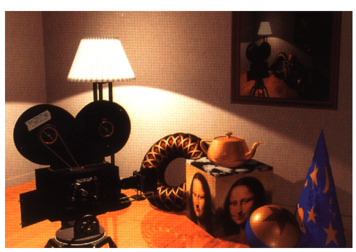
Lighting

Lighting/Shading

- Goal
  - Model the interaction of light with surfaces to render realistic images
  - Generate per (pixel/vertex) color



Factors

- Light sources
  - Location, type & color
- Surface materials
  - How surfaces reflect light
- Transport of light
  - How light moves in a scene
- Viewer position

Illumination Models/Algorithms

- Local illumination - Fast
  - Ignore real physics, approximate the look
  - Interaction of each object with light
    - Compute on surface (light to viewer)
- Global illumination – Slow
  - Physically based
  - Interactions between objects

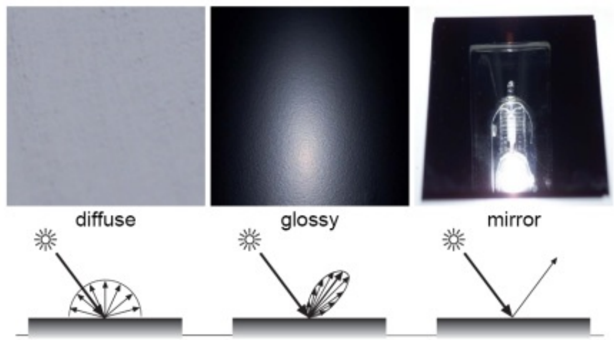
The big picture (basic)

- Light: energy in a range of wavelengths
  - White light – all wavelengths
  - Colored (e.g. red) – subset of wavelengths
- Surface “color” – reflected wavelength
  - White – reflects all lengths
  - Black – absorbs everything
  - Colored (e.g. red) absorbs all but the reflected color
- Multiple light sources add (energy sums)

Materials

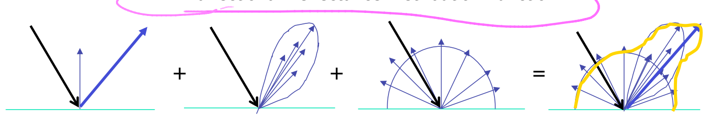
- Surface reflectance:
  - Illuminate surface point with a ray of light from different directions
  - How much light is reflected in each direction?

Basic Types



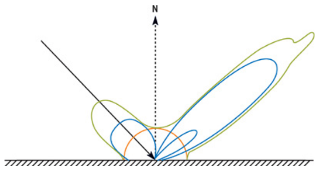
Reflectance Distribution Model

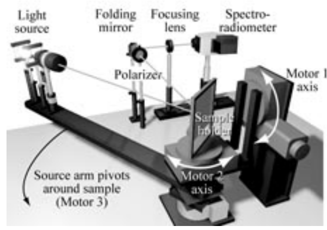
- Most surfaces exhibit complex reflectances
  - Vary with incident and reflected directions.
  - Model with combination – known as BRDF
    - BRDF: *Bidirectional Reflectance Distribution Function*

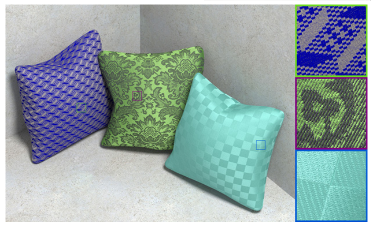


BRDF measurements/plots

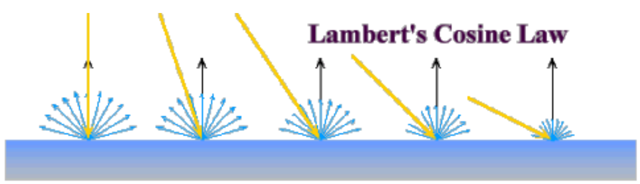
- 2D slice



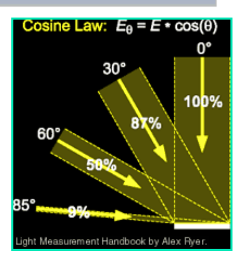




Lambert's "Law"

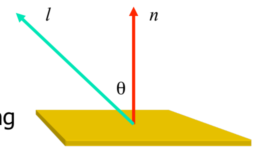


Intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- Depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d \, I_{light} \, \mathbf{cos}\,\theta$
- In practice use vector arithmetic
  - $I_{diffuse} = k_d \, I_{light} \, (\mathbf{n} \cdot \mathbf{l})$
- Always normalize vectors used in lighting
  - $\mathbf{n}$, $\mathbf{l}$ should be unit vectors
- Scalar (B/W intensity) or 3-tuple (color)
  - k_d: diffuse coefficient, surface color
  - I_{light}: incoming light intensity
  - $I_{diffuse}$: outgoing light intensity (for diffuse reflection)



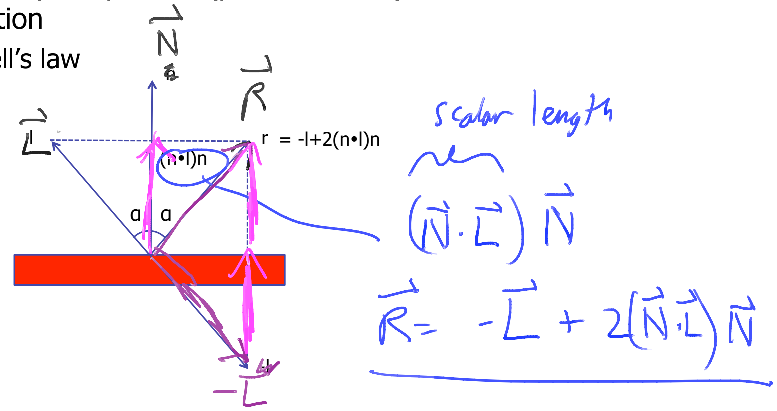
Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°

Physics of Specular Reflection

- Geometry of specular (perfect mirror) reflection
  - Snell's law

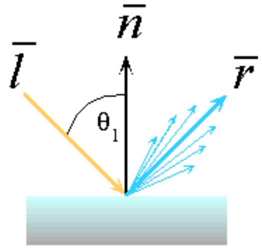


Empirical Approximation

- Snell's law = perfect mirror-like surfaces
  - But ..
    - few surfaces exhibit perfect specularity
    - Gaze and reflection directions never EXACTLY coincide
- Expect **most** reflected light to travel in direction predicted by Snell's Law
- But some light may be reflected in a direction slightly off the ideal reflected ray
- As angle from ideal reflected ray increases, we expect less light to be reflected

Empirical Approximation

- Angular falloff



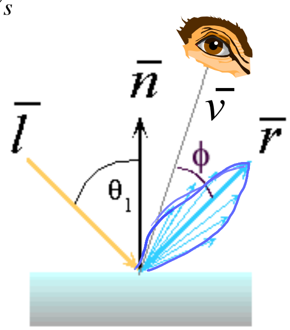
- How to model this falloff?

Phong Lighting

- Most common lighting model in computer graphics
  - (Phong Bui-Tuong, 1975)

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\cos\phi)^{n_s}$$

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\mathbf{v} \bullet \mathbf{r})^{n_s}$$



ϕ: angle between r and view direction v

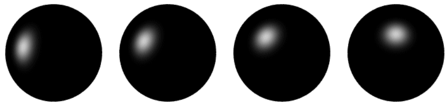
n_s : purely empirical constant, varies rate of falloff

k_s: specular coefficient, highlight color

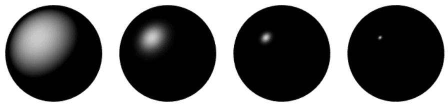
no physical basis, "plastic" look

Phong Examples

varying light position



varying n_s

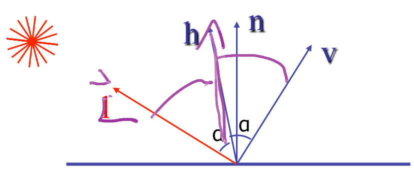


Alternative Model

- Blinn-Phong model (Jim Blinn, 1977)
  - Variation with better physical interpretation
    - **h**: halfway vector; r: roughness

$$I_{specular} = k_s \cdot (\mathbf{h} \cdot \mathbf{n})^{1/r} \cdot I_{light};\ \text{with}\ \mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$

largely equivalent to n in the Phong model.



Materials (last bit)

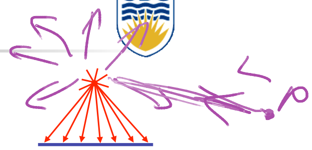
- Light is **linear**
  - If multiple rays illuminate the surface point the result is just the sum of the individual reflections for each ray

$$\sum_p I_p (k_d (n \cdot l_p) + k_s (r_p \cdot v)^n)$$

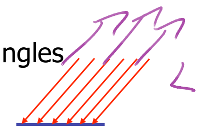
Ambient Light

- Non-directional light – environment light
- Object illuminated with same light everywhere
  - Looks like silhouette
- Illumination equation $I = I_a k_a$
  - I_a - ambient light intensity
  - k_a - fraction of this light reflected from surface

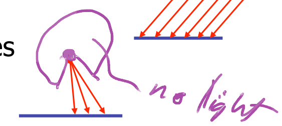
Light Source Types



- Point Light
  - light originates at a point
- Directional Light (point light at infinity)
  - light rays are parallel
  - Rays hit a planar surface at identical angles

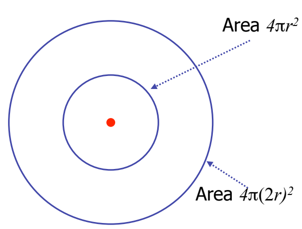


- Spot Light
  - point light with limited angles

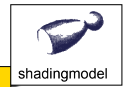


Light Source Falloff

- Quadratic falloff (point- and spot lights)
  - Brightness of objects depends on power per unit area that hits the object
  - The power per unit area for a point or spot light decreases quadratically with distance



Illumination Equation



- For multiple light sources:

$$I = I_a k_a + \sum_p \frac{I_p}{A(d_p)} (k_d (n \cdot l_p) + k_s (r_p \cdot v)^n)$$

- d_p - distance between surface and light source + distance between surface and viewer, A – attenuation function

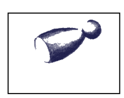
$A(d) \propto \frac{1}{d^2}$

Light

- Light has color
- Interacts with object color (r,g,b)

$$I = I_a k_a$$
$$I_a = (I_{ar}, I_{ag}, I_{ab})$$
$$k_a = (k_{ar}, k_{ag}, k_{ab})$$
$$I = (I_r, I_g, I_b) = (I_{ar} k_{ar}, I_{ag} k_{ag}, I_{ab} k_{ab})$$

- Blue light on white surface? → blue light reflected
- Blue light on red surface?



$I_a = (r,g,b) = (0,0,1)$
$k_a = (1,0,0)$
→ black

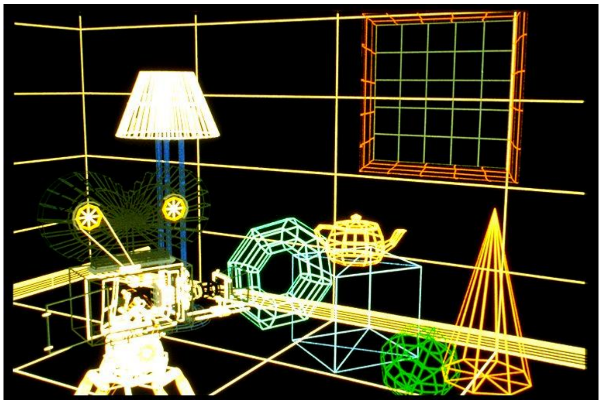
Light and Material Specification

- Light source: amount of RGB light emitted
  - value = percentage of full intensity, e.g., (1.0,0.5,0.5)
  - every light source emits ambient, diffuse, and specular light
- Materials: amount of RGB light reflected
  - value represents percentage reflected e.g., (0.0,1.0,0.5)
- Interaction: multiply components
  - Red light (1,0,0) x green surface (0,1,0) = black (0,0,0)

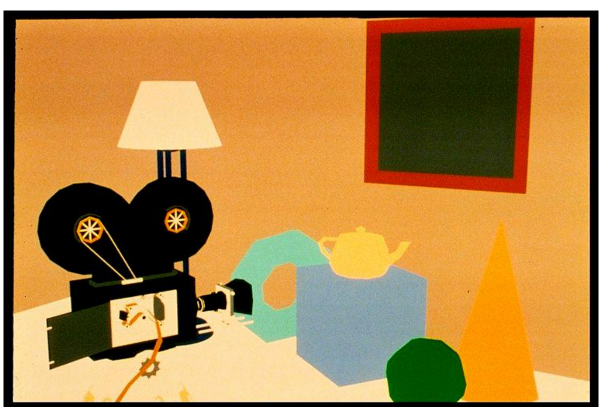
When to apply Lighting Model?

- per polygon
  - "flat shading"
- per vertex
  - "Gouraud shading"
- per pixel
  - "per pixel lighting", "Phong shading"

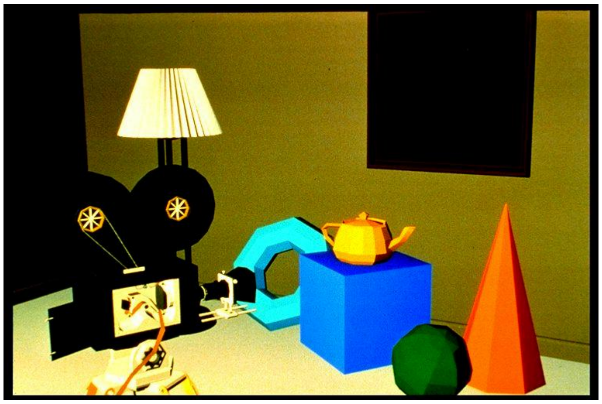
Colored Wireframes



Ambient Lighting

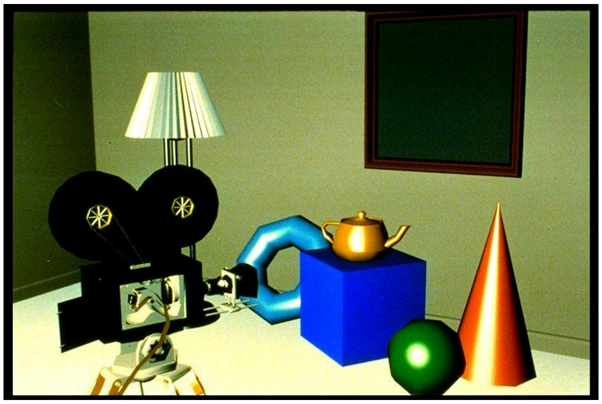


Per-Polygon Shading

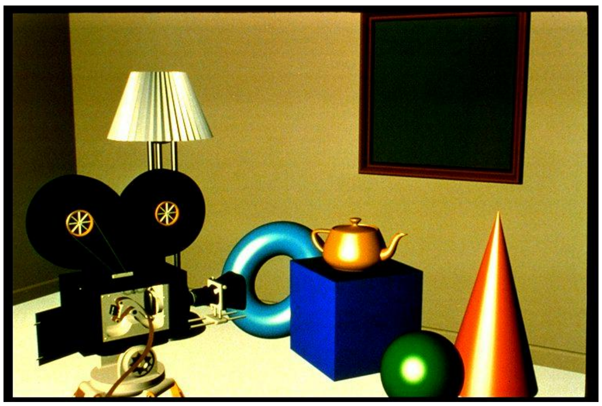


Per Vertex shading

Per Pixel Shading



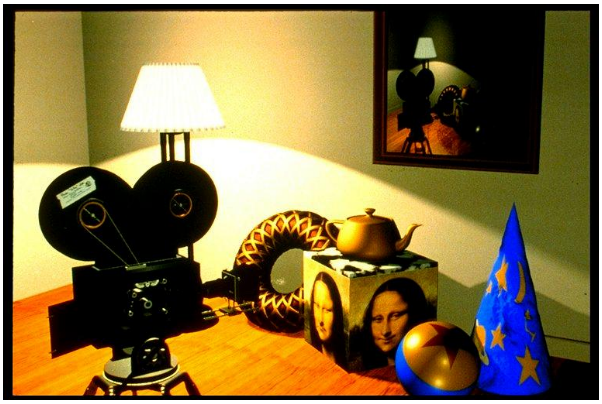
Curved Surfaces with Per-pixel Shading



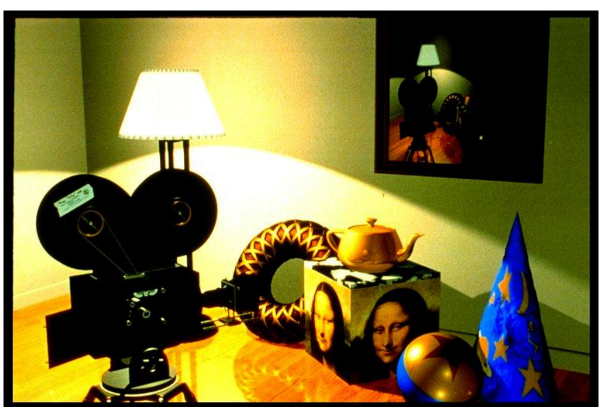
Complex Lighting and Shading

Texture Mapping

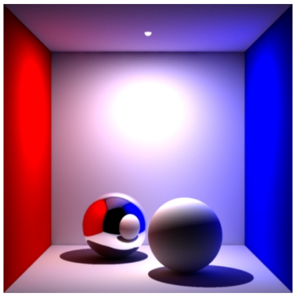
Displacement Mapping



Reflection Mapping



Global Illumination



Subsurface scattering