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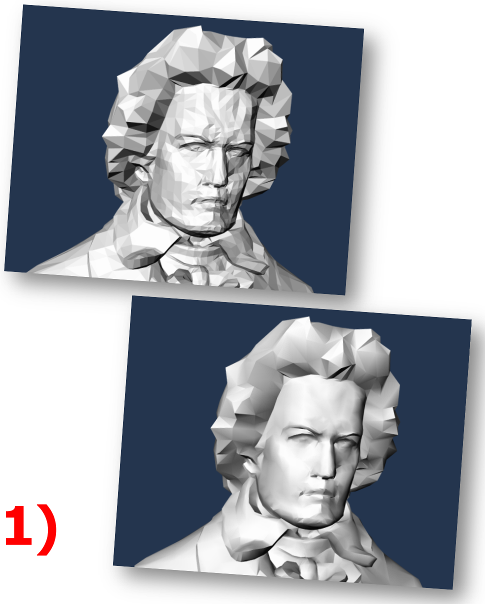
COMP27112

Computer Graphics and Image Processing

7: Rendering (1)



Toby.Howard@manchester.ac.uk

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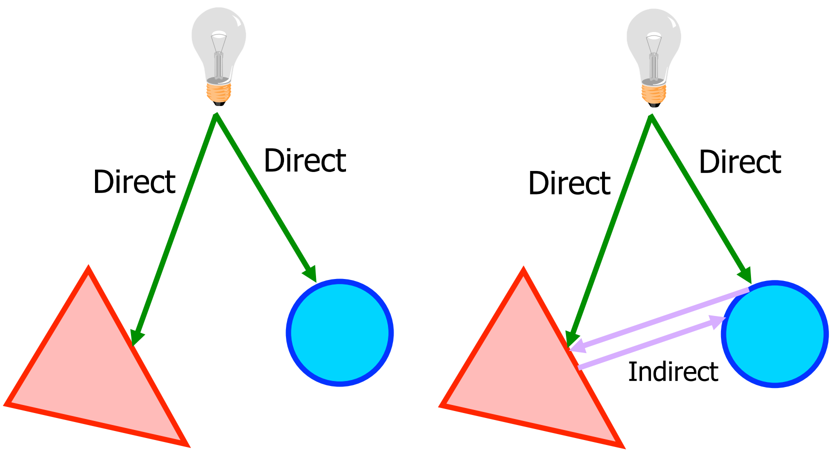
Local and global illumination



Local illumination model

Global illumination model

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Local and global models

- We can make models of light-matter interaction in two ways
  - **Locally**: we treat each object in a scene separately from any other object
  - **Globally**: we treat all objects together, and model the interactions between objects
- we'll develop a simple local illumination model in detail
- we'll look at global models in COMP37111 next year

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Illumination models

- The interaction of light and matter is an extremely complex process
- In computer graphics we try to **model** this process. In other words, we **approximate** it
- Computer pictures are digital, with finite precision. We can only ever approximate.

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Local illumination: elements

- We'll develop a model step-by-step, to include the following:
  - Ambient illumination
  - Diffuse reflection
  - Positional light source
  - Specular reflection
  - Colour of lights and surfaces

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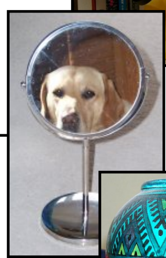
Reflectivity

- There are three kinds of reflection:
  - Perfect diffuse reflection
  - Perfect specular reflection
  - Imperfect specular reflection



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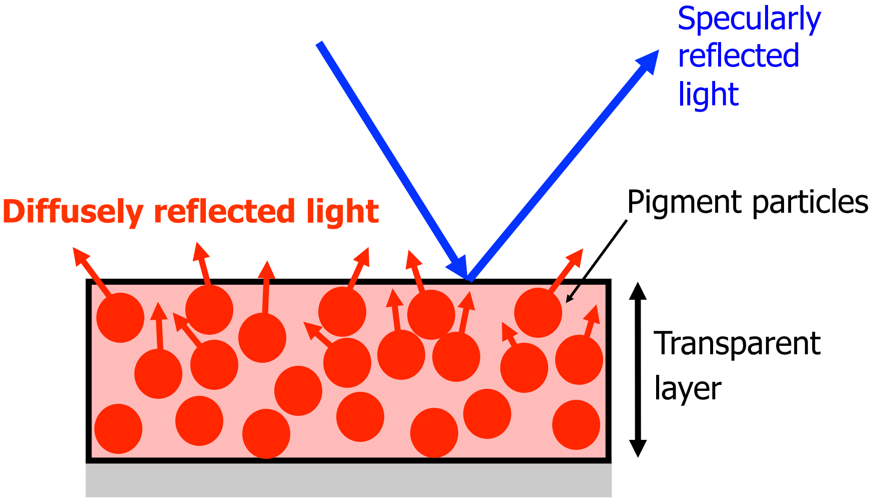
Light/surface interaction



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Diffuse and specular reflection

- **Diffuse** reflection is absorption and uniform re-radiation
  - Some wavelengths are absorbed, some are reflected
  - a green object looks green because it only reflects green
- **Specular** reflection is reflection at the air/ surface interface
  - To a first approximation, the colour of the specular reflection is that of the light source

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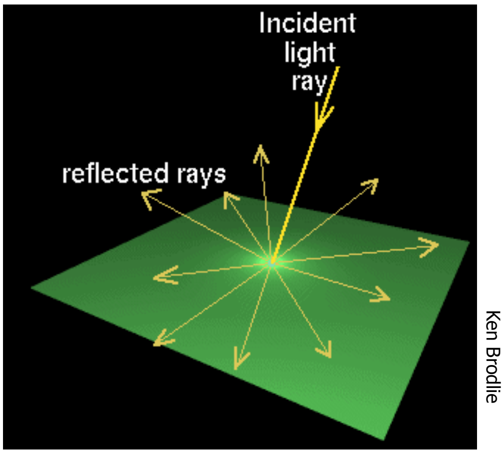
Perfect diffuse reflection



- Incident rays of light are reflected in all directions from the surface

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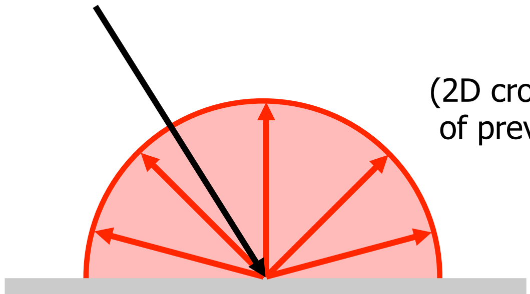
Perfect diffuse reflection

- A perfect diffuse surface reflects an incoming ray across all angles



(2D cross-section of previous slide)

- The surface looks dull, or matte

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Some diffuse reflectors

- Sponge

- Brick

- Carpet

- Felt

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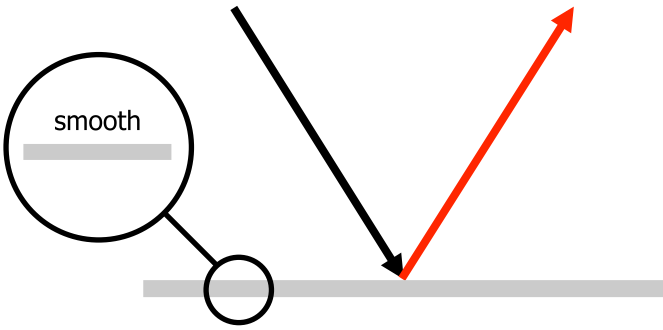
Perfect specular reflection

- A perfect specular surface reflects an incoming ray like a perfect mirror



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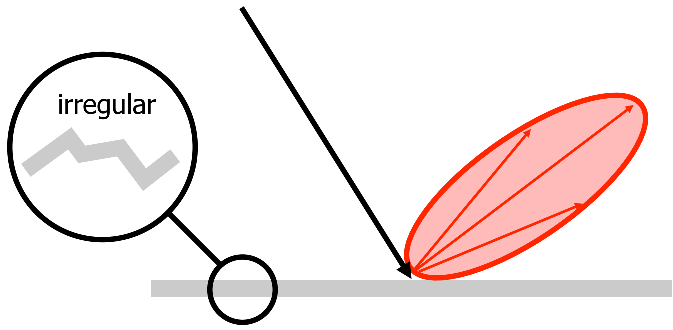
Imperfect specular reflection

- A imperfect specular surface reflects an incoming ray across a small range of angles



- The surface looks shiny, with highlights

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Some imperfect specular reflectors

- Lacquer-coated aluminium

- Glazed ceramic

- Stainless steel

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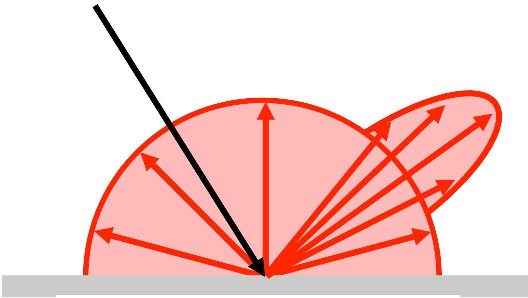
Diffuse/specular surfaces

- Most surfaces exhibit a combination of diffuse and specular reflection



- We can model these effects with varying degrees of realism

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Illumination sources

- We begin our development of the local illumination model by considering **diffuse** reflection, and **sources** of illumination:
  - Ambient illumination
  - Point illumination source at infinity (directional illumination)
  - Point illumination source in the scene

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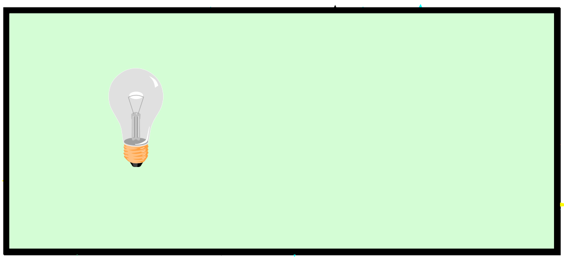
Ambient illumination

- Consider an environment with a light source
- Multiple reflections cause a general level of illumination in the scene



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Ambient illumination

- If intensity of ambient light is I_a
- Amount of light diffusely reflected from a surface is

$$I_{\text{ambient}} = k_a I_a$$

- Where k_a is the **ambient reflection coefficient** of the surface

$$0 \le k_a \le 1$$

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Local illumination model v1

- We now have the first term in the model we're developing
- I = ambient
- $\boxed{I = k_a I_a}$

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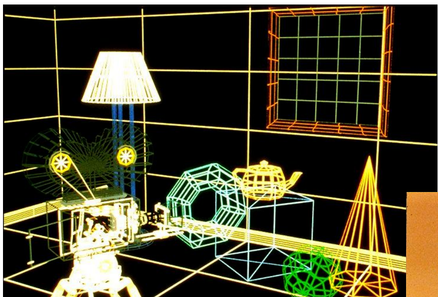
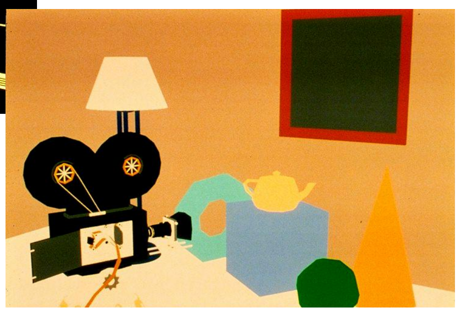
Wireframe versus ambient



Wireframe rendering

Rendering with ambient illumination



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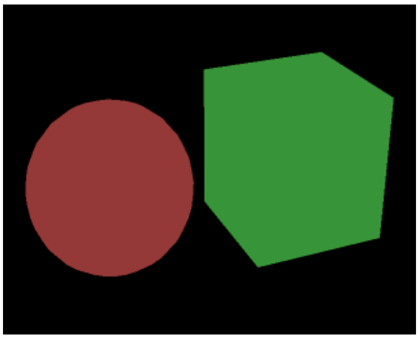
Effect of ambient illumination

- Each object is uniformly illuminated
- Lose 3D information



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Varying k_a

I_a is constant

$$k_a = 0.1 \longrightarrow k_a = 1.0$$

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True ambient lighting

Note: the

$$I = k_a I_a$$

term is a gross simplification of true ambient illumination, which is **not** constant in a scene

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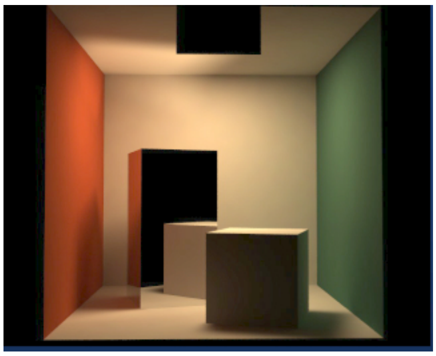
True ambient lighting

Real scene (photograph)



Scene modelled and rendered with accurate global illumination model

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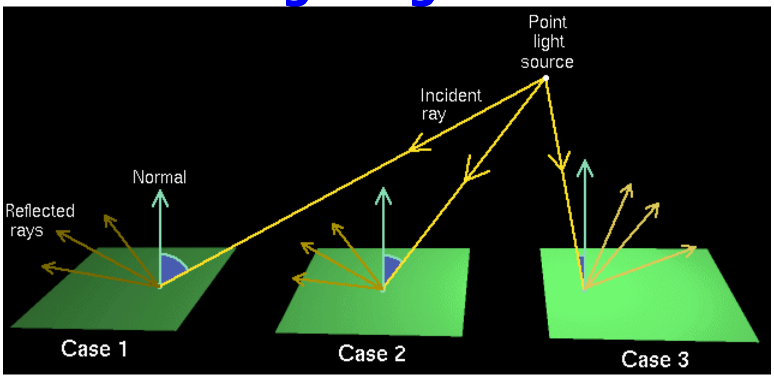
Directional lighting



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- We need to model the effects of
  - different angles of incidence
  - different distances from the light source

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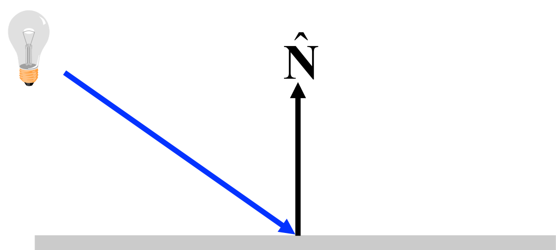
Directional lighting

- Let's consider light from a point source at infinity – so we're only concerned with the direction



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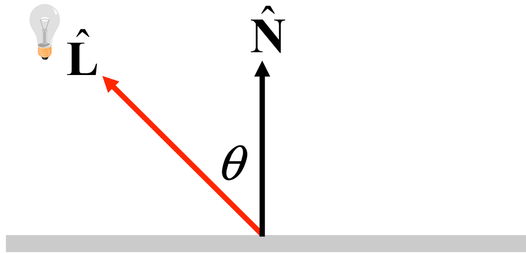
Describing surface orientation



- $\hat{\mathbf{N}}$ is surface normal
- $\hat{\mathbf{L}}$ is direction of light source
- θ is angle of incidence
- Note the vectors are **normalised**

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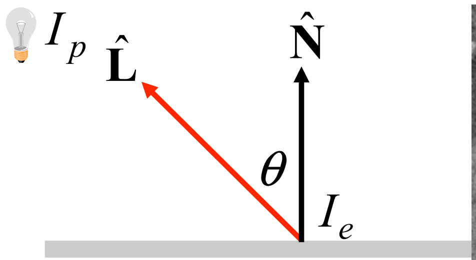
Diffuse reflection: Lambert's Law



Johann Heinrich Lambert (1728-1777)

- Light source of intensity I_p
- Effective intensity received is I_e
- Lambert's Law: $I_e = I_p \cos\theta$

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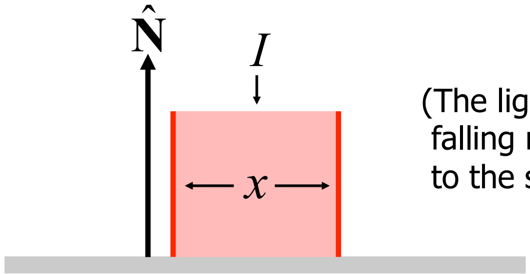
Lambert's Law derived

- Consider light of intensity I and cross-sectional width x falling on a surface:



(The light is falling **normal** to the surface)

- So width x on surface receives all of intensity I

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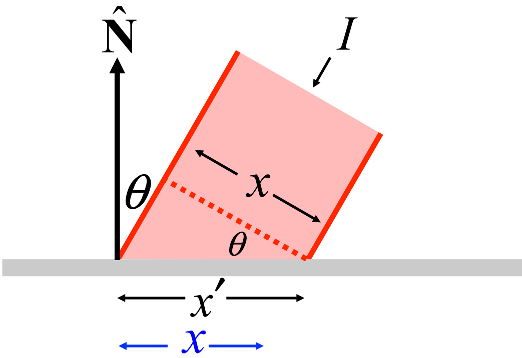
Lambert's Law derived

- Now consider the light inclined at θ
- $x' = x / \cos\theta$, so $x = x' \cos\theta$
- So width x receives intensity $I \cos\theta$



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Diffuse reflectivity

- We express how good a diffuse reflector a surface is using k_d
- k_d is the **diffuse reflection coefficient** of the surface, $0 \le k_d \le 1$
- Amount of diffusely reflected light is
  - $I_{\text{diffuse}} = I_p k_d \cos\theta$

    $I_{\text{diffuse}} = I_p k_d (\hat{\mathbf{N}} \cdot \hat{\mathbf{L}})$

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Local illumination model v2

- I = ambient + diffuse
- $$\boxed{I = k_a I_a + I_p k_d (\hat{\mathbf{N}} \cdot \hat{\mathbf{L}})}$$

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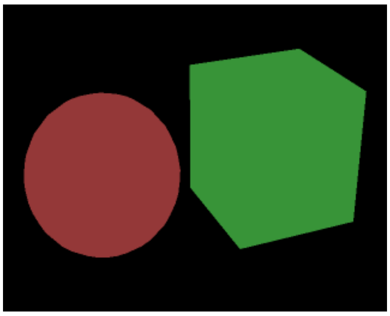
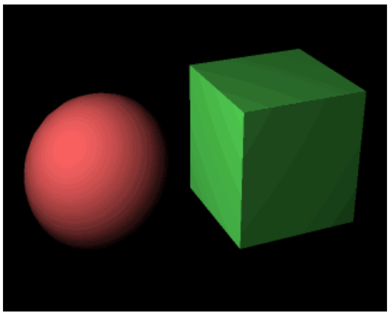
Ambient versus point source



Rendering with
ambient illumination

Rendering with
a point light source
and diffuse reflection



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Ambient versus point source

Rendering with
ambient illumination

Rendering with
a point light source
and diffuse reflection

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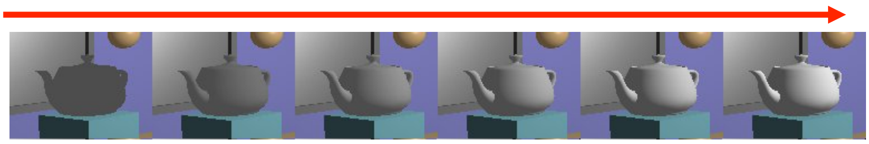
Effect of k_d

- Varying k_d from 0 to 1



Light source distance

- Physically, light intensity falls off with the square of distance travelled
- After travelling d, original intensity I_p is now I_e
- $I_e = \dfrac{I_p}{4\pi d^2}$

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Light source distance

- While this is physically correct, it doesn't always work well for computer graphics
- We only have a limited number of pixel intensities, and often the d^2 term changes too rapidly, so instead we use:

$$I_e = \frac{I_p}{k_c + k_l d + k_q d^2}$$

We can choose k_c, k_l, k_q for the best results

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Local illumination model v3

- I = ambient + distance (diffuse)
- $$\boxed{I = k_a I_a + \frac{I_p}{d'} k_d (\hat{\mathbf{N}} \cdot \hat{\mathbf{L}})}$$
- Where $d' = k_c + k_l d + k_q d^2$

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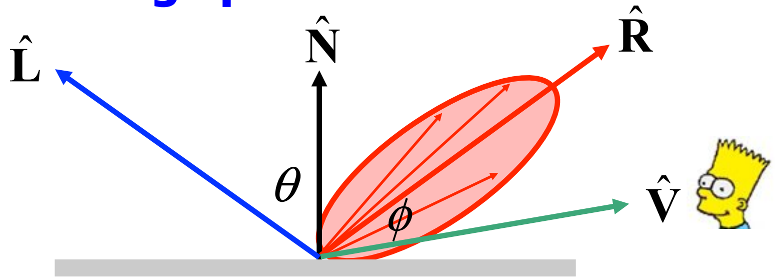
Modelling specular reflection



- Experiment shows specular reflection varies with:
  - Angle ϕ between $\hat{\mathbf{R}}$ and $\hat{\mathbf{V}}$
  - Incident angle θ and light wavelength λ
  - So we seek a function $I_{\text{specular}} = S(\phi, \theta, \lambda)$

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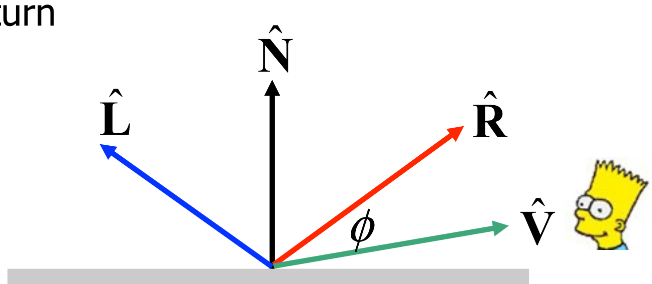
Modelling specular reflection

- What is this function $S(\phi, \theta, \lambda)$?
- We'll look at the effects of ϕ, θ, λ in turn
- First, ϕ



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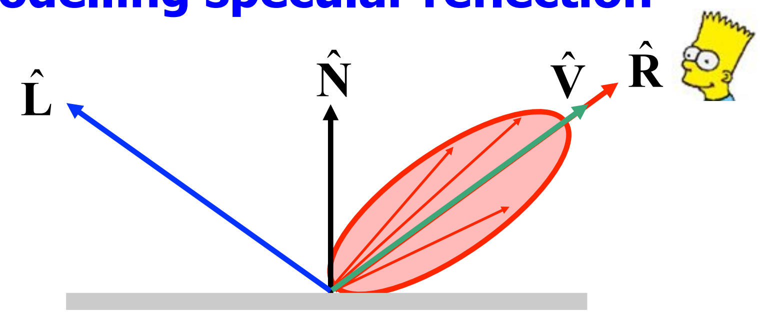
Modelling specular reflection



Observed specular = 100%

- Specular reflection spread out, around $\hat{\mathbf{R}}$
- Viewer sees maximum specular reflection when $\hat{\mathbf{V}}$ coincides with $\hat{\mathbf{R}}$

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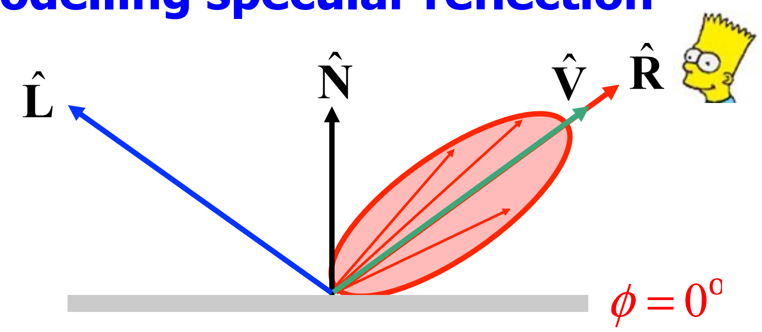
Modelling specular reflection



$\phi = 0^0$

Observed specular = 100%

- As $\hat{\mathbf{V}}$ diverges from $\hat{\mathbf{R}}$ by angle ϕ, viewer sees less specular reflection

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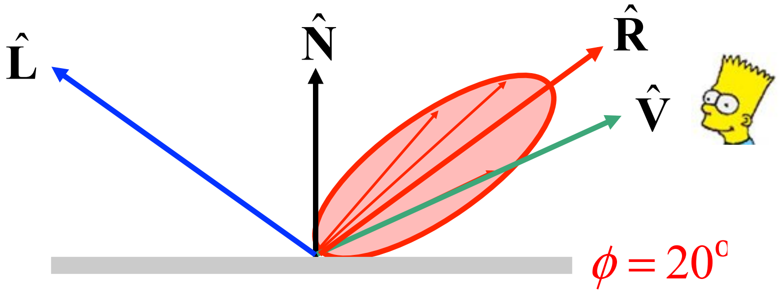
Modelling specular reflection



Observed specular = 60%

- As $\hat{V}$ diverges from $\hat{R}$ by angle ϕ, viewer sees less specular reflection

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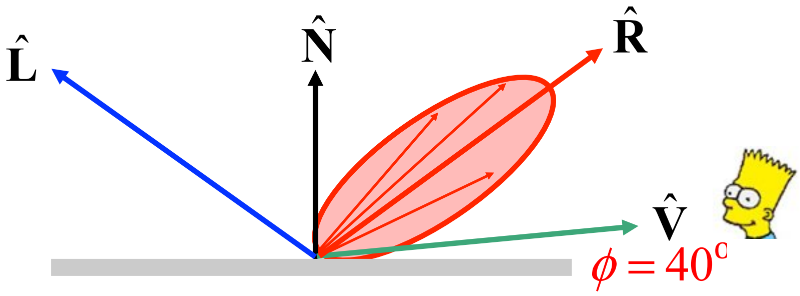
Modelling specular reflection



Observed specular = 5%

- As $\hat{V}$ diverges from $\hat{R}$ by angle ϕ, viewer sees less specular reflection

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Modelling specular reflection

- Variation of observed specular = $F(\phi)$
- But what is the function F ?
- Bui-Tuong Phong (1942-1975) proposed using the function $\cos^n \phi$

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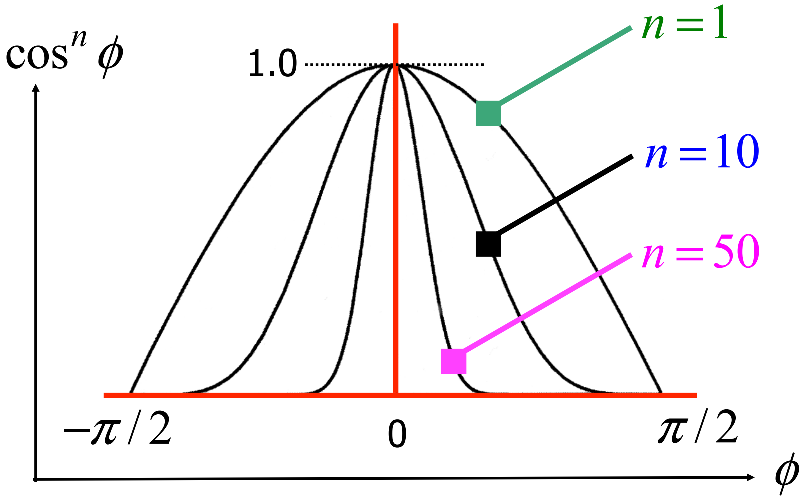
Phong's specular function

- This is a graph of $\cos^n \phi$ against ϕ



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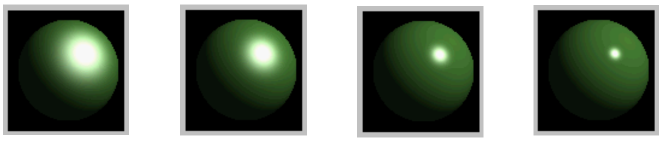
Phong's specular function

- So we now have
  - $$I_{\text{specular}} = I_p \cos^n \phi$$
- Which we can rewrite using vectors as
  - $$I_{\text{specular}} = I_p (\hat{\mathbf{R}} \cdot \hat{\mathbf{V}})^n$$
- Normally we use $1 \le n \le 200$



n =10 n =20 n =80 n =200

Richard Lobb

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Incident angle and wavelength

- Recall $I_{\text{specular}} = S(\phi, \theta, \lambda)$
- We've accounted for ϕ
- Now we look at the effects of θ and λ

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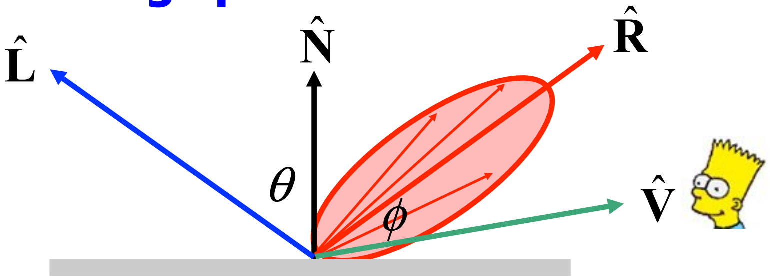
Modelling specular reflection



- Experiment shows specular reflection varies with:
  - Angle ϕ between $\hat{\mathbf{R}}$ and $\hat{\mathbf{V}}$
  - Incident angle θ and light wavelength λ
  - So we seek a function $I_{\text{specular}} = S(\phi, \theta, \lambda)$

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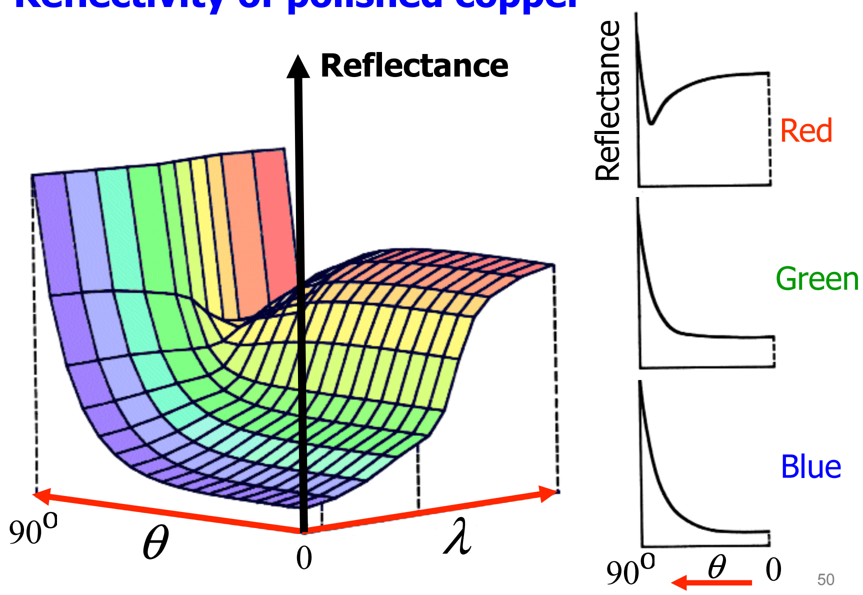
Reflectivity of polished copper



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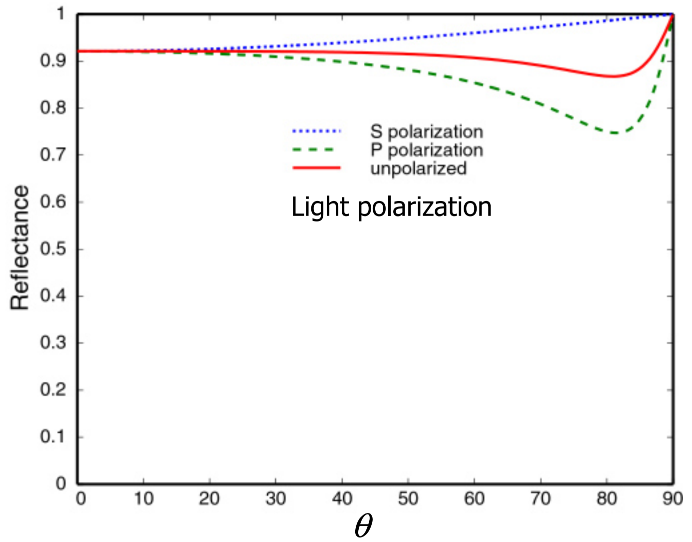
Reflectance of aluminium



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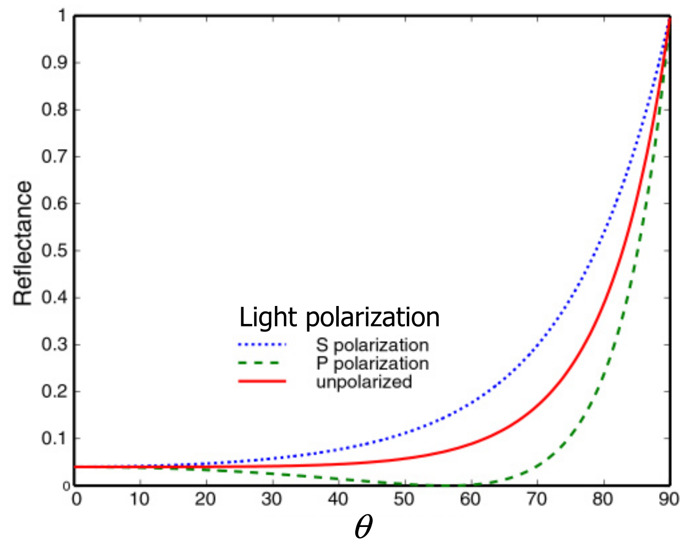
Reflectance of a non-conductor



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Incident angle and wavelength

- This complex variation is expressed by the Fresnel equation (Augustin-Jean Fresnel, 1788-1827)

  - A founder of the wave theory of light.
  - Developed theory of diffraction of light.
  - Obtained circularly polarised light
  - Developed the use of compound lenses instead of mirrors for lighthouses.

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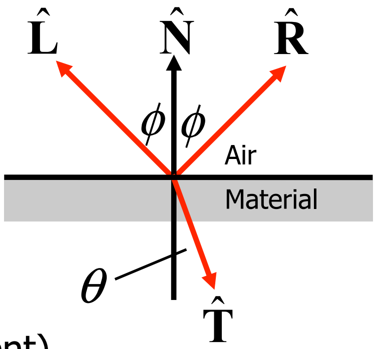
Incident angle and wavelength

- This complex variation is expressed by the Fresnel equation (Augustin-Jean Fresnel, 1788-1827)

$$F = \frac{1}{2}\left[\frac{\sin^2(\phi-\theta)}{\sin^2(\phi+\theta)} + \frac{\tan^2(\phi-\theta)}{\tan^2(\phi+\theta)}\right]$$

- F is the fraction of light reflected
- $\sin\theta = \sin\phi / \mu$
- μ is the refractive index of the material (λ dependent)



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Incident angle and wavelength

- In practice, we usually approximate F with a single constant k_s
- k_s is the **specular reflection coefficient** of the surface, $0 \le k_s \le 1$
- $I_{\text{specular}} = I_p k_s (\mathbf{R} \cdot \mathbf{V})^n$
- But, we sacrifice accuracy for efficiency

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Local illumination model v4

- I = ambient + distance (diffuse + specular)

$$\boxed{I = k_a I_a + \frac{I_p}{d'}\left[k_d(\hat{\mathbf{N}} \cdot \hat{\mathbf{L}}) + k_s(\hat{\mathbf{R}} \cdot \hat{\mathbf{V}})^n\right]}$$

- Where $d' = k_c + k_l d + k_q d^2$

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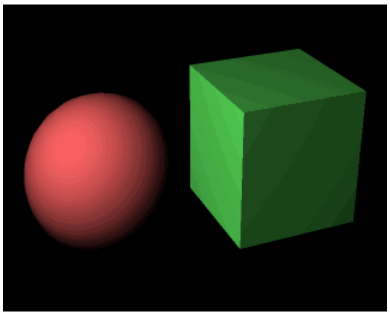
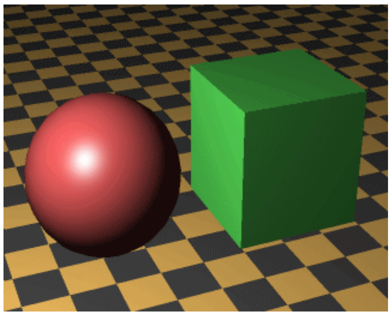
Diffuse and specular rendering



Rendering with
a point light source
and diffuse reflection

Rendering with
a point light source
and diffuse and
specular reflection



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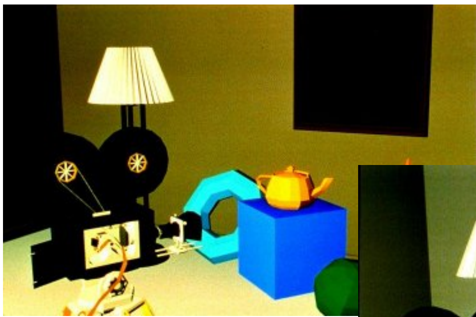
Diffuse and specular rendering



Rendering with
a point light source
and diffuse reflection

Rendering with
a point light source
and diffuse and
specular reflection

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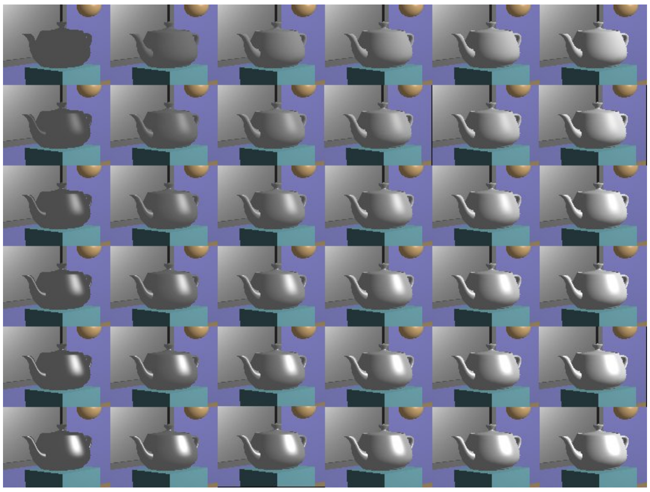
Varying k_d and k_s



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Varying k_s and exponent *n*

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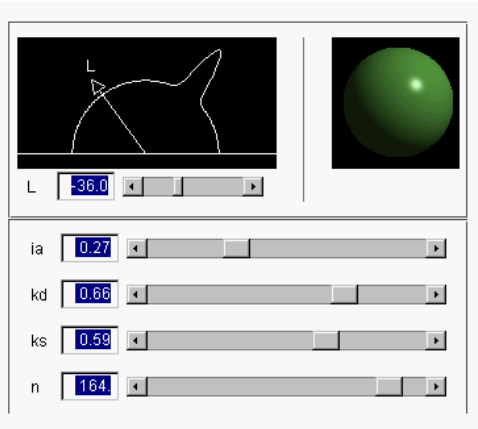
Phong applet



Richard Lobb

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

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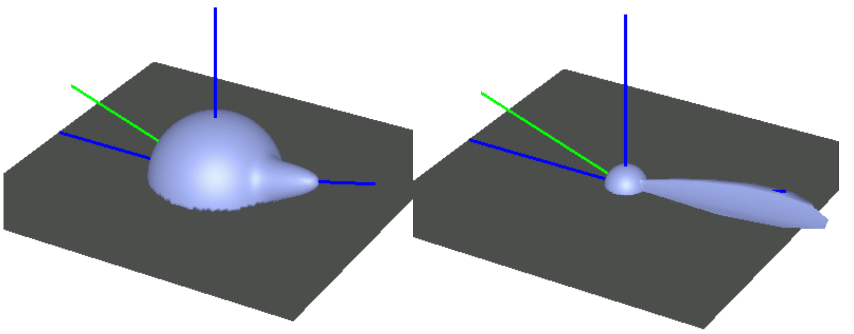
Inaccuracy of Phong model

- For a large angle of incidence, the Phong $\cos^n$ term is incorrect



Phong $\cos^n$ approximation

Accurate Fresnel-based reflection

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Incorporating colour

- So far, we've only considered light **intensity**, not colour
- It's easy to incorporate – we express light colour as a triple of RGB intensities:
  - I_{pR}, I_{pG}, I_{pB}
- And correspondingly we express surface colour using
  - k_{aR}, k_{aG}, k_{aB}
  - k_{dR}, k_{dG}, k_{dB}

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Local illumination model v5

- We now have a separate expression for each colour component. For example, for red:
- I_R = ambient$_{Red}$ + distance (diffuse$_{Red}$ + specular)
- $$\boxed{I_R = k_{aR} I_{aR} + \frac{I_{pR}}{d'} \left[k_{dR} (\hat{\mathbf{N}} \cdot \hat{\mathbf{L}}) + k_s (\hat{\mathbf{R}} \cdot \hat{\mathbf{V}})^n \right]}$$

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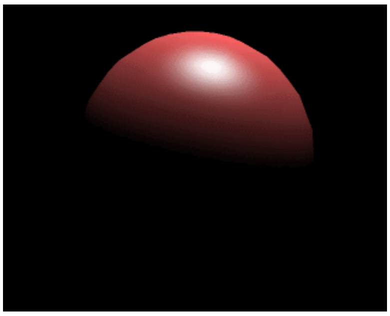
Multiple lights

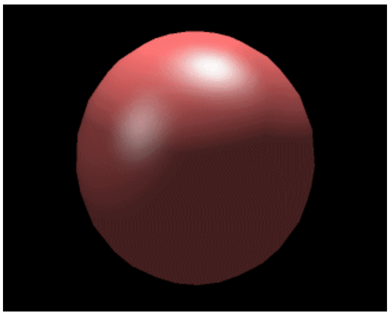
- Finally, what if we have more than one light?
- Easy, compute illumination separately for each and sum. For M lights:
- $I = ambient + \sum_{i=1}^{M} (\text{diffuse}_i + \text{specular}_i)$

Multiple lights

One light



Two lights



Ken Brodlie

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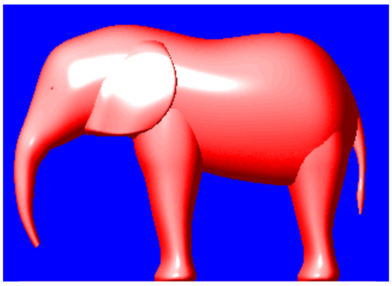
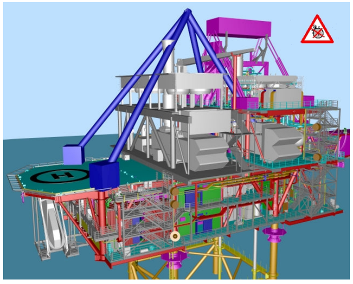
Examples of the model in use



Lex Lennings



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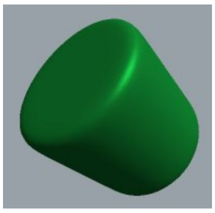
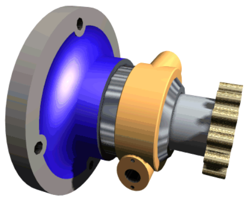


James Sinnott



Alan Watt

nVIDIA

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The “standard” model

- The local illumination model we’ve developed is the “standard” model in use today
- Implemented in OpenGL
- Implemented in hardware on consumer 3D graphics cards

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