IMGD 3000 - Technical Game Development I: Illumination & Graphical Effects

by

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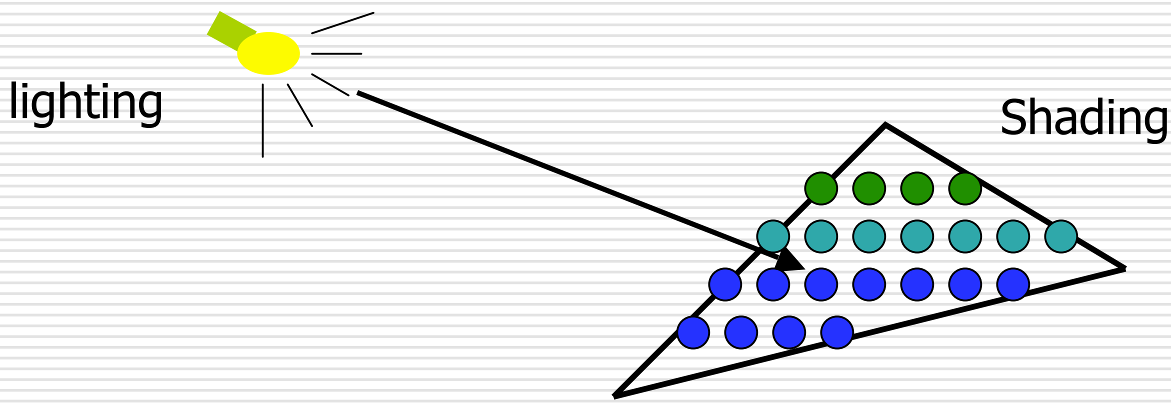
Motivation

- There is constant tension between realism and framerate
- Lots of techniques for improving realism
  - Ray tracing
  - Radiosity
  - Photon mapping
- But at what cost?
  - We want to handle dynamic scenes
  - We want only a modest impact on framerate

Illumination and Shading

- Problem: Model light/surface point interactions to determine final color and brightness
- Apply the lighting model at a set of points across the entire surface

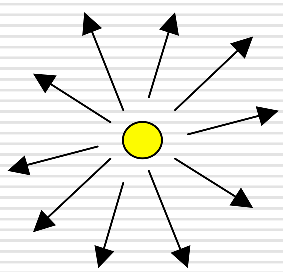


Illumination Model

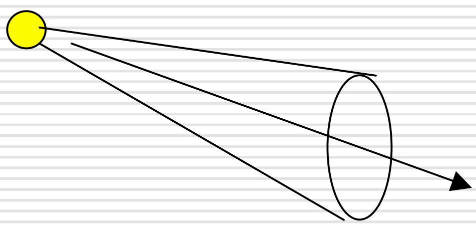
- The governing principles for computing the illumination
- An illumination model usually considers
  - Light attributes (intensity, color, position, direction, shape)
  - Object surface attributes (color, reflectivity, transparency, *etc.*)
  - Interaction among lights and objects

Basic Light Sources

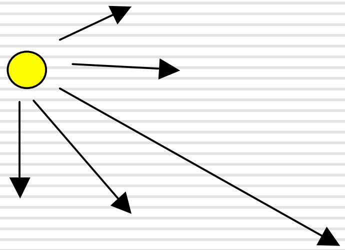
- Light intensity can be independent or dependent of the distance between object and the light source



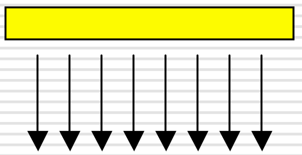
Point light



Spot light



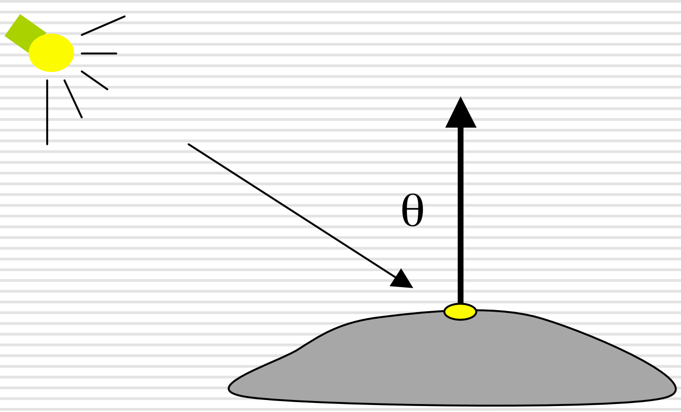
Directional light



Area light

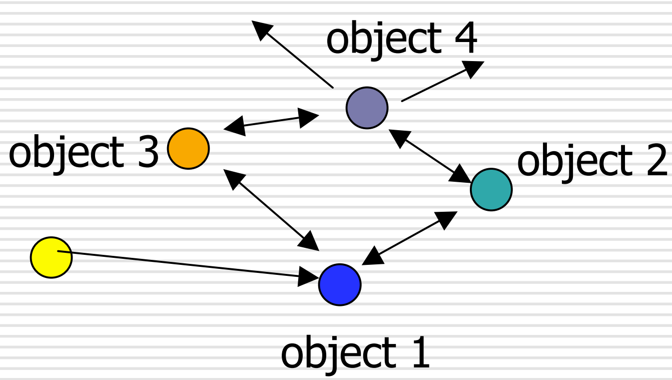
Local Illumination

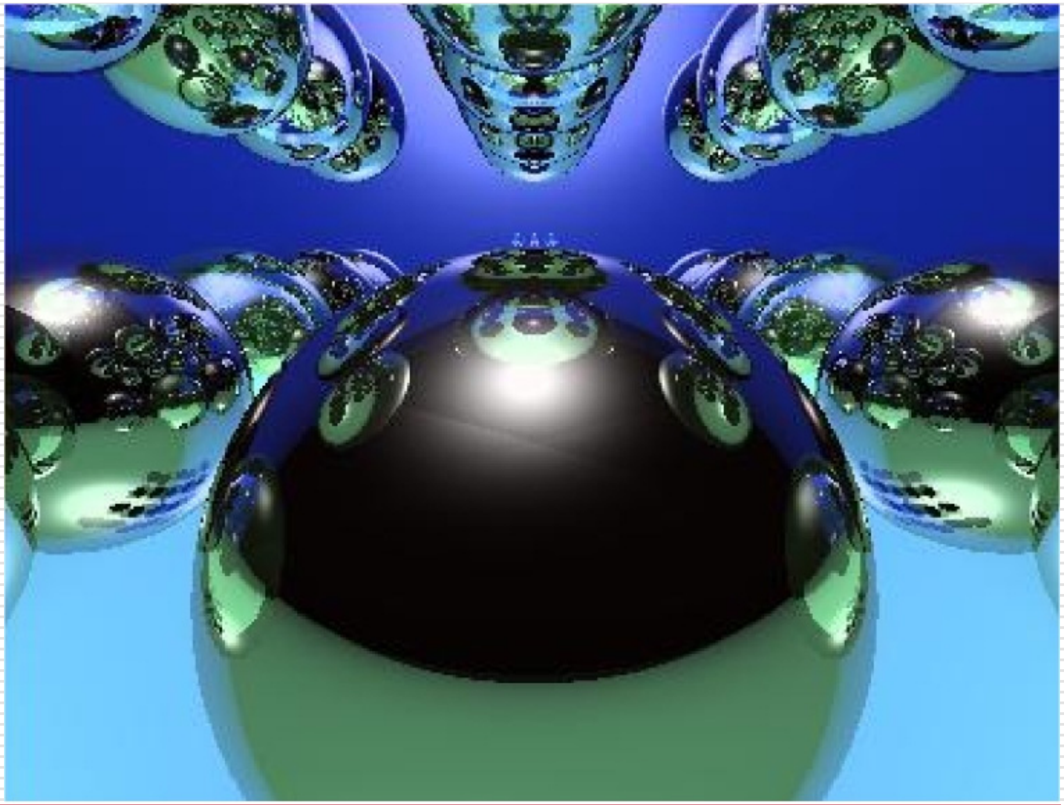
- Only consider the light, the observer position, and the object material properties



Global Illumination

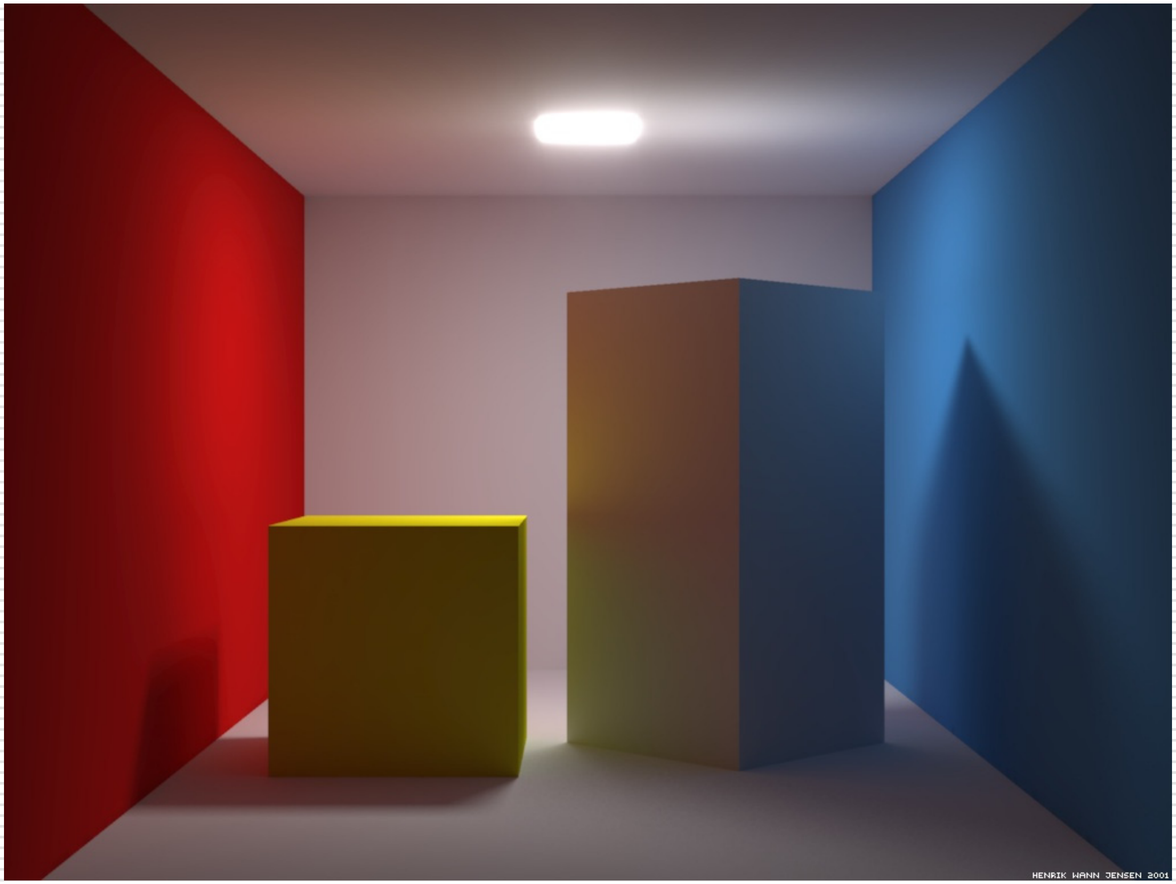
- Take into account the interaction of light from all the surfaces in the scene
- Example:
  - Ray Tracing





Global Illumination (cont.)

- Radiosity: View independent

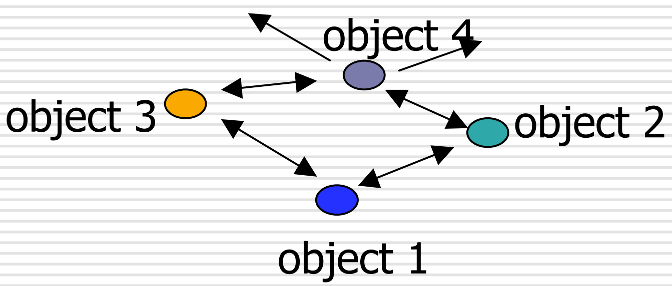


Simple Local Illumination

- Reduce the complex workings of light to three components
  - Ambient
  - Diffuse
  - Specular
- Final illumination at a point (vertex) = ambient + diffuse + specular
- Materials reflect each component differently
  - Use different material reflection coefficients
    - K_a, K_d, K_s

Ambient Light Contribution

- Ambient light = background light
- Light that is scattered by the environment
  - It's just there
- **Frequently assumed to be constant**
- Very simple approximation of global illumination
- No direction: independent of light position, object orientation, observer's position/orientation

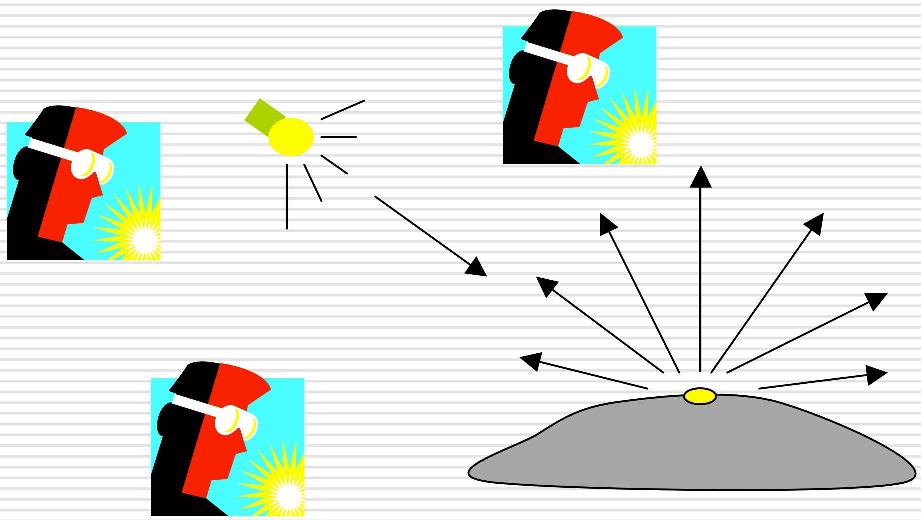


constant

$$\text{Ambient} = I \times K_a$$

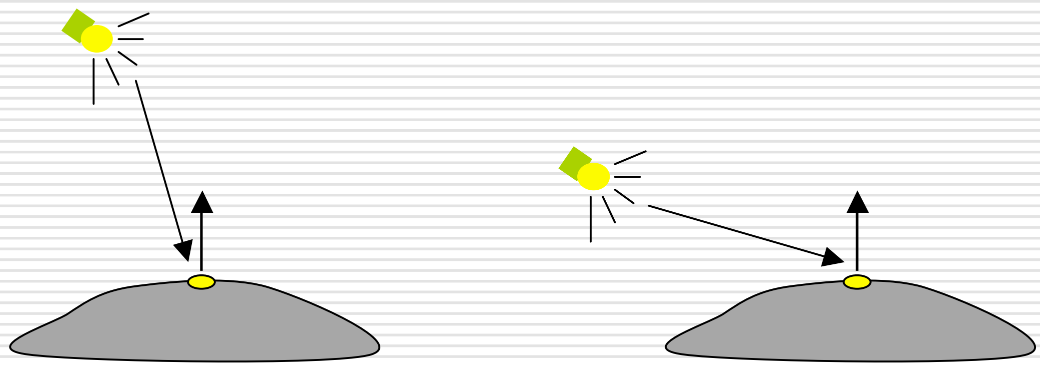
Diffuse Light Contribution

- Diffuse light: The illumination that a surface receives from a light source that reflects equally in all direction
  - Eye point does not matter



Diffuse Light Calculation

- Need to decide how much light the object point receives from the light source
  - Based on Lambert's Law



Receive more light   Receive less light

Diffuse Light Calculation (cont.)

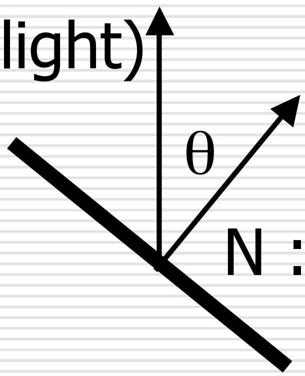
- Lambert's law: the radiant energy D that a small surface patch receives from a light source is:

$$\text{Diffuse} = K_d \times I \times \cos(\theta)$$

K_d: diffuse reflection coefficient

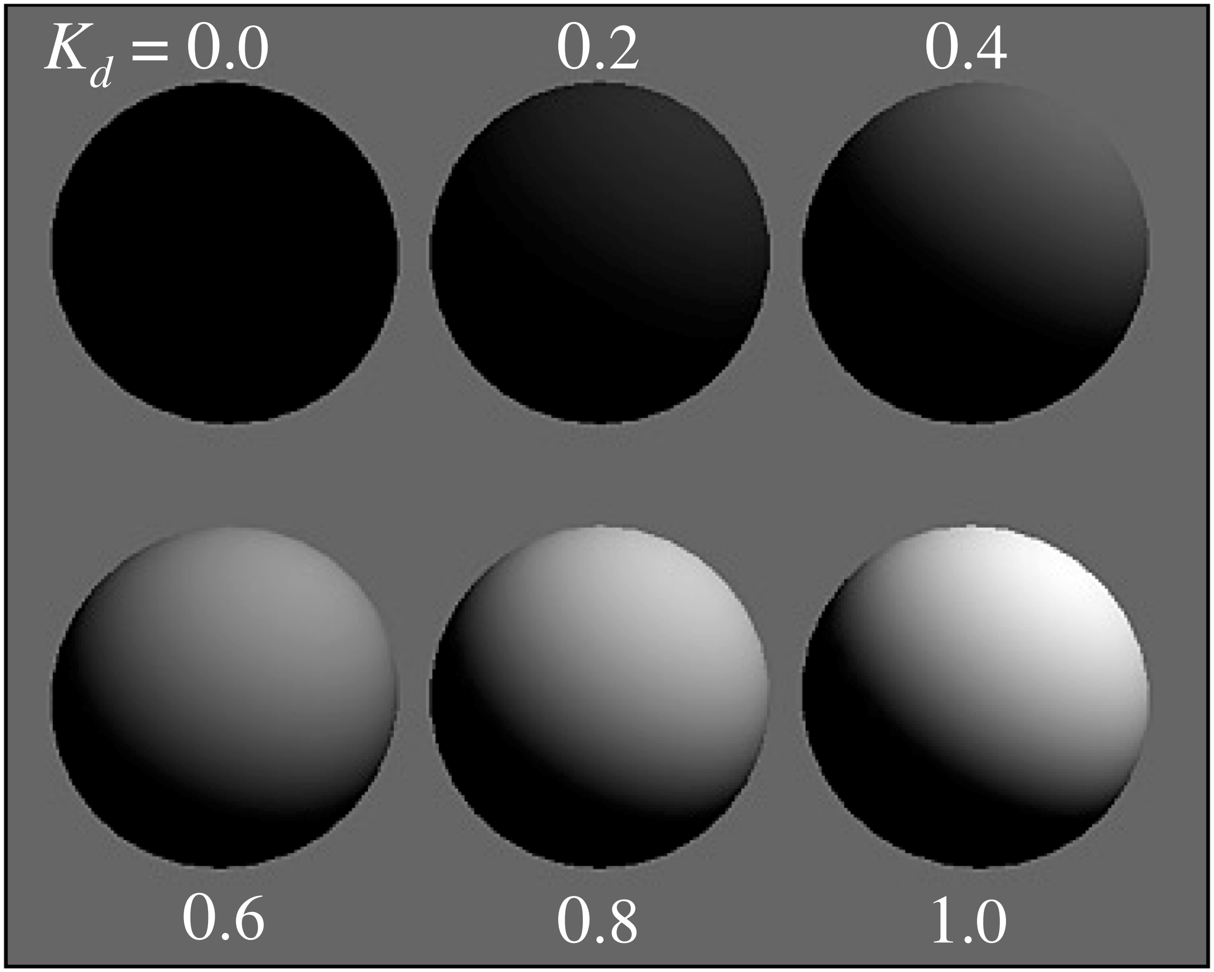
I: light intensity

θ: angle between the light vector and the surface normal



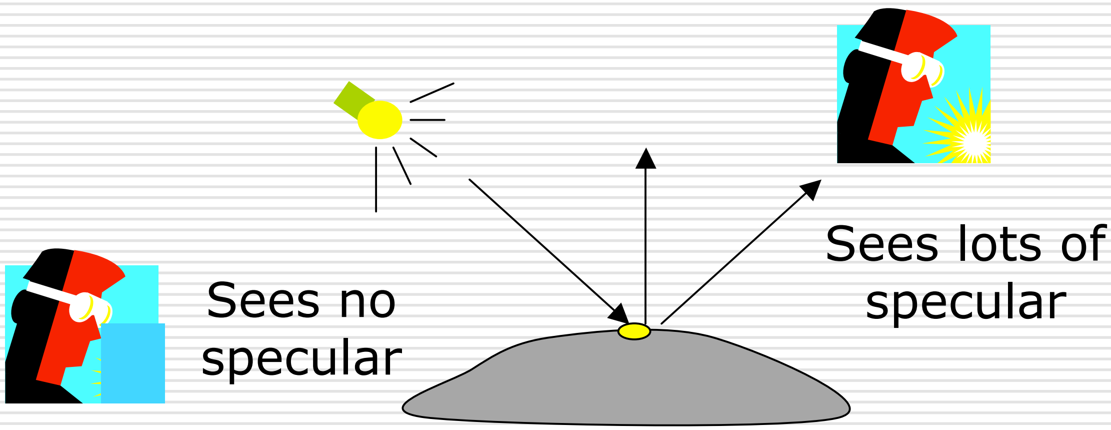
Diffuse Light Examples

I = 1.0



Specular Light Contribution

- The bright spot on the object
- The result of total reflection of the incident light in a concentrate region

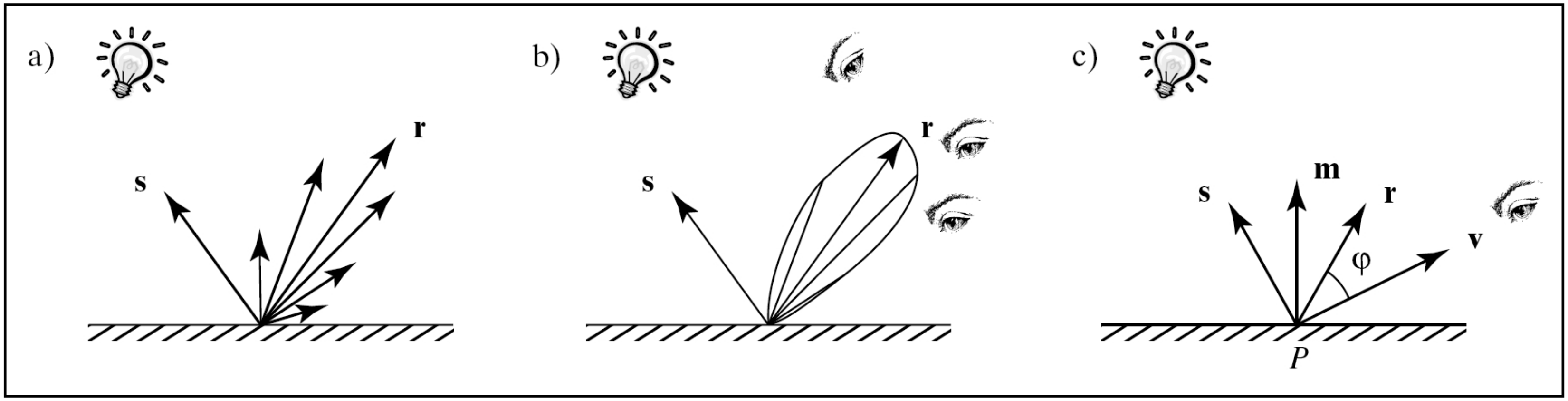


Specular Light Calculation

- How much reflection you can see depends on where you are
  - But for non-perfect surface you will still see specular highlight when you move a little bit away from the ideal reflection direction

Φ is deviation of view angle from mirror direction

  - When ϕ is small, you see more specular highlight



Specular Light Calculation (cont.)

- Phong lighting model
  - Not Phong *shading* model

$$\text{Specular} = K_s \text{ x } I \text{ x } \cos^{f}(\phi)$$

- The effect of 'f' in the Phong model

f = 10

f = 30

f = 90

f = 270

Putting It All Together

- Illumination from a light

$$\textbf{Illum} = \textbf{ambient} + \textbf{diffuse} + \textbf{specular}$$

$$= K_a \times I + K_d \times I \times \cos(\theta) + K_s \times I \times \cos^f(\phi)$$

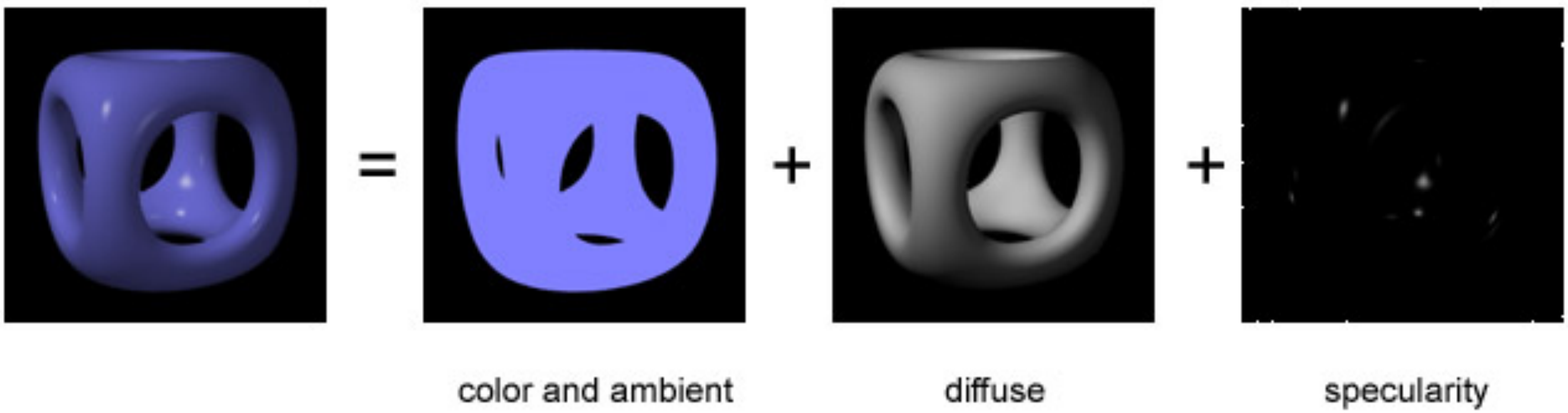
- If there are N lights

Total illumination for a point P = Σ (Illum)

- Some more terms to be added
  - Self emission
  - Global ambient
  - Light distance attenuation and spot light effect

Putting It All Together (cont.)

- **Illum = ambient + diffuse + specular**



Ambient Lighting Example

Diffuse Lighting Example

Specular Lighting Example

Adding Color

- Sometimes light or surfaces are colored
- Treat R, G and B components separately
  - *i.e.*, can specify different RGB values for either light or material
- Illumination equation goes from

Illum = ambient + diffuse + specular

$$= K_a \times I + K_d \times I \times \cos(\theta) + K_s \times I \times \cos^f(\phi)$$

To:

$$Illum_r = K_{ar} \times I_r + K_{dr} \times I_r \times \cos(\theta) + K_{sr} \times I_r \times \cos^f(\phi)$$

$$Illum_g = K_{ag} \times I_g + K_{dg} \times I_g \times \cos(\theta) + K_{sg} \times I_g \times \cos^f(\phi)$$

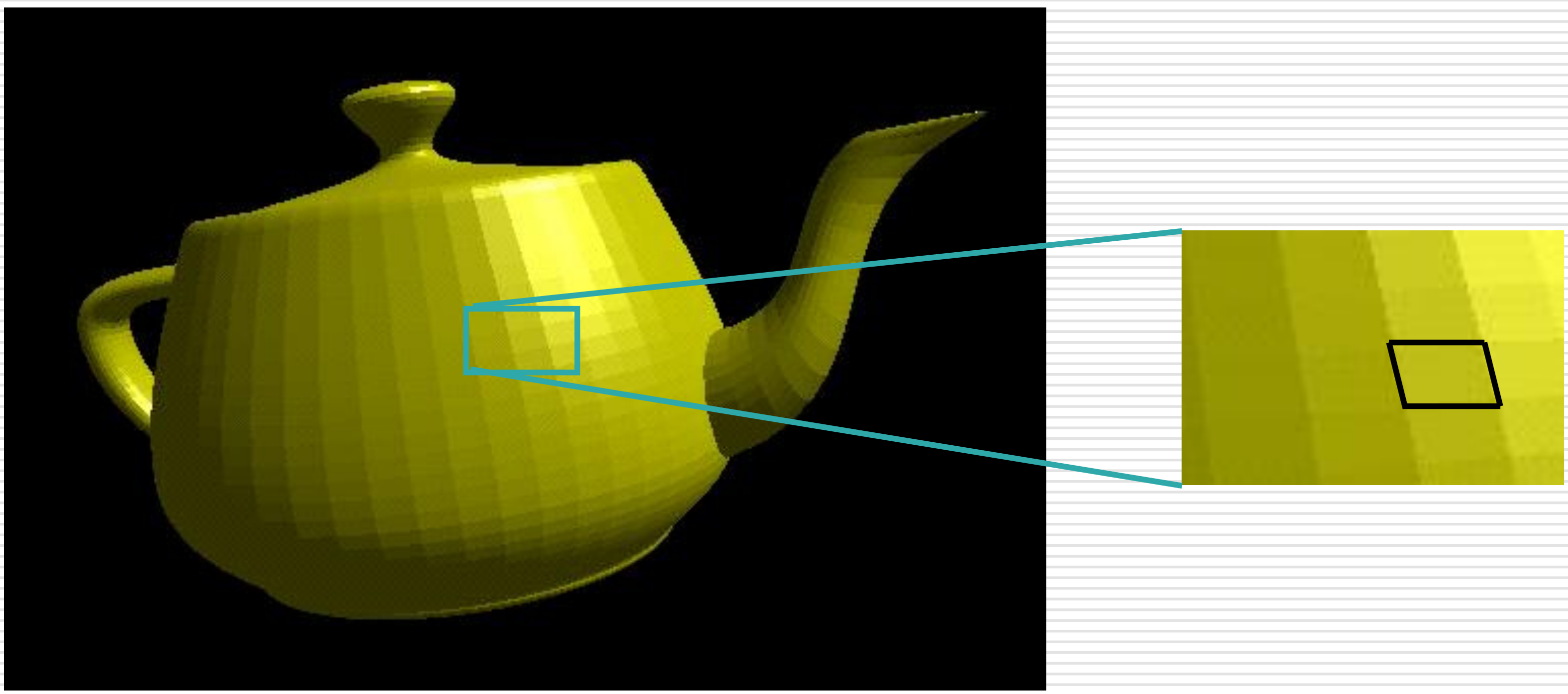
$$Illum_b = K_{ab} \times I_b + K_{db} \times I_b \times \cos(\theta) + K_{sb} \times I_b \times \cos^f(\phi)$$

Methods of Evaluation

- Flat shading
- Gouraud shading
- Phong shading
- Texture Mapping
- Bump Mapping
- Displacement Mapping
- Parallax Mapping
- More stuff...

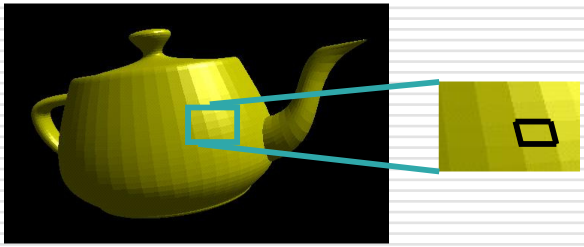
Polygon Shading Models

- Flat shading
  - Compute lighting once and assign the color to the whole polygon (or mesh)



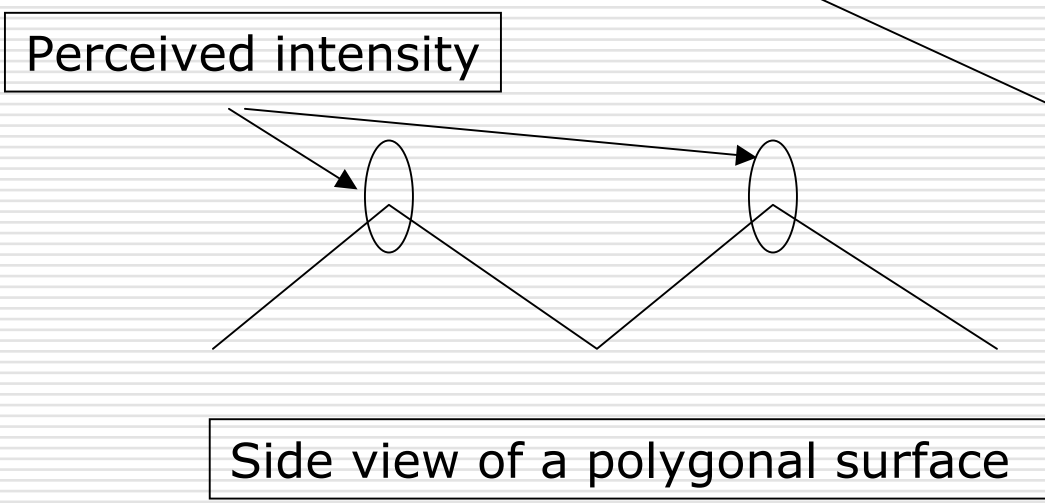
Flat Shading

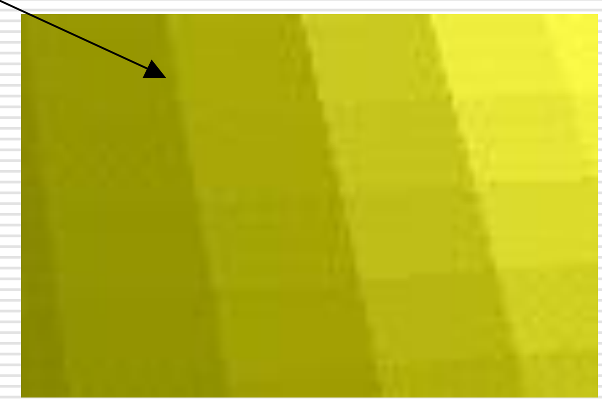
- Only use one vertex normal and material property to compute the color for the polygon
- Benefit: fast to compute
- Used when
  - Polygon is small enough
  - Light source is far away (why?)
  - Eye is very far away (why?)



Mach-Band Effect

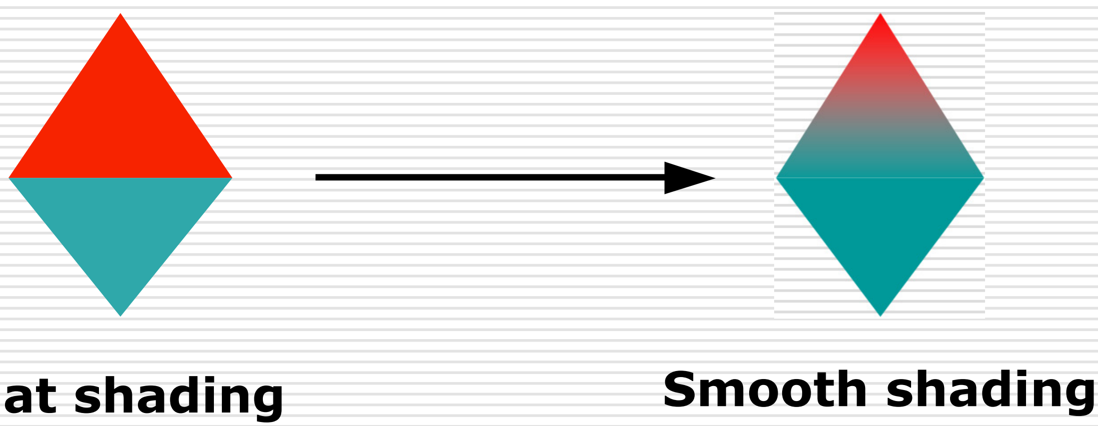
- Flat shading suffers from "mach banding"
  - Human eyes accentuate discontinuities at boundaries





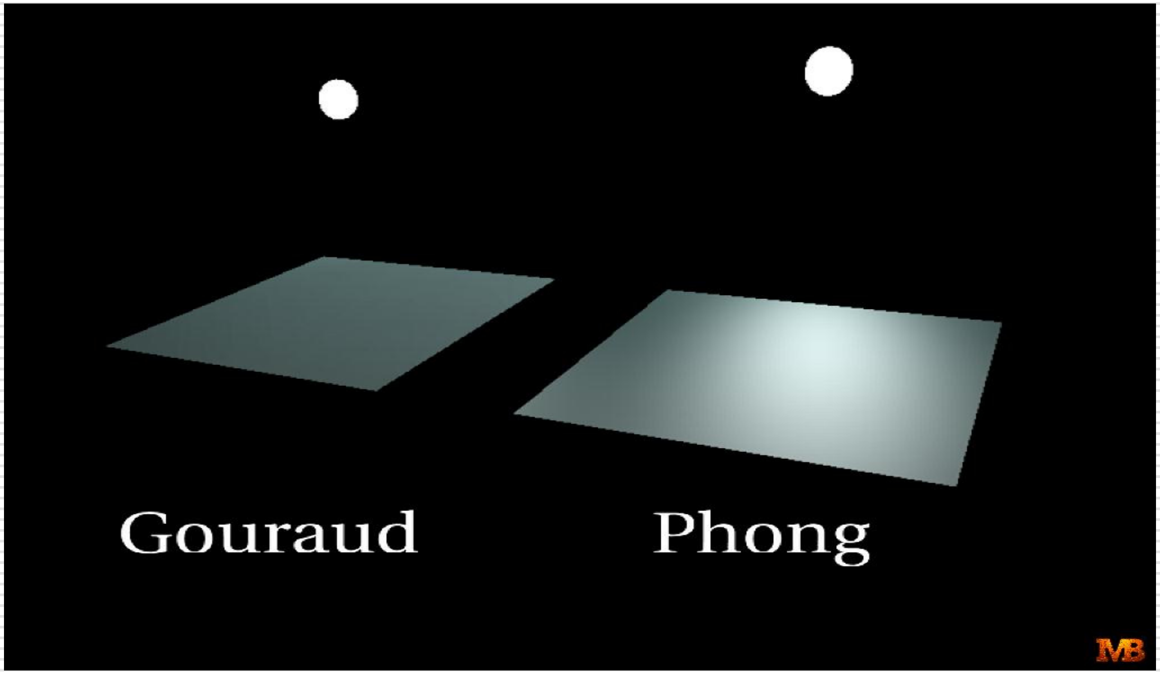
Smooth Shading

- Fix the mach banding
  - Remove edge discontinuities
- Compute lighting for more points on each face



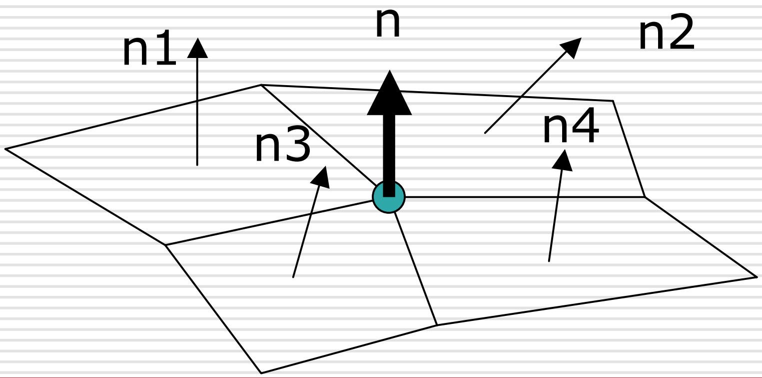
Smooth Shading (cont.)

- Two popular methods
  - Gouraud shading
  - Phong shading (better specular highlight)



Normals

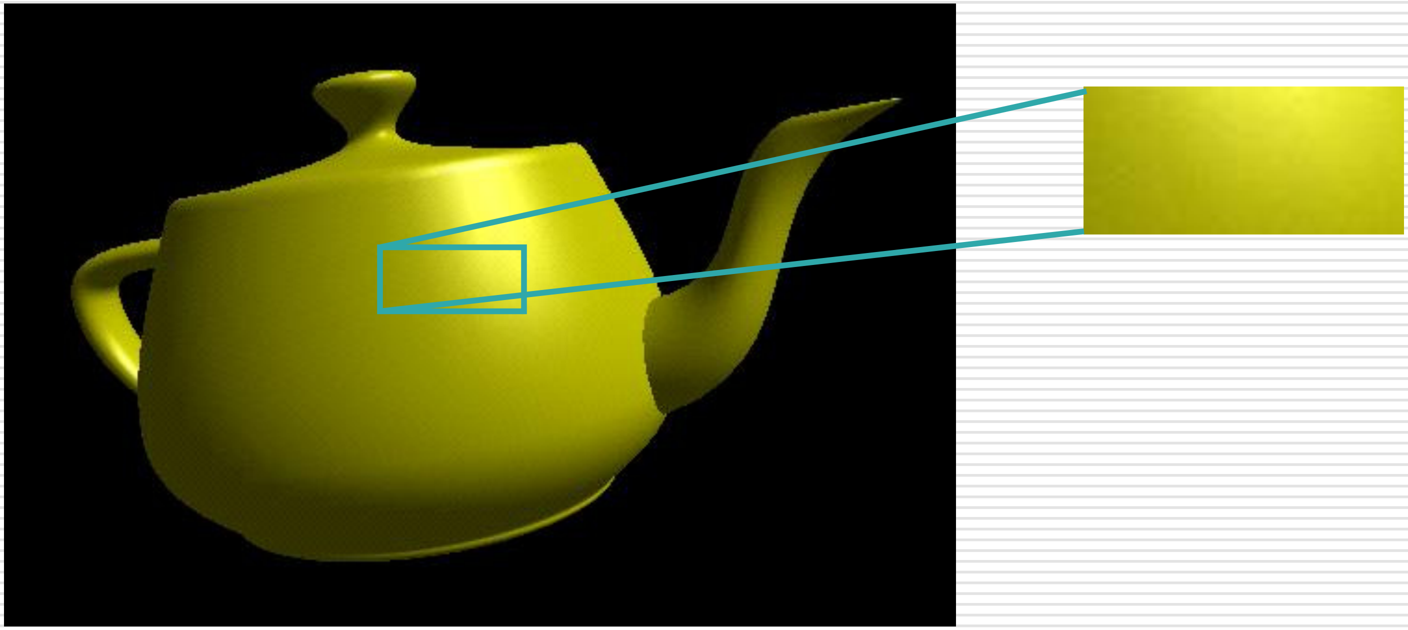
- Per-vertex lighting calculation
- Normal is needed for each vertex
- Per-vertex normal:
  - can be specified when modeling, or
  - can be computed by averaging the adjacent face normals



$$n = (n1 + n2 + n3 + n4) / 4.0$$

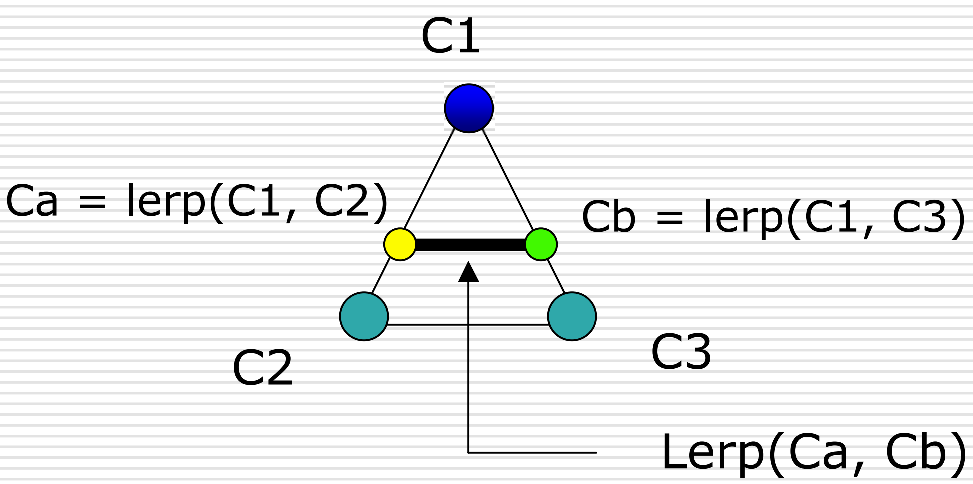
Gouraud Shading

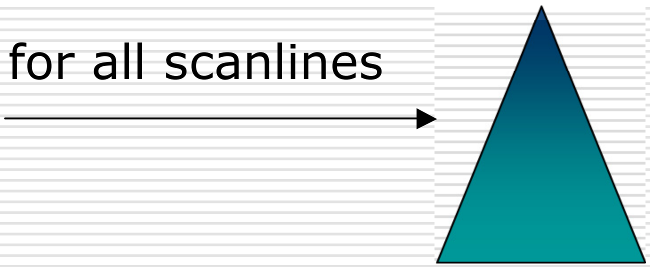
- Lighting is calculated for each of the polygon vertices
- Colors are interpolated for interior pixels



Gouraud Shading (cont.)

- Compute vertex illumination (color) before the projection transformation
- Shade interior pixels: color interpolation (normals are not needed)

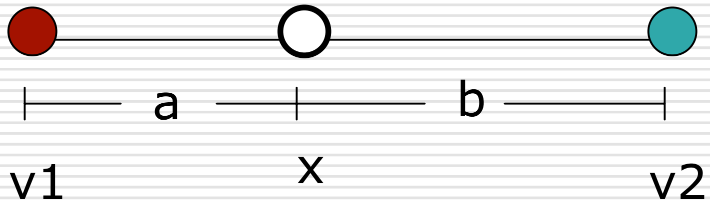




* lerp: linear interpolation

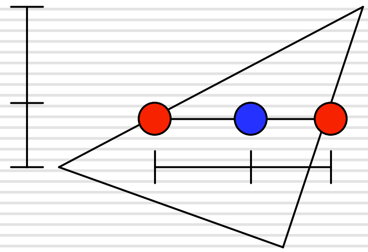
Gouraud Shading (cont.)

- Linear interpolation



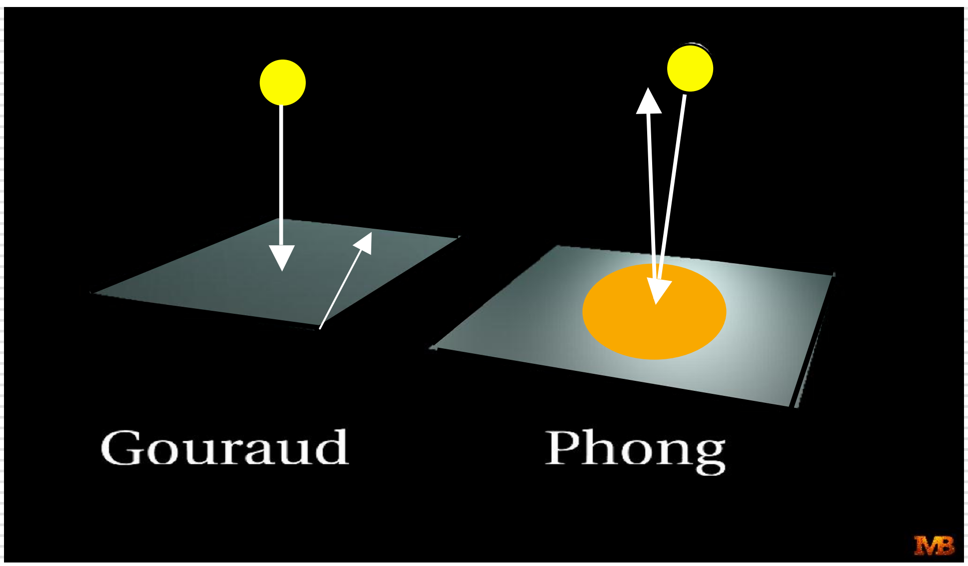
x = b / (a+b) * v1 + a/(a+b) * v2

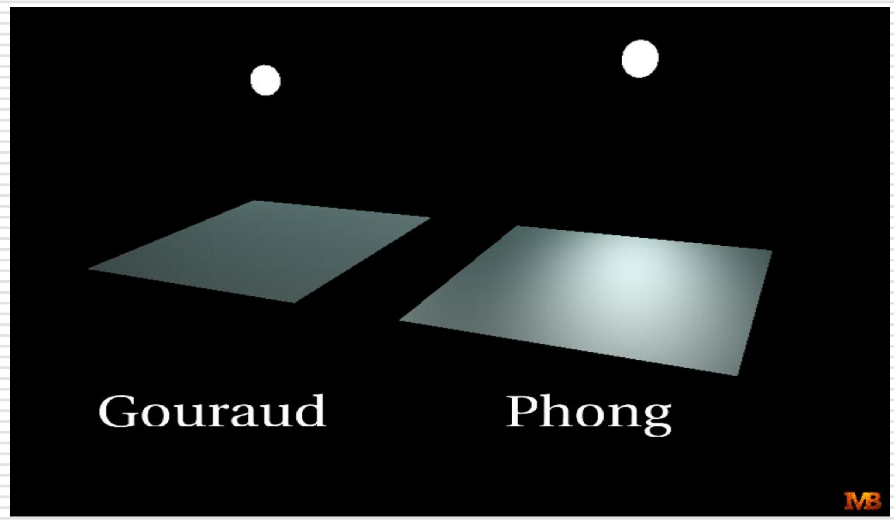
- Interpolate triangle color: use y distance to interpolate the two end points in the scanline, and use x distance to interpolate interior pixel colors



Gouraud Shading Problem

- Lighting in the polygon interior can be inaccurate



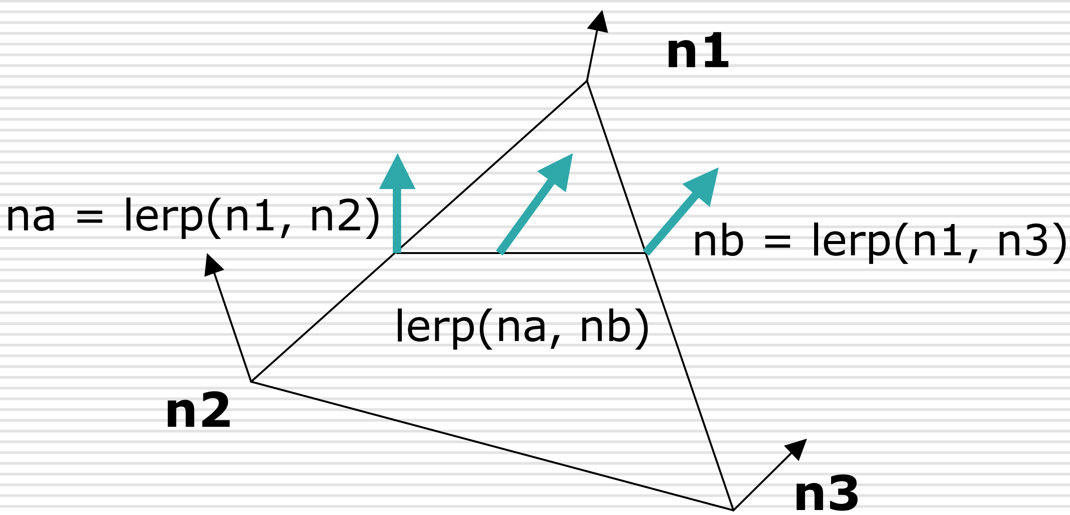


Phong Shading

- Instead of interpolation, we calculate lighting for each pixel inside the polygon (per-pixel lighting)
- Need normals for all the pixels
  - Not provided by user!
- Phong shading algorithm
  - Interpolate the normals across polygon
  - Compute lighting during rasterization
    - Need to map the normal back to world or eye space though

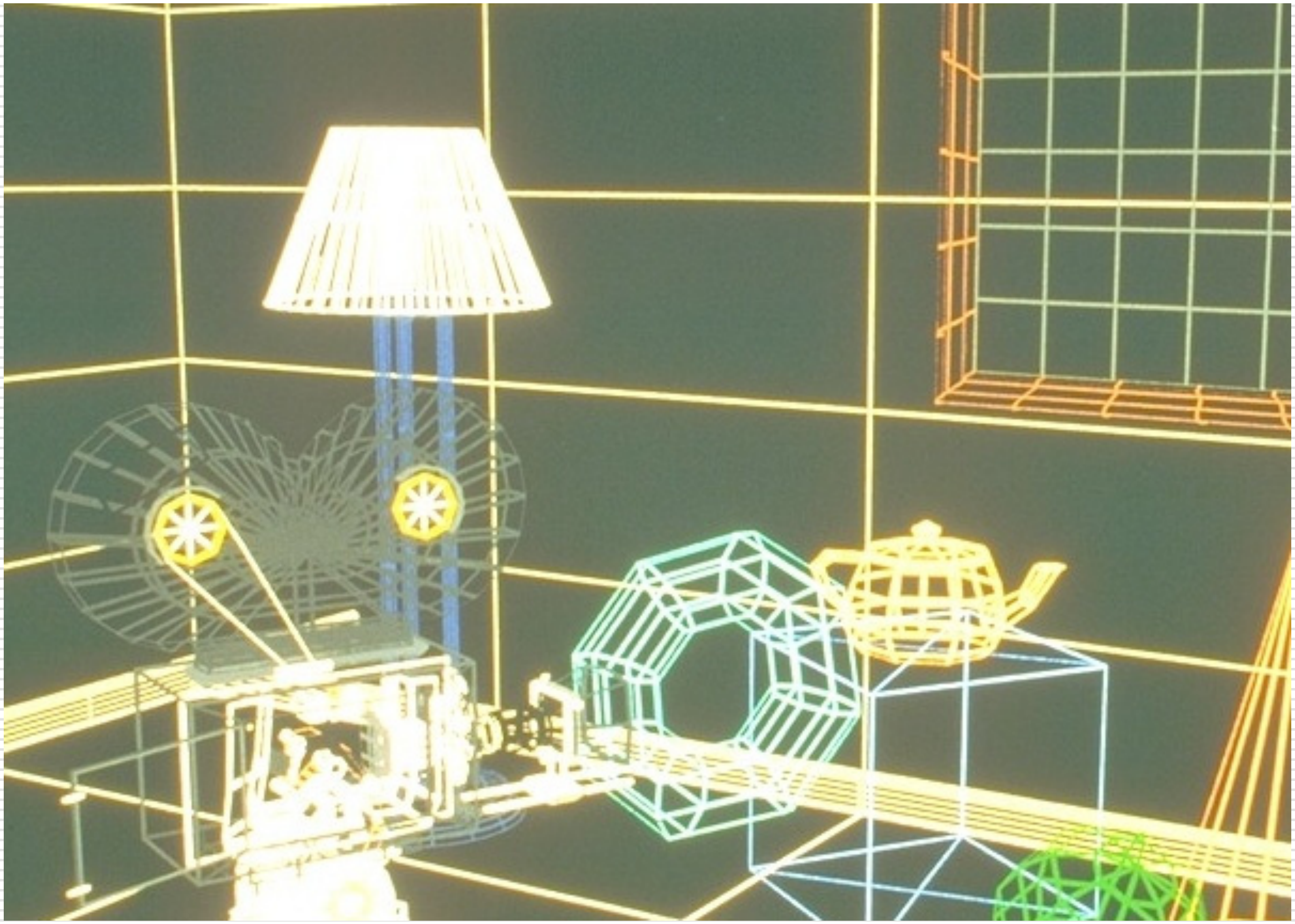
Phong Shading (cont.)

- Normal interpolation

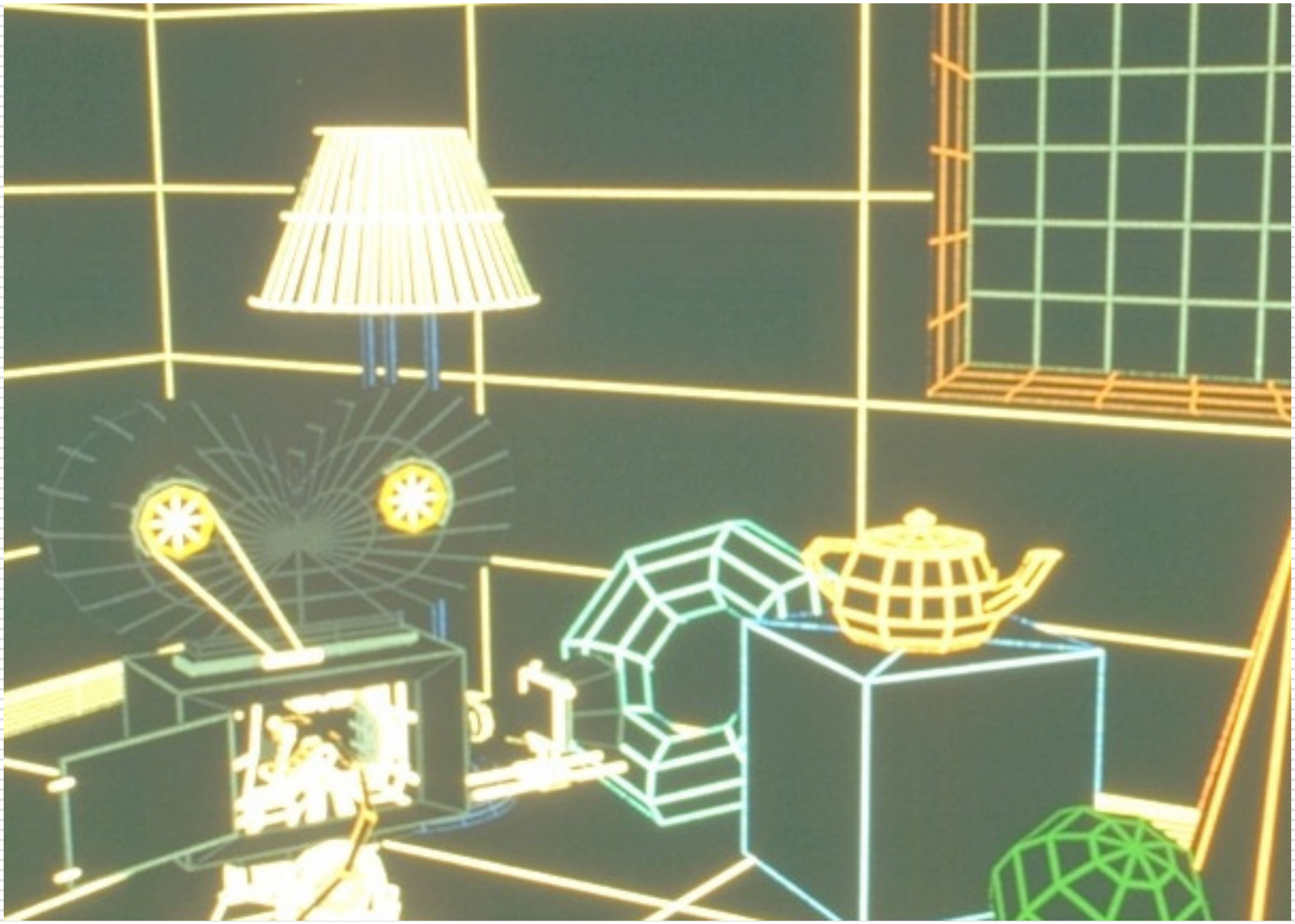


- Slow
  - Not supported by OpenGL and most graphics hardware

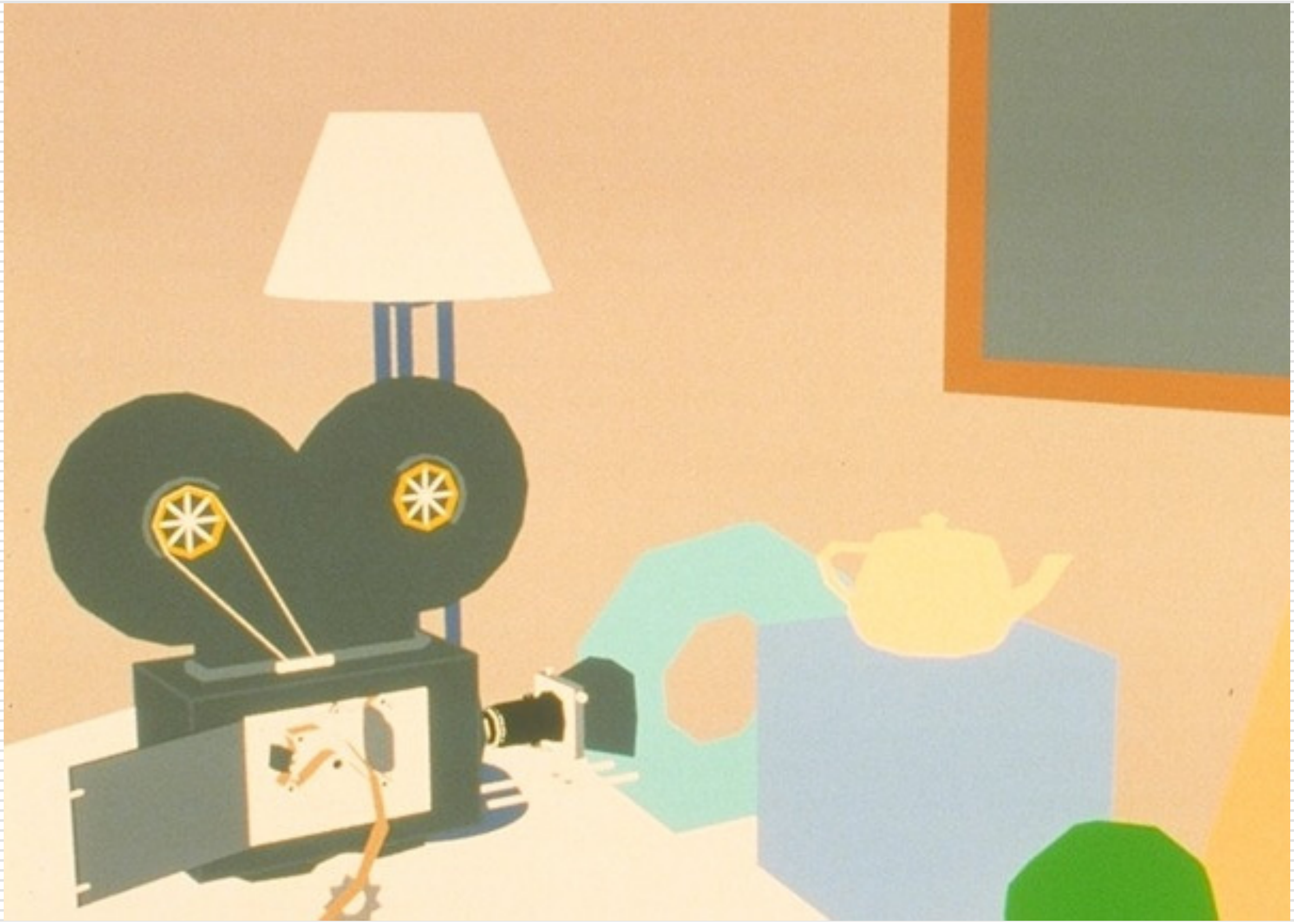
Colored Wireframe



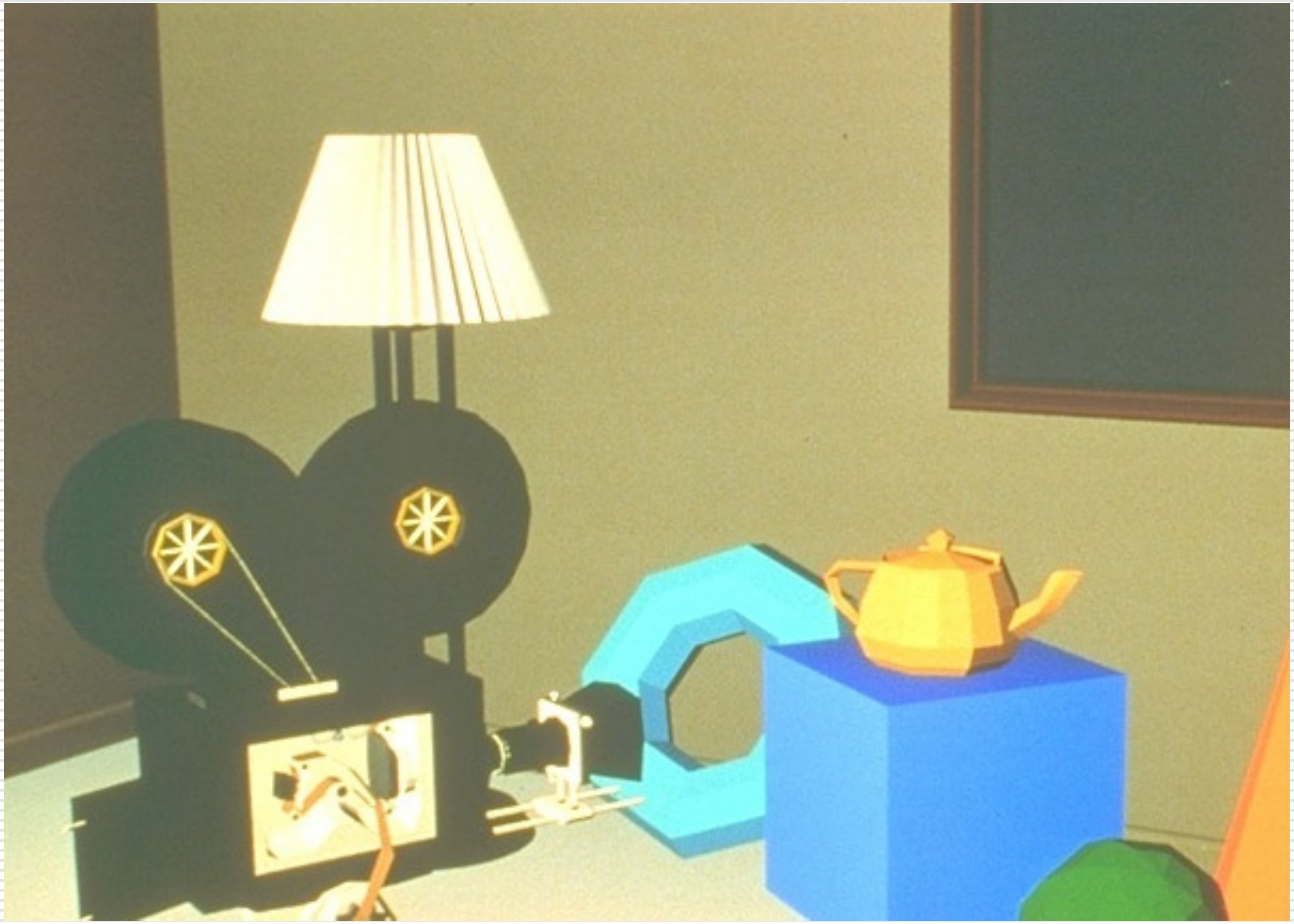
Colored Hidden-Line Removal



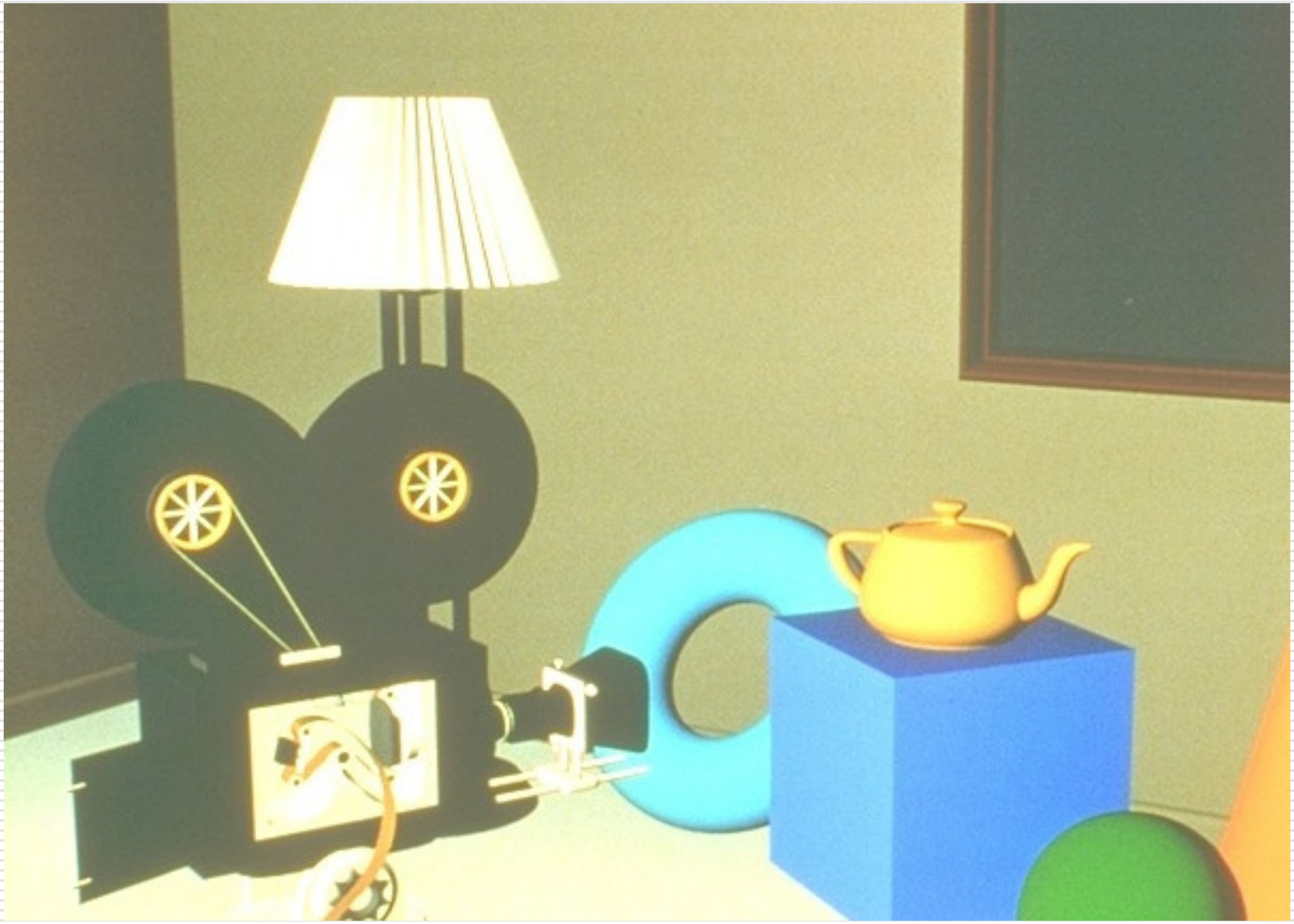
Ambient Term Only



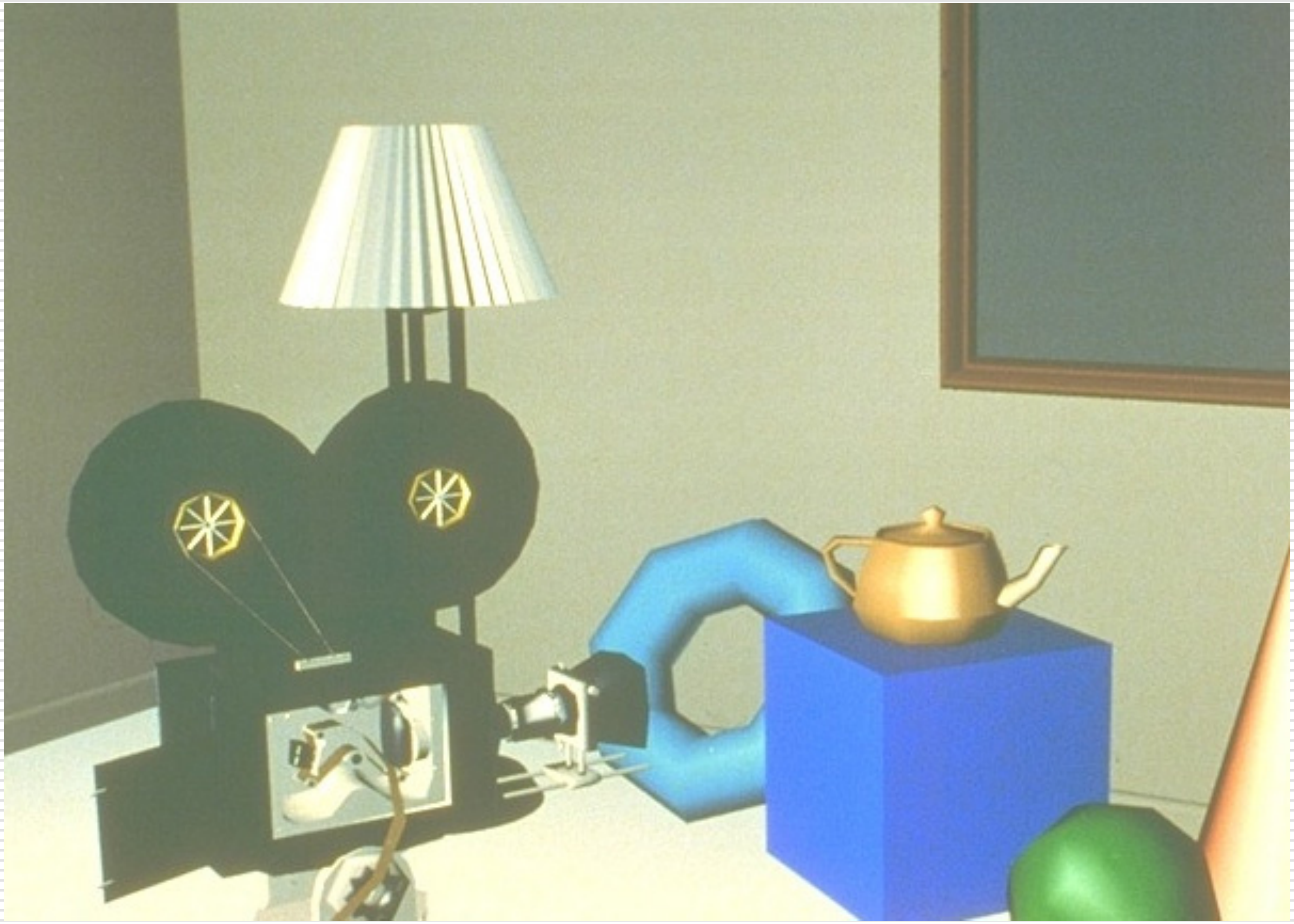
Flat Shading



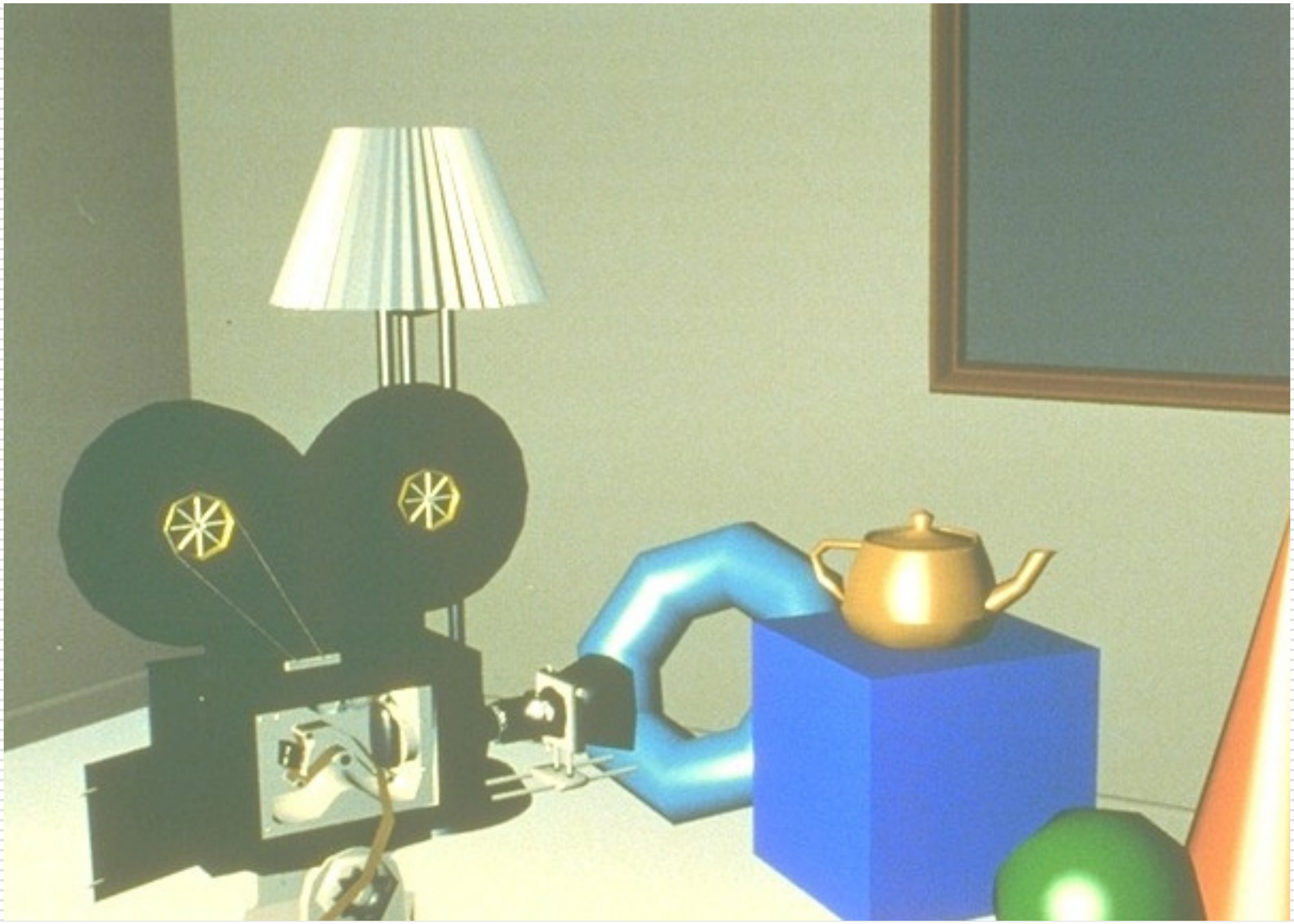
Diffuse Shading + Interp. Normals



Gouraud Shading



Ambient + Diffuse + Specular



Ambient + Diffuse + Specular + Interpolated Normals

Radiosity

Texture Mapping

Texture Mapping + Ray Tracing

Graphical Approaches

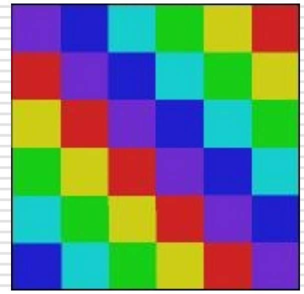
- Texture Mapping
- Bump Mapping
  - Normal Mapping: Perturb the normal
  - Silhouette remains smooth
- Displacement Mapping
  - Perturb the geometry itself
- Parallax Mapping
- Environment Mapping
- Horizon Mapping

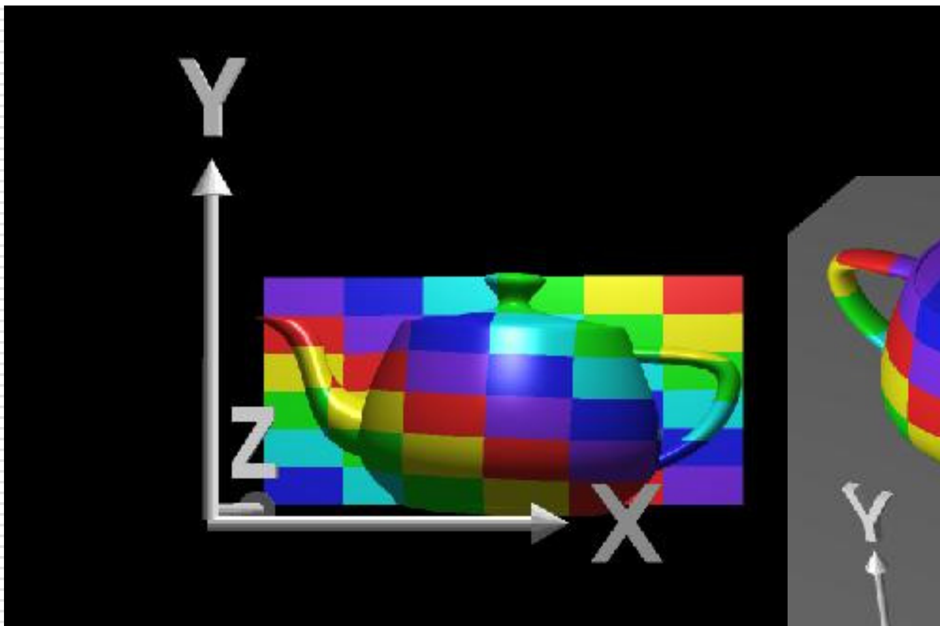
Texture Mapping

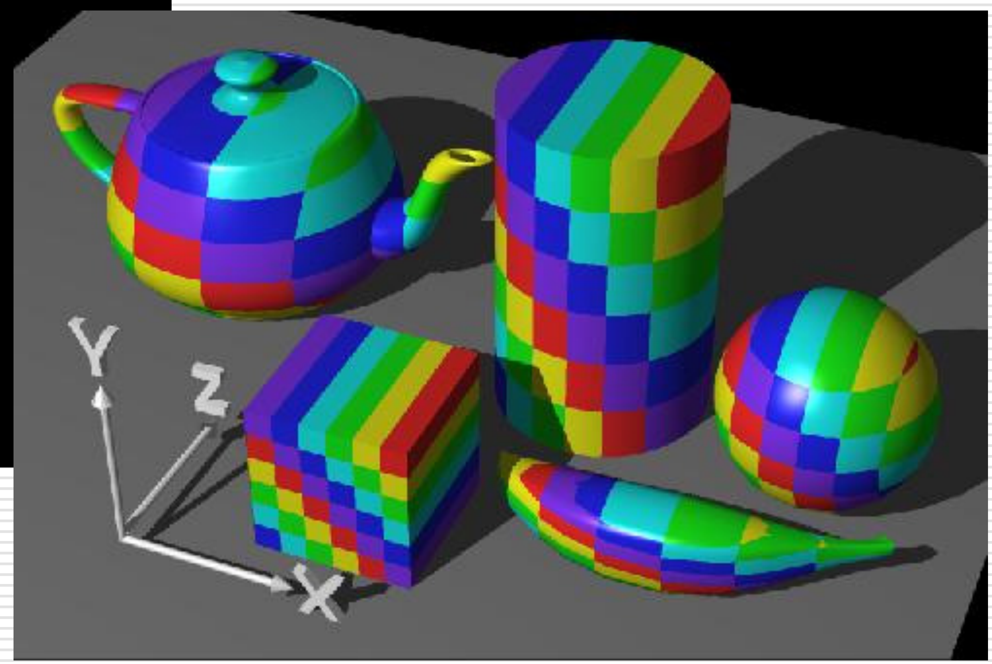
- Look up the color of a pixel in a picture
- Can blend with other things
  - Underlying polygon color
  - Other textures
- Main problem
  - Mapping square textures to triangles (or spheres, etc.)
- Define how a given texture should be applied to the polygon/primitive/model

Texture Mapping Examples

- Mapping (X,Y) textures



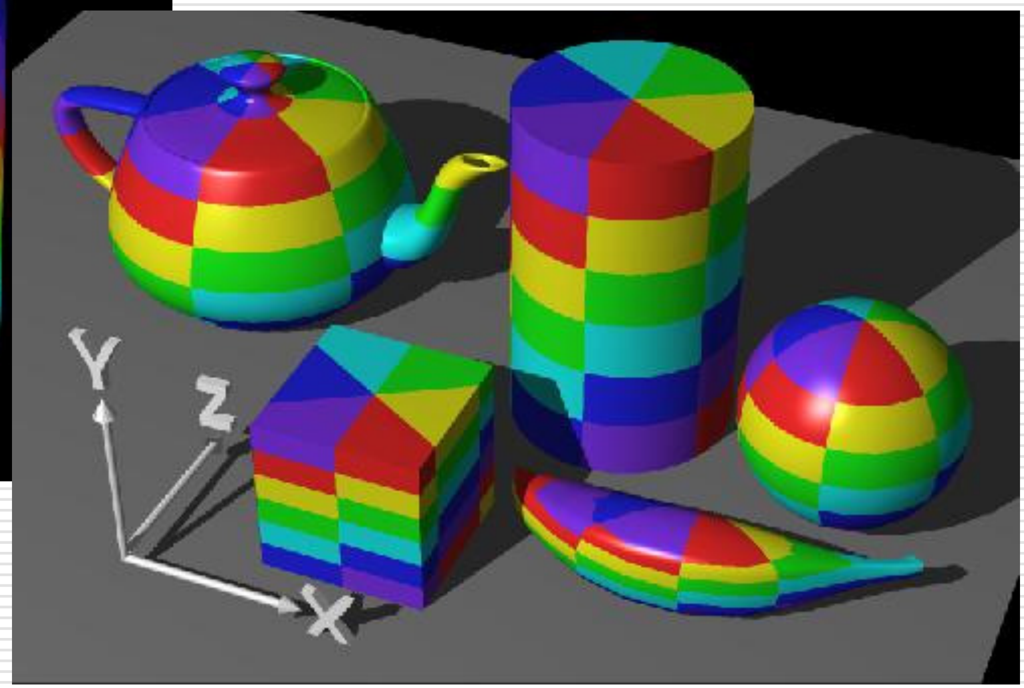




Images: Rosalee Wolfe

Texture Mapping Examples

- "Correct" mapping (but still not great)



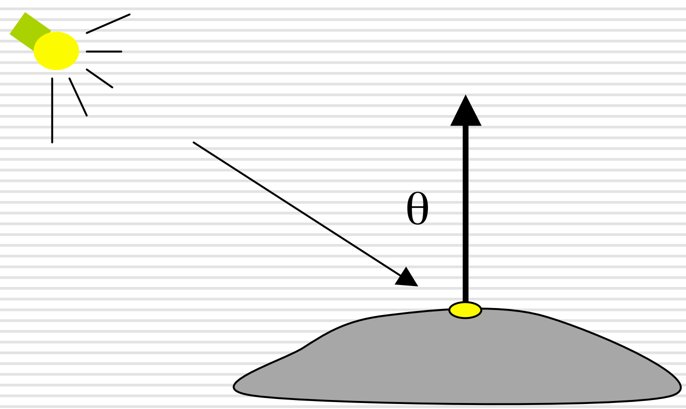
Images: Rosalee Wolfe

Texture Mapping (cont.)

- Use UV-Mapping
  - Define exactly how the texture(s) should be applied

Bump Mapping (Normal Mapping)

- Keep polygon count low
- Increase detail in texture space
- Recall how we evaluate lighting



- Take the normal from a texture (x,y,z)
- Show in C4

Displacement Mapping

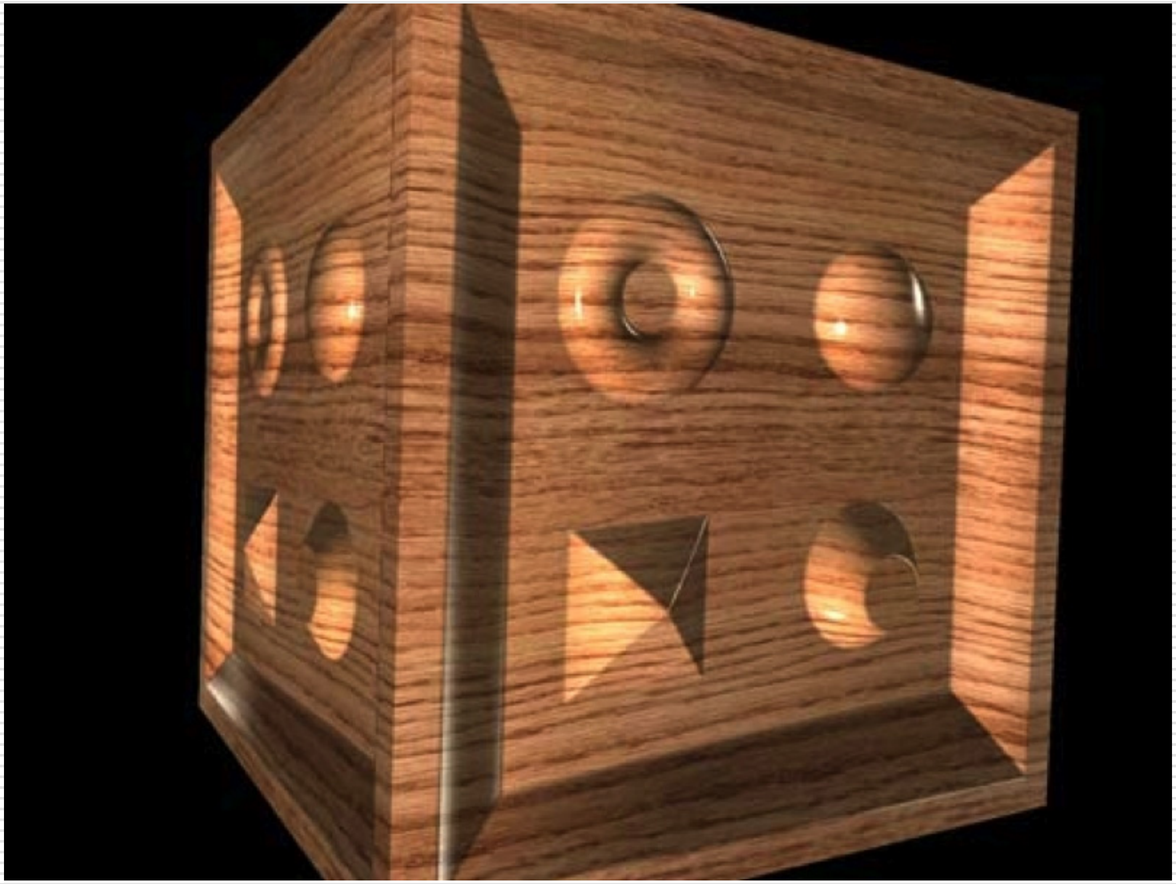
- Instead of moving the normal, move the geometry
  - Look up a surface displacement in a texture map
    - Can be 1 value (e.g., a height map)
    - Can be 3 values
- Produces proper silhouettes
- Evaluate the lighting equation using this new information
- Need to re-tessellate the surface to insure no aliasing

Parallax Mapping

- Parallax:
  - Things closer to you move more quickly by than things farther away
- Use the angle between the normal of the surface and the current view to increase height of bump
- Show in C4

Parallax Mapping (cont.)

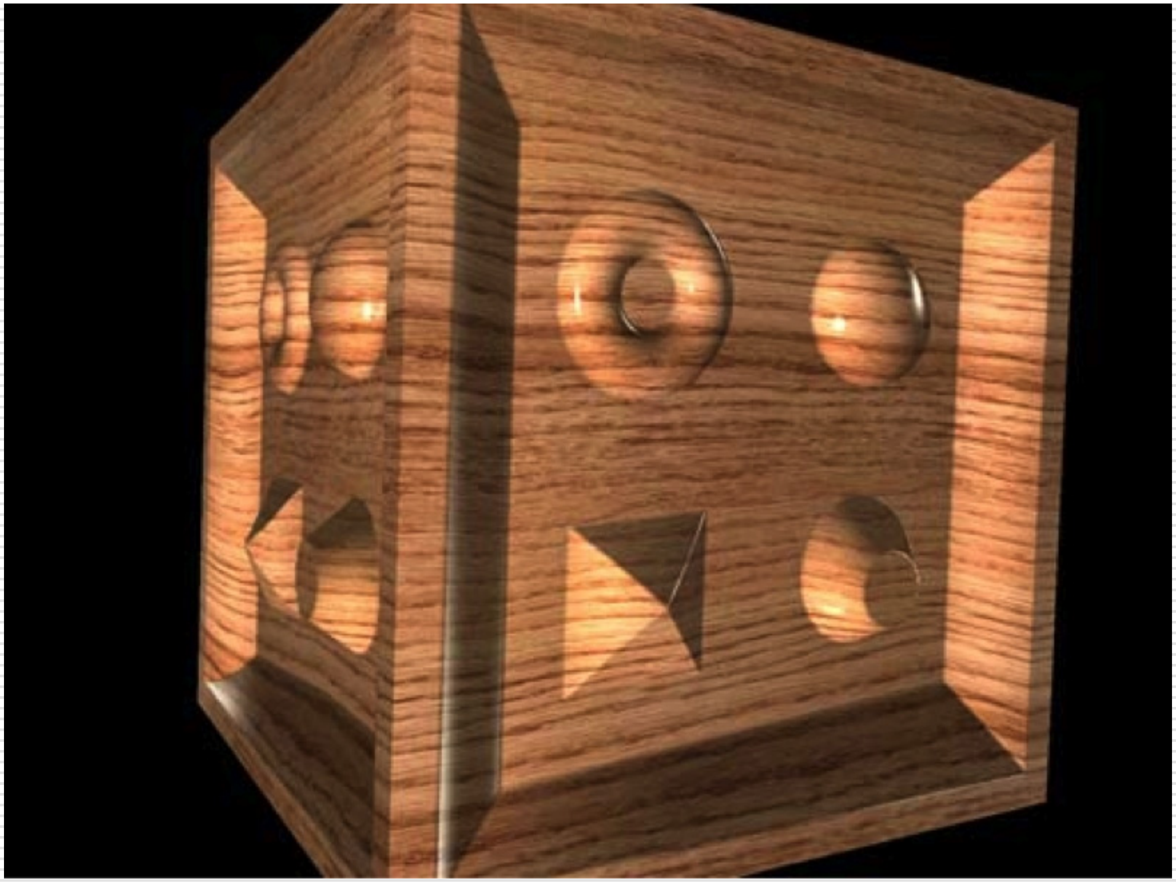
Relief Mapped



Tatarchuk, N. 2006. Practical parallax occlusion mapping with approximate soft shadows for detailed surface rendering. In ACM SIGGRAPH 2006 Courses (Boston, Massachusetts, July 30 - August 03, 2006).

Parallax Mapping (cont.)

Parallax Mapped

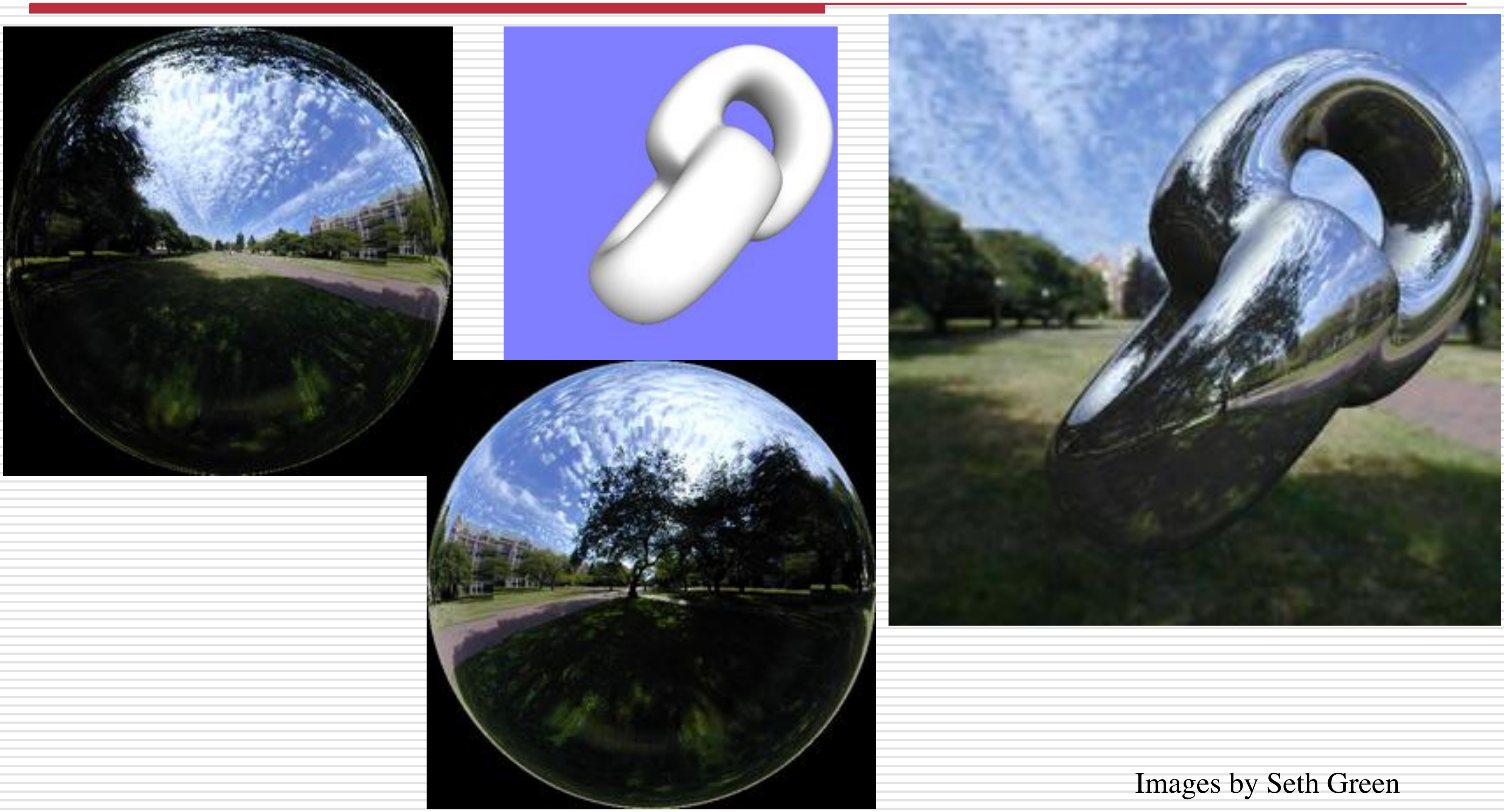


Tatarchuk, N. 2006. Practical parallax occlusion mapping with approximate soft shadows for detailed surface rendering. In ACM SIGGRAPH 2006 Courses (Boston, Massachusetts, July 30 - August 03, 2006).

Environment Mapping

- A.k.a. Reflection Mapping
- Create/capture images in all directions from a single point
- Texture map the inside of a cube/sphere
- At polygon vertices, compute the reflection point in the environment map
- Interpolate for interior pixels
- Can combine with normal mapping to get more-realistic effects

Environment Mapping Examples



Images by Seth Green

Environment Mapping Examples

Images by Seth Green

Environment Mapping Examples

- Star Wars Episode I (Chapter 27) DVD
  - Notice there are no other ships reflected in the Naboo ship, even in a place where "the whole planet is one big city."

Horizon Mapping

- Bump mapping is very useful
  - But cannot cast proper shadows, because there is no geometry
- Horizon mapping computes for each point the height at which it becomes visible (i.e., it can be seen from the horizon)