Ray Tracing 2

CSCI 4830/7000

Advanced Computer Graphics

Spring 2009

Interaction between Lights and Objects

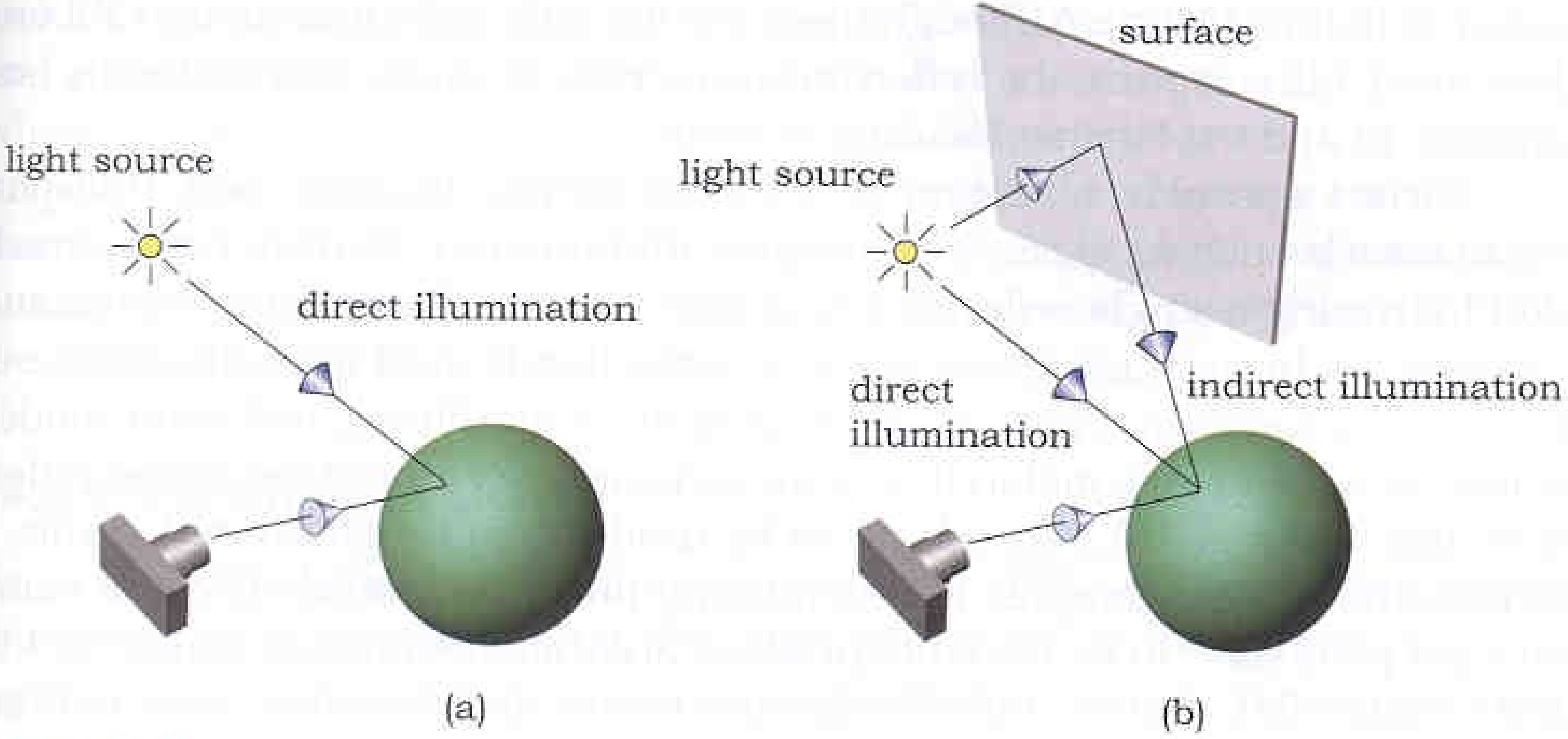


Figure 14.2. (a) Direct illumination hits the surface of an object directly from a light source; (b) indirect illumination hits a surface after being reflected from at least one other surface.

Intersecting a Complex Object

- Defining a complex object
  - Triangle mesh on vertexes
  - Gouraud shading
- Expensive to ray trace
  - Test every ray against every triangle in the object
  - Test bounding box of entire object
- Intersections
  - Plane
  - Axis-aligned box
  - Generic triangle

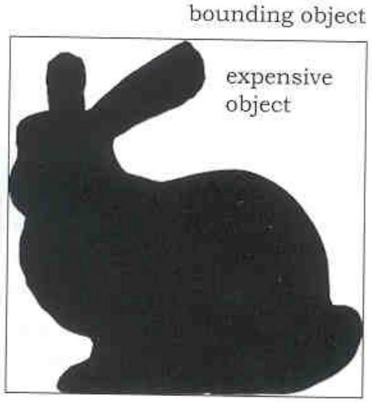


Figure 19.1. The Stanford bunny and a bounding box.

Perspective Ray Tracing

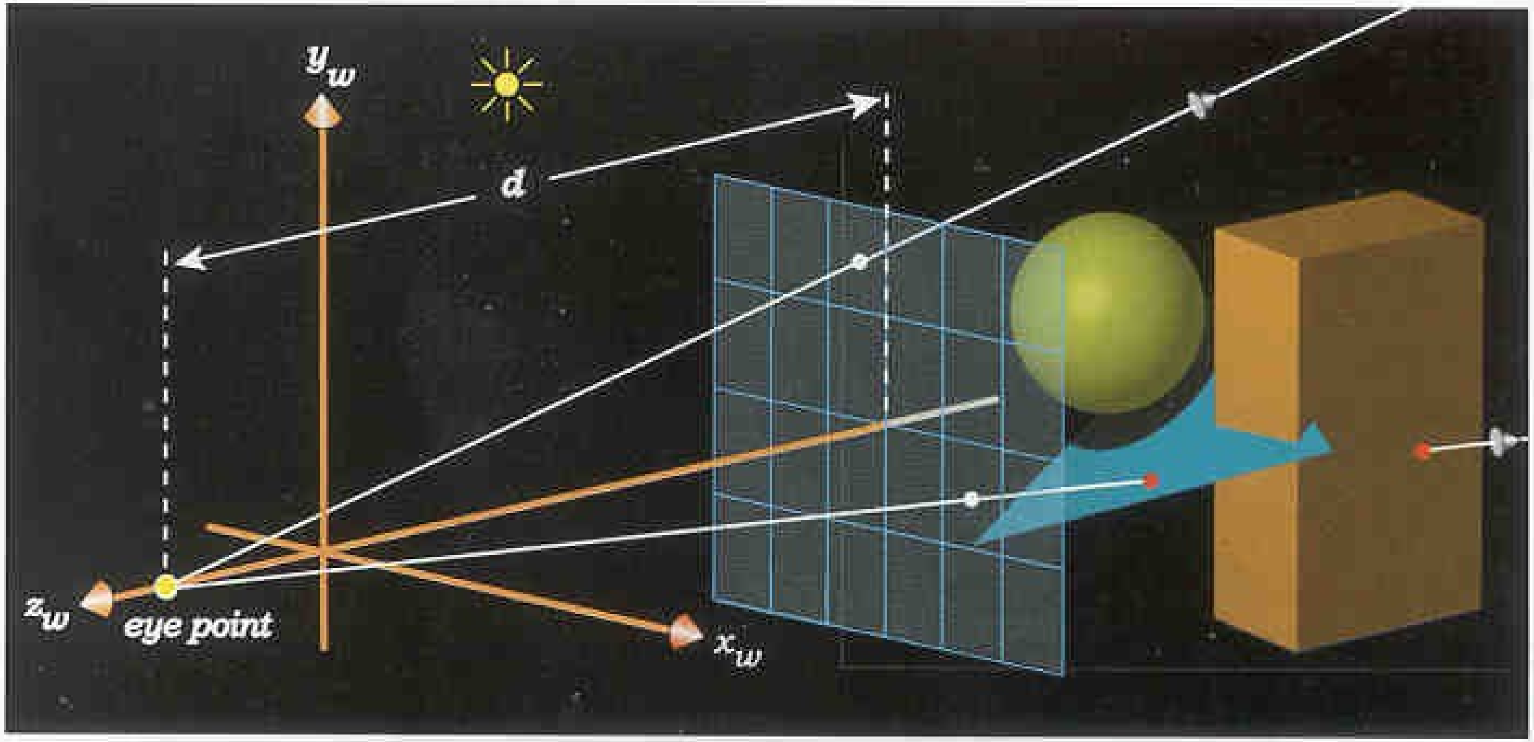
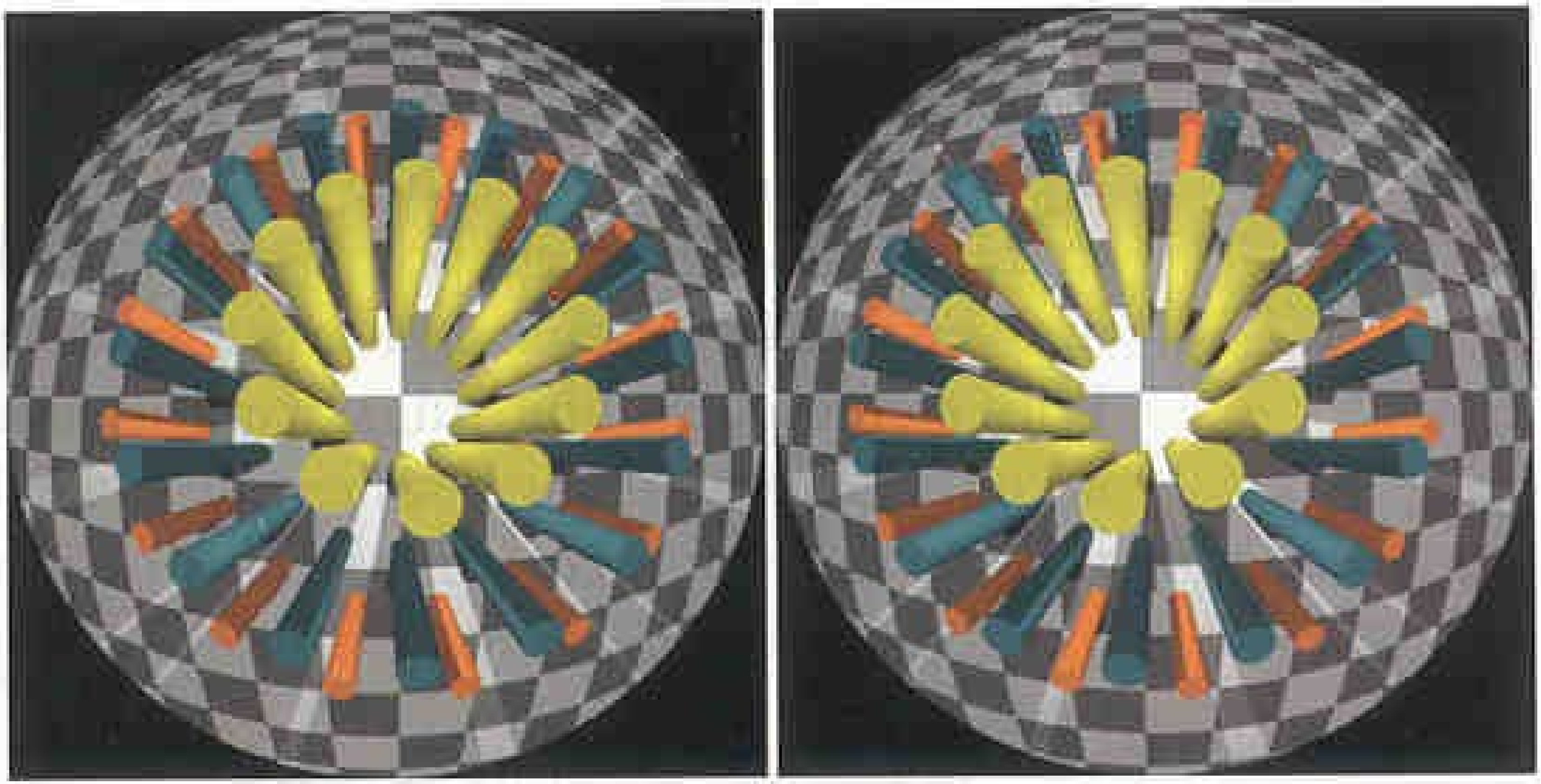


Figure 8.14. Set-up for axis-aligned perspective viewing with the eye point and two rays going through pixel centers.

Stereoscopy



left-eye view

right-eye view

How does a pixel get colored?

Theoretical foundations

Ray Tracing from the Ground Up Chapters 13-15

- Bidirectional Reflectance Distribution Function
  - BRDF
  - Describes how light is reflected on each bounce
  - Chains to transfer colors

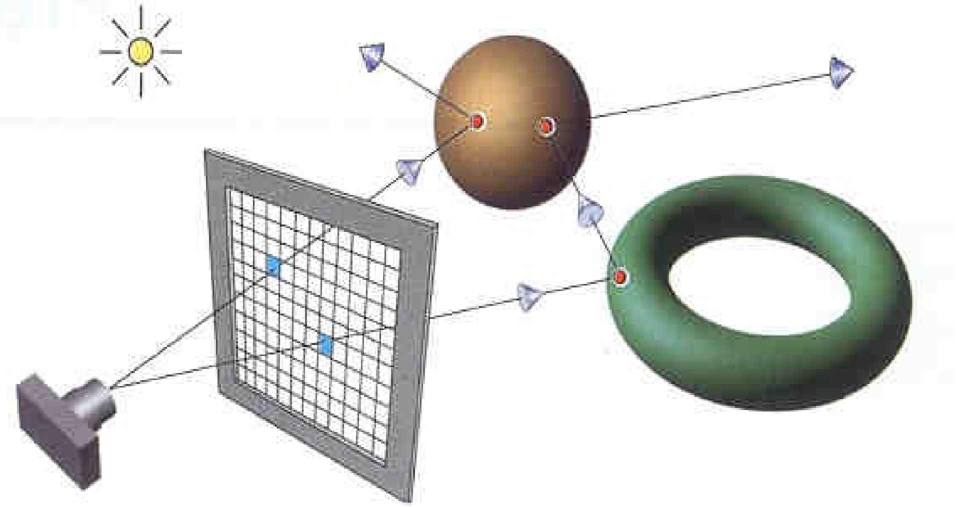


Figure 1. The ray-tracing process.

Radiometric Quantities

- Radiant Energy Q (J)
- Radiant Flux $\phi = dQ/dt$ (W)
- Radiant Flux Density $d\phi/dA$ (W/m^2)
- Irradiance E [Arriving flux density]
- Radiant exitance M [Leaving flux density]
- Radiant Intensity I $d\phi/d\omega$ (W/m^2/sr)
- Radiance L $d^2\phi/dAd\omega$ (W/m^2/sr)

Ray Properties

- Radiance is constant along rays
- Radiance can be defined at the eye
- Radiance can be defined at a point

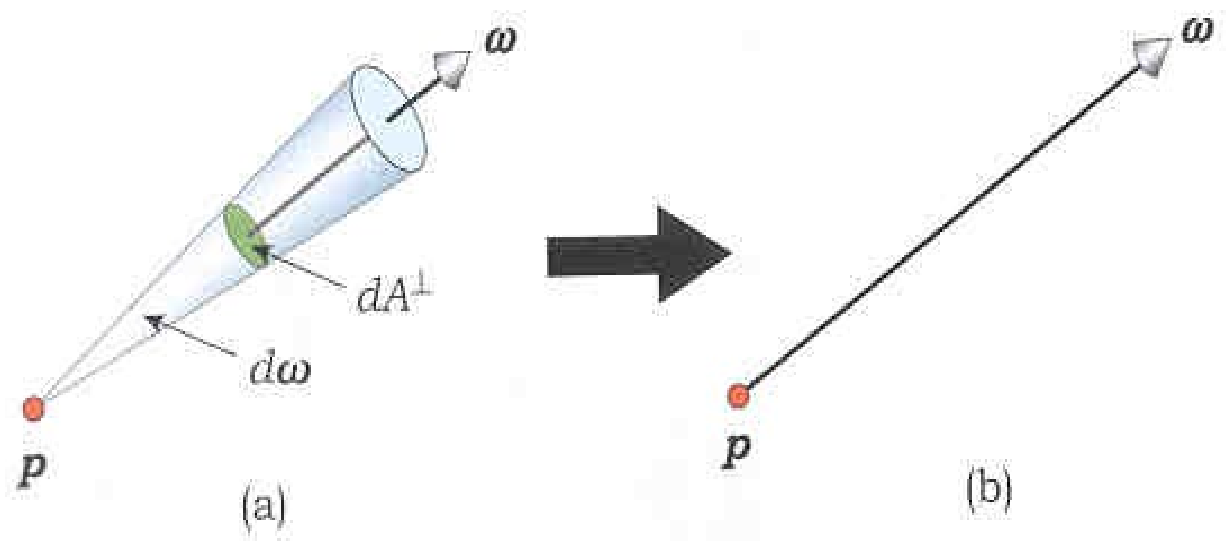


Figure 13.1. (a) Radiant flux in a cone of incident angles $d\omega$ passing through a surface element $dA^{\perp}$. (b) In the limit $d\omega \rightarrow 0$ and $dA \rightarrow 0$, the radiance is defined as coming from a single direction ω. The point p can be an arbitrary point in space.

Angular Dependence on Irradiance

- Lambert's Law
  - $L = d^2\phi / dA \cdot d\omega \cdot \cos\theta$

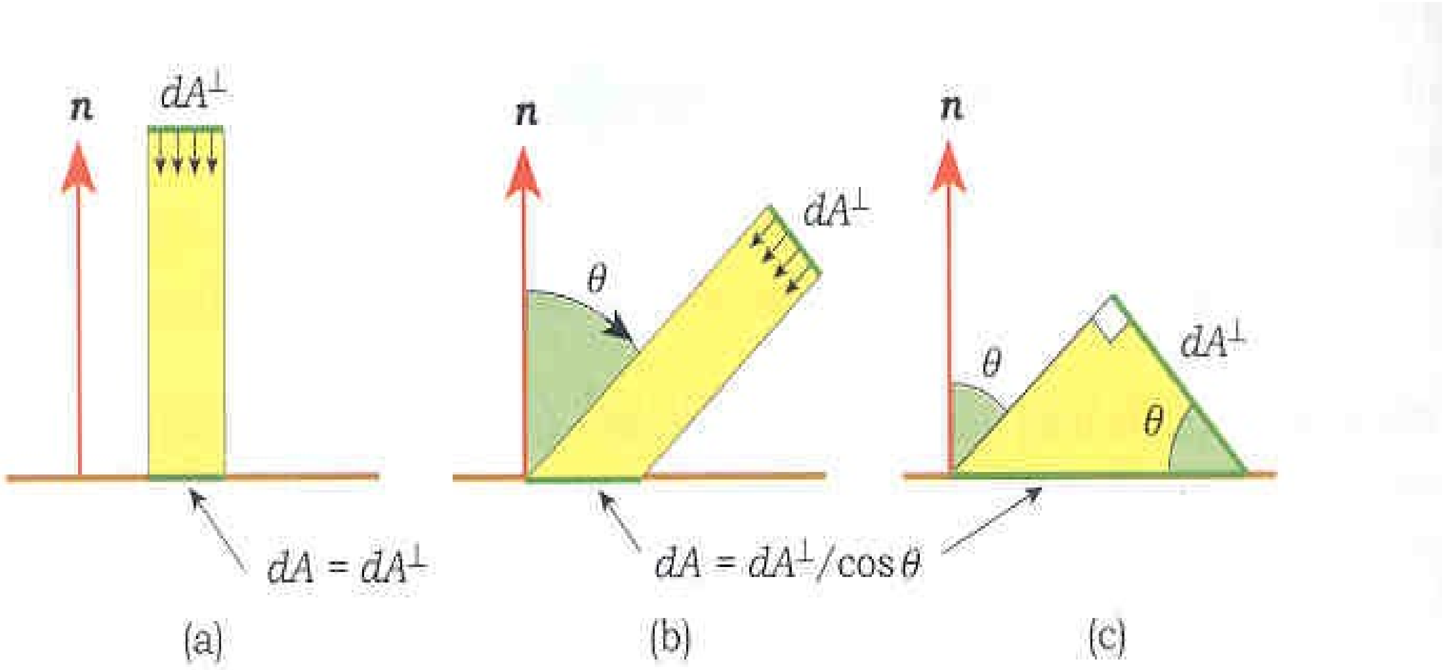


Figure 13.2. (a) and (b) Irradiance spreads out over a larger area as the incidence angle θ increases. (c) An enlarged view of the incident beam.

Notation and Directions

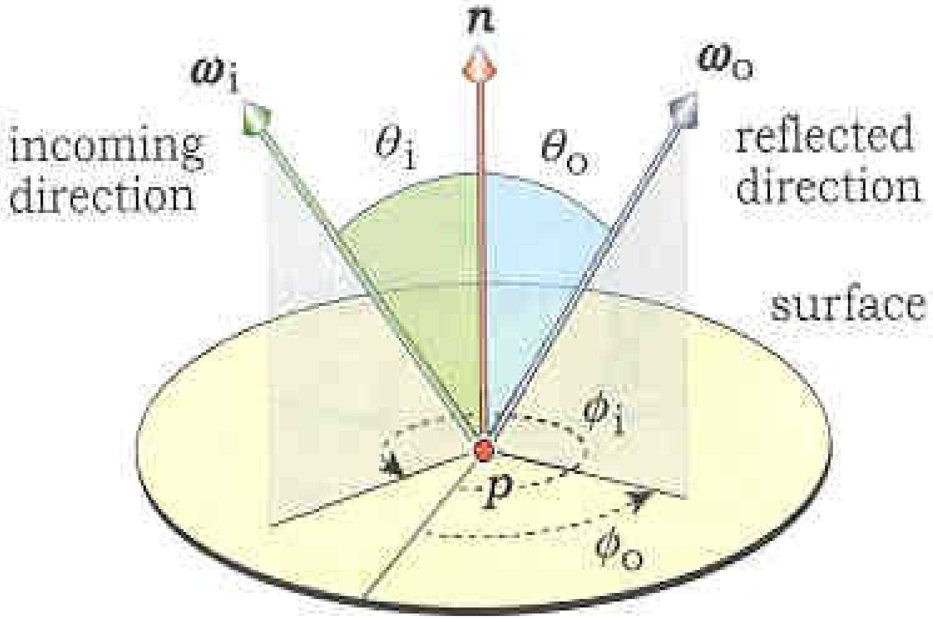


Figure 13.3. The incoming direction ω_i and reflected direction ω_o point away from the surface and are on the same side of the surface as the normal. Each direction is defined by its polar and azimuth angles (θ, ϕ). These are arbitrary directions; for perfect mirror reflection, $\phi_o = \phi_i \pm \pi$, as illustrated in Figure 24.2(b).

BRDF

- Definition
  - $f(p,\omega_i,\omega_o) = dL_o(p,\omega) / dL_i(p,\omega) \cos \theta_i \, d\omega_i$
- Properties
  - Reciprocity
    - $f(p,\omega_i,\omega_o) = f(p,\omega_o,\omega_i)$
  - Linearity
    - Sum all BDRFs at a point
  - Conservation of energy
    - Total re-radiated energy must be less than incident

Common BDRFs

- Diffuse $f(p,\omega_i,\omega_o) = M_d(p)$

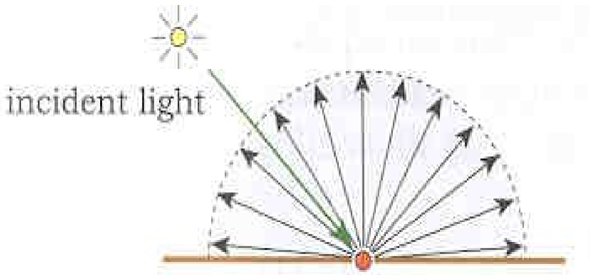


Figure 13.6. Light being scattered from a perfectly diffuse surface.

- Specular $f(p,\omega_i,\omega_o) = M_s(p)\,(R \bullet \omega_o)^S$
  - $R = 2(N \bullet L)N - L$

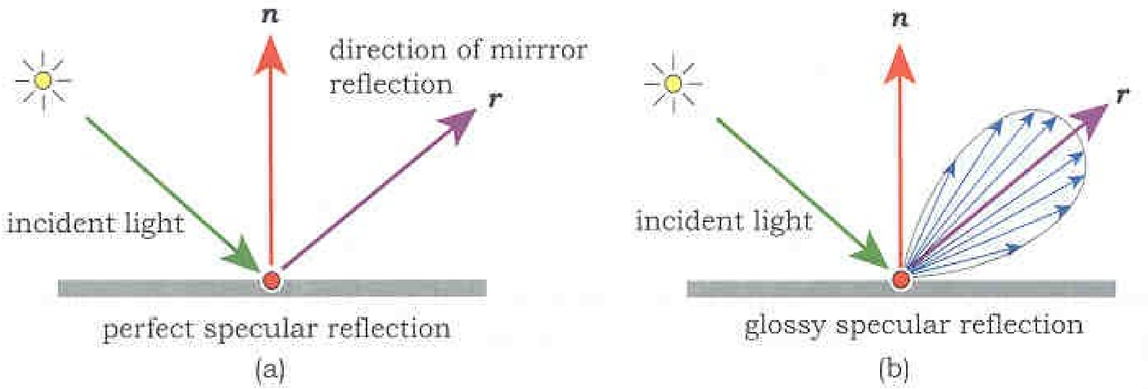


Figure 14.3. (a) Perfect specular reflection; (b) glossy specular reflection.

Bouncing Rays from Surfaces

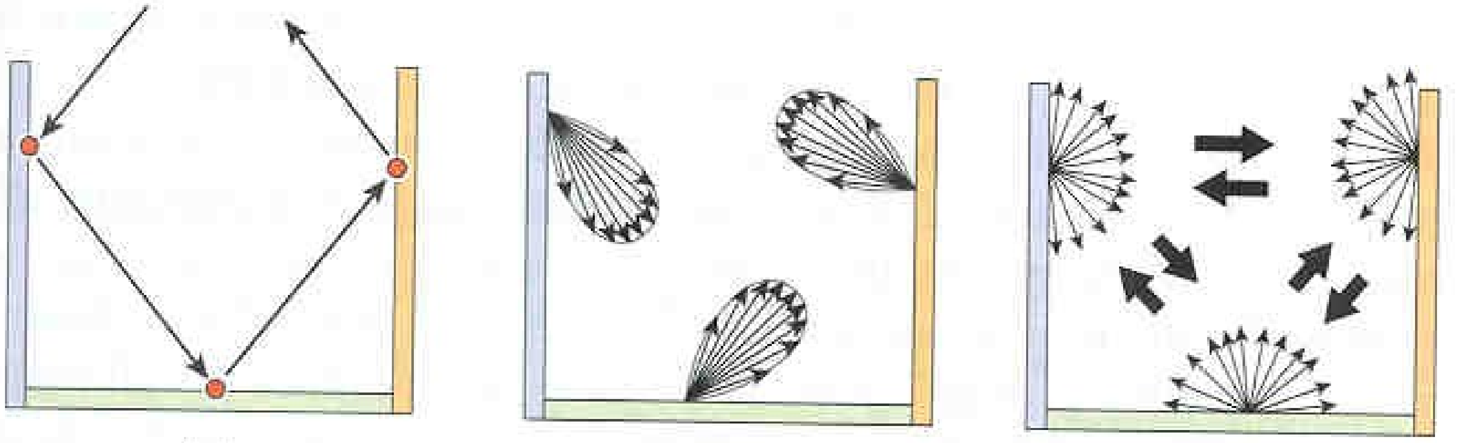

(a) (b) (c)

Figure 14.4. (a) Mirror reflection can be modeled by tracing a single reflected ray at each hit point; (b) modeling glossy specular light transport between surfaces requires many rays to be traced per pixel; (c) modeling perfect diffuse light transport between surfaces also requires many rays to be traced per pixel.

Antialiasing

(a) (b) (c)

Figure 4.4. Shaded sphere: (a) one sample per pixel; (b) 16 samples per pixel; (c) enlarged view of top-right section of (b).

Super-sampling Pixels

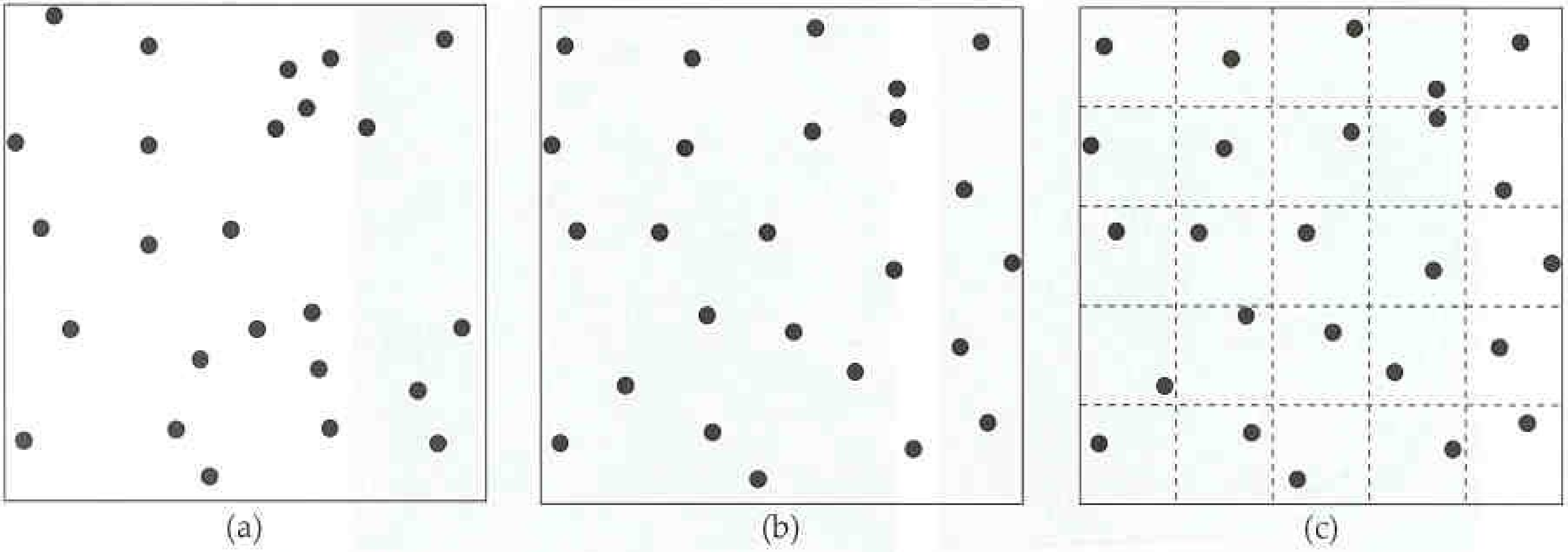

(a) (b) (c)

Figure 4.7. (a) 25 random samples in a pixel; (b) 25 jittered samples; (c) same as (b) but with sub-grid lines shown.

Super-sampling Area Lights

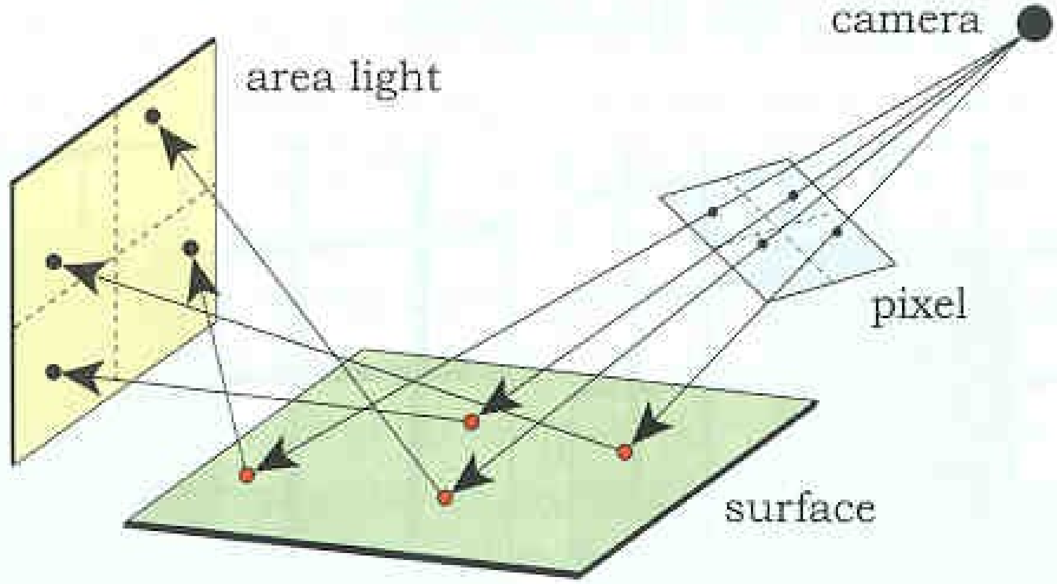
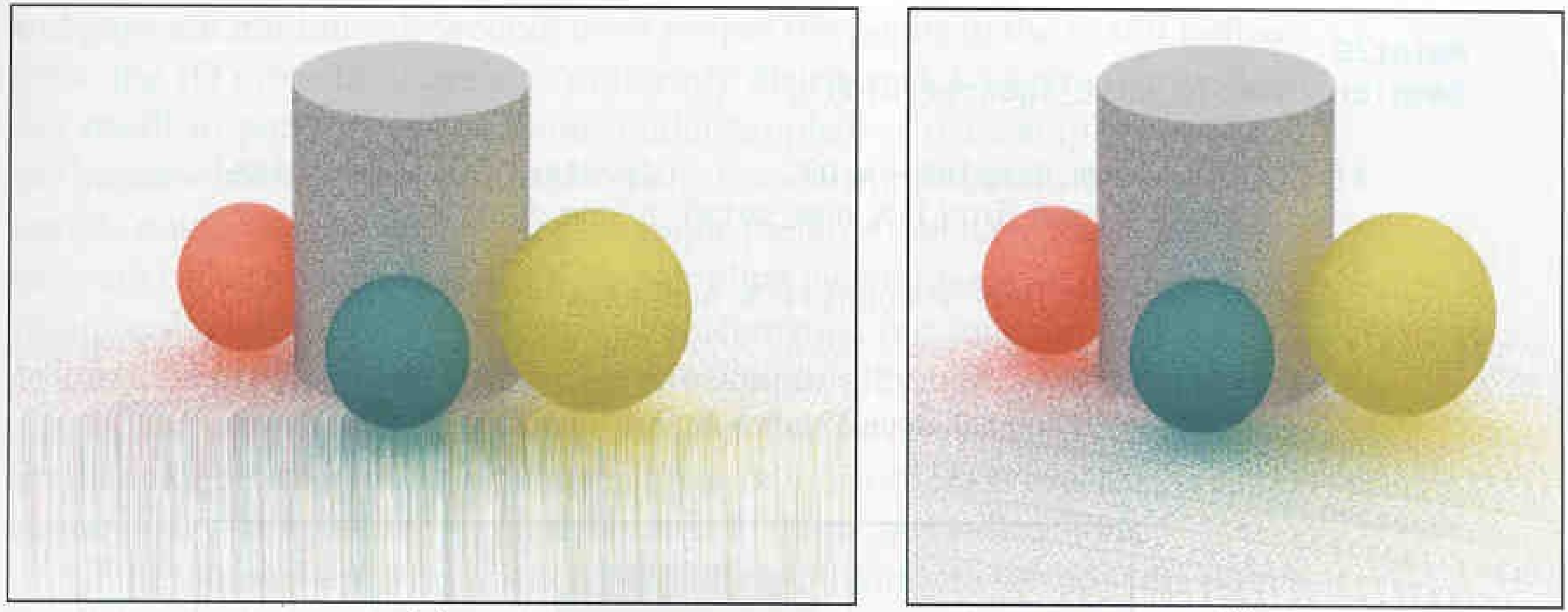


Figure 5.2. Shading a surface with an area light and four samples per pixel.

Side-effects of Sampling Pattern



(a) (b)

Figure 5.6. Global illumination images that exhibit bad aliasing caused by using the same samples in vertical columns (a) and in a regular horizontal displacement (b).

Depth of Field

- Important for realism
  - Background is 'fuzzy"
- Partly out of focus
  - Imperfect optics
  - Turbulence
- Graphic backgrounds are often too perfect

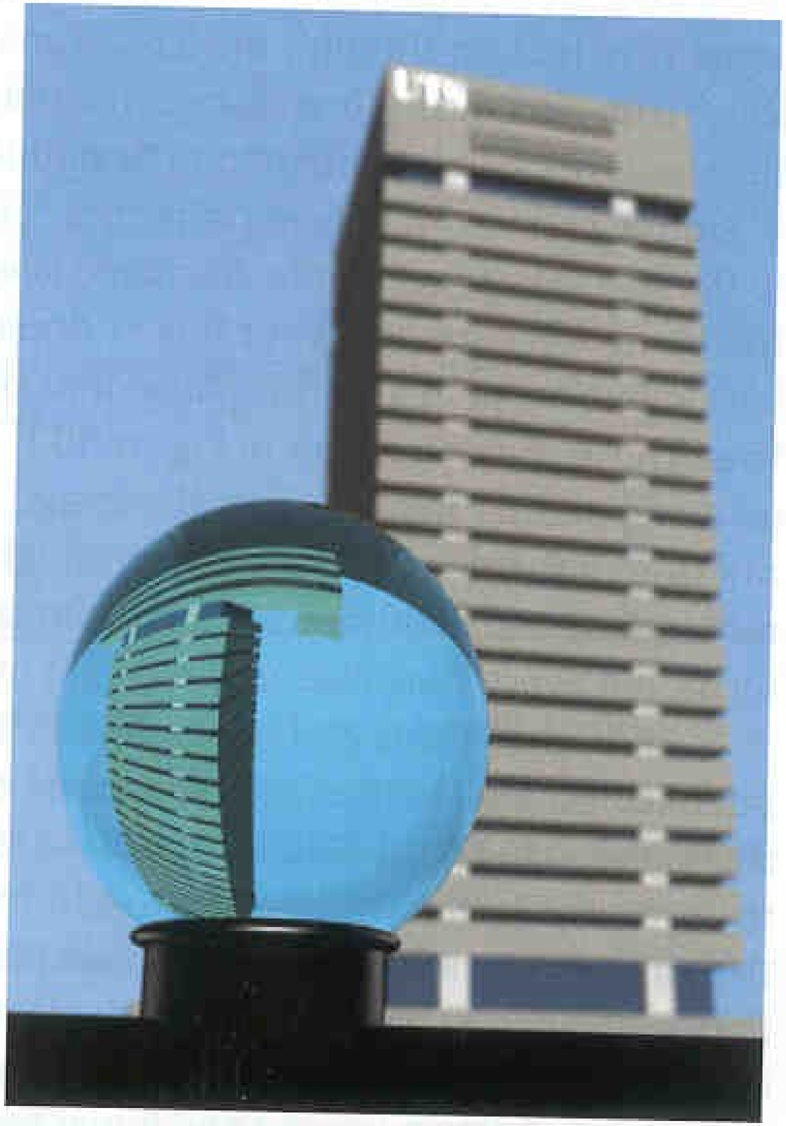


Image courtesy of Tania Humphreys

Thin Lens Theory

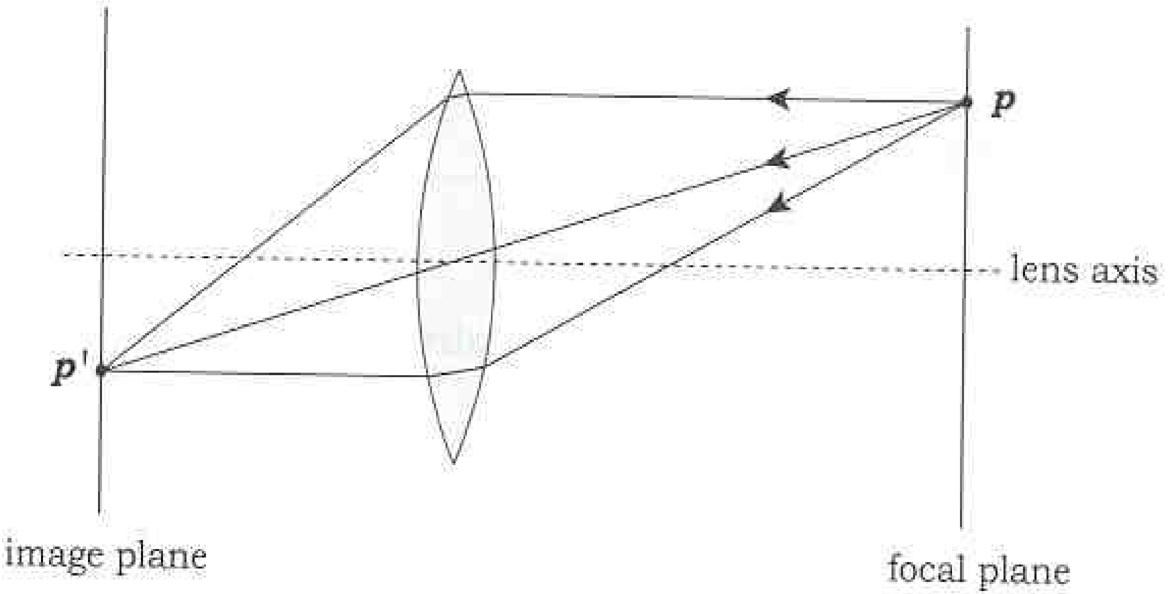


Figure 10.1. Cross section through a thin lens showing a focal plane and its corresponding image plane.

Out of Focus Images

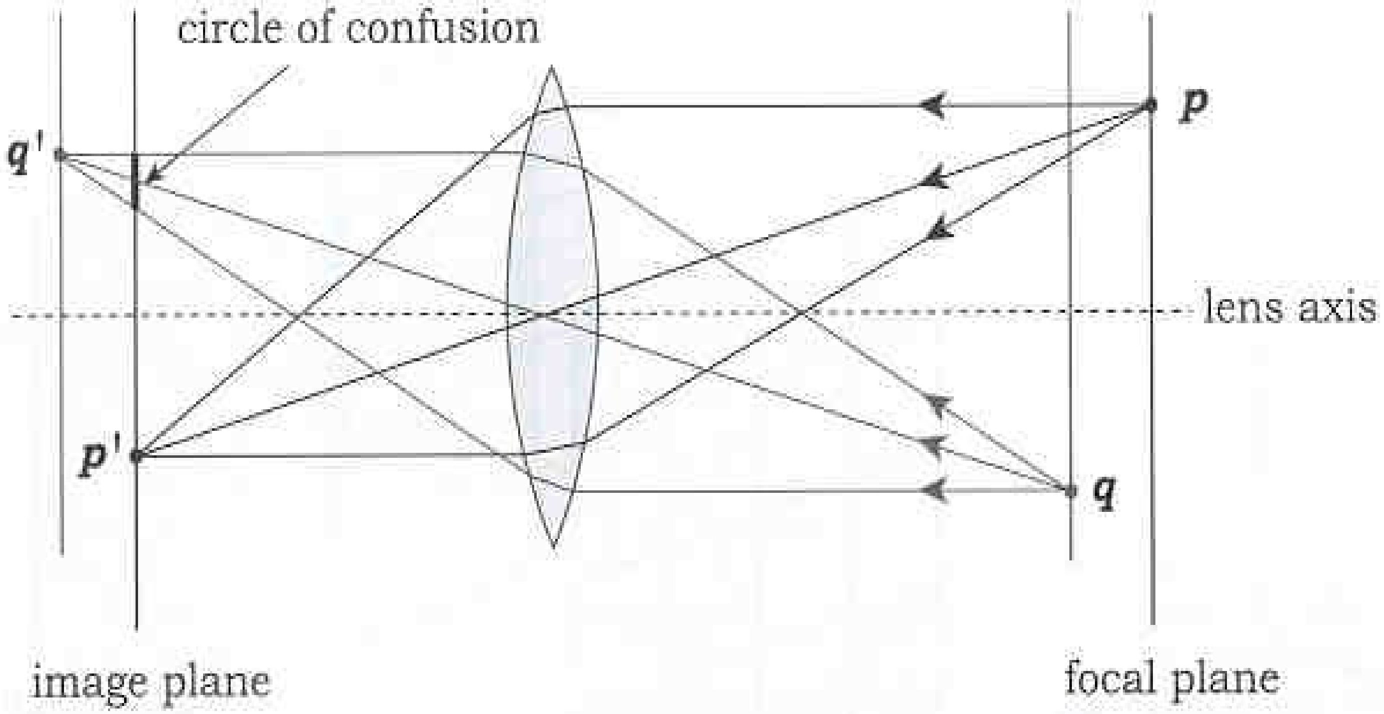


Figure 10.2. Rays starting a point q go through the image plane of p at different locations, with the result that q will appear out of focus.

Depth of Field Results

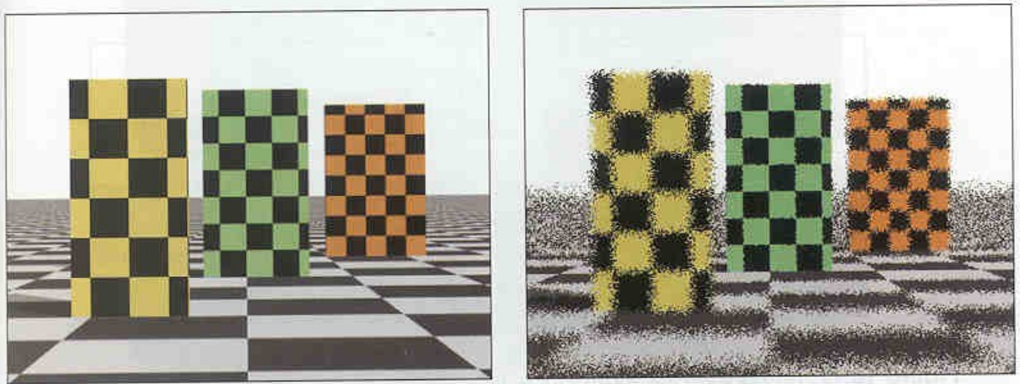

(a) (b)

Figure 10.9. (a) When the lens radius is zero, the image is the same as a pinhole-camera image with everything in focus; (b) noisy image from using one random sample per pixel.

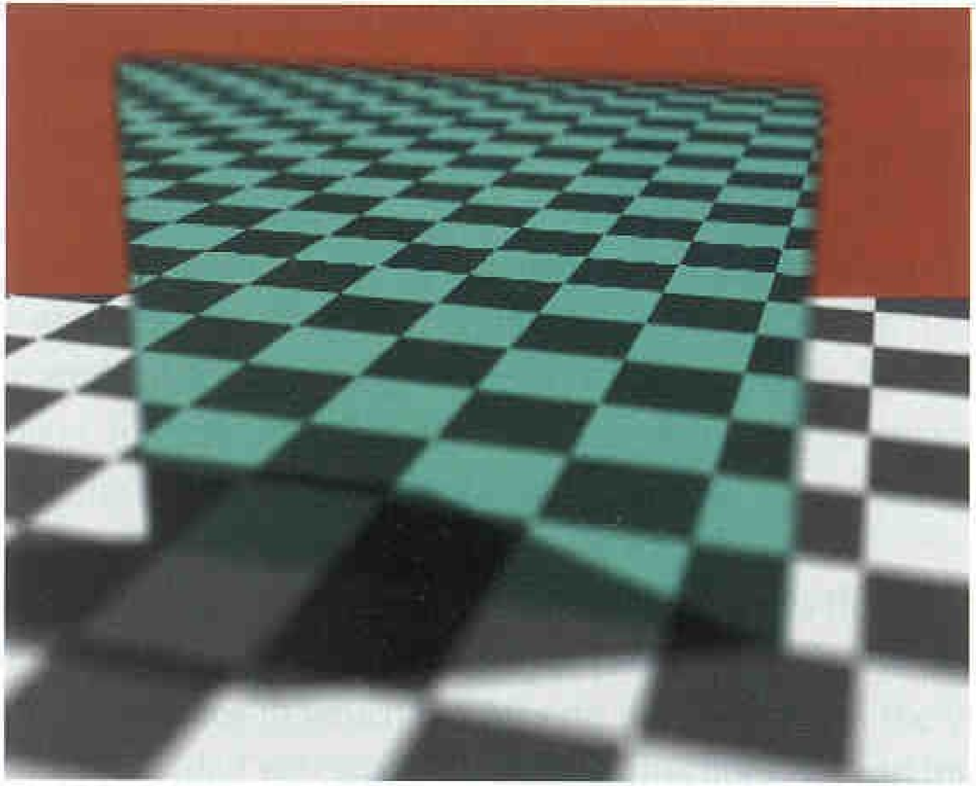


Figure 10.12. Mirrored surface.

Ambient Occlusion

- Floor has a vague shadow outline
- Parts of object near floor is darker
- Ambient light is not anisotropic and uniform

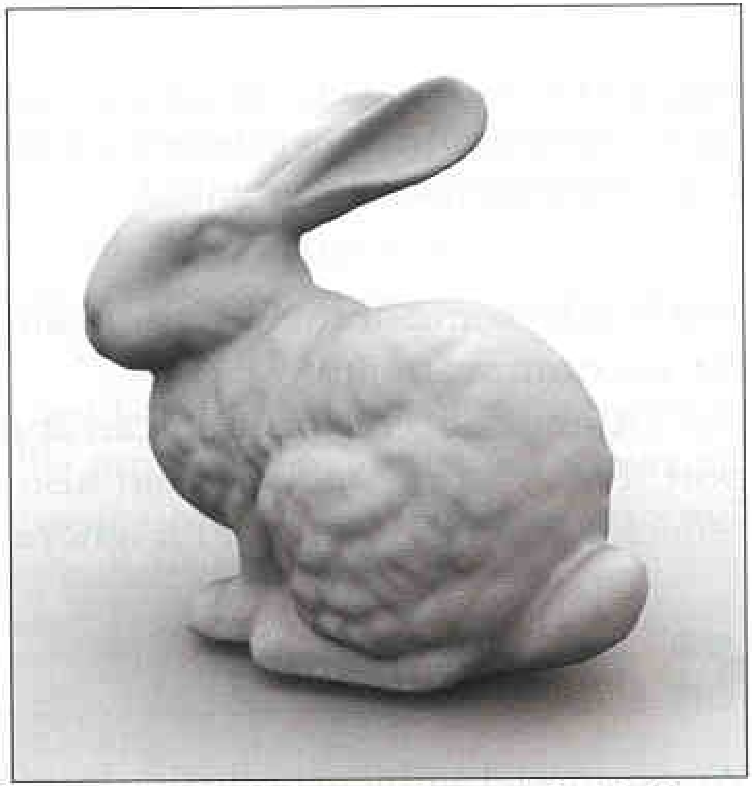


Image courtesy of Mark Howard, Stanford bunny model courtesy of Greg Turk and the Stanford University Graphics Laboratory

Computing Ambient Occlusion

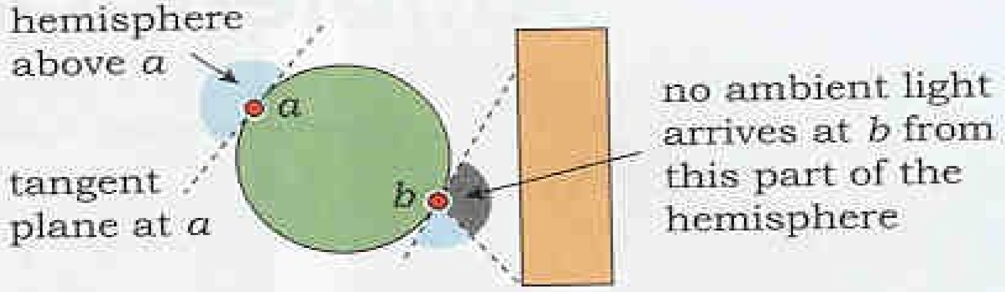


Figure 17.1. Point a on the sphere receives the maximum amount of ambient light because the box isn't visible; point b doesn't receive the maximum amount because the box blocks some of the incoming ambient light.

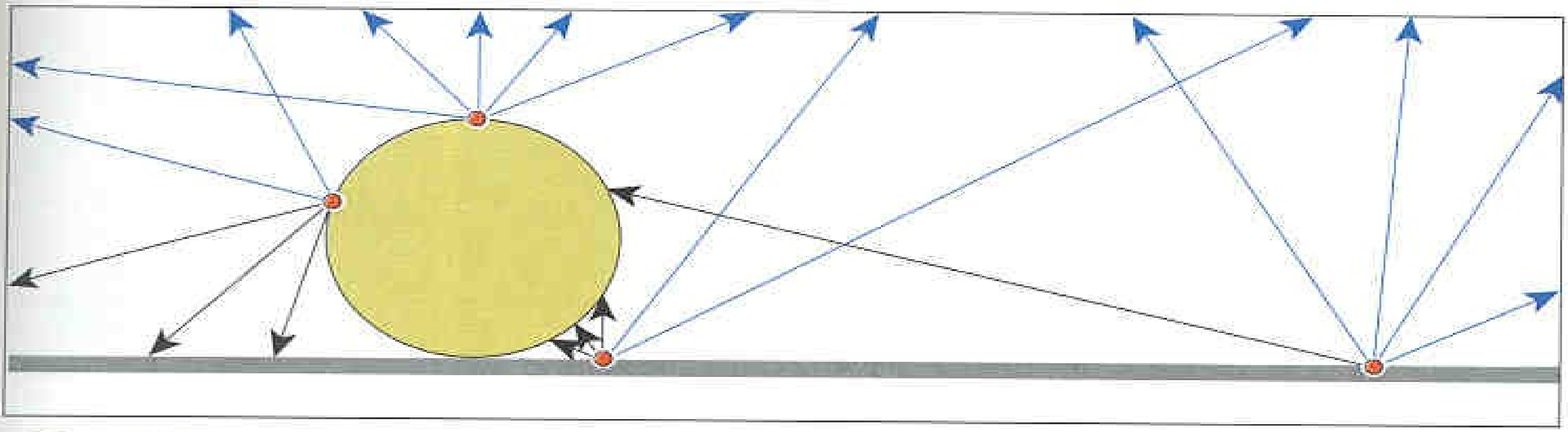
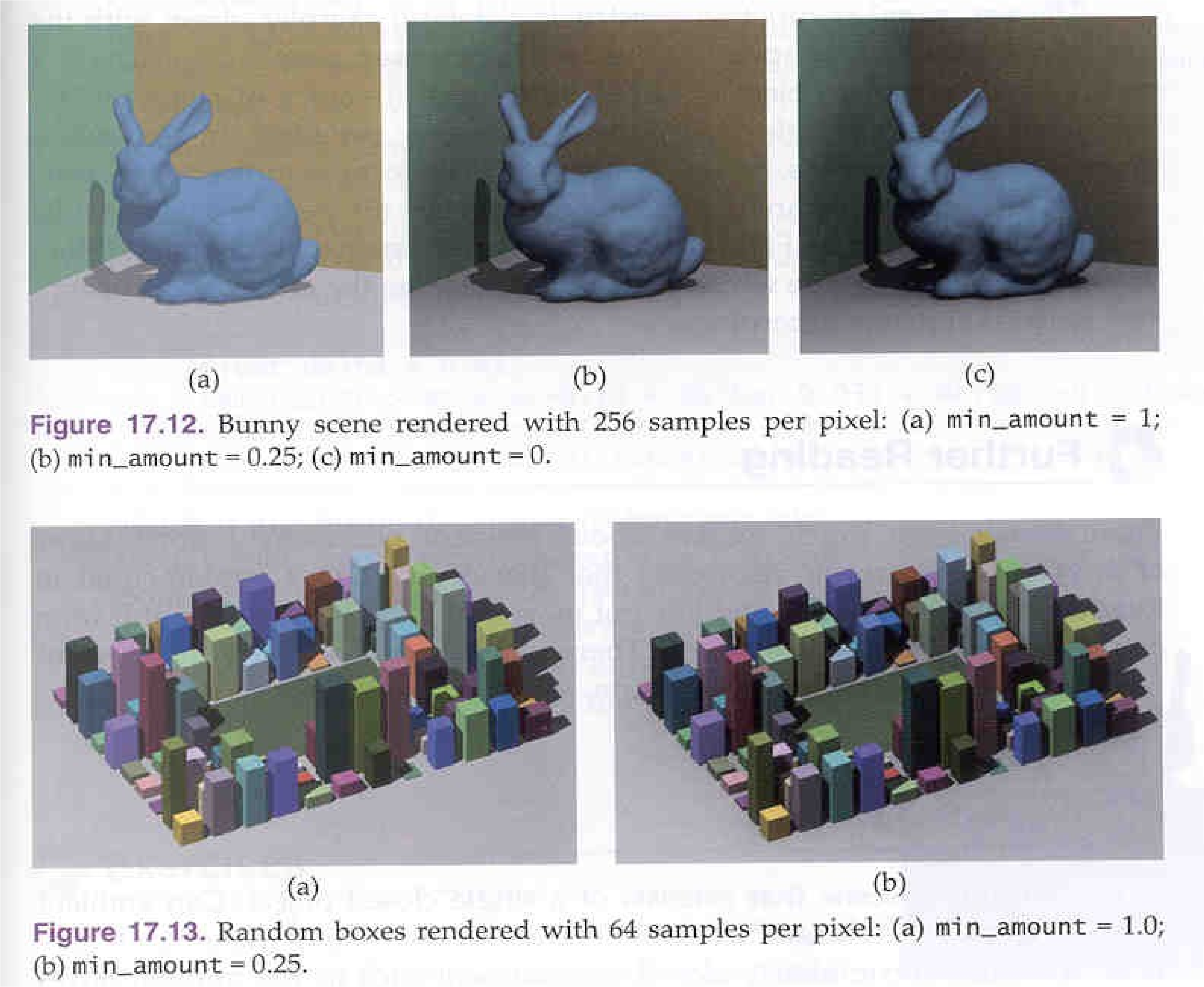


Figure 17.2. Various hit points on the plane and the sphere, with sample shadow rays.

Ambient Occlusion Results



(a) (b) (c)

Figure 17.12. Bunny scene rendered with 256 samples per pixel: (a) `min_amount` = 1; (b) `min_amount` = 0.25; (c) `min_amount` = 0.

(a) (b)

Figure 17.13. Random boxes rendered with 64 samples per pixel: (a) `min_amount` = 1.0; (b) `min_amount` = 0.25.