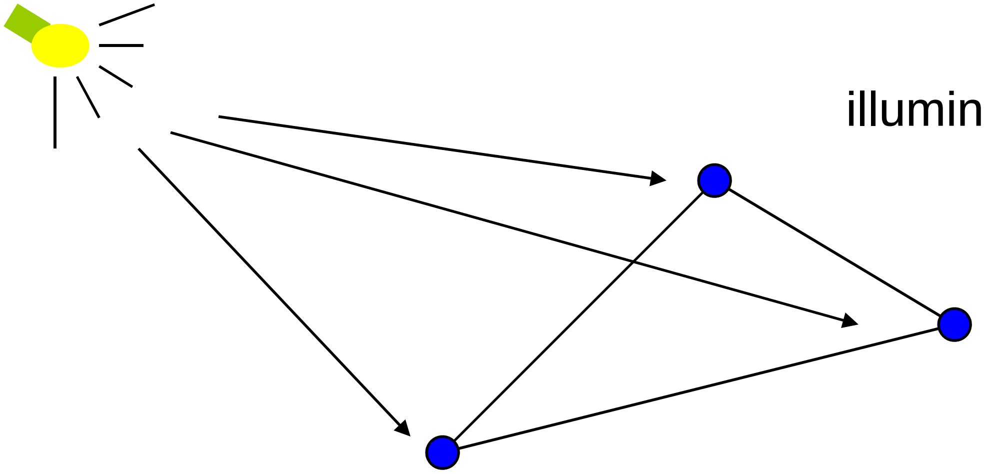
Illumination and Shading

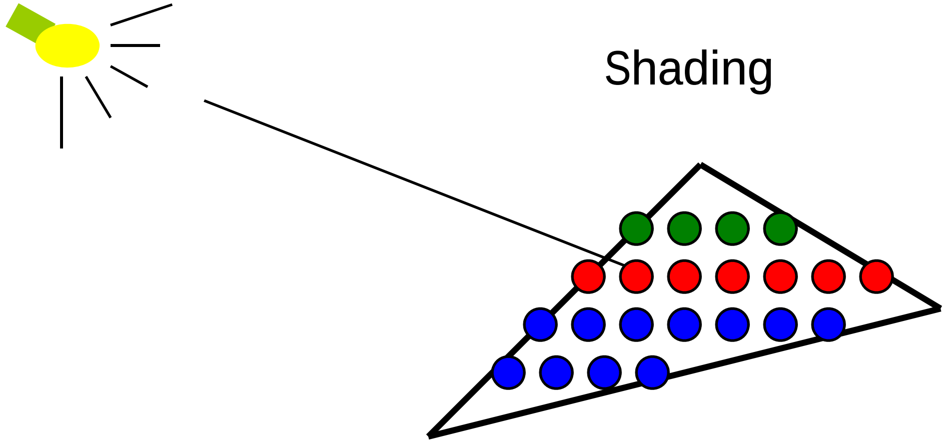
Illumination (Lighting)

- Model the interaction of light with surface points to determine their final color and brightness
- OpenGL computes illumination at vertices



Shading

- Apply the lighting model at a set of points across the entire surface

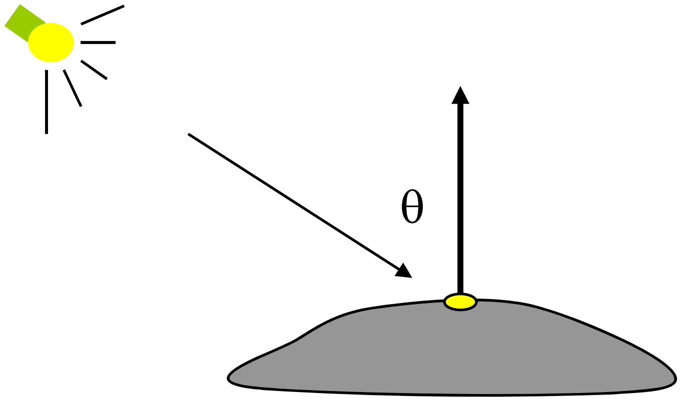


Illumination Model

- The governing principles for computing the illumination
- A illumination model usually considers:
  - Light attributes (light intensity, color, position, direction, shape)
  - Object surface attributes (color, reflectivity, transparency, etc)
  - Interaction among lights and objects (object orientation)
  - Interaction between objects and eye (viewing dir.)

Illumination Calculation

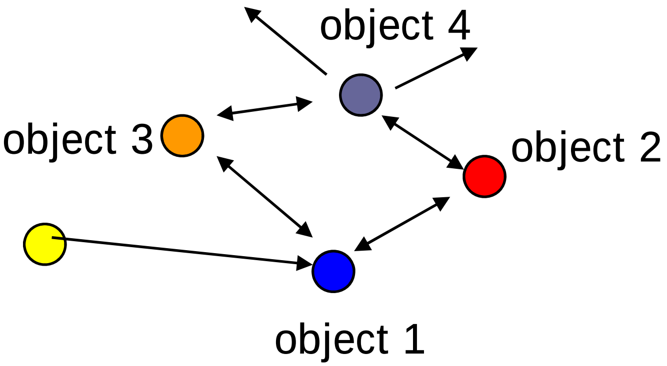
- Local illumination: only consider the light, the observer position, and the object material properties

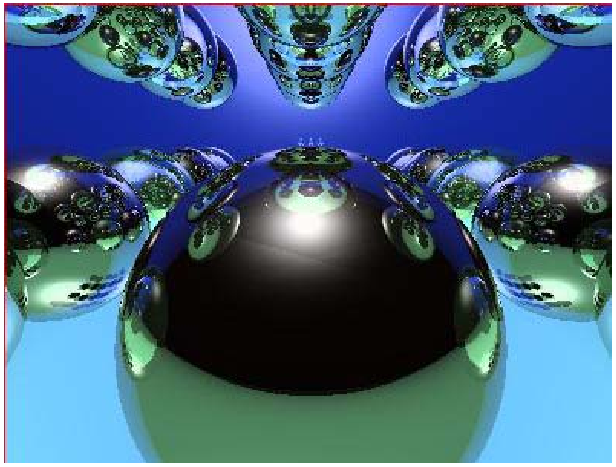


- Example: OpenGL

Illumination Models

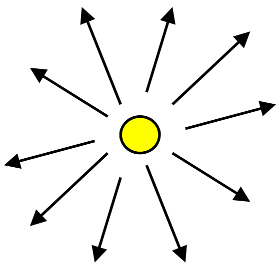
- Global illumination: take into account the interaction of light from all the surfaces in the scene



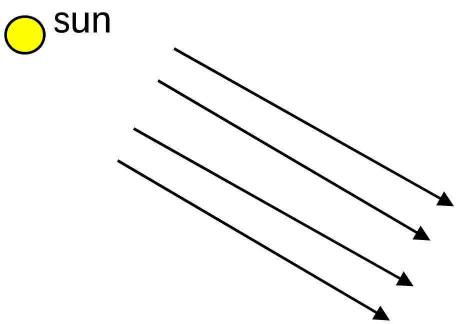


- Example: Ray Tracing (CIS681)

Basic Light Sources

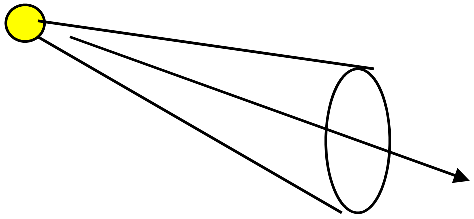


Point light



Directional light

Light intensity can be independent or dependent of the distance between object and the light source



Spot light

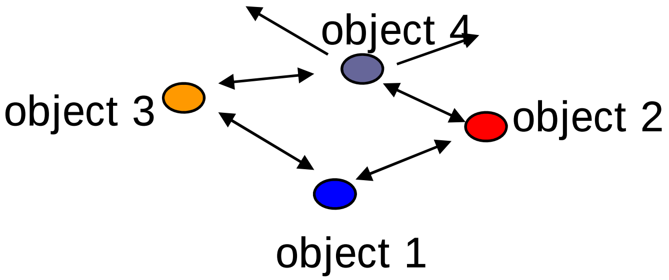
Simple local illumination

- The model used by OpenGL – consider three types of light contribution to compute the final illumination of an object
    - Ambient
    - Diffuse
    - Specular
- Final illumination of a point (vertex) =

  ambient + diffuse + specular

Ambient light contribution

- Ambient light (background light): the light that is scattered by the environment
- A very simple approximation of global illumination



- Independent of the light position,object orientation, observer's position or orientation – ambient light has no direction (Radiosity is the calculation of ambient light)

Ambient lighting example

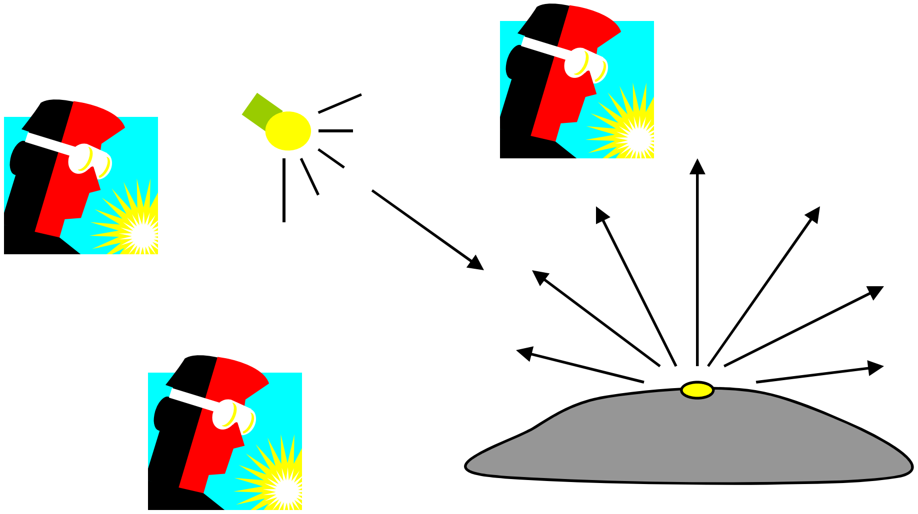
Ambient light calculation

- Each light source has an ambient light contribution (I_a)
- Different objects can reflect different amounts of ambient (different ambient reflection coefficient Ka, $0 <= K_a <= 1$)
- So the amount of ambient light that can be seen from an object is:

$$\boxed{\text{Ambient} = I_a * K_a}$$

Diffuse light contribution

- Diffuse light: The illumination that a surface receives from a light source and reflects equally in all direction

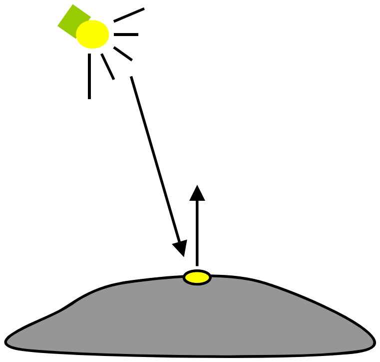


It does not matter where the eye is

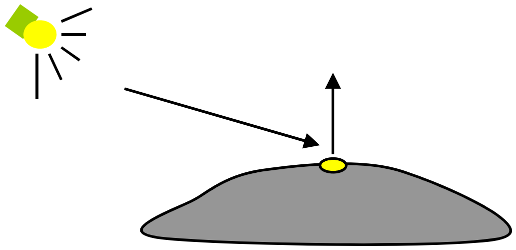
Diffuse lighting example

Diffuse light calculation

- Need to decide how much light the object point receive from the light source – based on Lambert's Law



Receive more light



Receive less light

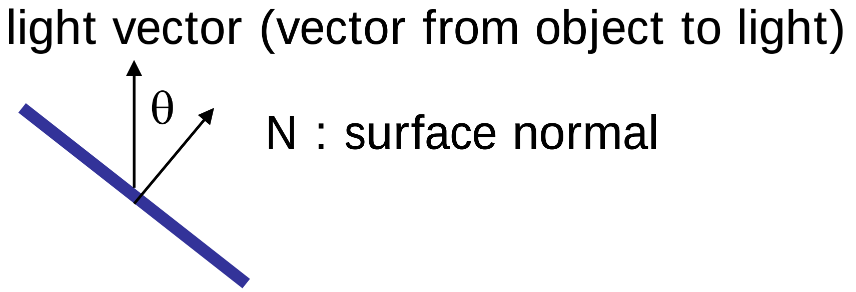
Diffuse light calculation (2)

- Lambert's law: the radiant energy D that a small surface patch receives from a light source is:

$$D = I * \cos(\theta)$$

I: light intensity

θ: angle between the light vector and the surface normal

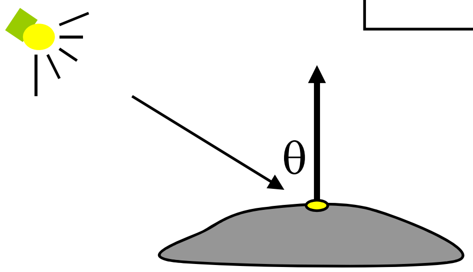


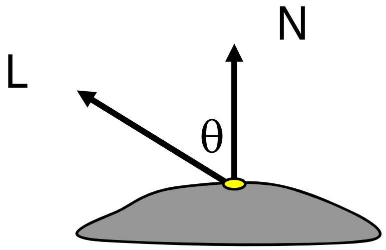
Diffuse light calculation (3)

- Like the ambient light case, different objects can reflect different amount of diffuse light (different diffuse reflection coefficient K_d, $0 <= K_d <= 1$))

- So, the amount of diffuse light that can be seen is:

$$\boxed{\text{Diffuse} = K_d * I * \cos(\theta)}$$

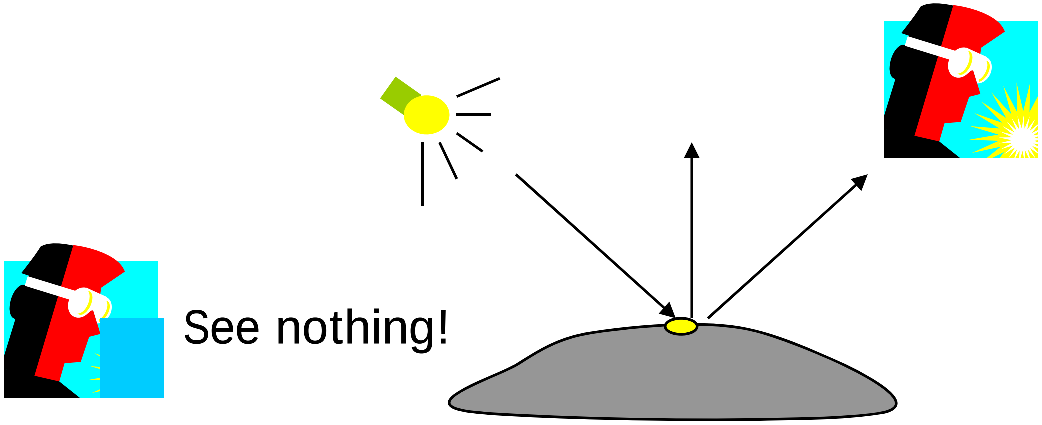




$\cos(\theta) = N.L$

Specular light contribution

- The bright spot on the object
- The result of total reflection of the incident light in a concentrate region

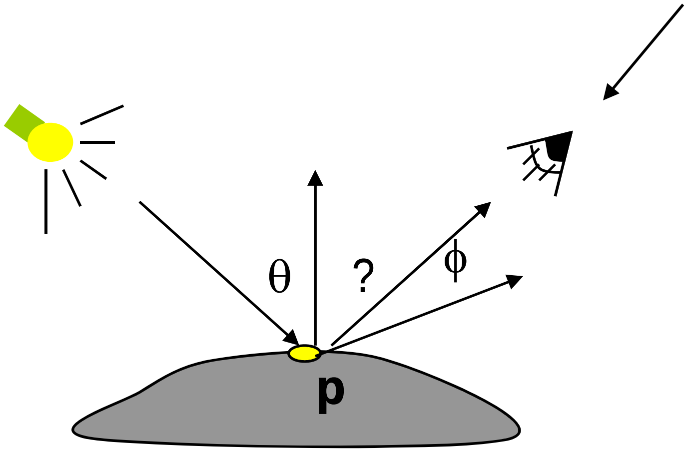


Specular light example

Specular light calculation

- How much reflection you can see depends on where you are

The only position the eye can see specular from P if the object has an ideal reflection surface



But for a non-perfect surface you will still see specular highlight when you move a little bit away from the idea reflection direction

When ϕ is small, you see more specular highlight

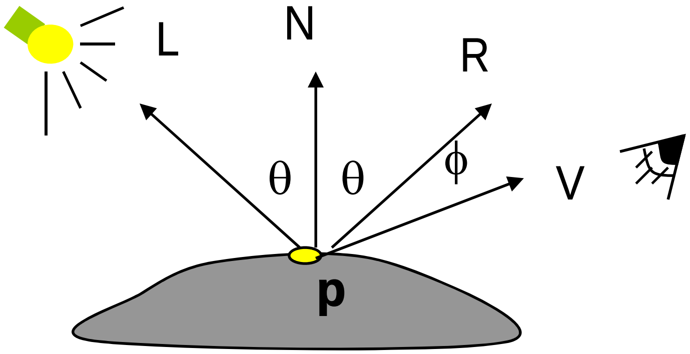
Specular light calculation (2)

- Phong lighting model

$$\boxed{\text{specular} = K_s * I * \cos^n(\phi)}$$

K_s: specular reflection coefficient
N: surface normal at P
I: light intensity
ϕ: angle between V and R

$\cos_{\mathbf{n}}(\phi)$: the larger is n, the smaller
is the cos value
$\cos(\theta) = R.V$



Specular light calculation (3)

- The effect of ‘n’ in the phong model

n = 10

n = 30

n = 90

n = 270

Put it all together

- Illumination from a light:

$$\text{Illum} = \text{ambient} + \text{diffuse} + \text{specular}$$

n

$$= K_a * I + K_d * I * (N.L) + K_s * I * \underline{(R.V)^n}$$

or

(N.H)

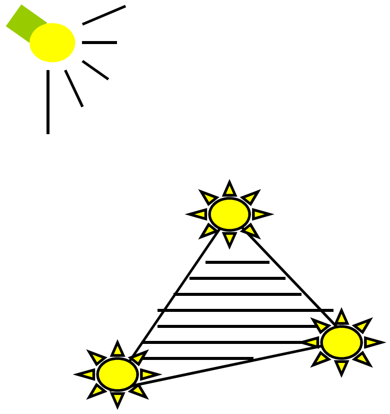
- If there are N lights

Total illumination for a point P = Σ (Illum)

- Some more terms to be added (in OpenGL):
  - Self emission
  - Global ambient
  - Light distance attenuation and spot light effect

Lighting in OpenGL

- Adopt Phong lighting model (specular) plus diffuse and ambient lights
  - Lighting is computed at vertices
    - Interpolate across surface (Gouraud/smooth shading) OR
    - Use a constant illumination (get it from one of the vertices)



- Setting up OpenGL Lighting:
  - Light Properties
  - Enable/Disable lighting
  - Surface material properties
  - Provide correct surface normals
  - Light model properties

Light Properties

- Properties:
  - Colors / Position and type / attenuation

`glLightfv(light, property, value)`

① ② ③

(1) constant: specify which light you want to set the property
example: GL_LIGHT0, GL_LIGHT1, GL_LIGHT2 ... you can create multiple lights (OpenGL allows at least 8 lights)

(2) constant: specify which light property you want to set the value
example: GL_AMBIENT, GL_DIFFUSE, GL_SPECULAR, GL_POSITION
(check the red book for more)

(3) The value you want to set to the property

Property Example

- Define colors and position a light

```
GLfloat light_ambient[] = {0.0, 0.0, 0.0, 1.0};
GLfloat  light_diffuse[] = {1.0, 1.0, 1.0, 1.0};
GLfloat light_specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat light_position[] = {0.0, 0.0, 1.0, 1.0};

glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient);
glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse);
glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular);
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

colors

Position

What if I set the Position to (0,0,1,0)?

Types of lights

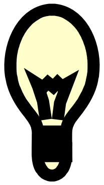
- OpenGL supports two types of lights
  - Local light (point light)
  - Infinite light (directional light)
- Determined by the light positions you provide
  - w = 0: infinite light source (faster)
  - w != 0: point light – position = (x/w, y/w, z/w)

```
GLfloat light_position[] = {x,y,z,w};
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

Turning on the lights

- Turn on the power (for all the lights)
  - glEnable(GL_LIGHTING);

  - glDisable(GL_LIGHTING);



- Flip each light's switch
  - glEnable(GL_LIGHT*n*) (n = 0,1,2,...)

Controlling light position

- Modelview matrix affects a light’s position
- You can specify the position relative to:
  - Eye space: the highlight remains in the same position relative to the eye
    - call glLightfv() before gluLookAt()
  - World space: a light’s position/direction appears fixed in the scene
    - Call glLightfv() after gluLookAt()
- See Nat Robin’s Demo
http://www.xmission.com/~nate/tutors.html

Material Properties

- The color and surface properties of a material (dull, shiny, etc)
- How much the surface reflects the incident lights (ambient/diffuse/specular reflecetion coefficients)

glMaterialfv(face, property, value)

Face: material property for which face (e.g. GL_FRONT, GL_BACK,
GL_FRONT_AND_BACK)
Property: what material property you want to set (e.g. GL_AMBIENT, GL_DIFFUSE,
GL_SPECULAR, GL_SHININESS, GL_EMISSION, etc)
Value: the value you can to assign to the property

Material Example

- Define ambient/diffuse/specular reflection and shininess

```
GLfloat mat_amb_diff[] = {1.0, 0.5, 0.8, 1.0};
GLfloat mat_specular[] = {1.0, 1.0, 1.0, 1.0};
GLfloat shininess[] = {5.0};

glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT_AND_DIFFUSE,
                    mat_amb_diff);
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_speacular);
glMaterialfv(GL_FRONT, GL_SHININESS, shininess);
```

refl. coefficient

(range: dull 0 – very shiny128)

Global light properties

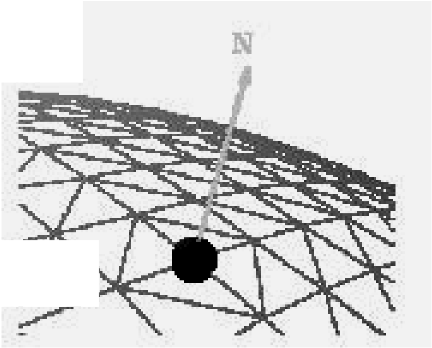
glLightModelfv(property, value)

- Enable two sided lighting
  - property = GL_LIGHT_MODEL_TWO_SIDE
  - value = GL_TRUE (GL_FALSE if you don’t want two sided lighting)
- Global ambient color
  - Property = GL_LIGHT_MODEL_AMBIENT
  - Value = (red, green, blue, 1.0);
- Check the red book for others

Surface Normals

- Correct normals are essential for correct lighting
- Associate a normal to each vertex

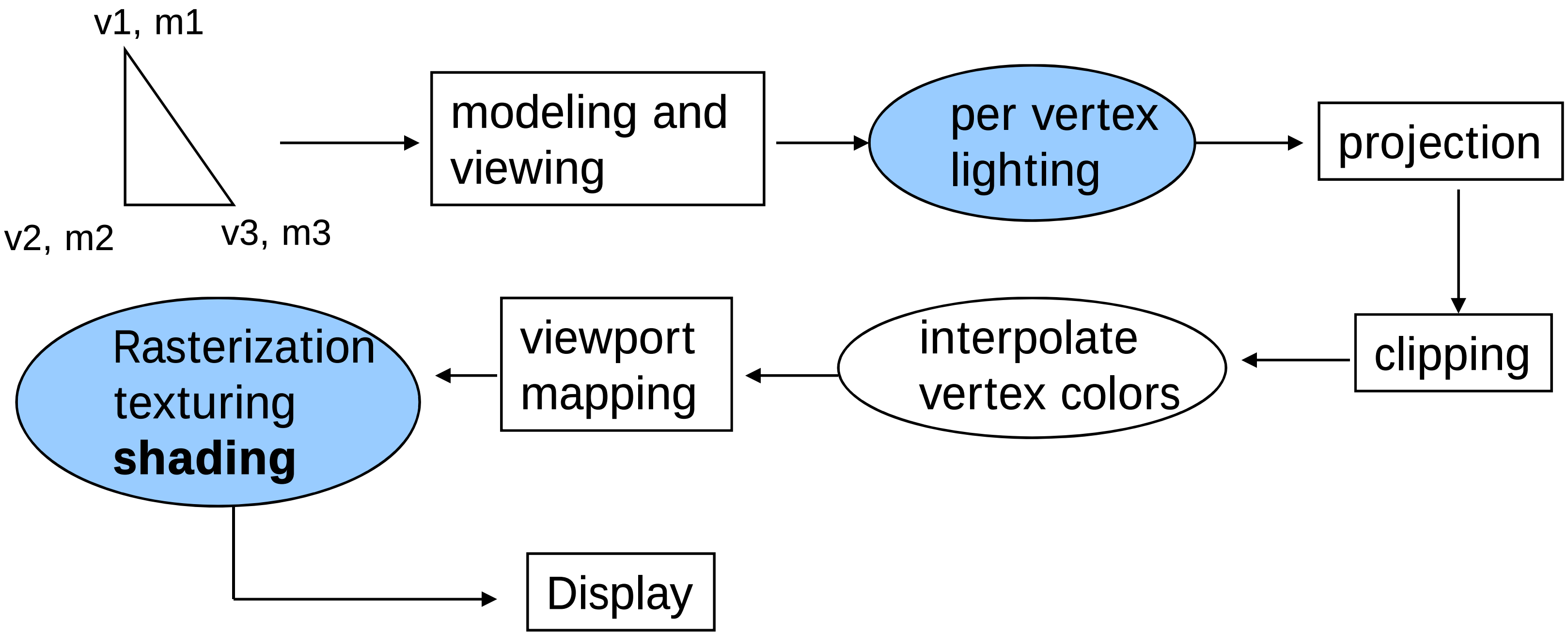
```
glBegin(...)
 glNormal3f(x,y,z)
 glVertex3f(x,y,z)
 ...
glEnd()
```



- The normals you provide need to have a unit length
  - You can use glEnable(GL_NORMALIZE) to have OpenGL normalize all the normals

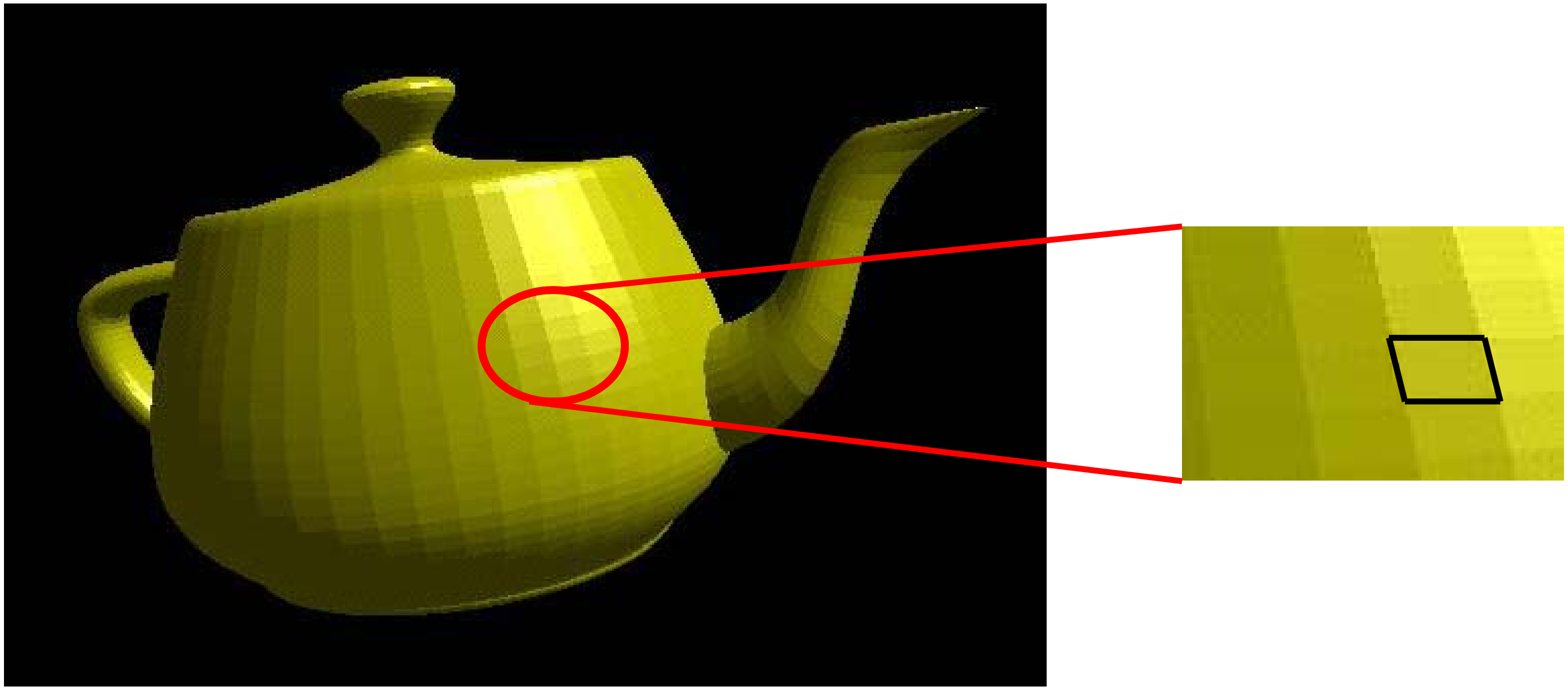
Lighting revisit

- Where is lighting performed in the graphics pipeline?



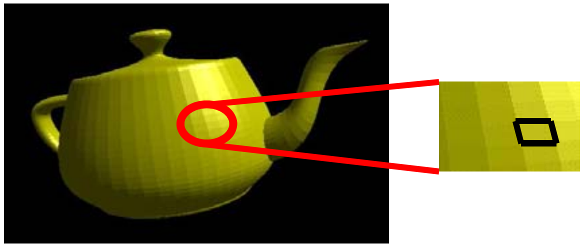
Polygon shading model

- Flat shading – compute lighting once and assign the color to the whole polygon



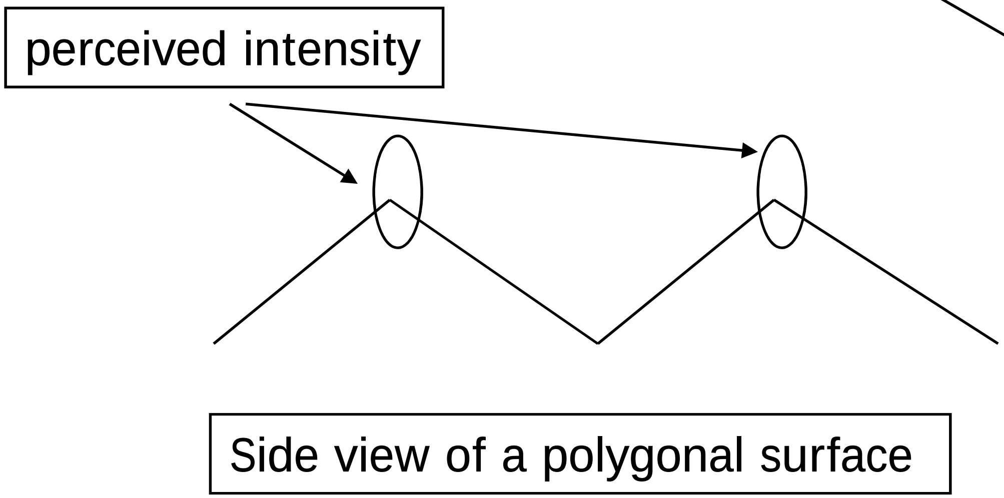
Flat shading

- Only use one vertex (usually the first one) normal and material property to compute the color for the polygon
- Benefit: fast to compute
- It is used when:
  - The polygon is small enough
  - The light source is far away (why?)
  - The eye is very far away (why?)
- OpenGL command: glShadeModel(GL_FLAT)



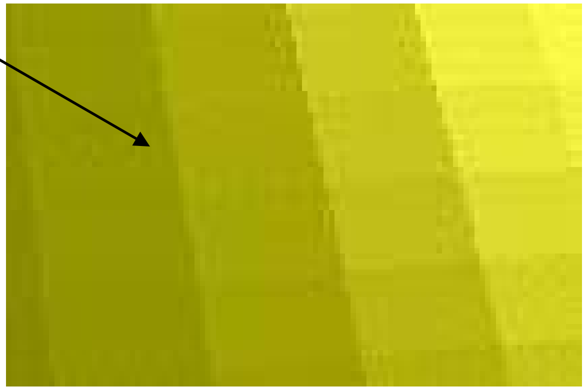
Mach Band Effect

- Flat shading suffers from “mach band effect”
- Mach band effect – human eyes accentuate the discontinuity at the boundary



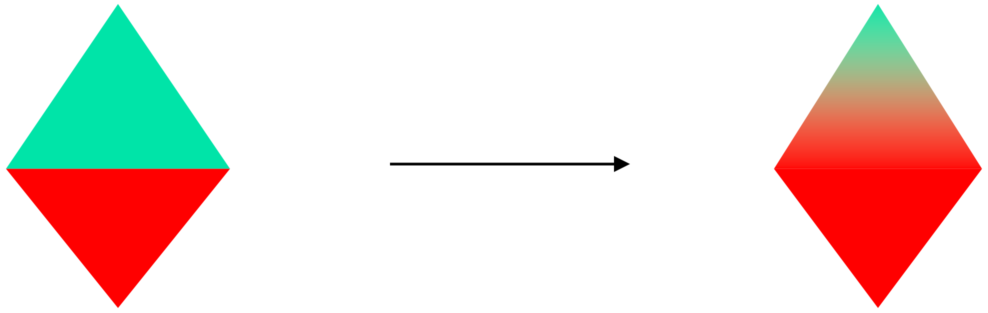
perceived intensity

Side view of a polygonal surface



Smooth shading

- Reduce the mach band effect – remove value discontinuity
- Compute lighting for more points on each face

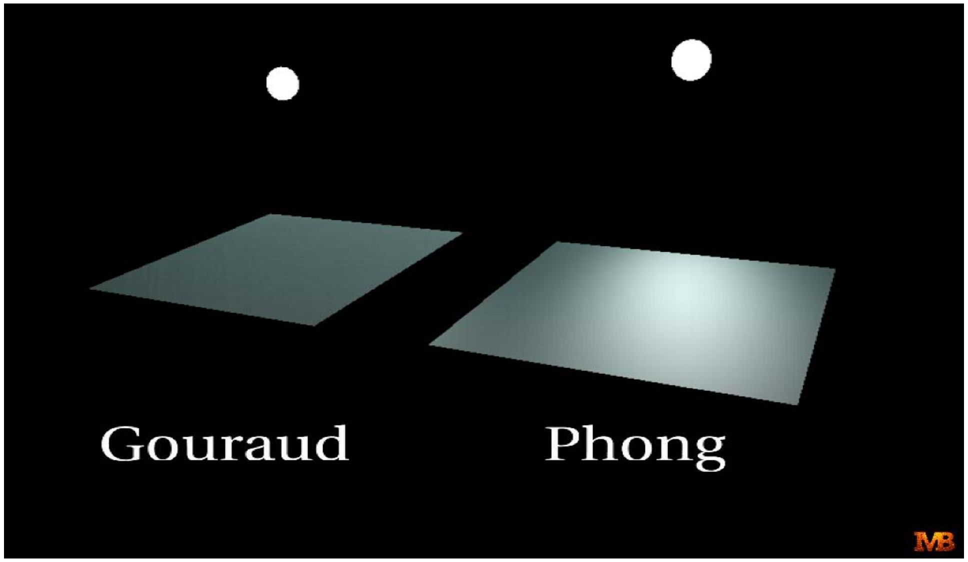


Flat shading

smooth shading

Smooth shading

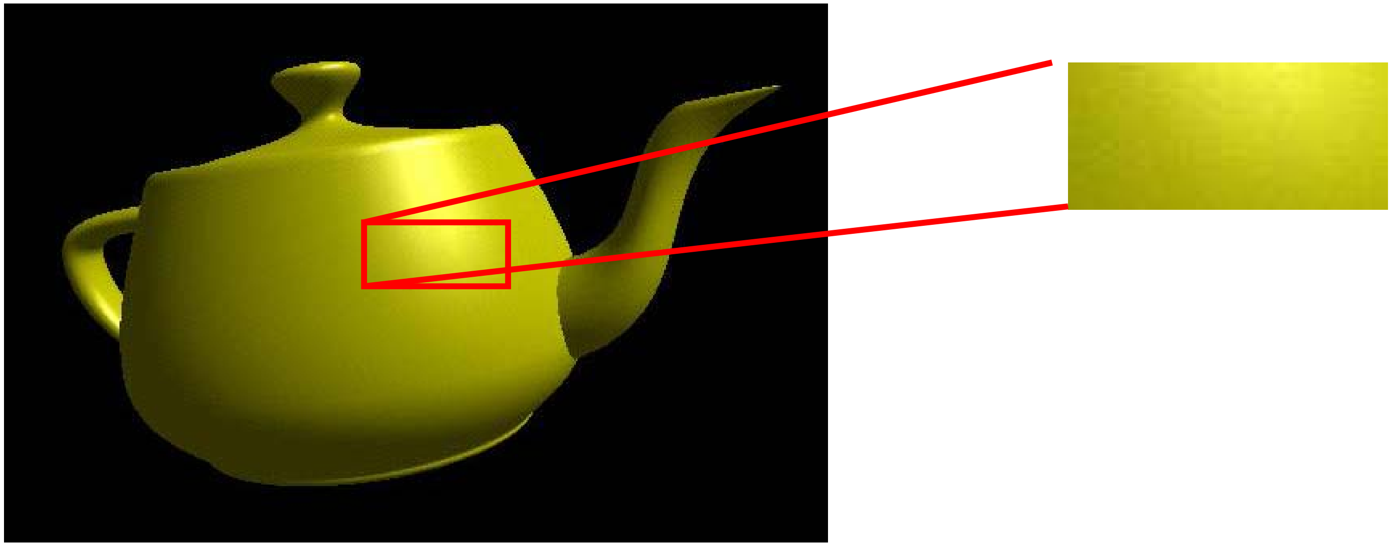
- Two popular methods:
  - Gouraud shading (used by OpenGL)
  - Phong shading (better specular highlight, not supported by OpenGL)



Gouraud Shading (1)

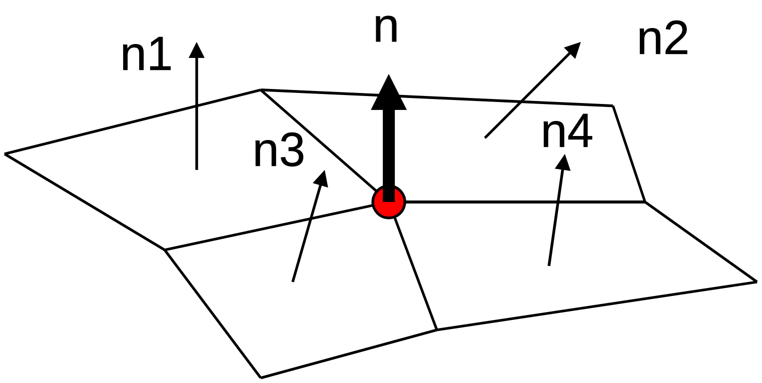
- The smooth shading algorithm used in OpenGL

  `glShadeModel(GL_SMOOTH)`
- Lighting is calculated for each of the polygon vertices
- Colors are interpolated for interior pixels



Gouraud Shading (2)

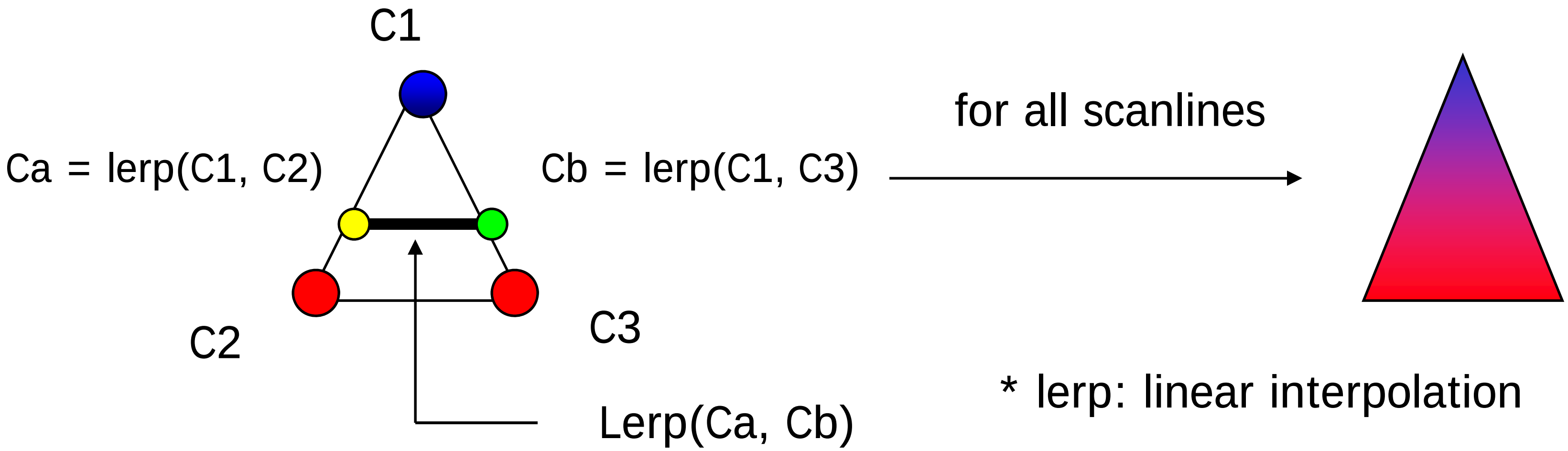
- Per-vertex lighting calculation
- Normal is needed for each vertex
- Per-vertex normal can be computed by averaging the adjust face normals



$n = (n1 + n2 + n3 + n4) / 4.0$

Gouraud Shading (3)

- Compute vertex illumination (color) before the projection transformation
- Shade interior pixels: color interpolation (normals are not needed)



C1

Ca = lerp(C1, C2)

Cb = lerp(C1, C3)

for all scanlines

C2

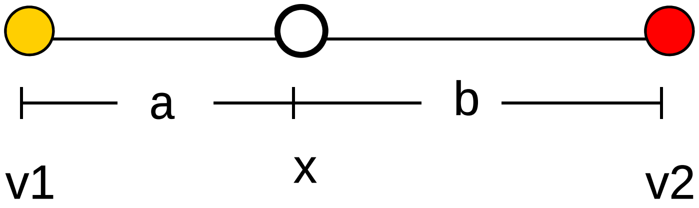
C3

Lerp(Ca, Cb)

* lerp: linear interpolation

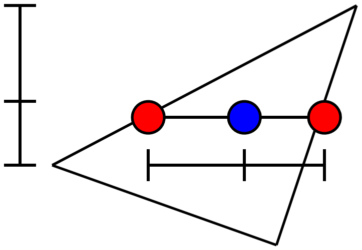
Gouraud Shading (4)

- Linear interpolation



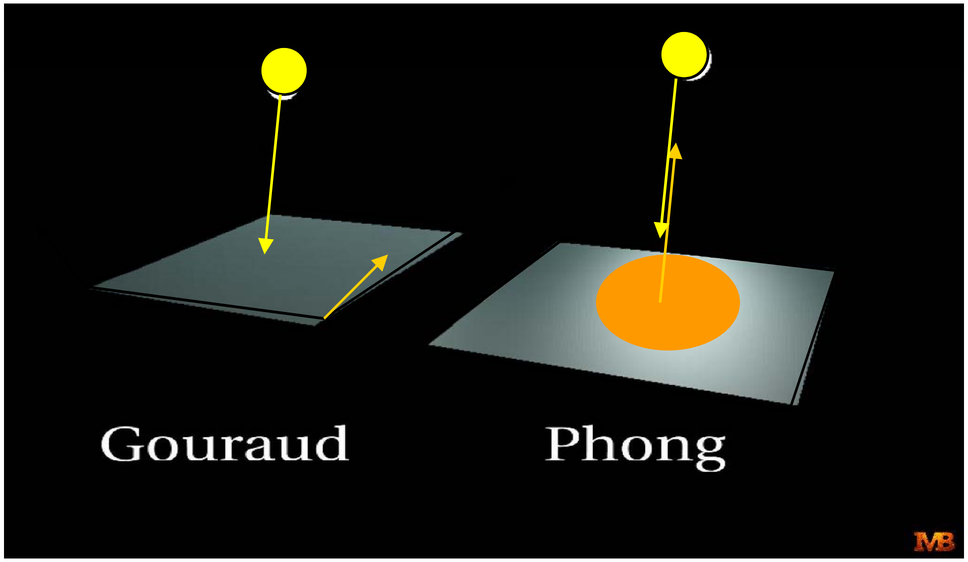
x = a / (a+b) * v2 + b/(a+b) * v1

- Interpolate triangle color: use y distance to interpolate the two end points in the scanline, and use x distance to interpolate interior pixel colors



Gouraud Shading Problem

- Lighting in the polygon interior can be inaccurate



Gouraud Shading Problem

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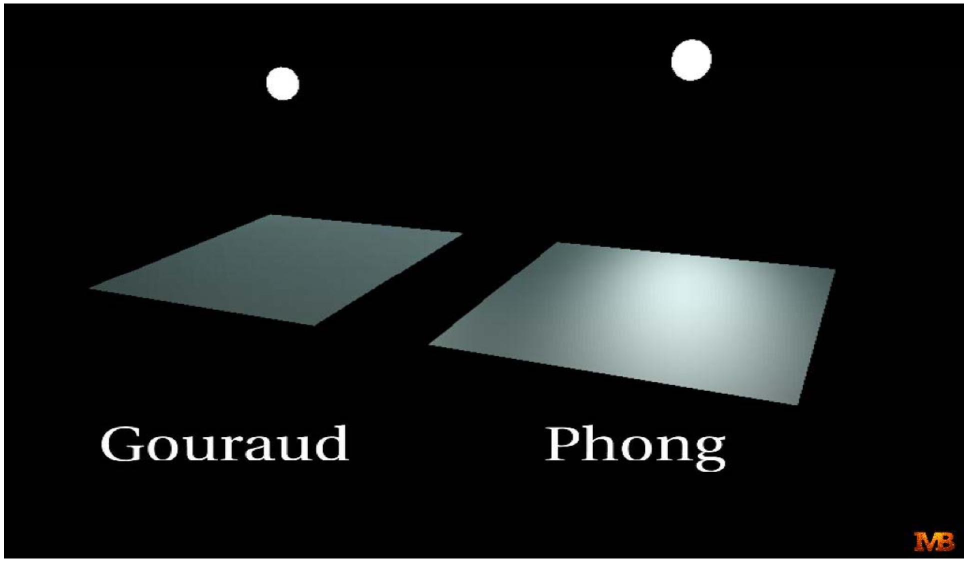
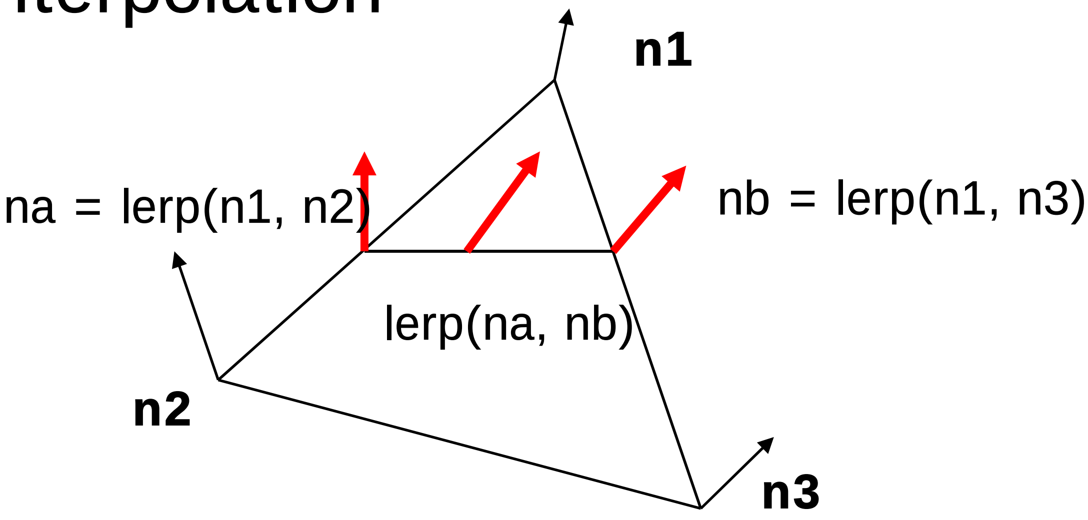


Phong Shading

- Instead of color interpolation, we calculate lighting for each pixel inside the polygon (per pixel lighting)
- We need to have normals for all the pixels – not provided by the user
- Phong shading algorithm interpolates the normals and compute lighting during rasterization (need to map the normal back to world or eye space though - WHY?)

Phong Shading (2)

- Normal interpolation



- Slow – not supported by OpenGL and most of the graphics hardware