CS148: Introduction to Computer Graphics and Imaging

Rendering

Modeling & Simulating Appearance

Models

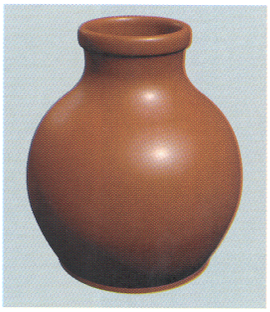
- Cameras
- Light sources
- Materials
  - Reflection
  - Texture

Lighting simulation

- Solving the rendering equation
- Ray tracing

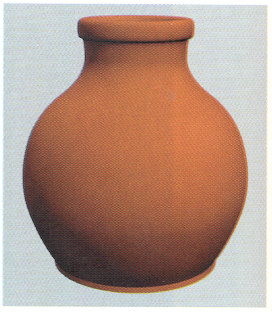
Reflection

Materials



Plastic

Metal



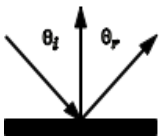
Matte

From Apodaca and Gritz, *Advanced RenderMan*

Types of Reflection

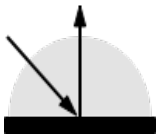
Mirror

- Ideal reflection
- Reflection Law



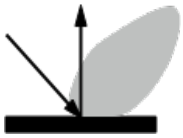
Diffuse

- Matte
- Lambert's Law



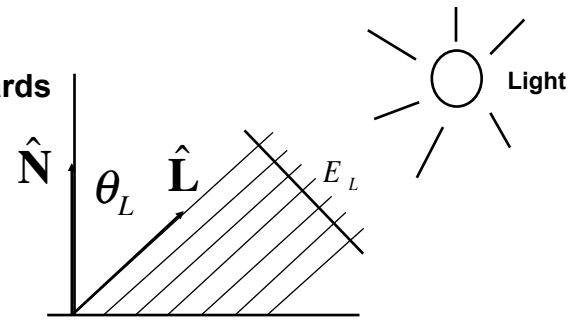
Specular

- Highlights and gloss
- Microfacet model



Lambert's Law

N points towards the outward



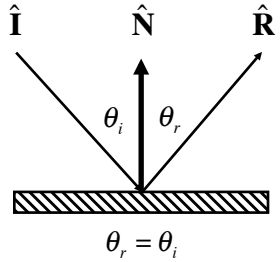
$$E = E_L \cos\theta_L = E_L \max(0, \hat{\mathbf{N}} \cdot \hat{\mathbf{L}})$$

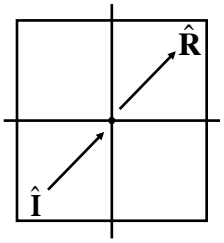
Lights only illuminate one side of the surface

Thus the max(0,N.L)

Mirror: Ideal Specular Surface

Law of Reflection



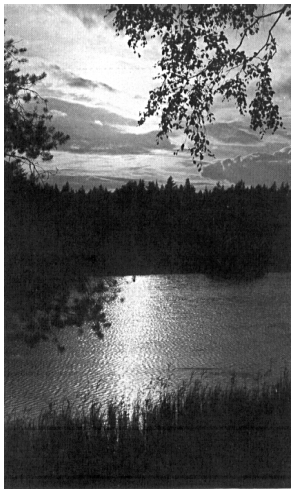


$$\hat{\mathbf{R}} + (-\hat{\mathbf{I}}) = 2\cos\theta_i \hat{\mathbf{N}} = -2(\hat{\mathbf{I}} \bullet \hat{\mathbf{N}})\hat{\mathbf{N}}$$

$$\hat{\mathbf{R}} = \hat{\mathbf{I}} - 2(\hat{\mathbf{I}} \bullet \hat{\mathbf{N}})\hat{\mathbf{N}}$$

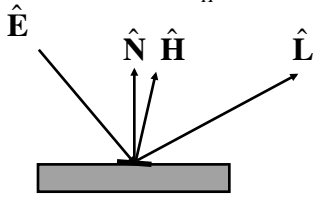
Microfacets: Glossy Reflection

Rough Surface



Minnaert p. 28

$$\cos\theta_H = \hat{\mathbf{N}} \bullet \hat{\mathbf{H}}$$



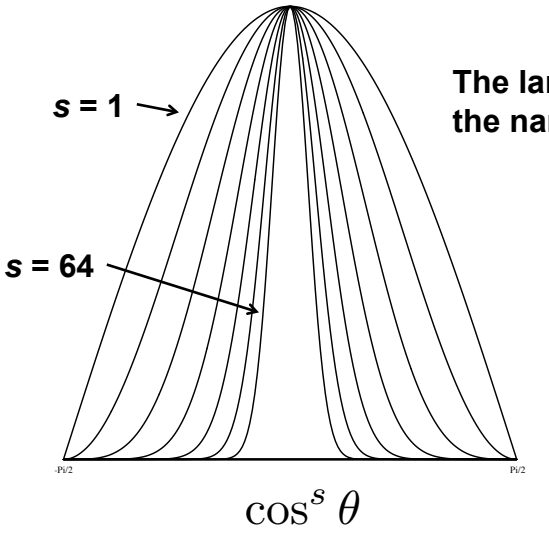
Halfway vector $\hat{\mathbf{H}} = \dfrac{\hat{\mathbf{L}} + \hat{\mathbf{E}}}{\left|\hat{\mathbf{L}} + \hat{\mathbf{E}}\right|}$

Microfacet distribution

$$(\cos\theta_H)^s = (\hat{\mathbf{N}} \cdot \hat{\mathbf{H}})^s$$

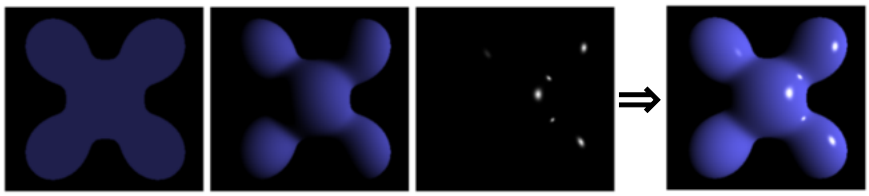
Shininess *s*

Shininess *s*

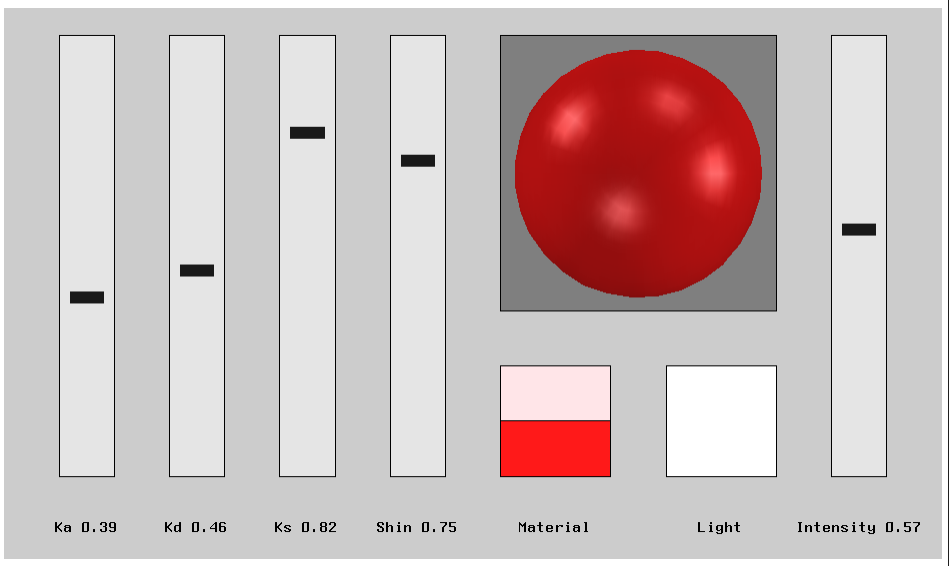


The larger the value s, the narrower the highlight

OpenGL Material Properties



Ambient	Diffuse	Specular	Final Color
(Ka)	(Kd)	(Ks, s)	



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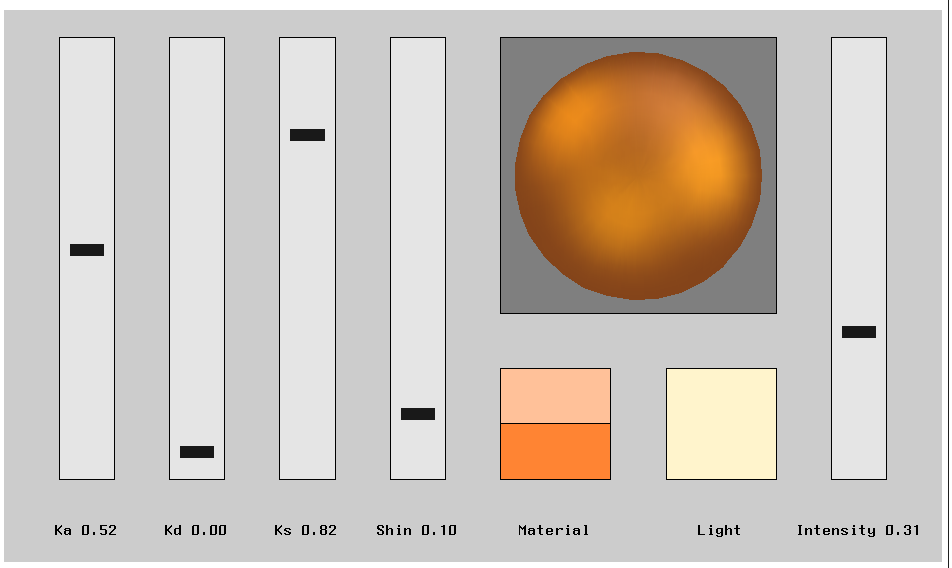

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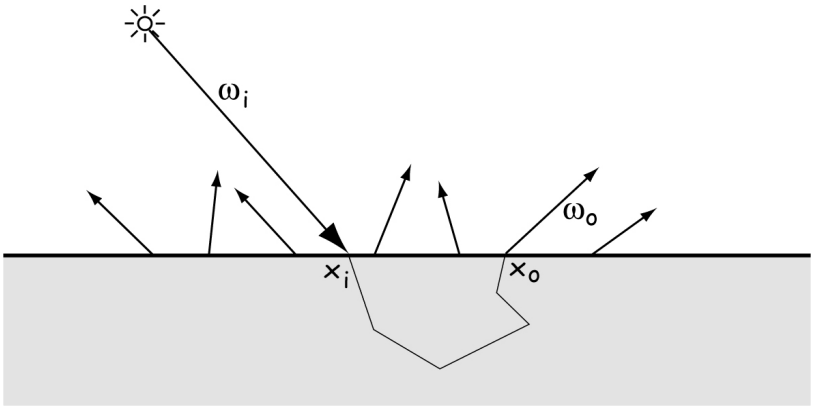
GLSL Lighting Calculation

```
vec3 N, L, V, H; float NdotL, NdotH;

vec4 Cd = gl_FrontMaterial.diffuse * gl_LightSource[0].diffuse;
vec4 Ca = gl_FrontMaterial.ambient * gl_LightSource[0].ambient;
Vec4 Cs = vec4(0.0);

N = normalize(gl_NormalMatrix * gl_Normal);
L = normalize(vec3(gl_LightSource[0].position));
NdotL = max(dot(N, L), 0.0);
if (NdotL > 0.0) {
    Cs = gl_FrontMaterial.specular * gl_LightSource[0].specular;
    H = normalize( gl_LightSource[0].halfVector.xyz );
    NdotH = max(dot(N, H), 0.0);
    Cs *= pow(NdotH, gl_FrontMaterial.shininess);
}
gl_FrontColor = Ca + NdotL * Cd + Cs;
```


Materials

Surface vs. Subsurface

Subsurface Scattering



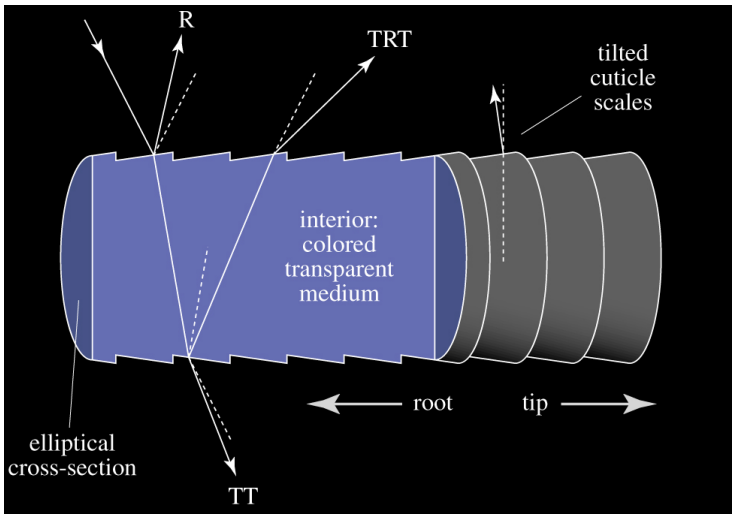
Skin: Subsurface

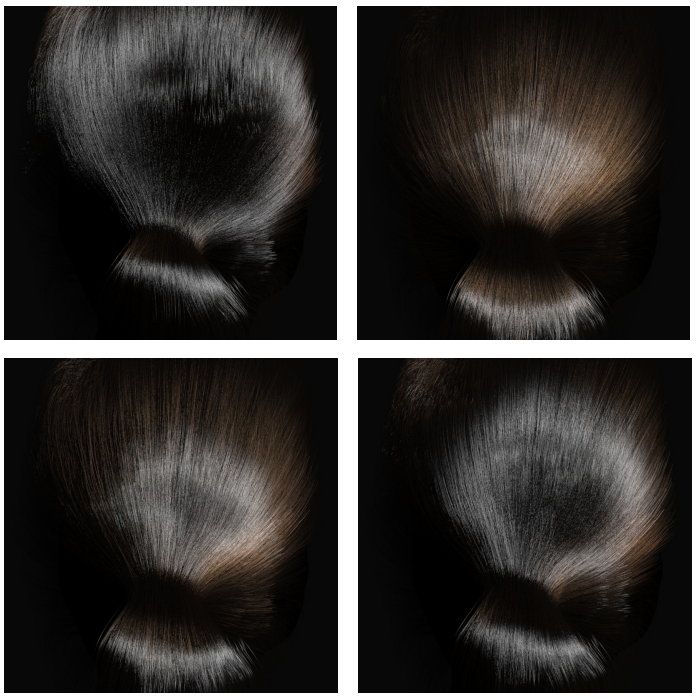
Modeled by Stephen Stahlberg

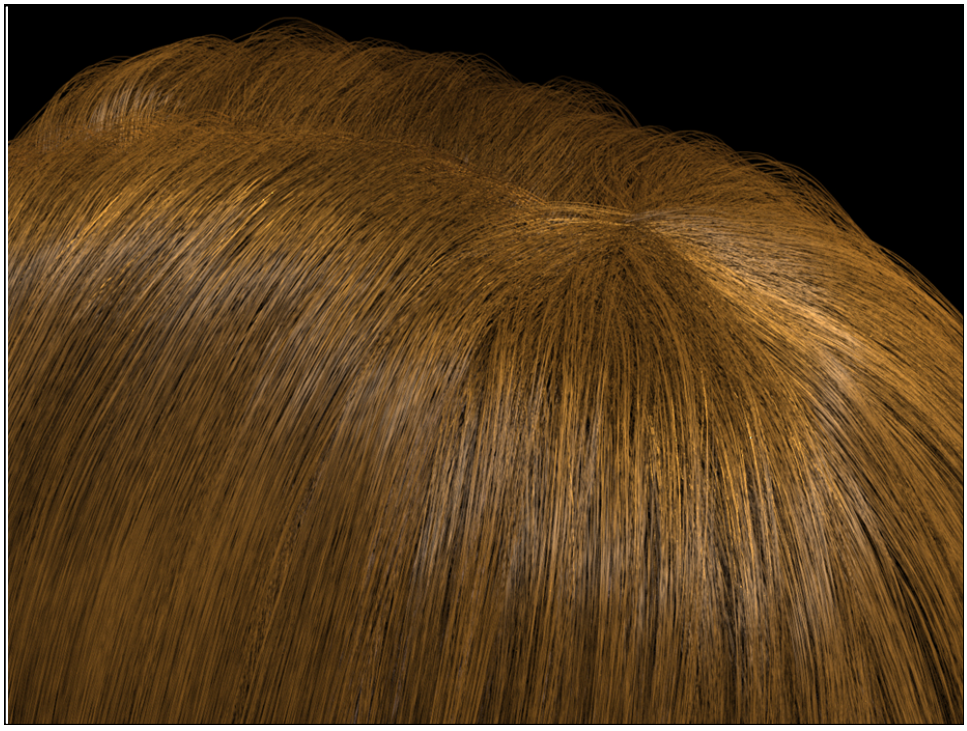
Skin: Surface Only

Modeled by Stephen Stahlberg

Fiber Model


R
TRT
tilted
cuticle
scales
interior:
colored
transparent
medium
root
tip
elliptical
cross-section
TT





Sasquatch: Hair Modeling System

www.worley.com **Stuart Aitken**

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Lighting

Lighting Simulation

The Rendering Equation

Given a scene consisting of geometric primitives with material properties and a set of light sources, compute the illumination at each point on each surface

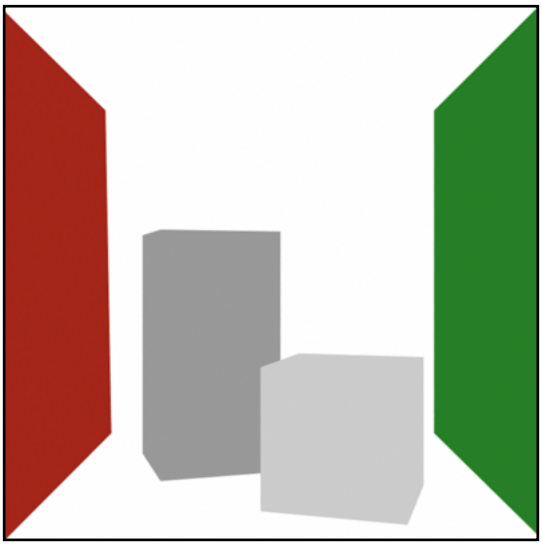
Challenges

- **Primitives complex: lights, materials, shapes**
- **Infinite number of light paths**

Solution

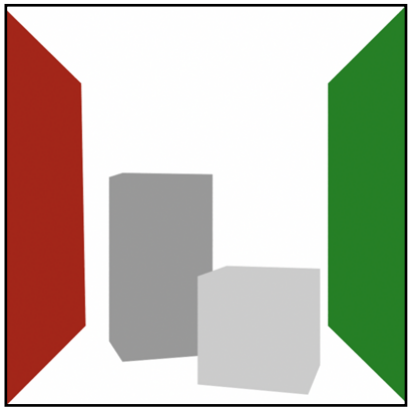
- **Ray tracing**

Lighting Example: Cornell Box

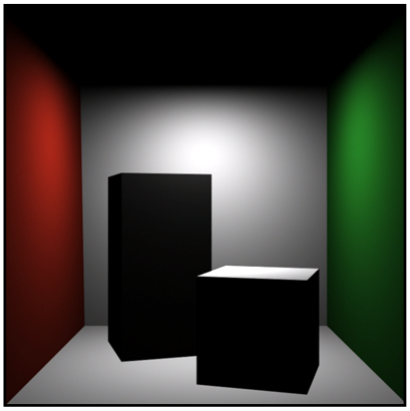


Surface Color

Lighting: Diffuse Reflection

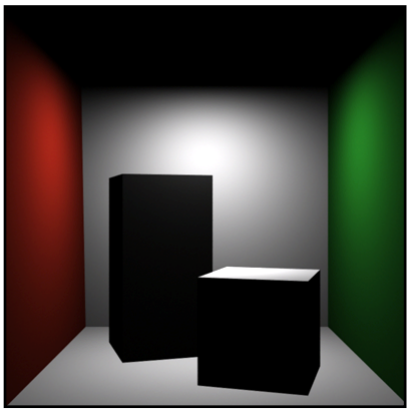


Surface Color

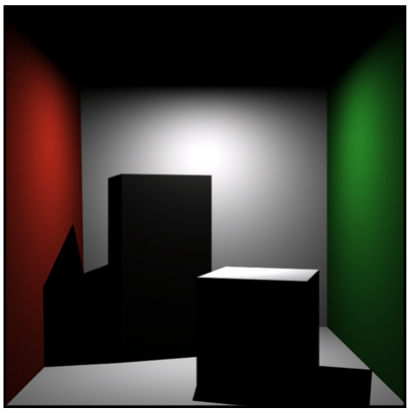


Diffuse Shading
Point Light Source

Lighting: Shadows

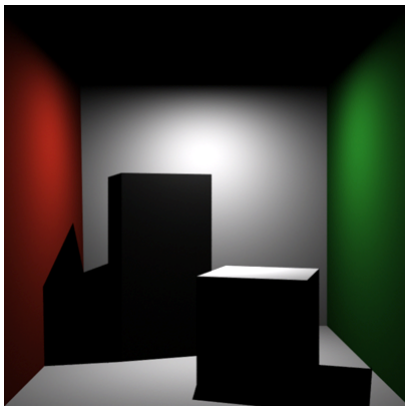


No Shadows
Point Light Source

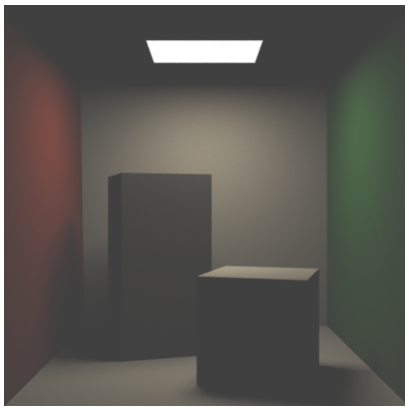


Shadows
Point Light Source

Lighting: Soft Shadows

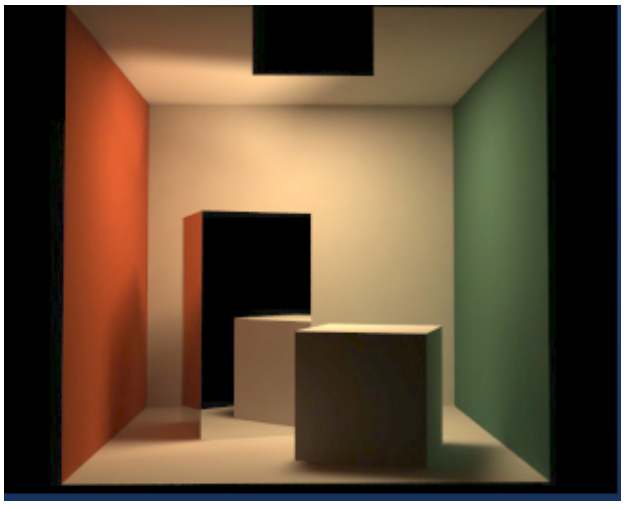


Hard Shadows
Point Light Source

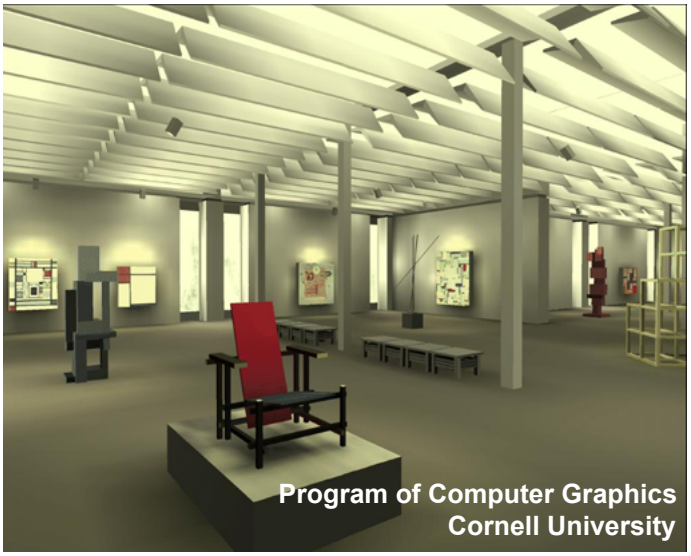


Soft Shadows
Area Light Source

Lighting: Indirect Illumination



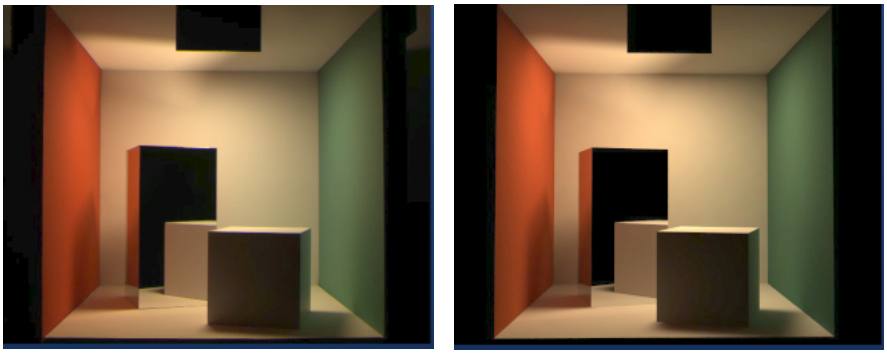
Lighting: Indirect Illumination



Complex Indirect Illumination

Modeling: Stephen Duck; Rendering: Henrik Wann Jensen

“Turing Test”



Measured Simulated

Program of Computer Graphics
Cornell University

Things to Remember

Three major reflection models

- Mirror reflection
  - Angle of incidence equals angle of reflection
- Diffuse reflection
  - Reflection proportional to the energy falling on the surface
- Specular reflection
  - Microfacet models

Materials

- Combination of diffuse and specular
- Natural materials: e.g. skin and hair

Lighting

- Direct vs. indirect
- Point vs. area
- Shadows requires visibility query