

Ray Tracing: Transparency

CSCI 4239/5239

**Advanced Computer Graphics
Spring 2026**

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

Refraction

- Index of refraction $\eta = c/v$
 - Vacuum 1
 - Air 1.0003
 - Water 1.33
 - Glass 1.5
 - Diamond 2.42
- Snell's law
 - $\sin\theta_i / \sin\theta_t = \eta$

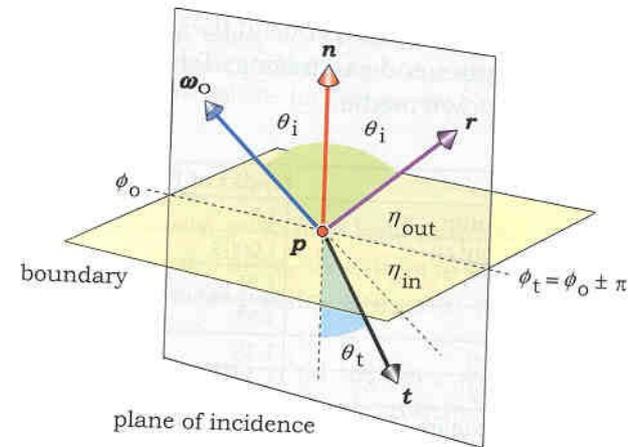


Figure 27.2. Reflected and transmitted rays at the boundary between two transparent media.

Media Transitions

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

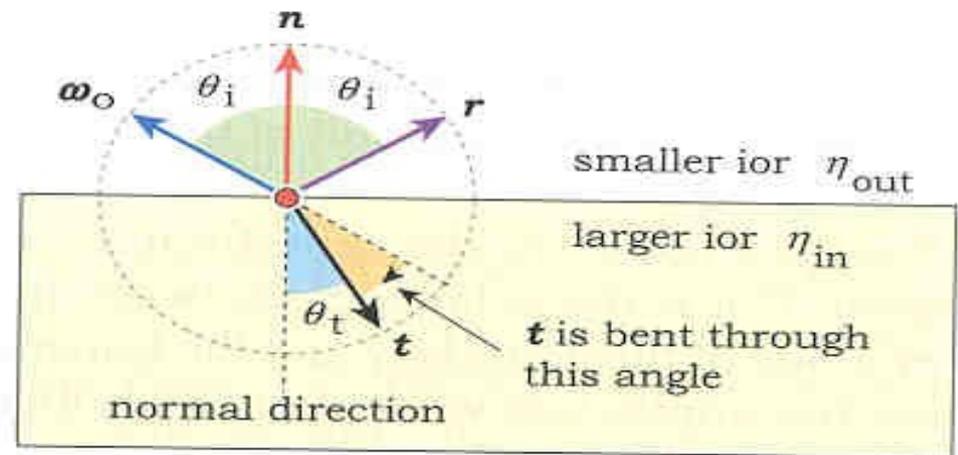


Figure 27.3. Direction change of t when $\eta > 1$.

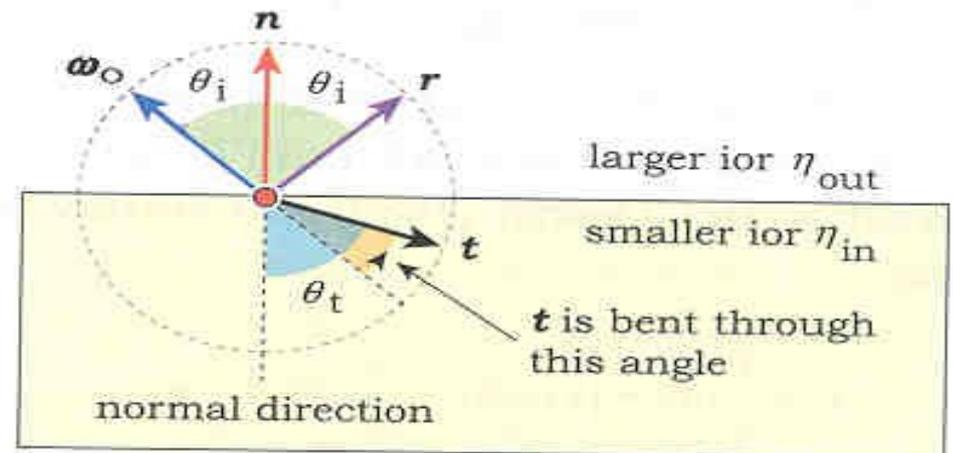


Figure 27.4. Direction change of t when $\eta < 1$.

Internal reflections

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

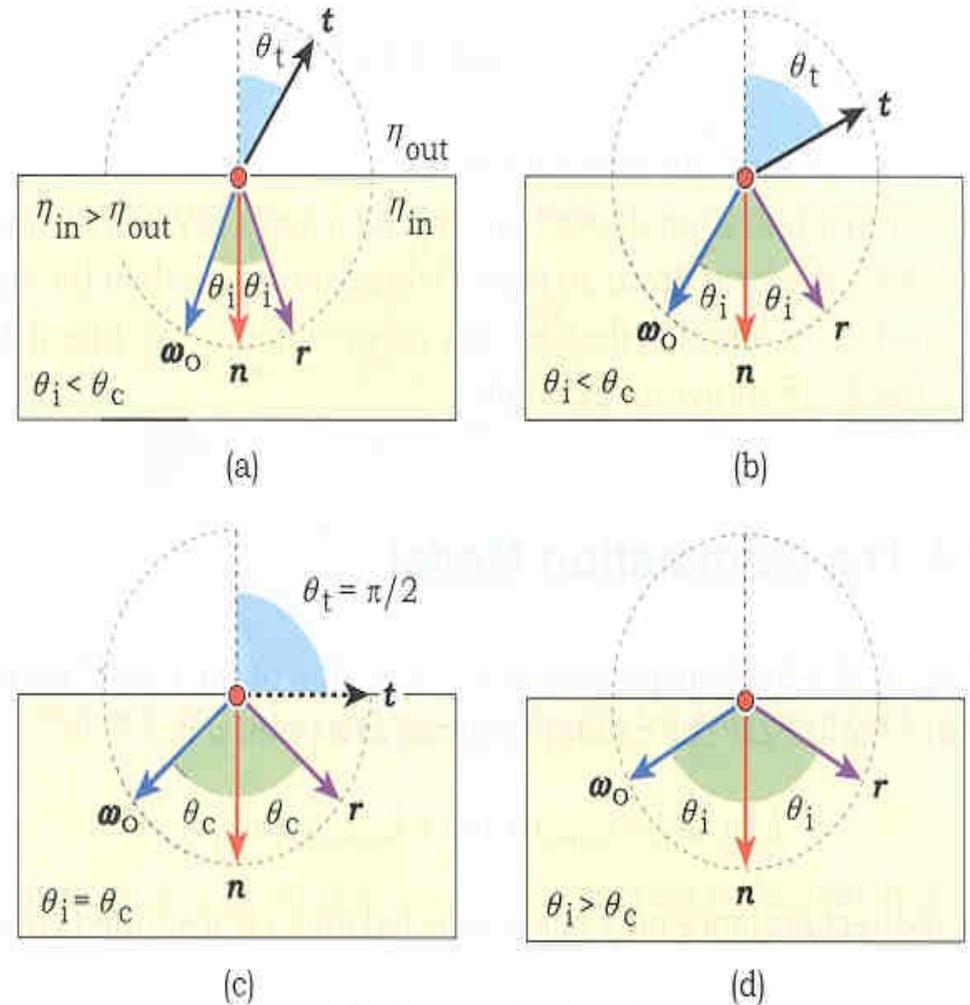


Figure 27.5. Total internal reflection: (a) and (b) $\theta_i < \theta_c$; (c) $\theta_i = \theta_c$; (d) $\theta_i > \theta_c$.

Transparency require bifurcating rays

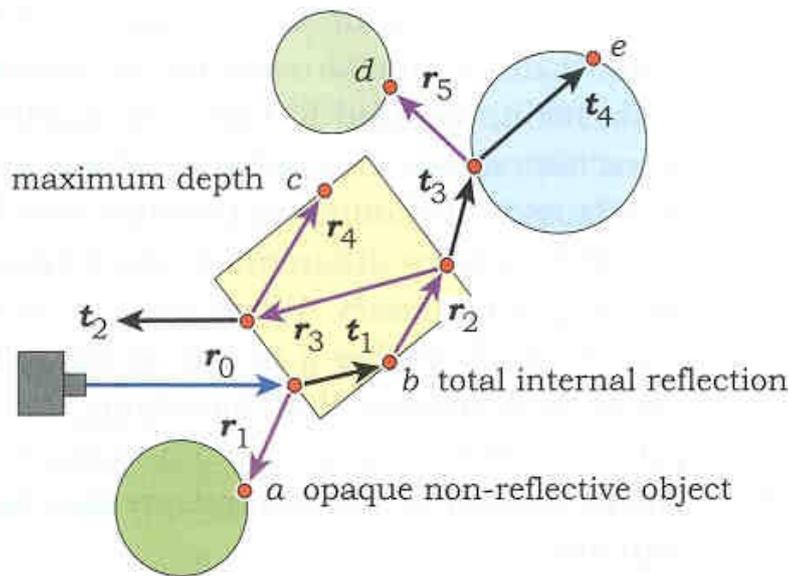


Figure 27.6. Transparent objects with reflected and transmitted rays.

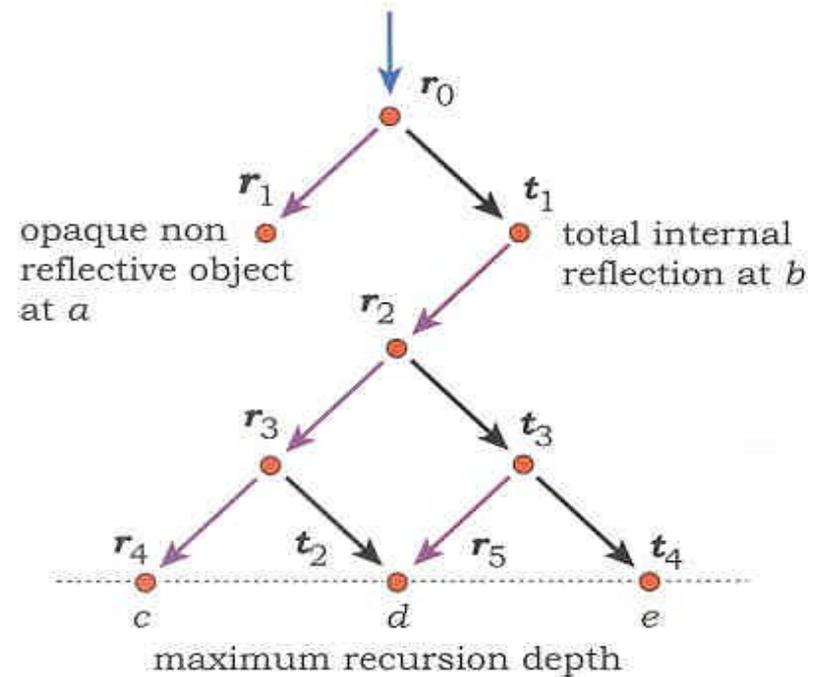


Figure 27.7. The ray tree that corresponds to Figure 27.6.

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

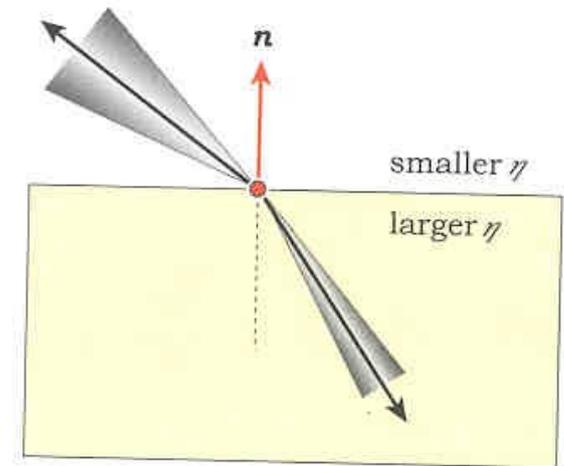


Figure 27.8. The angle of a differential cone of incident radiance changes as it crosses the boundary between two dielectrics.

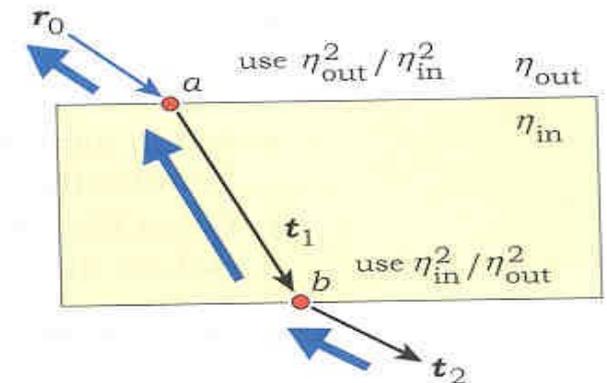


Figure 27.9. Ray and radiance-transfer directions through a transparent object.

Distortion by Glass Spheres

- Sphere as a lens



Figure 27.22. Transparent sphere in front of text.

- Eye position is critical

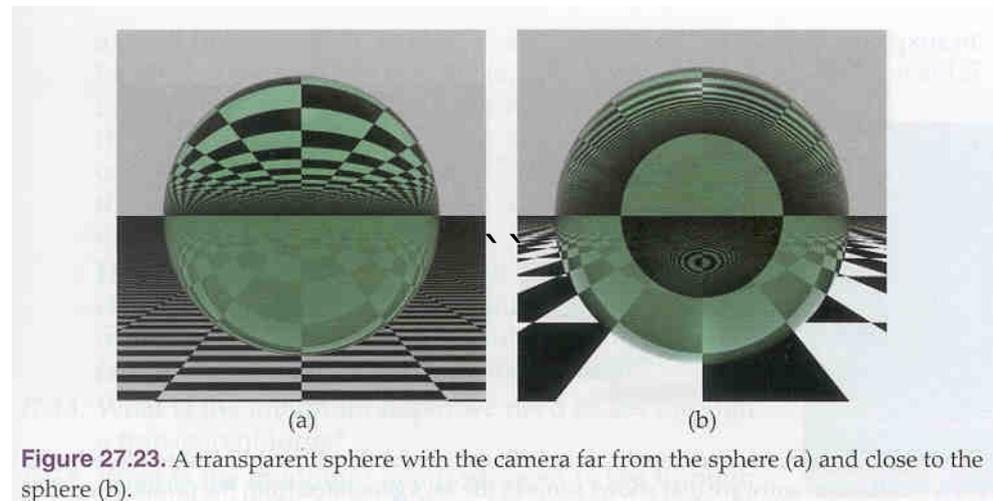


Figure 27.23. A transparent sphere with the camera far from the sphere (a) and close to the sphere (b).

Light movement through sphere

- Magnification

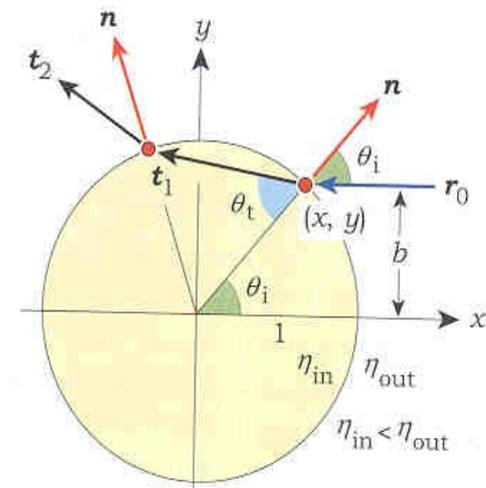


Figure 27.17. Reflected and transmitted rays generated by a ray r_0 that hits a unit sphere with impact parameter b , where the sphere has $\eta < 1$.

- Internal reflection

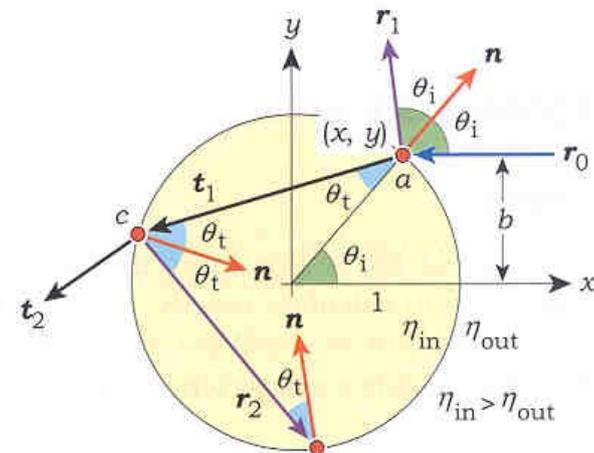


Figure 27.11. Reflected and transmitted rays generated by a ray r_0 that hits a unit sphere with impact parameter b . The lengths of the (unit) normals and the sphere are not drawn on the same scale.

Realistic Transparency

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

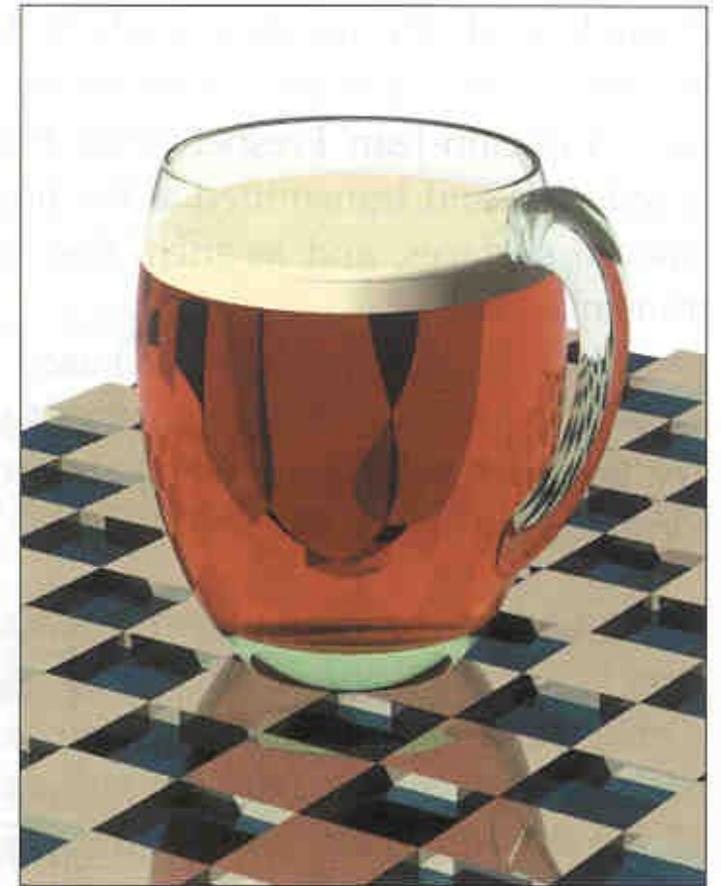


Image courtesy of John Avery

Reflectance and Attenuation

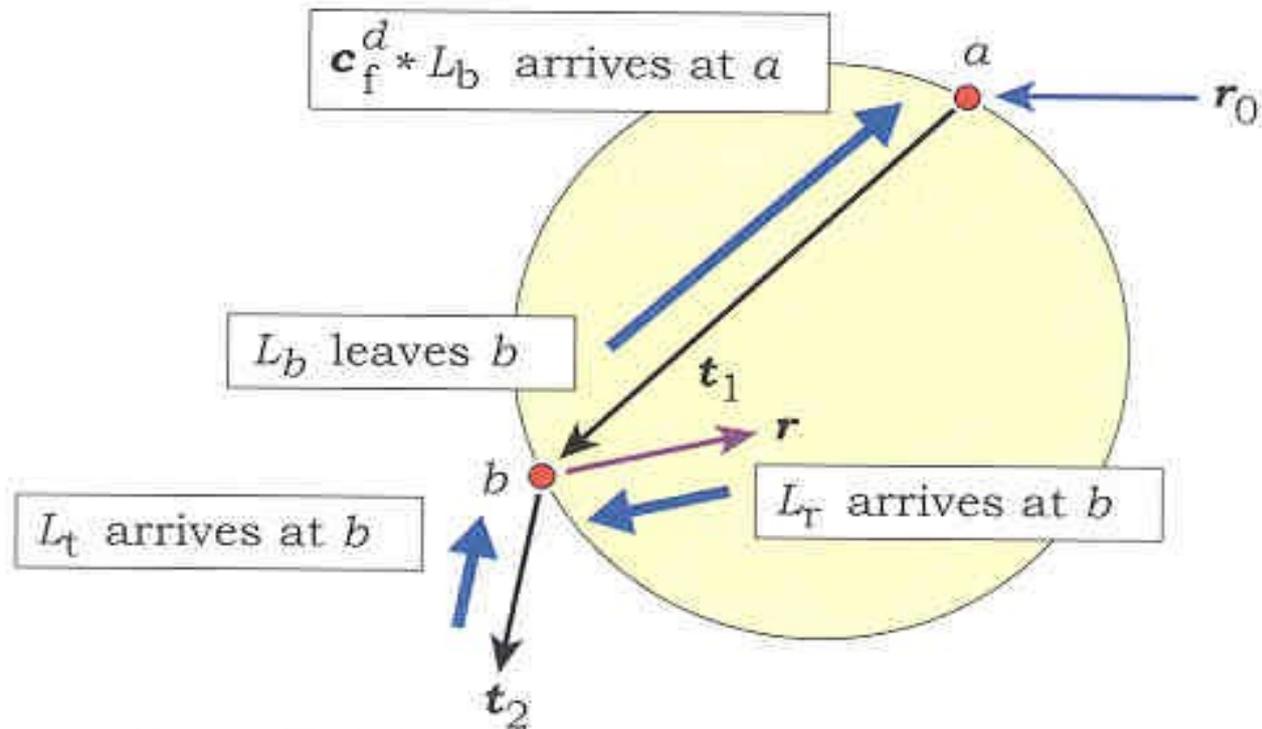


Figure 28.4. Radiance attenuation in a dielectric.

Multiple Internal Reflections

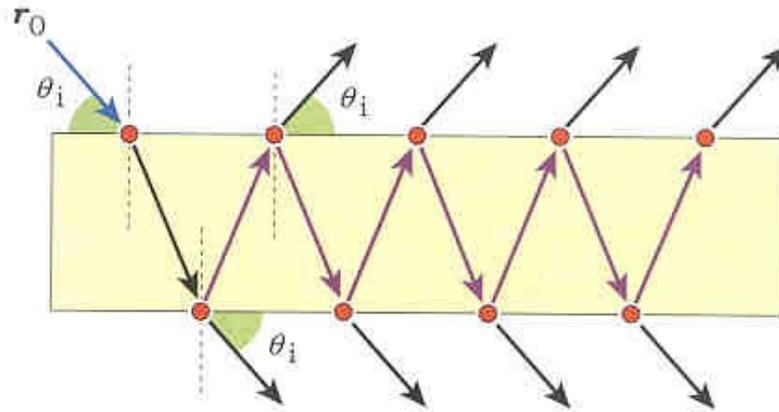
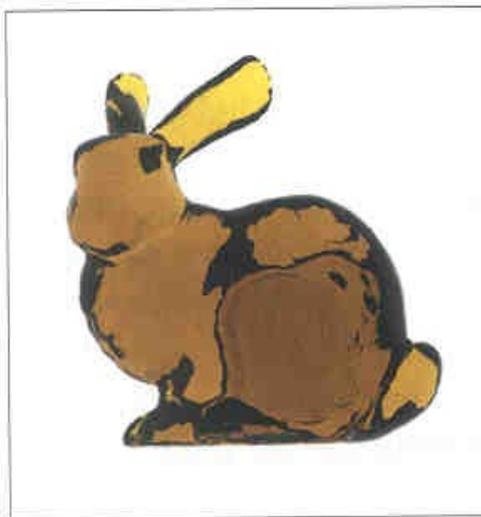
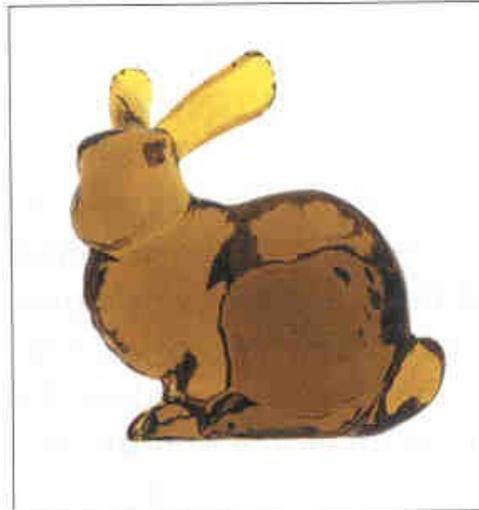


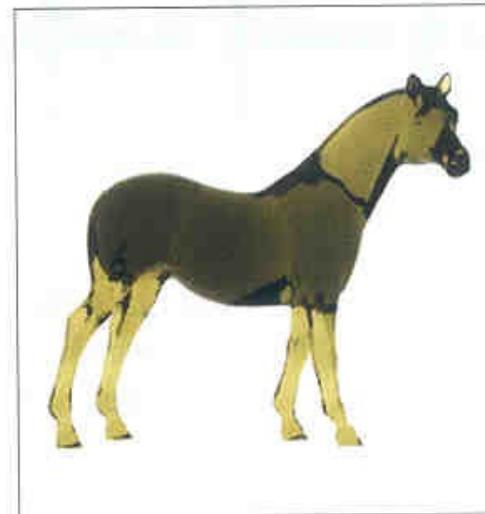
Figure 28.19. A transparent box with multiple reflected and transmitted rays.



(a)



(b)



(c)

Figure 28.12. (a) Stanford bunny rendered with $c_r = (0.65, 0.45, 0)$ and $\text{max_depth} = 2$; (b) $\text{max_depth} = 10$; (c) horse model rendered with $c_r = (0.65, 0.65, 0.1)$ and $\text{max_depth} = 10$.

Colored Beaker

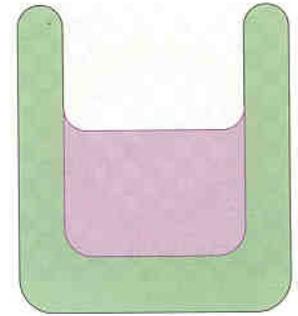
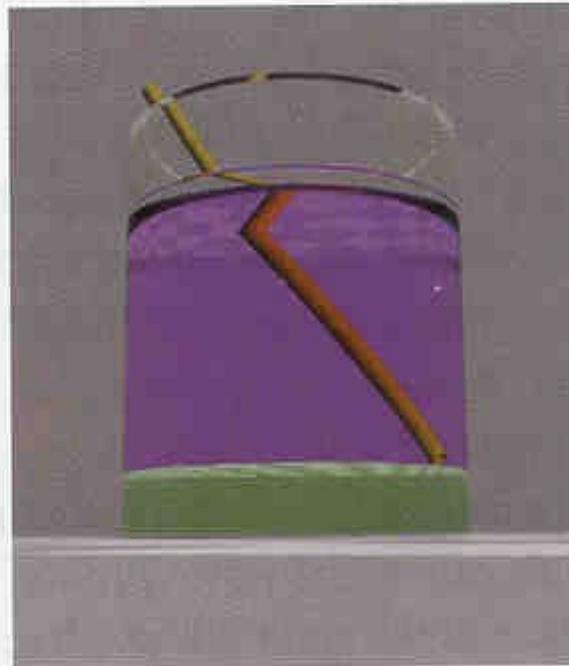


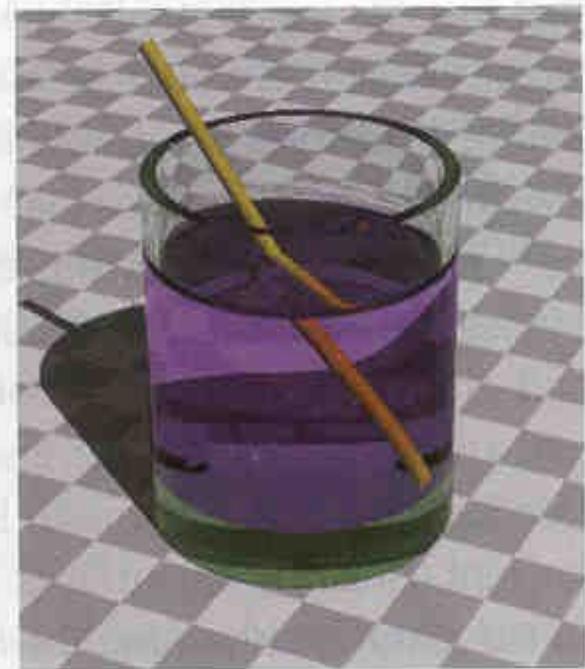
Figure 28.37. A more sophisticated glass of water has a curved top, rounded edges, and a meniscus for the water.



(a)



(b)



(c)

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 reflections
 - Refraction

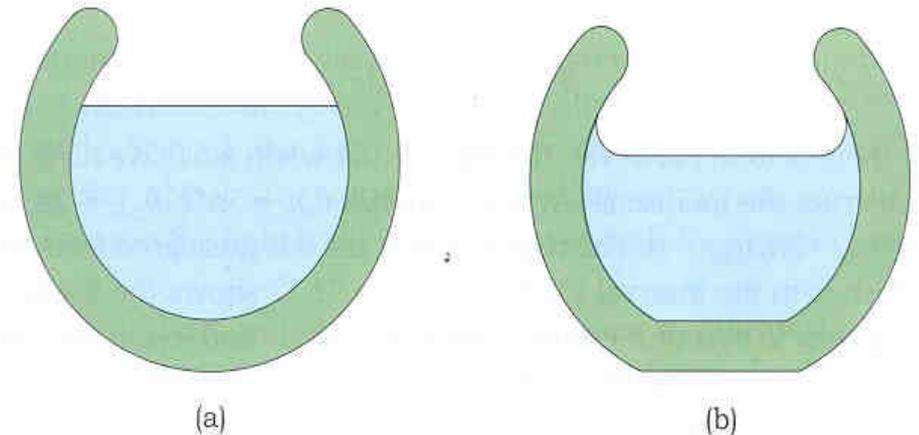


Figure 28.39. (a) Basic fishbowl; (b) fishbowl with flat base and meniscus.

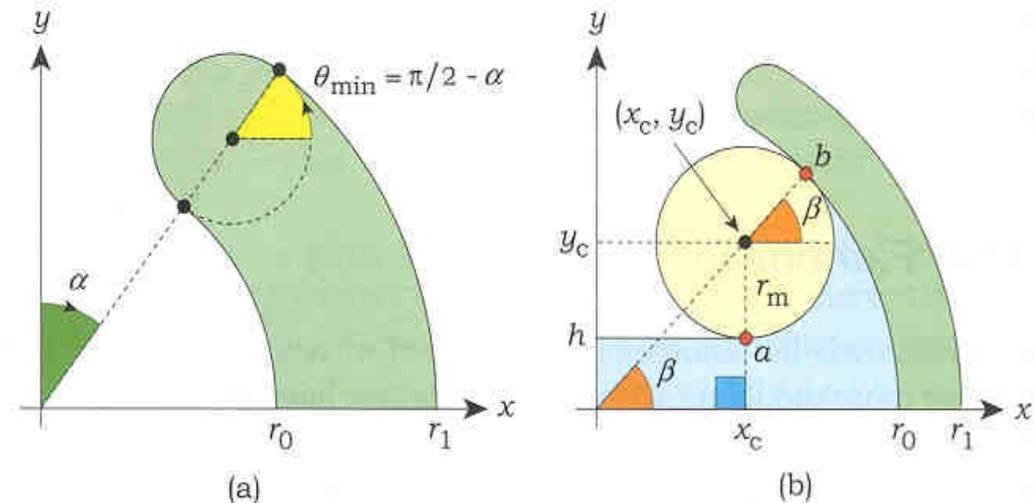
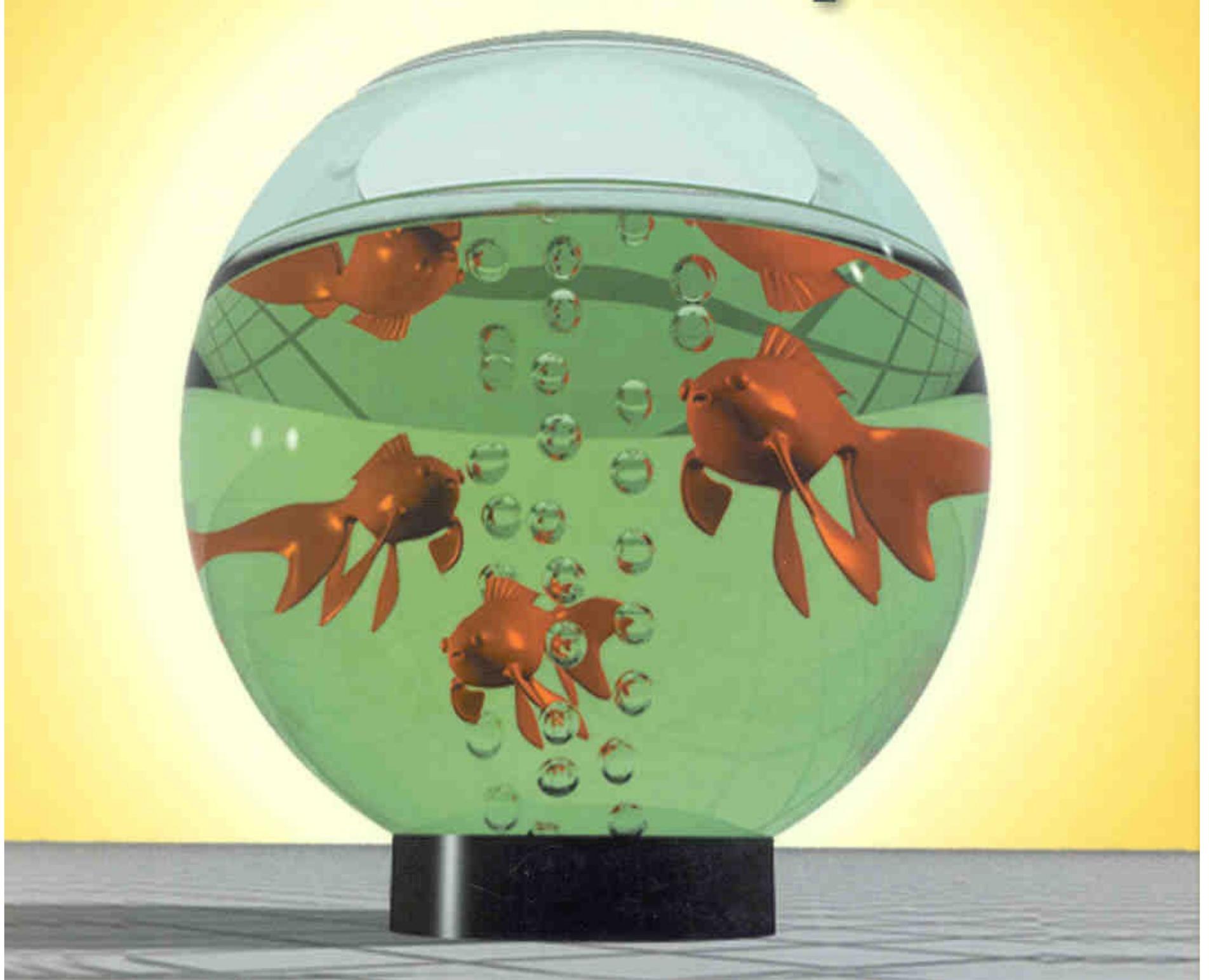


Figure 28.40. (a) Construction of the rim; (b) construction of the meniscus.



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

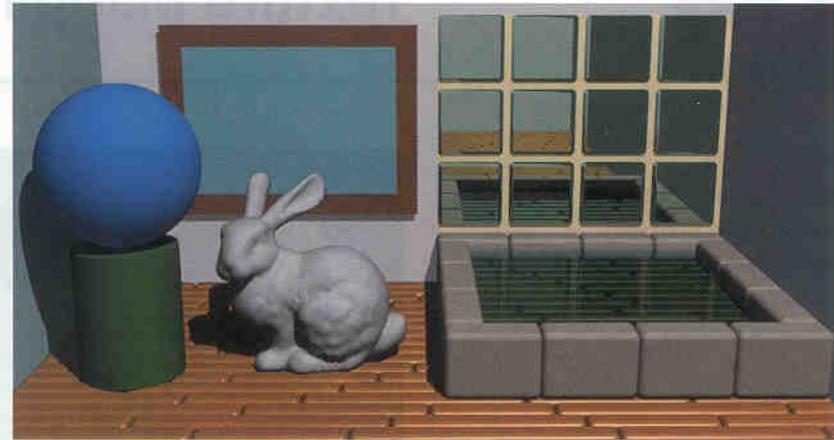
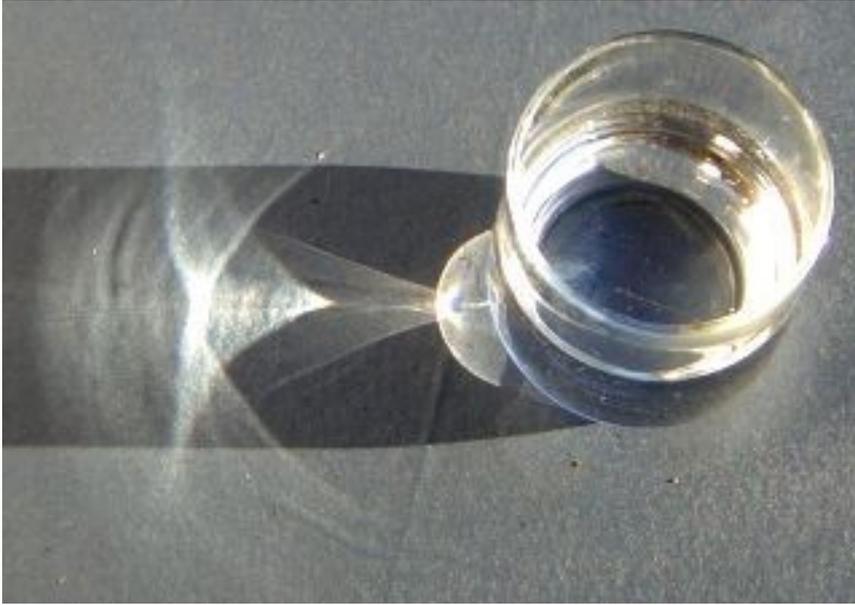


Figure 29.1. Interior scene rendered with no textures.

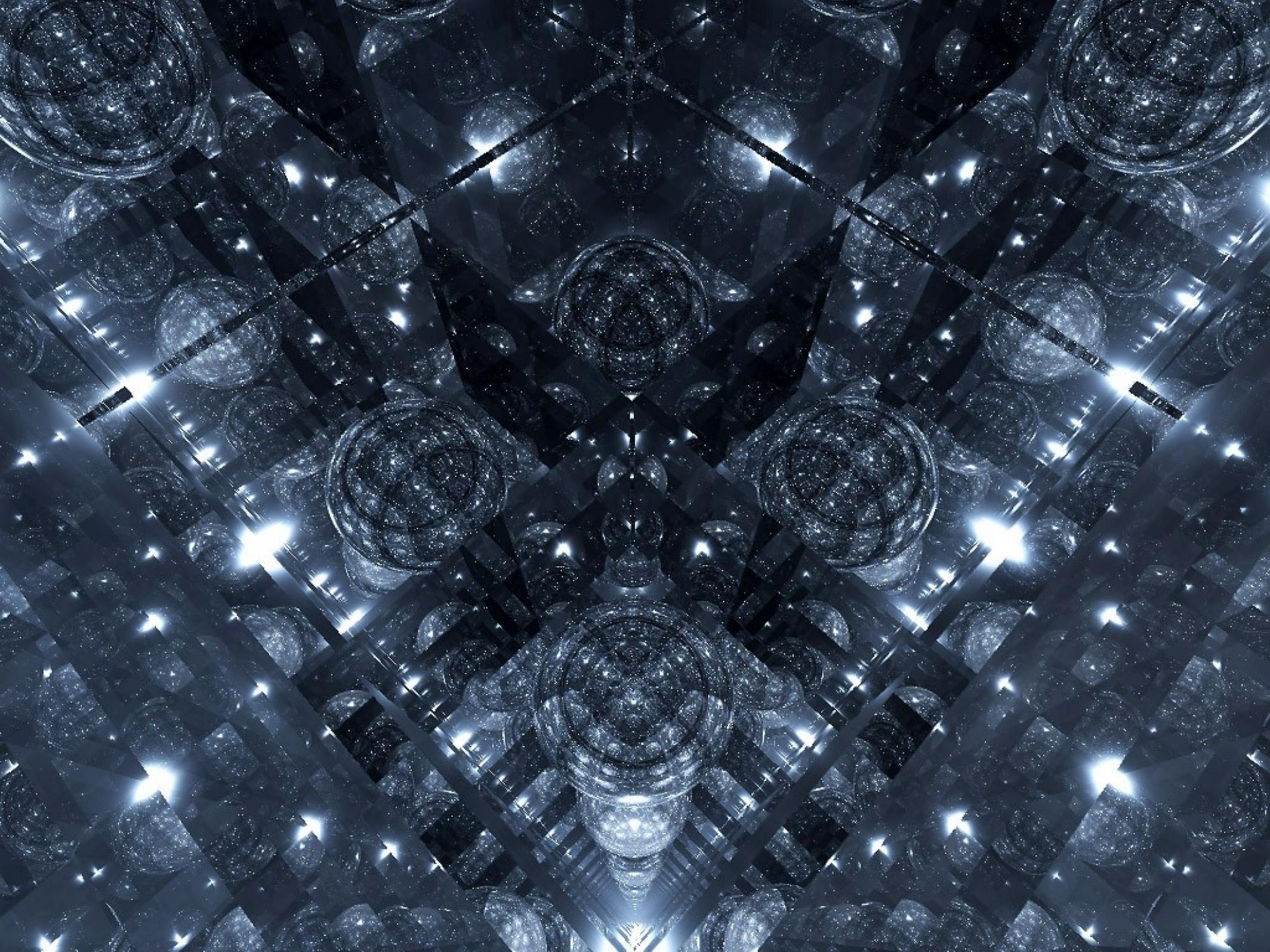


Figure 29.2. Same scene as in Figure 29.1 but rendered with a variety of textures. The water surface is Ken Musgrave's water bump map, as described in Musgrave (2003b).

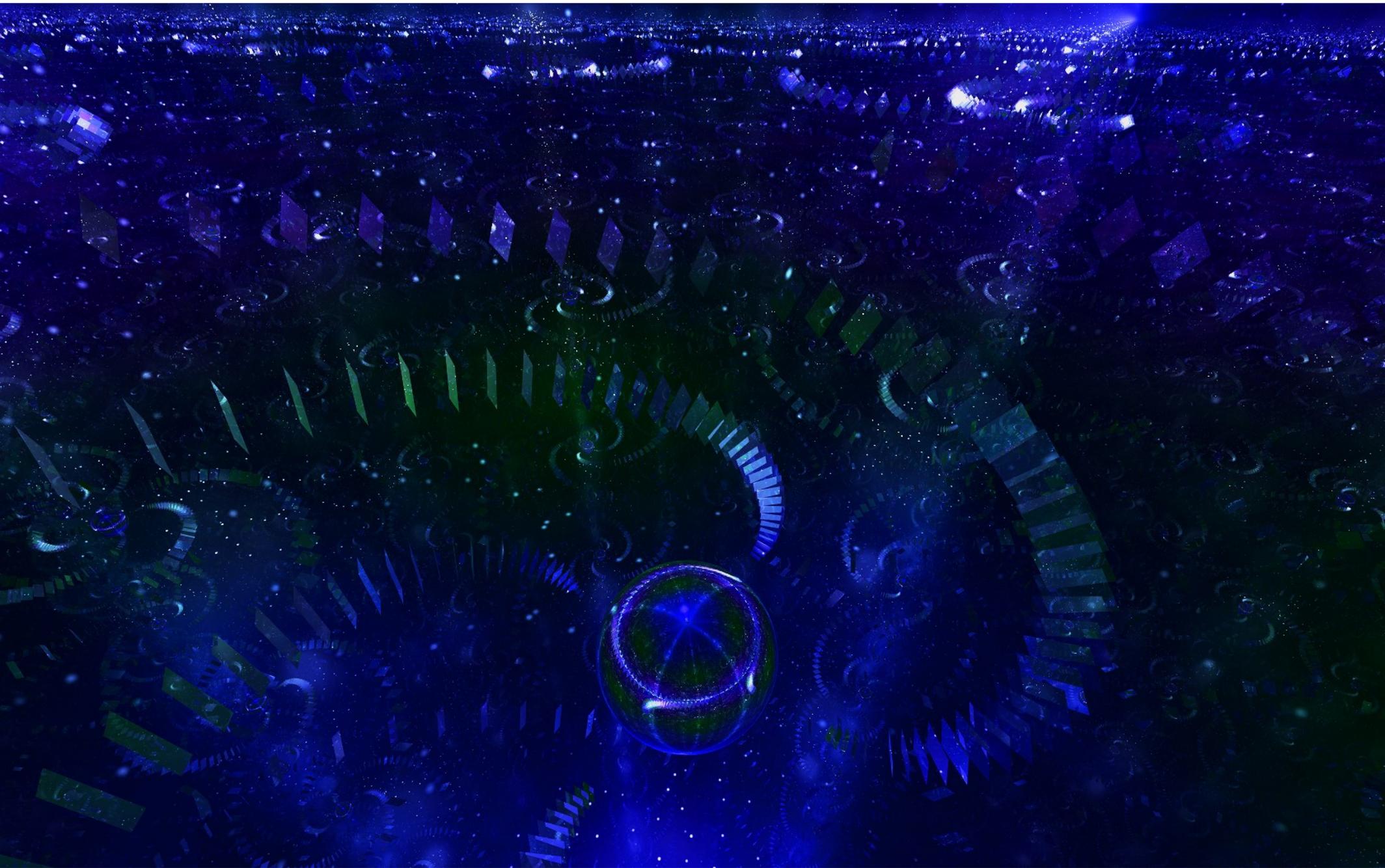
Caustics

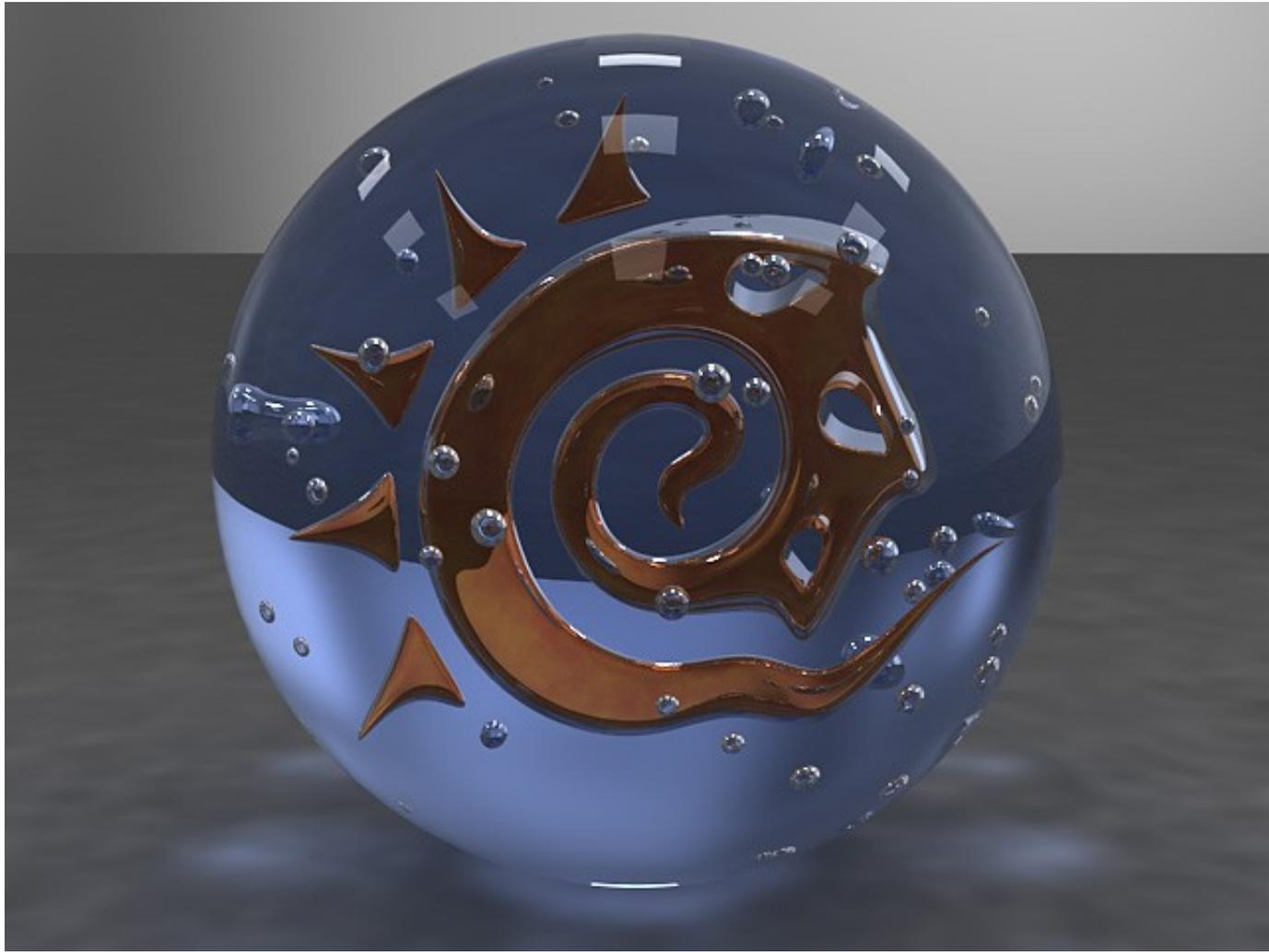


Tim Dunn's Gallery









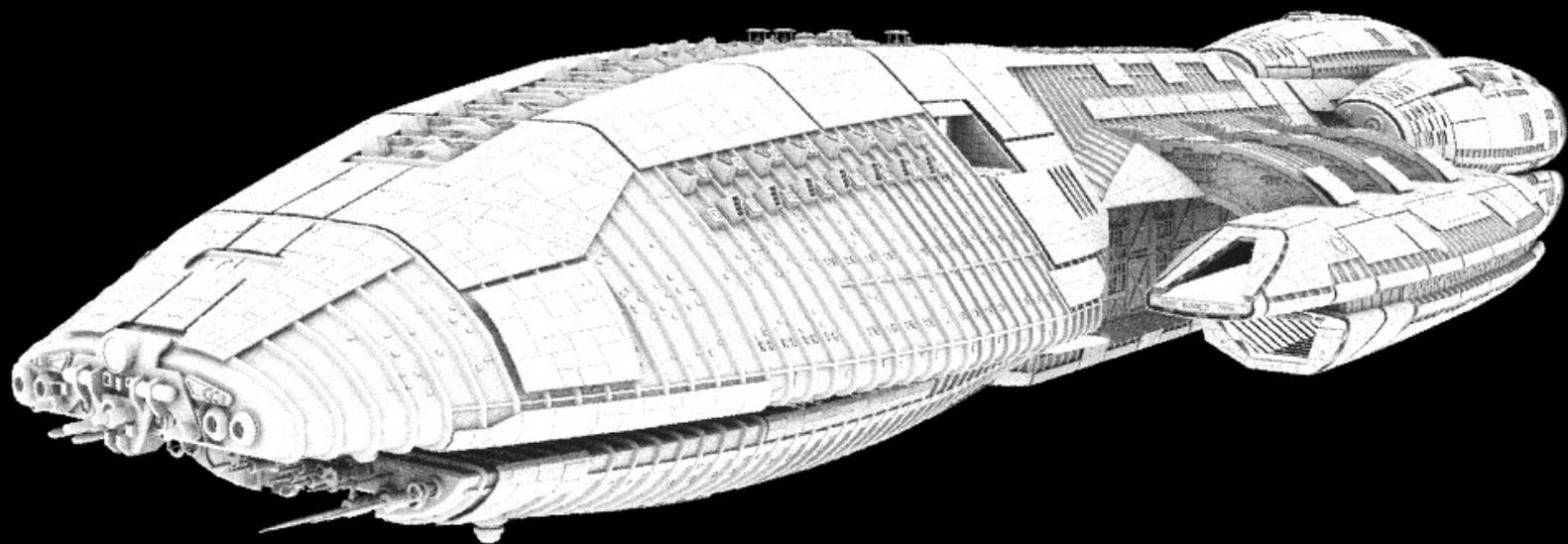


Production Ray Tracing

Tim Dunn

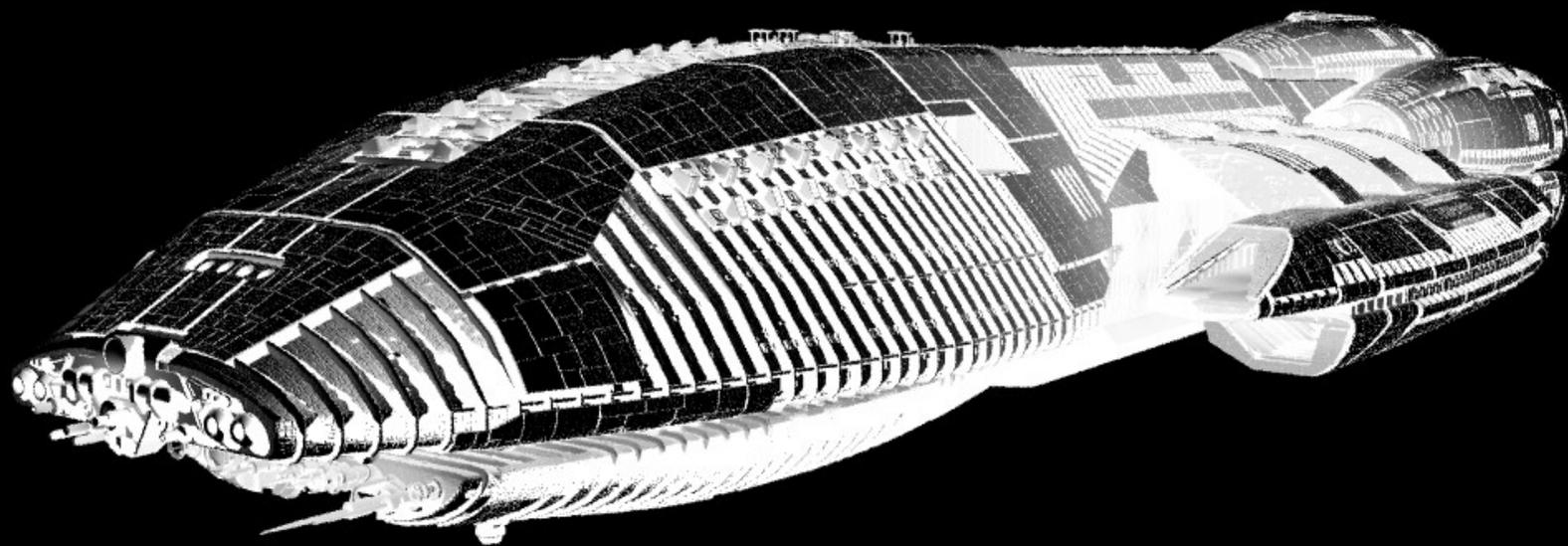


Raw Render Pass

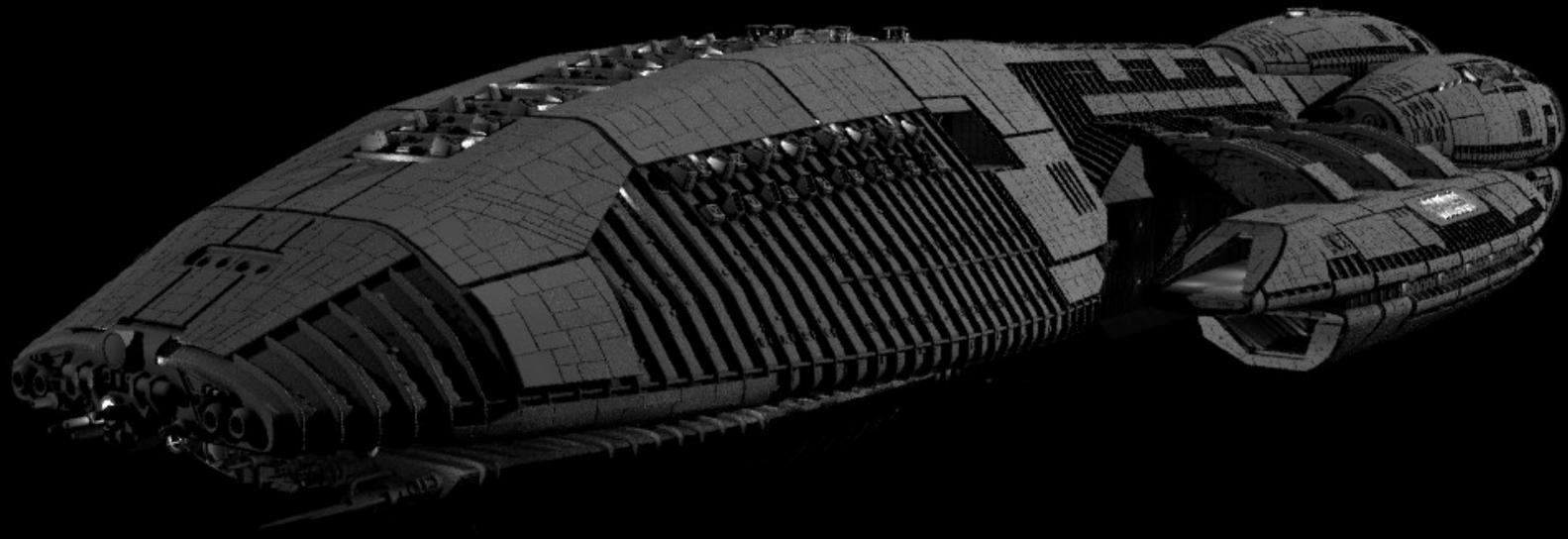


Ambient Occulsion Pass

Luminosity Pass



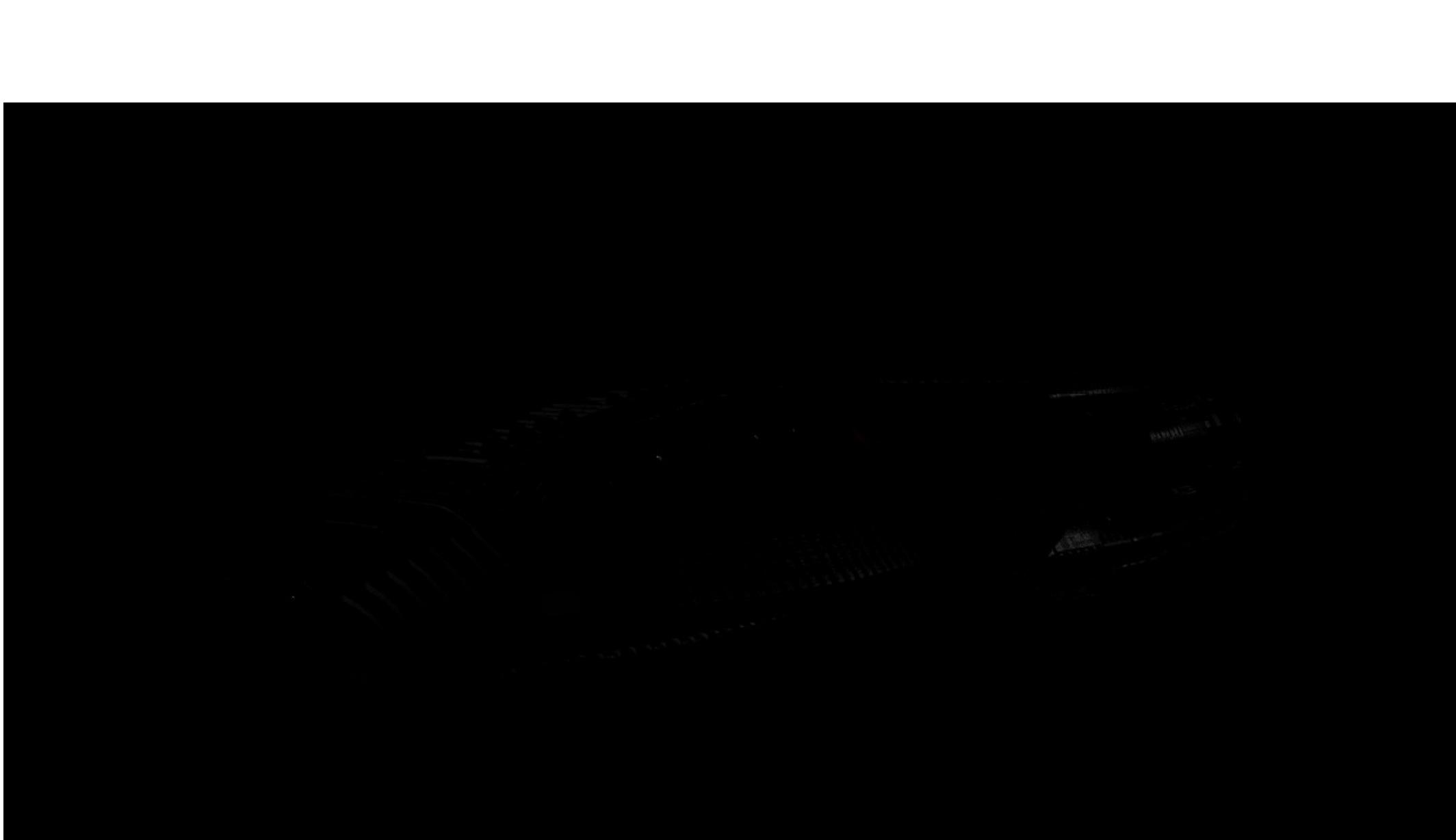
Shadow Pass



Diffuse Pass



Dissue Lighting Pass



Specular Color Pass



Background Plate Pass



Final Composite