Fundamentals of
Computer Graphics and Image Processing

Shading and Lighting (04)

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Overview

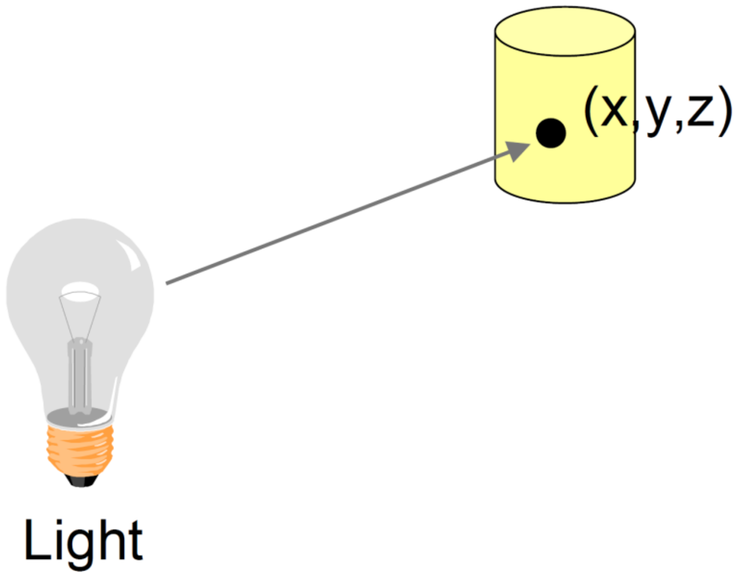
- Direct Illumination
  - **Emission at light sources**
  - Scattering at surfaces
  - Gouraud shading
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections

How the lectures should look like #1

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

Overview

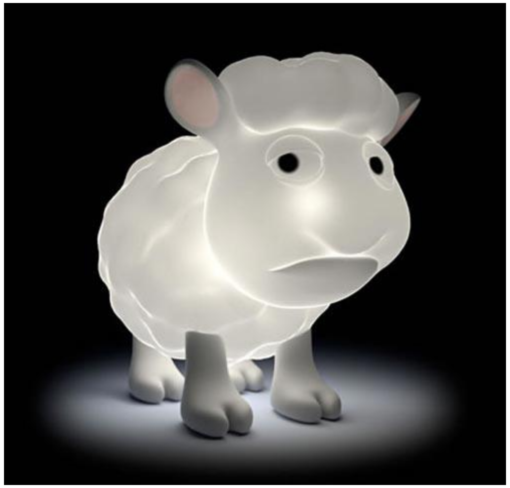
- $I_L(x, y, z, \theta, \varphi, \lambda)$
  - describes intensity of energy,
  - leaving a light source, ...
  - arriving at location (x,y,z), ...
  - from direction (θ,ϕ), ...
  - with wavelength λ



Light Source types

- Omnidirectional
- Spotlight
- Area
- Directional
- Object

- what are the differences?

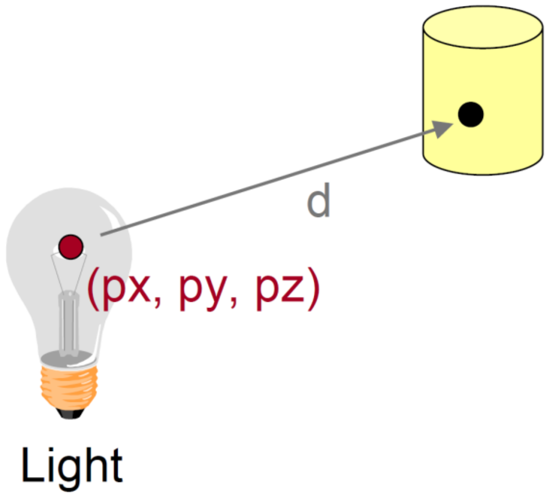


Light Source Models

- Simple mathematical models
- OpenGL support
  - Point light
  - Directional light
  - Spot light

Point Light Source

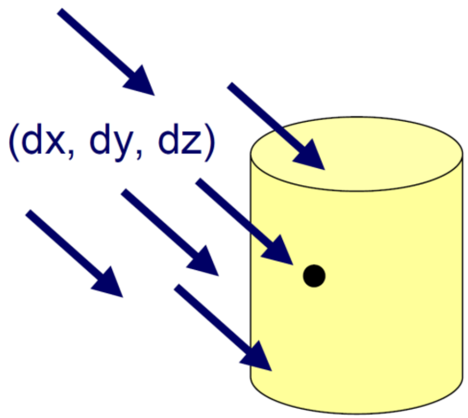
- Models omni-directional source
  - intensity (I_0),
  - position (x, y, z),
  - factors (k_c, k_l, k_q) for attenuation with distance (d)



$$I_L = \frac{I_0}{k_c + k_l d + k_q d^2}$$

Directional Light Source

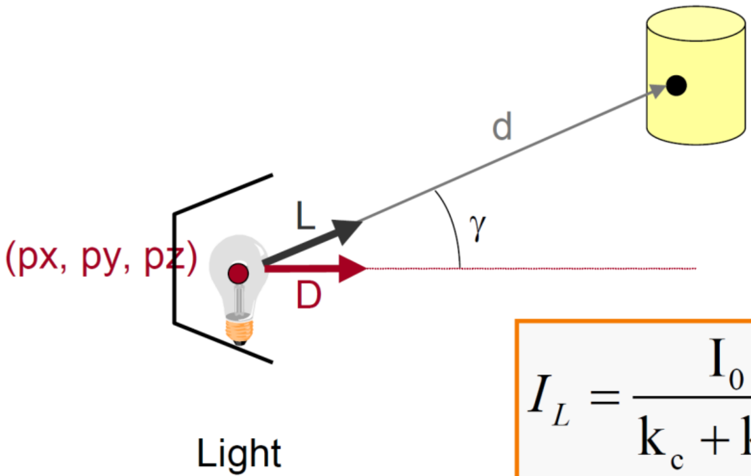
- Models point light source at infinity
  - intensity (I_0),
  - direction (dx, dy, dz),
  - no attenuation with distance



$$\boxed{I_L = I_0}$$

Spot Light Source

- Models point light source with direction
  - intensity (I_0),
  - position (x, y, z),
  - direction (d),
  - attenuation $\left(k_c, k_l, k_q\right)$.



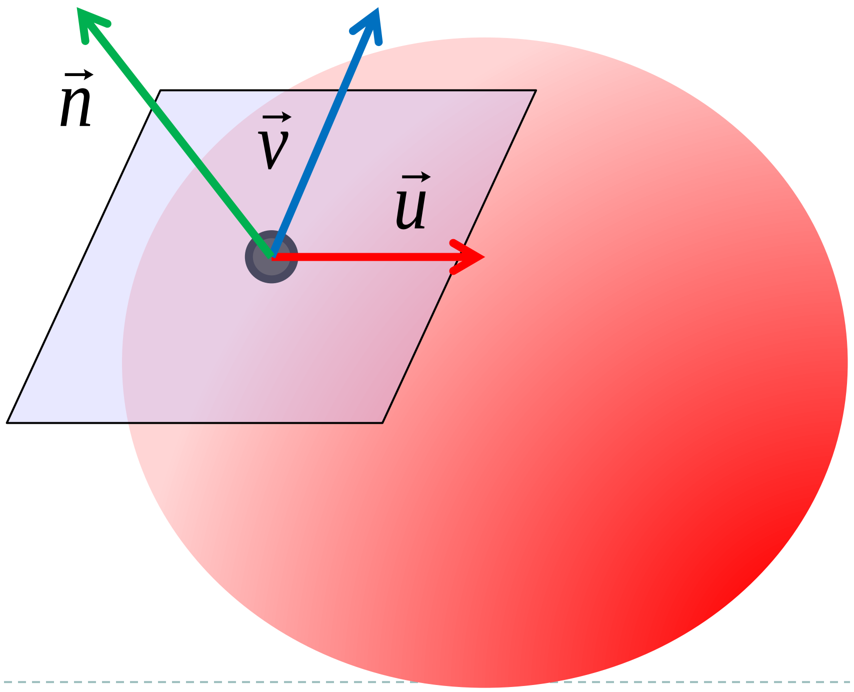
$$I_L = \frac{\mathrm{I}_0 (D \bullet L)}{\mathrm{k_c} + \mathrm{k_l} d + \mathrm{k_q} d^2}$$

Overview

- Direct Illumination
  - Emission at light sources
  - **Scattering at surfaces**
  - Gouraud shading
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections

Surface normal vector

- Perpendicular to the surface at the point
- Computation:
  - Usually from tangent vectors
  - Vector cross product $\vec{n} = \vec{u} \times \vec{v}$
  - Depends on the object representation



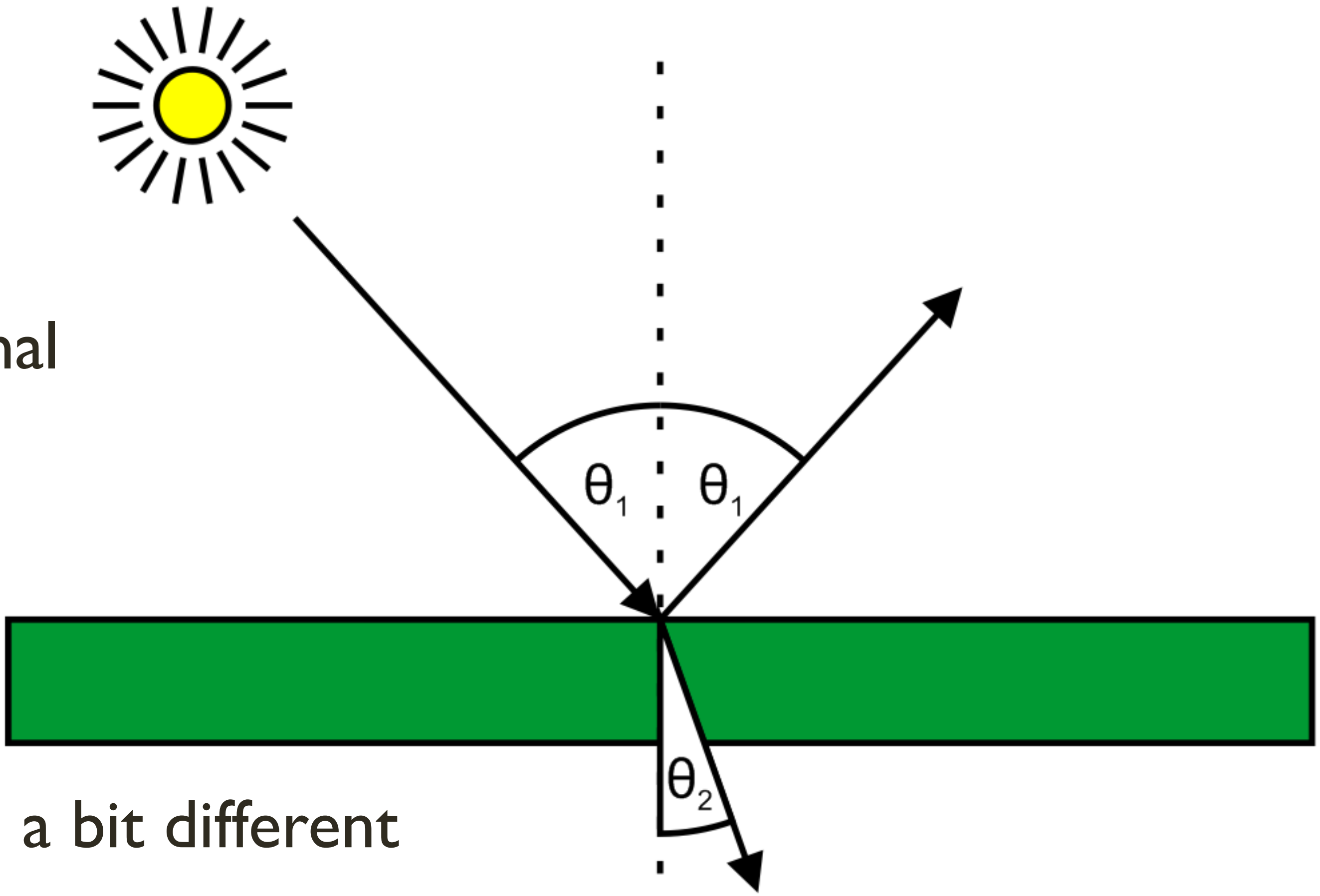
- Vector normalization $\hat{n} = \dfrac{\vec{n}}{|\vec{n}|}$

Tangent vectors

- Parametric representation
  - $X = x(u,v)$
  - $Y = y(u,v)$
  - $Z = z(u,v)$
  - Partial derivation by $u,v \rightarrow$ vectors t_u, t_v
- Polygonal representation
  - Tangent vectors are edge vectors
  - Mind the orientation!

Elementary theory

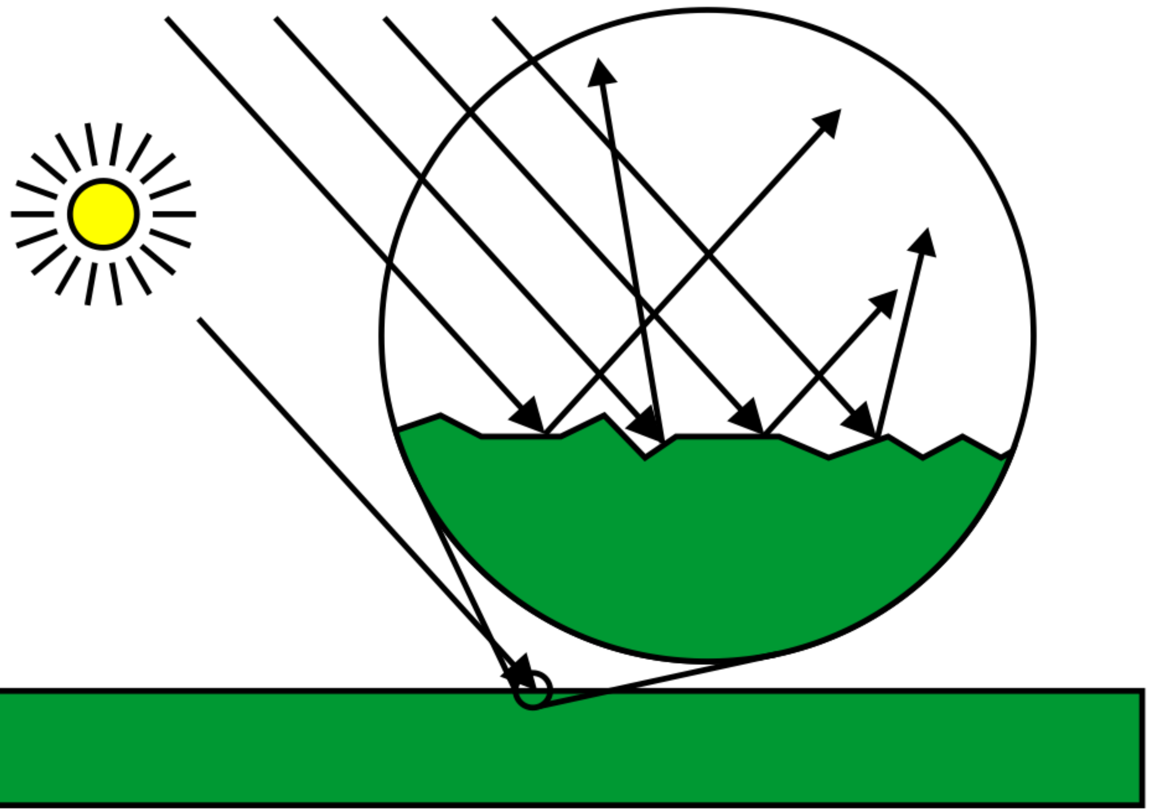
- Light-surface interaction
- Reflection
- Refraction
  - Snell's law
- Surface normal vector



- Real world is a bit different

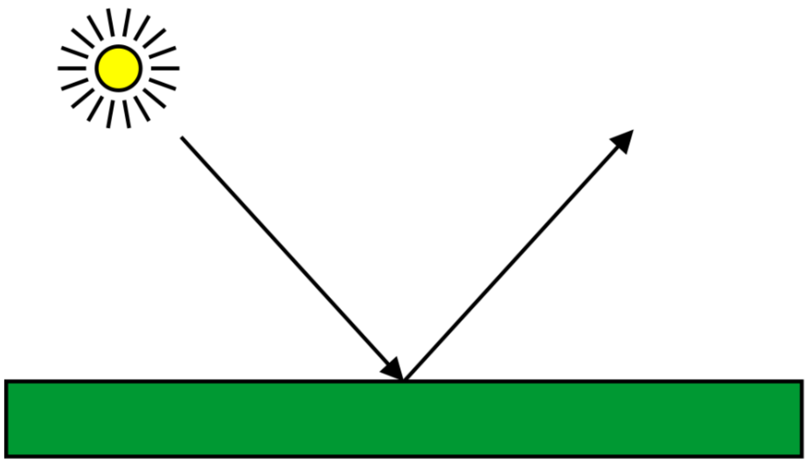
Surface types

- Reflective
- Diffuse – Lambertian
- Both

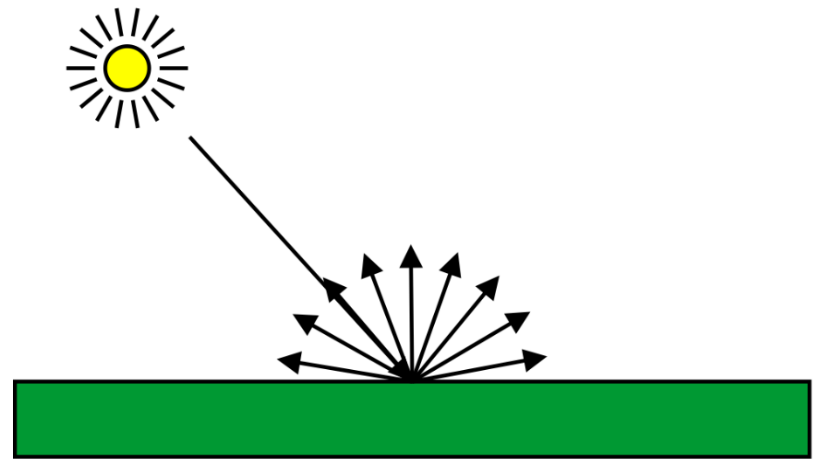


Surface types

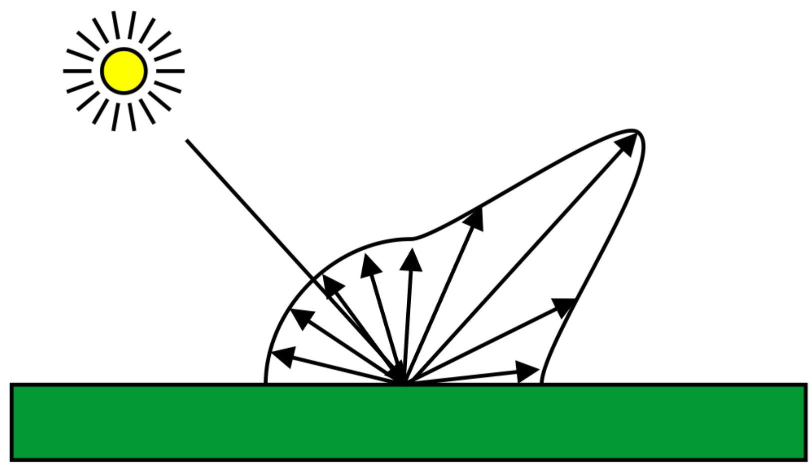
Mirror



Matte



directional component



indirectional component

Light models

- Empiric – e.g. Phong lighting model
  - cheap computation
  - physically incorrect
  - visually plausible

- Physically-based
  - energy transfer, light propagation
  - closer to real-world physics
  - expensive

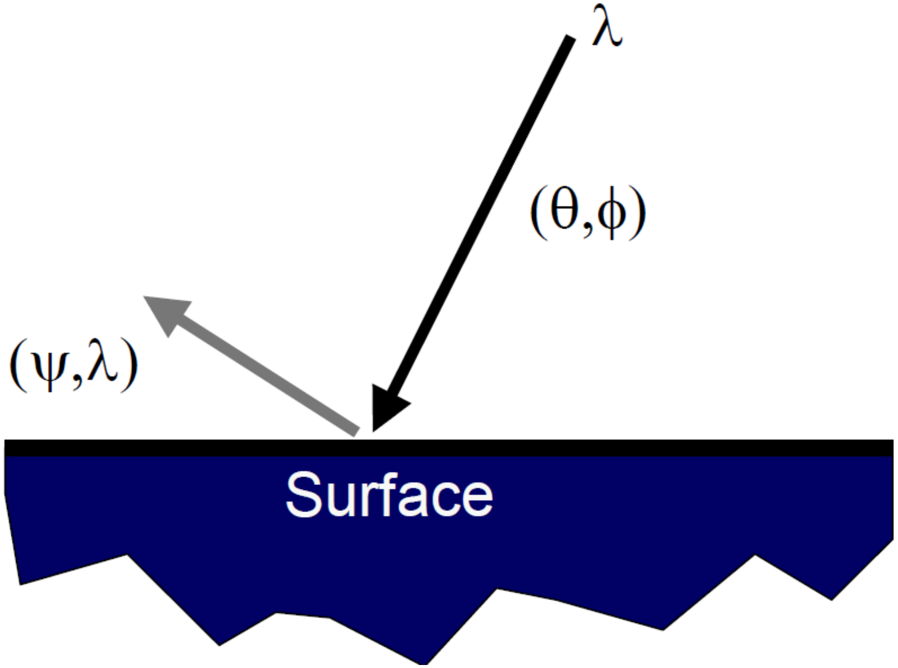
Local illumination models

- Fast but inaccurate
- Empirical (no physical background)
- Many physical effects are impossible to achieve

- Computer games, real-time rendering

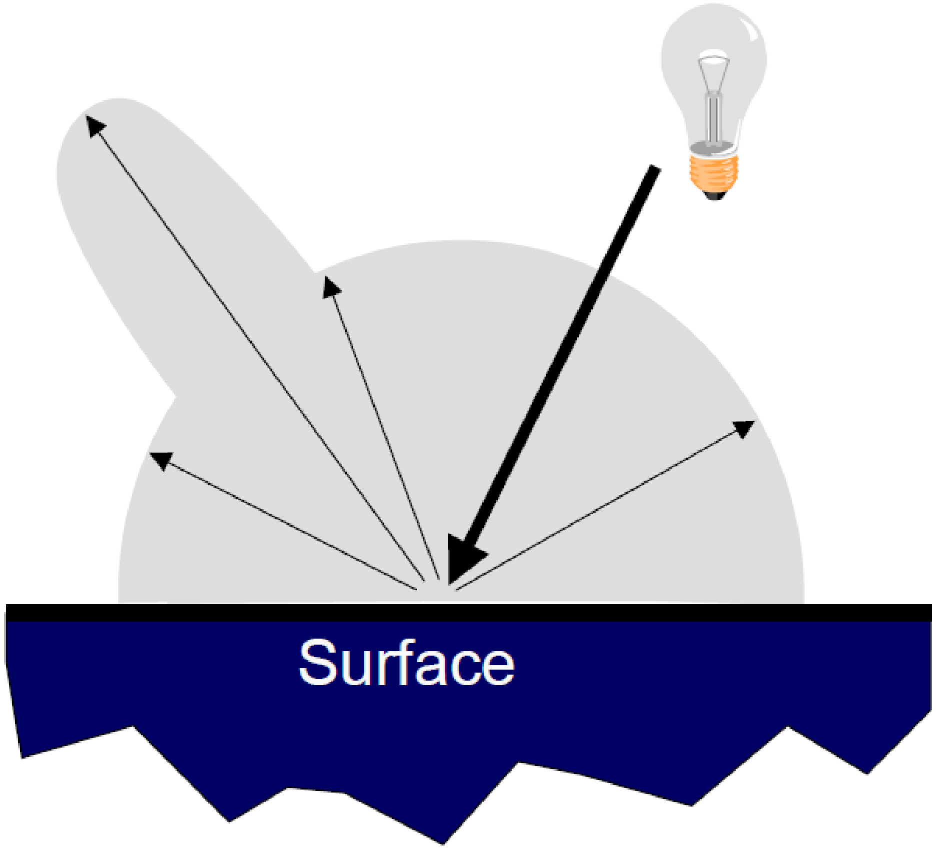
Modeling Surface Reflectance

- Rs(θ,ϕ,γ,ψ,λ) …
  - describes the amount of incident energy, …
  - arriving from direction (θ,ϕ), …
  - leaving in direction (γ,ψ), …
  - with wavelength λ



OpenGL Reflectance Model

- Simple empirical model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”
  - Bui Tuong Phong, 1973



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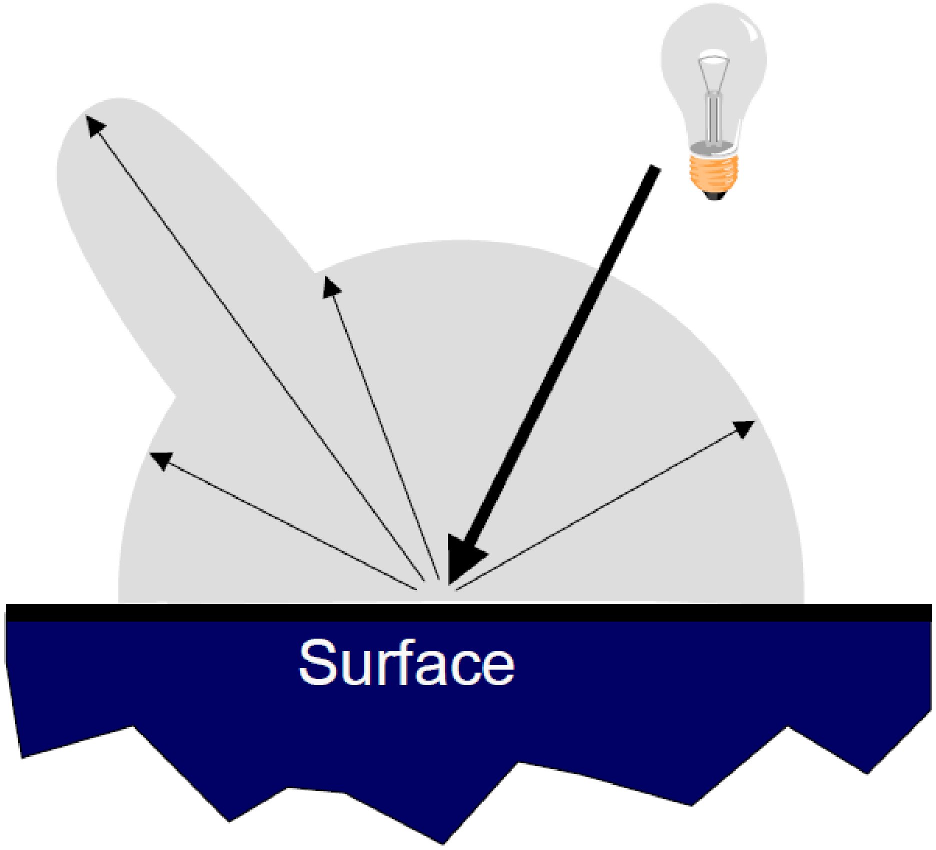
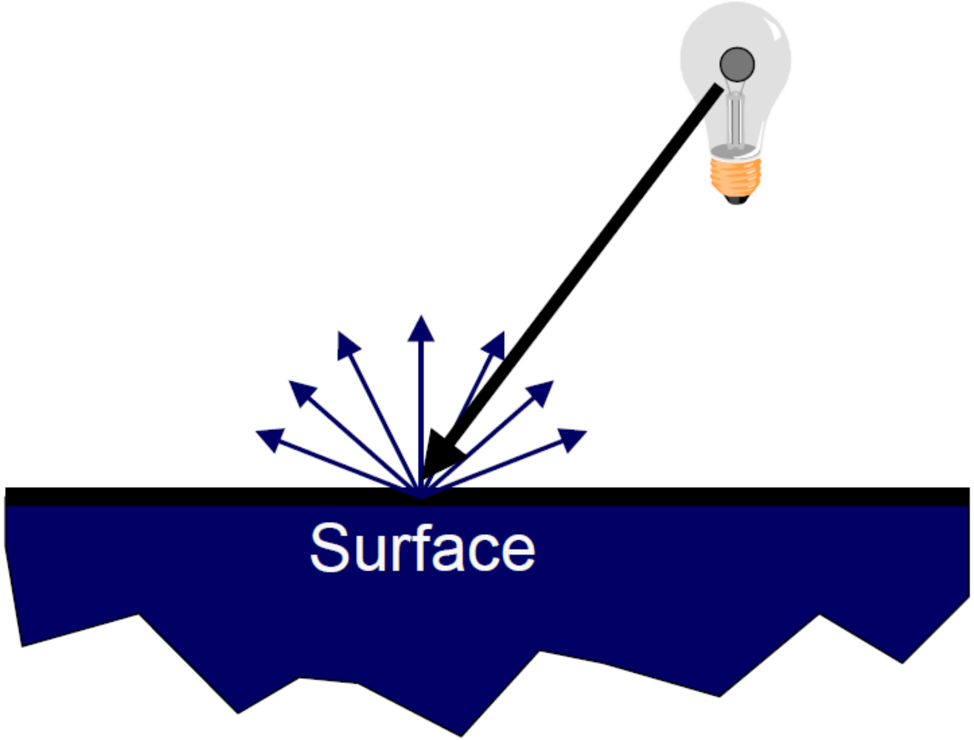


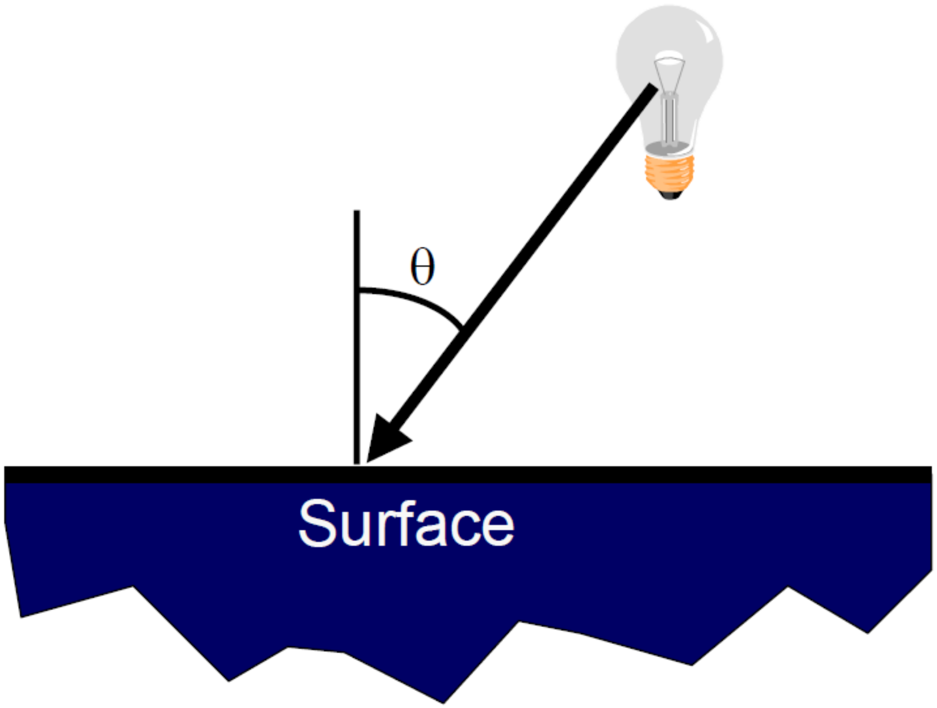
Diffuse Reflection

- Assume surface reflects equally in all directions
  - Examples: chalk, clay



Diffuse Reflection

- How is light reflected ?
  - Depends on an angle of incident light



Diffuse Reflection

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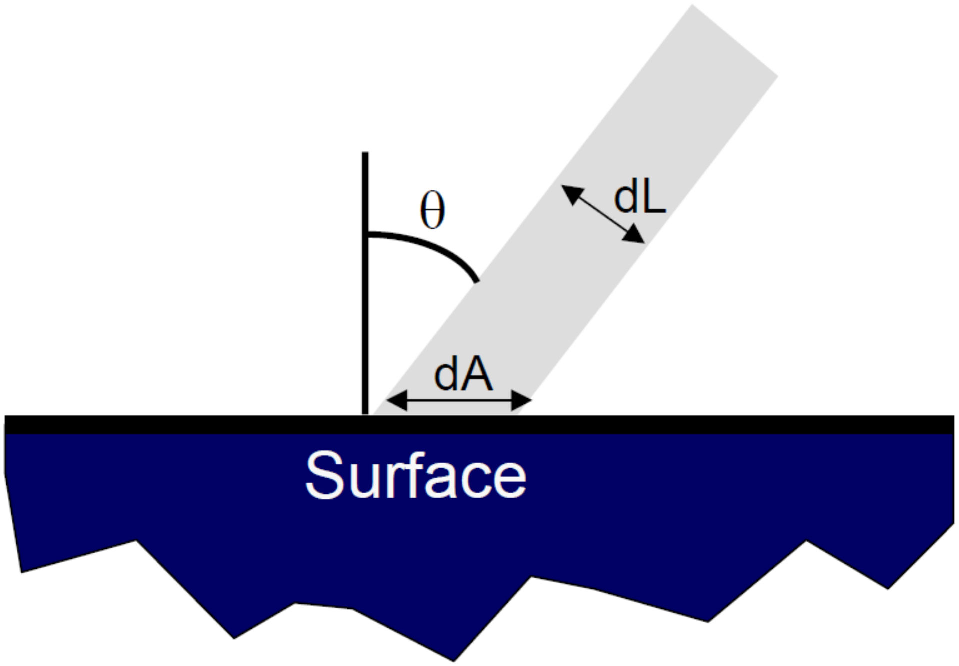
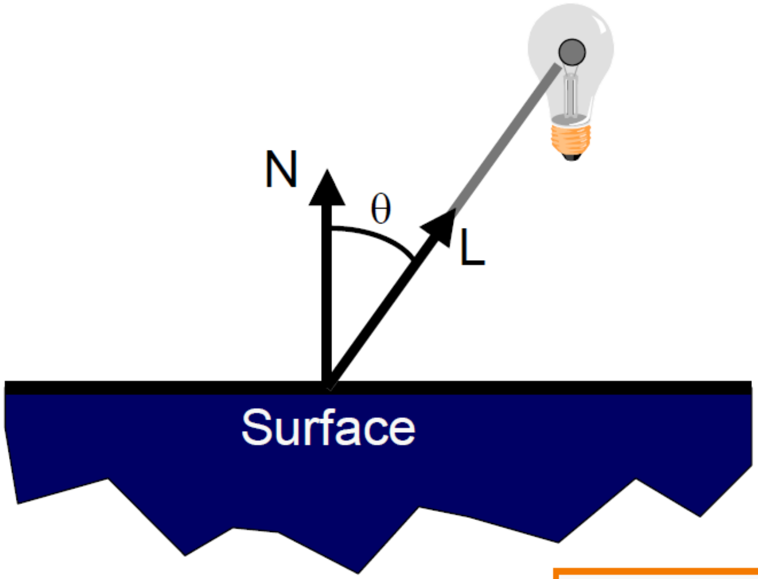
  - Depends on an angle of incident light

$$dL = dA \cos \Theta$$



Diffuse Reflection

- Lambertian model
  - cosine law (dot product)



$$\boxed{I_D = K_D (N \bullet L) I_L}$$

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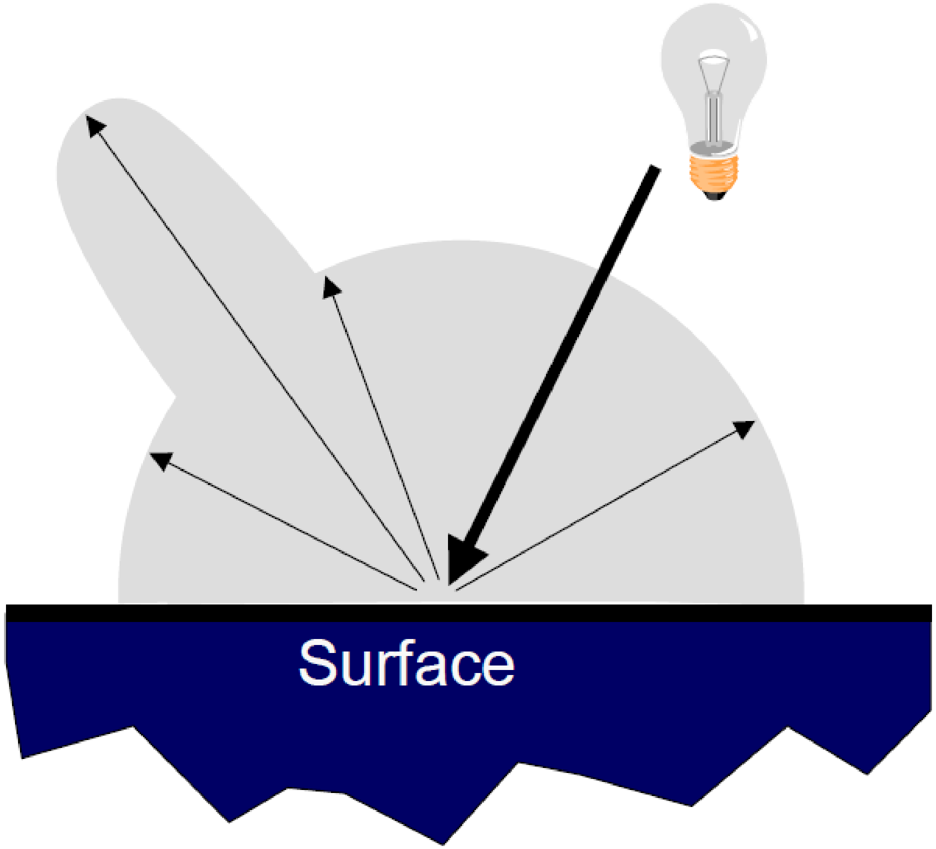
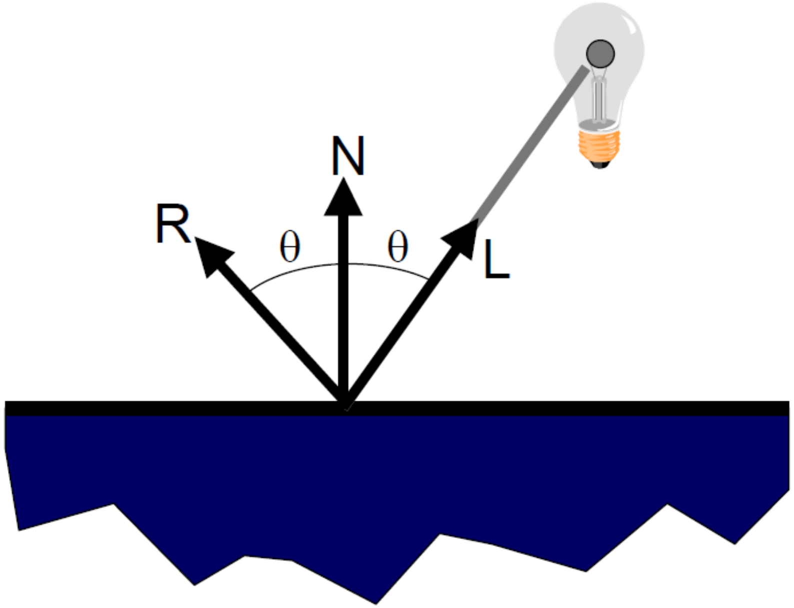


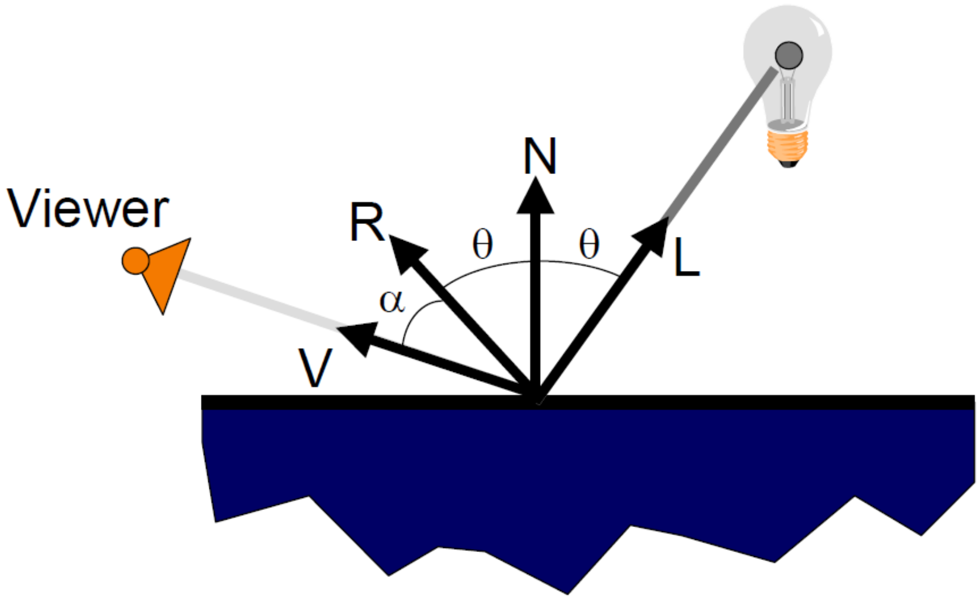
Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: Mirrors, Metals



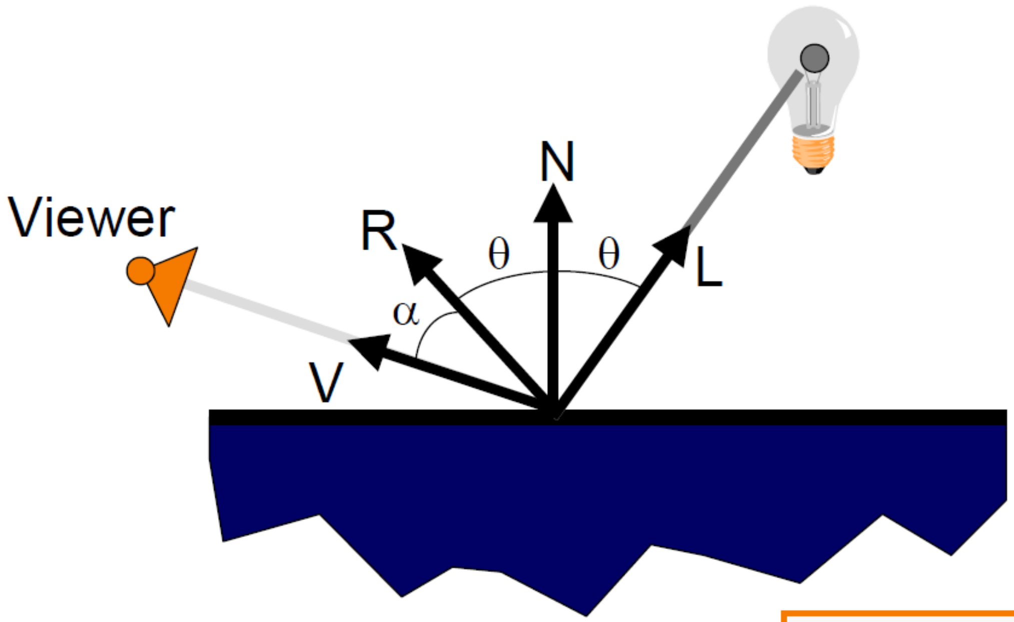
Specular Reflection

- How much light is seen ?
- Depends on:
  - angle of incident light
  - angle of viewer



Specular Reflection

- Phong Model
  - cos(α)n *This is a physically motivated hack!*



$$\boxed{I_S = K_S (V \bullet R)^n I_L}$$

OpenGL Reflectance Model

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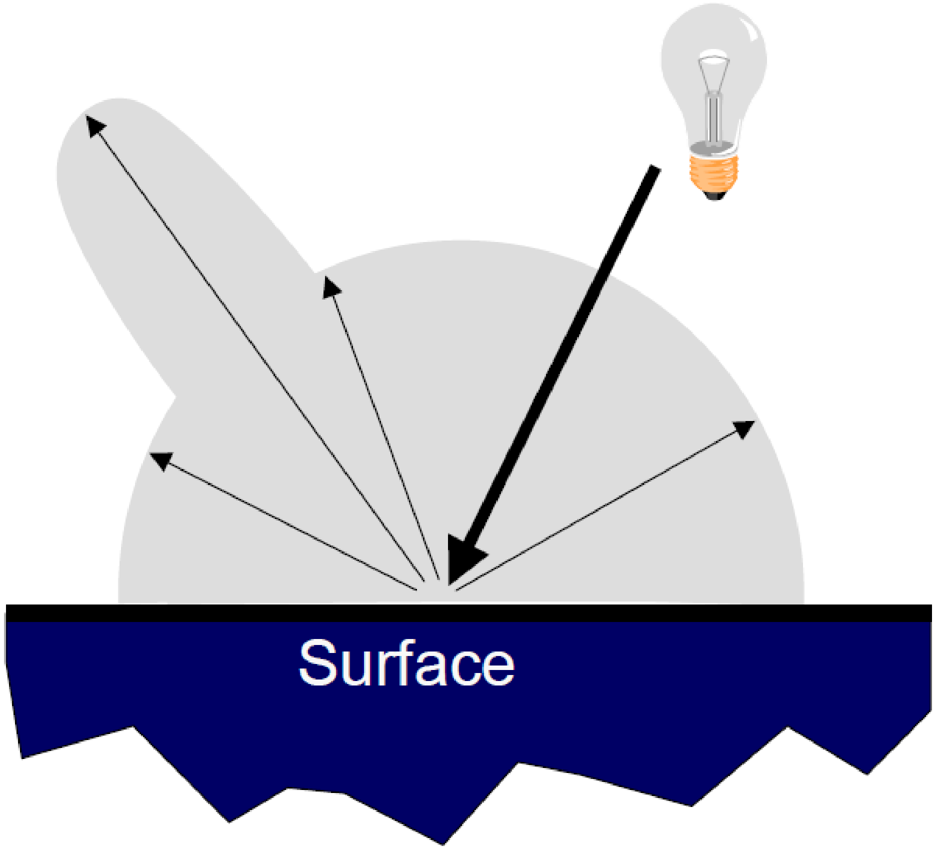
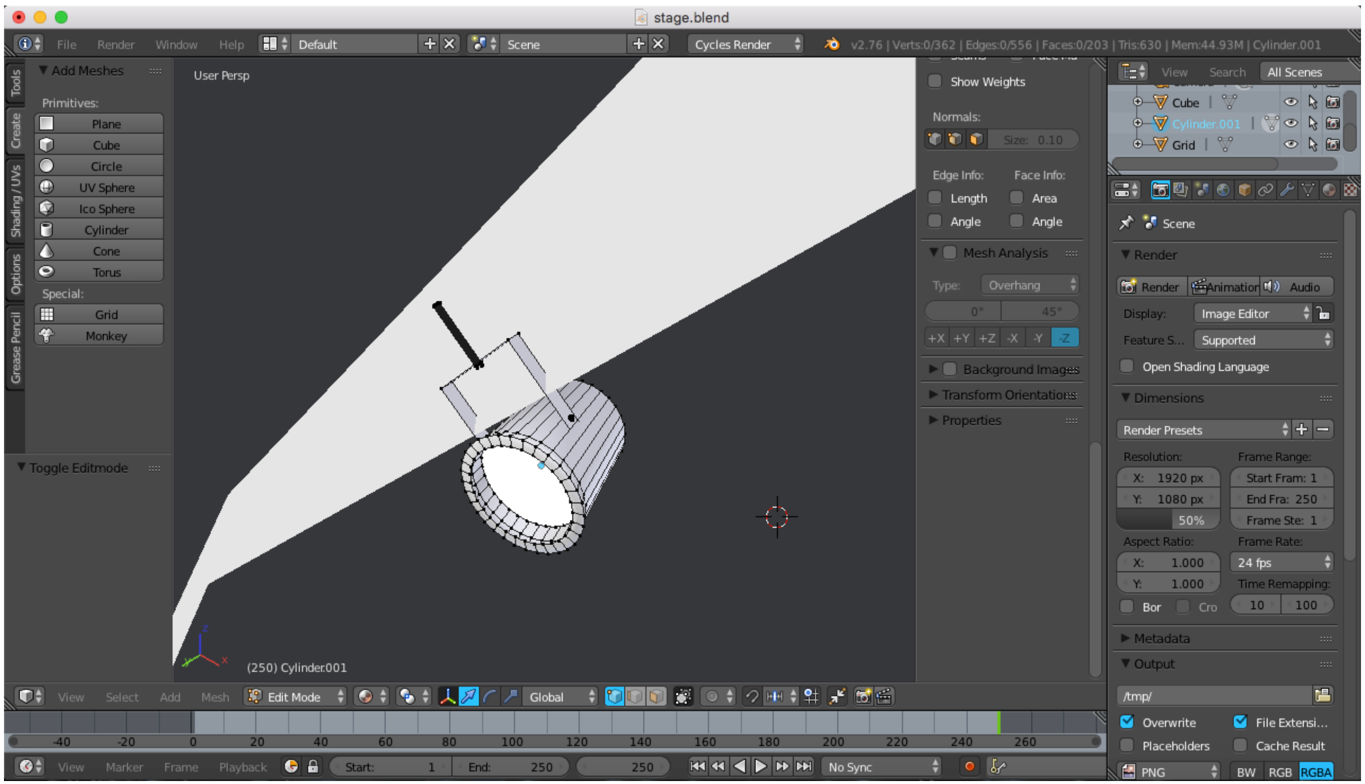


Emission

- Represents light emitted directly from surface



OpenGL Reflectance Model

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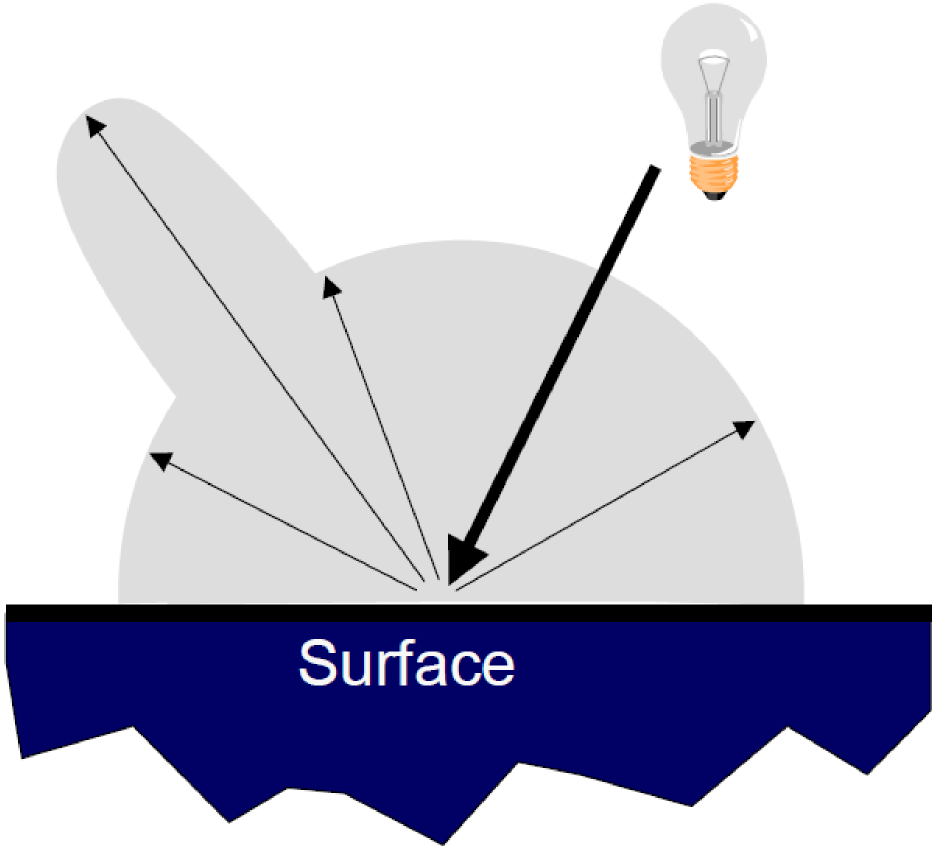
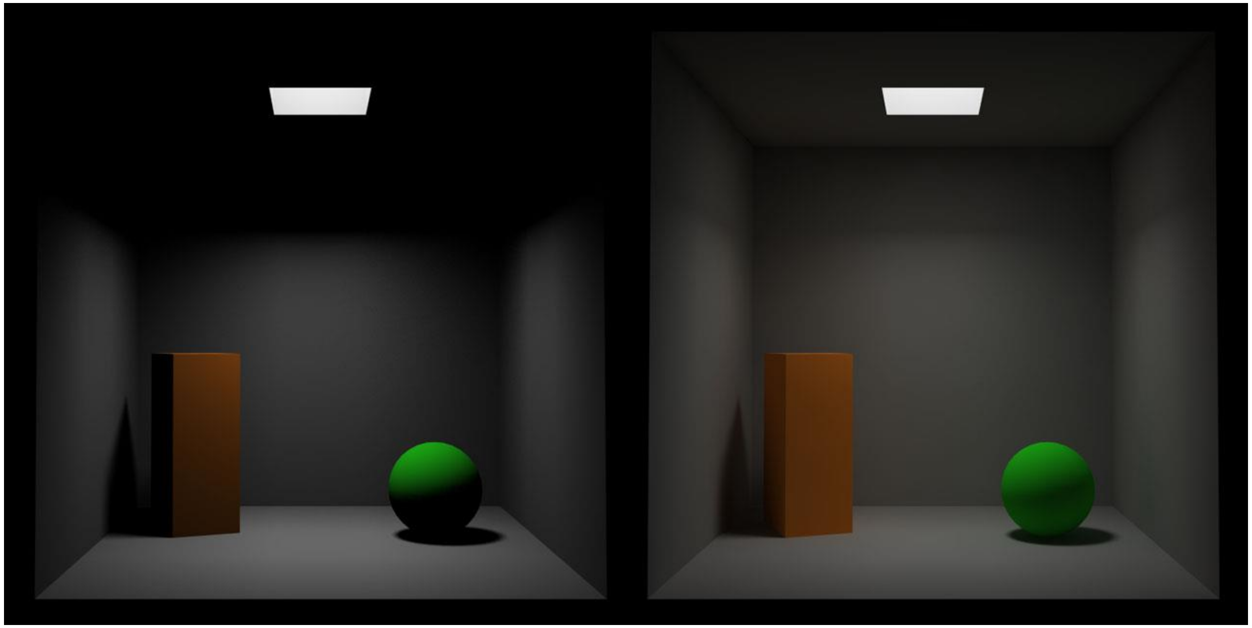


Ambient term

- Represents reflection of all indirect illumination
- This is a total hack
  - (avoids complexity of global illumination)!



OpenGL Reflectance Model

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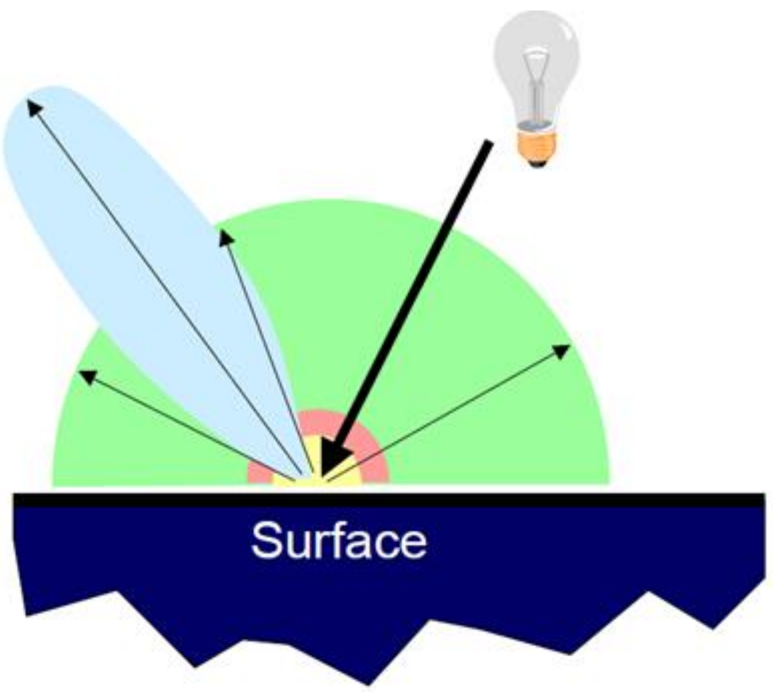

OpenGL Reflectance Model

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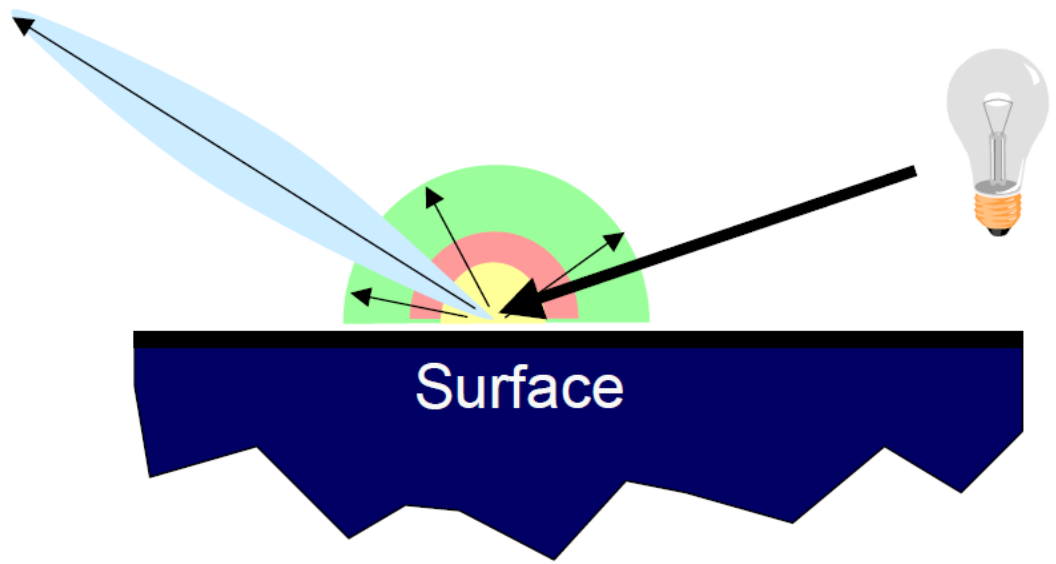

OpenGL Reflectance Model

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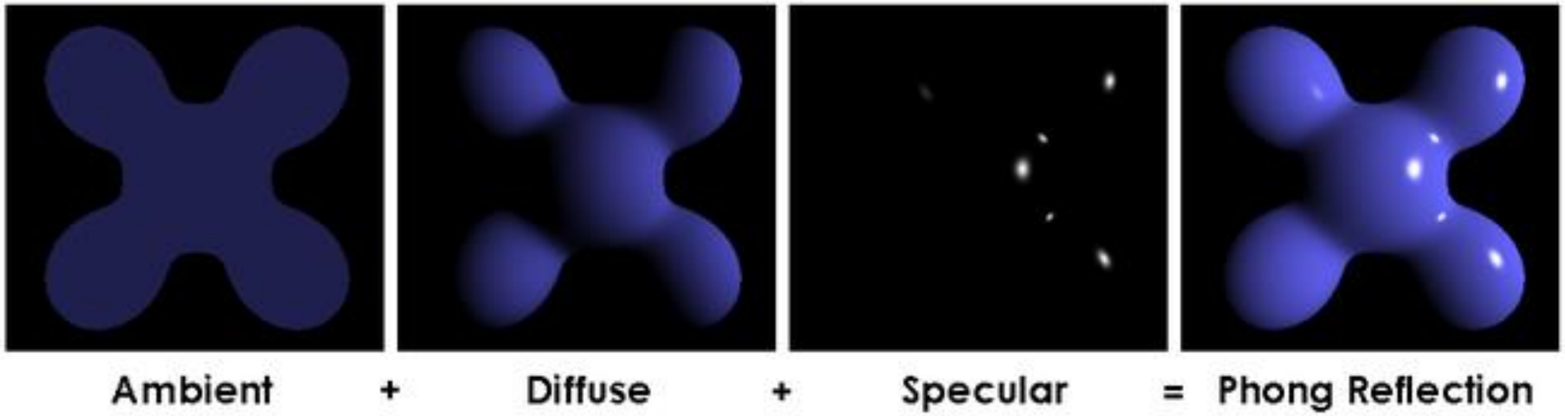
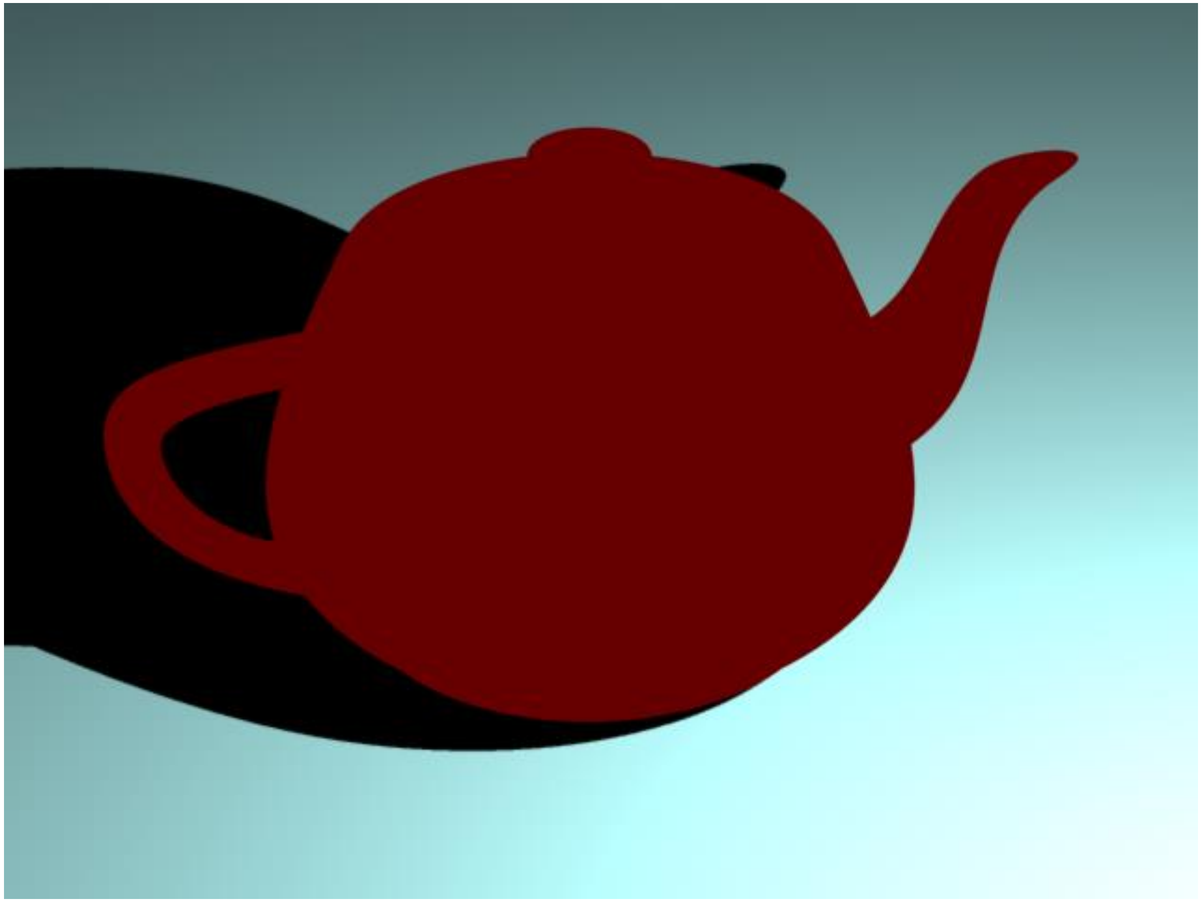


Diffuse light

Ambient light

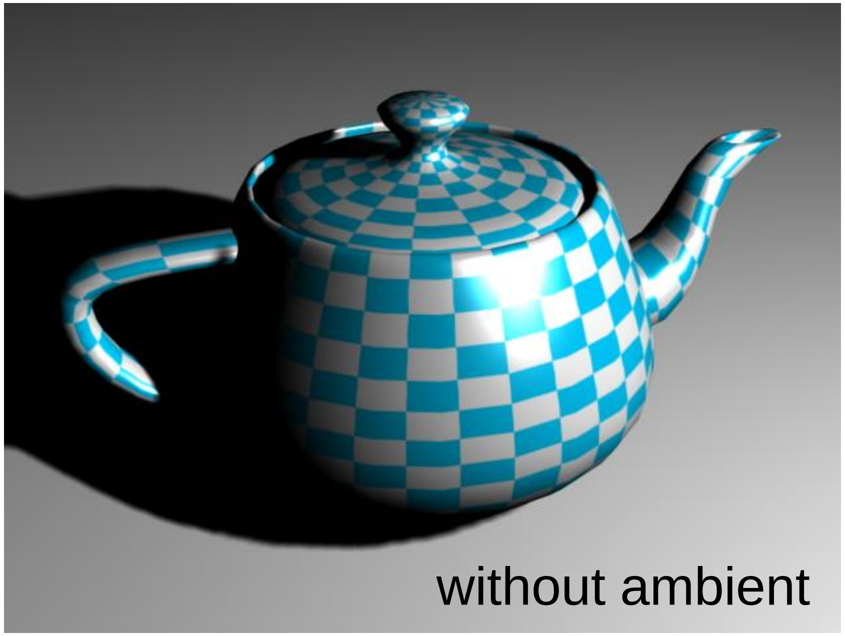


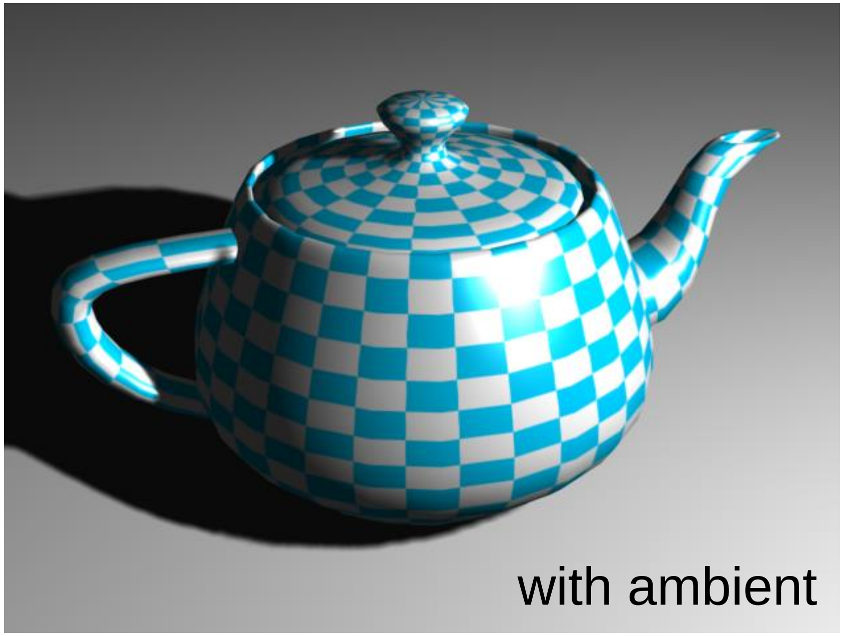
Diffuse + Ambient light

Specular + Diffuse + Ambient light

Phong lighting model

- **Ambient** + Diffuse + Specular components





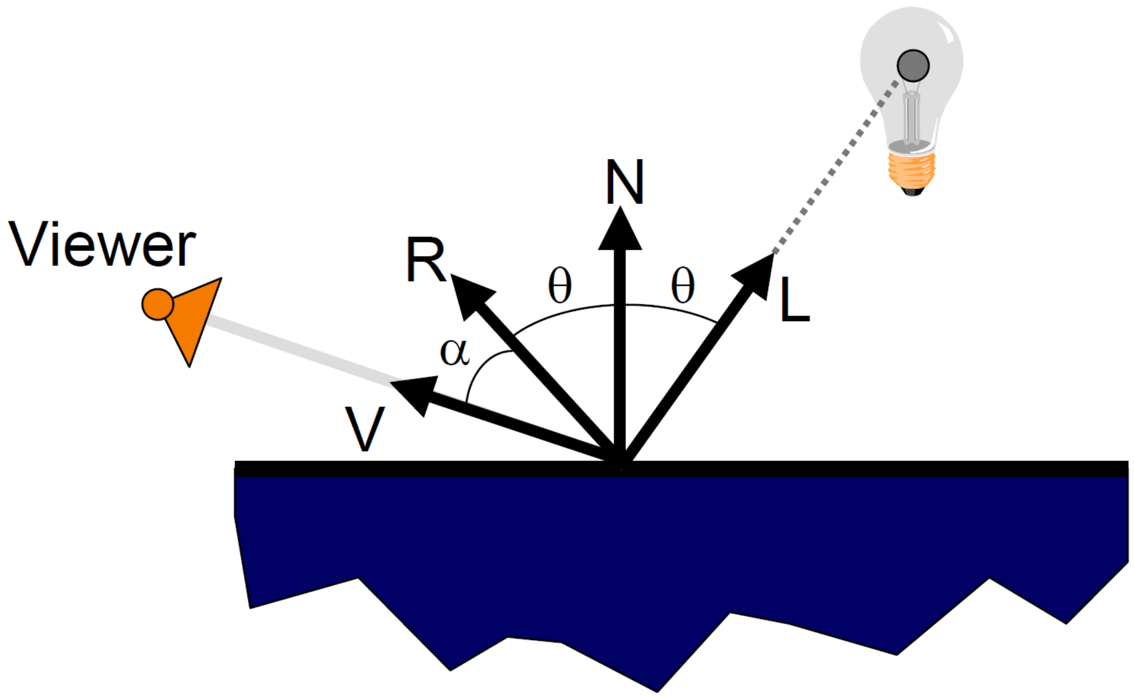
- Simulates global light scattered in the scene and reflected from other objects

Other lighting models

- Blinn-Phong
  - generalization of Phong's model
- Cook-Torrance
  - microfacets
- Oren-Nayar
  - rough surfaces
- Anisotropic microfacet distribution

Direct Illumination

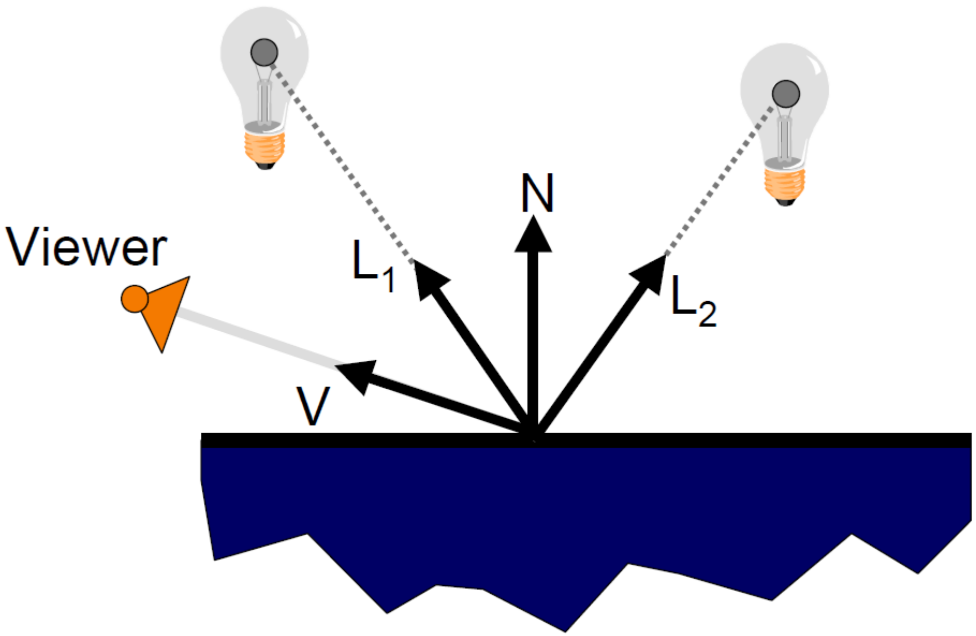
- Single light source example



$$I = I_E + K_A I_{AL} + K_D (N \bullet L) I_L + K_S (V \bullet R)^n I_L$$

Direct Illumination

- Multiple light source example



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

3D rendering pipeline

3D polygons

Modeling Transformation

⇩

Lighting

⇩

Viewing Transformation

⇩

Projection Transformation

⇩

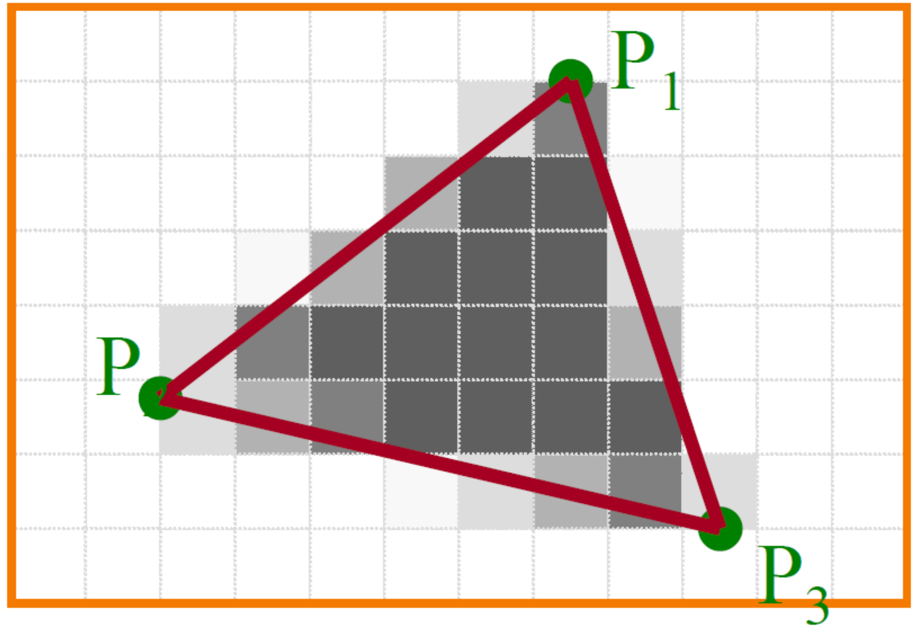
Clipping

⇩

Scan Conversion

2D Image

Draw pixels

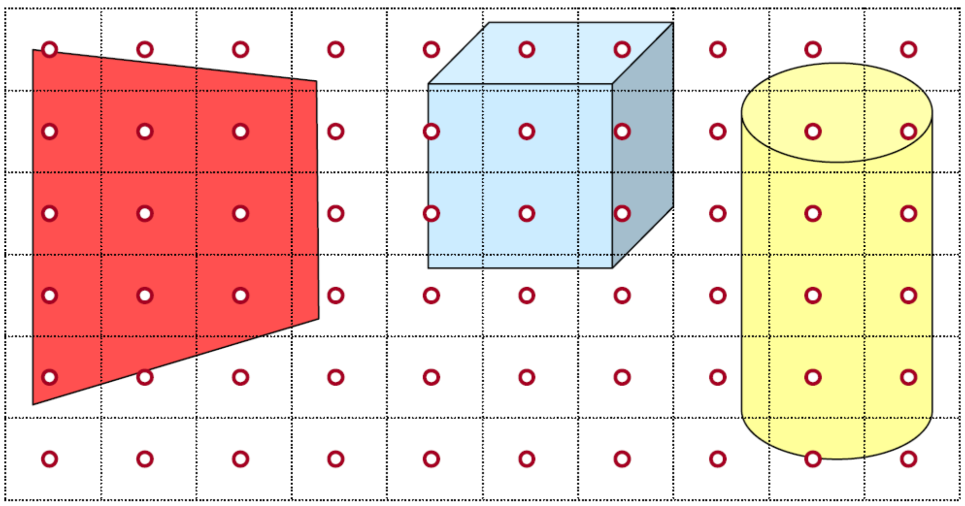


Pixel Shading

How to effectively get the value
of the illumination model
for each pixel ?

Ray Casting

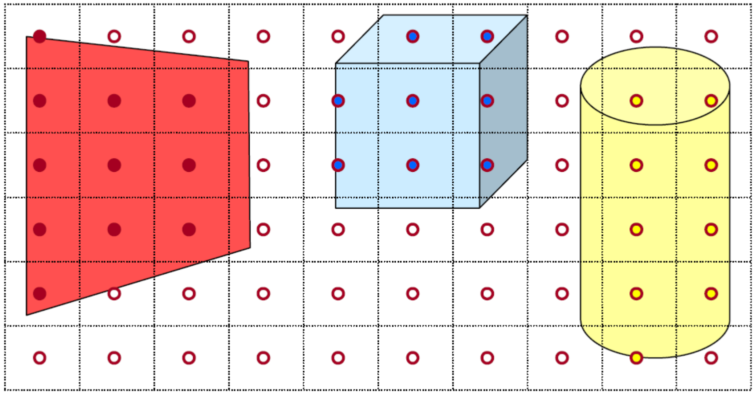
- Independent lighting calculation for each pixel
  - Computationally expensive

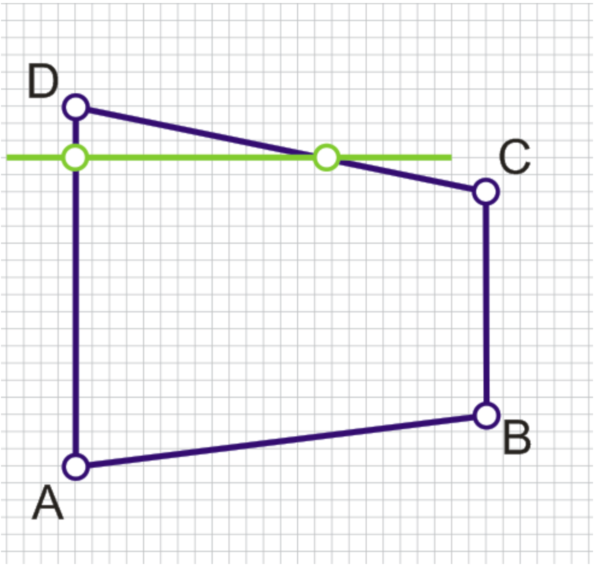


$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Polygon Shading

- Can take advantage of spatial coherence
  - Illumination calculations of pixels of a triangle are related
  - Scanline rasterization





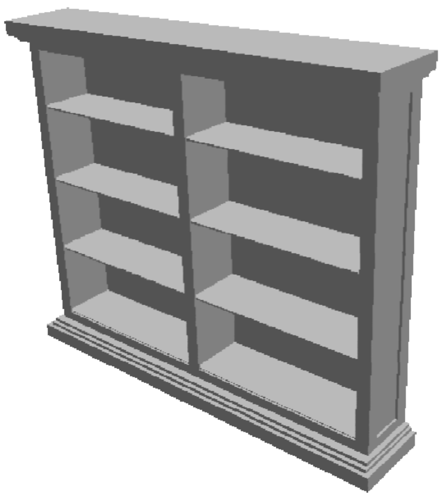
$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Overview

- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections
- **Shading**
  - Flat
  - Gouraud
  - Phong

Flat Shading

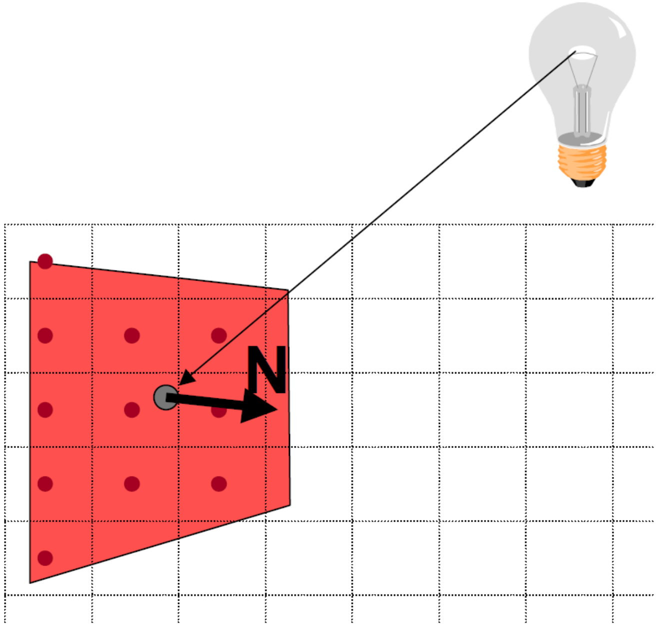
- Fill triangles using single calculated color



$$\boxed{I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)}$$

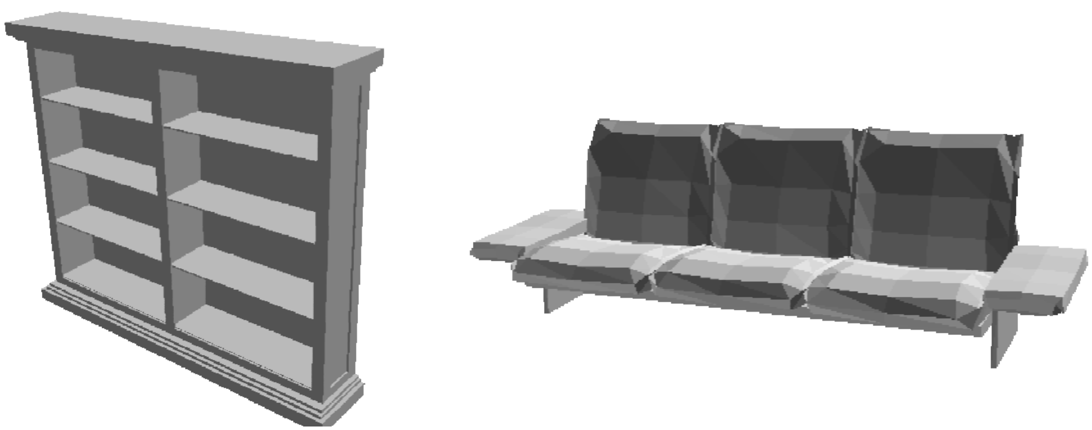
Flat Shading

- One Illumination calculation per polygon
- Assign all pixels of each polygon the same color



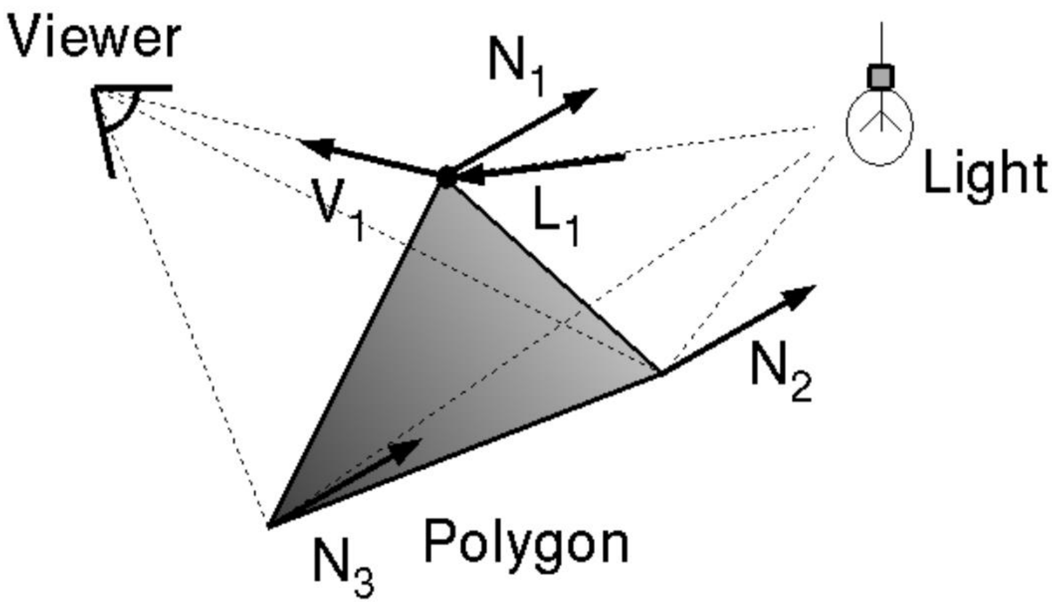
Flat Shading

- Objects look like they are composed of polygons
- Ok for polyhedral objects
- Not so good for smooth surfaces



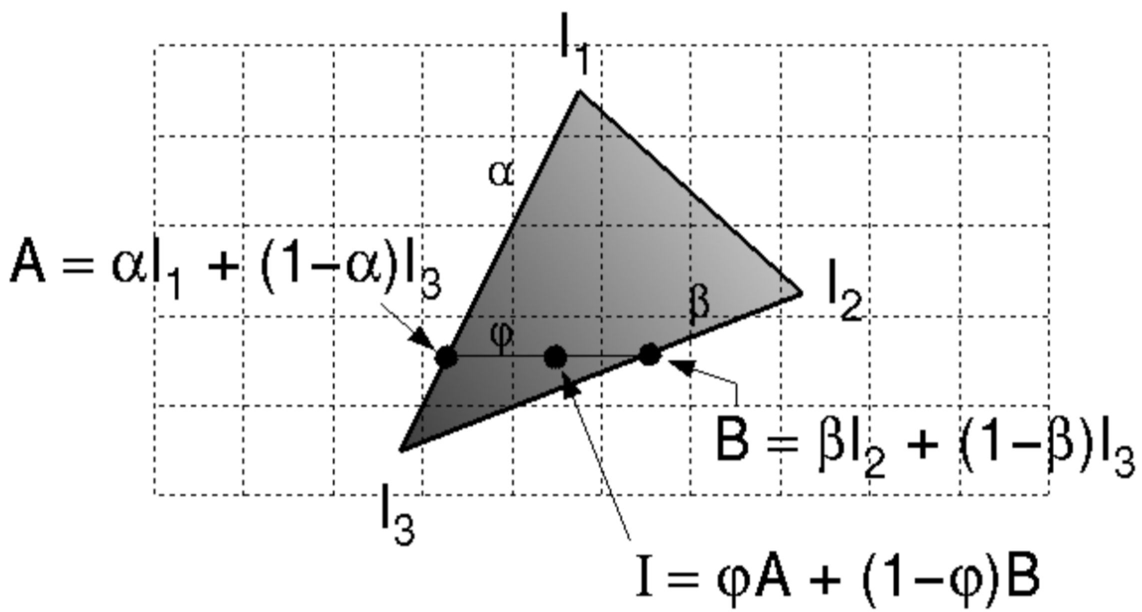
Gouraud Shading

- One lighting calculation per vertex
- Assign pixels inside polygon by interpolating colors computed at vertices



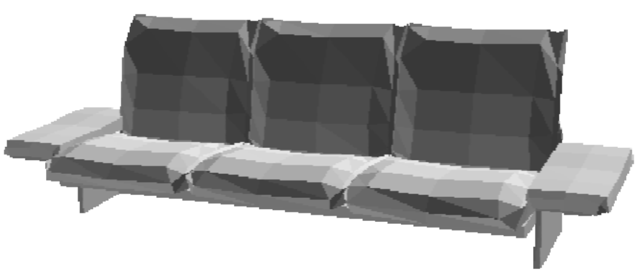
Gouraud Shading

- Bilinearly interpolate colors of triangle across scan line

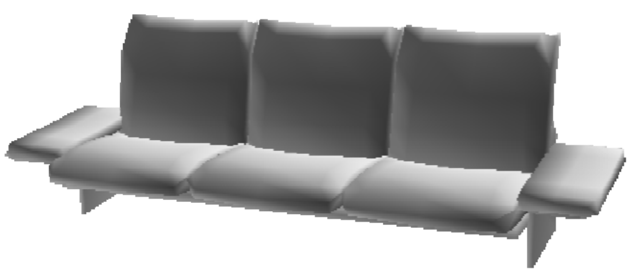


Gouraud Shading

- Smooth shading over adjacent polygons
  - Curved surfaces
  - Illumination highlights
- Produces smoothly shaded polygonal mesh
  - Fast linear approximation
  - Needs fine mesh to capture subtle lighting effects

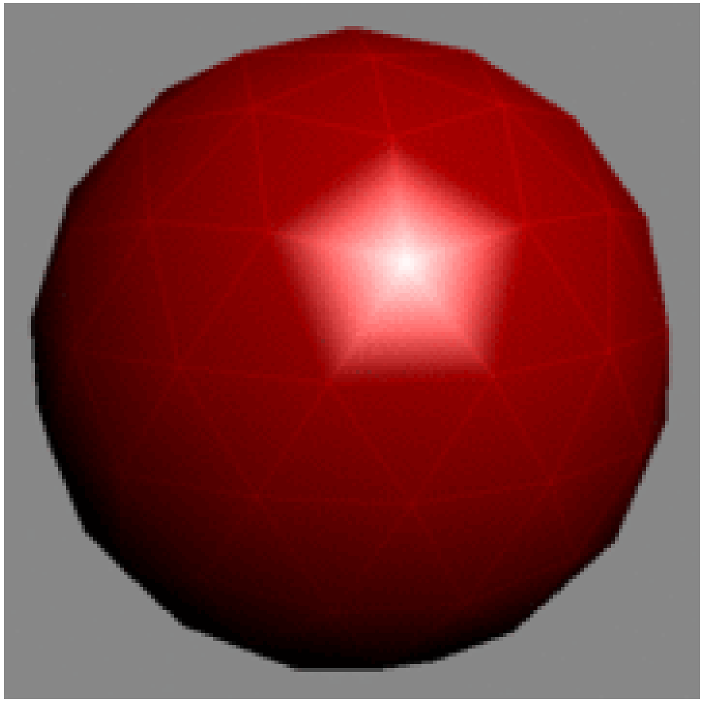


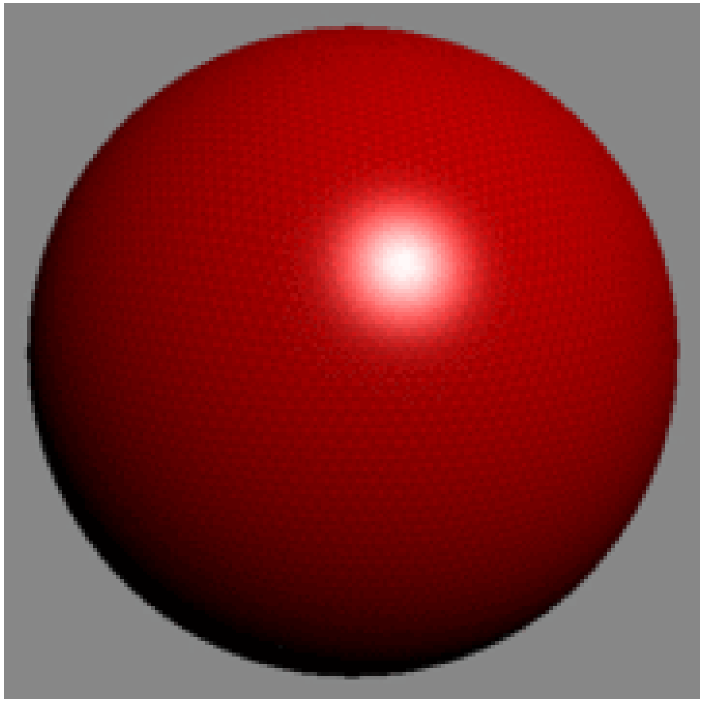
Flat Shading



Gouraud Shading

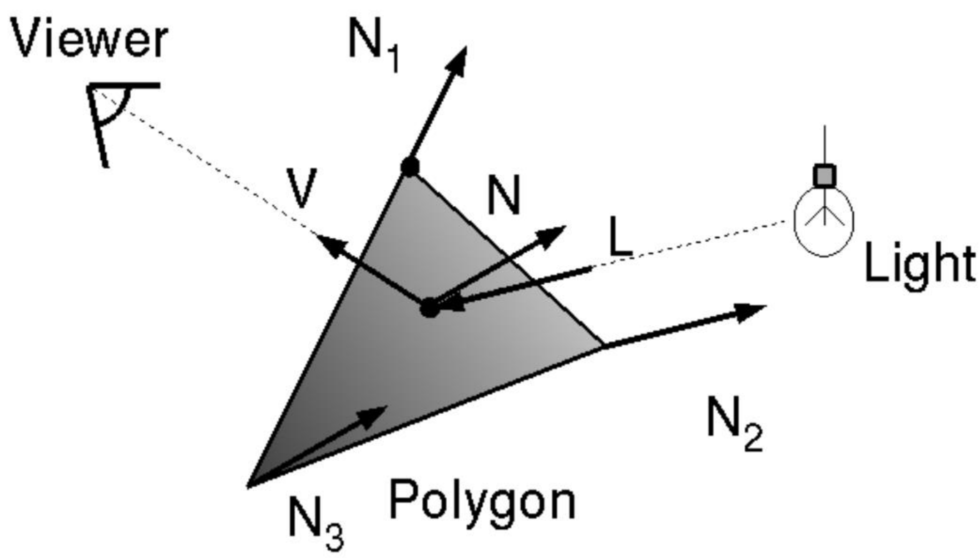
Gouraud Shading





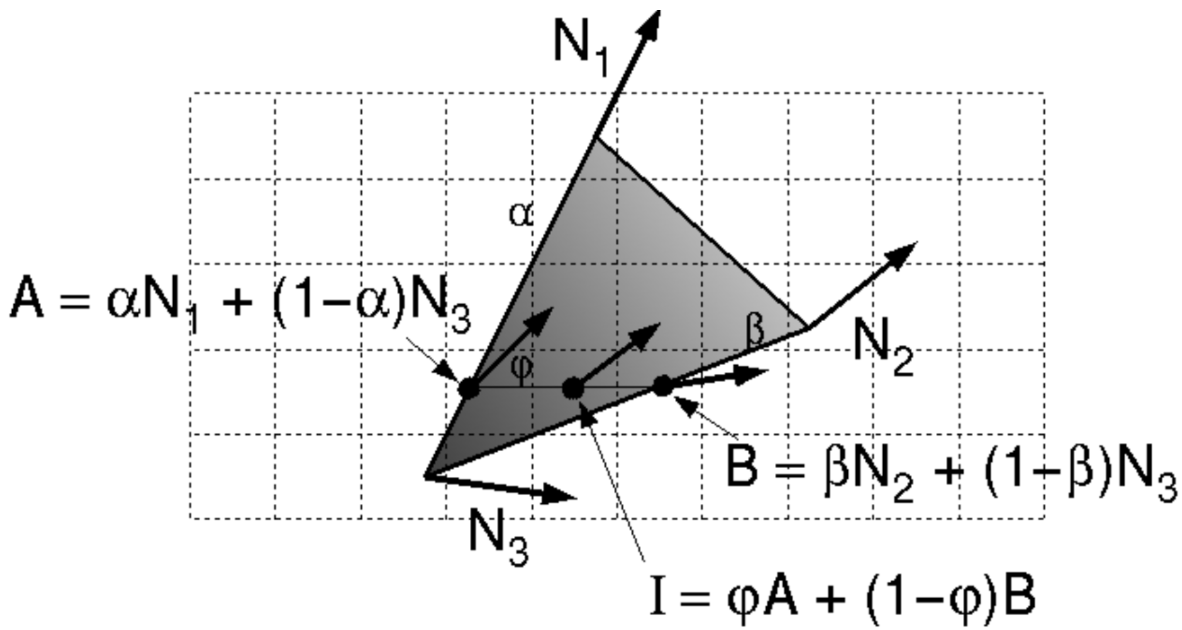
Phong Shading

- NOT Phong lighting model
- One lighting calculation per pixel
  - Approximate surface normals inside polygon using bilinear interpolation of normals from vertices

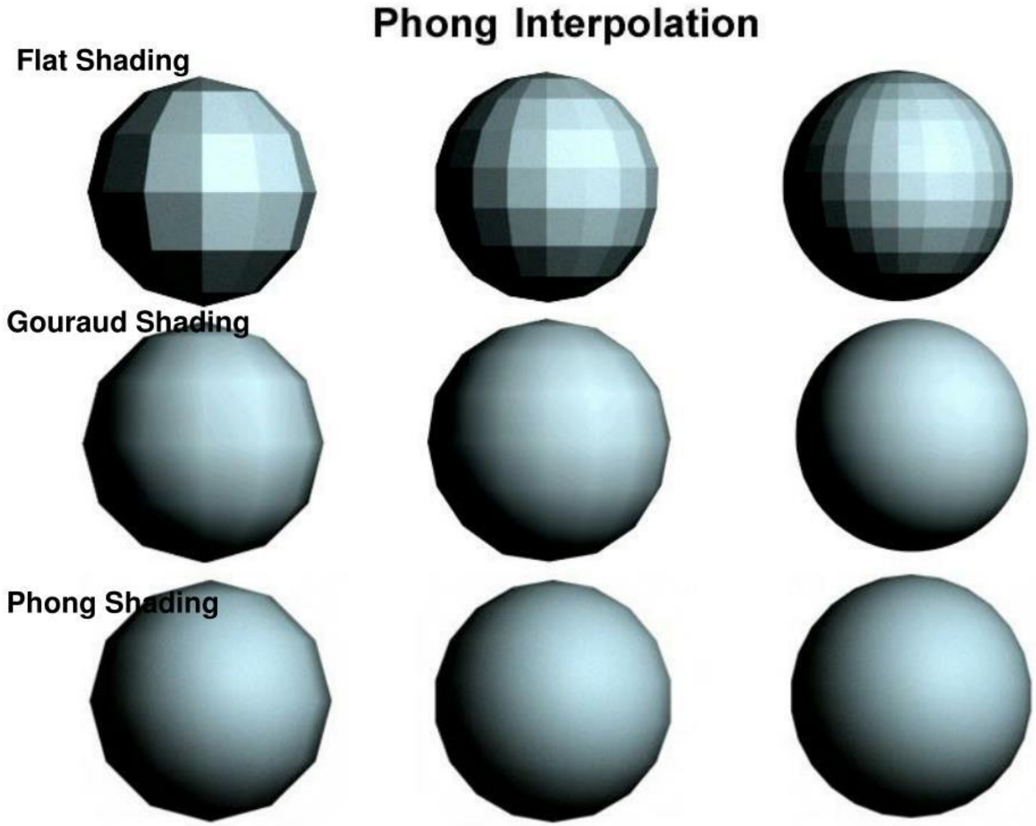


Phong Shading

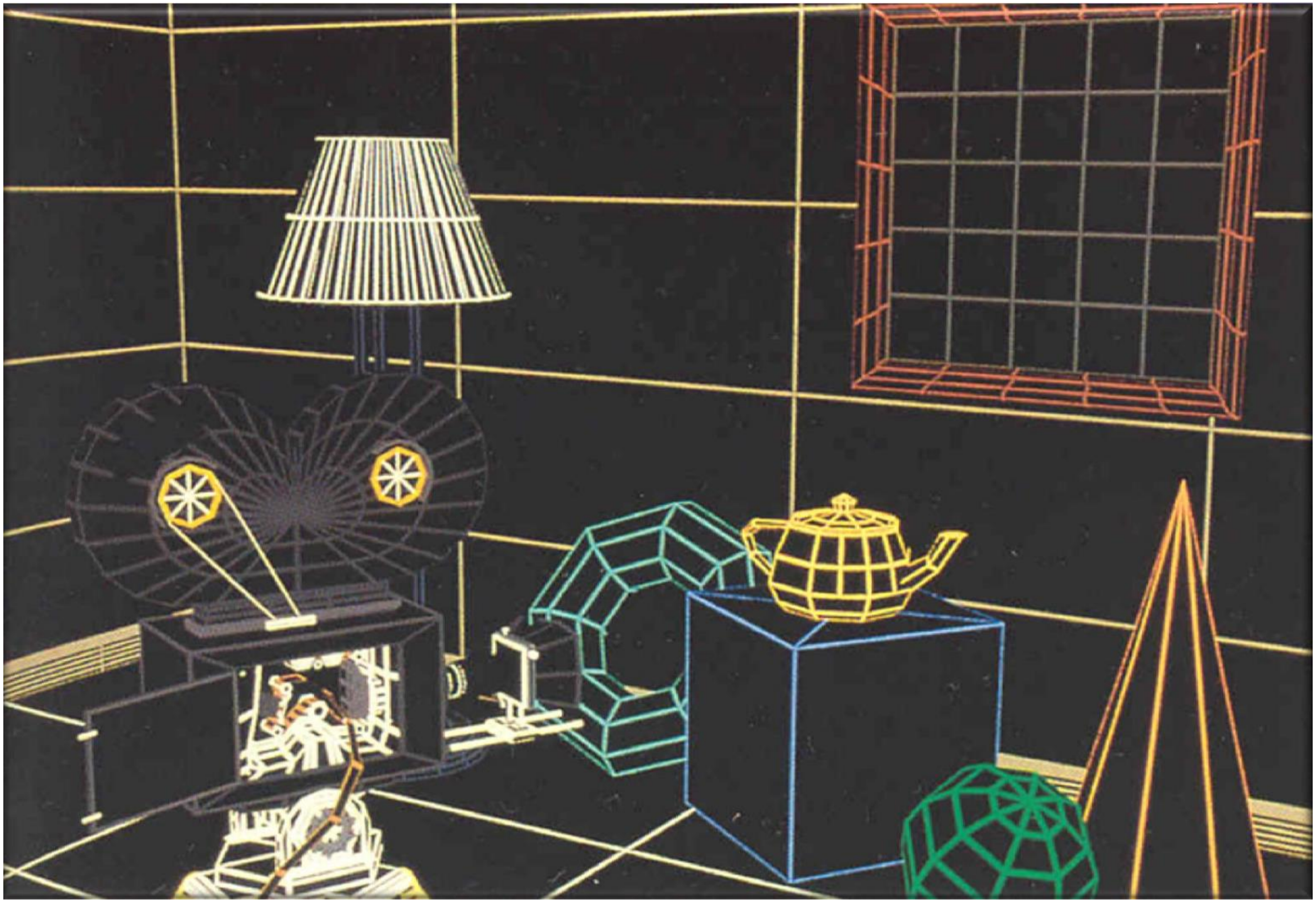
- Bilinearly interpolate surface normals at vertices down and across scan lines



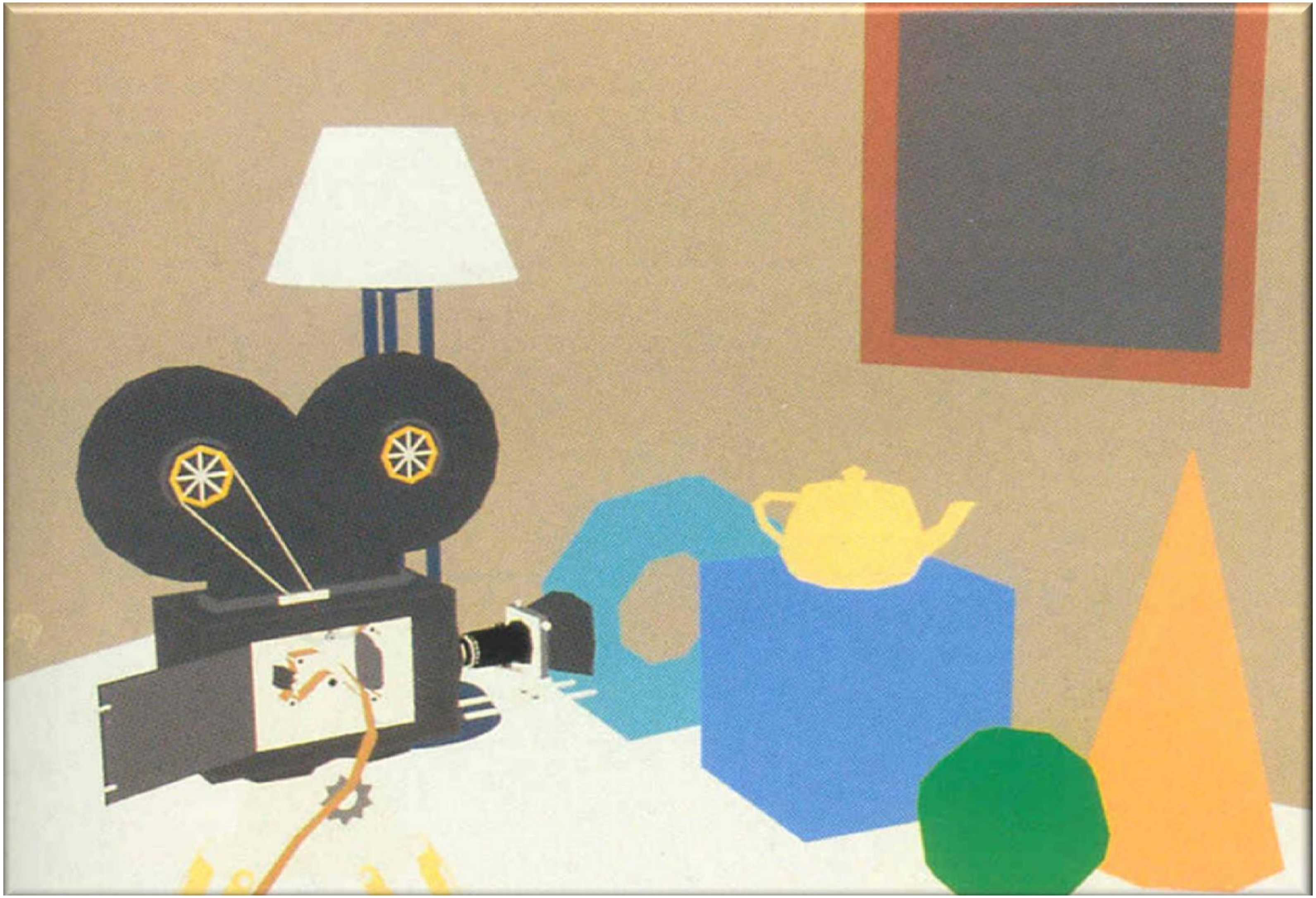
Polygon Shading Algorithms



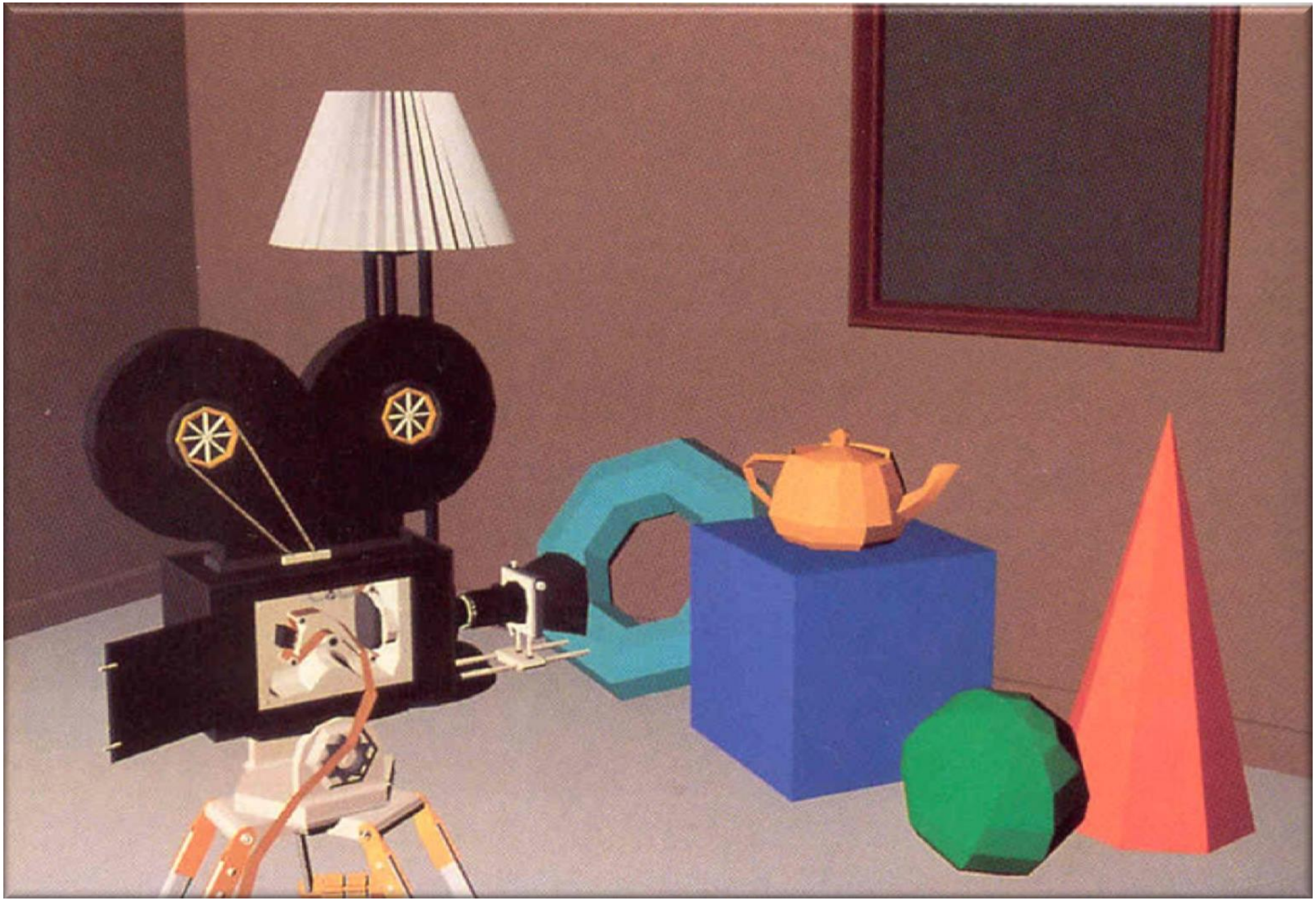
Example: Wireframe scene



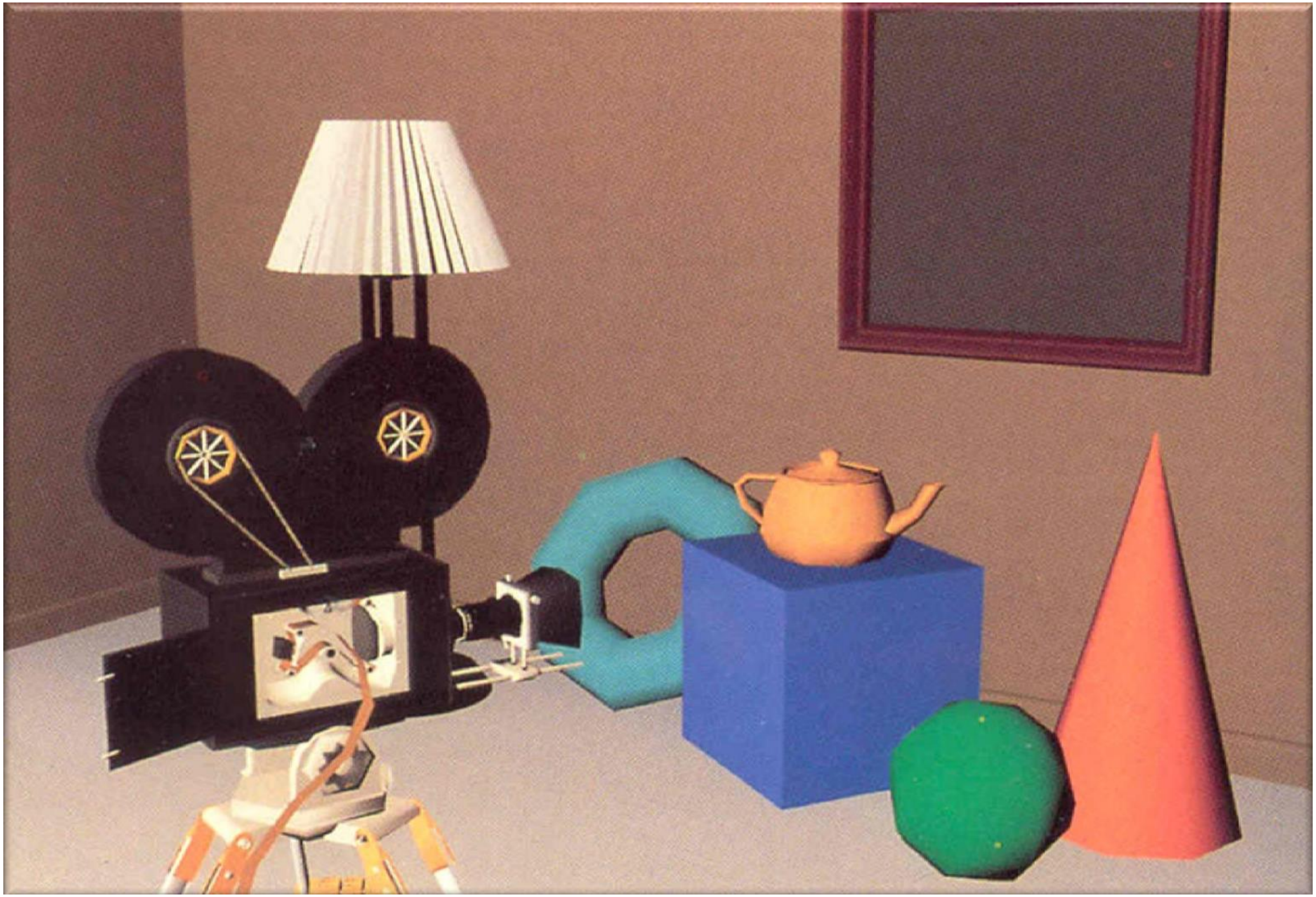
Example: Ambient only



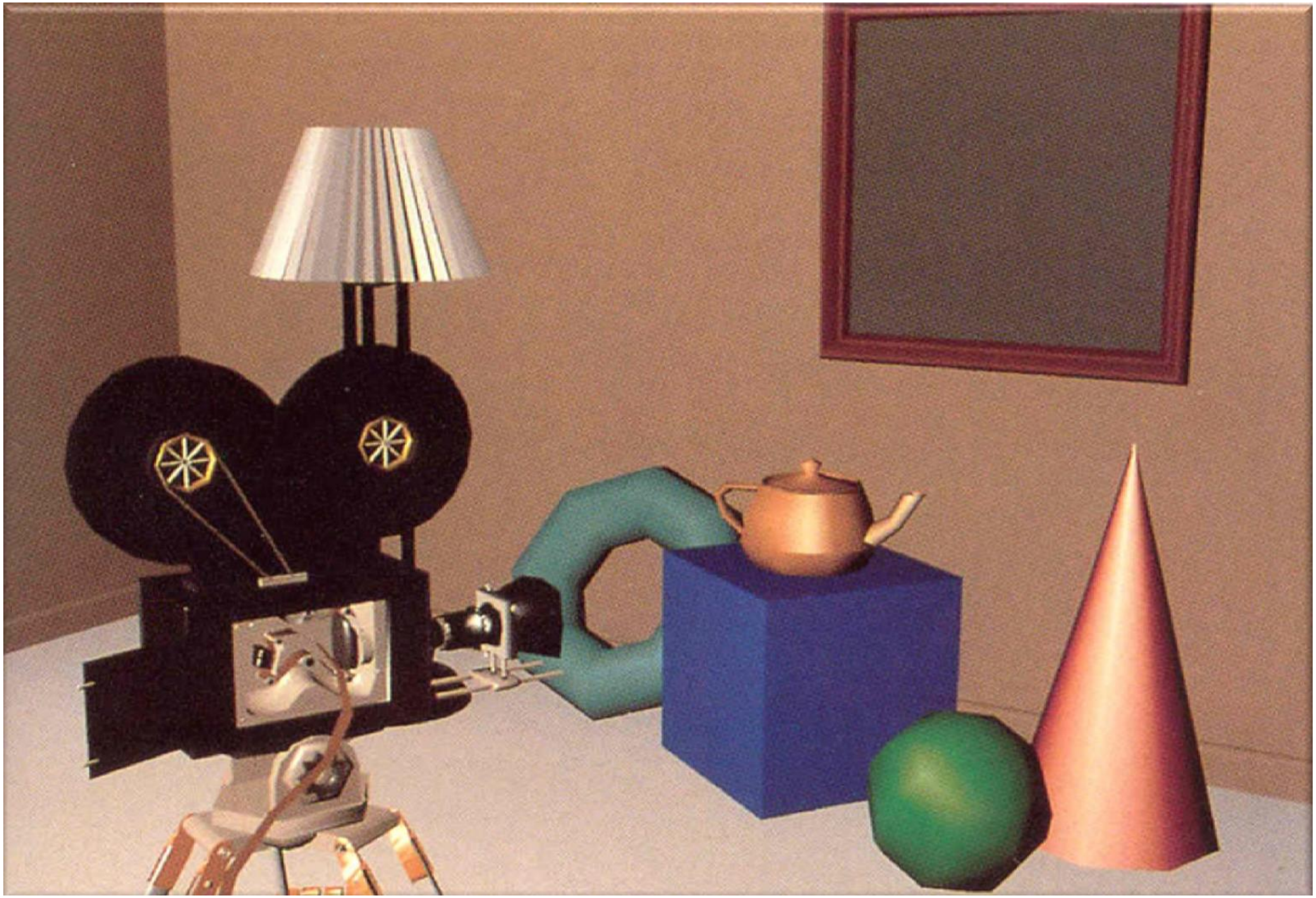
Example: Flat shading with Diffuse



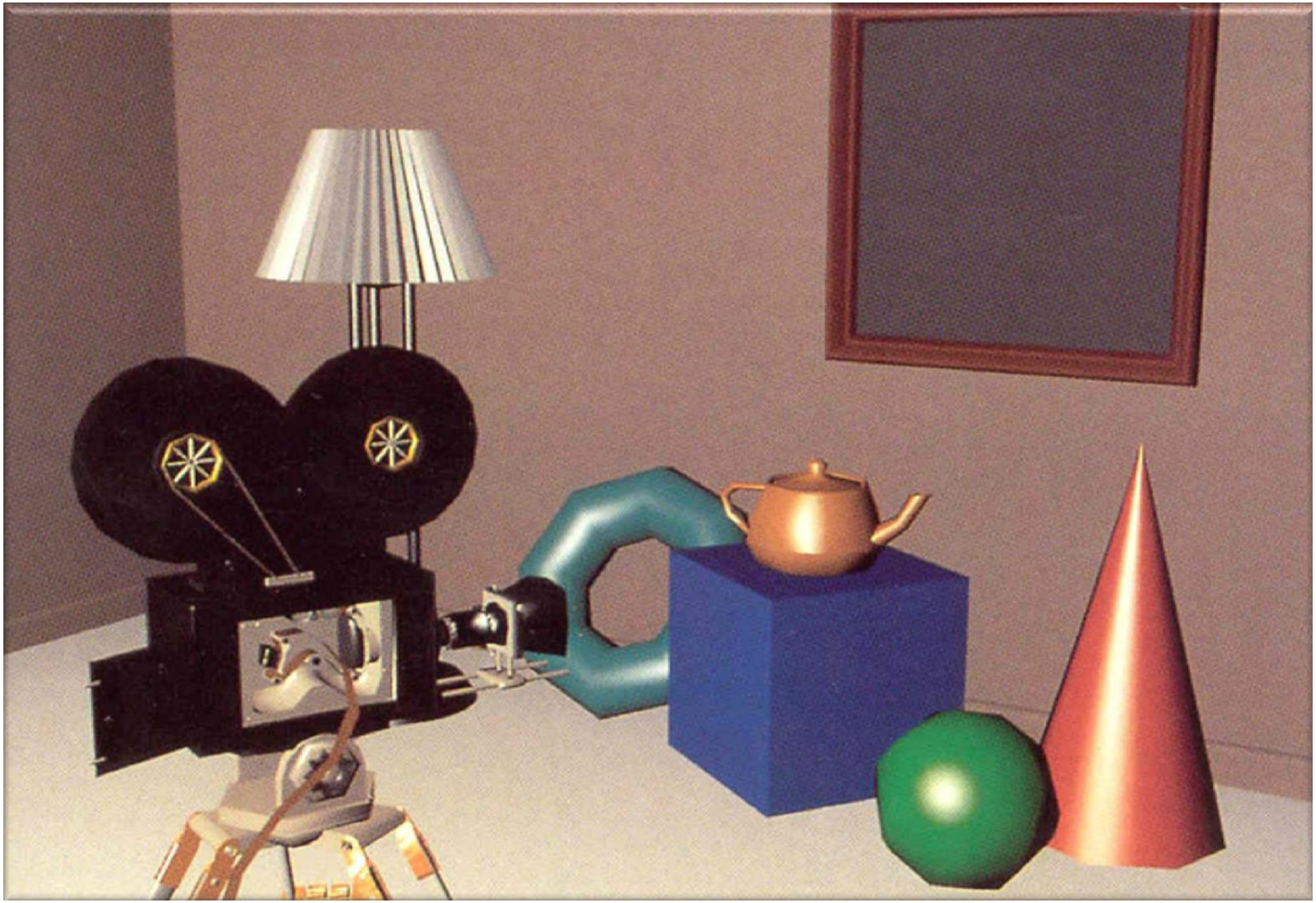
Example: Gouraud shading with Diffuse



Example: Gouraud shading with Specular



Example: Phong shading with Specular



Shading Issues

- Problems with interpolated shading
  - Problems computing shared vertex normals
  - Perspective distortion
  - Problems at T-vertices

Shading Benefits

- Good performance and quality of output
  - Excellent for hardware
  - Works well with subdivision surfaces

How the lectures should look like #2

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

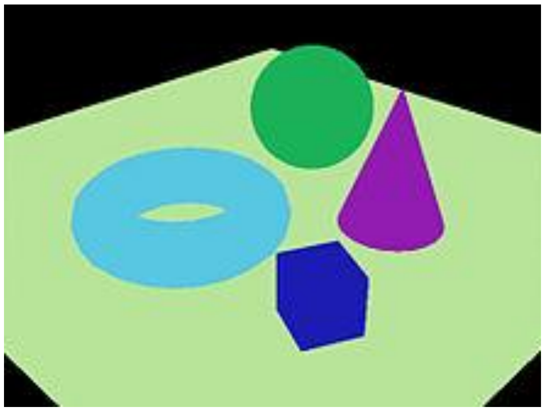
Overview

- Advanced Shading and Mapping
  - Deferred Shading

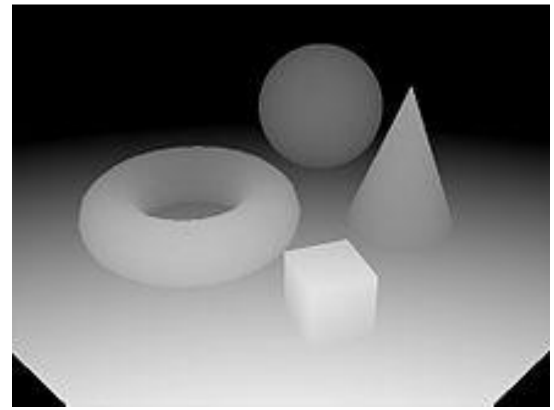
Deferred Shading

- Compute Lighting in Screen-Space
- Two pass approach
- Decoupling of geometry and lighting
- G-Buffer stores positions, normals, materials …
- Lighting is a per-pixel operation
- Problems with transparency and G-buffer size
- O(objects+lights)

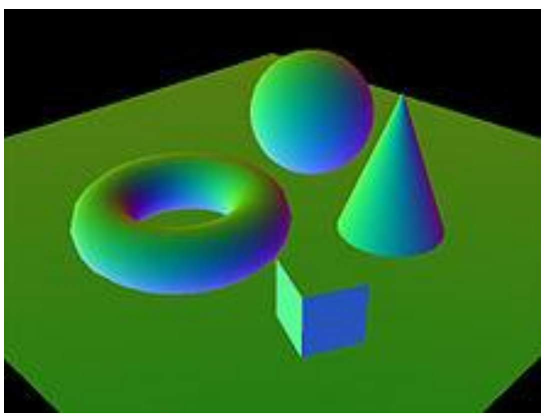
Deferred Shading



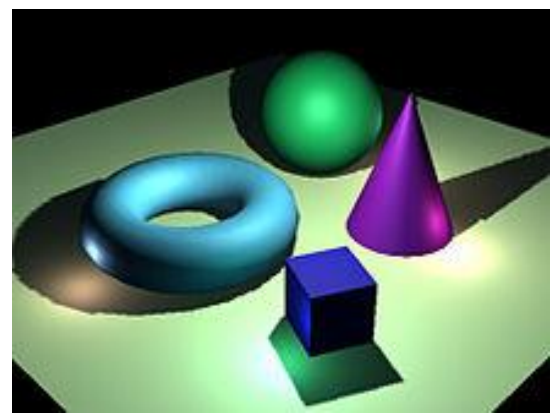
Diffuse Color



Z Buffer



Surface Normals

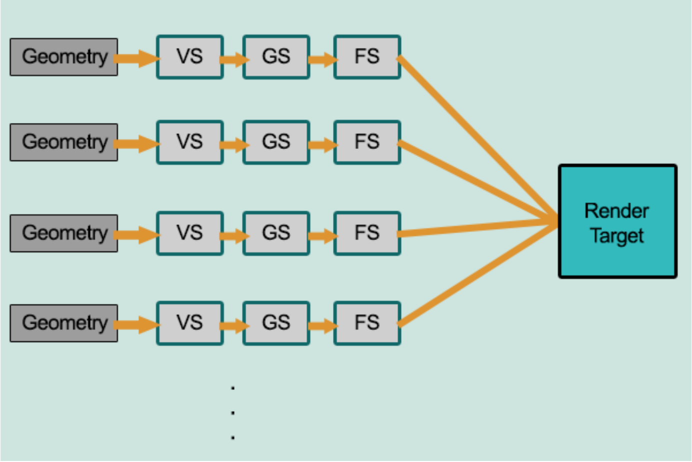


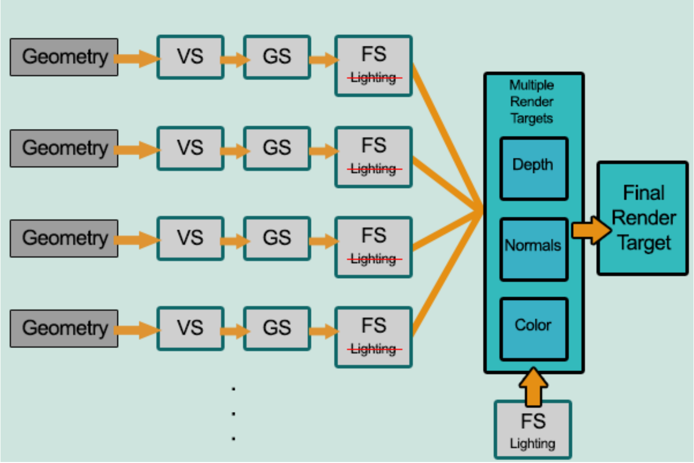
Final Composition

Deferred Shading

Forward rendering

O(num_geometry_fragments * num_lights)





https://gamedevelopment.tutsplus.com/articles/forward-rendering-vs-deferred-rendering--gamedev-12342

Deferred shading

O(screen_resolution * num_lights)

Deferred Shading Pros/Cons

- Pros
  - The primary advantage of deferred rendering is that the lighting is only computed for fragments that are visible
  - In forward rendering, each fragment requires a loop over all light sources and for each, an evaluation of the lighting model
  - Deferred rendering provides better scalability as the number of light sources increases.
- Cons
  - The primary disadvantage of deferred rendering is the additional storage for the g-buffer
  - This becomes a difficulty when different materials are required for different objects in the scene

Next Lecture

Visibility, Culling

Acknowledgements

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Output of all the publications and great team work

Very best data from 3D cameras

Questions ?!

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