Computer Graphics 5 - Illumination and Shading

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Slides courtesy of Taku Komura
www.inf.ed.ac.uk/teaching/courses/cg

Overview

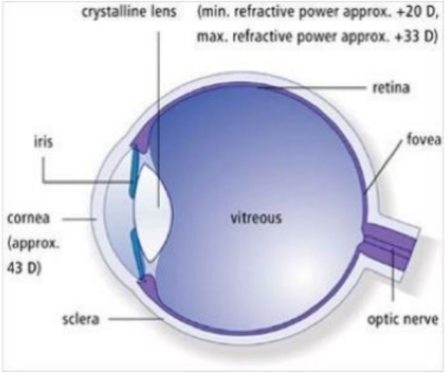
Lighting

- Phong illumination model

Shading

- Flat shading
- Gouraud shading
- Phong shading

Background of illumination

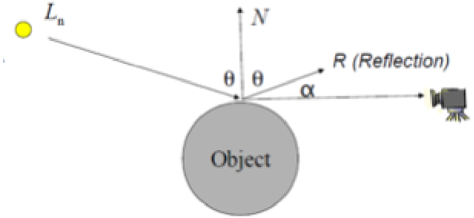


The eye works like a camera

- Sensors at the back of eye
- Sense the amount of light coming from different directions
- Similar to CMOS and CCDs

Light coming into the eye

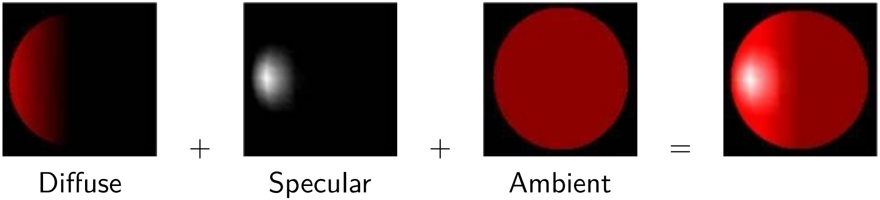
- Position of the point the eye is looking at
- Position of the light source
- Colour and intensity of light
- Vector from eye to point
- Normal vector of surface at point
- Physical properties of the object



Phong illumination model

A simple 3 parameter model comprised of 3 illumination terms

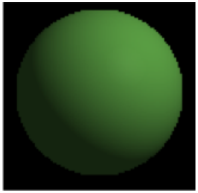
- *Diffuse*: non-shiny illumination and shadows
- *Specular*: shiny reflections
- *Ambient*: background illumination

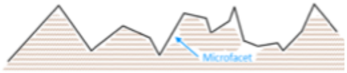


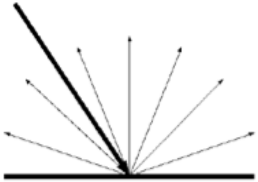
Diffuse (Lambertian) reflection

When light hits an object with a rough surface, it is reflected in all directions

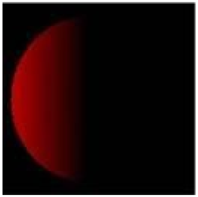
- Amount of light hitting the surface depends on the angle between the normal vector and the incident vector of the incoming light.
- The larger the angle (up to 90 degrees), the larger the area the incident light is spread over





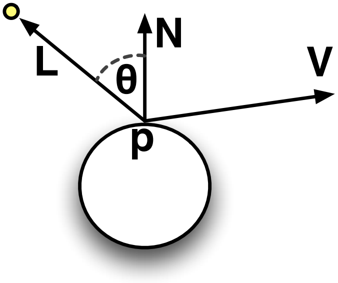


Diffuse reflection



$I = I_p k_d \cos\theta$

I_p	Light intensity
θ	Angle between normal vector and direction to light source
k_d	Diffuse reflectivity



Note that there is no dependence on the angle between the direction to the camera and the surface normal.

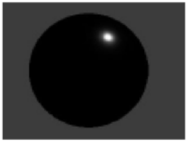
Specular reflection

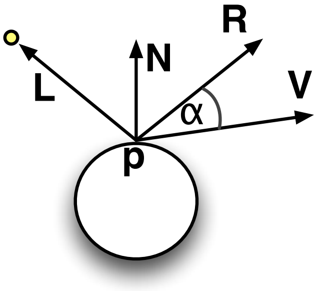
- Direct reflections of the light source off of a shiny surface
- Smooth surfaces

Specular reflection

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

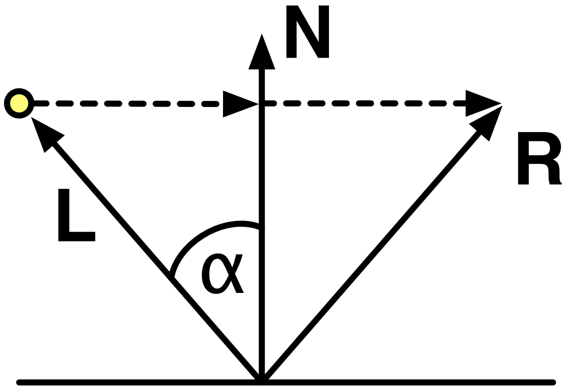
I_p	Light intensity
α	Angle between reflection vector and direction to camera
k_s	Specular reflectivity
n	Specular intensity





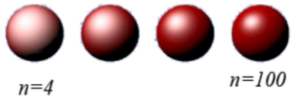
Specular reflection

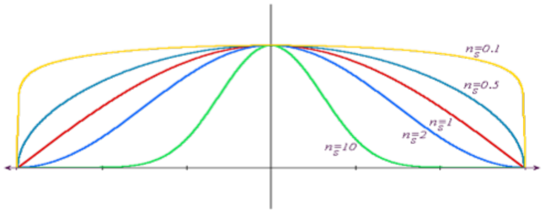
$$R = 2N(N \cdot L) - L$$

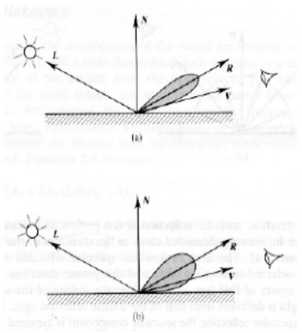


Specular reflection

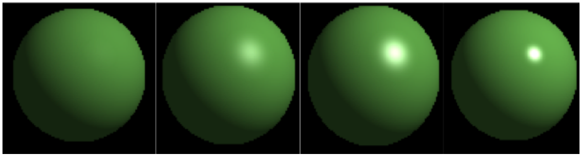
- Specular light with different *n* values





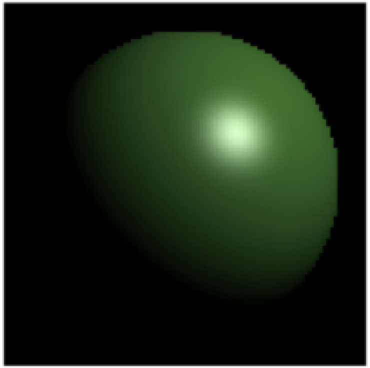


Combining diffuse and specular reflection



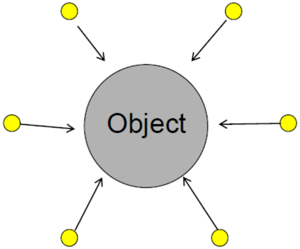
What is missing?

- Only points on the surface that are directly lit by the light are illuminated

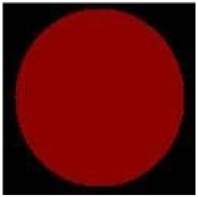


Ambient lighting

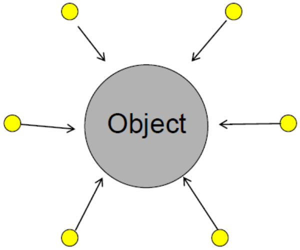
- Light reflected or scattered from other objects in the scene
- Enivornmental light
- Precise simulation of this is very hard!



Ambient lighting



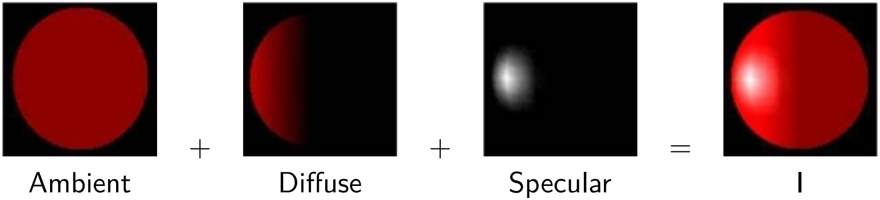
Very simple approximation:
$I = k_a I_a$



Combined lighting models

Combining ambient, diffuse and specular highlights gives the Phong Illumination model

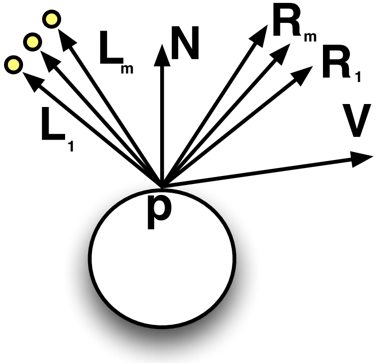
$$I = I_a k_a + I_p(k_d \cos\theta + k_s \cos^n \alpha)$$



Multiple light sources

- For multiple light sources we simply compute the illumination from each source and sum them.

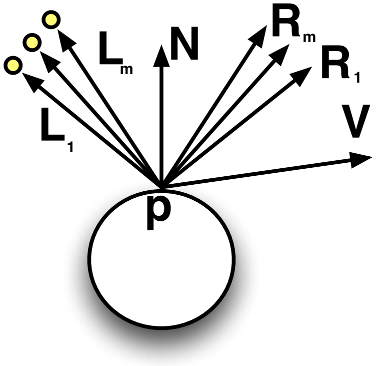
$$I = I_a k_a + \sum_{l=1}^{m} I_l (k_d \cos\theta + k_s \cos^n \alpha)$$



Using dot products

$$I = I_a k_a + \sum_l^m I_{l=1}(k_d(\overline{N} \cdot \overline{L}_l) + k_s(\overline{V} \cdot \overline{R}_l)^n)$$

V	Vector from the surface to the viewer
N	Normal vector at point on surface
R	Reflection vector
L	Vector from surface to light source



$\overline{L}$ means the vector L normalized to be of unit length.

Colour

$I^R = I_a^R k_a^R + \sum_{p=1}^P I_p^R (k_d^R (\overline{N} \cdot \overline{L}) + k_s^R (\overline{V} \cdot \overline{R})^n)$

$I^G = I_a^G k_a^G + \sum_{p=1}^P I_p^G (k_d^G (\overline{N} \cdot \overline{L}) + k_s^G (\overline{V} \cdot \overline{R})^n)$

$I^B = I_a^B k_a^B + \sum_{p=1}^P I_p^B (k_d^B (\overline{N} \cdot \overline{L}) + k_s^B (\overline{V} \cdot \overline{R})^n)$

Local illumination model

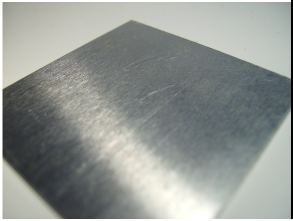
This model considers only light sources and the properties of surfaces. We don't consider light reflected from other surfaces.

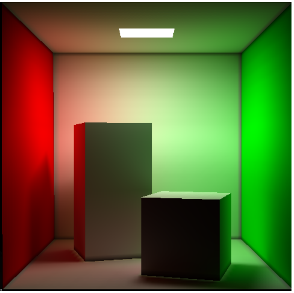
- Real time rendering
- Cost depends on number of light sources

Problems

Certain things cannot easily be rendered with this model:

- Brushed metal
- Marble (subsurface scattering)
- Colour bleeding





Overview

Lighting

- Phong illumination model

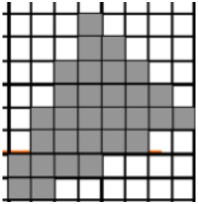
Shading

- Flat shading
- Gouraud shading
- Phong shading

How do we colour the surface?

We know how to colour single points on the surface, but how do we colour the whole object

- Shading
- Performed during rasterisation

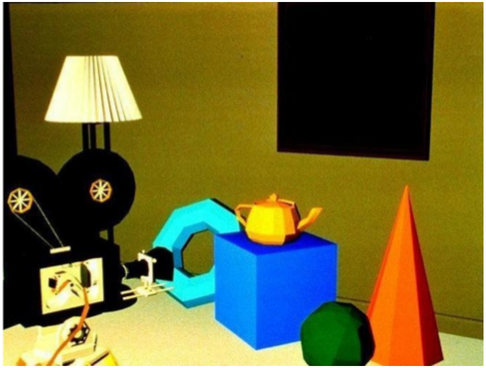
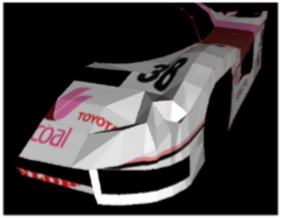


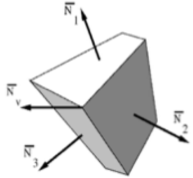
Shading models

- Flat shading (one lighting calculation per polygon)
- Gouraud shading (one lighting calculation per vertex)
- Phong shading (one calculation per pixel)

Flat shading

- Colour is computed once for each polygon
- All pixels in a polygon are set to the same colour
- Works for objects made of flat faces

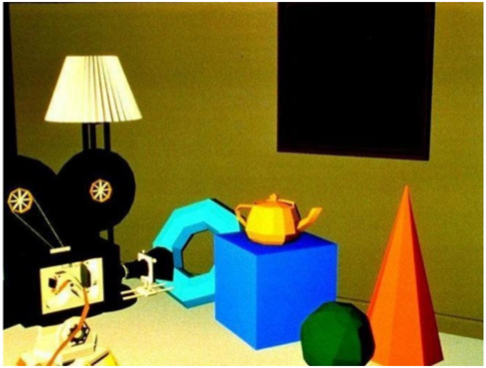



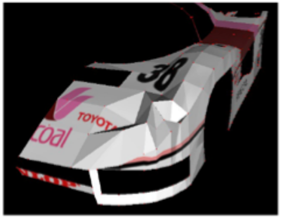


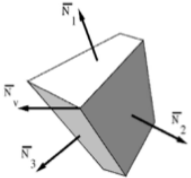
Flat shading

Suffers from an effect called Mach banding

- Eyes are sensitive to sudden changes in brighness
- Artificial changes in brightness are introduced on either side of the boundary

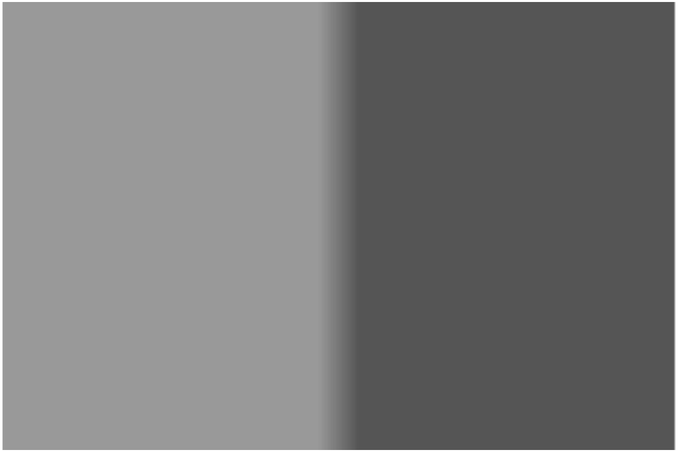




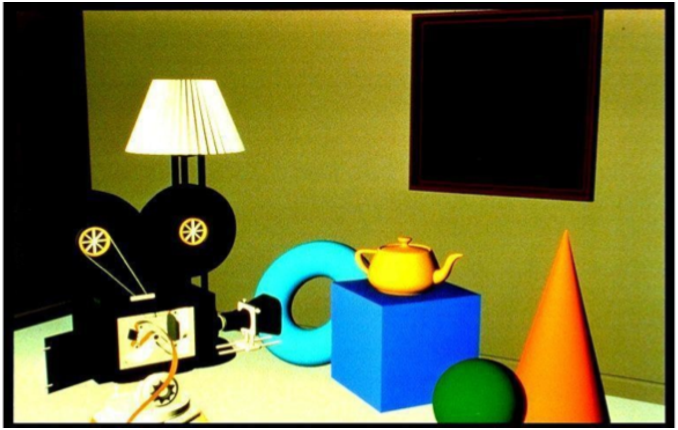


Mach band

An optical illusion, discovered by Ernst Mach

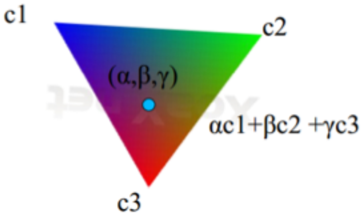


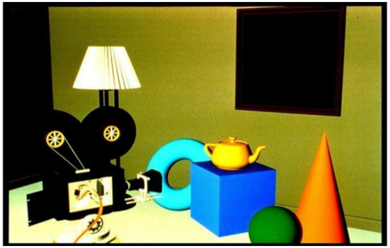
Gouraud shading



Gouraud shading

- Colour is computed once per vertex using the local illumination model
- Polygons interpolate colours over their surface

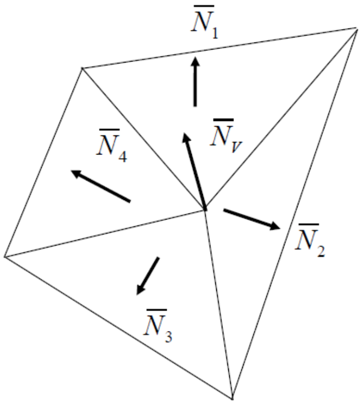




Computing vertex normals

Vertex normals are found by averaging the face normals:

$$\overline{N}_V = \frac{\sum_{i=1}^{n} \overline{N}_i}{\|\sum_{i=1}^{n} \overline{N}_i\|}$$



Computing vertex normals

Transforming vertex normals, we need to take care to ensure they remain perpendicular to the surface.

Tangent vectors remain tangent to the surface after transformation. For any tangent vector t:

$$\begin{aligned} n \cdot t &= 0 \\ n^T(M^{-1}M)t &= 0 \\ (n^T M^{-1})(Mt) &= 0 \end{aligned}$$

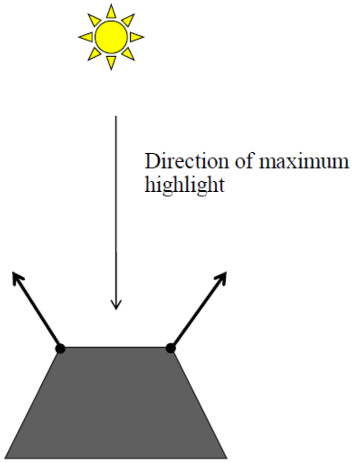
Therefore $n^T M^{-1}$ is perpendicular to the transformed Mt for any t. So the desired normal vector is:

$n' = (M^{-1})^T n$

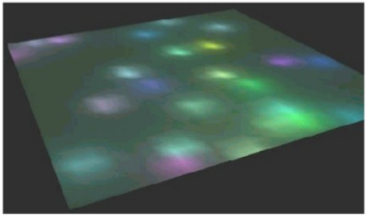
Problems with Gouraud shading

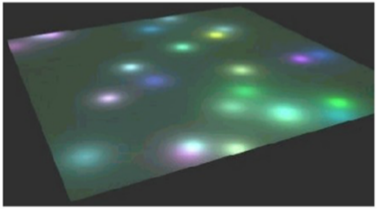
In specular reflection the highlight can be sharp, depending on the shape of $\cos^n \alpha$

- Gouraud shading interpolates linearly and so can make the highlight much bigger
- Gouraud shading can miss highlights that occur in the middle of a polygon

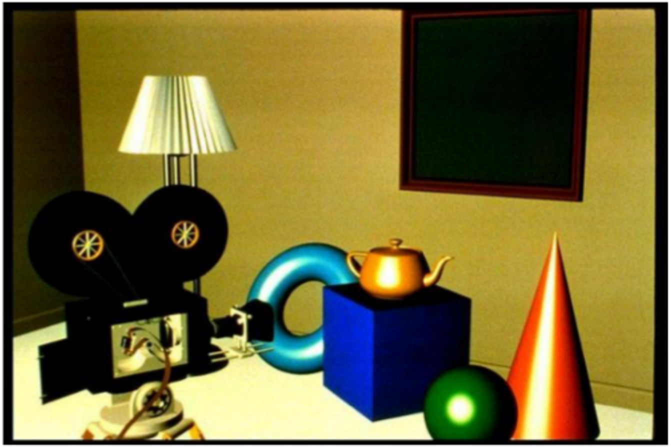


Problems with Gouraud shading



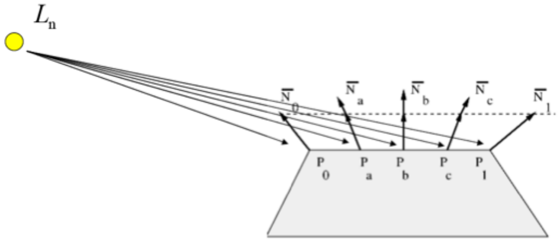


Phong shading



Phong shading

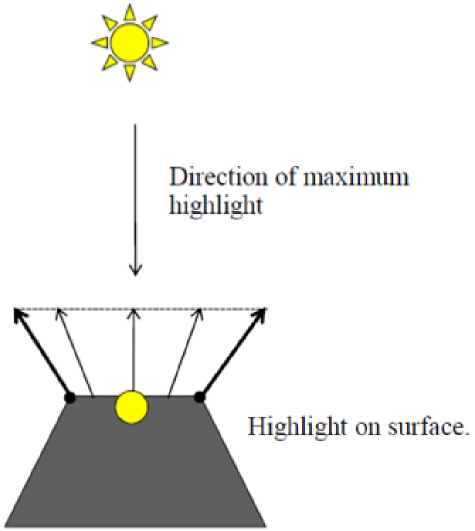
- Lighting computation is performed at each pixel
- Normal vectors are interpolated over the polygon



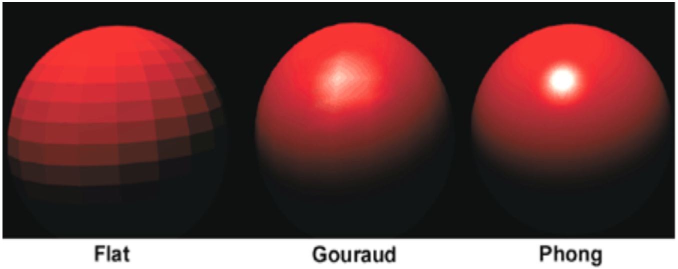
Phong shading model

Phong shading

Able to produce highlights that occur in the middle of a polygon

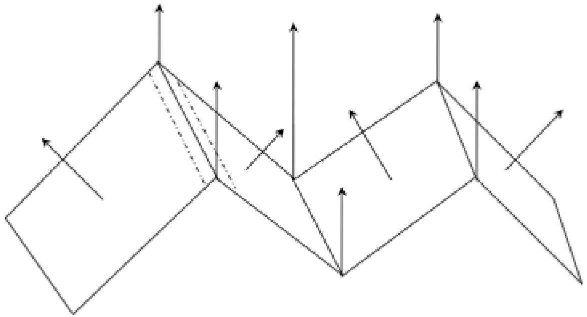


Phong example



Problems with interpolation shading

Vertex normals can be incorrect when calculated as average of face normals

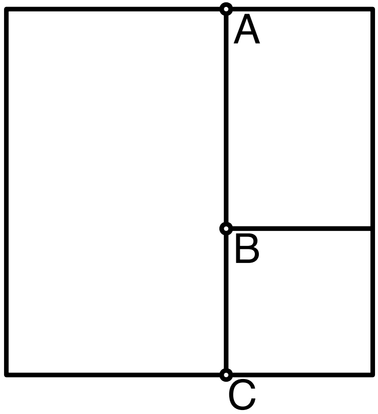


Solutions:

- Add more polygons
- Test for angles and use different vertex normals for adjacent polygons

Problems with interpolation shading

Vertices not shared by all polygons



B is not a vertex of the large polygon. Shading calculated at vertex B won't necessarily be the same as the interpolated calculations made when shading the large polygon.

Summary

Illumination

- Phong Illumination model combining ambient, diffuse and specular lighting

Shading

- Gouraud shading
- Phong shading

References

- Foley, Chapter 16 (Illumination and shading), up to 16.3
- Shirley, Chapter 10 (Surface shading)