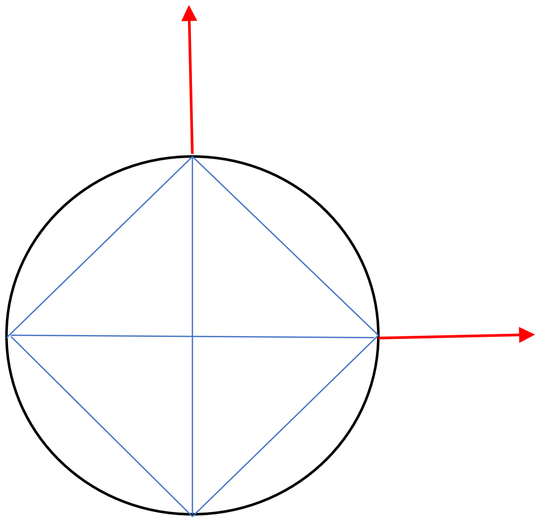
Gouraud vs. Phong Shading

- Gouraud shading may miss some highlights in the middle of a polygon
  - It scarifies the quality to improve rendering speed

- Q. Is there a way to improve the quality without using Phong shading?



Original model



Approximate model

Gouraud vs. Phong Shading

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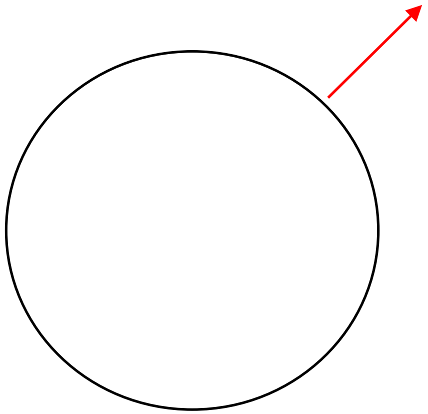
- Q. Is there a way to improve the quality without using Phong shading?
  - We can subdivide a polygon into multiple polygons



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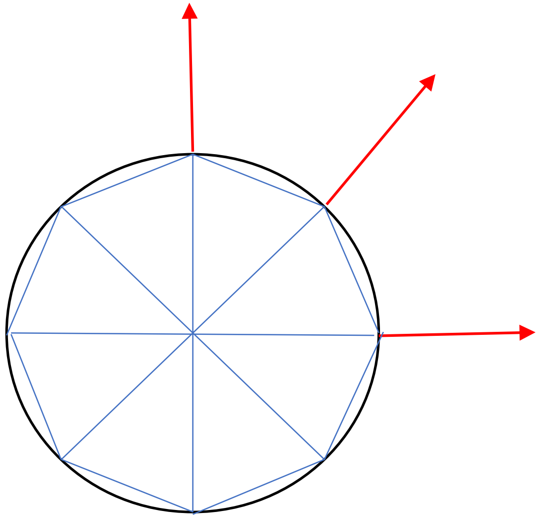

Approximate model

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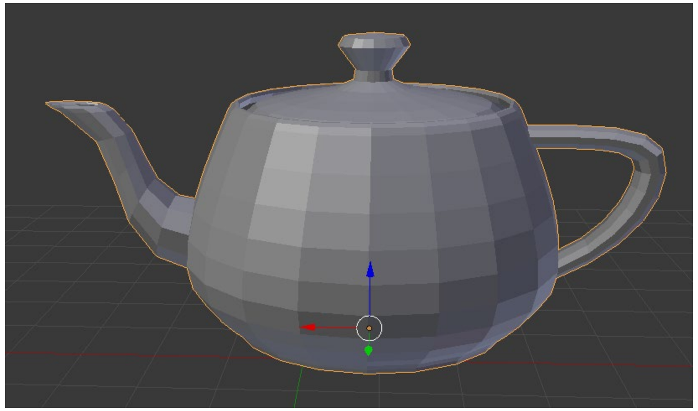
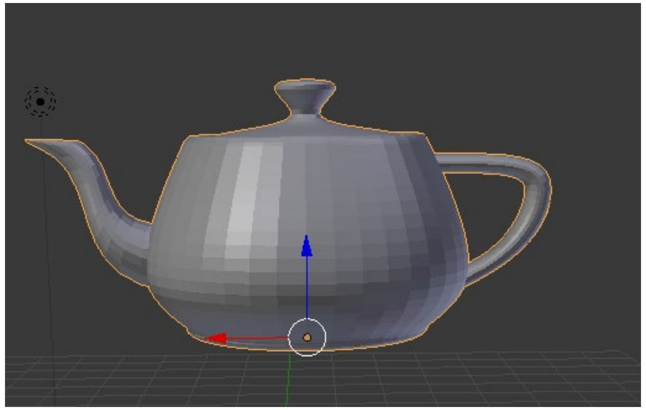
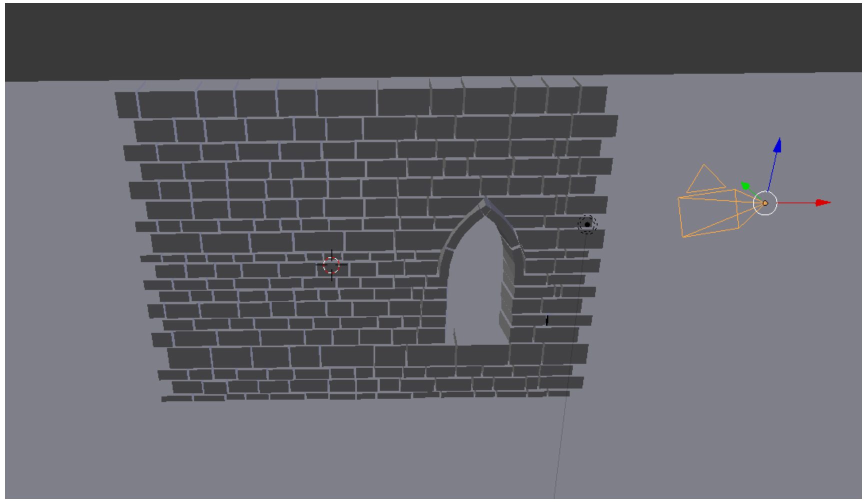




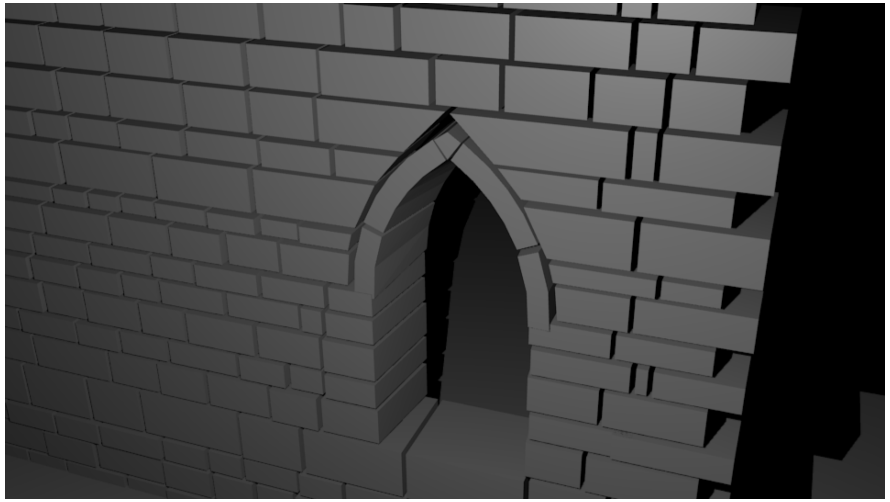
Illumination Models

- Local illumination
- Global illumination



Local Illumination

- Determine the colors of surface points based on only local information:
  - Materials of the surface
  - Geometry (normal and position) of the point
  - Lights

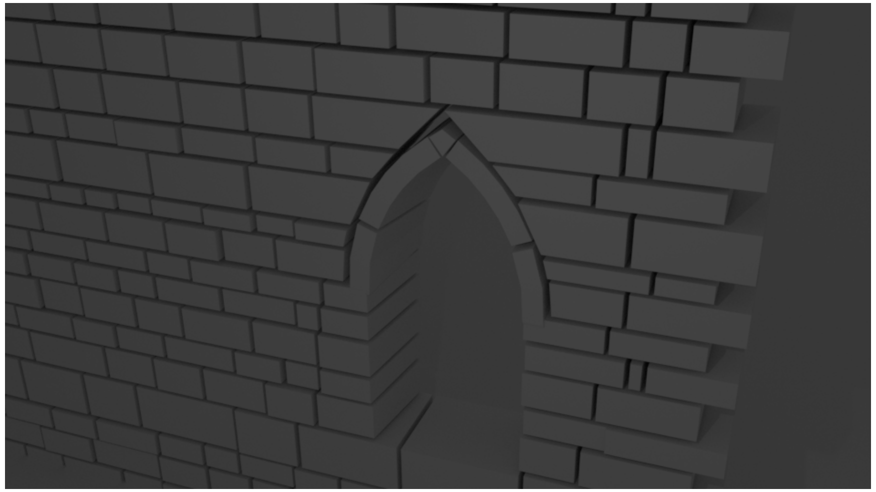


- Limitations:
  - One-bounce reflection of light
  - Hack (ambient term) for approximation indirect illumination
- Phong illumination model
  - Empirical model for local illumination

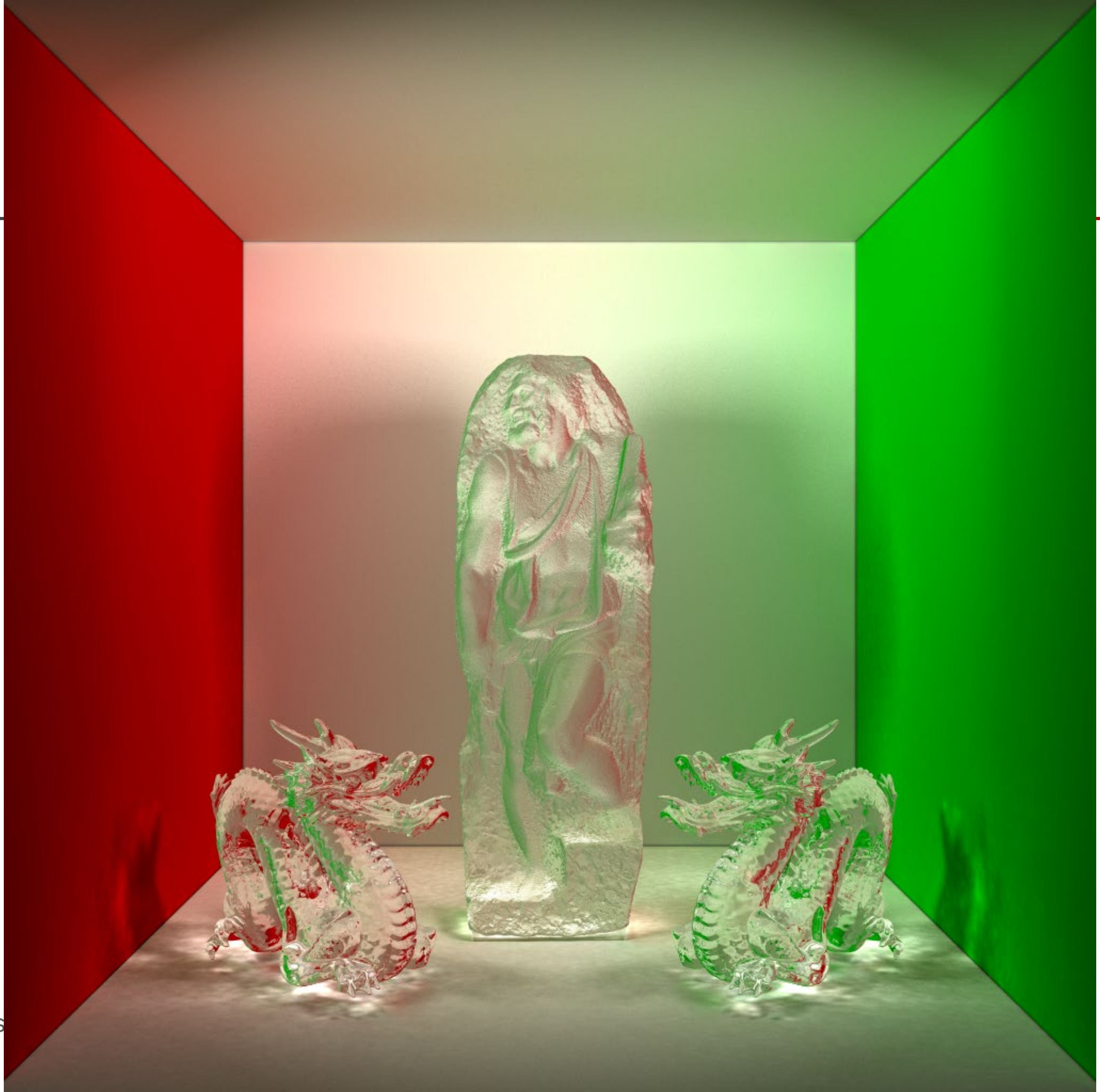
Global Illumination

- Light can traverse in the virtual world:
  - Colors of a surface can be affected by lights and other surfaces

- e.g., ray tracing



Global Illu



[Moon et al. 10]

Computer Graphics
Laboratory

Some
videos?

[Moon et al. 16]

Further Readings

- Chapter 4.5
- Chapter 10