Illumination Models and Surface-Rendering Methods

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Illumination and surface rendering model

- Once visible surface has been identified by hidden surface algorithm, a shading model is used to compute the intensities and color to display for the surface. For realistic displaying of 3d scene it is necessary to calculate appropriate color or intensity for that scene.

Illumination and surface rendering model

- Illumination model or a lighting model is the model for calculating light intensity at a single surface point. Sometimes also referred to as a shading model.

Illumination and surface rendering model

- An illumination model is also called lighting model and sometimes called as a shading model which is used to calculate the intensity of light that we should see at a given point on the surface of a object.

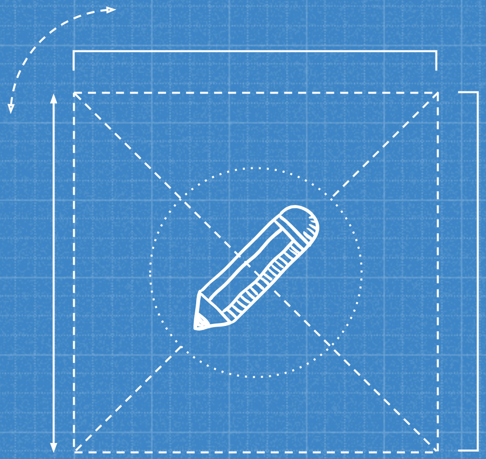
Illumination and surface rendering model

- A surface-rendering algorithm uses the intensity calculations from an illumination model.

- Components of Illumination model
  - Light Sources: type , color, and direction of the light source
  - Surface Properties : réflectance, opaque/transparent, shiny/dull.

Illumination and rendering

- An illumination model in computer graphics
  - also called a lighting model or a shading model
  - used to calculate the color of an illuminated position on the surface of an object
  - Approximations of the physical laws
- A surface-rendering method determine the pixel colors for all projected positions in a scene



LIGHT SOURCES

Light Sources

- Object that radiates energy are called light sources, such as sun, lamp, bulb, fluorescent tube etc.
- Sometimes light sources are referred as light emitting object and light reflectors. Generally light source is used to mean an object that is emitting radiant energy e.g. Sun.

Light Sources

- Total Reflected Light = Contribution from light sources + contribution from reflecting surfaces

Light Sources

- Point source: Simplest model for a light emitter like tungsten filament bulb
- Distributed light source: The area of the source is not small compared to the surfaces in the scene like fluorescent light on any object in a room
- Diffuse reflection: Scatter reflected light in all direction by rough or grainy surfaces.
- Specular-reflection: highlights or bright spots created by light source, particularly on shiny surfaces than on dull surfaces.

ILLUMINATION MODELS

Illumination Models

Illumination models are used to calculate light intensities that we should see at a given point on the surface of an object. Lighting calculations are based on the optical properties of surfaces, the background lighting conditions and the light source specifications. All light sources are considered to be point sources, specified with a co-ordinates position and an intensity value (color).

Some illumination models are:

- Ambient Light
- Diffuse Reflection
- Specular Reflection and phong model

Ambient light

- This is a simplest illumination model
- We can think of this model, which has no external light source-self-luminous objects. A surface that is not exposed directly to light source still will be visible if nearby objects are illuminated.
- The combination of light reflections form various surfaces to produce a uniform illumination is called ambient light or background light.
- Also called background light.

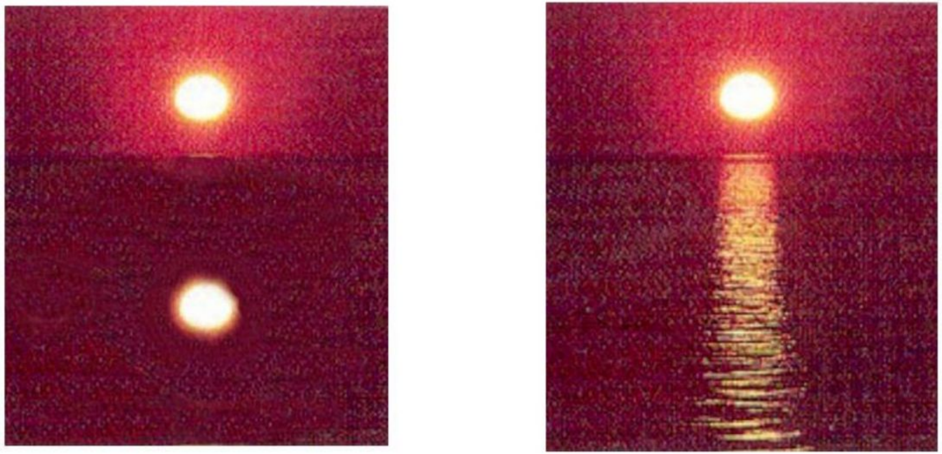
Diffuse Reflection

- Illuminating object by a point light source, whose rays enumerate uniformly in all directions from a single point. The object's brightness varies from one part to another, depending on the direction of and distance to the light source.
- Color of an object is determined by the color of the diffuse reflection of the incident light.
- If any object surface is red then there is a diffuse reflection for red component of light and all other components are absorbed by the surface.

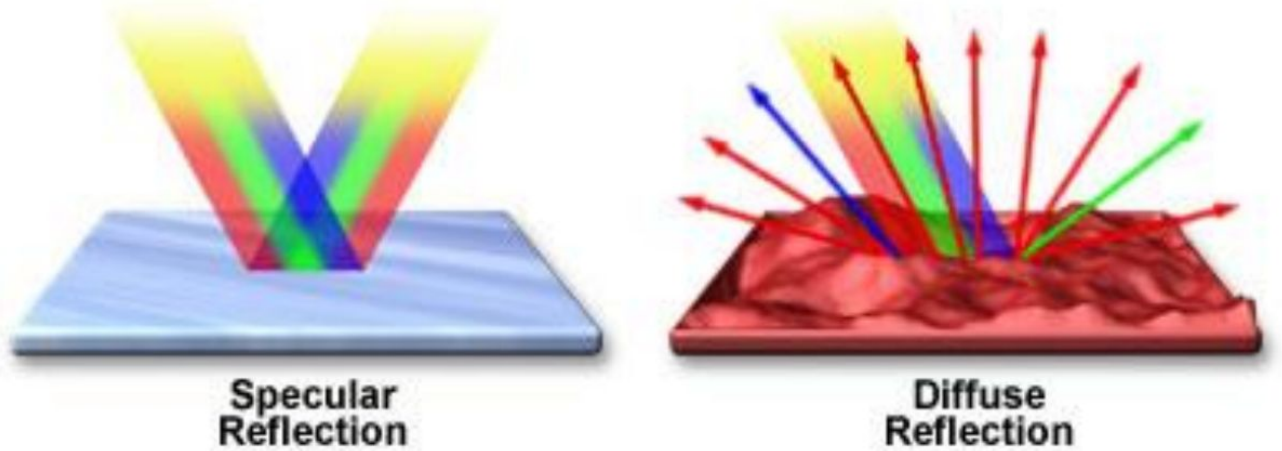
Specular reflection and phong model

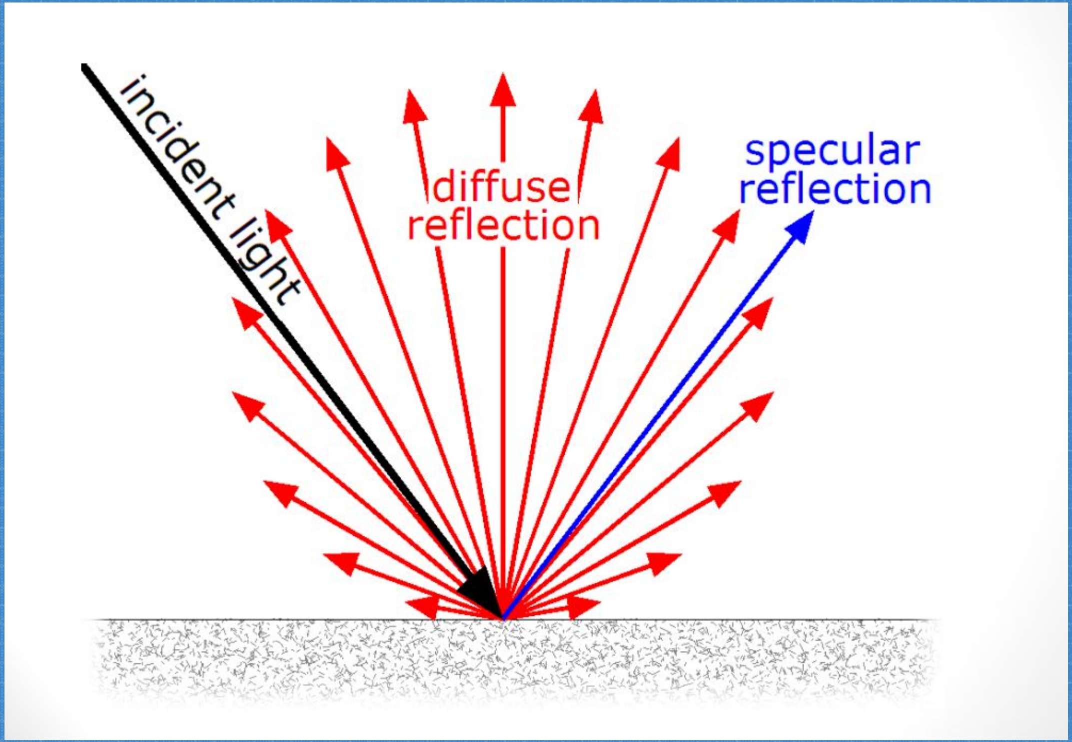
- When we look at an illuminated shiny surface, such as polished metal, a person's forehead, we see a highlight or bright spot, at certain viewing direction. Such phenomenon is called specular reflection.
- It is the result of total or near total reflection of the incident light in a concentrated region around the "specular reflection angle = angle of incidence".
- Perfect reflector (mirror) reflects all lights to the direction where angle of reflection is identical to the angle of incidence
- It accounts for the highlight.

Two kinds of reflection



Specular reflection   Diffuse reflection


Specular and Diffuse Reflection
Specular Reflection
Diffuse Reflection
Figure 1


incident light
diffuse reflection
specular reflection

Intensity Attenuation

As radiant energy from a point light source travels through space, its amplitude is attenuated by the factor $1/d^2$, where d is the distance that the light has traveled.

This means that a surface close to the light source (small d) receives higher incident intensity from the source than a distant surface (large d).

Intensity Attenuation

Therefore to produce realistic lighting effects, illumination model should take intensity attenuation into account. Otherwise we are likely to illuminate all surfaces with same intensity.

- For a point light source attenuation factor is $1/d^2$
- And for a distributed light source attenuation factor is given by inverse quadratic attenuation function,

$$f(d) = 1/(a_0 + a_1 d + a_2 d^2)$$

Intensity Attenuation

- Intensity attenuation must be considered for producing realistic lighting effects.
- Intensity of radiant energy at a point *d* distance far from source is attenuated by $1/d^2$
- **attenuation factor $1/d^2$** *produces* too much intensity variation
- Using inverse linear quadratic function of d for intensity attenuation as:

$$f(d) = \frac{1}{a_0 + a_1 d + a_2 d^2}$$

  - a_0 can be adjusted to prevent f(d) from becoming too large when d is very small
  - Magnitude of attenuation function is limited to 1 as

$$f(d) = \min\left(1, \frac{1}{a_0 + a_1 d + a_2 d^2}\right)$$

The Phong illumination model considering attenuation is:

$$I = k_a I_a + \sum_{i=1}^{n} f(d_i) I_{li} \left[k_d (N.L_i) + k_s (N.H_i)^{n_s}\right]$$

Color Consideration

- For RGB description, each color in a scene is expressed in terms of R,G and B components
- Various methods:
  - Described by considering the RGB components for e.g. (k_{dR}, k_{dG}, k_{dB}) of diffuse reflection coefficient vector
    - e.g. For blue light $(k_{dR}=k_{dG}=0)$

$$I_B = k_{aB} I_{aB} + \sum_{i=1}^{n} f(d_i) I_{lBi} \left[k_{dB} (N.L_i) + k_{sB} (N.H_i)^{n_s} \right]$$

  - Described by specifying components of diffuse and specular color vectors for each surface and retaining the reflectivity (k) as a single valued constants

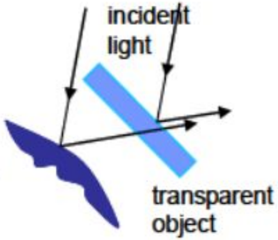
$$I_B = k_a S_{dB} I_{aB} + \sum_{i=1}^{n} f(d_i) I_{lBi} \left[k_d S_{dB} (N.L_i) + k_s S_{sB} (N.H_i)^{n_s} \right]$$

  - Described by specifying wavelength for a color specification. This specification is useful to specify color as more than three components

$$I_B = k_a S_{d\lambda} I_{a\lambda} + \sum_{i=1}^{n} f(d_i) I_{l\lambda i} \left[k_d S_{d\lambda} (N.L_i) + k_s S_{s\lambda} (N.H_i)^{n_s} \right]$$

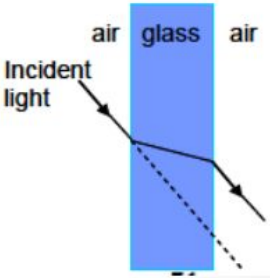
Transparency

- Transparent surface produces both reflected and transmitted light
- Light intensity depends on relative transparency and position of light source or illuminated object behind or in front of the transparent surface
- To model transparent surface, intensity contribution of light from various sources (illuminated objects) that are transmitted from the surface must be considered in the intensity equation



- Both diffuse and specular reflection take place on transparent surface
- Diffuse effects are important for partially transparent surfaces such as frosted glass
- The Snell's law is used to calculate the refracted ray direction

$$\sin\theta_r = \frac{\eta_i}{\eta_r}\sin\theta_i$$



Transparency

- Transmitted intensity I_{trans} through a transparent surface from a background object and Reflected intensity I_{refl} from the transparent surface with ***transparency coefficient*** k_t is given by

$$I = (1-k_t)I_{refl} + k_t I_{trans}$$

where $(1-k_t)$ is ***opacity factor***

Transparency effects Implementation:

1. *Process opaque objects first to determine depths for visible opaque surfaces.*
2. *Depth positions of the transparent objects are compared to the values previously stored in the depth buffer.*
3. *If any transparent surface is visible, its reflected intensity is calculated and combined with the opaque-surface intensity previously stored in the frame buffer.*
4. *Visible transparent surfaces are then rendered by combining their surface intensities with those of the visible and opaque surfaces behind them.*

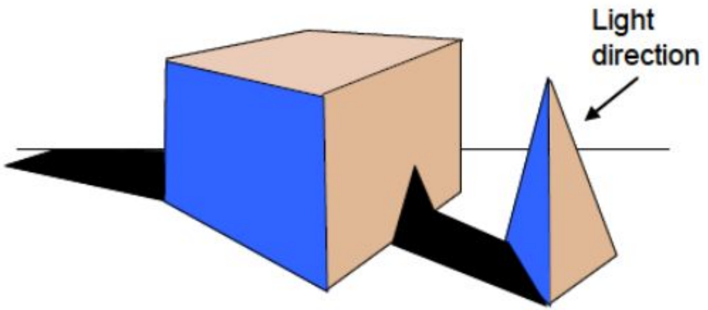
Shadow

- Shadow can help to create realism. Without it, a cup, e.g., on a table may look as if the cup is floating in the air above the table.
- By applying hidden-surface methods with pretending that the position of a light source is the viewing position, we can find which surface sections cannot be "seen" from the light source
=> shadow areas.
- We usually display shadow areas with ambient-light intensity only.

Shadow

- Hidden surface method with light source at the view position can be used

- The shadow area for all light sources are determined and these shadows could be treated as a surface pattern arrays



HALFTONE PATTERNS AND DITHERING TECHNIQUES

Halftone Techniques

Principles and methods

• Halftoning is the process of generating a binary pattern of black and white dots from an image.

• In traditional newspaper and magazine production, this process is carried out photographically by projection of a transparency through a ‘halftone screen’ onto film.

• The screen is a glass plate with a grid etched into it. Different screens can be used to control the size and shape of the dots in the halftoned image.

• The dots vary in size or/and spacing, generate a gradient-like effect.

Halftone Techniques


Figure. Black-and-white cat photo

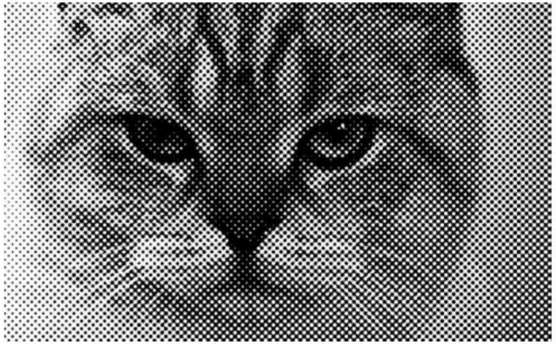


Figure. Halftone image generated by Photoshop

Halftone Techniques

Intensity and dot patterns:

• A simple digital halftoning technique known as patterning involves replacing each pixel by a pattern from a 'binary font'.

• The font with n x n pixels can be used to print an image consisting of n2+1 grey levels representing the intensity.

Halftone Techniques

Dot pattern problems

- Moiré pattern occurs when repeated use of the same dot pattern for different shades results in repeated pattern.
- Increasing dot size on intensity to eliminate graininess in flat tone area. This may demand higher resolution plates/images to maintain consistency.

Dithering Techniques

- Approximating halftone image to create an output image with the same number of dots as the number of pixels in the source image.
- Whenever the pixel value of the image is greater than the value in the matrix, a dot on the output image is filled.
- There are three dithering methods:
    - Random dither
    - Ordered dither
    - Error diffusion dither

Dithering Techniques

Random Dither

- Random values added to the dither matrix.
- Creating noise over the entire picture.
- Soften intensity boundaries.

Dithering Techniques

Ordered Dither

- Pseudo-random values added to the dither matrix.
- The matrix stores pattern of thresholds.

$$D_n = \begin{bmatrix} 4D_{n/2} + D_2(1,1)U_{n/2} & 4D_{n/2} + D_2(1,2)U_{n/2} \\ 4D_{n/2} + D_2(2,1)U_{n/2} & 4D_{n/2} + D_2(2,2)U_{n/2} \end{bmatrix}$$

$$D_2 = \begin{bmatrix} 3 & 1 \\ 0 & 2 \end{bmatrix} \qquad D_4 = \begin{bmatrix} 15 & 7 & 13 & 5 \\ 3 & 11 & 1 & 9 \\ 12 & 4 & 14 & 6 \\ 0 & 8 & 2 & 10 \end{bmatrix}$$

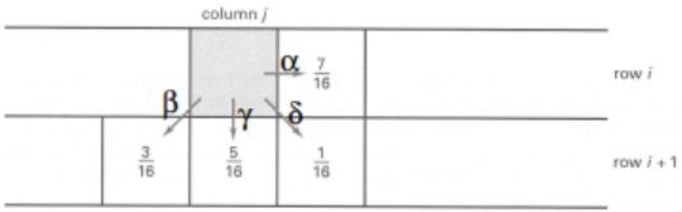
Dithering Techniques

Error Diffusion Dither

- Spread error over neighbor pixels right and below.
- Produce higher quality result than previous methods.
- Requires more computation.

Dithering Techniques

Error Diffusion Dither: Floyd-Steinberg Algorithm



$$\alpha + \beta + \gamma + \delta = 1.0$$

```
for (x = 0; x < width; x++) {
        for (y = 0; y < height; y++) {
                P(x,y) = trunc(I(x,y) + 0.5)
                e = I(x,y) - P(x,y)
                I(x,y+1) += α*e;
                I(x+1,y-1) += β*e;
                I(x+1,y) += γ*e;
                I(x+1,y+1) += δ *e;
        }
}
```

POLYGON RENDERING METHOD

Polygon Rendering Method

- Objects usually polygon-mesh approximation
- Illumination model is applied to fill the interior of polygons
- Curved surfaces are approximated with polygon meshes
    - But polyhedra that are not curved surfaces are also modeled with polygon meshes
- Two ways of polygon surface rendering:

1. Single intensity for all points in a polygon
2. Interpolation of intensities for each point in a polygon

Polygon Rendering Method

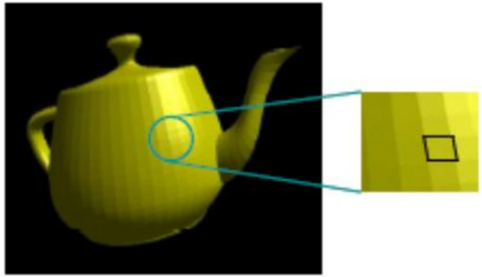
- Methods:

1. Constant Intensity Shading
2. Gouraud Shading
3. Phong Shading

1. Constant Intensity Shading

-Fast and simple method for rendering an object with polygon surface

-Each polygon shaded with single intensity calculated for the polygon

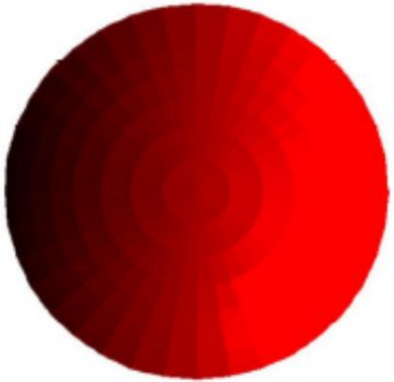


PROCEDURE

1. Take a point on the object surface and calculate the intensity
2. Render the surface with same intensity throughout the surface
3. Repeat above procedure for each polygon surface

ASSUMPTIONS

1. Object is a polyhedron
2. light sources should be sufficiently (i.e. **N.L** and attenuation function are constant)
3. Viewing position is sufficiently far (i.e. **V.R** is constant over the surface)



DRAWBACK: intensity discontinuity at the edges of polygons

2. Gouraud Shading

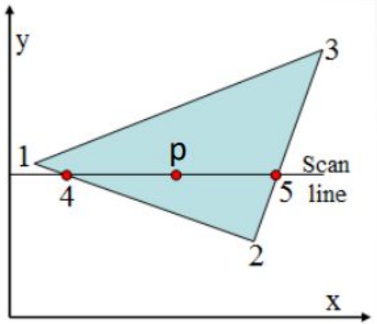
- Intensity interpolation method
- Renders a polygon surface by linearly interpolating intensity values across the surface.
- Intensity discontinuity at the edges of polygons is eliminated by matching intensity values of each polygon with adjacent polygons

PROCEDURE

1. Determine the average unit normal vector at each polygon vertex
2. Calculate each of the vertex intensities by applying an illumination model
3. Linearly interpolate the vertex intensities over the polygon surface

2. Gouraud Shading

- For Gouraud shading, the intensity at point 4 is linearly interpolated from the intensities at vertices 1 and 2.
- The intensity at point 5 is linearly interpolated from intensities at vertices 2 and 3.
- An interior point p is then assigned an intensity value that is linearly interpolated from intensities at positions 4 and 5.



$$\mathbf{I_4} = \frac{y_4 - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y_4}{y_1 - y_2} I_2 \qquad \mathbf{I_p} = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x_5 - x_4} I_5$$

2. Gouraud Shading

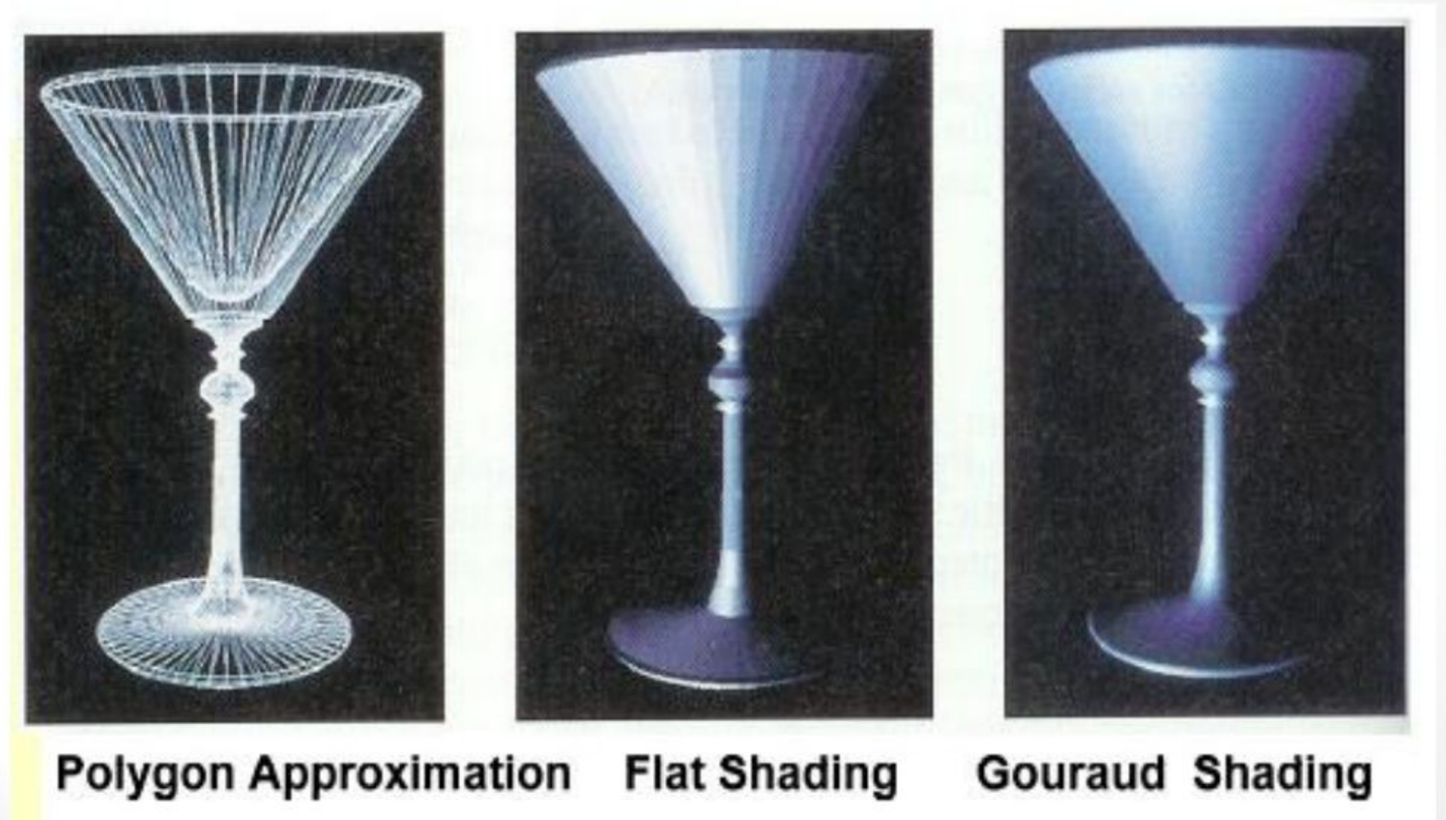
Advantages:

Removes discontinuities of intensity at the edge compared to constant shading model

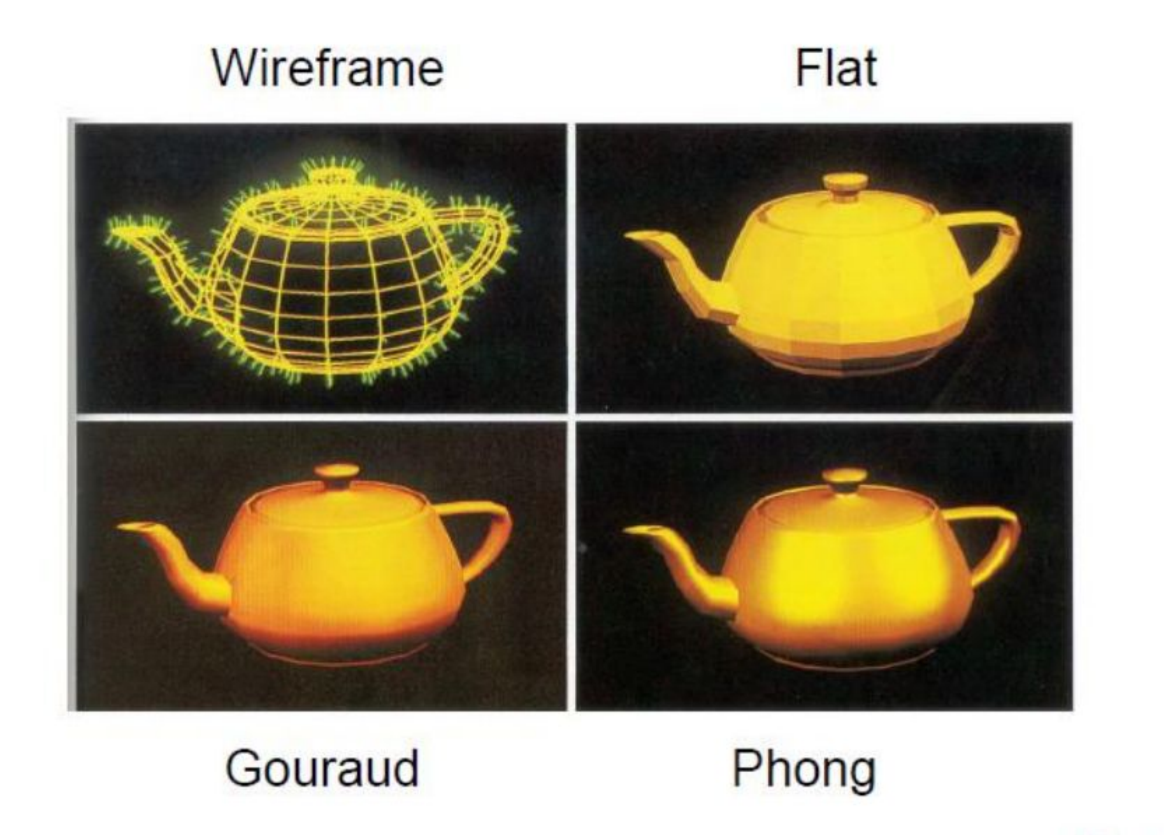
Limitations:

Highlights on the surface are sometimes displayed with anomalous(irregular) shapes and linear intensity interpolation can cause bright or dark intensity streaks, called Mach Bands to appear on the surfaces. Mach bands can be reduced by dividing the surface into a greater number of polygon faces or Phong shading (requires more calculation).

Surface Rendering



Polygon Shading Algorithms



3. Phong Shading

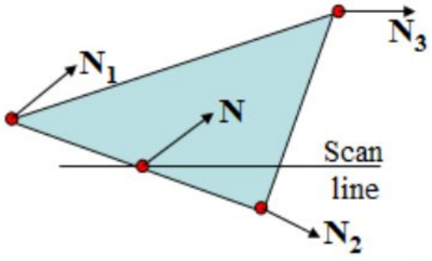
- A more accurate method for rendering a polygon surface is Phong shading, or normal vector interpolation shading which first interpolate normal vectors, and then apply the illumination model to each surface point. It displays more realistic highlights on a surface and greatly reduces the Mach-band effect.

3. Phong Shading

- A polygon surface is rendered using Phong shading by carrying out the following steps:
    - Determine the average unit normal vector at each polygon Vertex.
    - Linearly interpolate the vertex normals over the surface of the Polygon.
    - Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points.

3. Phong Shading

The normal vector **N** for the scan-line intersection point along the edge between vertices 1 and 2 can be obtained by vertically interpolating between edge endpoint normal:

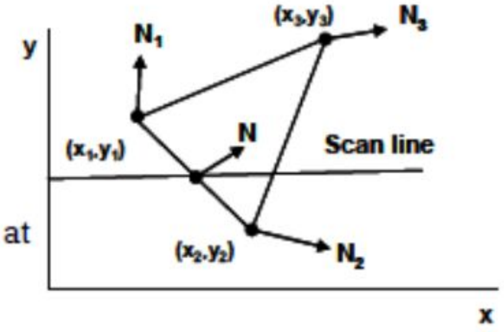


$$\mathbf{N} = \frac{y - y_2}{y_1 - y_2}\mathbf{N}_1 + \frac{y_1 - y}{y_1 - y_2}\mathbf{N}_2$$

Incremental methods are used to evaluate normal between scan lines and along each individual scan line (as in Gouraud). At each pixel position along a scan line the illumination model is applied to determine the surface intensity at that point. Intensity calculations using an ***approximated normal vector*** at each point along the scan line produce more accurate results than the ***direct interpolation of intensities***, as in Gouraud shading but it requires considerable more calculations.

3. Phong Shading

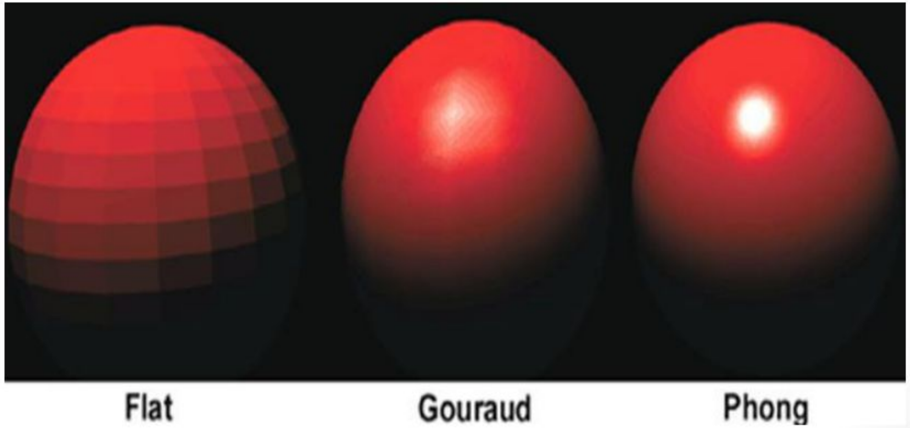
- More accurate method for rendering
- Interpolate normal vectors and apply illumination model to each surface point
- **PROCEDURE**
  1. Determine average unit normal vectors at each polygon vertex
  2. Linearly interpolate the vertex normals over the surface of the polygon
  3. Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points



$$N = \frac{y - y_2}{y_1 - y_2} N_1 + \frac{y_1 - y}{y_1 - y_2} N_2$$

Gouraud Vs Phong Shading

- Gouraud shading is faster than Phong shading
- Phong shading is more accurate



Thanks!

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