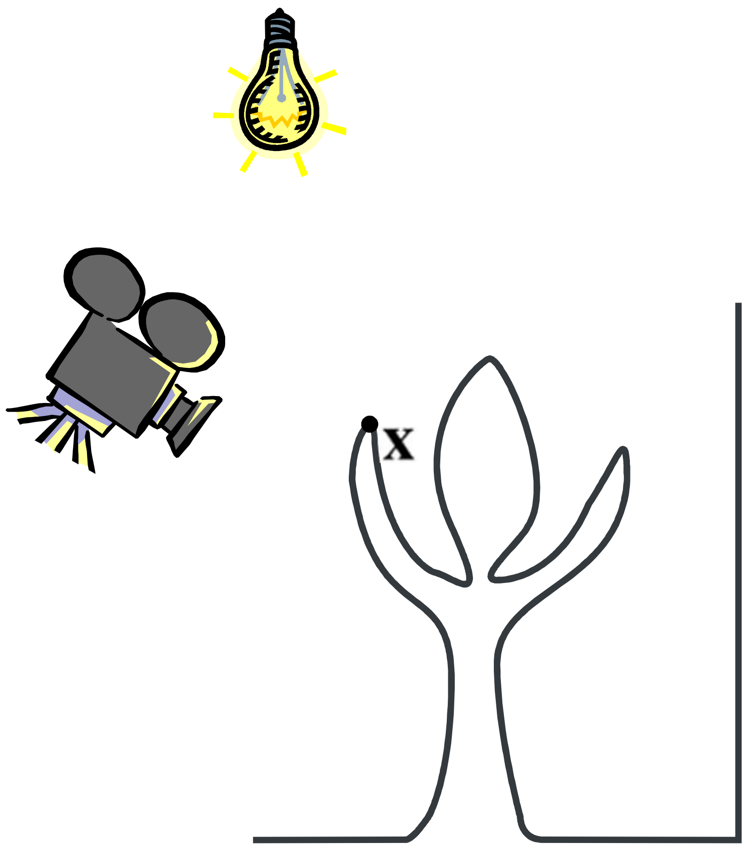
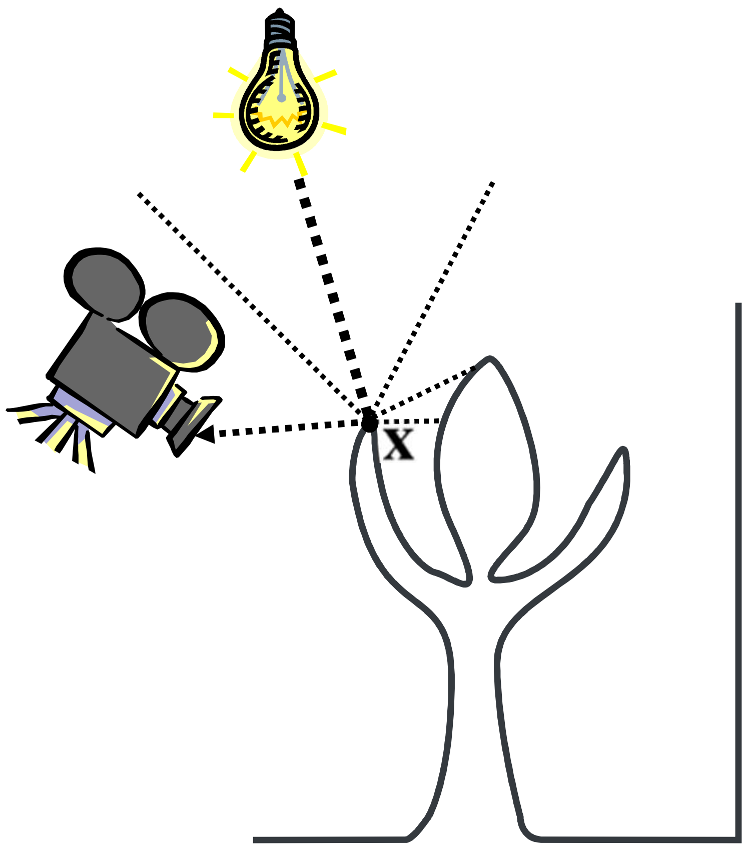
Global Illumination

Light Transport

Light Transport

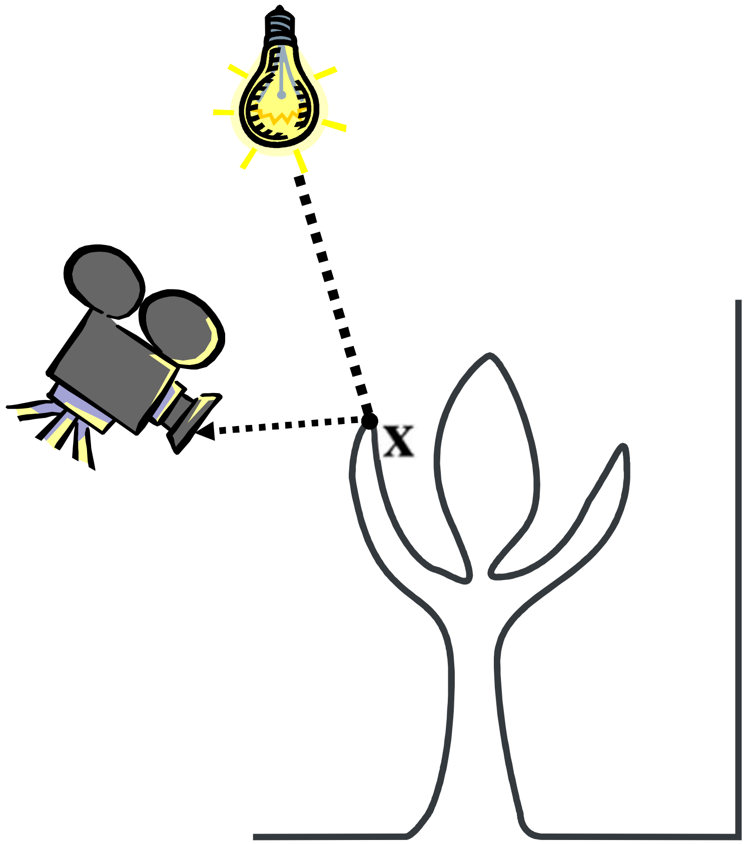


Light Transport

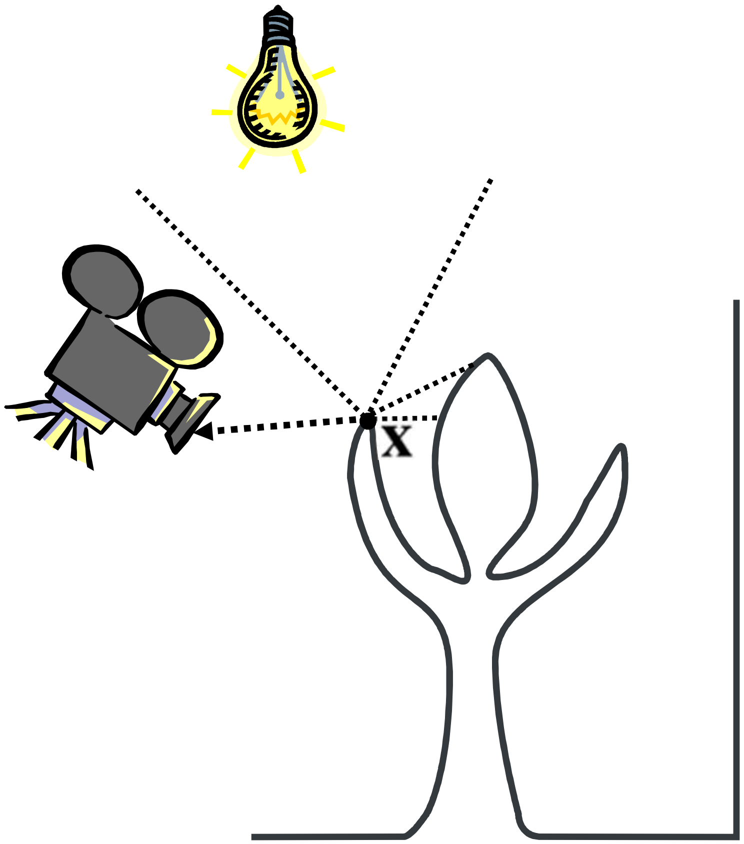


- Incident light arrives at **x**
- Calc outgoing radiance that arrives at the camera

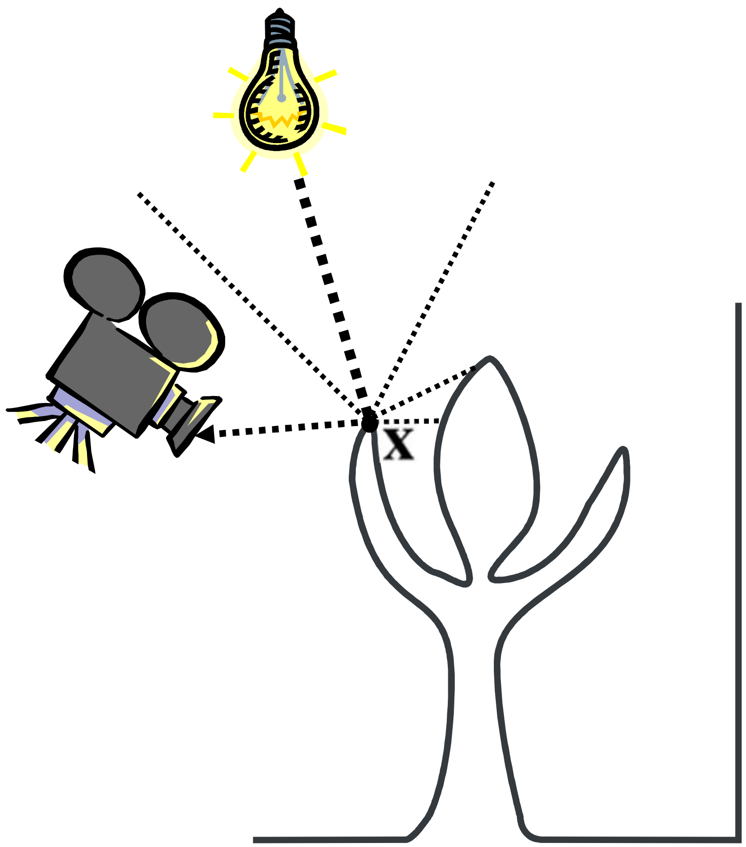
Light Transport – Direct



Light Transport – Indirect

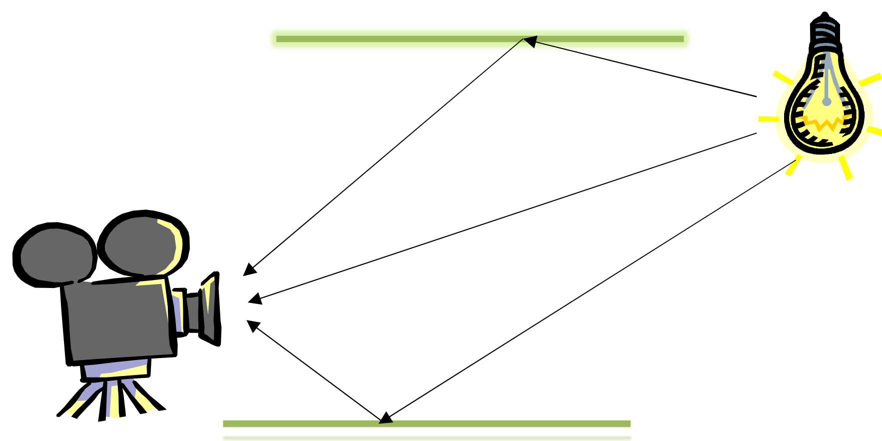


Light Transport



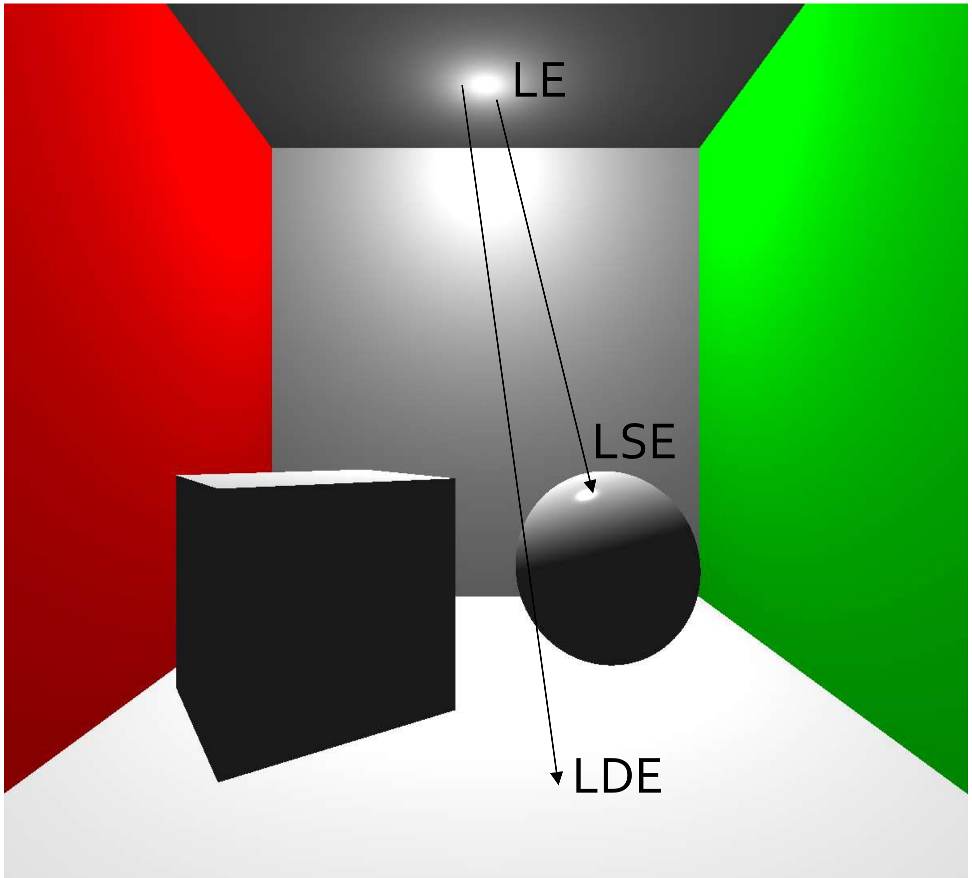
Classify Rendering Algorithms by Light Paths

- Paths
  - Start at a light source, L
  - End at the eye, E
- Two types of surface interactions
  - Pure diffuse, D
  - Pure specular, S
- Regular expressions L(D|S)*E describes all valid light paths



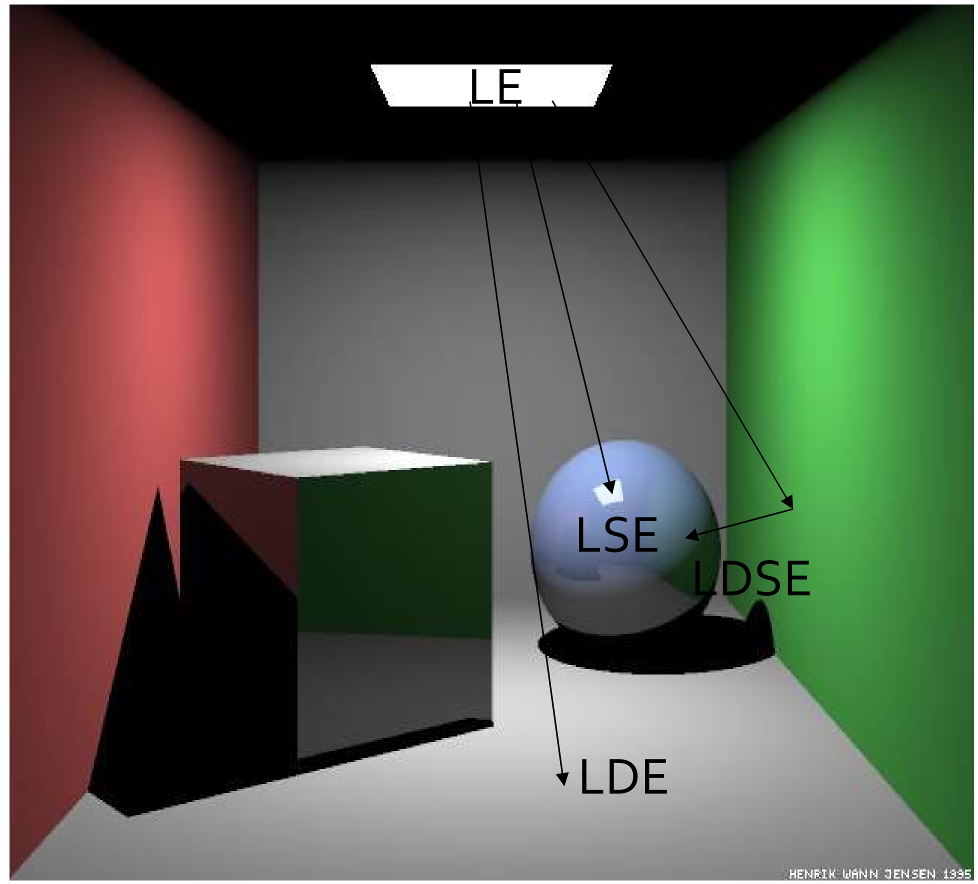
Light Path Examples – Local Illumination

- LE - from light to viewer
- LDE - from light to diffuse surface to viewer
- LSE - light is reflected off a specular surface into the viewer's eyes (only point lights)
- L(D|S)?E - light is reflected off either a diffuse surface or a specular surface or directly to the viewer



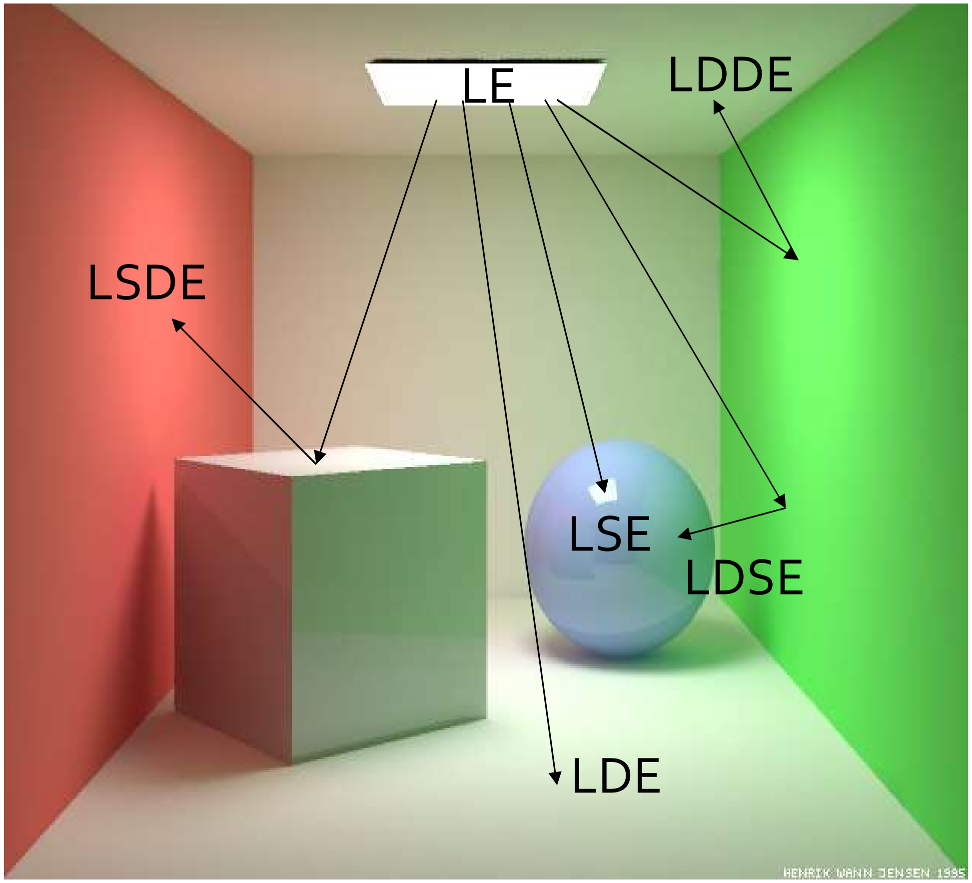
Light Path Examples – Classic Ray Tracing

- LDSE - light is reflected off a diffuse surface onto a specular surface toward the viewer
- LD?S*E - recursion of specular reflections optionally starting with a diffuse surface
- Simple light occlusion (hard shadows)



Light Path Examples – Path Tracer

- LSDE - light is reflected off a specular surface onto a diffuse surface toward the viewer (caustics)
- LDDE - light is reflected off a diffuse surface onto a diffuse surface toward the viewer (color bleeding)
- Complex light occlusion (soft shadows, ambient occlusion)

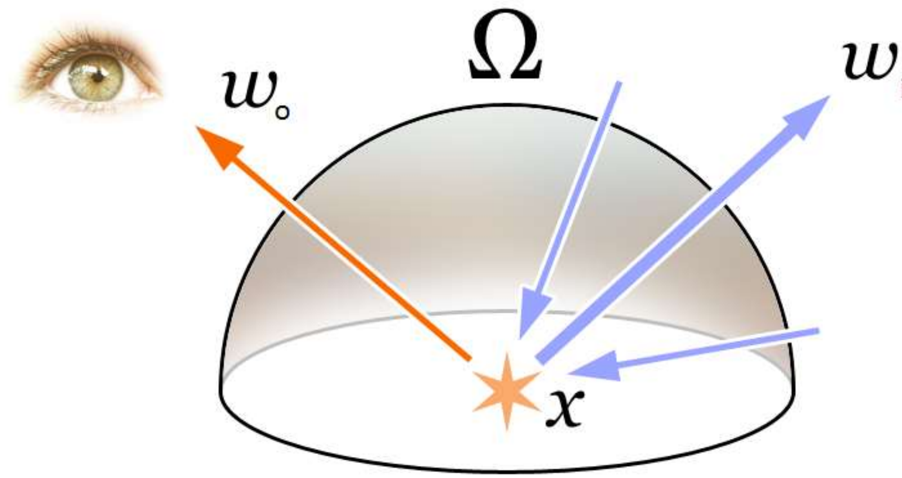


Global Illumination

The Rendering Equation

Rendering Equation [Kajiya86]

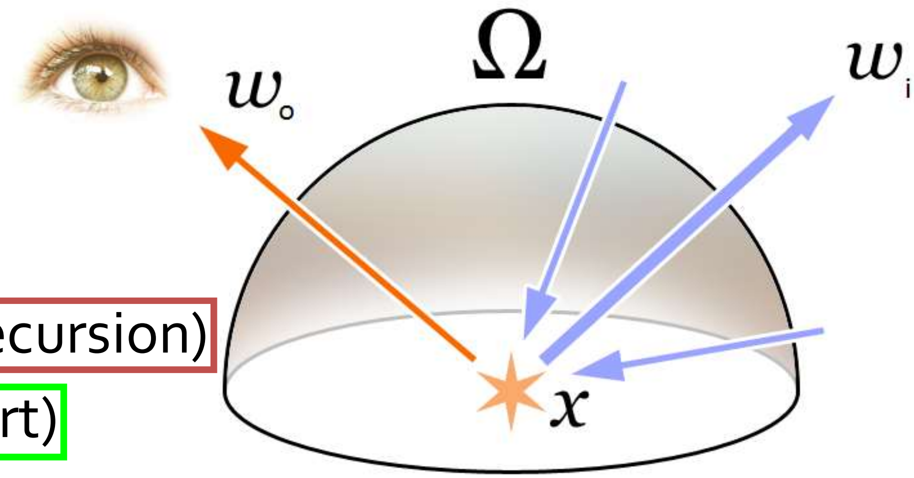
- Total amount of light emitted from a point $\boldsymbol{x}$ along a particular viewing direction $\boldsymbol{\omega_o}$ at wavelength λ and time t



$$L_{\mathrm{o}}(\mathbf{x},\,\omega_{\mathrm{o}},\,\lambda,\,t)\,=\,L_e(\mathbf{x},\,\omega_{\mathrm{o}},\,\lambda,\,t)\,+\,\int_\Omega f_r(\mathbf{x},\,\omega_{\mathrm{i}},\,\omega_{\mathrm{o}},\,\lambda,\,t)\,L_{\mathrm{i}}(\mathbf{x},\,\omega_{\mathrm{i}},\,\lambda,\,t)\,(\omega_{\mathrm{i}}\,\cdot\,\mathbf{n})\,\mathrm{d}\,\omega_{\mathrm{i}}$$

Rendering Equation [Kajiya86]

- Emitted energy
  - Outgoing light
  - Locally emitted light
  - Reflected incoming light
  - Surface reflection (BRDF)
  - Incoming light from direction $\boldsymbol{\omega_i}$ (recursion)
  - Attenuation of inward light (Lambert)

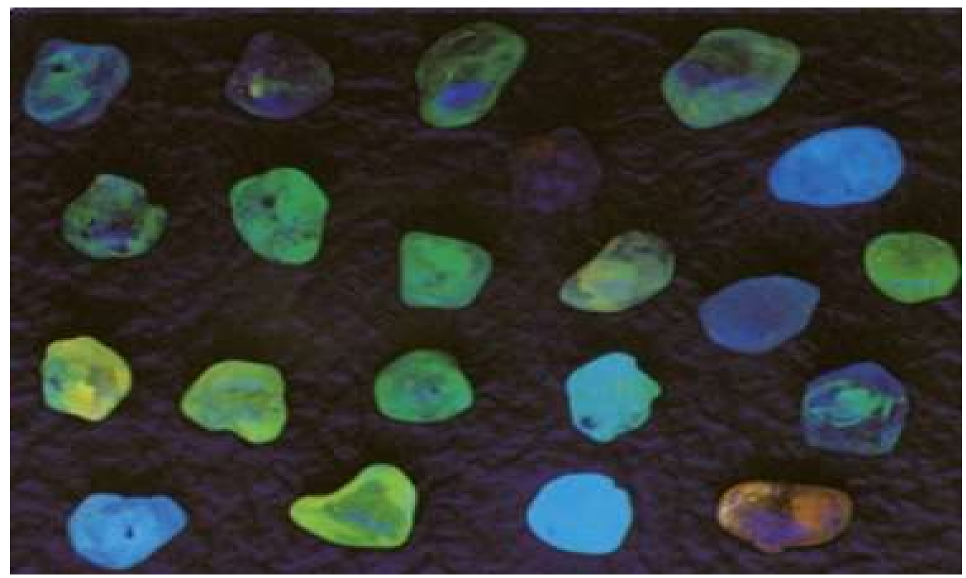


$$\boxed{L_o(\mathbf{x},\,\omega_o,\,\lambda,\,t)} = \boxed{L_e(\mathbf{x},\,\omega_o,\,\lambda,\,t)} + \boxed{\int_\Omega \boxed{f_r(\mathbf{x},\,\omega_i,\,\omega_o,\,\lambda,\,t)}\boxed{L_i(\mathbf{x},\,\omega_i,\,\lambda,\,t)}\boxed{(\omega_i\,\cdot\,\mathbf{n})}\,\mathrm{d}\,\omega_i}$$

Rendering Equation – Missing Aspects

- **Phosphorescence**, which occurs when light is absorbed at one moment in time and emitted at a different time

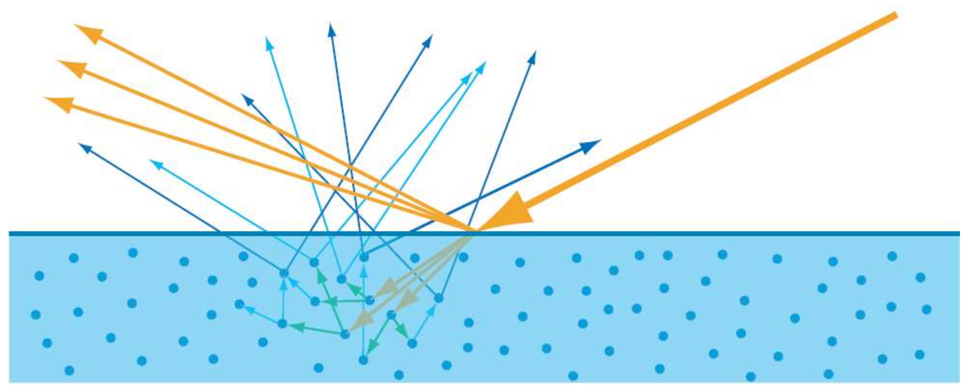
- **Fluorescence** , where the absorbed and emitted light have different wavelengths



Rendering Equation – Missing Aspects

- **Interference**, where the wave properties of light are exhibited

- **Subsurface scattering**, where the spatial locations for incoming and departing light are different



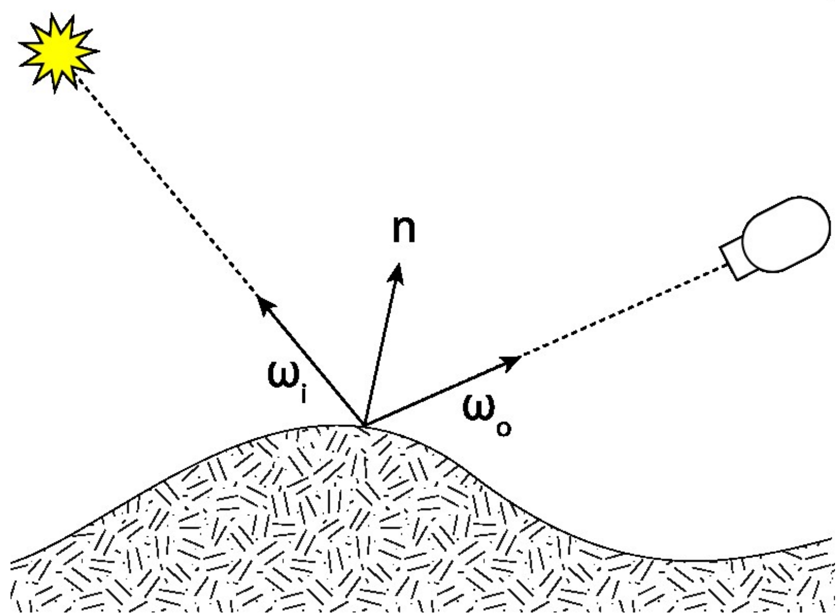
Rendering Equation – Missing Aspects

- **Interference**, where the wave properties of light are exhibited

- **Subsurface scattering**, where the spatial locations for incoming and departing light are different

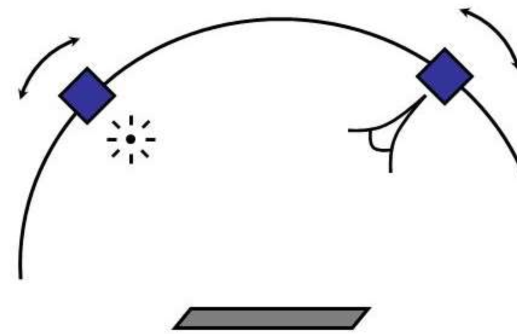
Bidirectional reflectance distribution function

- Describes how light is reflected at an (opaque) surface (physical material)
- Different versions that depend on varying numbers of parameters
  - Incoming light direction $\boldsymbol{\omega_i}$
  - Outgoing light direction $\boldsymbol{\omega_o}$
  - [Surface position $\boldsymbol{x}$ (spatially varying)]
  - Many more optional parameters for scattering, wavelength change, …

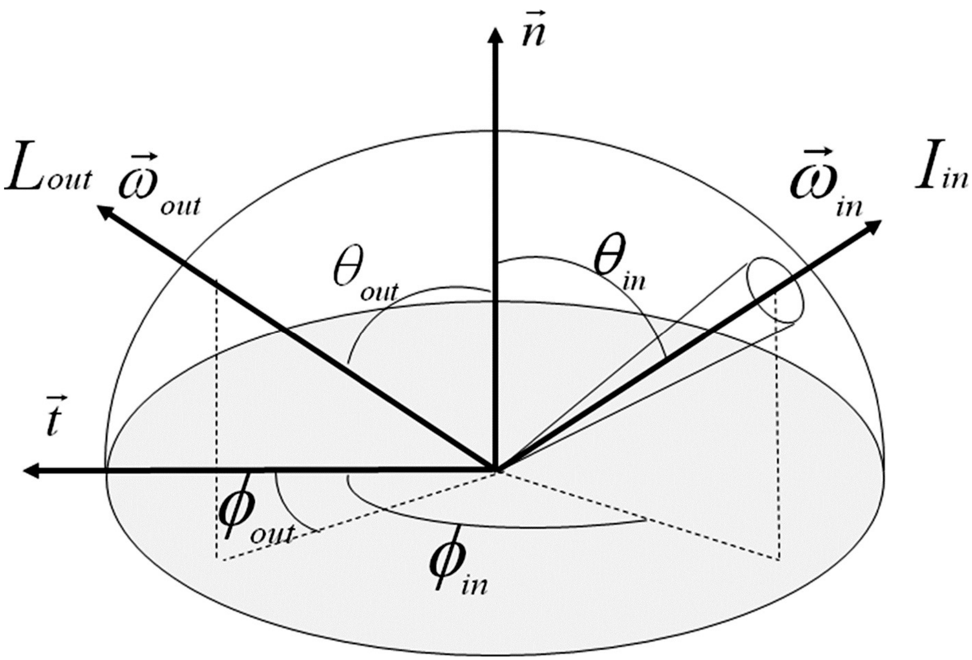


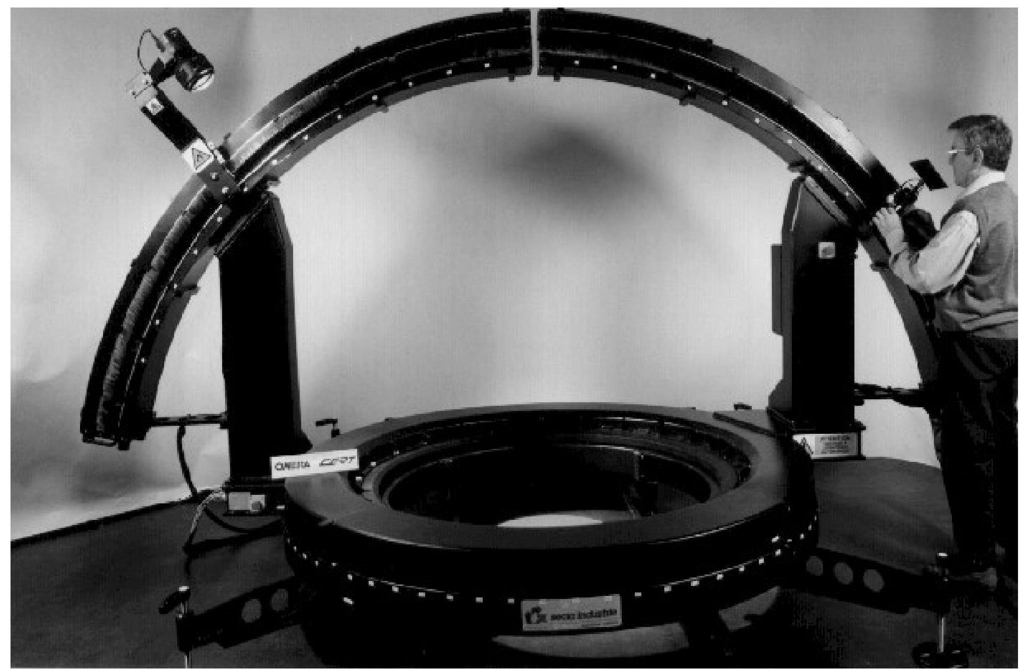
$$L_o(\mathbf{x}, \omega_o, \lambda, t) = L_e(\mathbf{x}, \omega_o, \lambda, t) + \int_\Omega \boxed{f_r(\mathbf{x}, \omega_i, \omega_o, \lambda, t)} L_i(\mathbf{x}, \omega_i, \lambda, t)\, (\omega_i \cdot \mathbf{n})\, d\,\omega_i$$

Measuring BRDFs



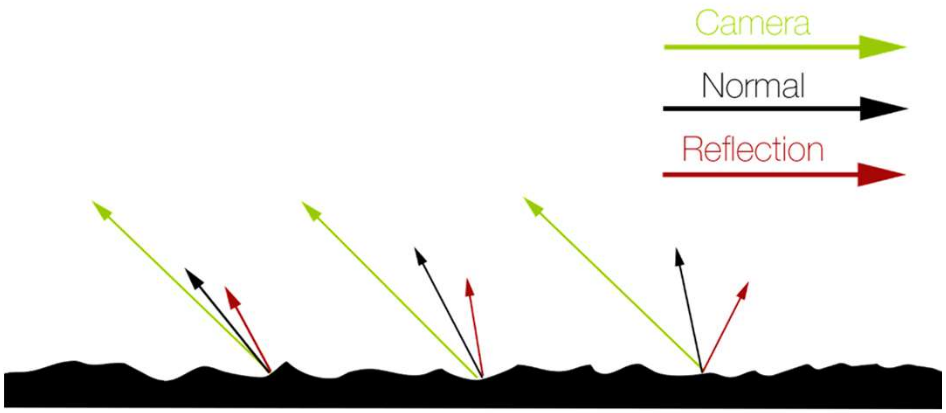
- Using real materials
- Often only 4D





BRDF -Models

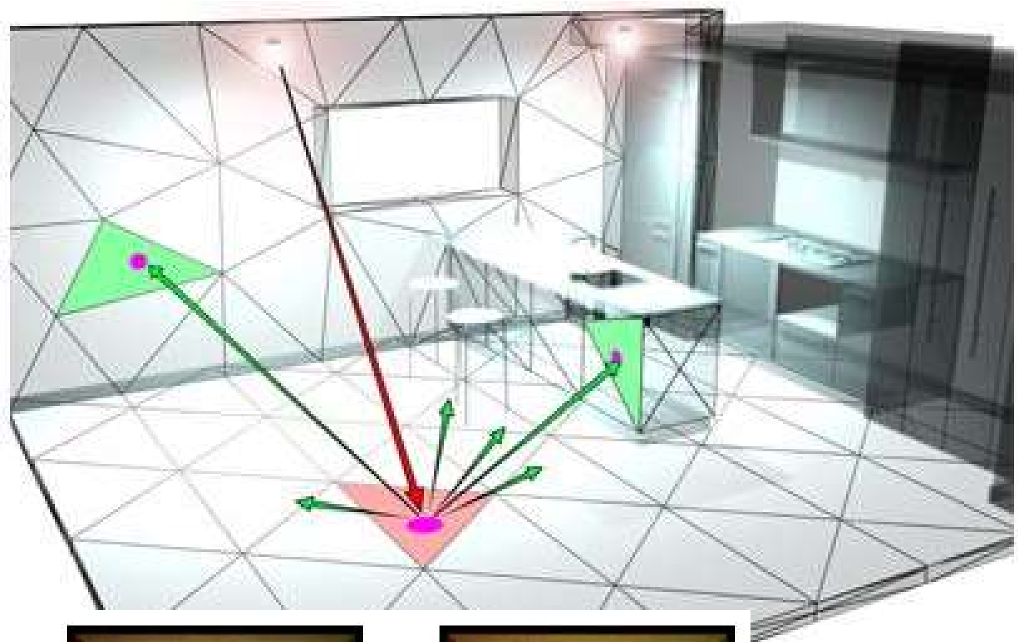
- *Lambertian:* perfectly diffuse (matte) surfaces with constant BRDF
- *Phong*: plastic-like specularity
- *Cook–Torrance:* specular-microfacet, Fresnel term, self-shadowing
- *Ward:* specular-microfacet, anisotropic
- *Oren–Nayar:* diffuse microfacet model

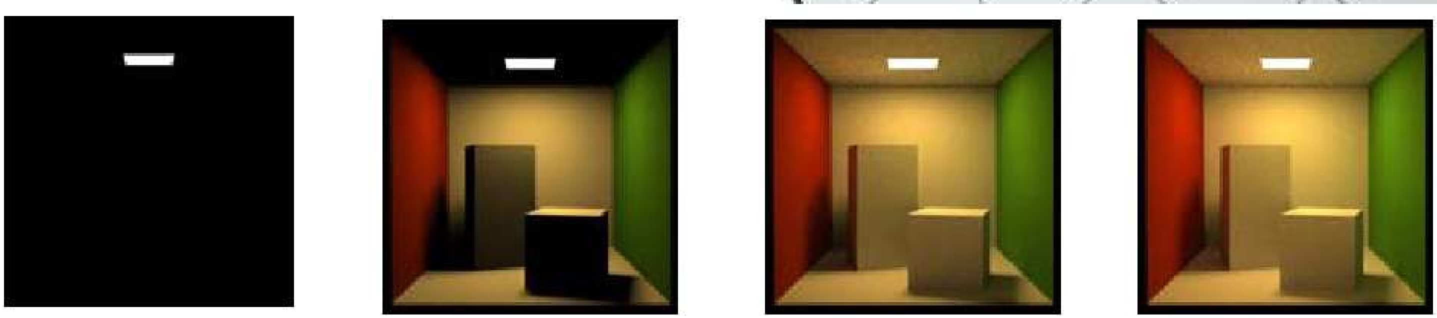


Microfacet BRDF

Solving the Rendering Equation – Radiosity

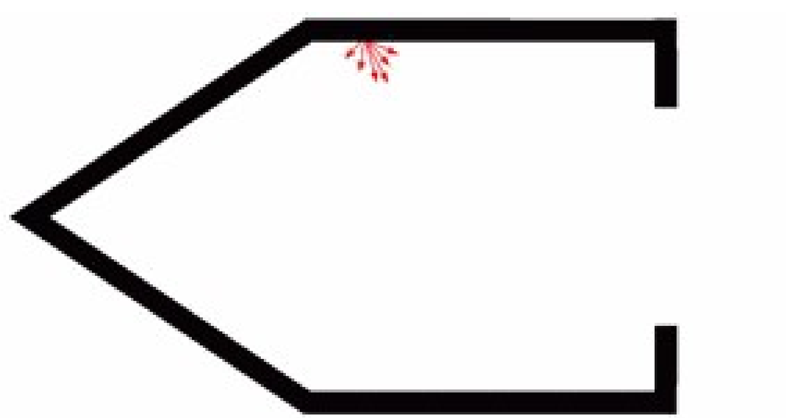
- Finite elements method
  - Recursive energy propagation between elements
- Soft shadows and indirect lighting
- View independent solution
- Only diffuse

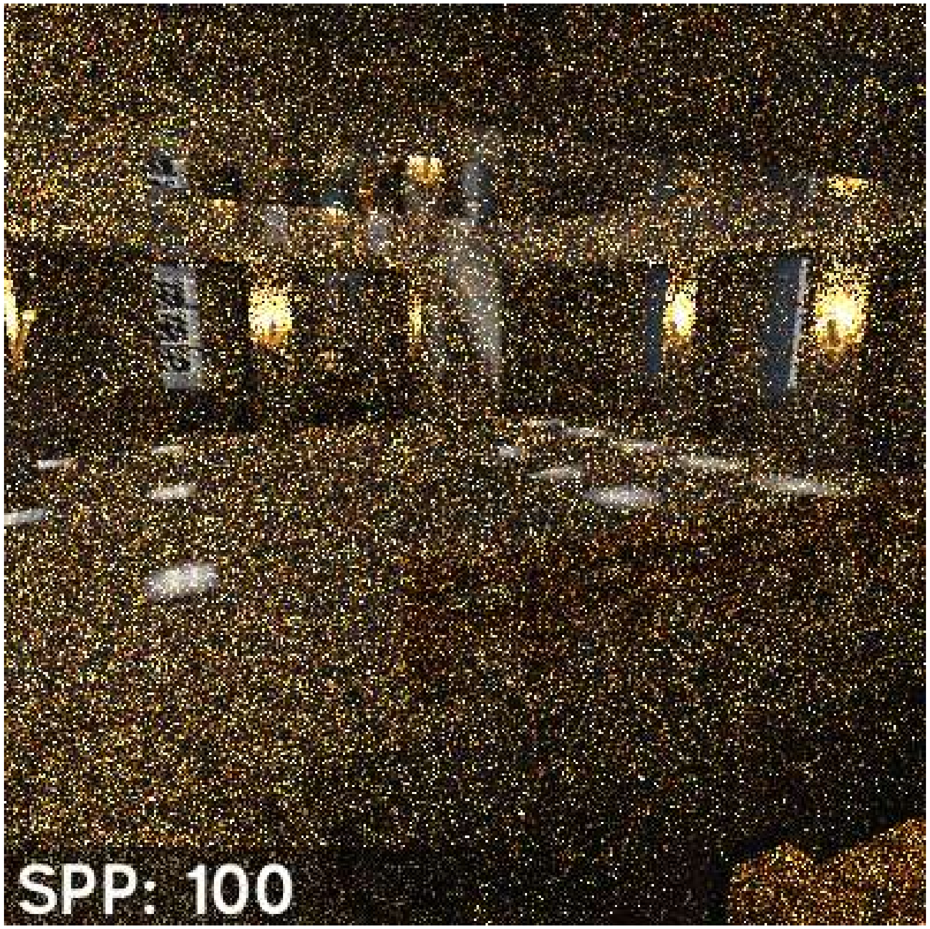




Solving the Rendering Equation – Path Tracing

- Monte Carlo method
  - Numerical integration
  - Repeated random sampling
- Sample = follow one ray per pixel






FOR LEASE
6500 SQ FT LOWER FLOOR
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CRITTENDEN