Computer Graphics 2 - Illumination and shading

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

Overview

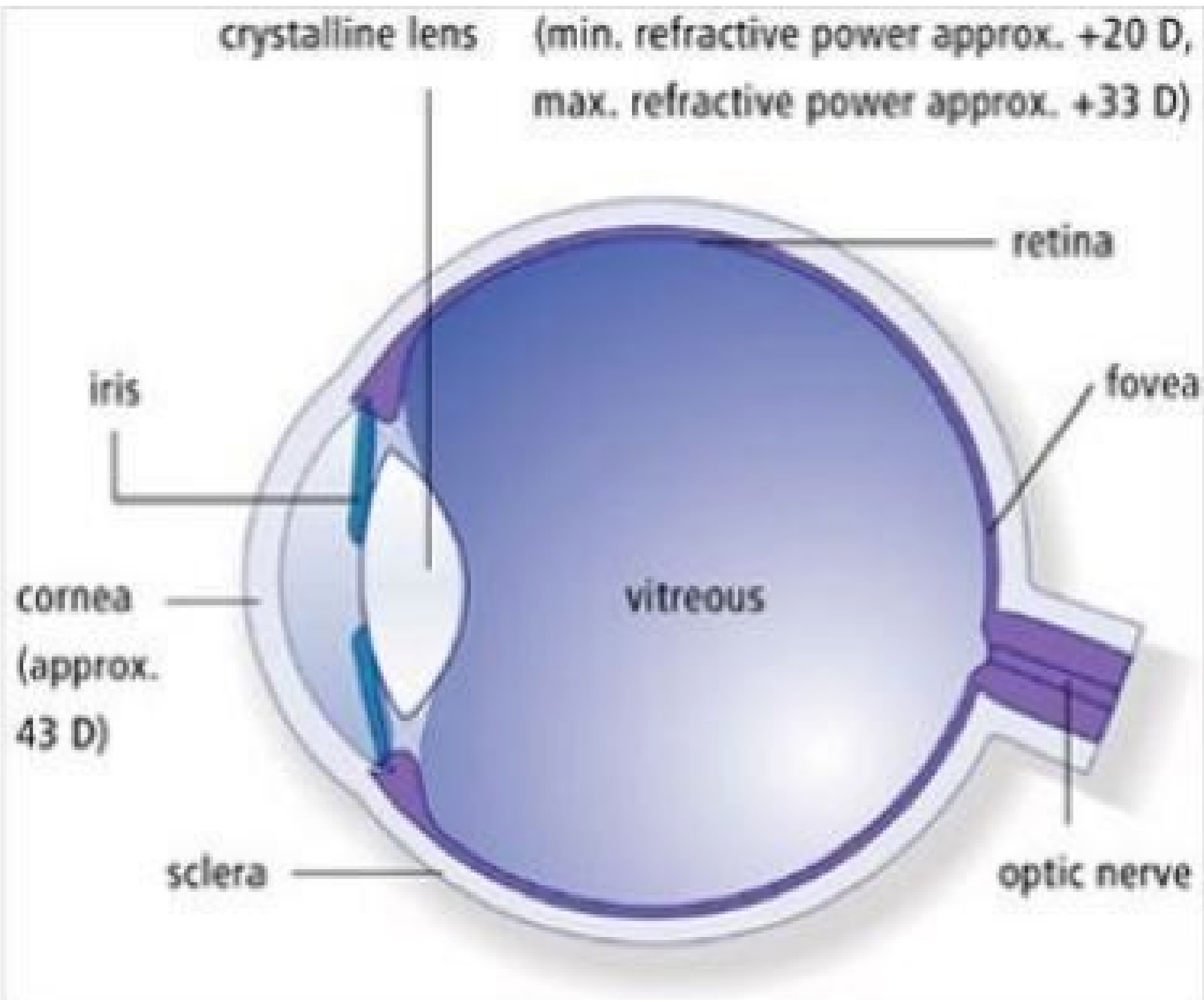
Lighting

- Phong illumination model

Shading

- Flat shading
- Gouraud shading
- Phong shading

Background of illumination

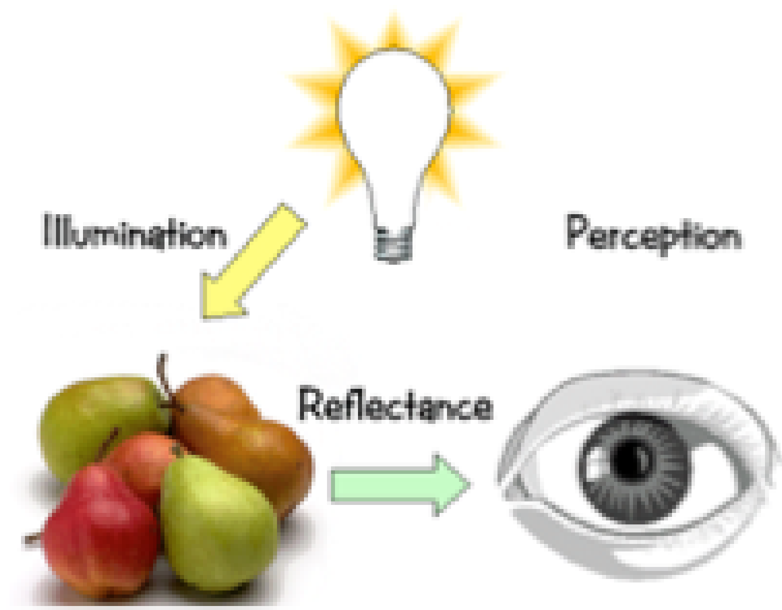


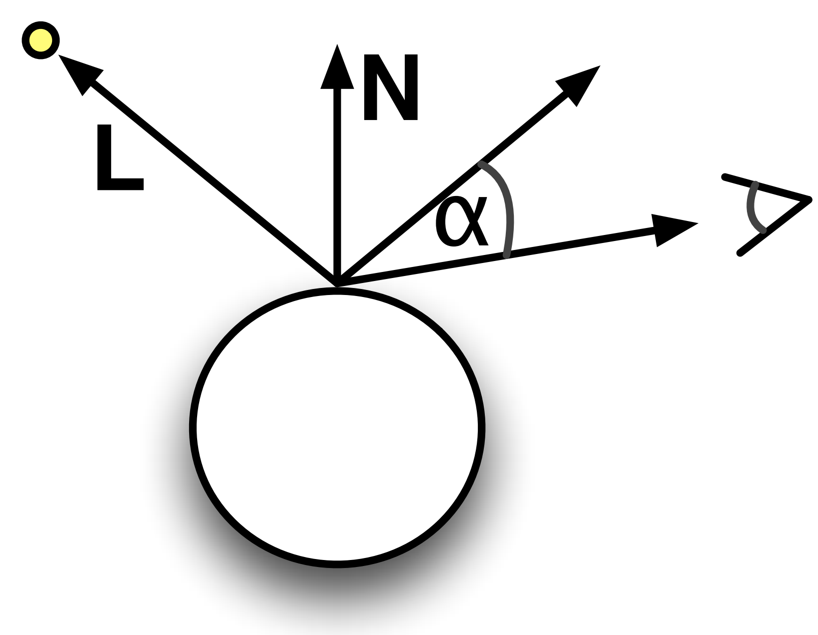
The eye works like a camera

- 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

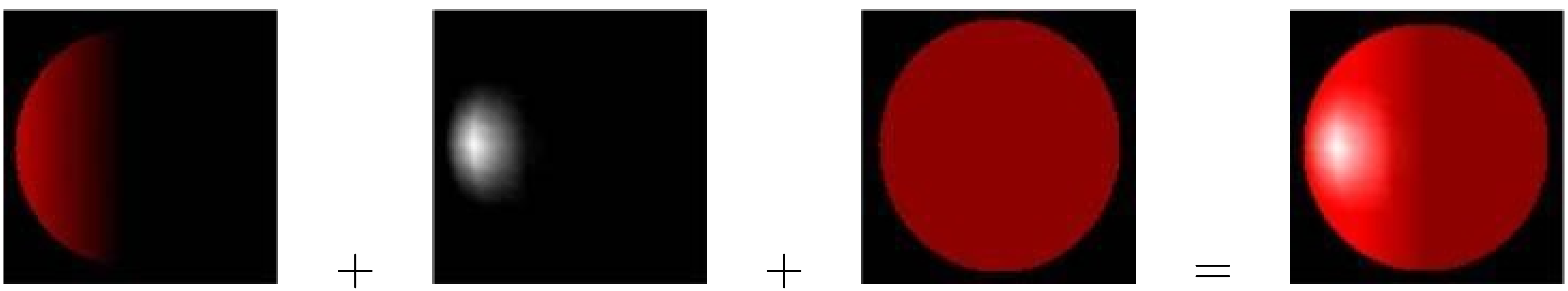




Phong illumination model

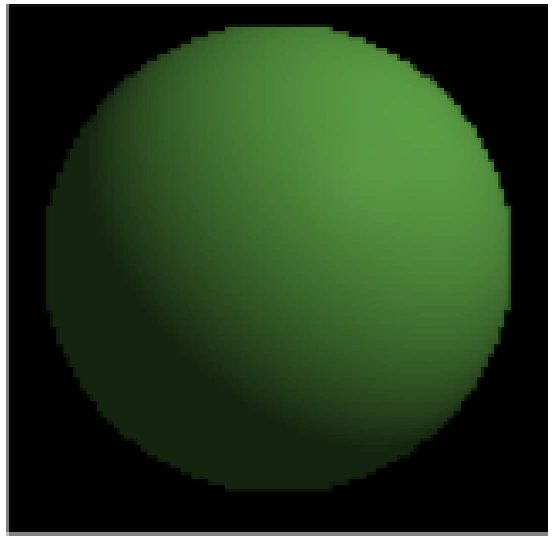
A simple 3 parameter model comprised of 3 illumination terms

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

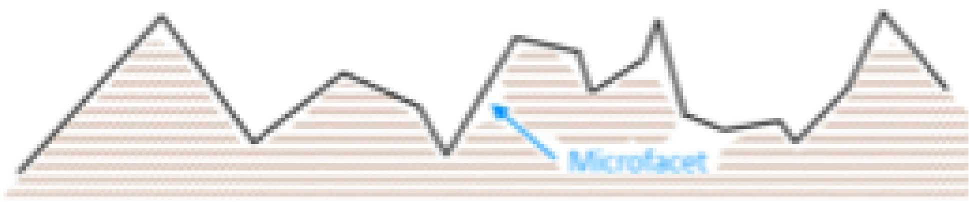


Diffuse + Specular + Ambient =

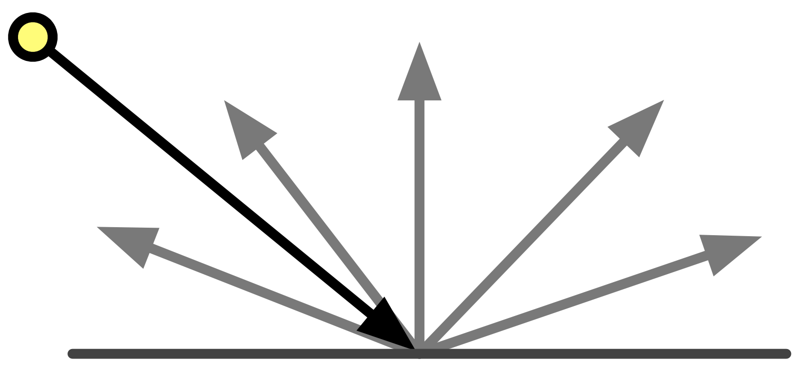
Diffuse (Lambertian) reflection



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



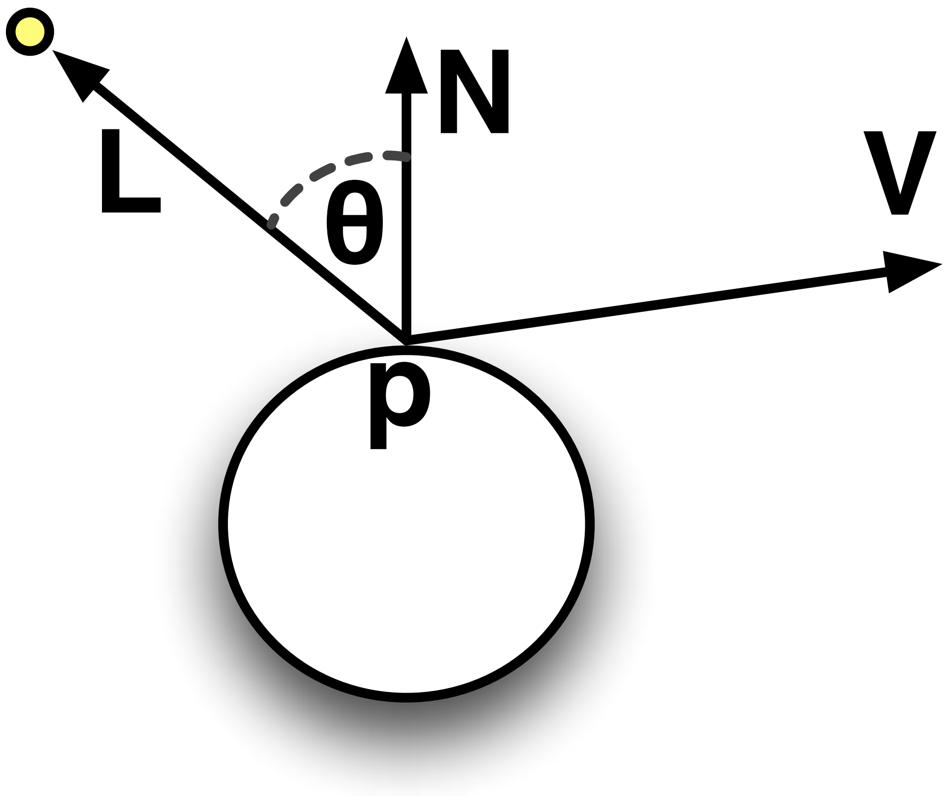
- Amount of light hitting the surface depends on the angle between the normal vector and the incident vector of the incoming light.
- The larger the angle (up to 90 degrees), the larger the area the incident light is spread over



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

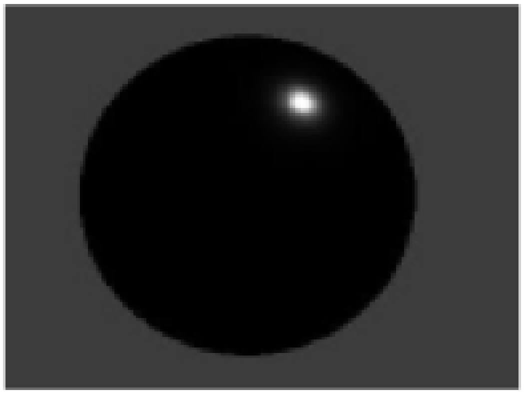


Note that there is no dependence on the angle between the direction to the camera and the surface normal.

Specular reflection

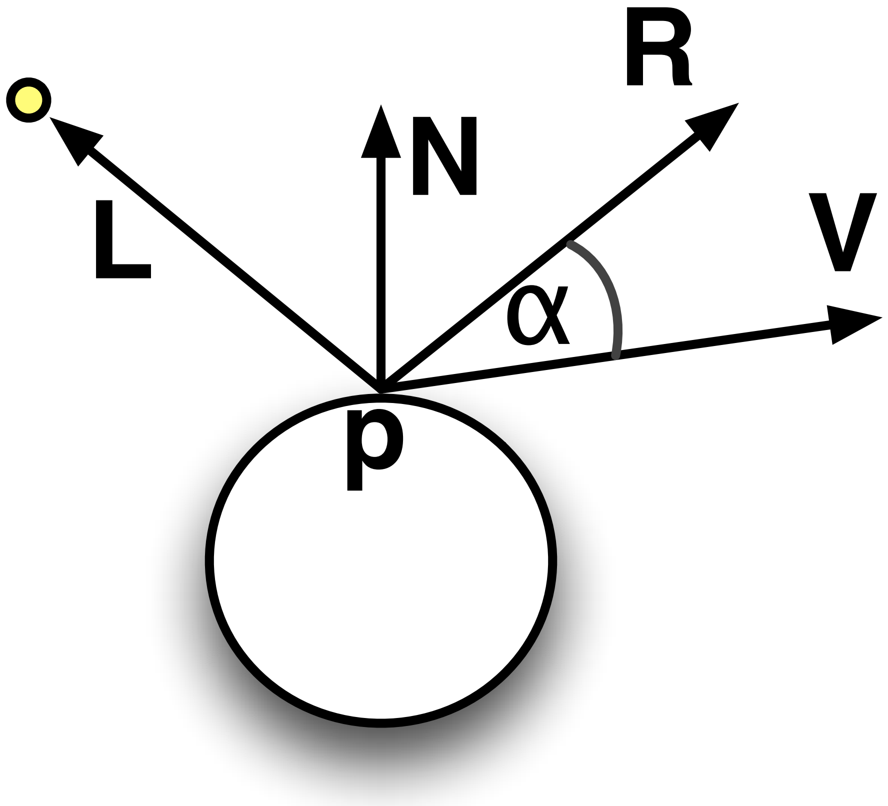
- Direct reflections of the light source off of a shiny surface
- Smooth surfaces

Specular reflection



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

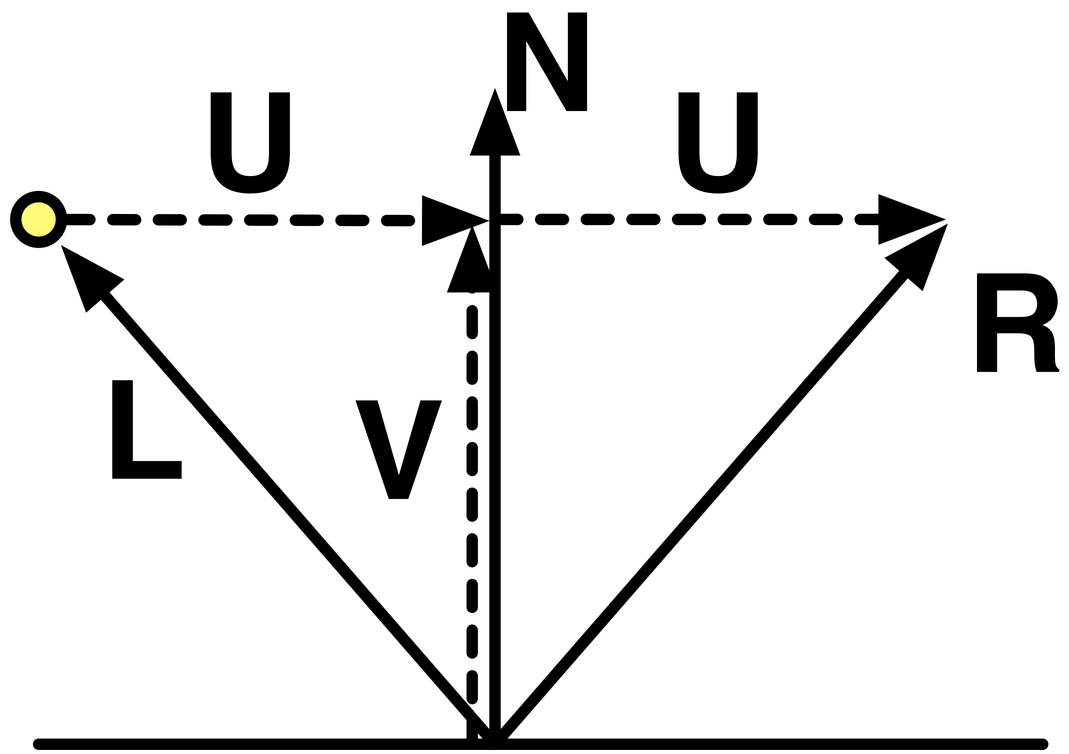
- I_p Light intensity
- α Angle between reflection vector and direction to camera
- k_s Specular reflectivity
- n Specular intensity



Specular reflection

To calculate the reflection vector R (used to calculate angle α on the previous slide) from the vector to the light source L and the normal vector N:

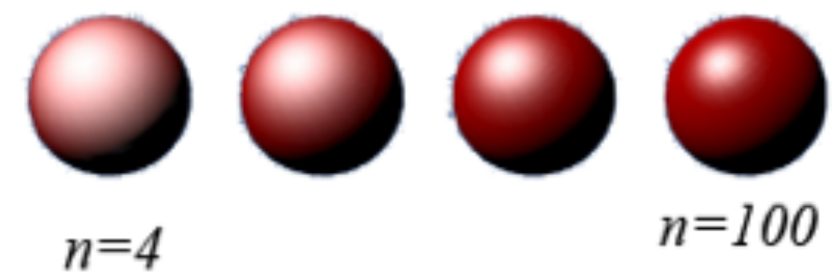
$$
\begin{aligned}
R &= L + 2U \\
&= L + 2(-L + V) \\
&= L + 2(-L + N(N \cdot L)) \\
&= 2N(N \cdot L) - L
\end{aligned}
$$

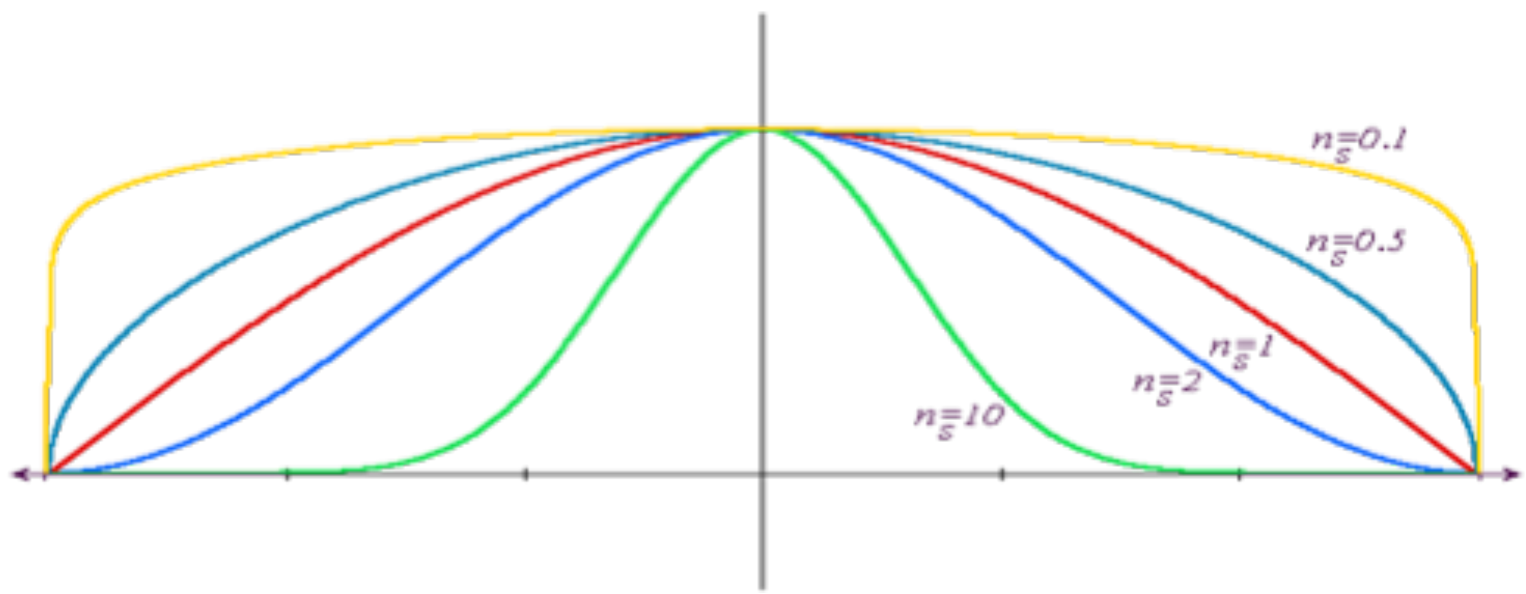


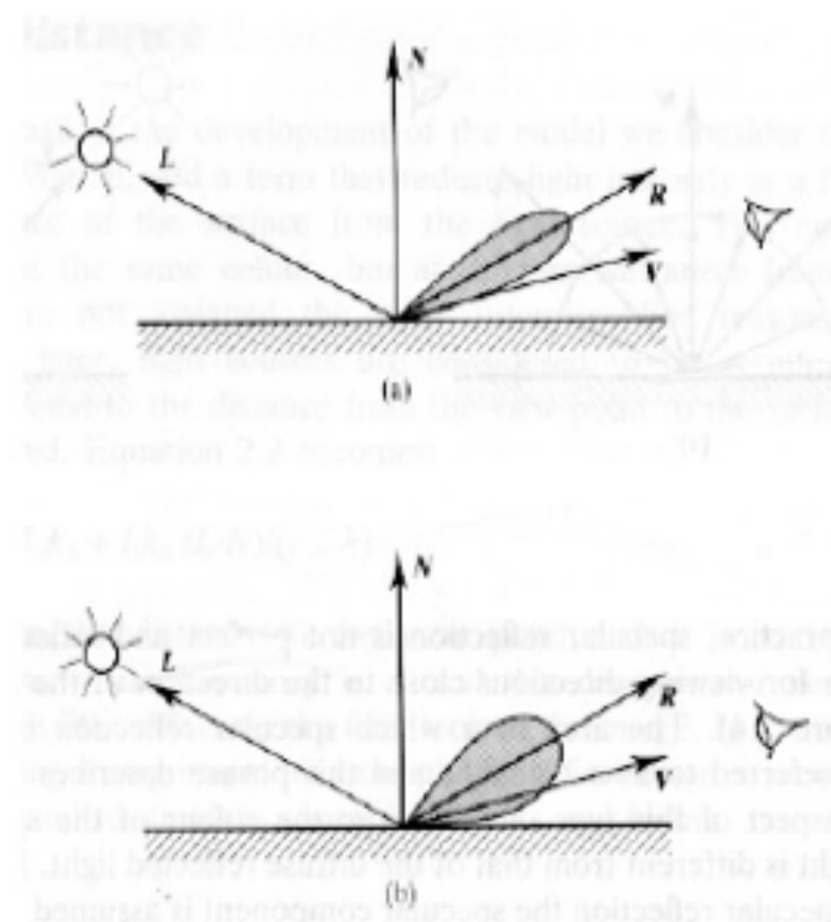
This is assuming that N, R and L are all of unit length.

Specular reflection

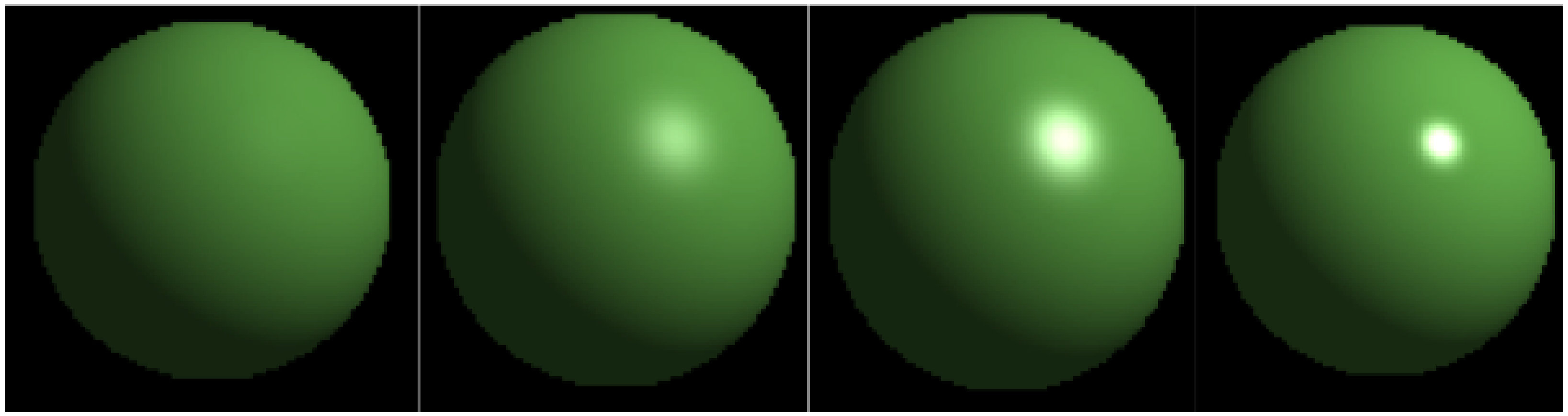
- Specular light with different *n* values







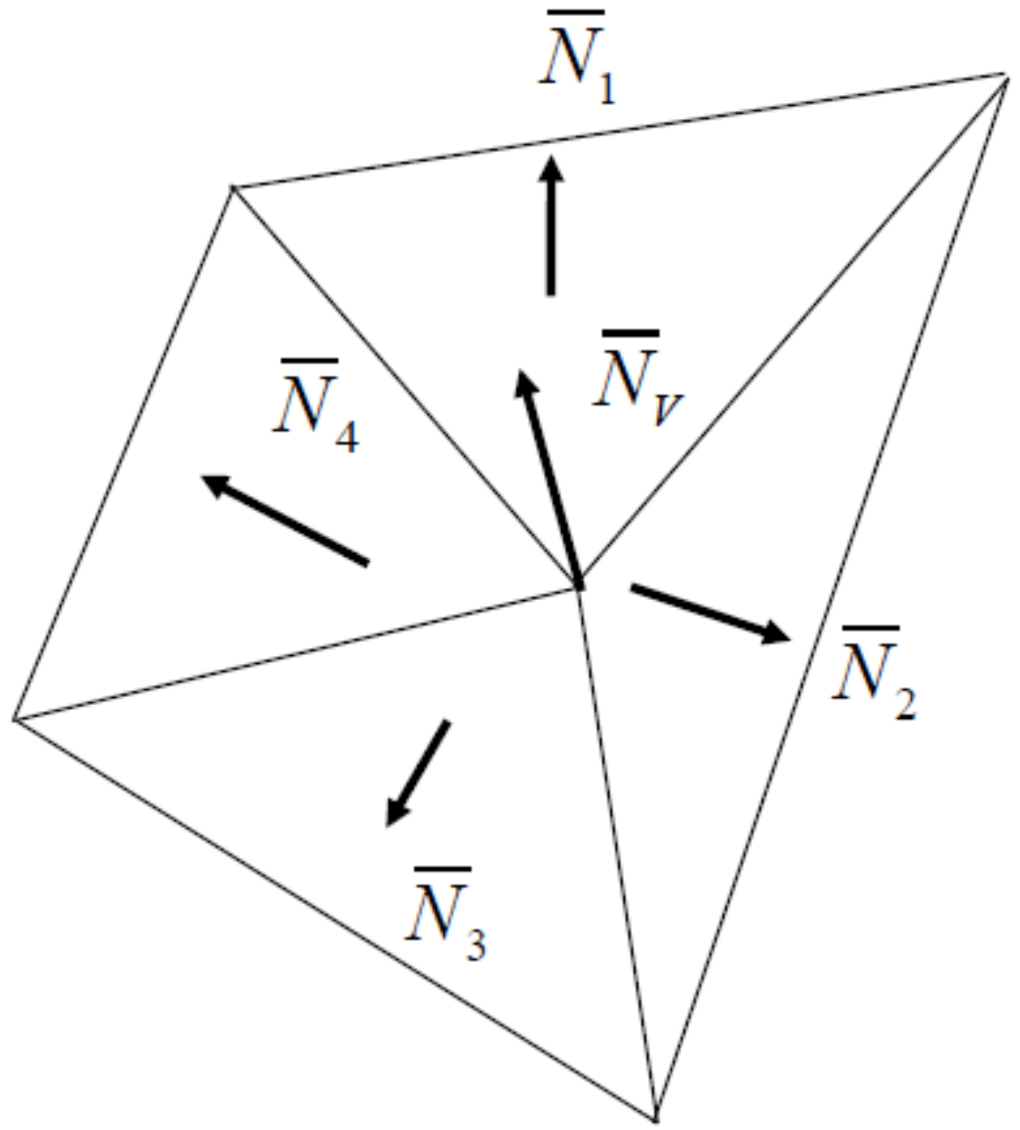
Combining diffuse and specular reflection



Computing vertex normals

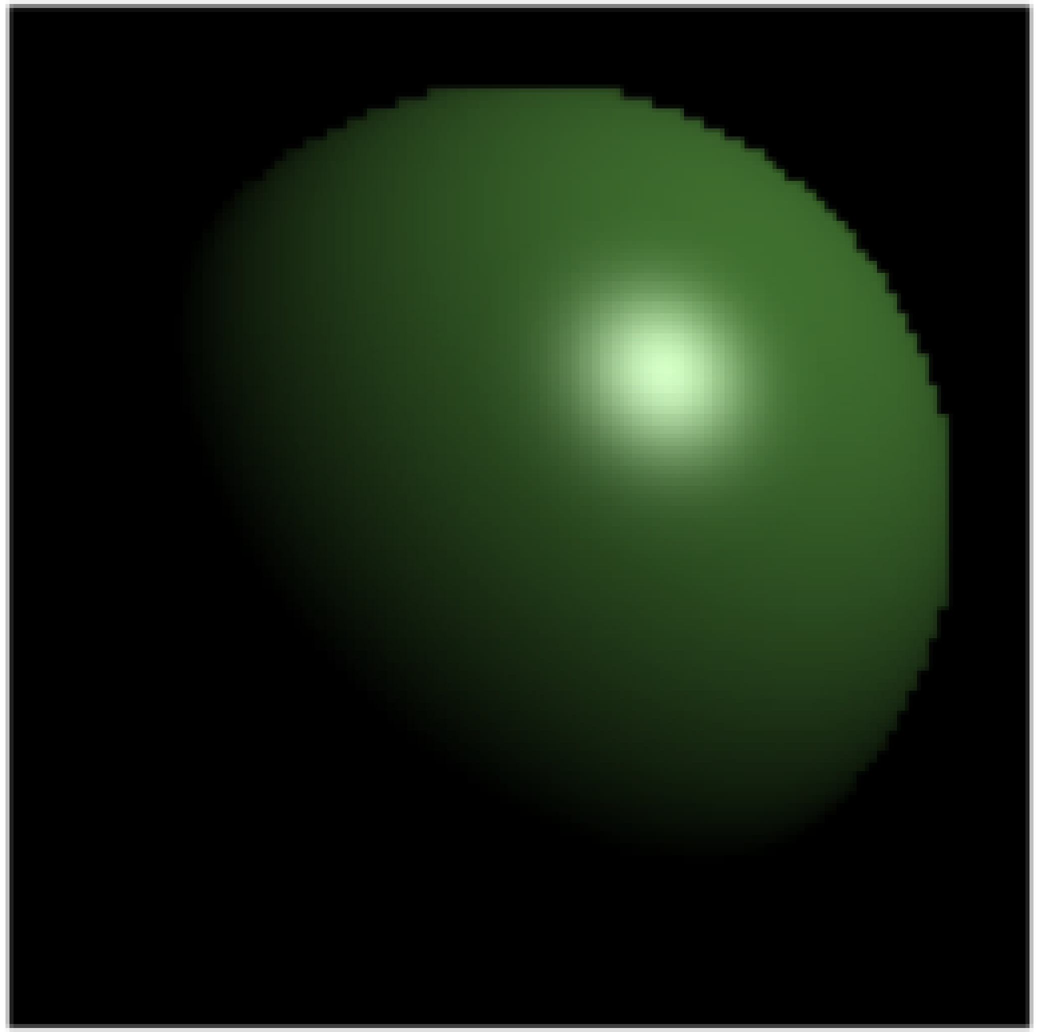
Vertex normals are found by averaging the face normals:

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



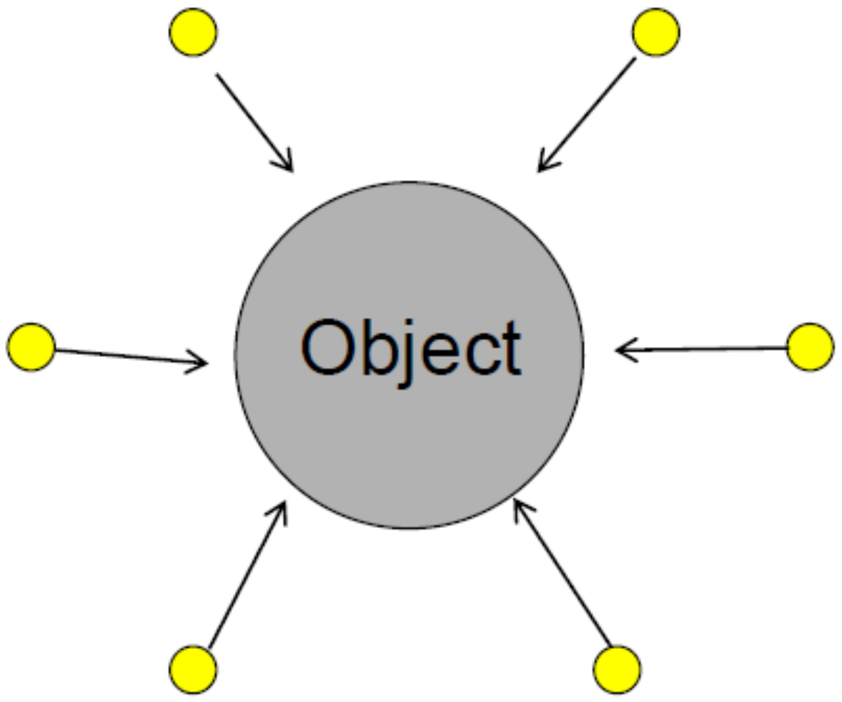
What is missing?

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



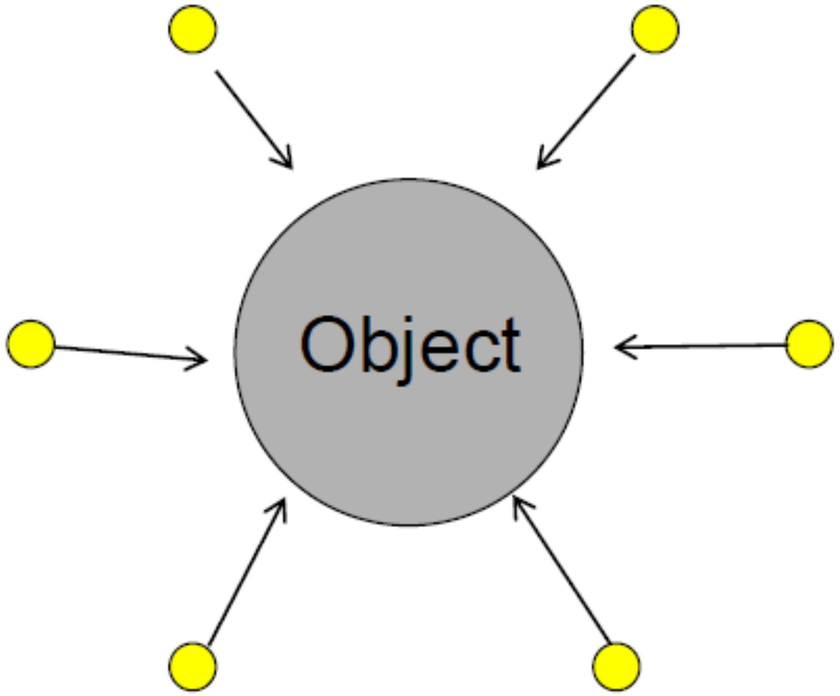
Ambient lighting

- 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

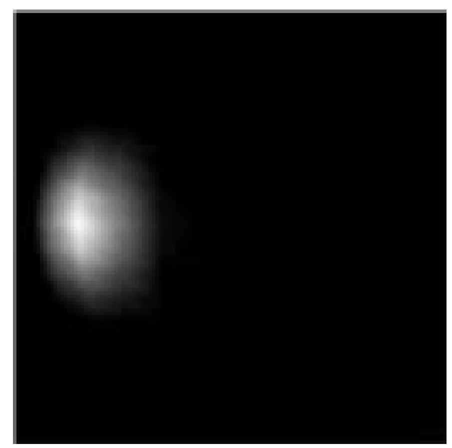
$$I = I_a k_a + I_p(k_d \cos\theta + k_s \cos^n \alpha)$$

Ambient

+

Diffuse

+



Specular

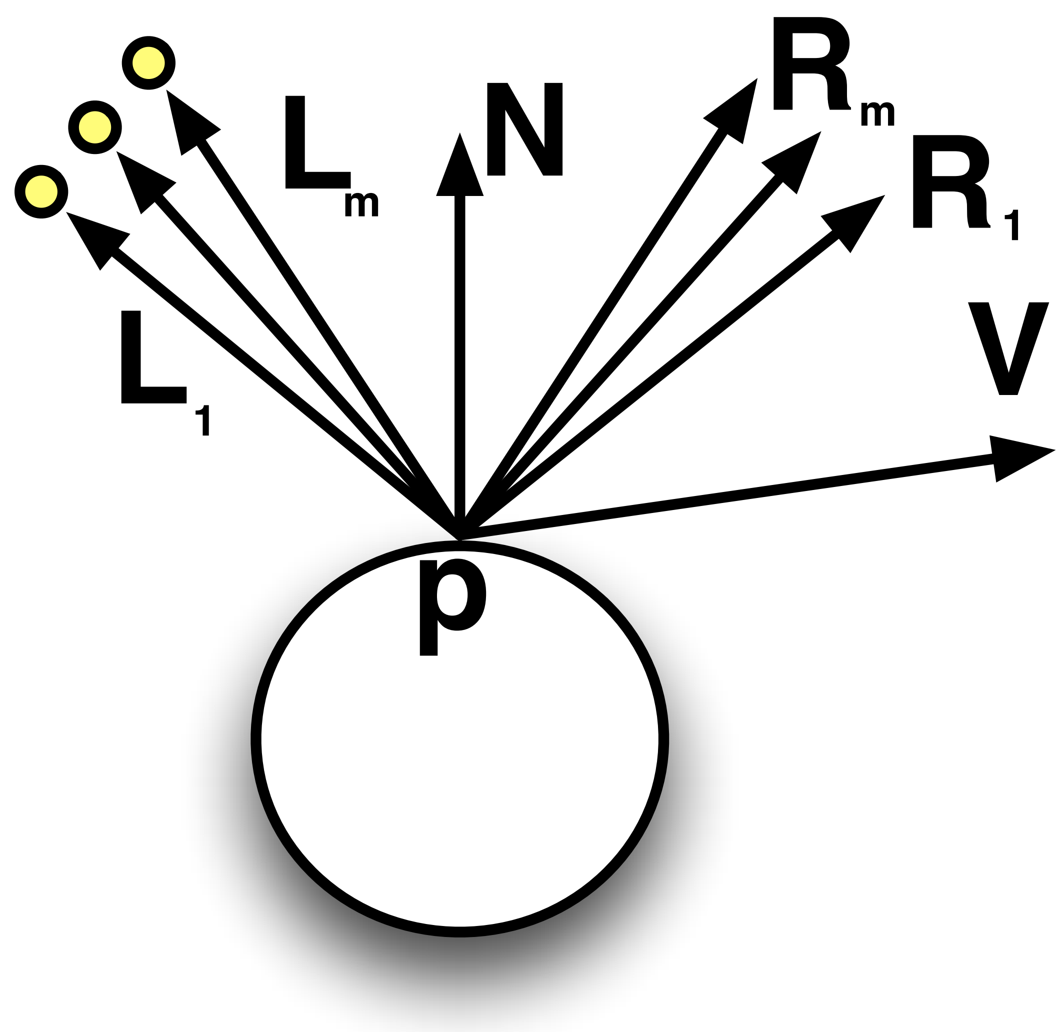
=

I

Multiple light sources

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

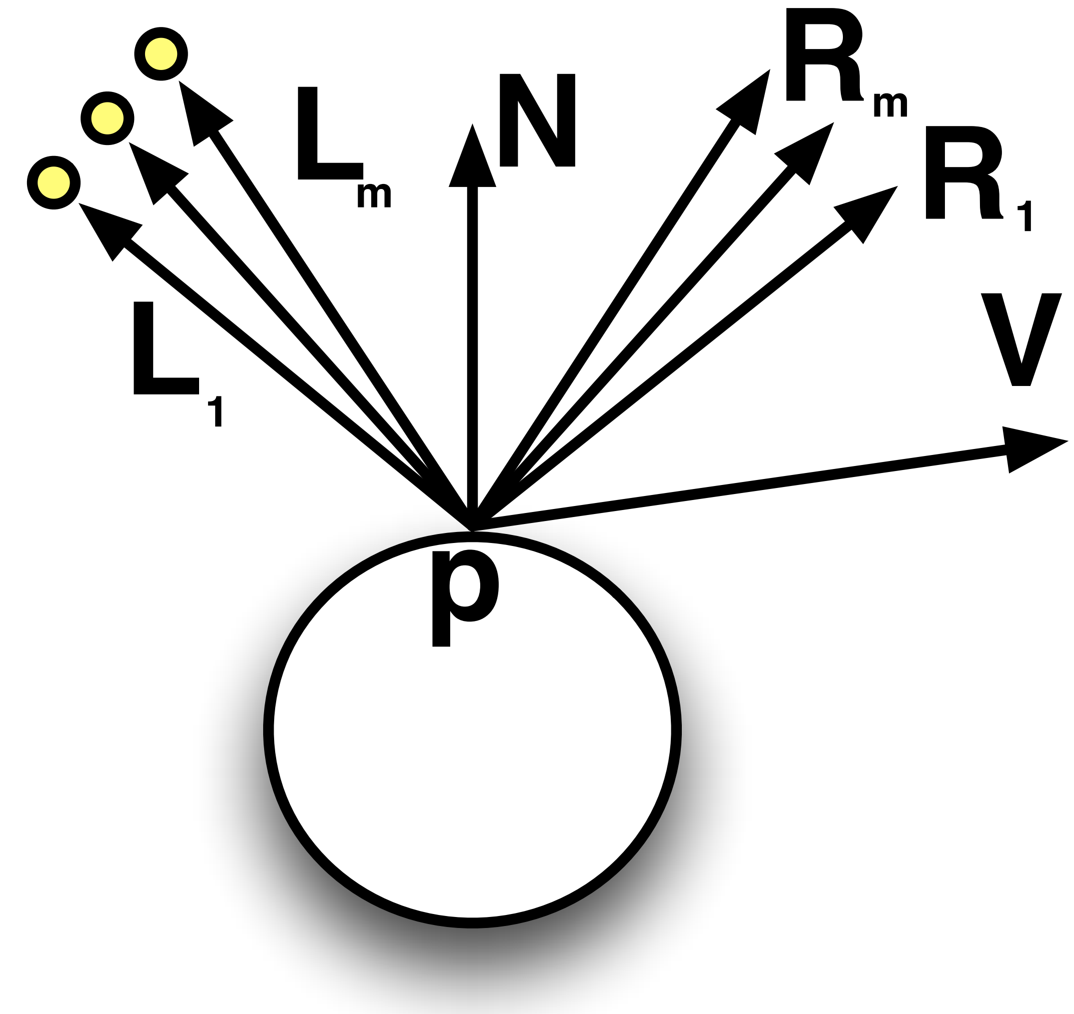
$$I = I_a k_a + \sum_{l=1}^{m} I_l (k_d \cos\theta + k_s \cos^n \alpha)$$



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

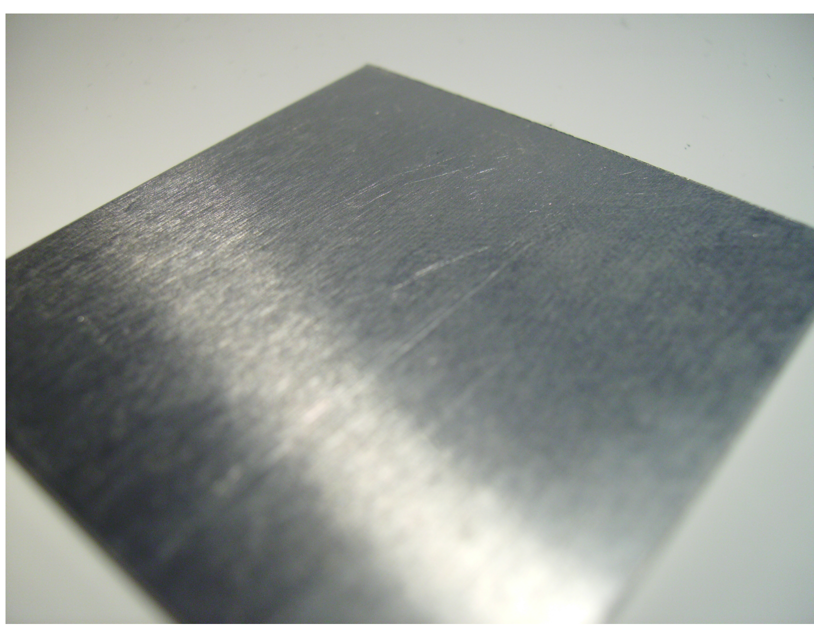
This model considers only light sources and the properties of surfaces. We don't consider light reflected from other surfaces.

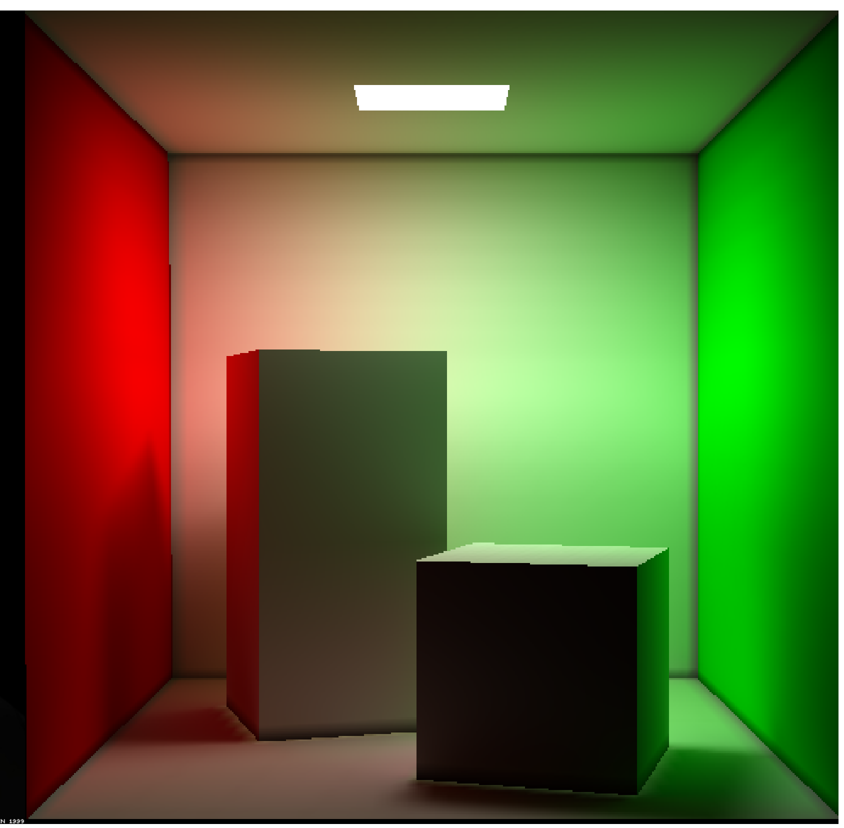
- Real time rendering
- Cost depends on number of light sources

Problems

Certain things cannot easily be rendered with this model:

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





Overview

Lighting

- Phong illumination model

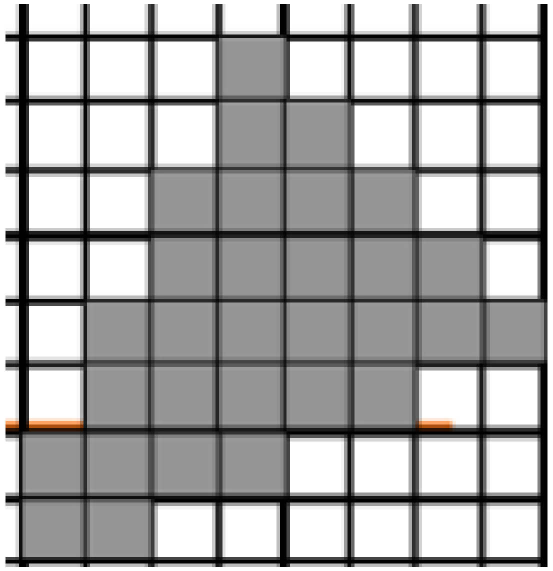
Shading

- 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

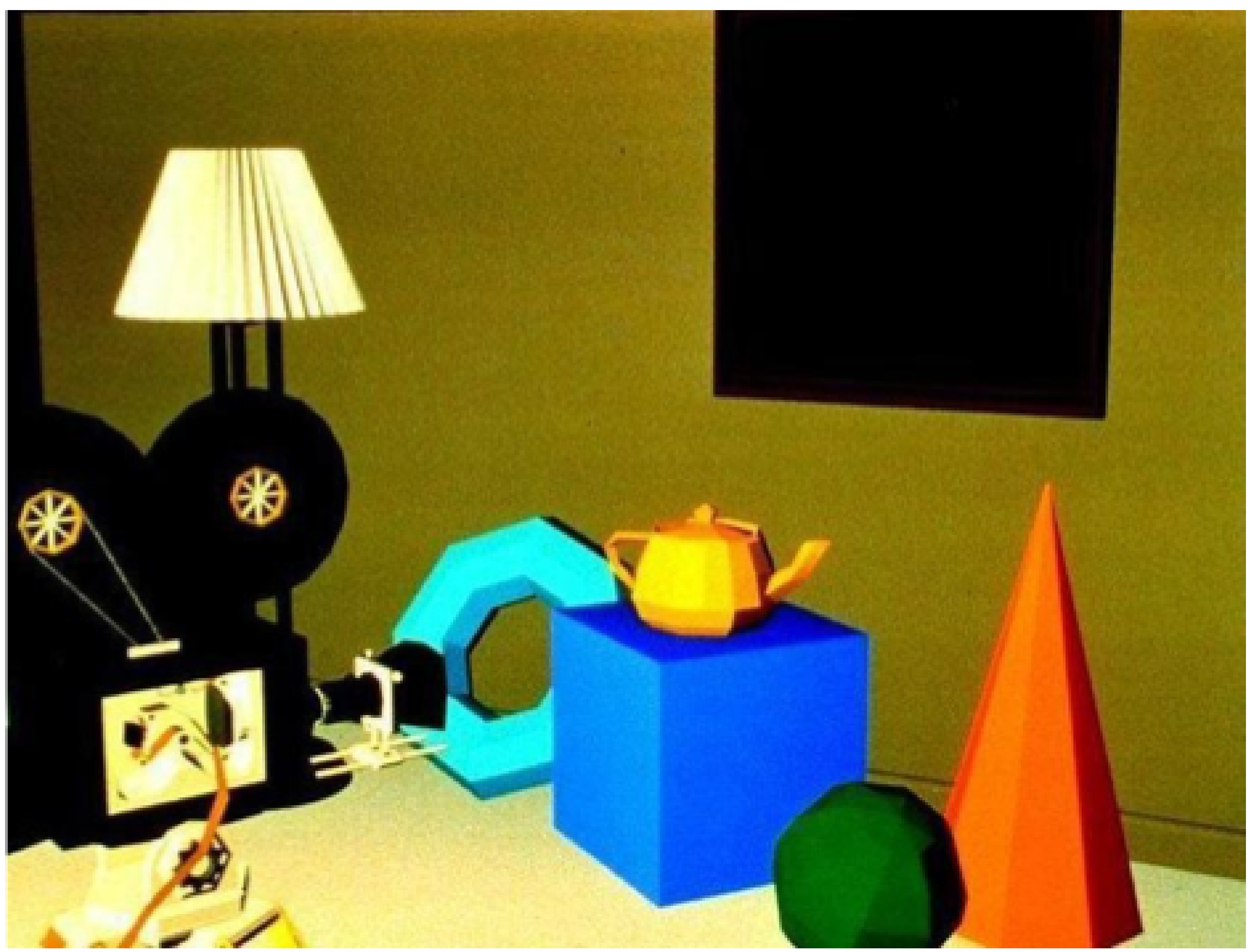


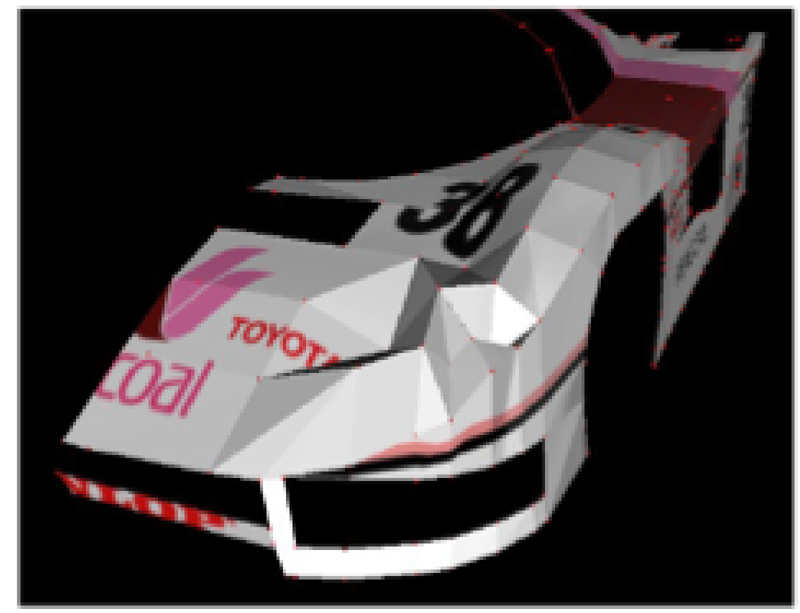
Shading models

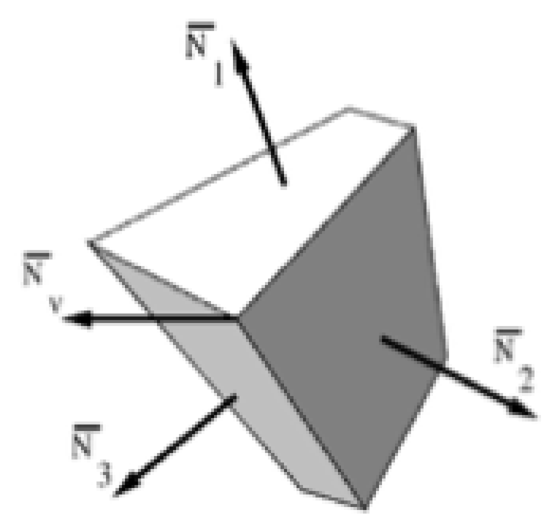
- Flat shading (one lighting calculation per polygon)
- Gouraud shading (one lighting calculation per vertex)
- Phong shading (one calculation per pixel)

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



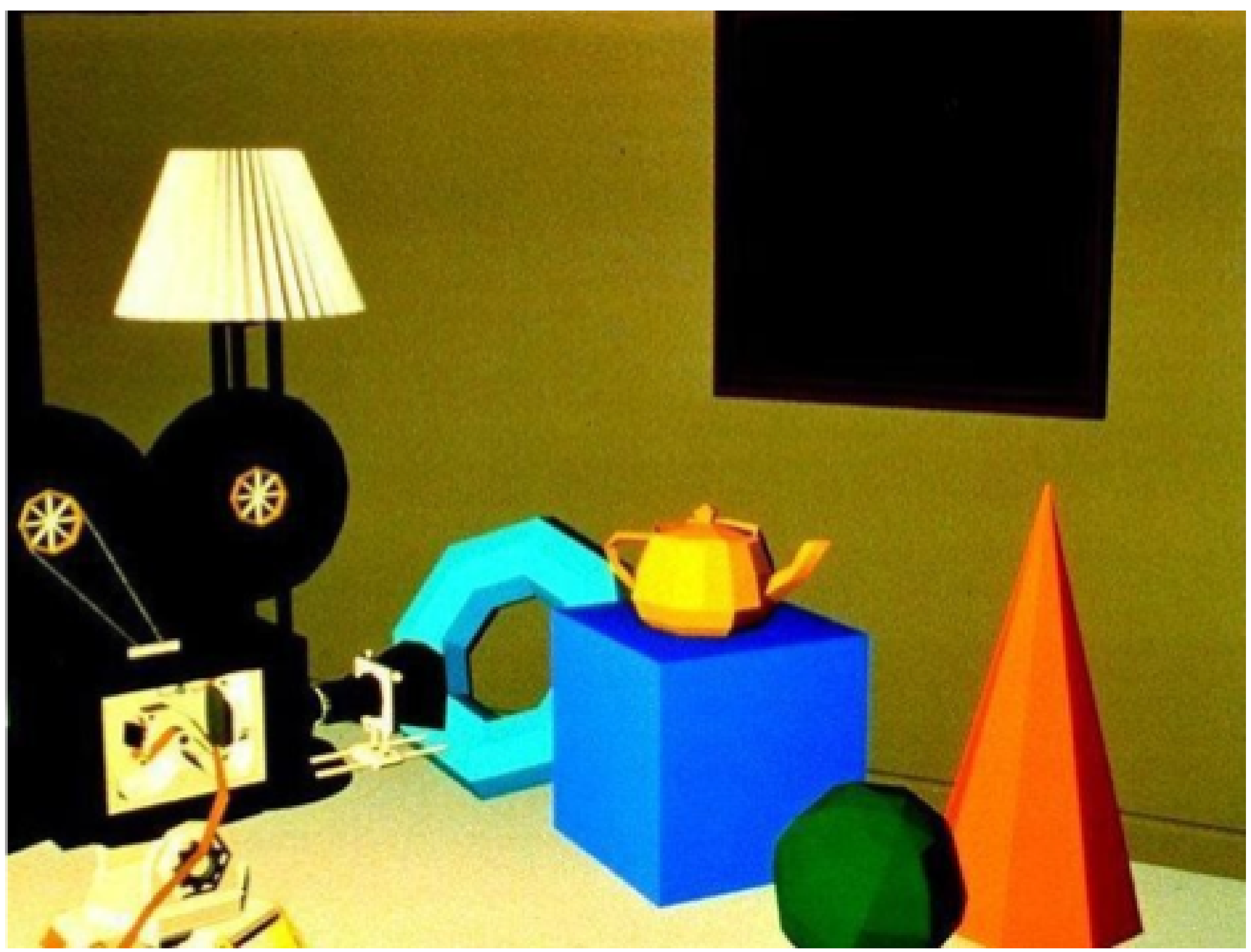


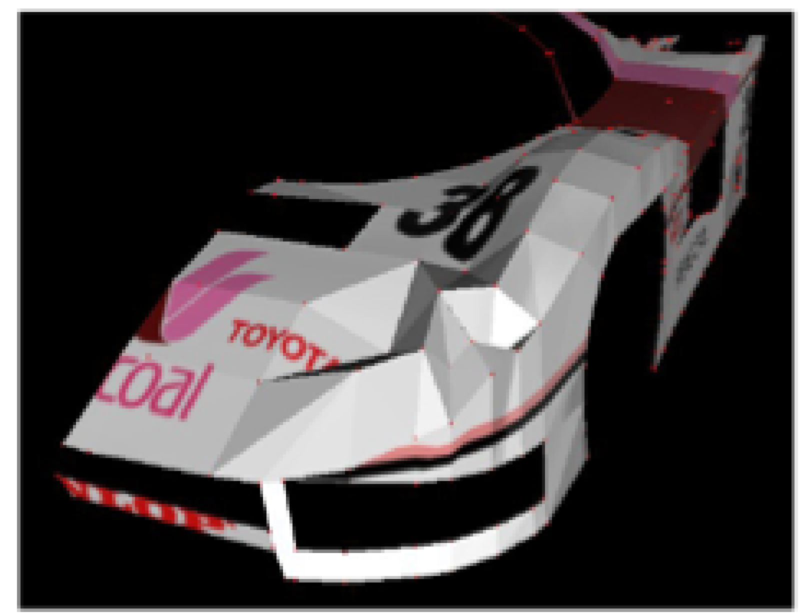


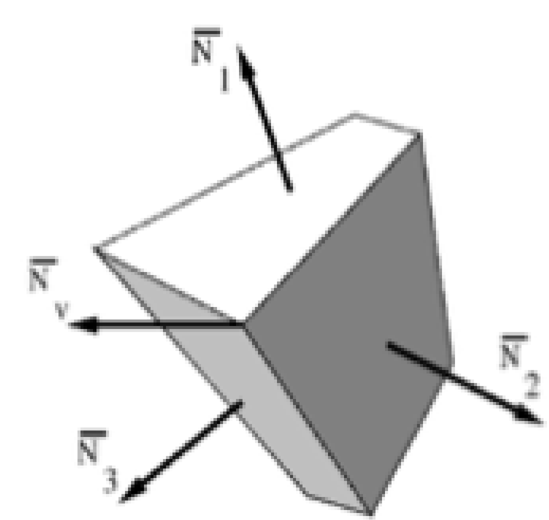
Flat shading

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



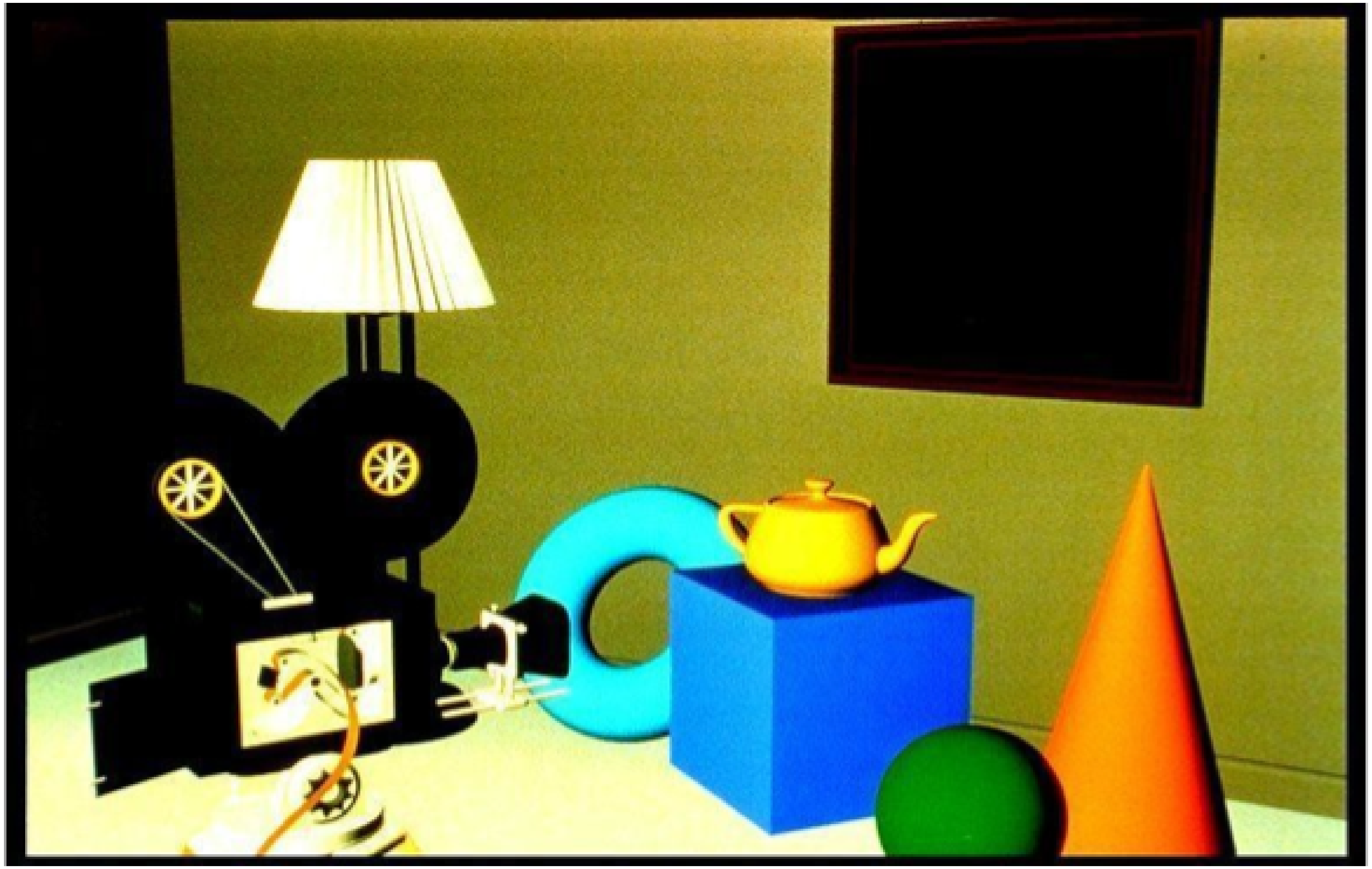




Mach band

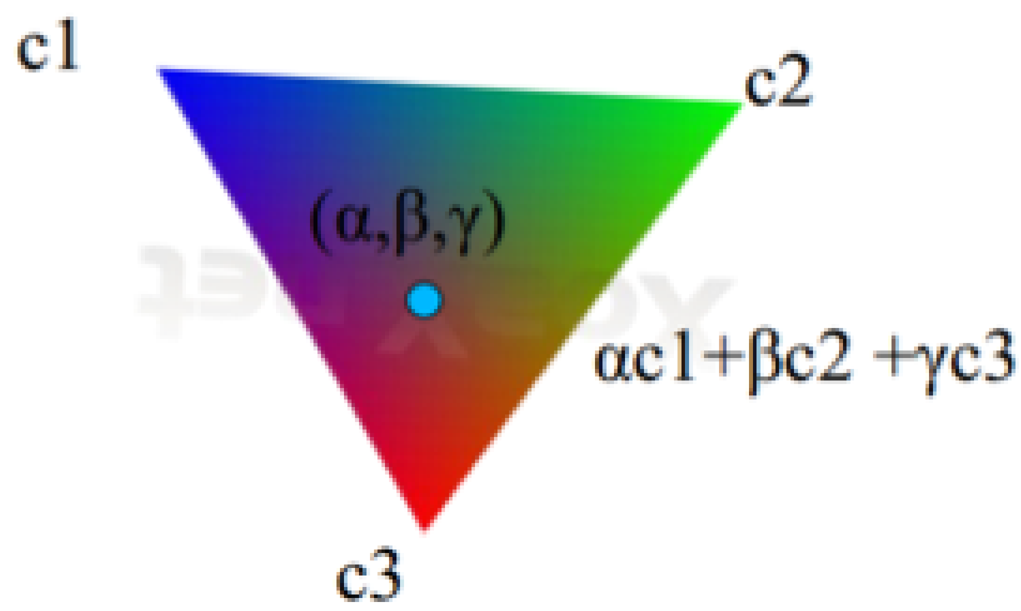
An optical illusion, discovered by Ernst Mach

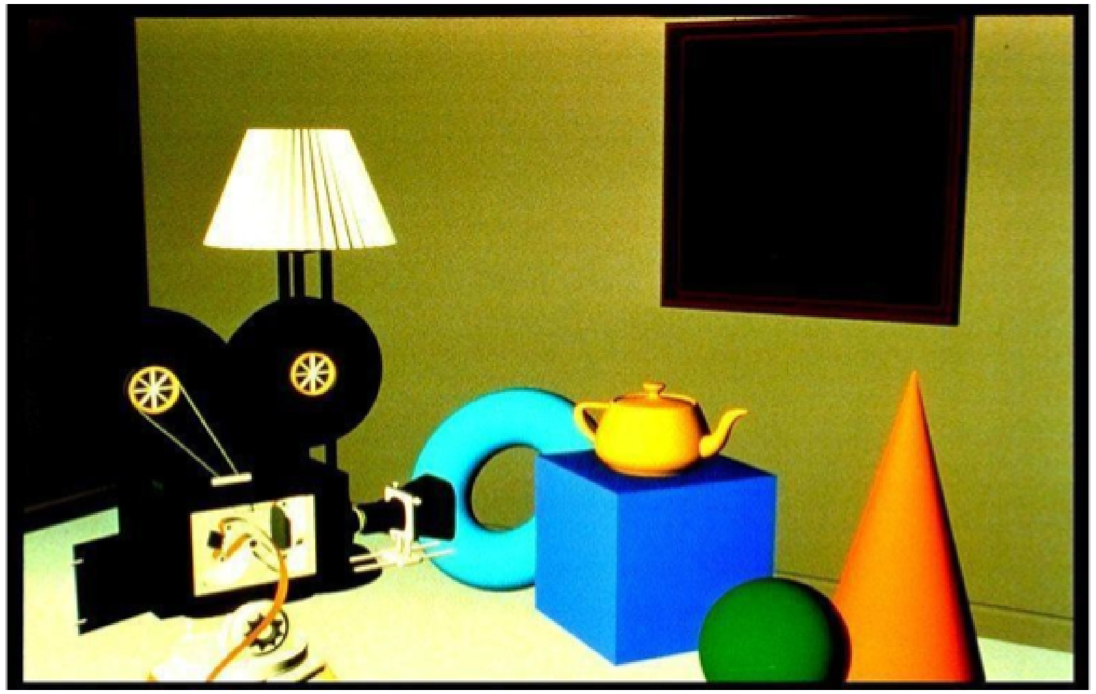
Gouraud shading



Gouraud shading

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

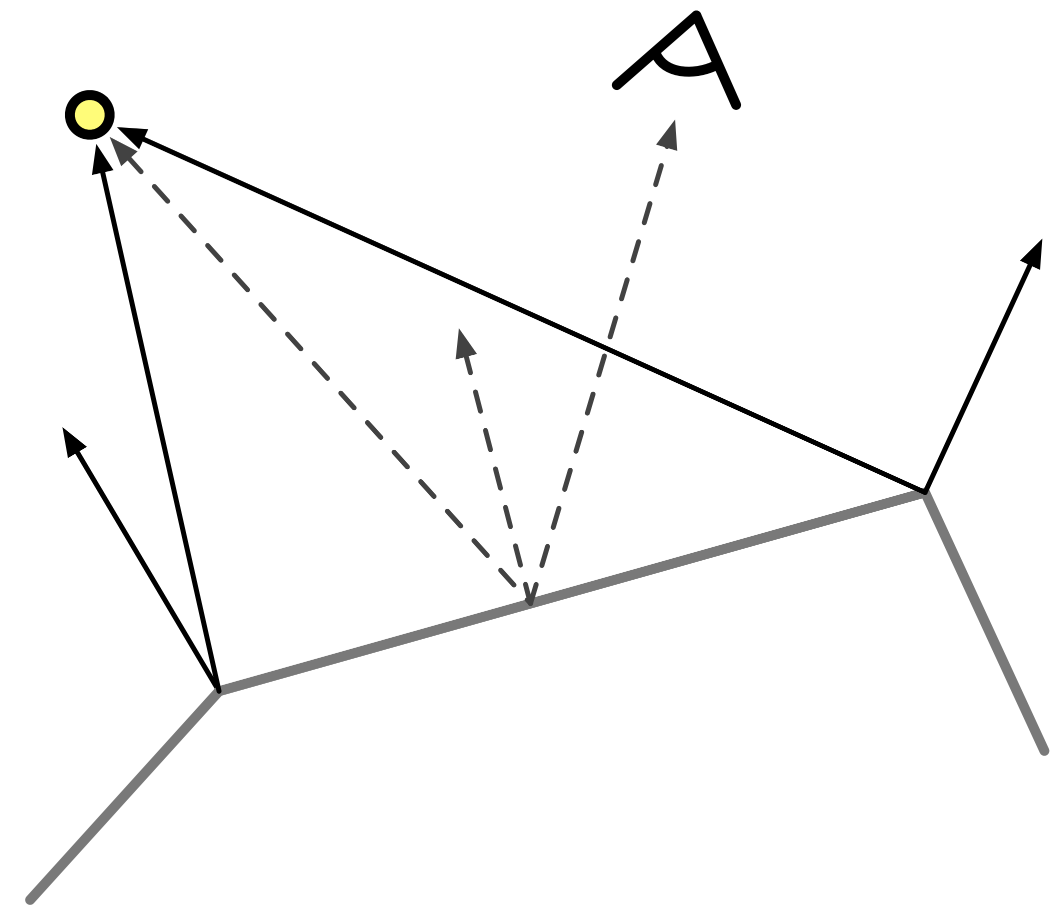




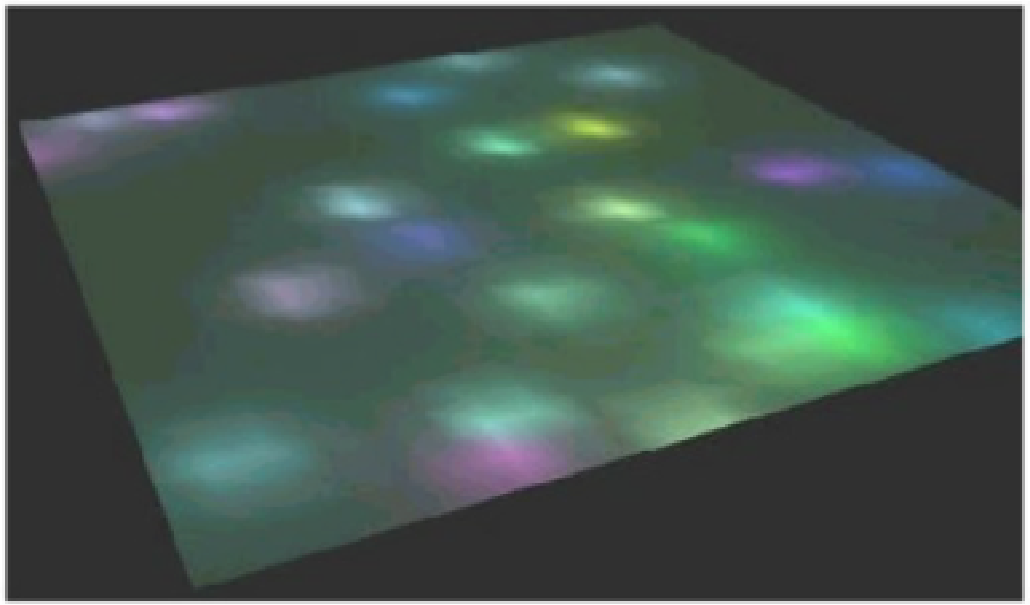
Problems with Gouraud shading

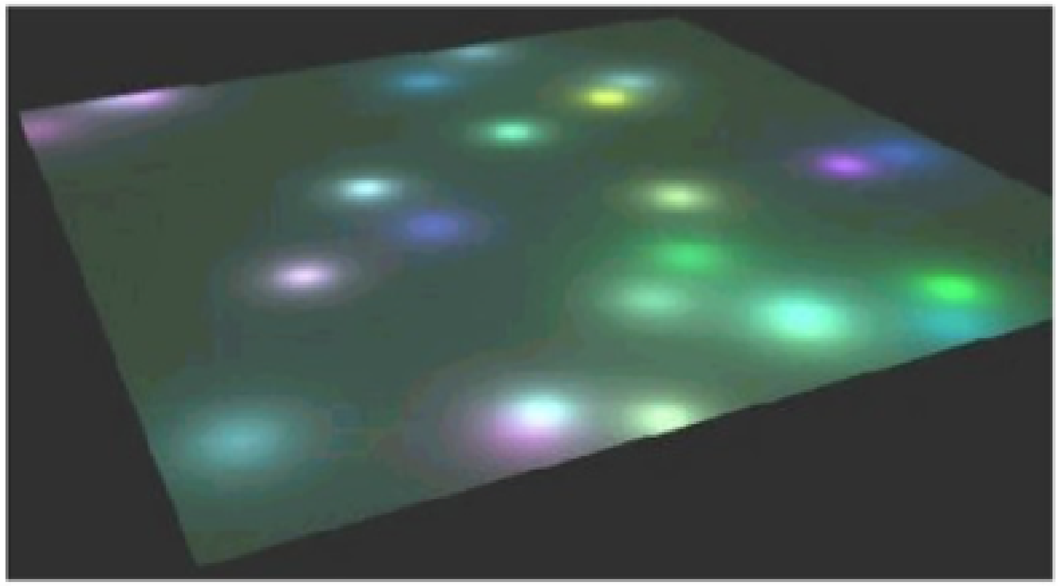
In specular reflection the highlight can be sharp, depending on the shape of $\cos^n \alpha$

- 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

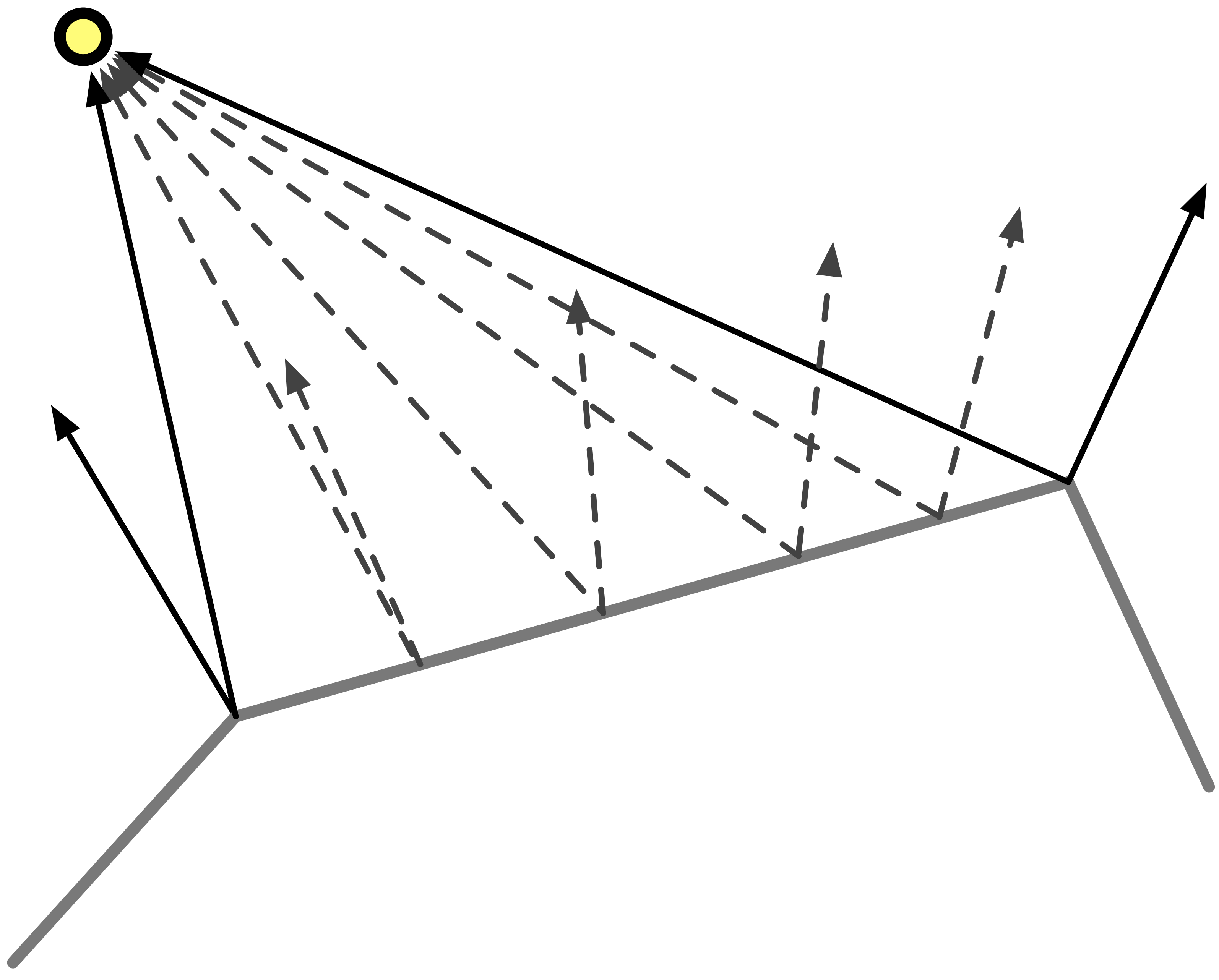




Phong shading

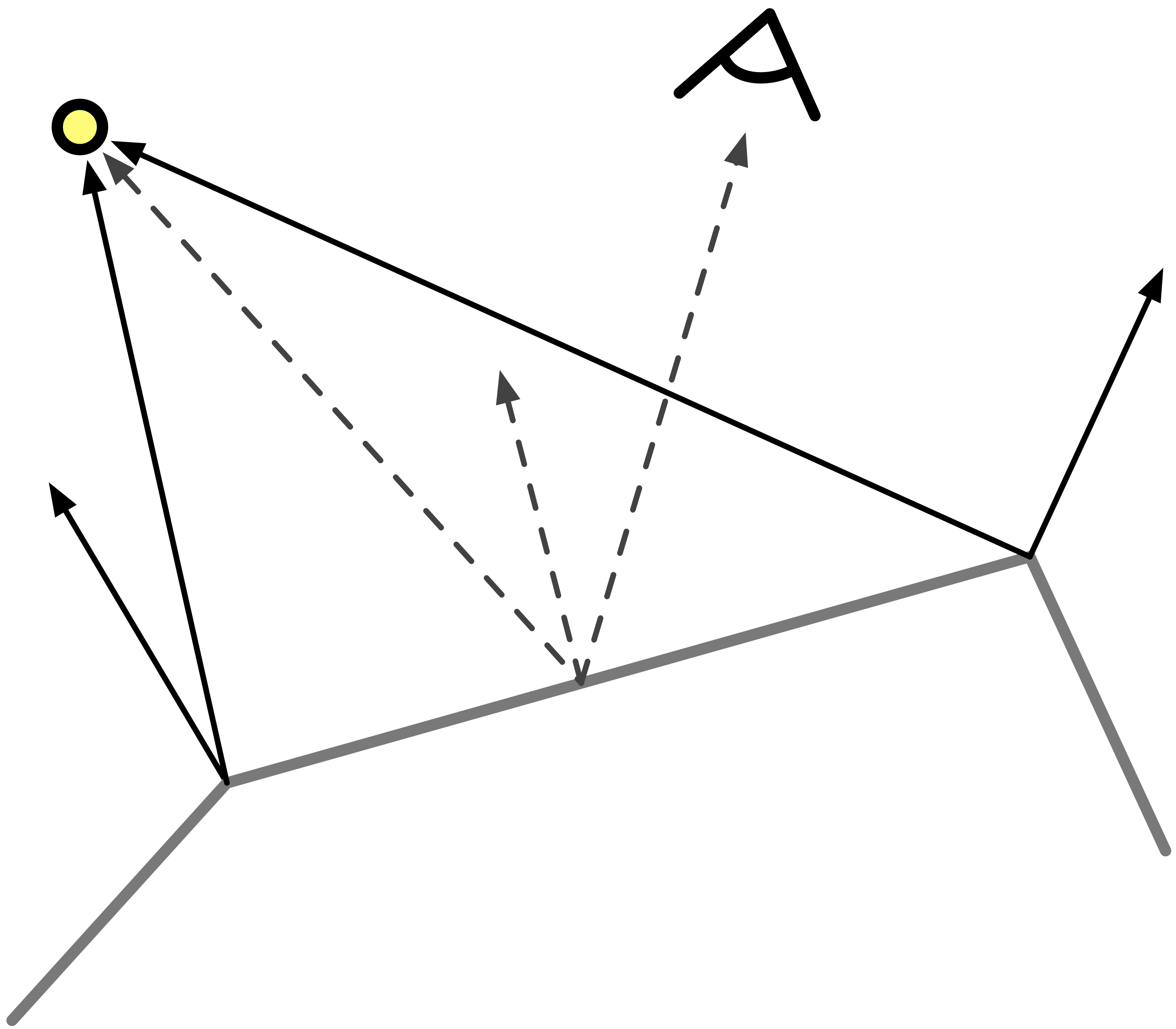
Phong shading

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

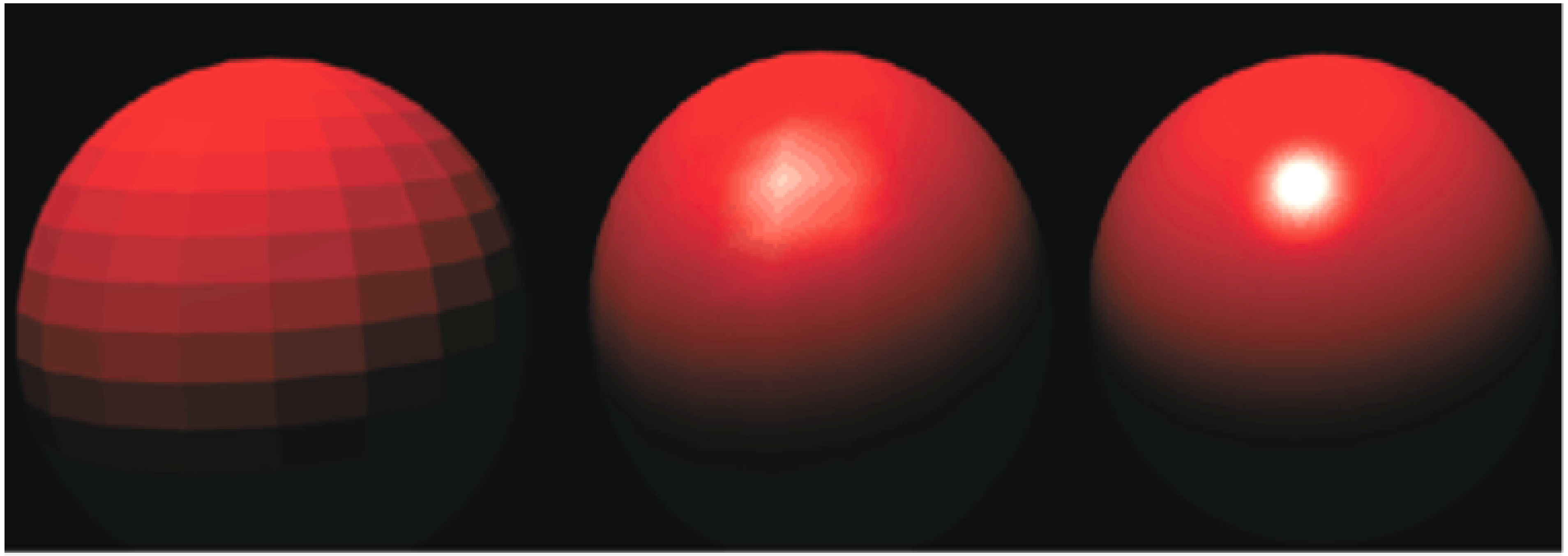


Phong shading

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



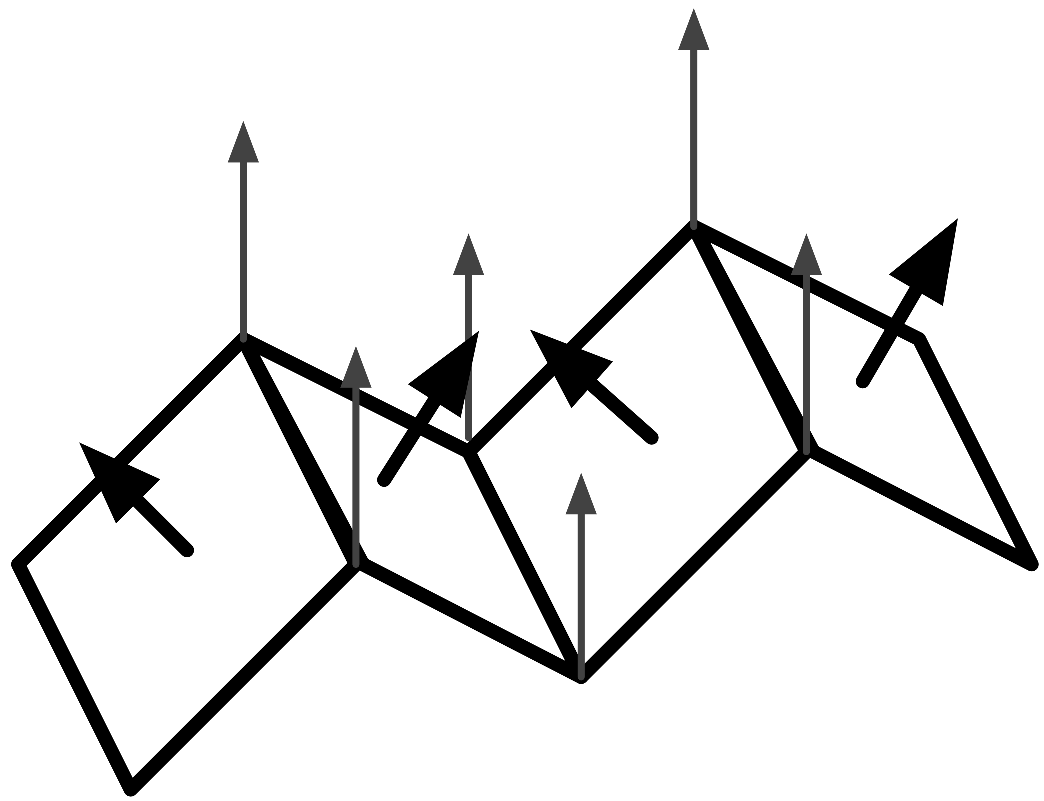
Phong example



Flat Gouraud Phong

Problems with interpolation shading

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

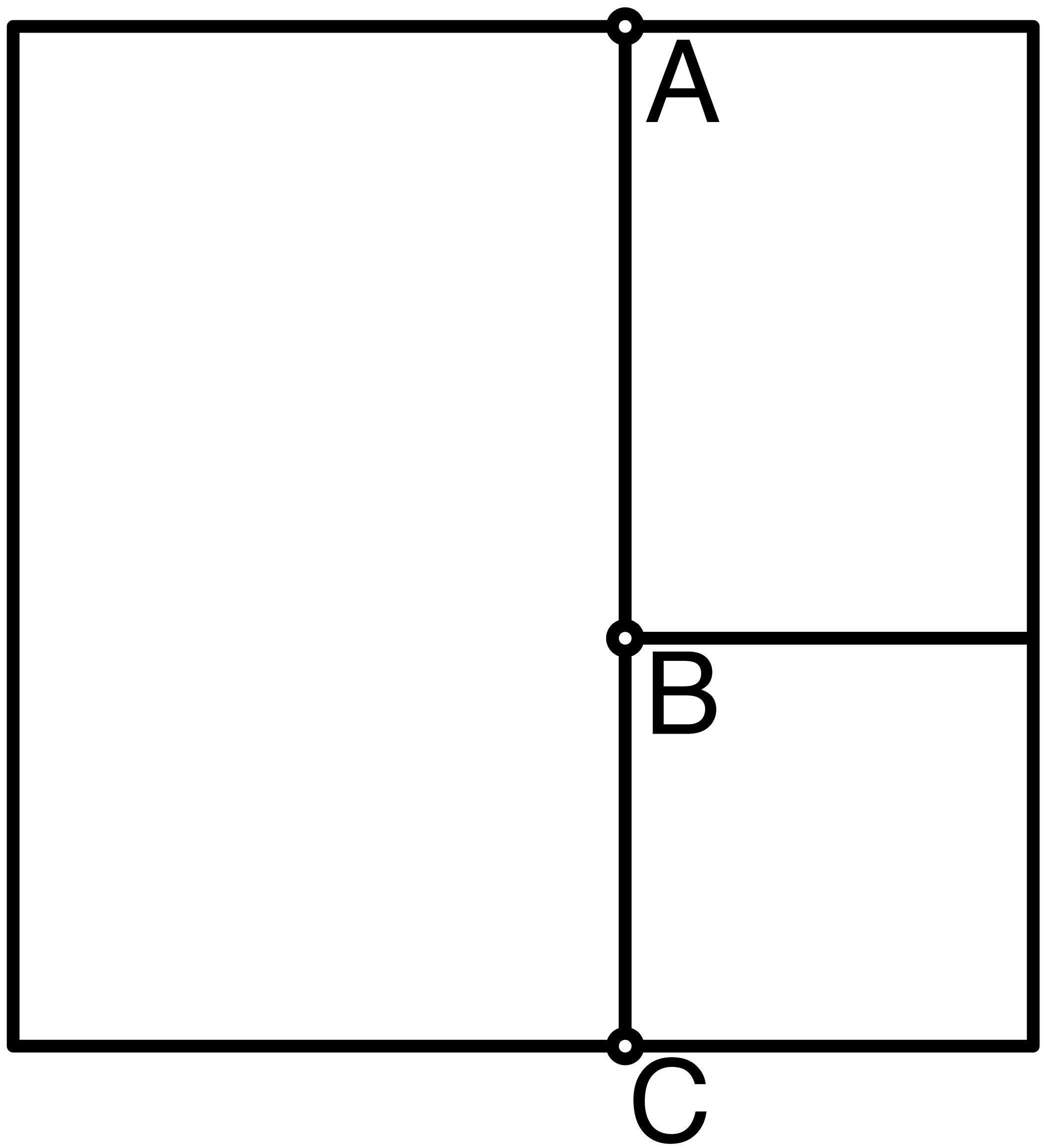


Solutions:

- 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

- Shirley, Chapter 10.1-10.2.2 (Surface shading)
- Foley, Chapter 16 (Illumination and shading), up to 16.3