Ray Tracing 3

CSCI 4830/7000
Advanced Computer Graphics
Spring 2009

Mirror Reflection

- Mirror reflections are a signature of ray tracing
  - Shiny objects
    - Glass
    - Metal
  - Multiple reflections may occur
- Occurs naturally in ray tracing
- Requires tracing ray through multiple bounces
- Adds significant effort

Reflective spheres by Burt Flugleman, Rundle Street Mall, Adelaide. Photograph by Kevin Suffern.

Conservation of Energy

- Mirrors reflect almost all the energy
- Retains beam geometry

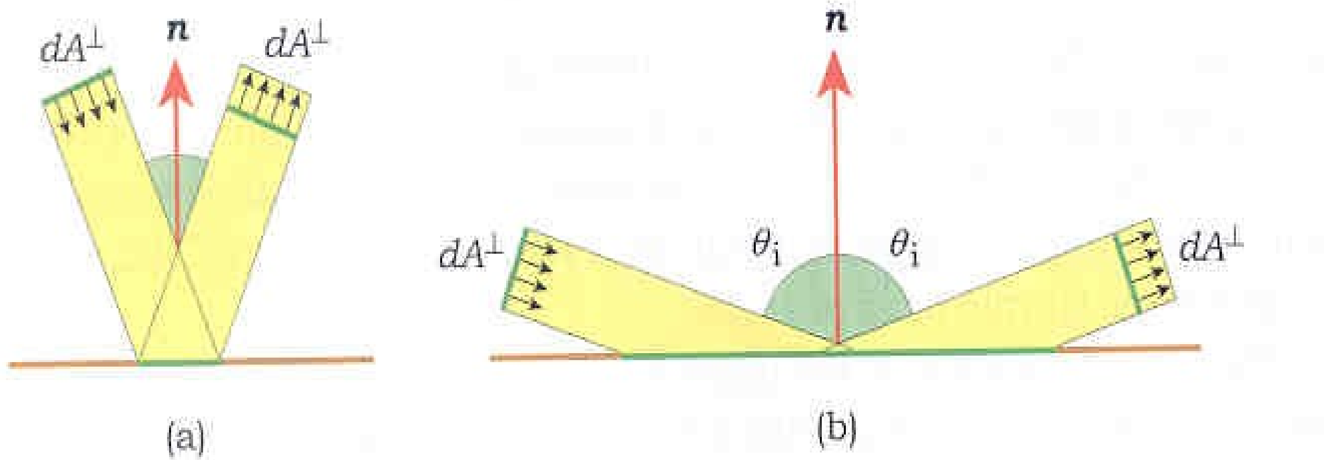
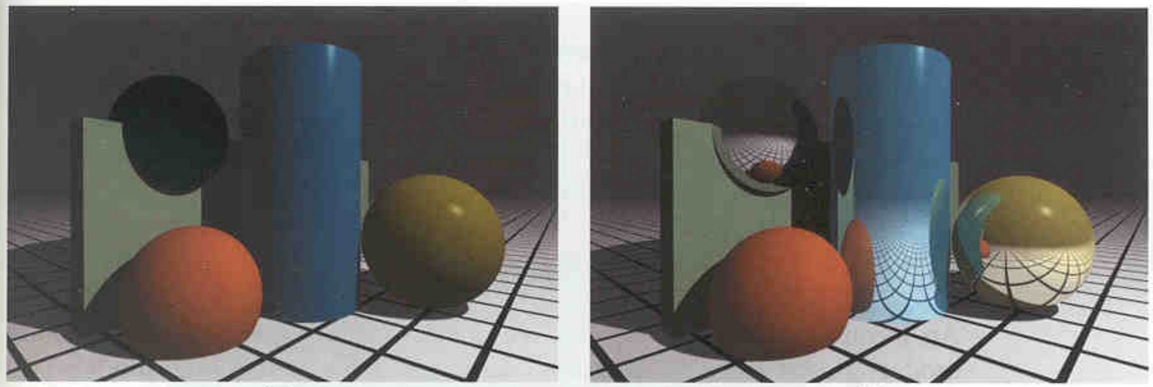


Figure 24.3. When a beam of light is reflected from a perfect mirror, its cross section area is unchanged after reflection and is therefore independent of the angle of incidence θ_i.

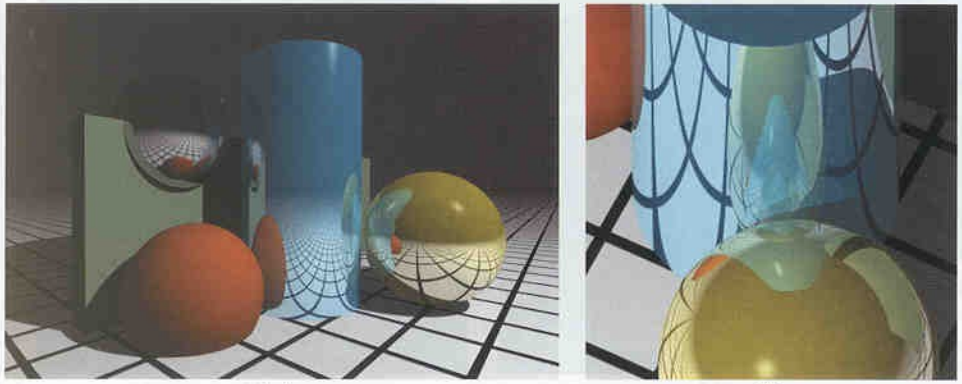
Number of Reflections

- 0 dull
- 1 “simple” mirror
- >1 “hall of mirrors”
- Effort grows with number of bounces



(a) (b)

Figure 24.6. A scene rendered with max_depth = 0 (a) and max_depth = 1 (b).



(a) (b)

Figure 24.7. (a) The scene from Figure 24.6 rendered with max_depth = 10; (b) close-up view of the yellow-green sphere and the cylinder from a different viewpoint than in (a).

Hall of Mirrors
(Showcases Ray Tracing)

(a) (b)

Figure 24.18. (a) Hall of mirrors with max_depth = 19; (b) close-up view of the multiple reflections between the floor mirror and the sphere.

Mirror vs Glossy Reflection

- Mirror reflections are "perfect"
- Glossy reflections are "imperfect"
  - Reflected ray = $2(N \bullet V)N - V + \varepsilon$
  - Super-sample for many values of ε

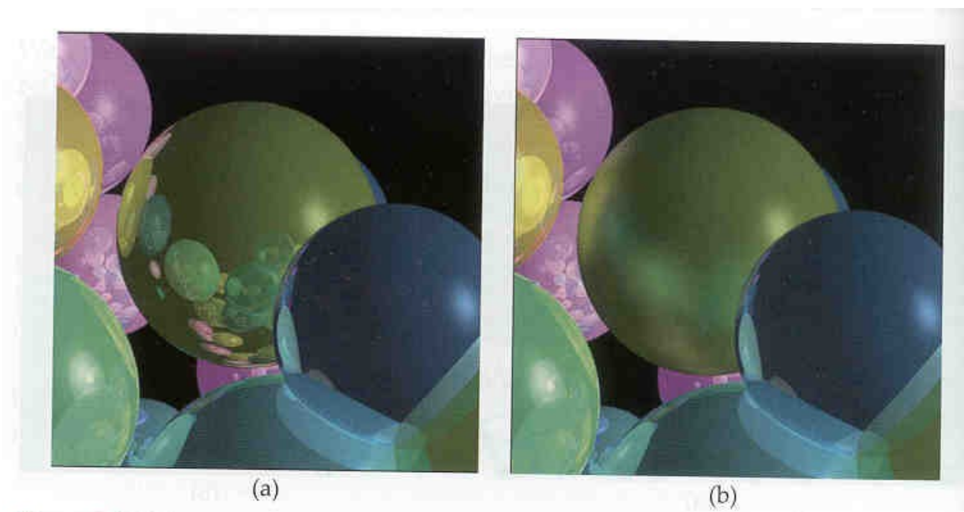


Figure 24.8. The green sphere has glossy specular highlights and perfect mirror reflections (a) and glossy reflections (b).

Degrees of perfection

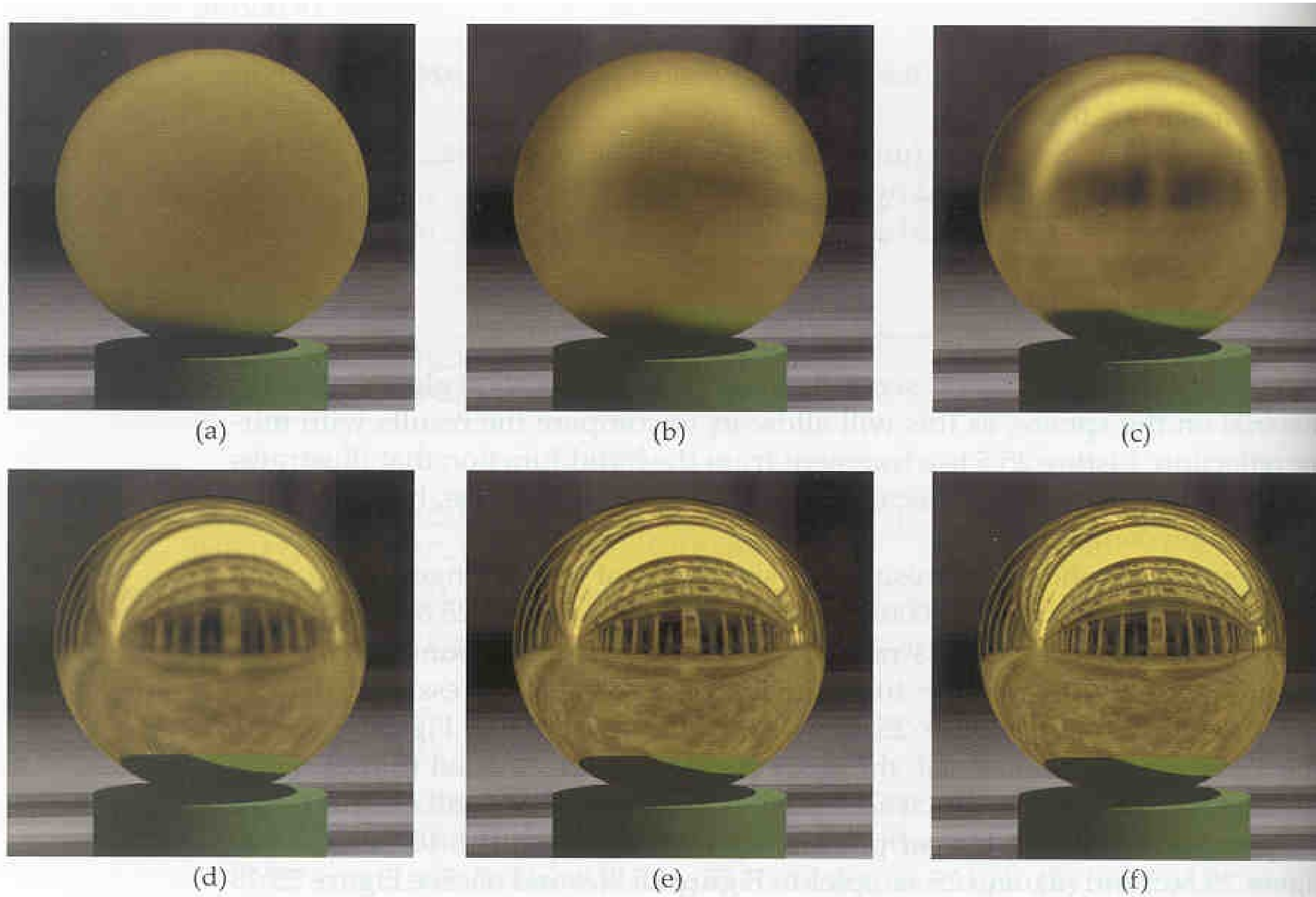


Figure 25.8. Glossy sphere surrounded by the Uffizi image and rendered with the following values of e: (a) 1.0; (b) 10.0; (c) 100.0; (d) 1000.0; (e) 10000.0; (f) 100000.0.

Simple Transparency

- Light passes through objects
- Light changes through object
  - Rays are bent
  - Colors are changed
- Rays multiply
  - Reflected
  - Transmitted

Photograph courtesy of Steve Agland

Refreaction

- Index of refraction $\eta = c/v$
  - Vacuum 1
  - Air 1.0003
  - Water 1.33
  - Glass 1.5
  - Diamond 2.42

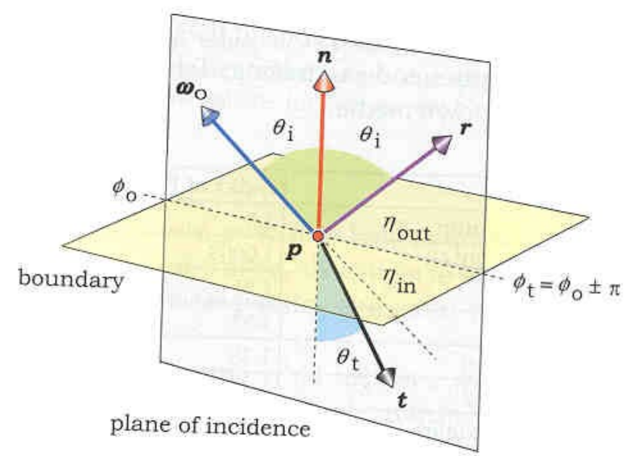


Figure 27.2. Reflected and transmitted rays at the boundary between two transparent media.

- Snell's law
  - $\sin\theta_i / \sin\theta_t = \eta$

Media Transitions

- Direction of bend depends on whether the refrection index increases or decreases
  - Air η is very low
  - Angles decrease into liquids
  - Angles increase out of liquids

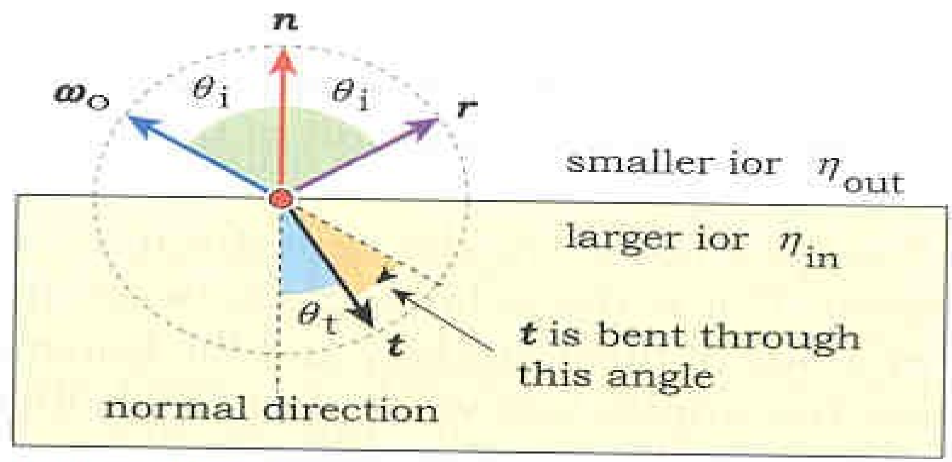


Figure 27.3. Direction change of t when $\eta > 1$.

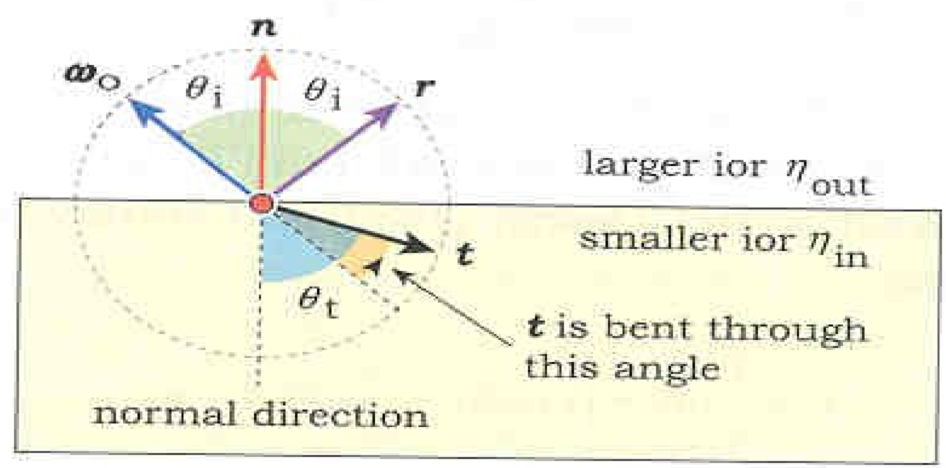


Figure 27.4. Direction change of t when $\eta < 1$.

Internal reflections

- Critical angle
  - Refraction bends ray back into medium
- Higher η contrast causes larger critical angle
  - That is why diamonds are so sparkly

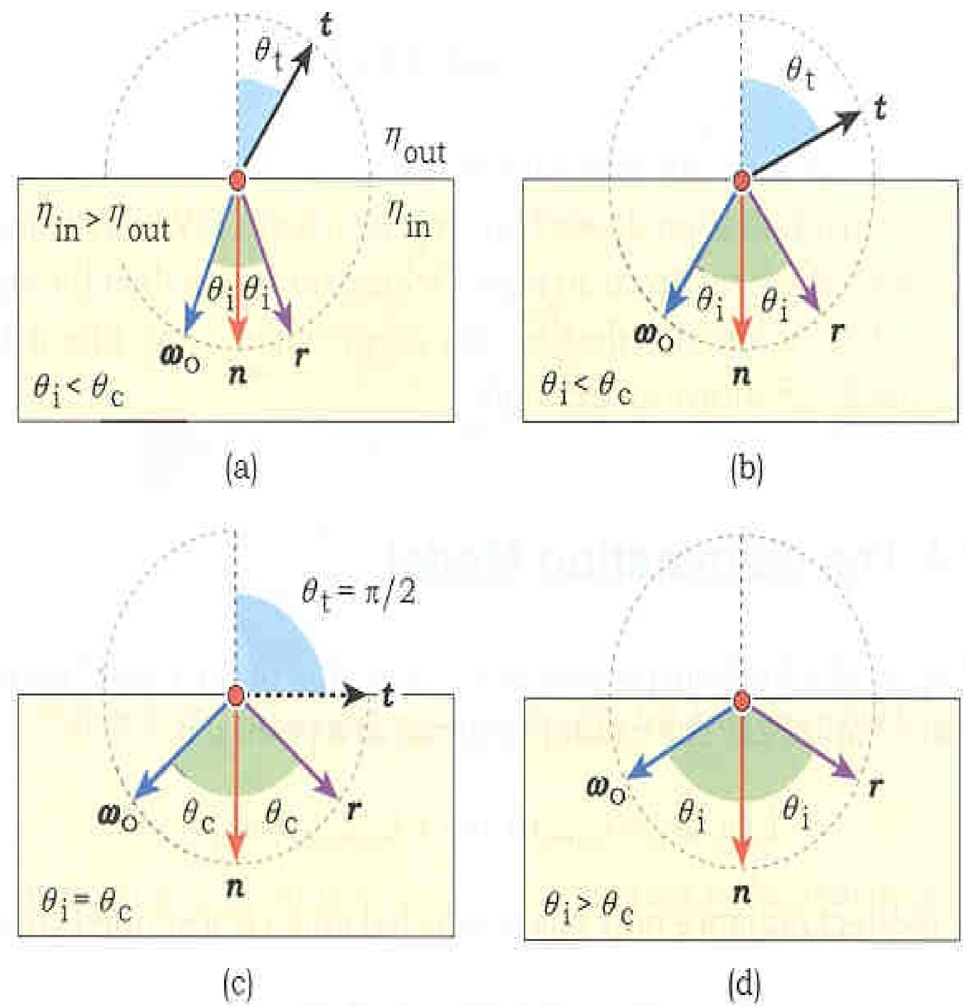


Figure 27.5. Total internal reflection: (a) and (b) $\theta_i < \theta_c$; (c) $\theta_i = \theta_c$; (d) $\theta_i > \theta_c$.

Transparency require bifurcating rays

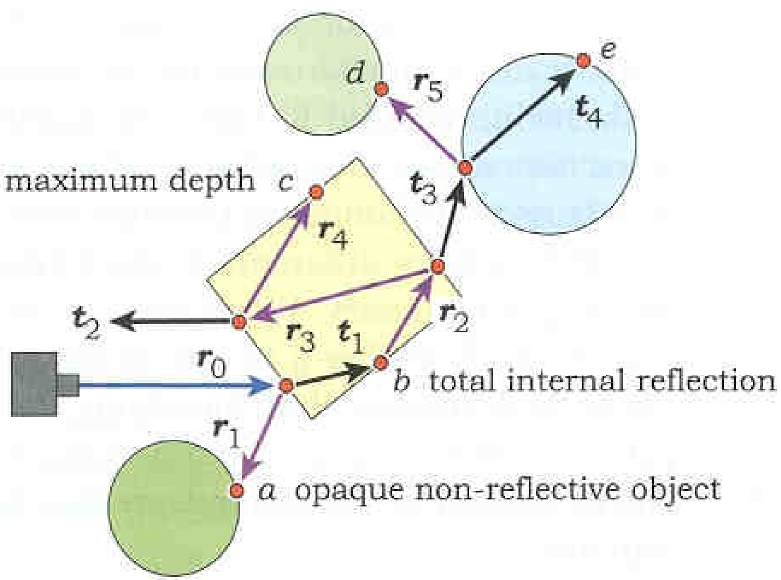


Figure 27.6. Transparent objects with reflected and transmitted rays.

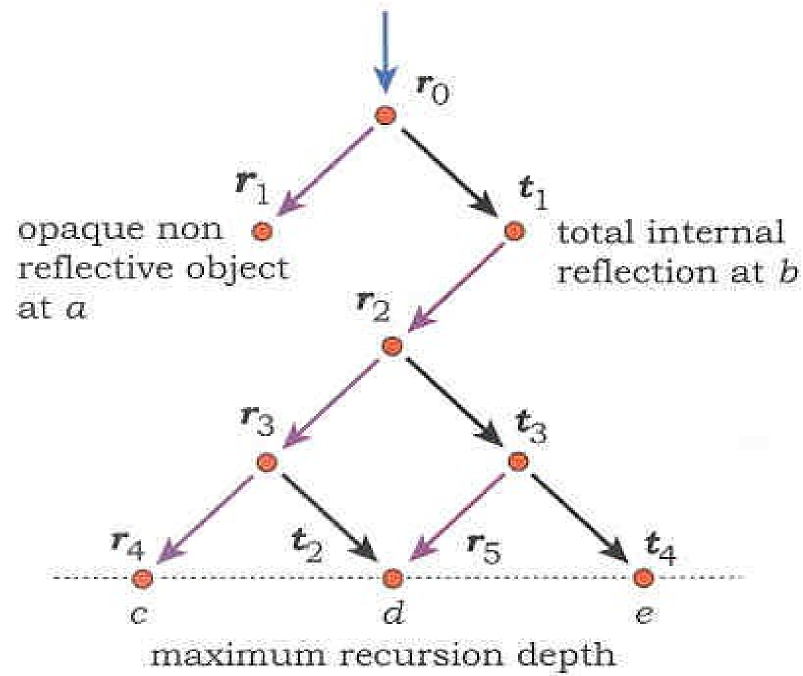


Figure 27.7. The ray tree that corresponds to Figure 27.6.

Objects Appearance

- Object inside other material
  - Objects are magnified when not viewed parallel to the normal
  - Object's apparent position is displaced
- Objects on other side
  - Objects apparent position is displaced

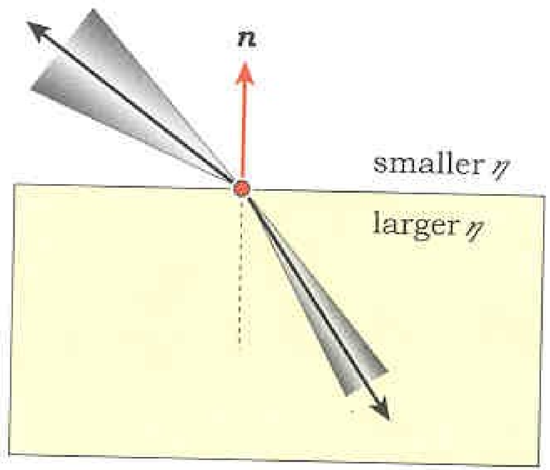


Figure 27.8. The angle of a differential cone of incident radiance changes as it crosses the boundary between two dielectrics.

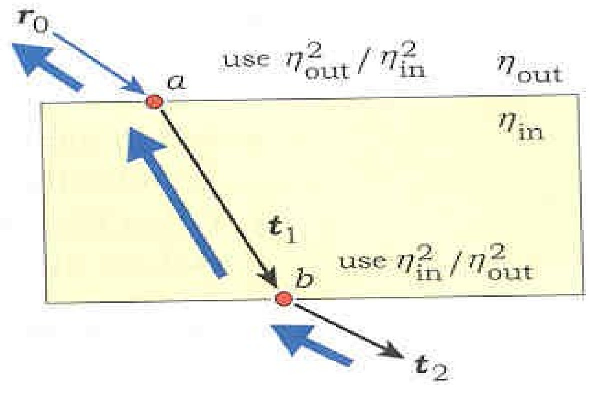


Figure 27.9. Ray and radiance-transfer directions through a transparent object.

Distortion by Glass Spheres

- Sphere as a lens

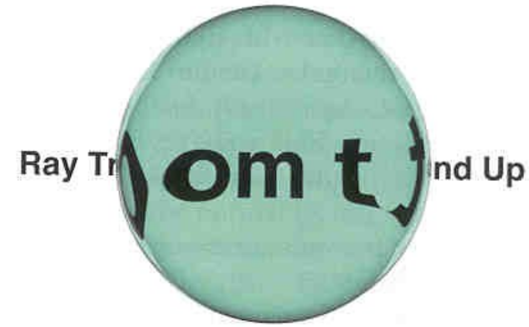
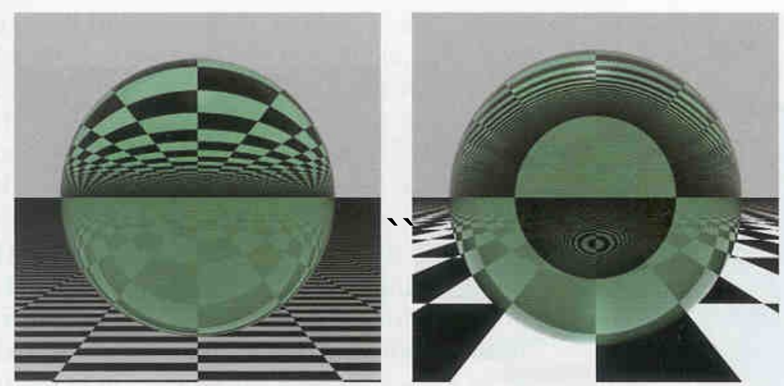


Figure 27.22. Transparent sphere in front of text.

- Eye position is critical



(a) (b)

Figure 27.23. A transparent sphere with the camera far from the sphere (a) and close to the sphere (b).

Light movement through sphere

- Magnification

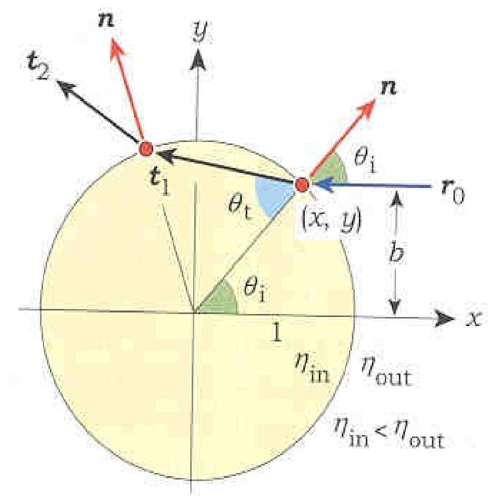


Figure 27.17. Reflected and transmitted rays generated by a ray r_0 that hits a unit sphere with impact parameter b, where the sphere has $\eta < 1$.

- Internal reflection

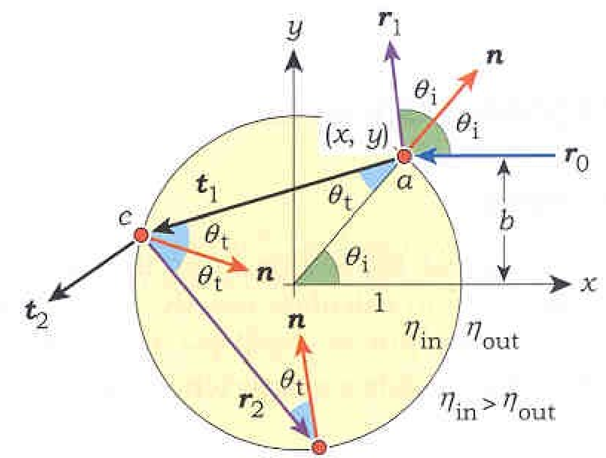


Figure 27.11. Reflected and transmitted rays generated by a ray r_0 that hits a unit sphere with impact parameter b. The lengths of the (unit) normals and the sphere are not drawn on the same scale.

Realistic Transparency

- Three η's
  - Air
  - Glass
  - Water
- Colored liquid
- Beveled edges
  - Glass
  - Meniscus
- Mixed transparency
  - Foam is opaque

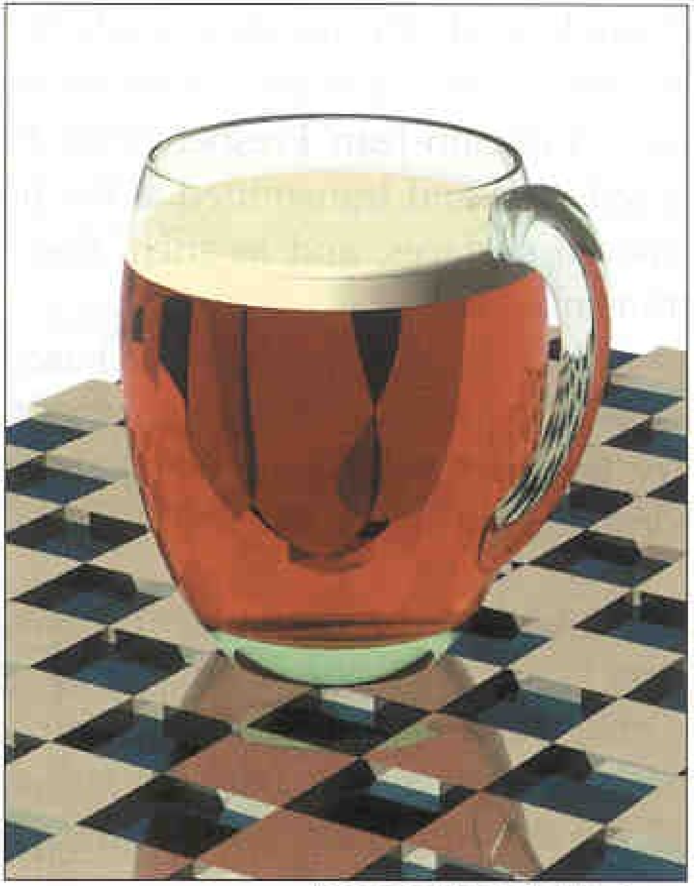


Image courtesy of John Avery

Reflectance and Attenuation

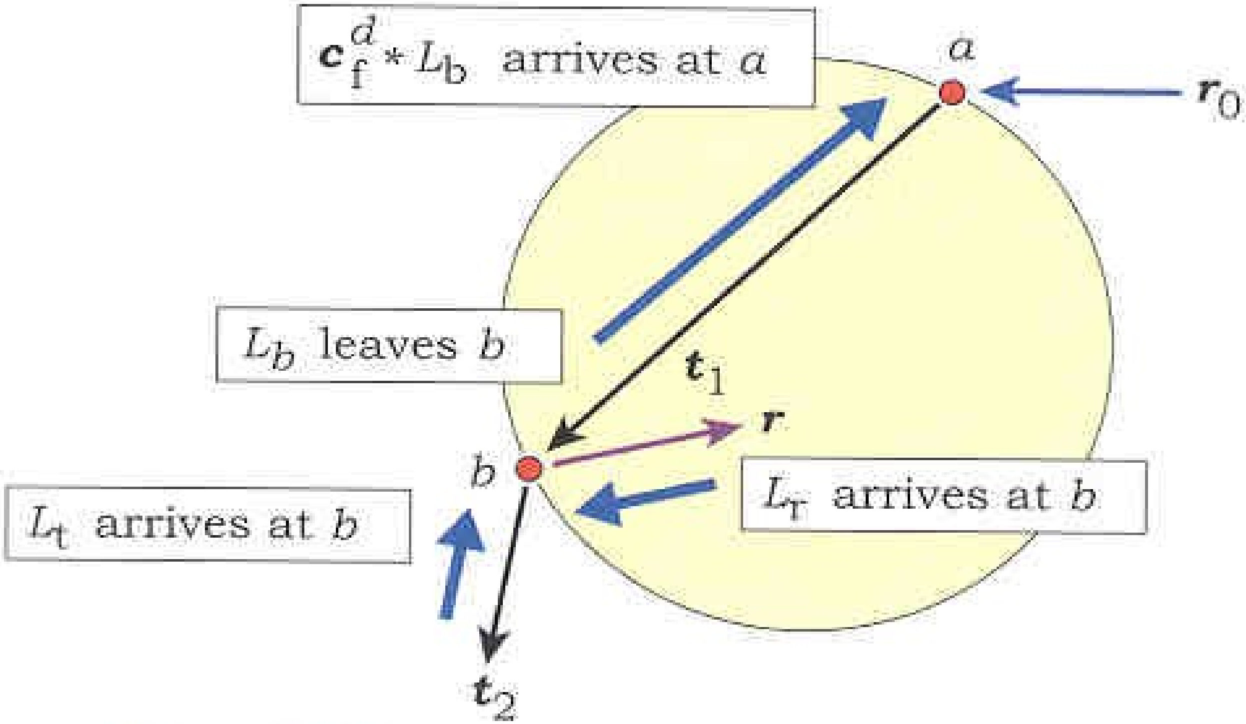


Figure 28.4. Radiance attenuation in a dielectric.

Multiple Internal Reflections

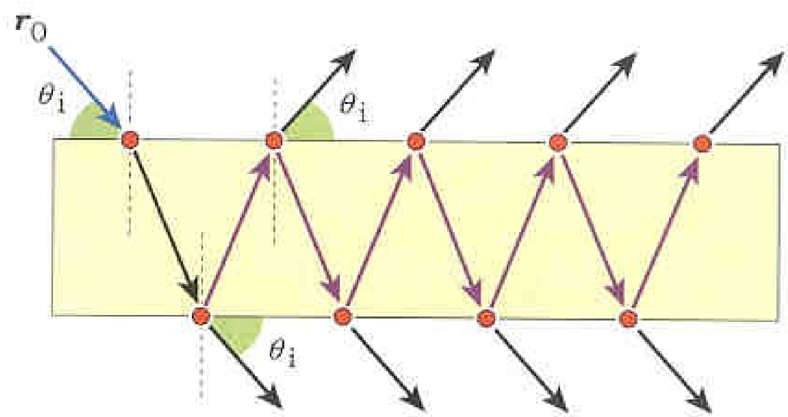
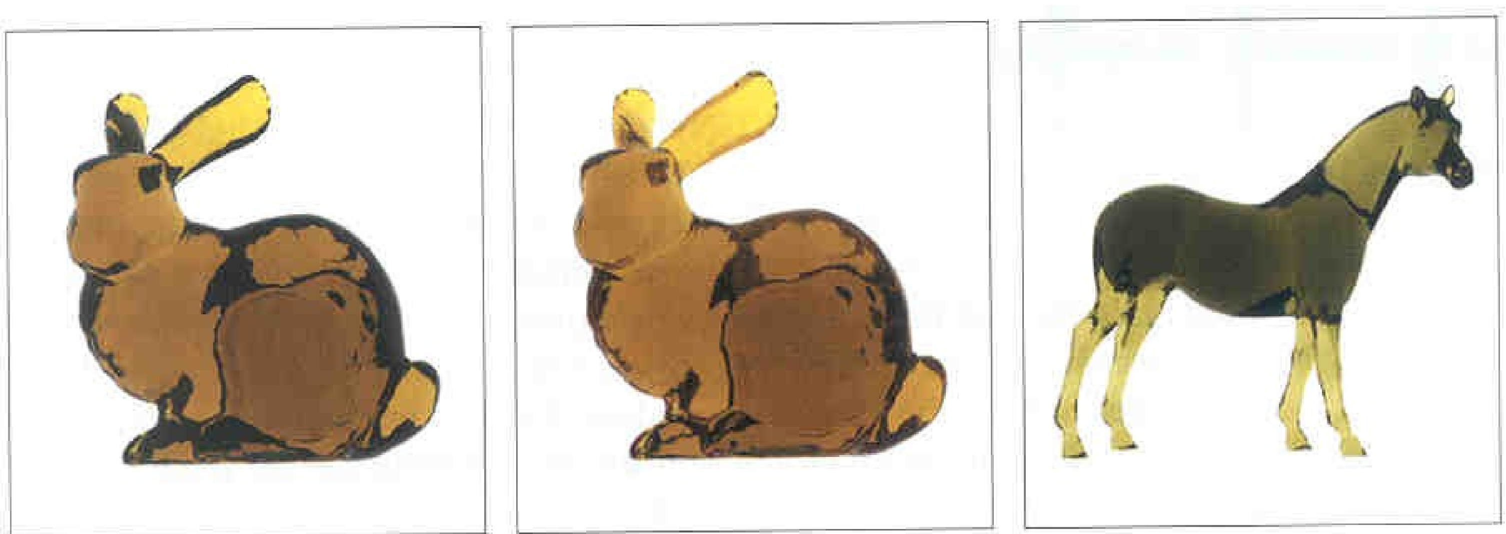


Figure 28.19. A transparent box with multiple reflected and transmitted rays.



(a) (b) (c)

Figure 28.12. (a) Stanford bunny rendered with c_f = (0.65, 0.45, 0) and `max_depth` = 2; (b) `max_depth` = 10; (c) horse model rendered with c_f = (0.65, 0.65, 0.1) and `max_depth` = 10.

Colored Beaker

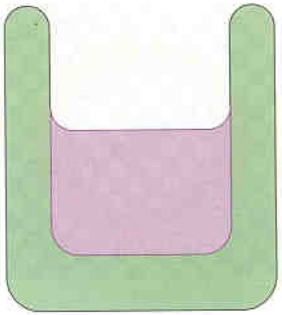


Figure 28.37. A more sophisticated glass of water has a curved top, rounded edges, and a meniscus for the water.

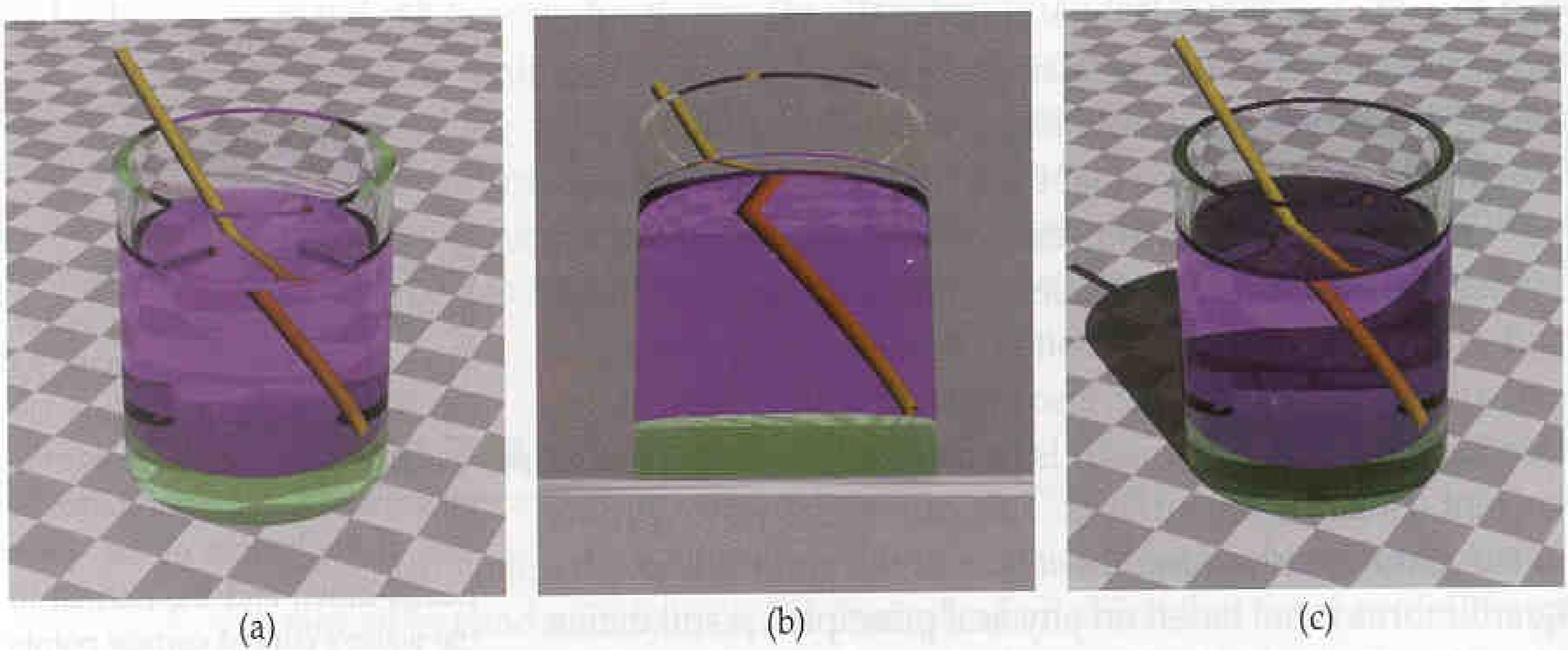


Figure 28.38. Glass of water and straw rendered with: (a) no shadows; (b) camera looking up; (c) shadows and direct illumination on the straw.

The Fish Bowl

- Making it real
  - Complex shape
  - Three media
  - Colored media
  - Beveled edges
- Challenges
  - Multiple relfections
  - Refraction

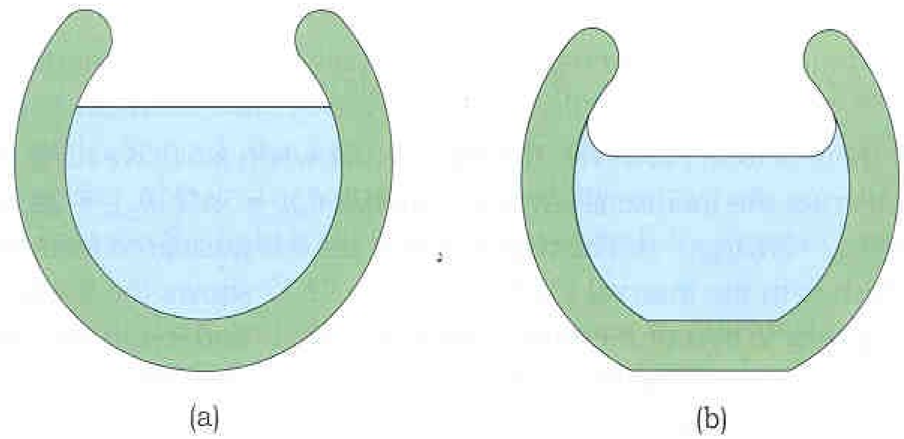


Figure 28.39. (a) Basic fishbowl; (b) fishbowl with flat base and meniscus.

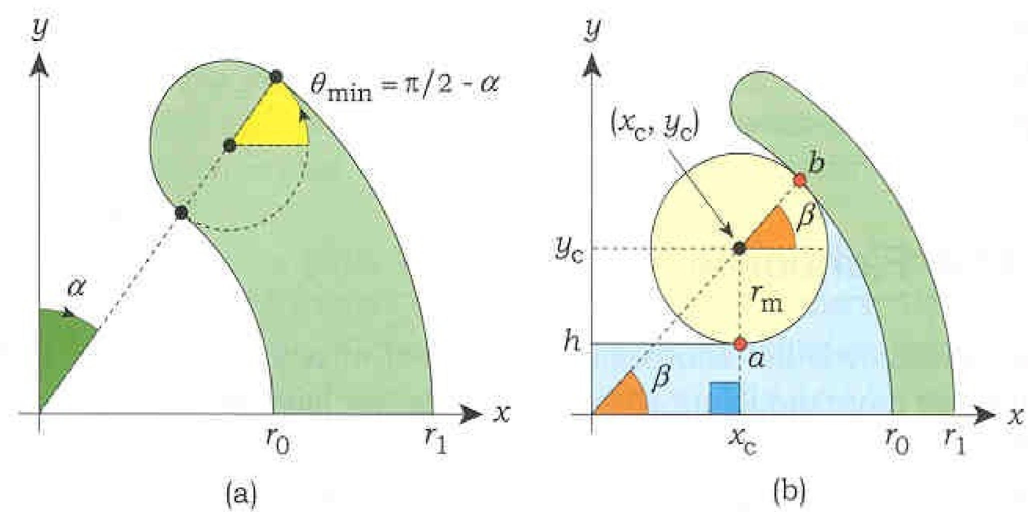


Figure 28.40. (a) Construction of the rim; (b) construction of the meniscus.

Adding Textures

- Per pixel modification of surface appearance
- Use texture coordinates to map textures to objects
  - When ray tracing, you have to do this yourself
- Textures modify ray color on each bounce

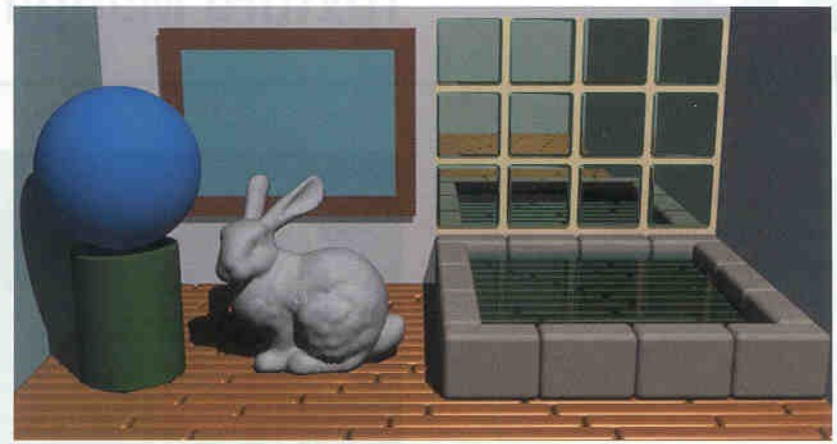
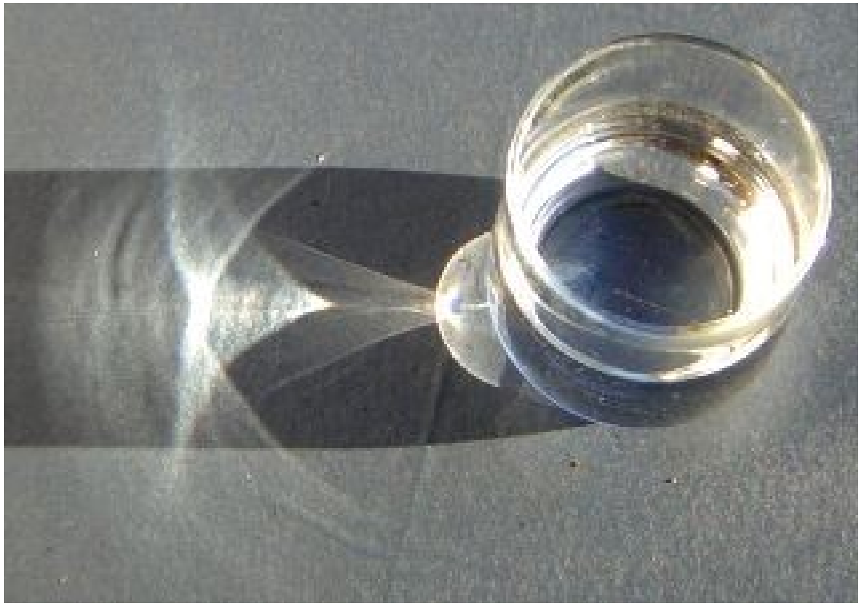


Figure 29.1. Interior scene rendered with no textures.

Figure 29.2. Same scene as in Figure 29.1 but rendered with a variety of textures. The water surface is Ken Musgrave's water bump map, as described in Musgrave (2003b).

Caustics



Building a Ray Tracer in C++

- Base classes
  - Ray
  - Object
  - Light
  - Material
- Derived Object Classes
  - Sphere
  - Cube
  - Triangle
  - Triangle Mesh

Object Class

- Type of object
  - Implicit Surface
    - Sphere
    - Torus, cylinder, cube, ...
  - Compound objects
    - Triangular mesh
- Intersection with a ray
  - Point of intersection
  - Normal
  - Textures, etc

Virtual Methods

- Base class
  - hit
  - sample
  - color
- Each object class overrides the base class