Illumination and Shading

Computer Graphics – Lecture 5

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What are Lighting and Shading?

- Lighting
  - How to compute the color of objects according to the position of the light, normal vector and camera position
    - Phong illumination model
- Shading
  - Different methods to compute the color of the entire surface

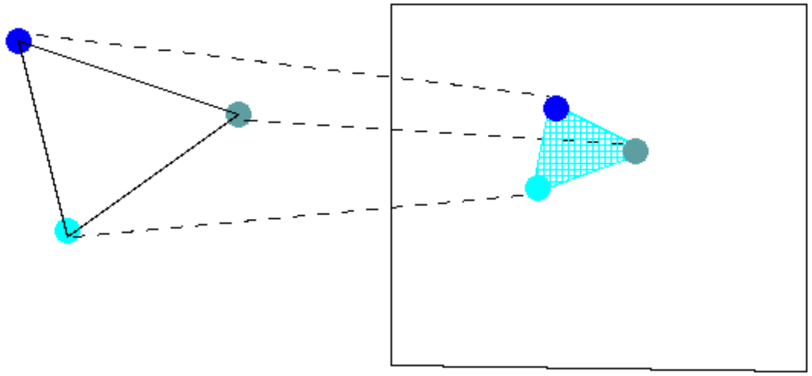
The procedure of producing images

1. For every vertex of the object, prepare its attributes (normal vectors, colors, etc)

   -> vertex shader in GLSL

2. Project the vertices onto the screen
3. Interpolate the attributes to determine the color of the pixel (rasterization)

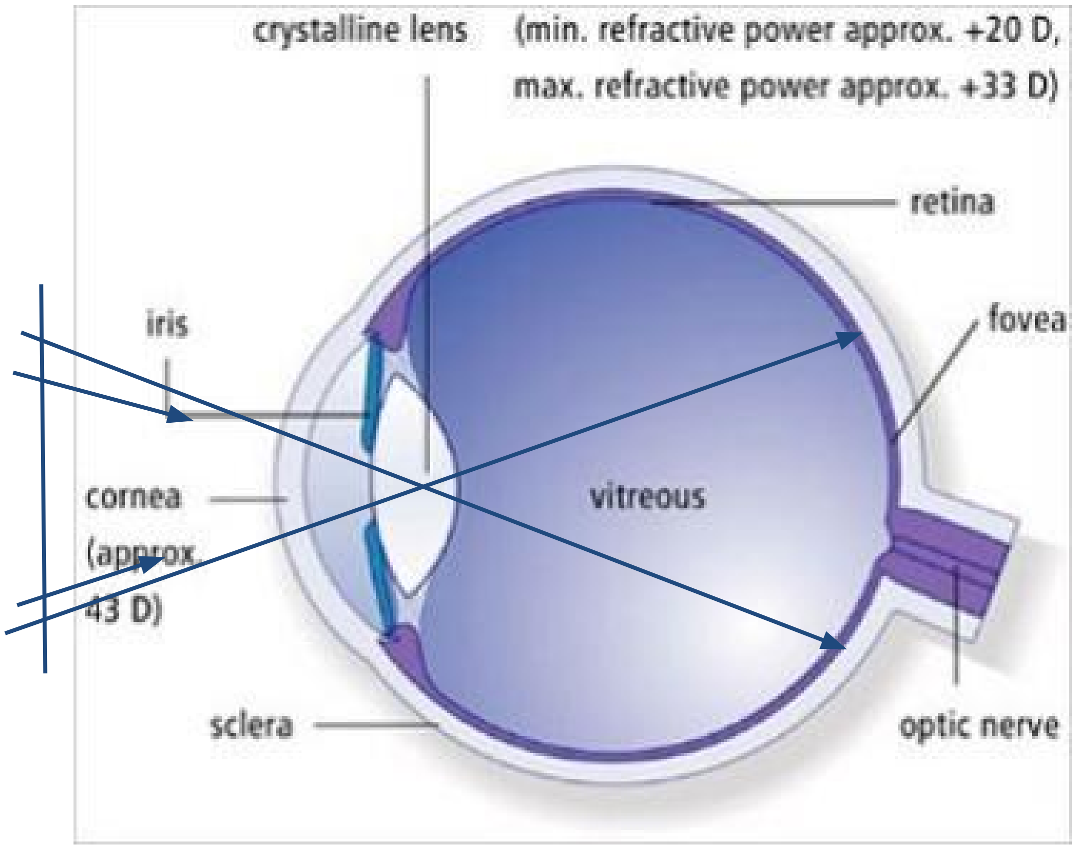
   -> fragment shader in GLSL



Overview

- Lighting
  - Phong Illumination model
    - diffuse, specular and ambient lighting
- Shading
  - Flat shading
  - Gouraud shading
  - Phong shading

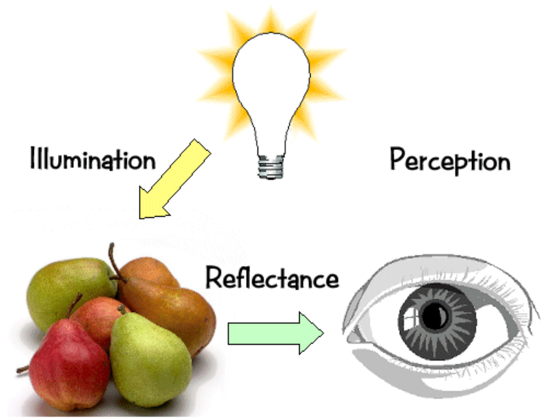
Back ground of illumination

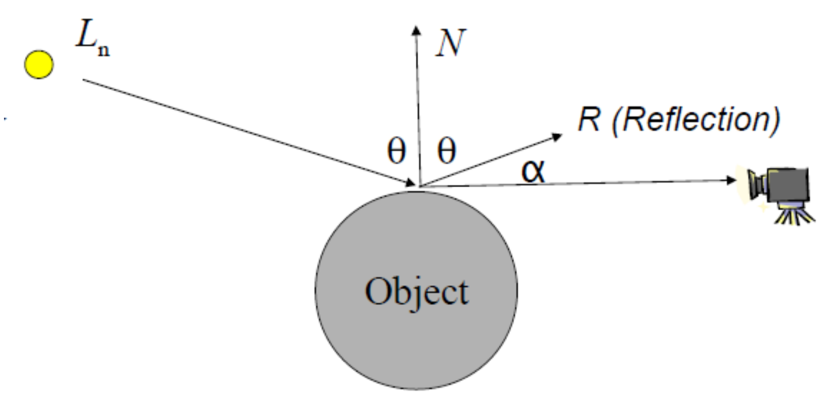


- The eye works like a camera
- Lots of photo sensors at the back of the eye
- Sensing the amount of light coming from different directions
- Similar to CMOS and CCDs

What Affects the Light that Comes into the Eye

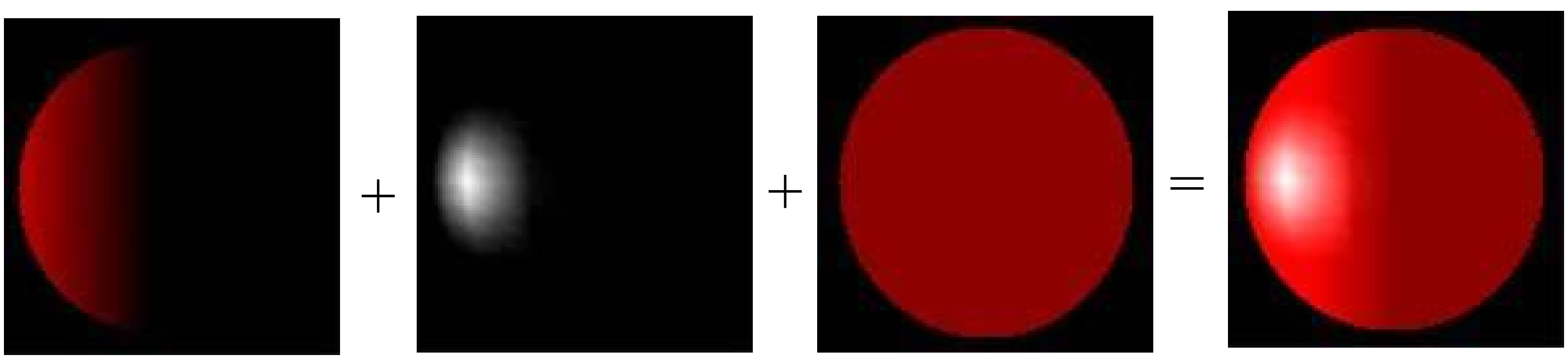
- position of the point
- position of the light
- color and intensity of the light
- camera vector
- normal vector of the surface at the vertex
- physical characteristics of the object (reflectance model, color)





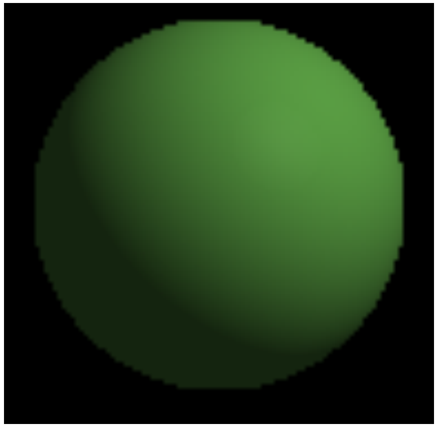
Phong Illumination Model

- Simple 3 parameter model
  - The sum of 3 illumination terms:
    - **Diffuse :** non-shiny illumination and shadows
    - **Specular :** bright, shiny reflections
    - **Ambient :** 'background' illumination

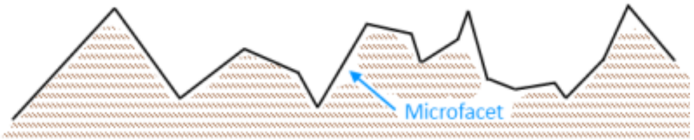


Diffuse (directional) + Specular (highlights) + Ambient (color) = R_c

Diffuse Reflection (Lambertian Reflection)

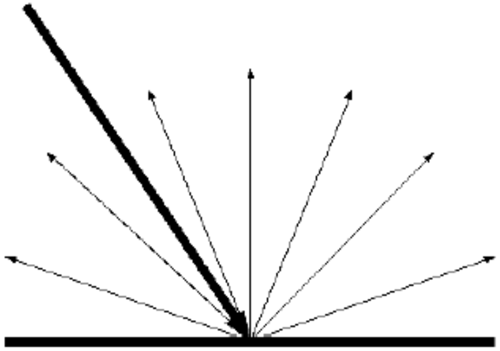


- When light hits an object
  - If the object has a rough surface, it is reflected to various directions



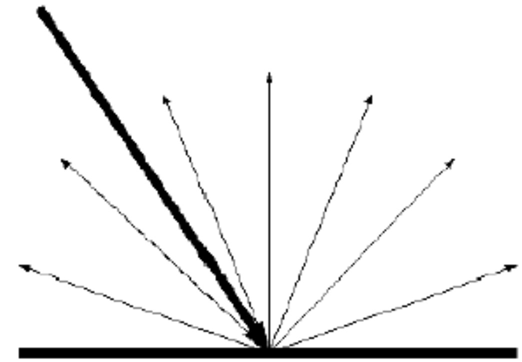
- Result: Light reflected to all directions

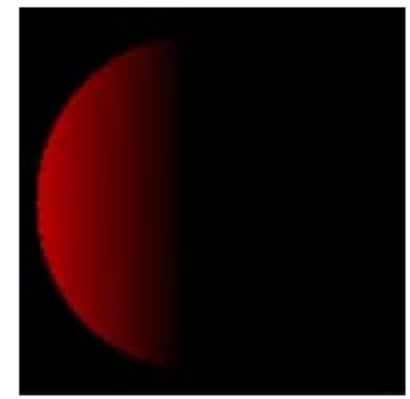
- The smaller the angle between the incident vector and the normal vector is, the higher the chance that the light is reflected back



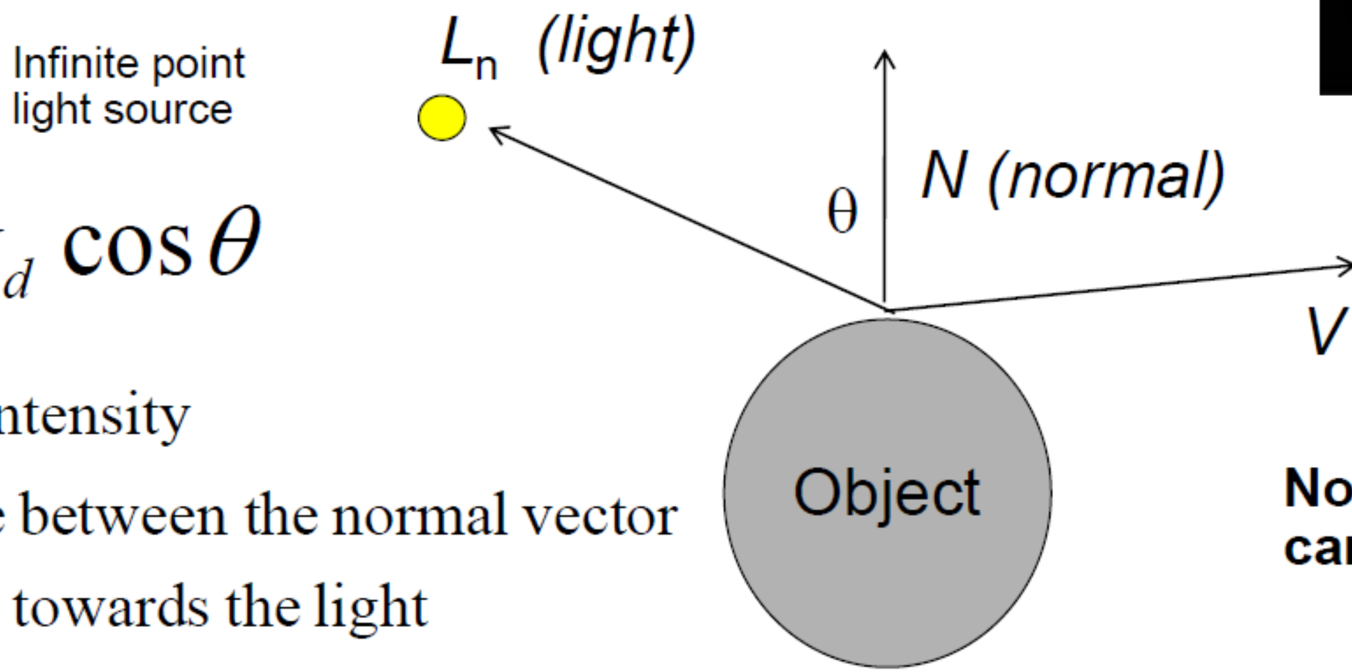
- When the angle is larger, the reflection light gets weaker because the chance the light is shadowed / masked increases

Diffuse Reflection





Example: sphere
(lit from left)



$$I = I_p k_d \cos\theta$$

I_p : Light Intensity

θ : the angle between the normal vector direction towards the light

k_d : diffuse reflectivity

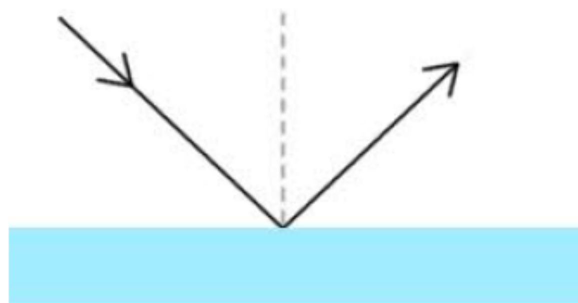
No dependence on camera angle!

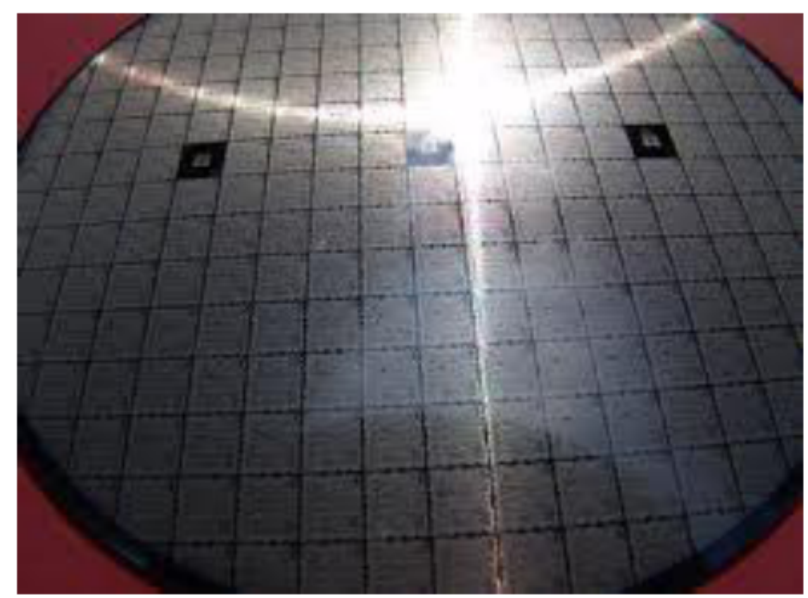
Specular Reflection

•Direct reflections of light source off shiny object

–The object has a very smooth surface

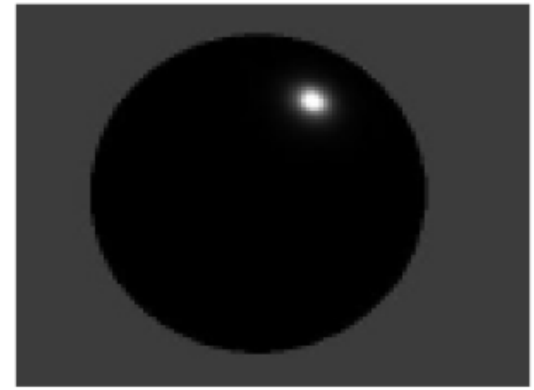
–specular highlight on object



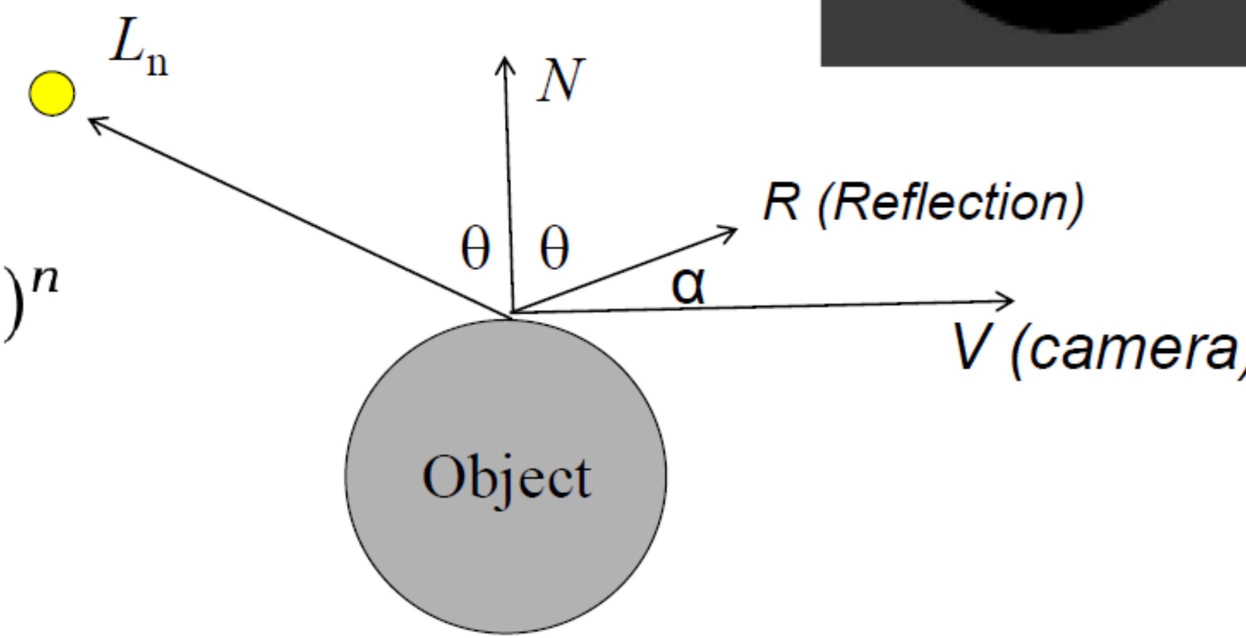


Specular Reflection

- Direct reflections of light source off shiny object
  - specular intensity n = shiny reflectance of object
  - Result: **specular highlight on object**



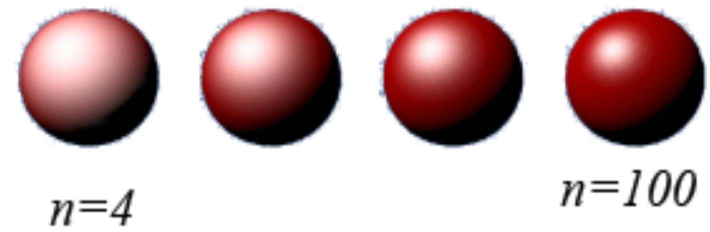
Infinite point light source

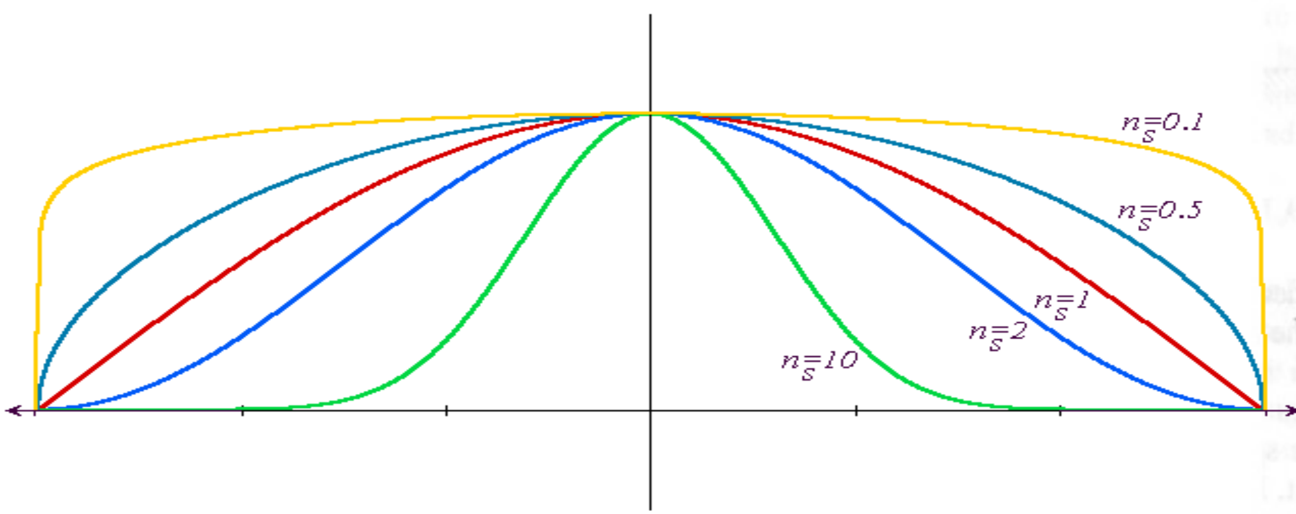


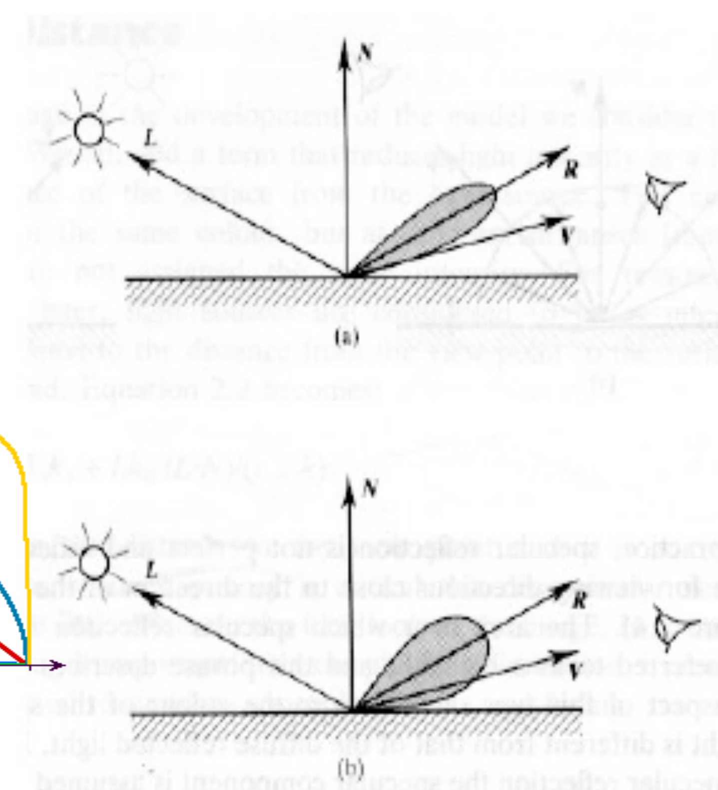
$$I = I_p k_s (\cos \alpha)^n$$

No dependence on object color.

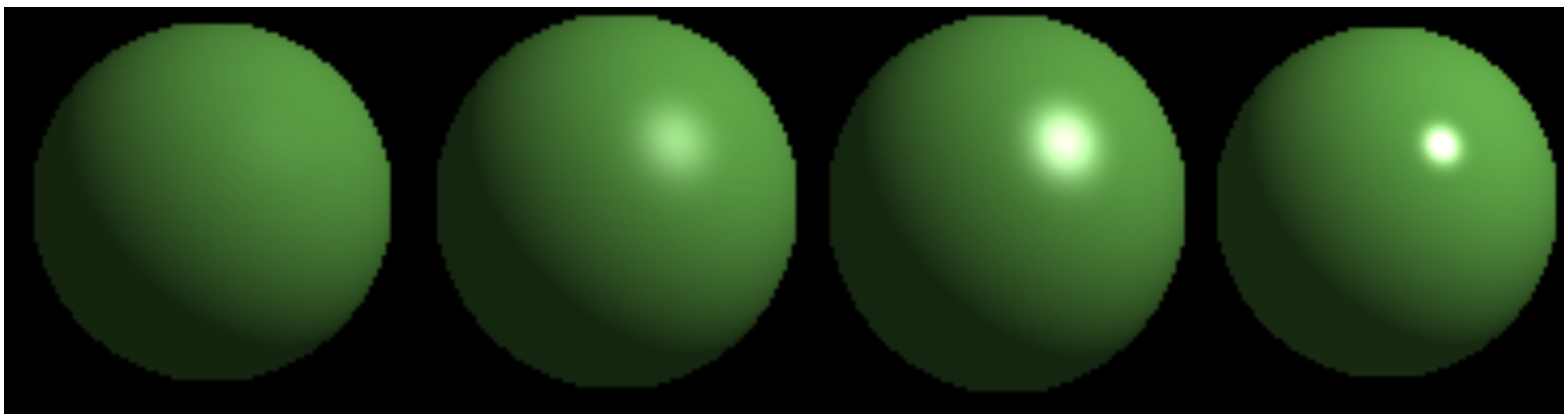
- Specular light with different *n* values





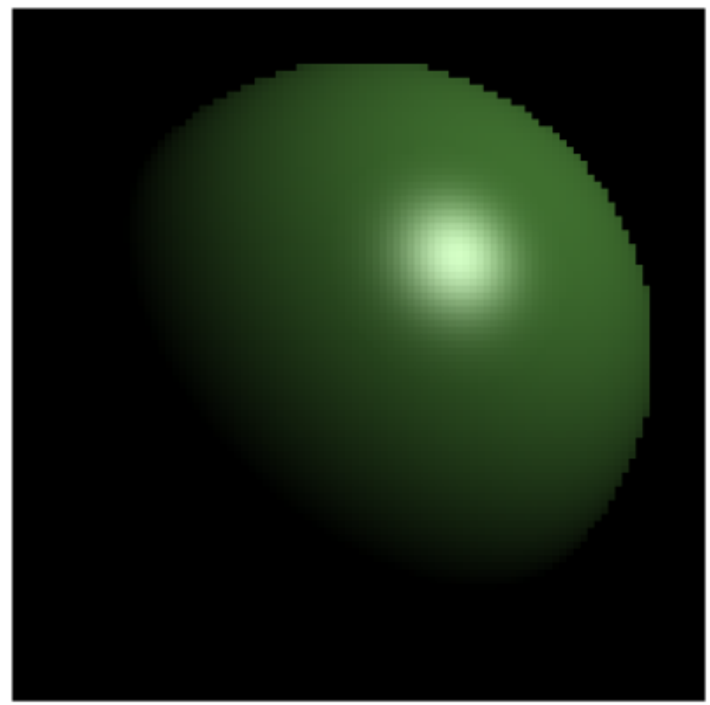


Combining Diffuse and Specular Reflections



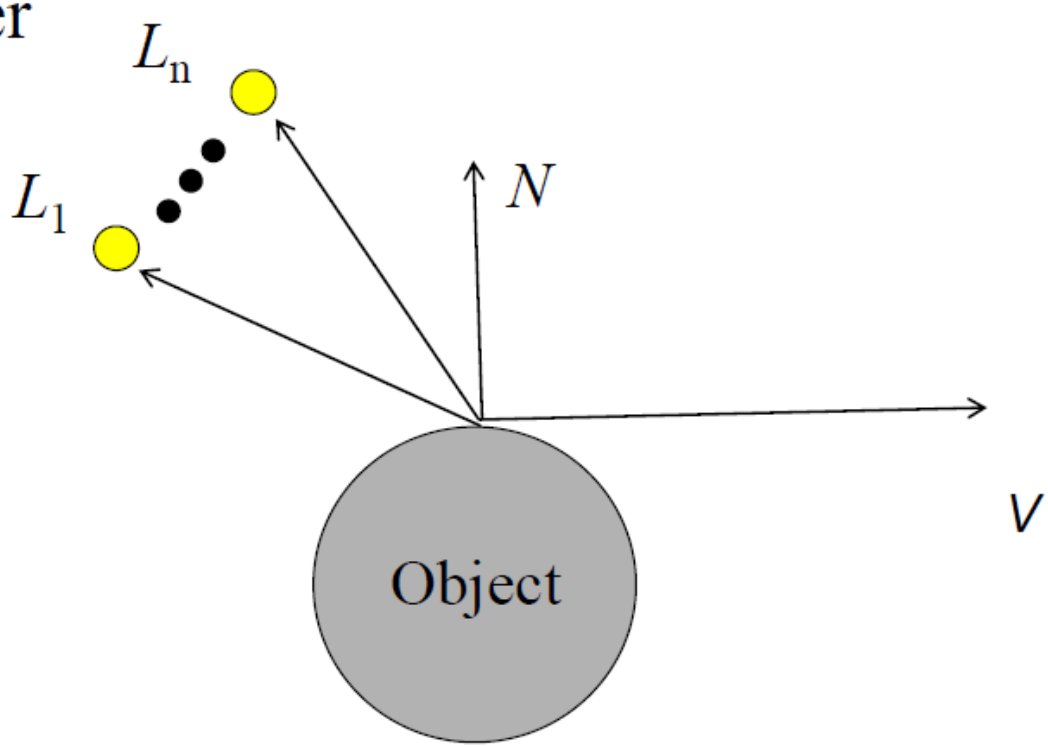
What is Missing?

- Only the side that is lit by the light appears brighter
- The other side of the object appears very dark, as if it is in the space



Multiple Light Sources

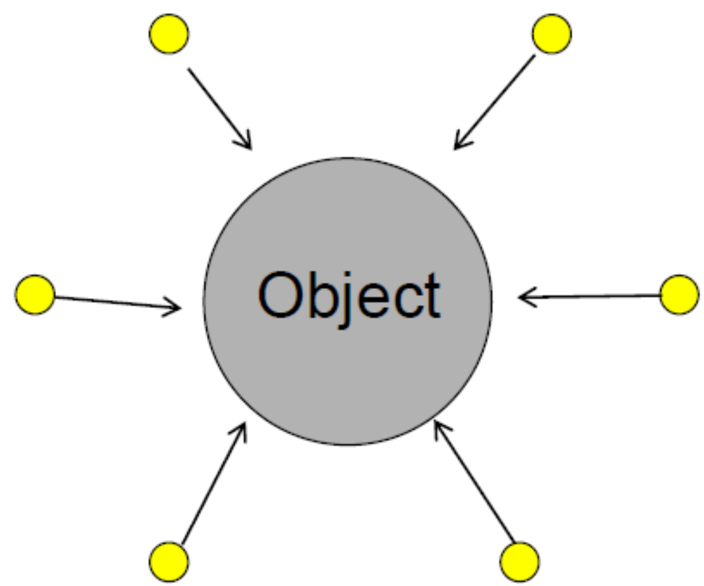
- If there are multiple light sources, we need to do the lighting computation for each light source and sum them altogether



$$I_\lambda = I_a k_a + \sum_{p=1}^{lights} I_p [k_d \cos\theta + k_s \cos^n \alpha]$$

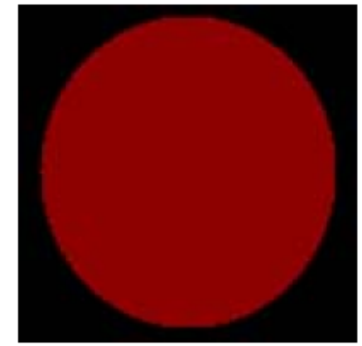
Ambient Lighting

- Light from the environment
- Light reflected or scattered from other objects
- Coming uniformly from all directions and then reflected equally to all directions
- A precise simulation of such effects requires a lot of computation



Ambient Lighting

Simple approximation to complex 'real-world' process



Example: sphere

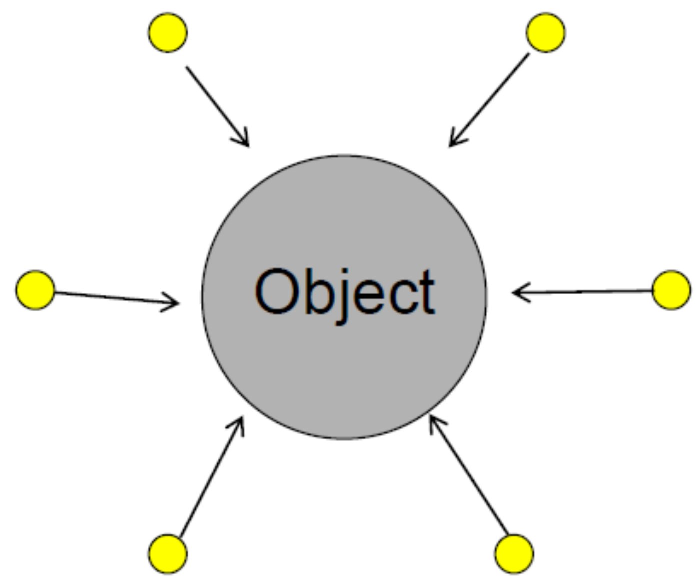
Result: **globally uniform color for object**

I = resulting intensity

I_a = light intensity

k_a = reflectance

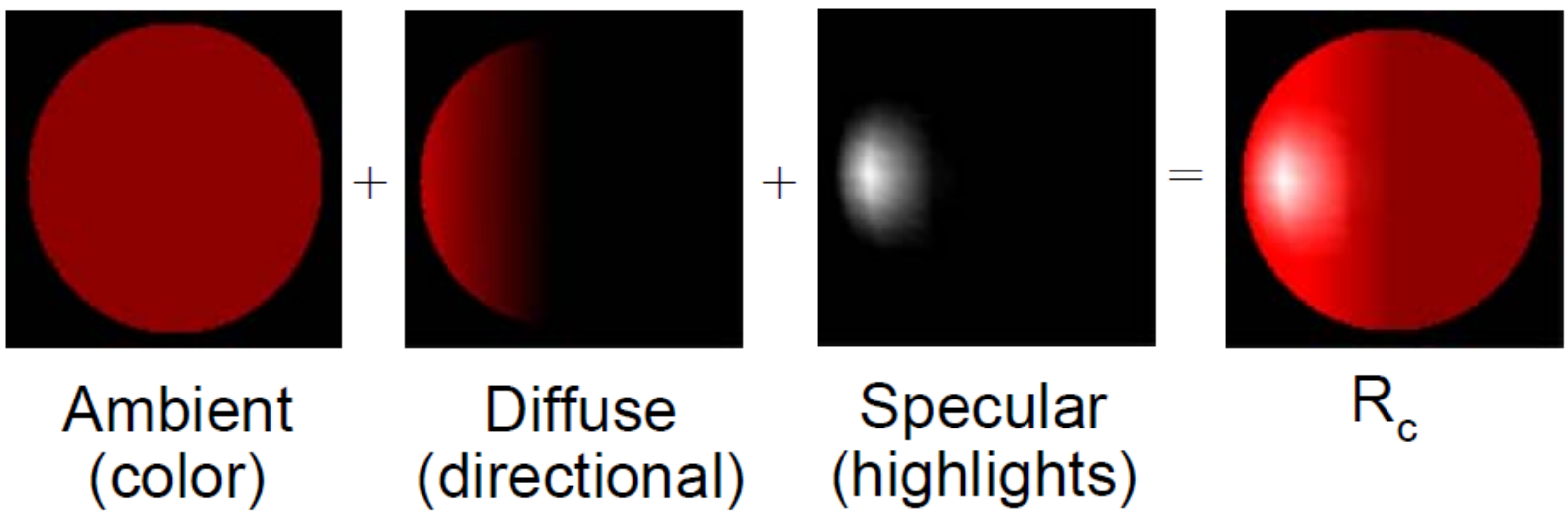
$$I = k_a I_a$$



Combined Lighting Models

- Summing it altogether : Phong Illumination Model

$$I_\lambda = I_a k_a + I_p [k_d \cos\theta + k_s \cos^n \alpha]$$

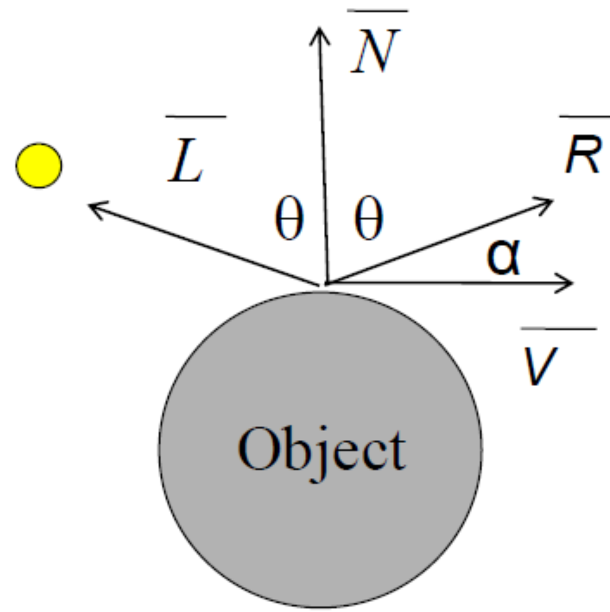


Using the Dot Products

Use dot product of the vectors instead of calculating the angles θ, α

$$\cos\theta \qquad \cos\alpha$$

$$I_\lambda = I_a k_a + \sum_{p=1}^{lights} I_p [k_d (\overline{N} \bullet \overline{L}) + k_s (\overline{V} \bullet \overline{R})^n]$$



$\overline{V}$: Vector from the surface to the viewer

$\overline{N}$: Normal vector at the colored point

$\overline{R}$: Normalized reflection vector

$\overline{L}$: Normalized vector from the colored point towards the light source

Demo applets

- http://www.cs.auckland.ac.nz/~richard/research-topics/PhongApplet/PhongDemoApplet.html

Color

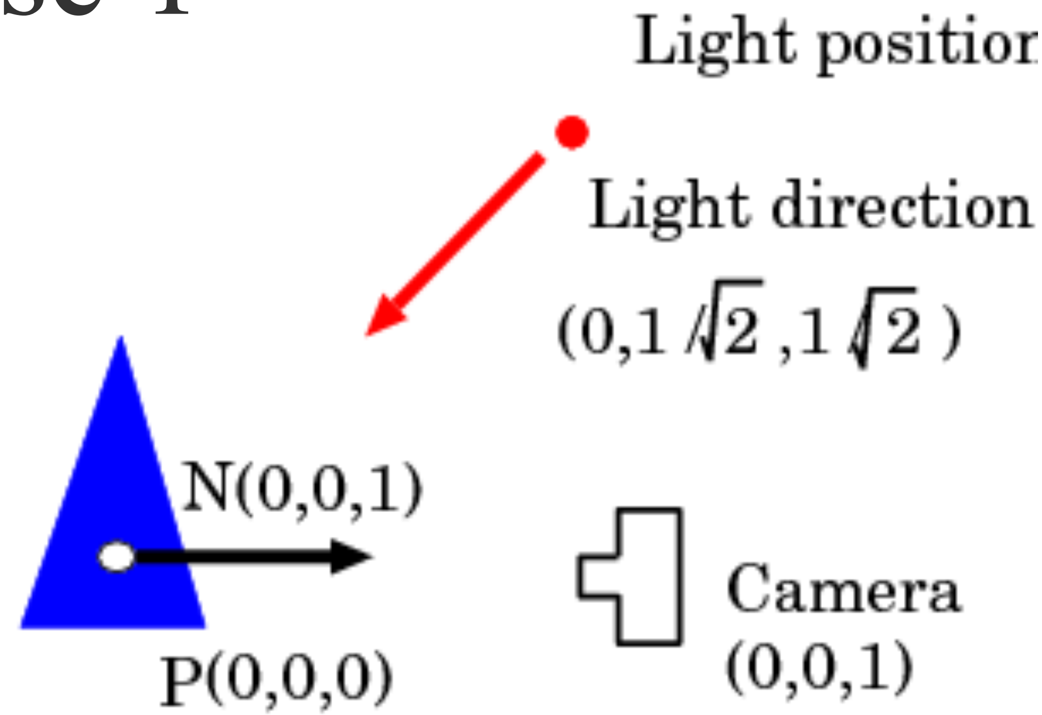
$$I_\lambda^R = I_a^R k_a^R + \sum_{p=1}^{lights} I_p^R \left(k_d^R (\overline{N} \bullet \overline{L}) + k_s^R (\overline{V} \bullet \overline{R})^n\right)$$

$$I_\lambda^G = I_a^G k_a^G + \sum_{p=1}^{lights} I_p^G \left(k_d^G (\overline{N} \bullet \overline{L}) + k_s^G (\overline{V} \bullet \overline{R})^n\right)$$

$$I_\lambda^B = I_a^B k_a^B + \sum_{p=1}^{lights} I_p^B \left(k_d^B (\overline{N} \bullet \overline{L}) + k_s^B (\overline{V} \bullet \overline{R})^n\right)$$

- Finally color the pixel by the RGB color

Exercise 1



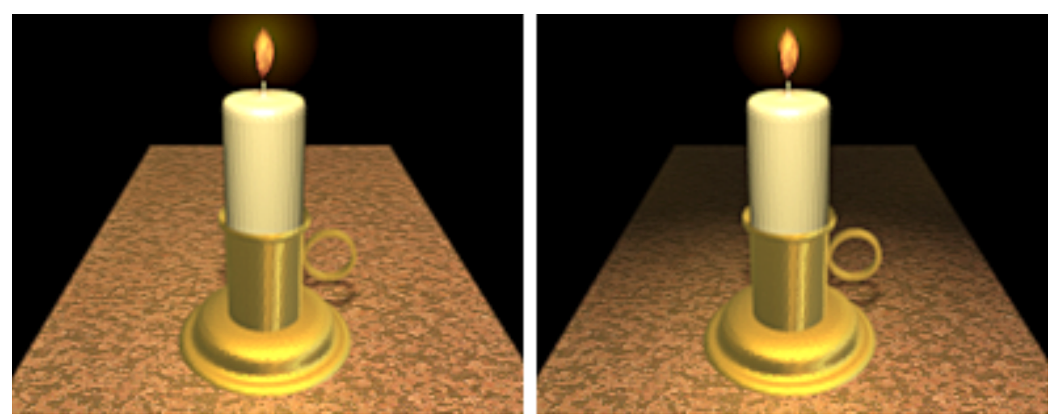
Ip = 1, kd = 1, ks = 1, n = 2

What is the diffuse colour?
What is the specular colour?
What is the specular colour if the camera position $(0,\sqrt{3}/2,1/2)$?

Attenuation

- Haven't considered light attenuation – the light gets weaker when the object is far away
- Use 1/(*s*+*k*) where *s* relates to eye-object distance and *k* is some constant for scene.

$$I_\lambda = I_a k_a + \sum_{p=1}^{lights} \frac{I_p}{(s_o + k)} (k_d(\bar{N} \bullet \bar{L}) + k_s(\bar{V} \bullet \bar{R})^n) + I_t k_t$$

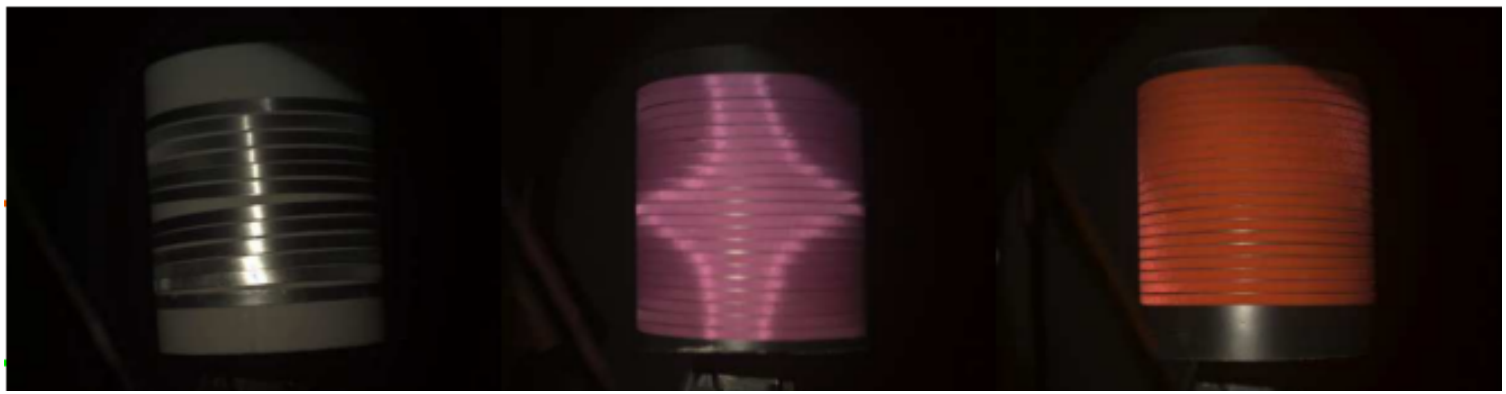


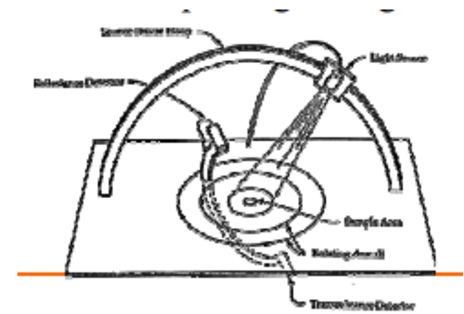
Local Illumination Model

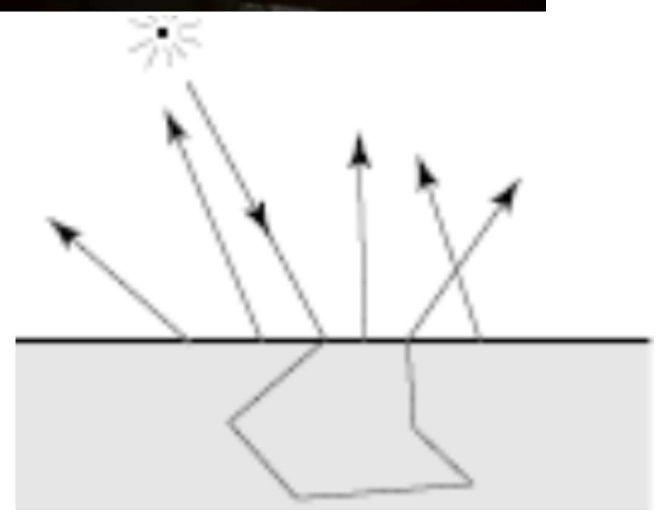
- Considers light sources and surface properties only.
  - Not considering the light reflected back onto other surfaces
- Fast real-time interactive rendering.
- Cost increases with respect to the number of light sources
- Most real-time graphics (games, virtual environments) are based on local illumination models
- Implementation - OpenGL, Direct3D

What Cannot be Rendered by The Emperical Reflectance Model

- Brushed Metal
- Marble surface







Overview

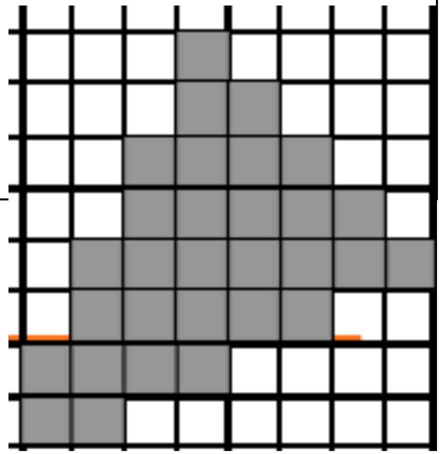
- Lighting
  - Phong Illumination model
    - diffuse, specular and ambient lighting
- **Shading**
  - **Flat shading**
  - **Gouraud shading**
  - **Phong shading**

How do we color the whole surface?

- The illumination model computes the color of sample points
- How do we color the entire object?

→ This is done at the rasterization level

The procedure to color the entire surface is called **shading**



Shading Models

– Flat Shading (lighting computation is done once per polygon)

→ less computation needed

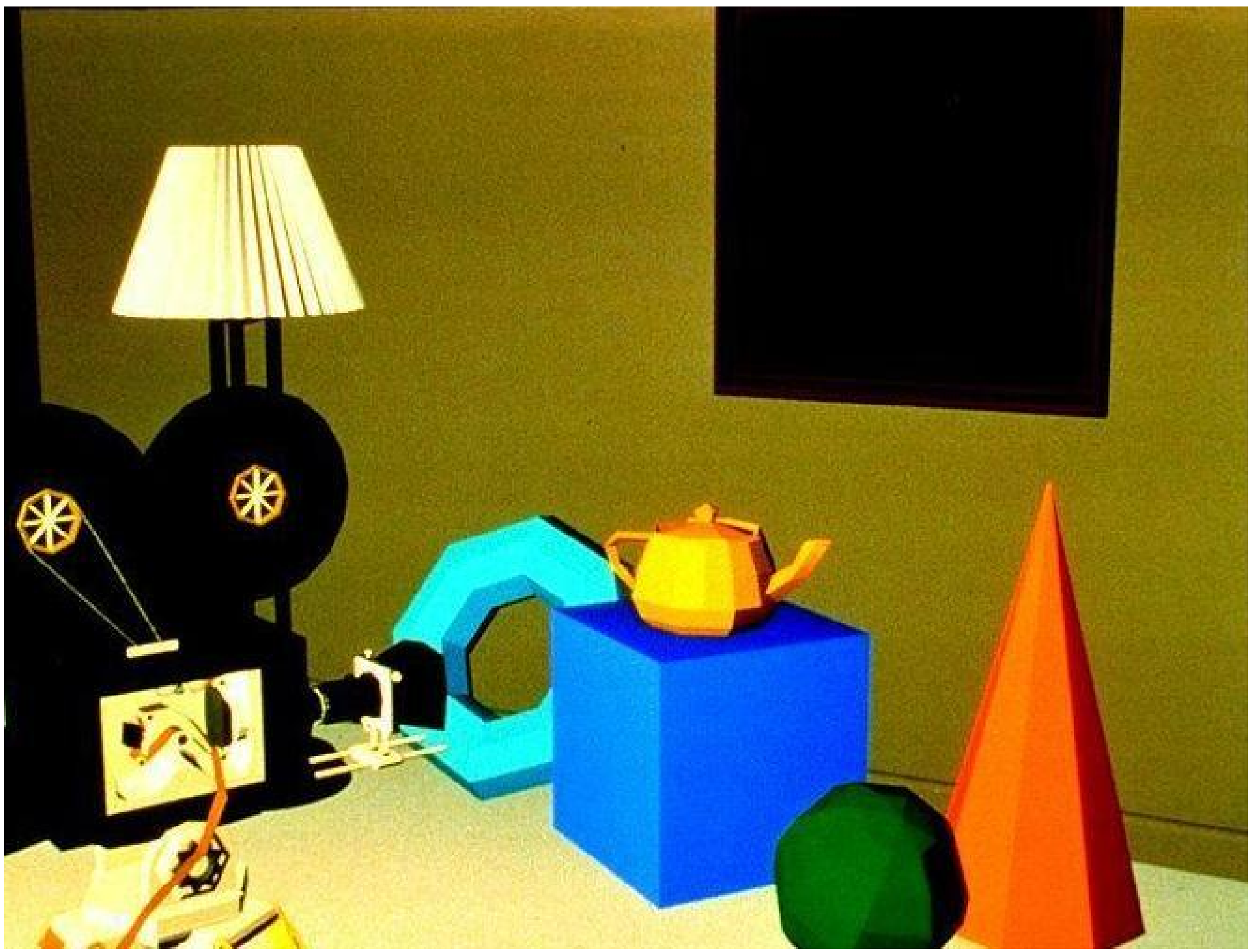
– Gouraud shading (once per vertex)

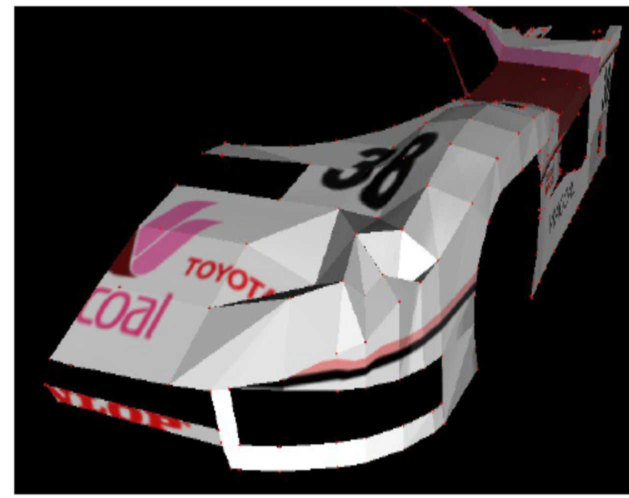
– Phong Shading (once per pixel)

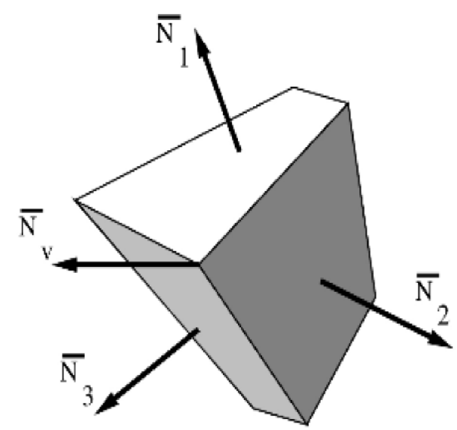
→ heavy computation needed

Flat Shading

- Compute the color at the middle of the polygon
- All pixels in the same polygon are colored by the same color
- Works well for objects really made of flat faces.

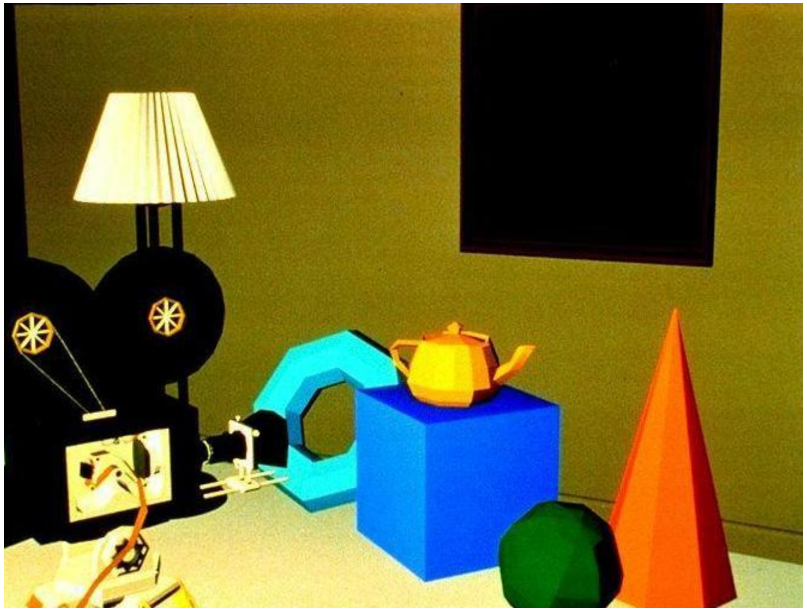


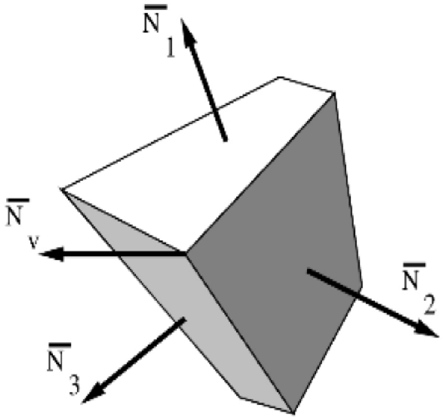


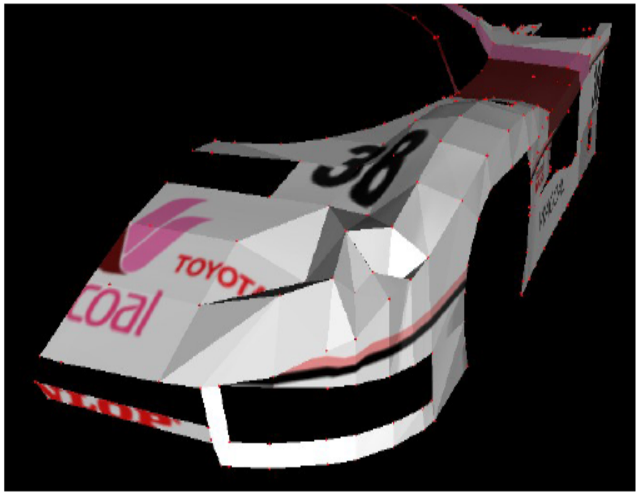


Flat Shading

- Suffers from Mach band effect
- Humans are very sensitive to the sudden change of the brightness
- The artefact remains although the polygon number is increased

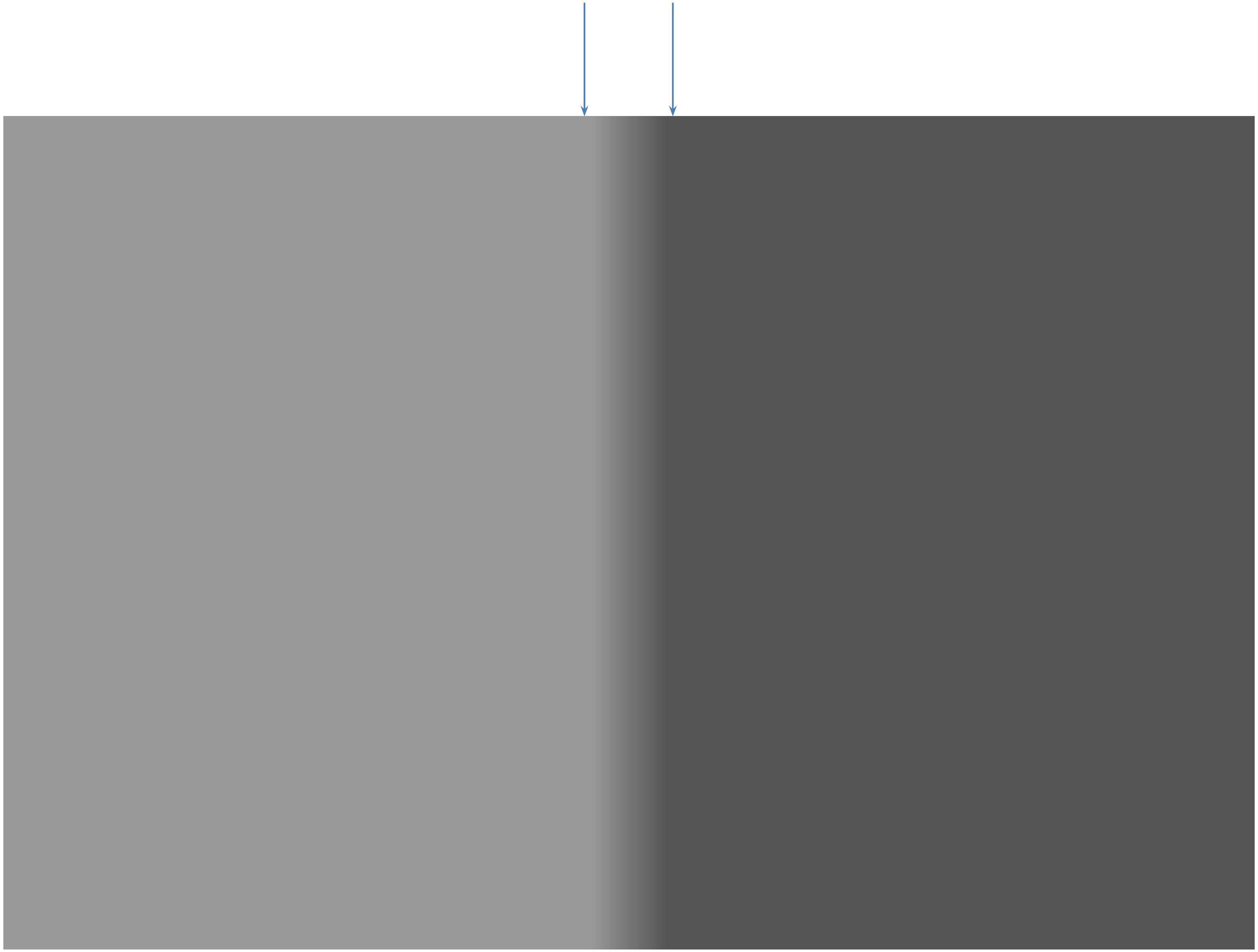




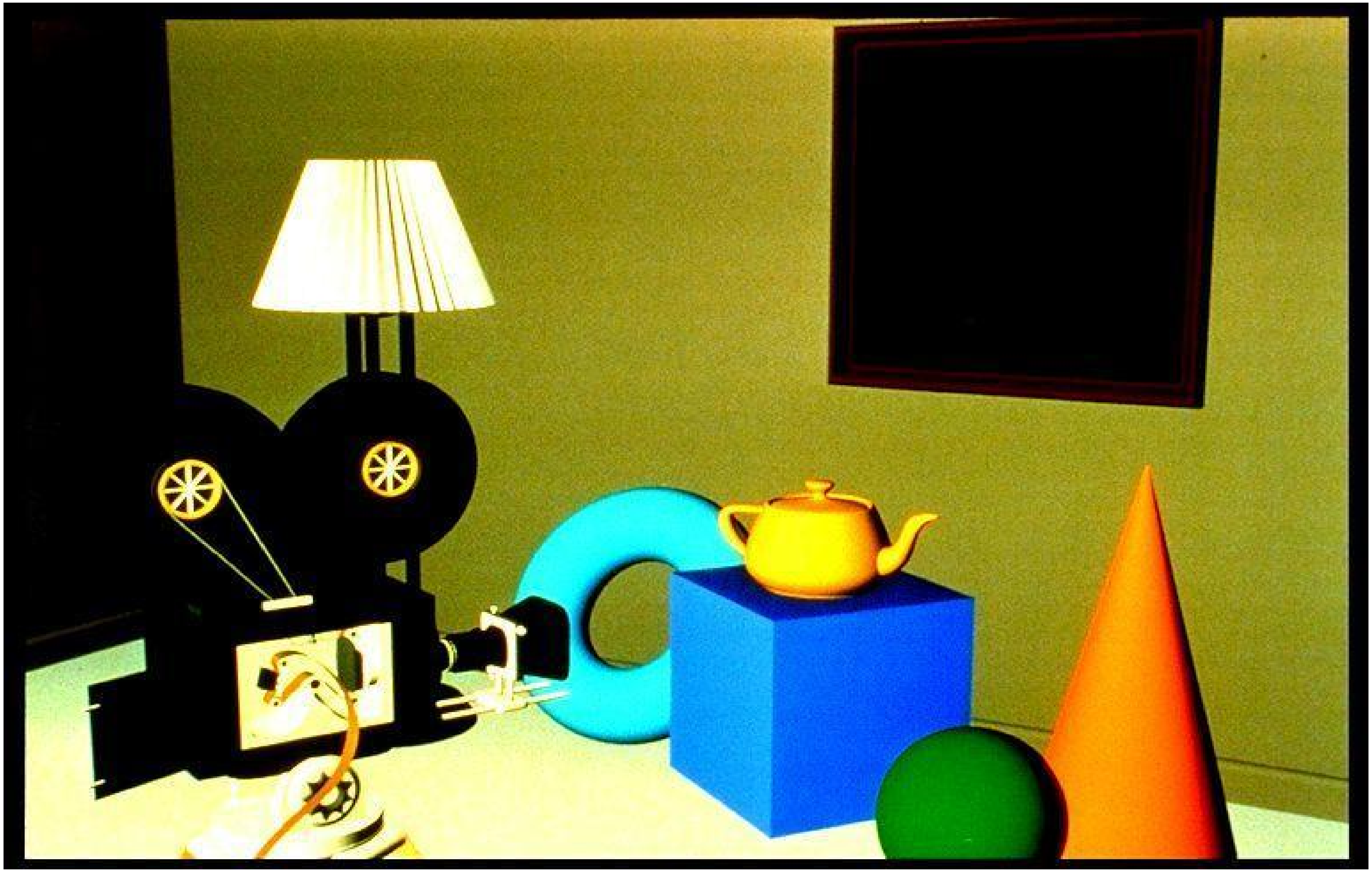


Mach Band (by Ernst Mach)

- An optical illusion

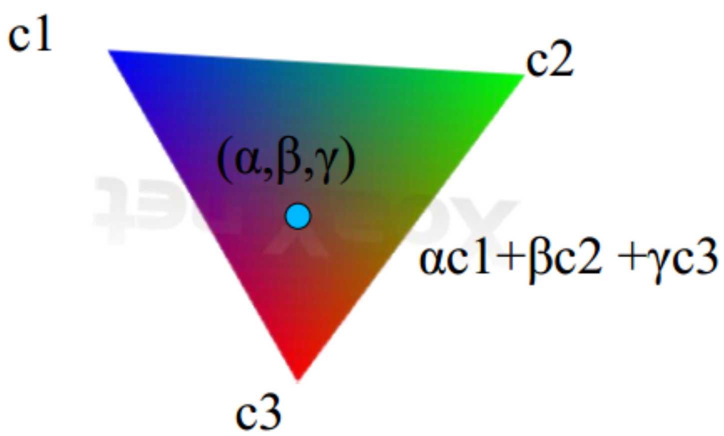


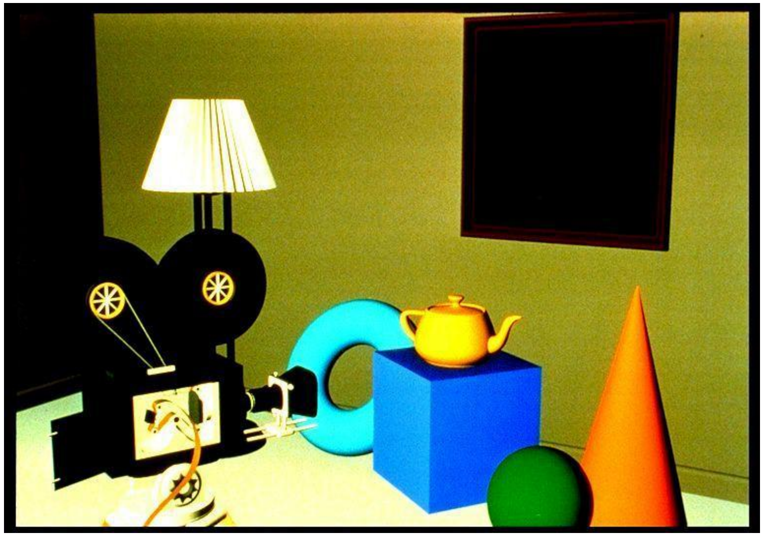
Gouraud Shading



Gouraud Shading (by Henri Gouraud)

- Computing the color per vertex by local illumination model
- Then, interpolating the colors within the polygons





We can interpolate the color by barycentric coordinates

Gouraud Shading with GLSL

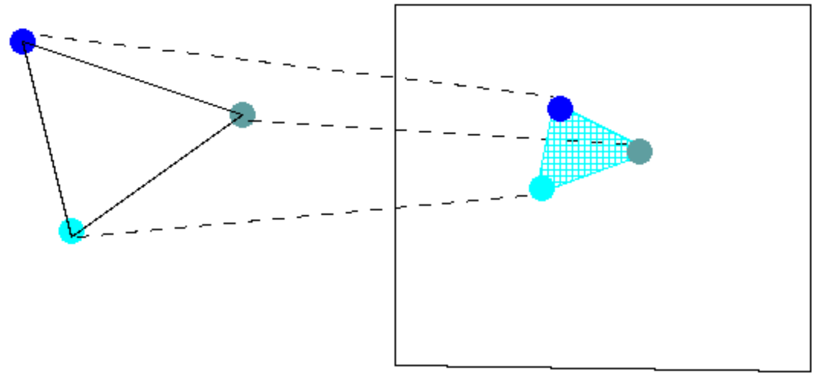
Vertex Shader

Compute the color per vertex

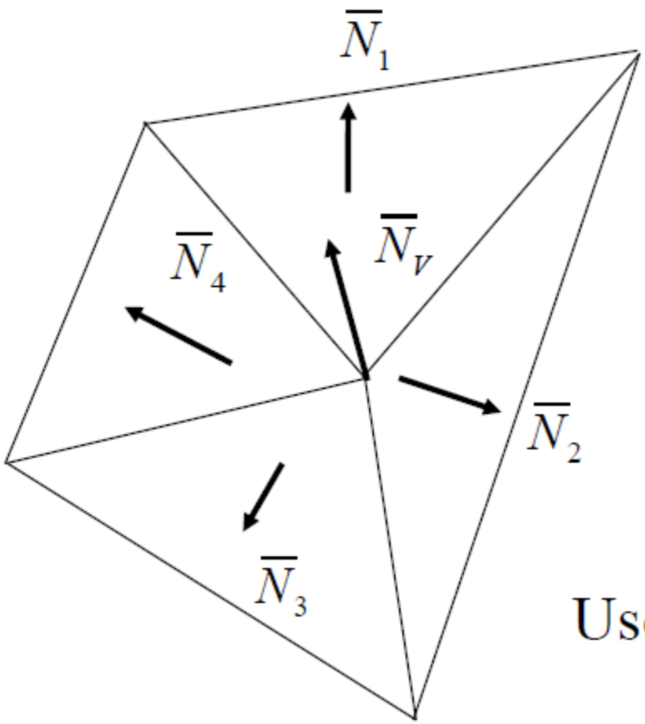
→

Fragment Shader

Interpolates the color for every pixel



Computing the Vertex Normals



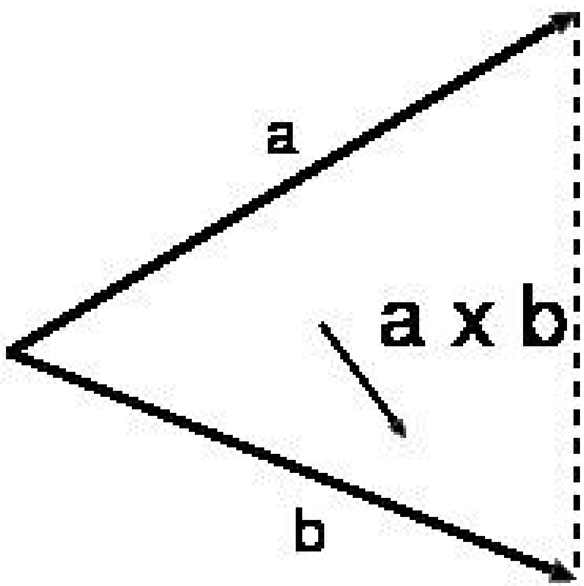
Find vertex normals by averaging face normals

$$\overline{N}_V = \frac{\sum_{1 \le i \le n} \overline{N}_i}{\left| \sum_{1 \le i \le n} \overline{N}_i \right|}$$

Use vertex normals with desired shading model,

Interpolate vertex intensities along edges.

Interpolate edge values across a scanline.



vertex 1	triangle 1, triangle 2,
vertex 2	triangle 6, triangle 7,
vertex 3	triangle 9, triangle 1
:	:

Passing the normals to the vertex shader

```
//Find the location for our vertex position variable
const char * attribute_name = "in_position";
int positionLocation = glGetAttribLocation(shader.ID(), attribute_name);
if (positionLocation == -1) {
        std::cout << "Could not bind attribute " << attribute_name << std::endl;
        return;
}
//Tell OpenGL we will be using vertex position variable in the shader
glEnableVertexAttribArray(positionLocation);
//Bind our vertex position buffer
glBindBuffer(GL_ARRAY_BUFFER, vbo);
//Define how to use our vertex buffer object.  This applies to whatever VBO is currently bound to GL_ARRAY_BUFFER
glVertexAttribPointer(
        positionLocation, // attribute (location of the in_position variable in our shader program)
        3,                  // number of elements per vertex, here (x,y,z)
        GL_FLOAT,           // the type of each element
        GL_FALSE,           // take our values as-is
        0,                  // no extra data between each position
        0                   // offset of first element
);
```

```
//Find the location for our vertex position variable
const char * attribute_name2 = "in_normal";
int normalVectors = glGetAttribLocation(shader.ID(), attribute_name2);
if (normalVectors == -1) {
        std::cout << "Could not bind attribute " << attribute_name2 << std::endl;
        return;
}
//Tell OpenGL we will be using normal vector variables in the shader
glEnableVertexAttribArray(normalVectors);
//Bind our normal vector buffer
glBindBuffer(GL_ARRAY_BUFFER, nbo);
//Define how to use our normal buffer object.  This applies to whatever NBO is currently bound to GL_ARRAY_BUFFER
glVertexAttribPointer(
        normalVectors, // attribute (location of the in_normal vector variable in our shader program)
        3,                  // number of elements per vertex, here (x,y,z)
        GL_FLOAT,           // the type of each element
        GL_FALSE,           // take our values as-is
        0,                  // no extra data between each position
        0                   // offset of first element
);
```

```
//Do the actual rendering of the primitives using all active attribute arrays
glDrawArrays(GL_TRIANGLES,0,trig.VertexCount());

//Disable usage of the array
glDisableVertexAttribArray(positionLocation);
glDisableVertexAttribArray(normalVectors);
```

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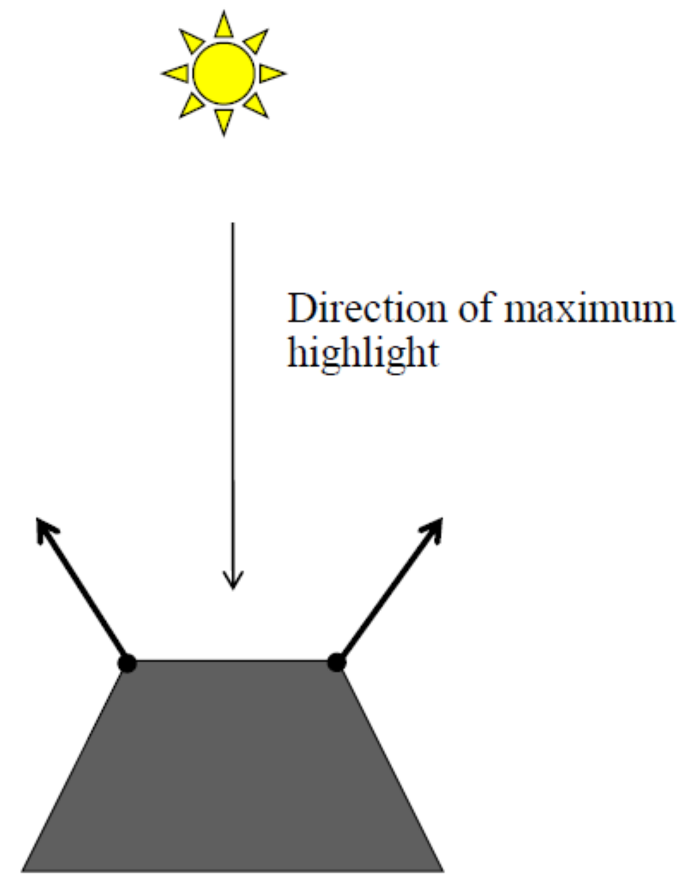
Problems with Gouraud Shading.

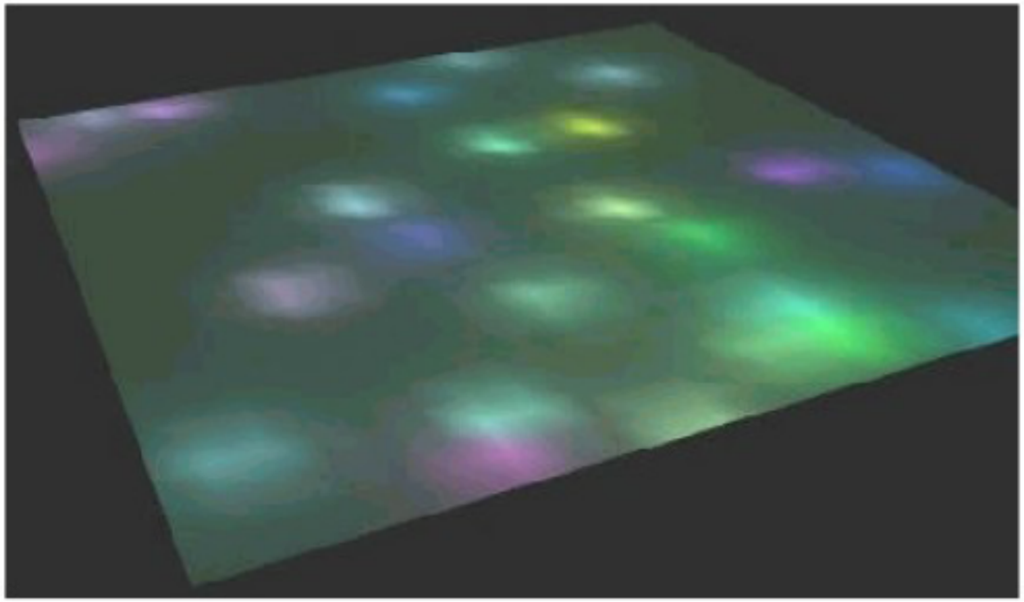
- For specular reflection, highlight falls off with $\cos^n \alpha$

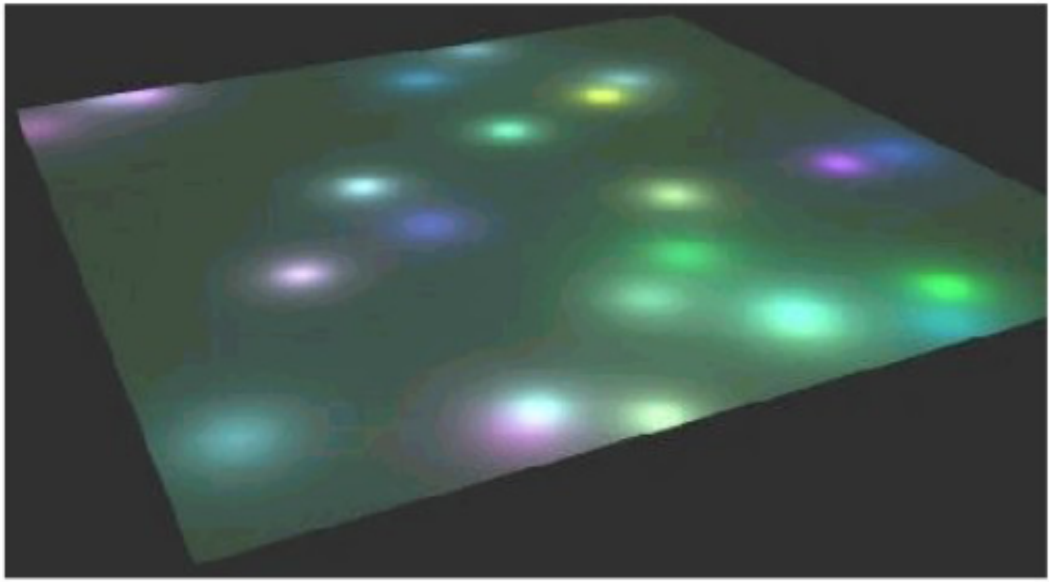
- Gouraud shading linear interpolates – makes highlight too big.

- Gouraud shading may well miss a highlight that occurs in the middle of the face.

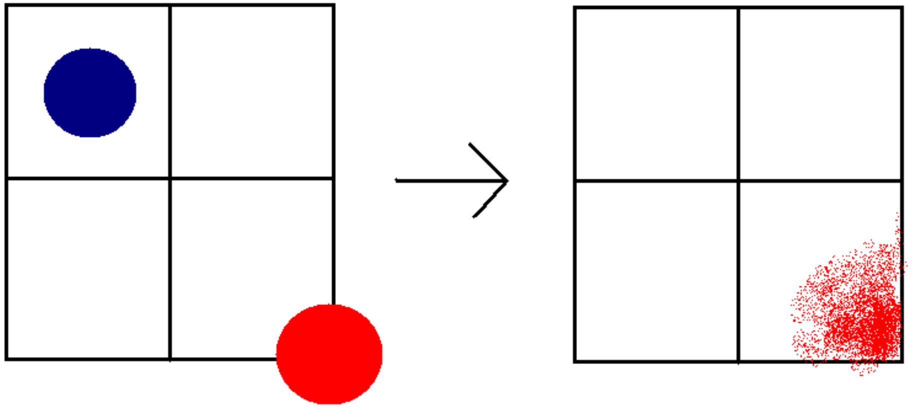


Gouraud Shaded Floor | Phong Shaded Floor





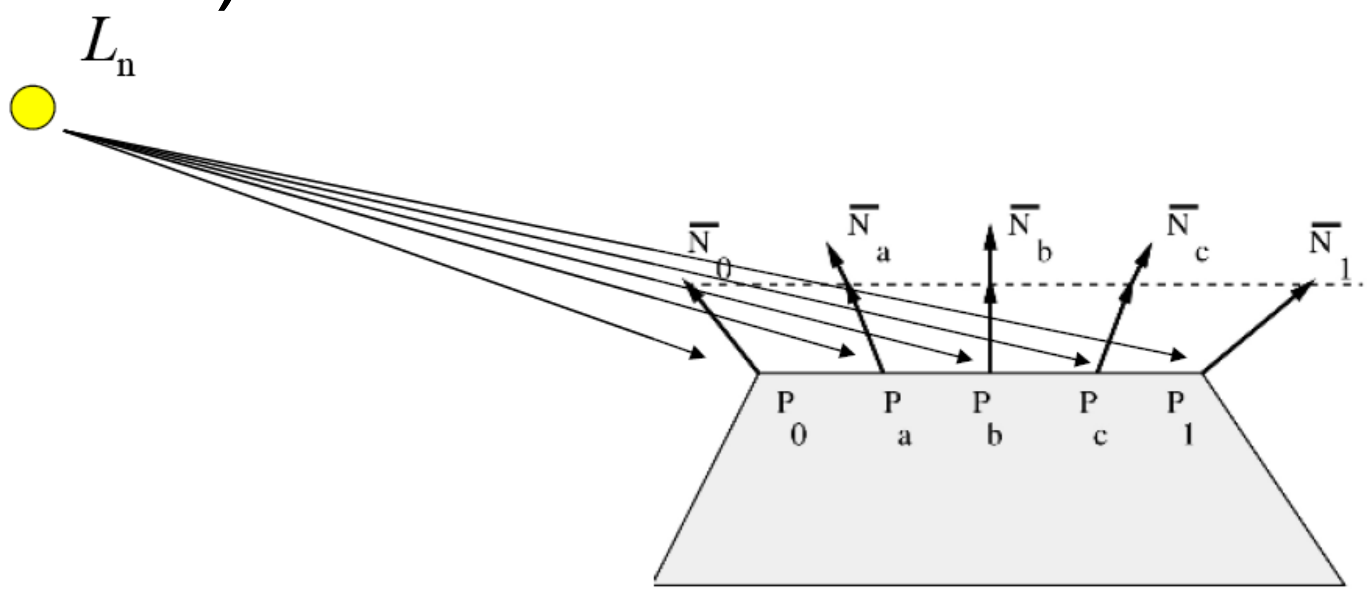
Gouraud shading is not good when the polygon count is low



Phong Shading (by Bui Tuong Phong)

Phong Shading (by Bui Tuong Phong)

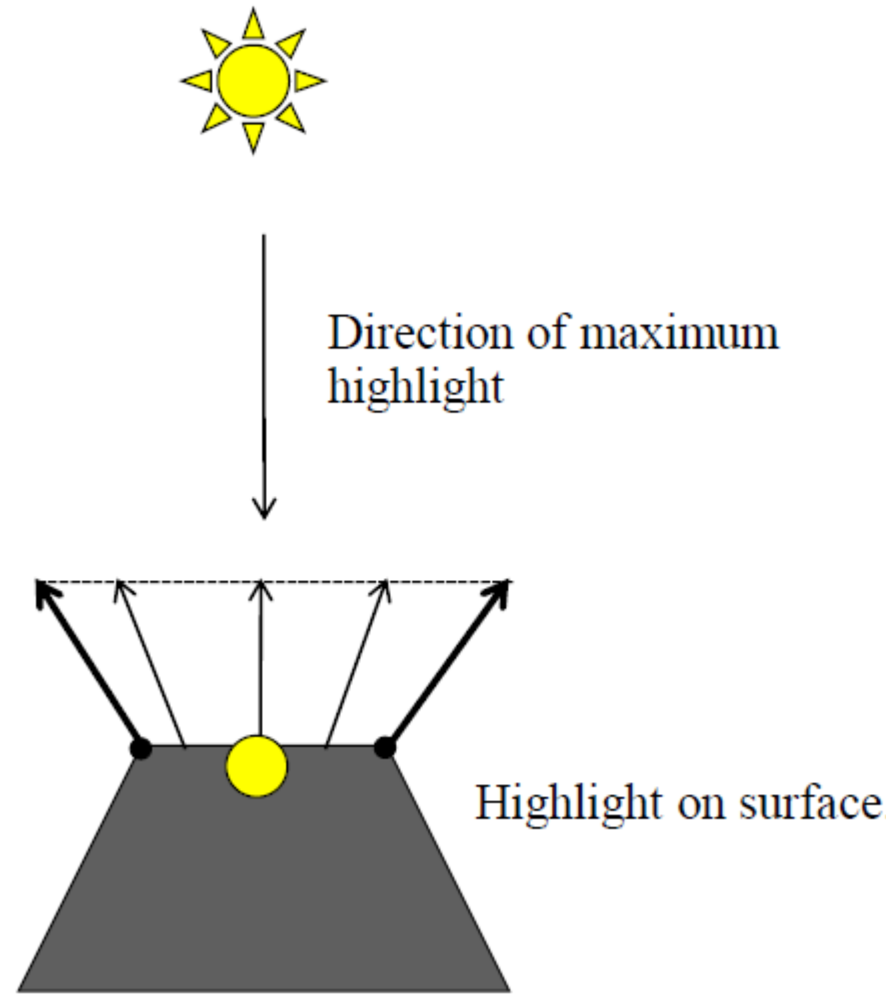
- Doing the lighting computation at every pixel during rasterization
- Interpolating the normal vectors at the vertices (again using barycentric coordinates)



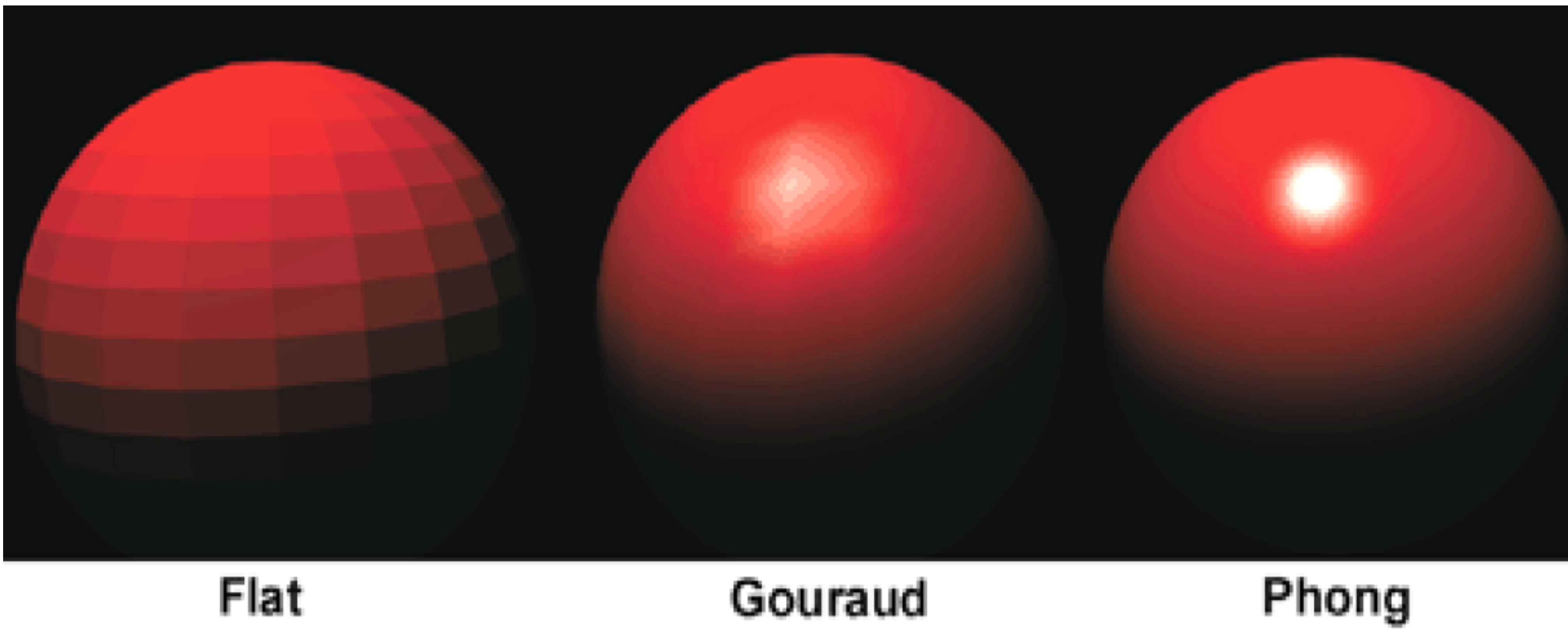
Phong shading model

Phong Shading

- For specular reflection, highlight falls off with $\cos^n \alpha$
- Can well produce a highlight that occurs in the middle of the face.



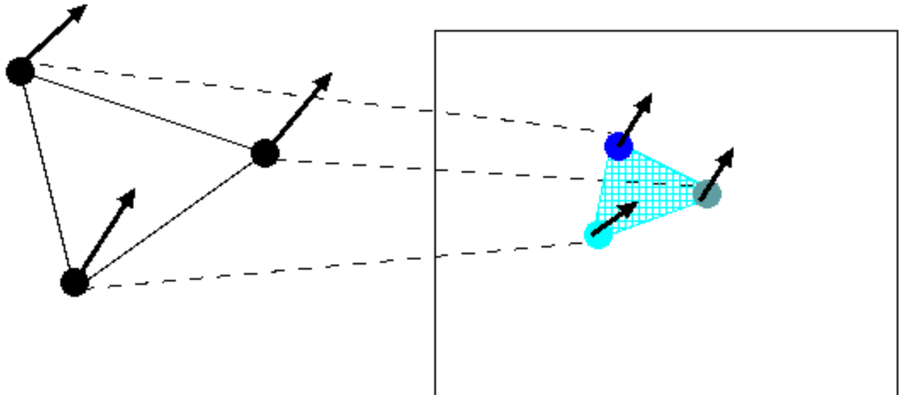
Phong example



Phong Shading with GLSL

Vertex Shader (*.
vert)
Prepare the normal
vector per vertex

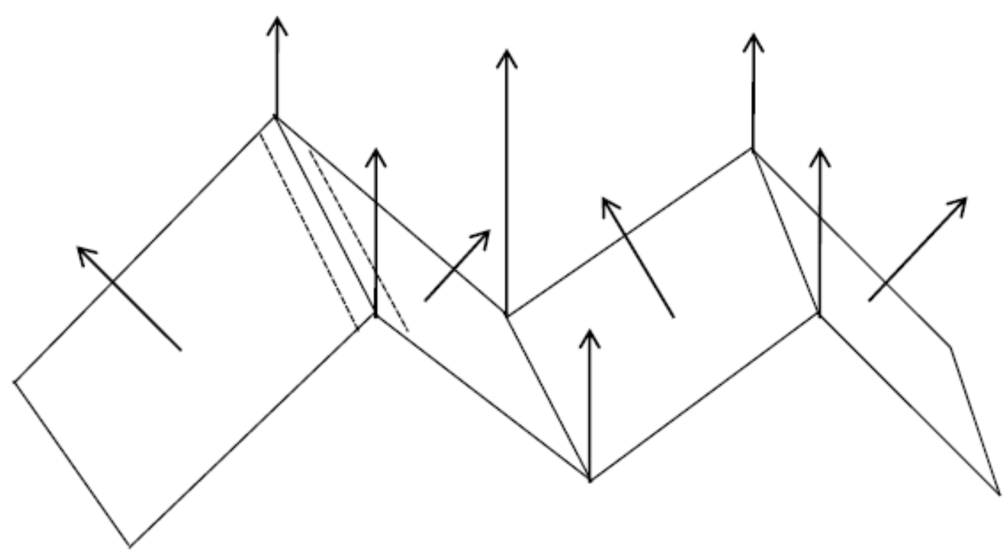
Fragment Shader
(*.frag)
Interpolates the normal
vector and do the lighting
computation for every pixel



Problems with interpolation shading.

- Problems with computing vertex normals.

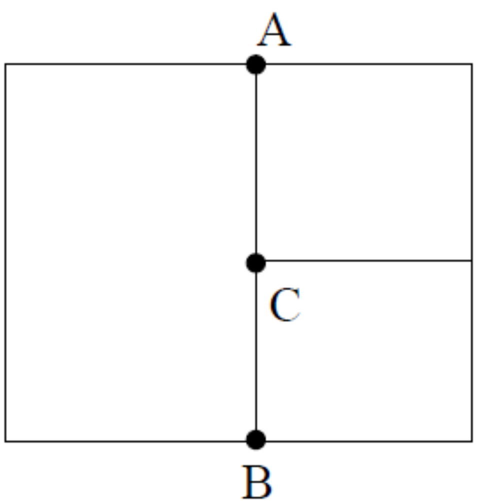
Face surface normals and averaged vertex normals shown.



Unrepresentative so add small polygon strips along edges or test angle and threshold to defeat averaging.

Problems with interpolation shading.

- Problems with computing vertex normals.



A,B are shared by all polygons, but C is not shared by the polygon on the left.

Shading information calculated to the right of C will be different from that to the left.

Shading discontinuity.

Solution 1: subdivide into triangles that that share all the vertices
Solution 2 : introduce a 'ghost' vertex that shares C's values

Recommended Reading

- Foley et al. Chapter 16, sections 16.1.6 up to and including section 16.3.4.
- Introductory text Chapter 14, sections 14.1.6 up to and including section 14.2.6.
- Fundamentals of Computer Graphics, Shiley et al. Chapter 9