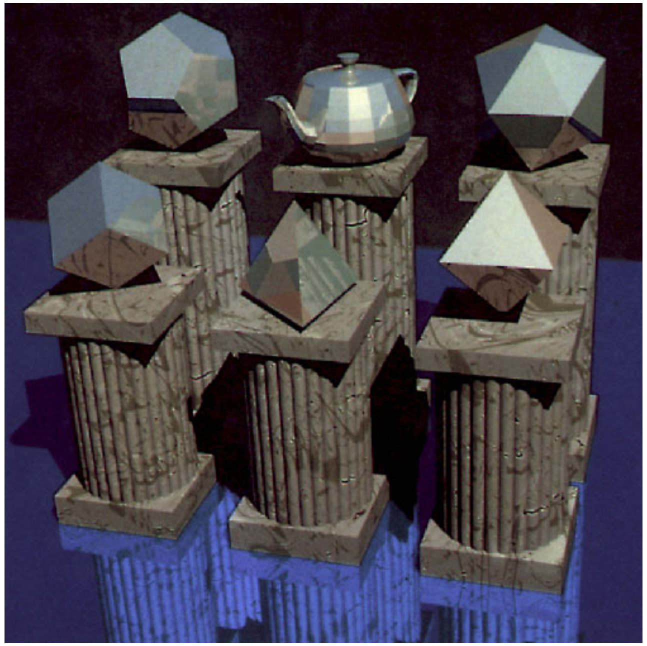
Ray Tracing



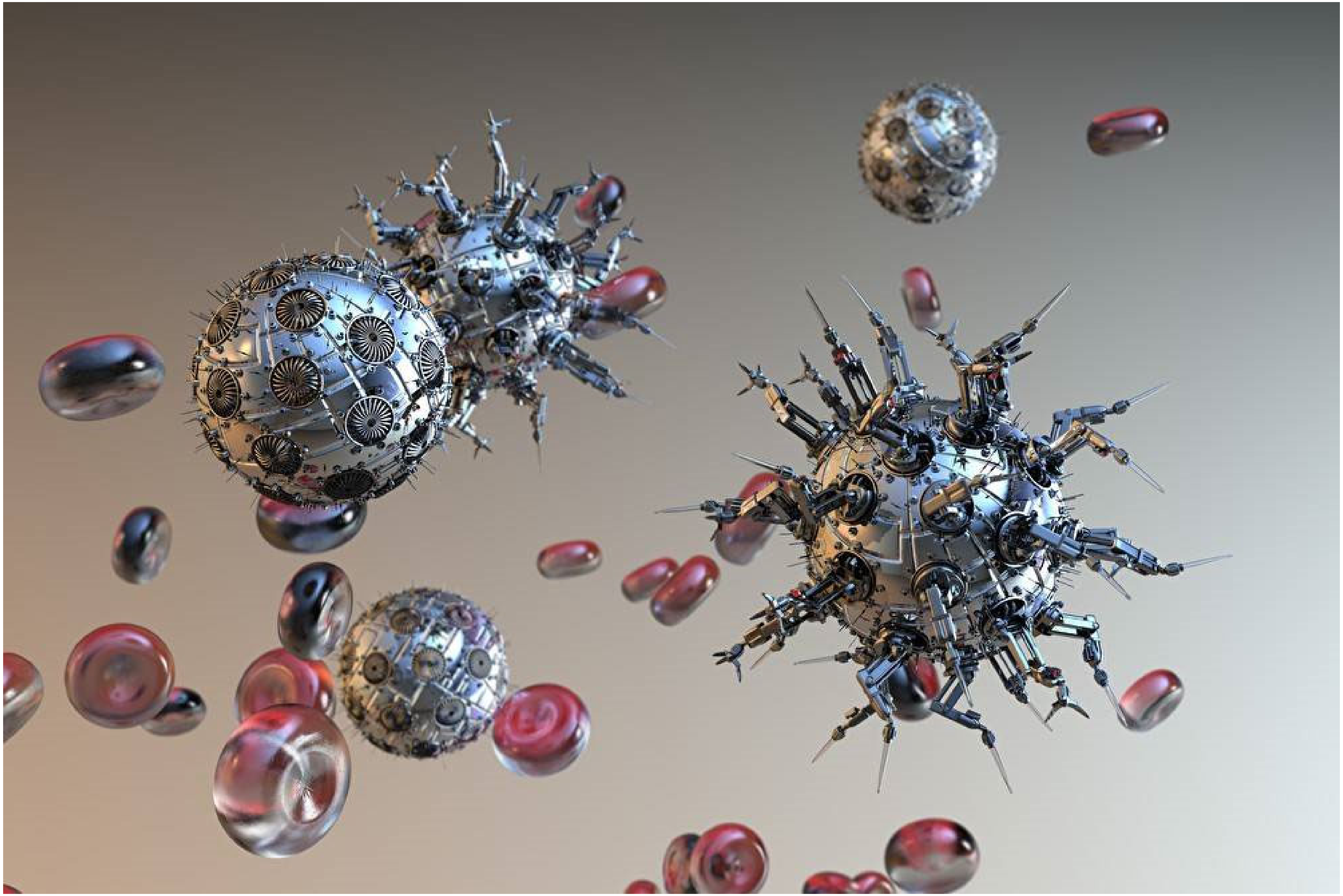
MIT EECS 6.837

Most slides are taken from Frédo Durand and Barb Cutler

Some slides courtesy of Leonard McMillan


BONSAIS - Jaime Vives Piqueres,

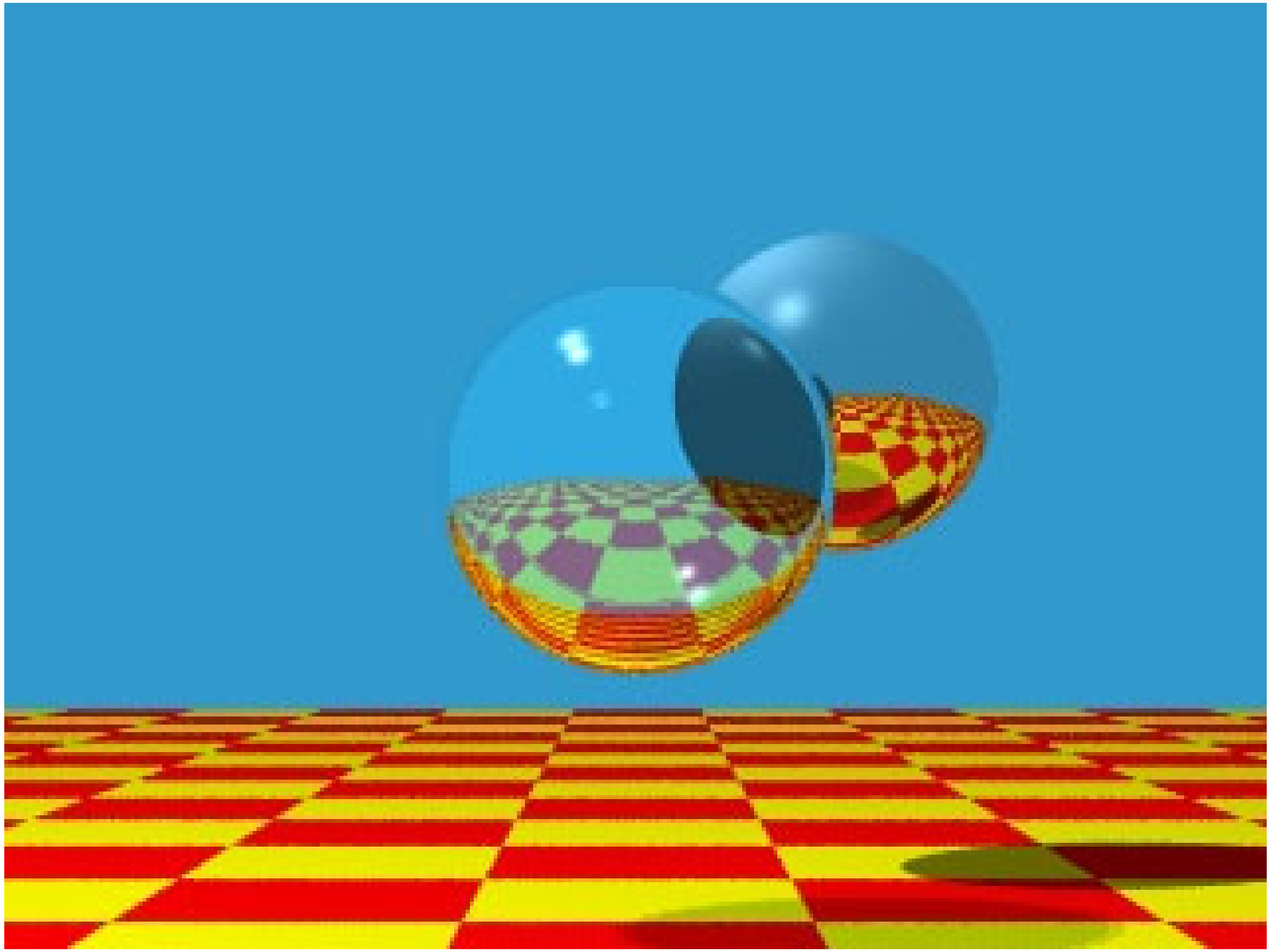

Pov
is
great!
DELICIOUS
PRIMITIVES
POV
FLAKES



Ray Tracing

- Ray Tracing kills two birds with one stone:
  - Solves the Hidden Surface Removal problem
  - Evaluates an improved global illumination model
    - shadows
    - ideal specular reflections
    - ideal specular refractions
  - Enables direct rendering of a large variety of geometric primitives
- Book: A. Glassner, An Introduction to Ray Tracing
- Web: http://www.cs.cf.ac.uk/Ray.Tracing

Ray Tracing



Recursive ray tracing: Turner Whitted, 1980

Backward Tracing

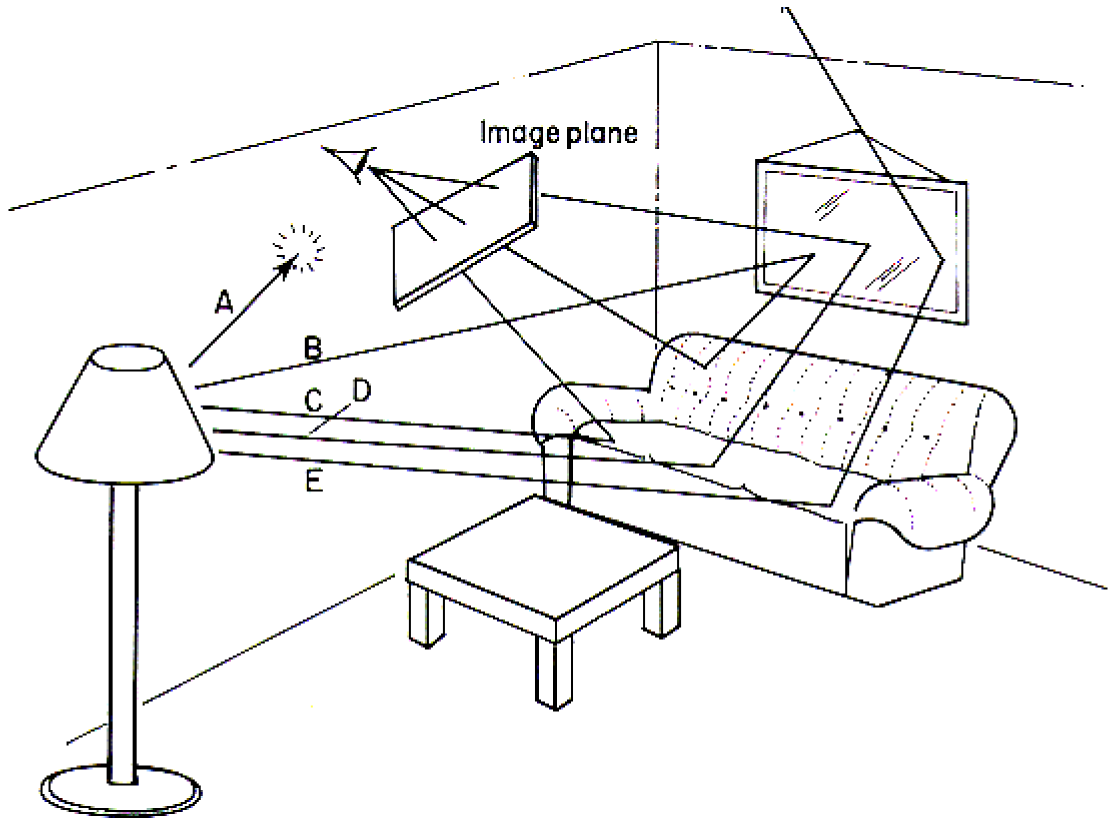
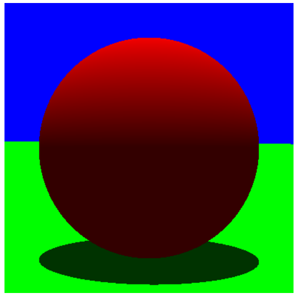


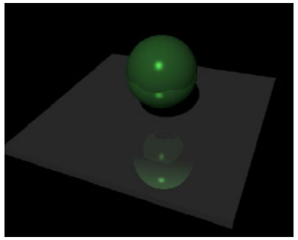
Fig. 5. Some light rays (like A and E) never reach the image plane at all. Others follow simple or complicated routes.

Overview of today

- Shadows

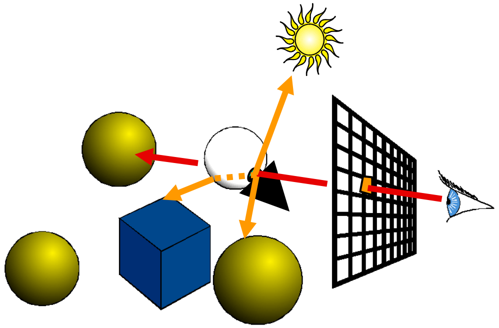


- Reflection



- Refraction

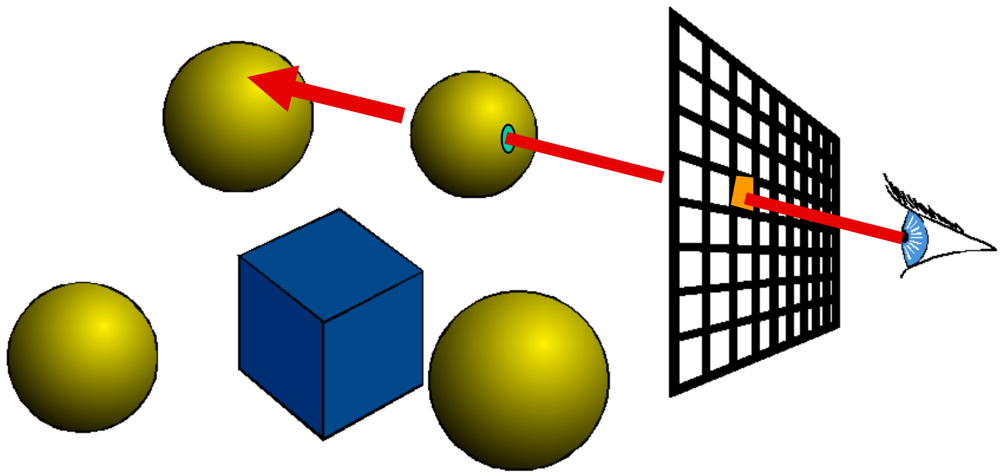
- Recursive Ray Tracing



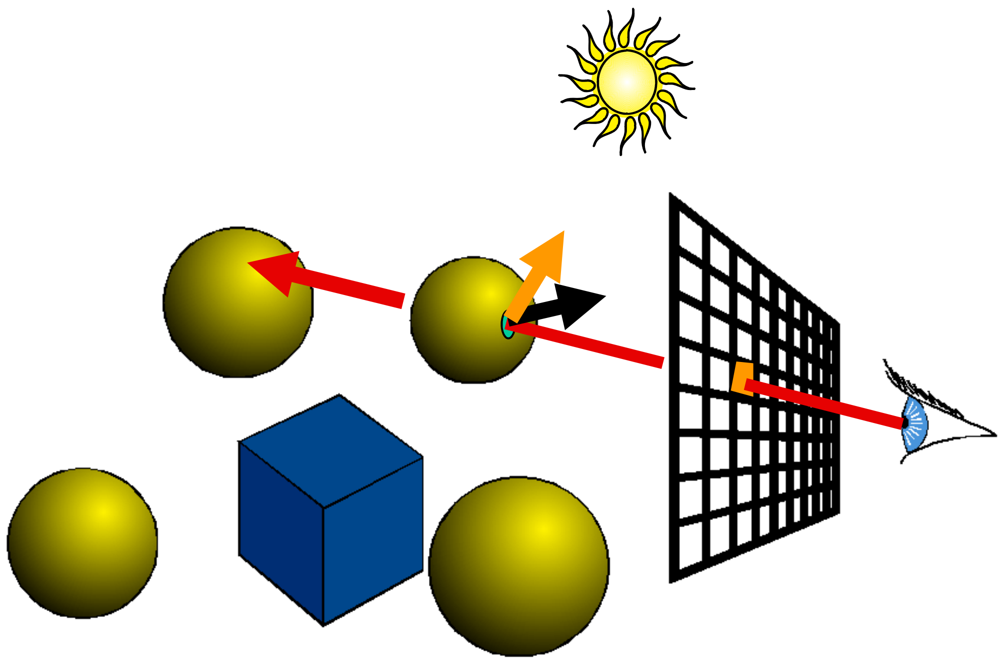
Ray Casting (a.k.a. Ray Shooting)

```
For every pixel (x,y)
  Construct a ray from the eye
  color[x,y]=castRay(ray)
```

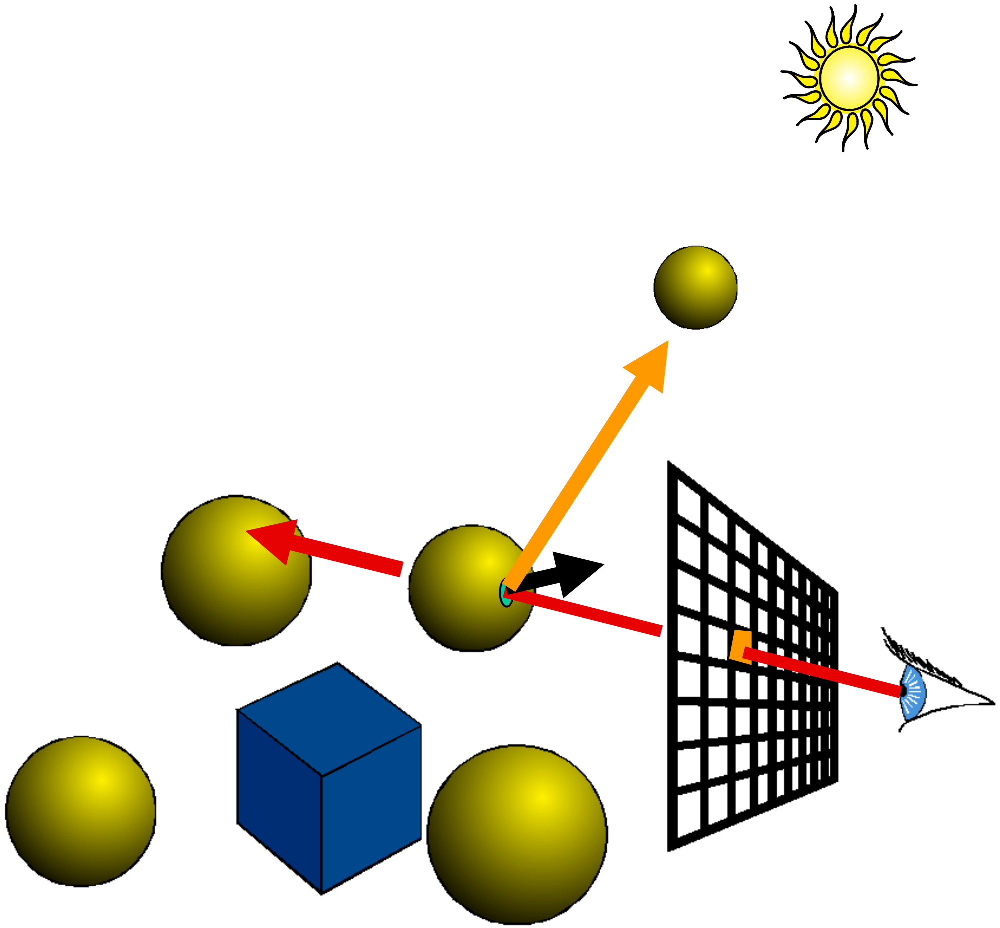
- Complexity?
  - O(n * m)
  - n: number of objects, m: number of pixels



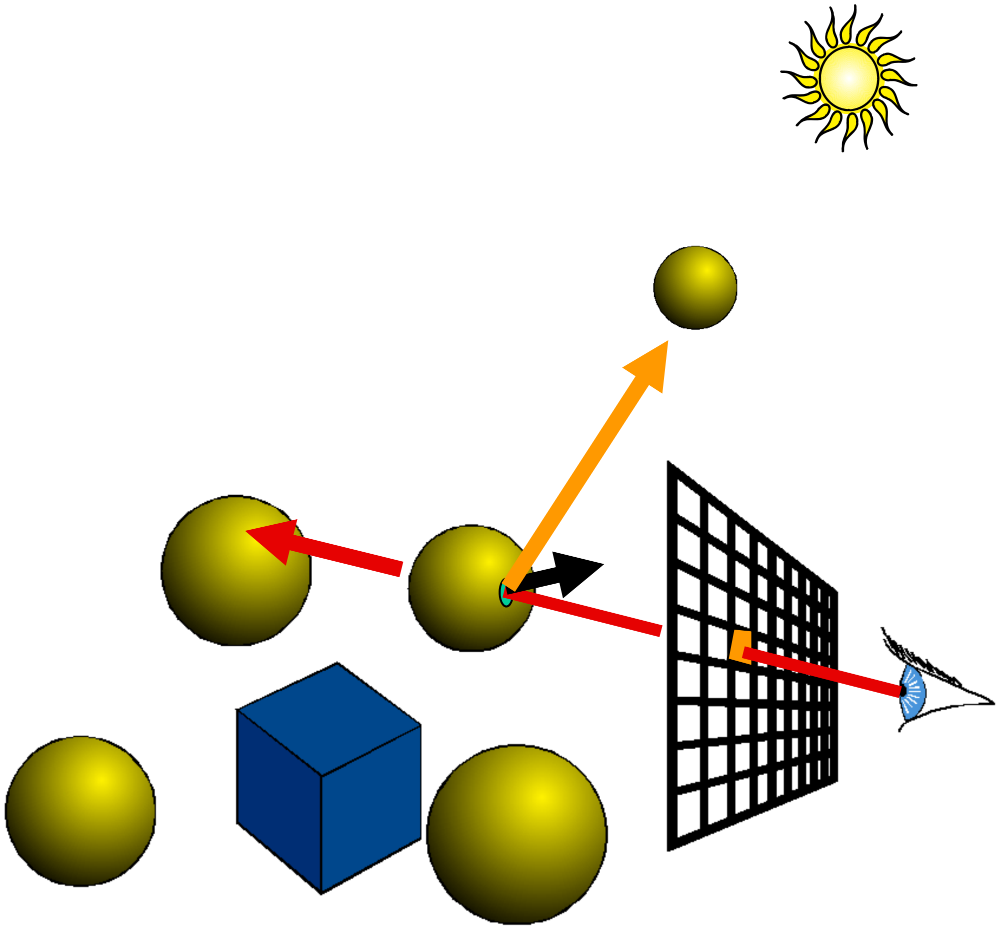
Ray Casting with diffuse shading

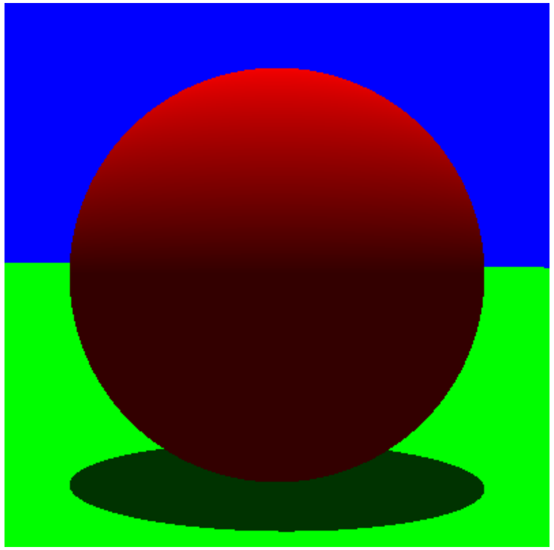


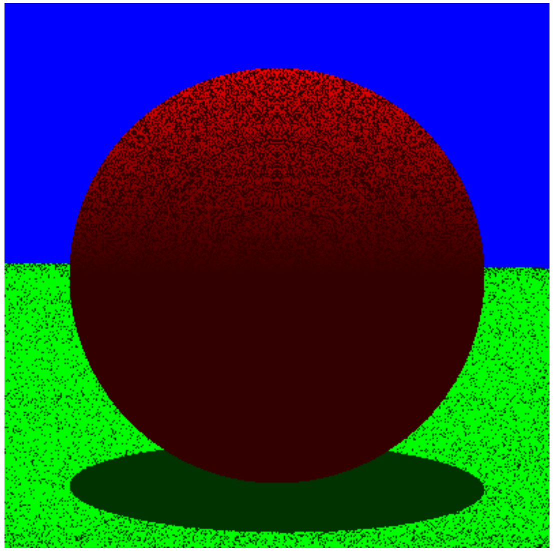
Shadows



Shadows

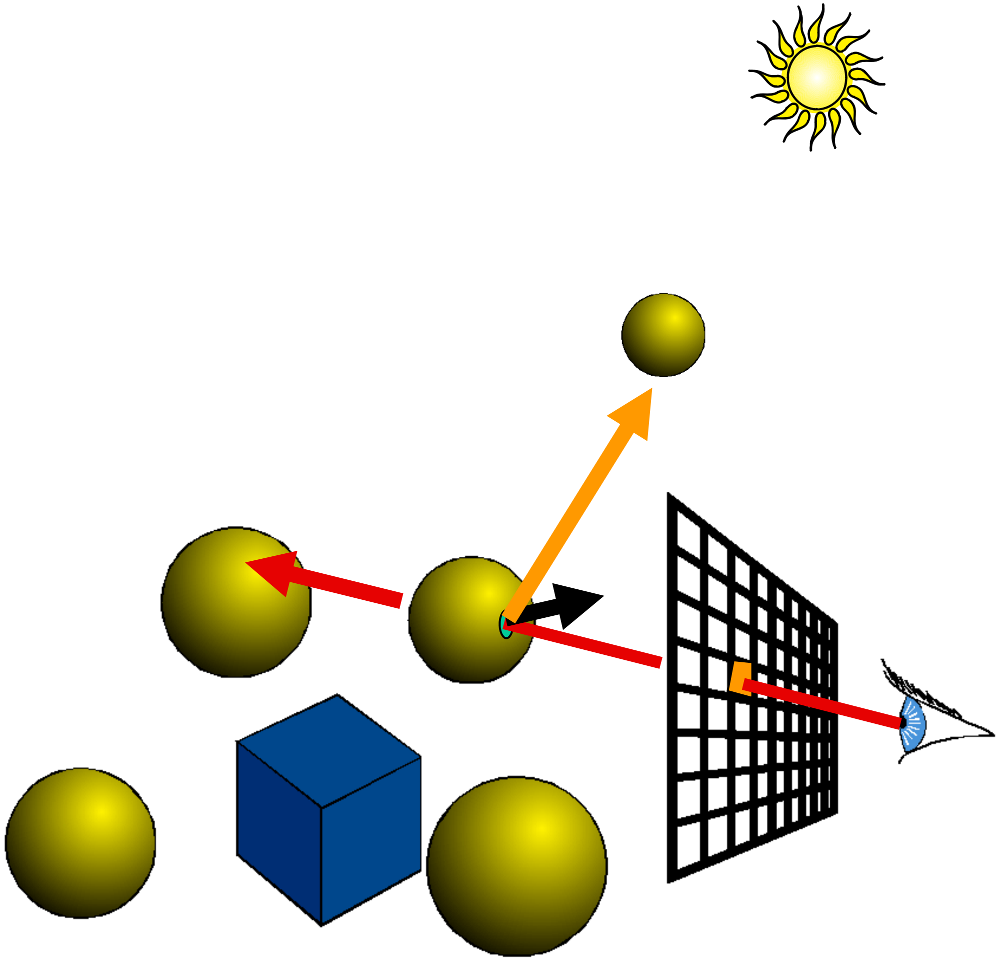






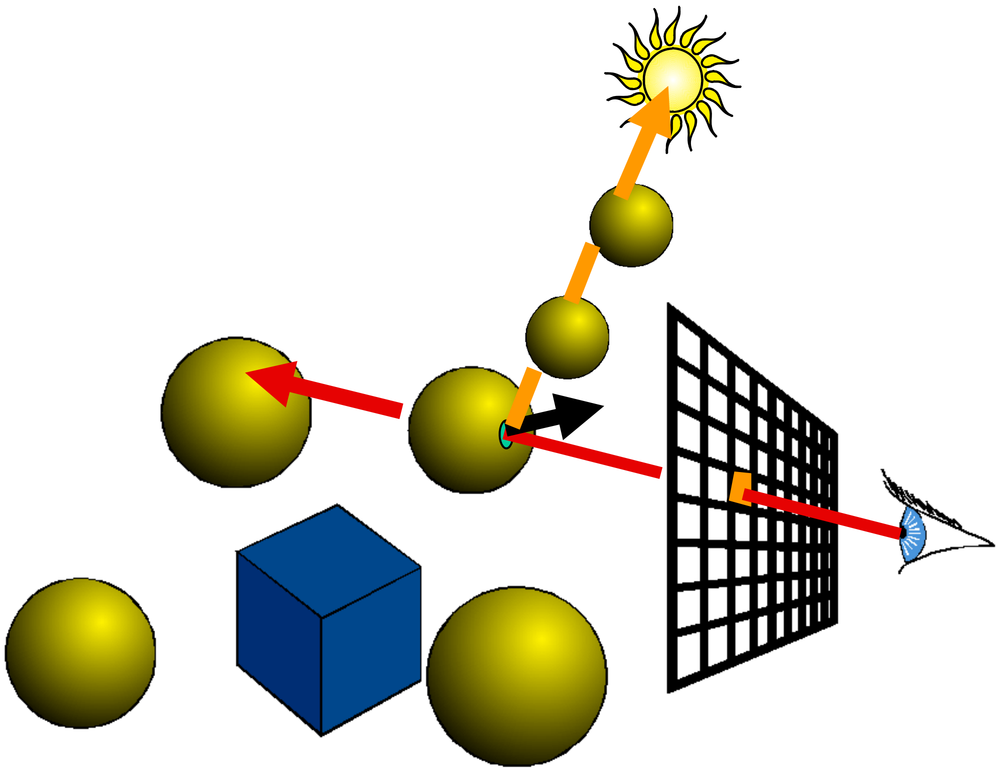
Shadow optimization

- Shadow rays are special
- How can we accelerate our code?

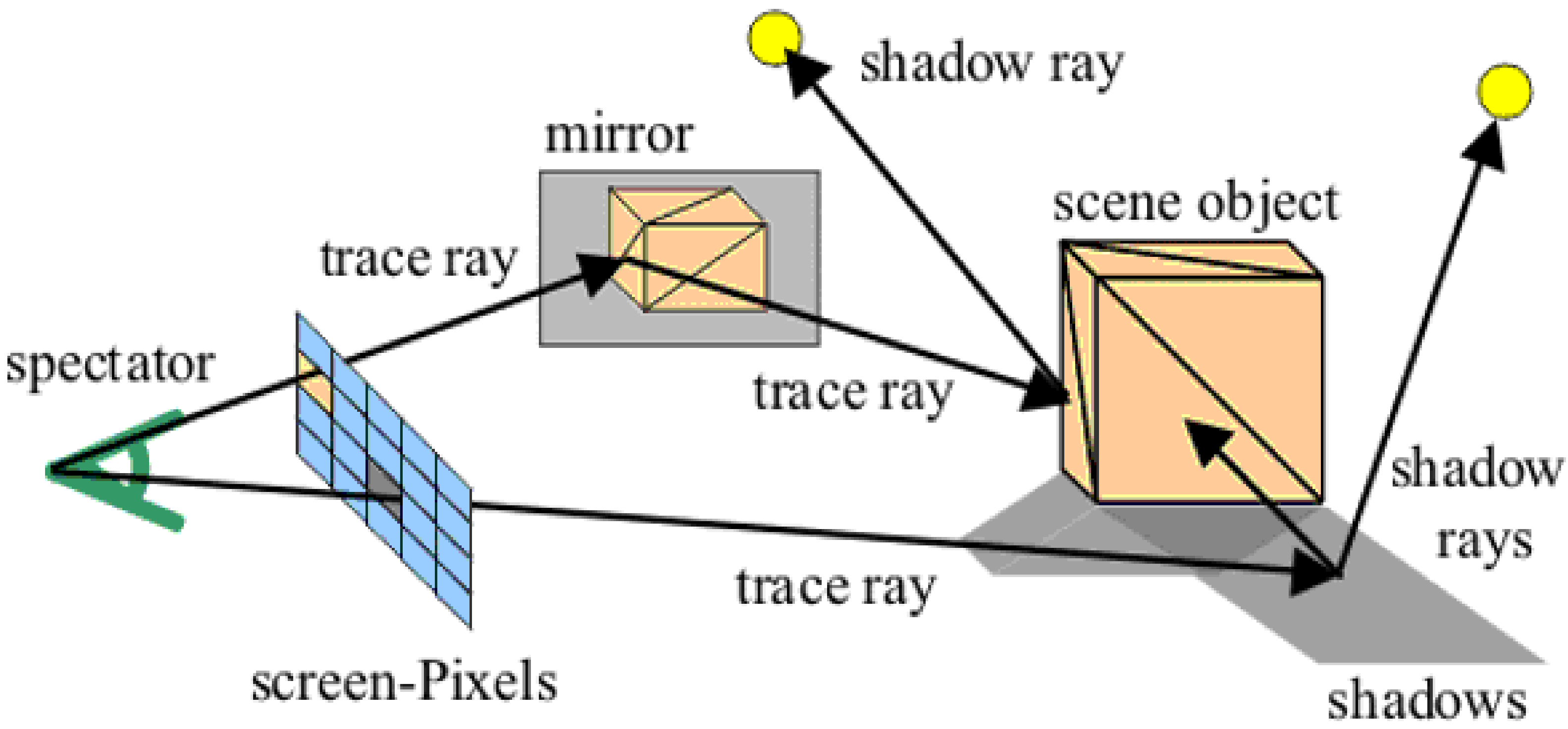


Shadow optimization

- We only want to know whether there is an intersection, not which one is closest
  - Stops at first intersection

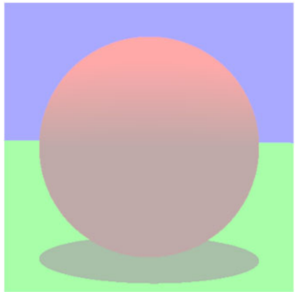


Recursive Ray Tracing

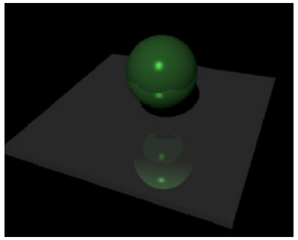


Overview of today

- Shadows

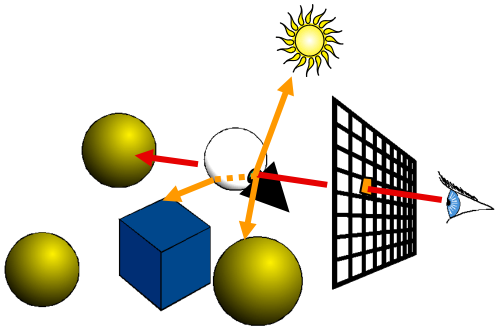


- Reflection



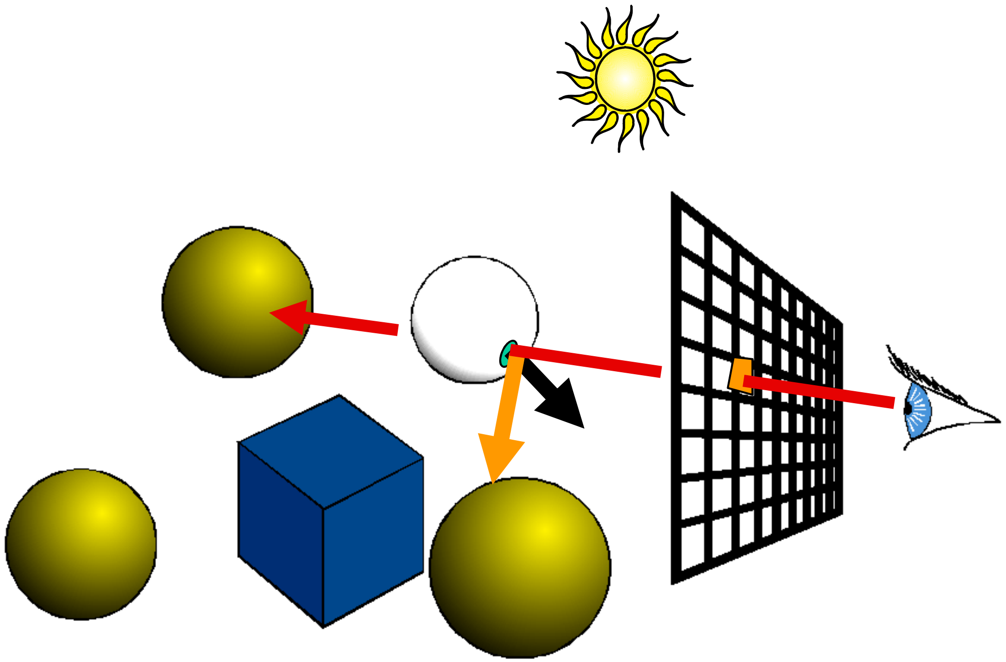
- Refraction

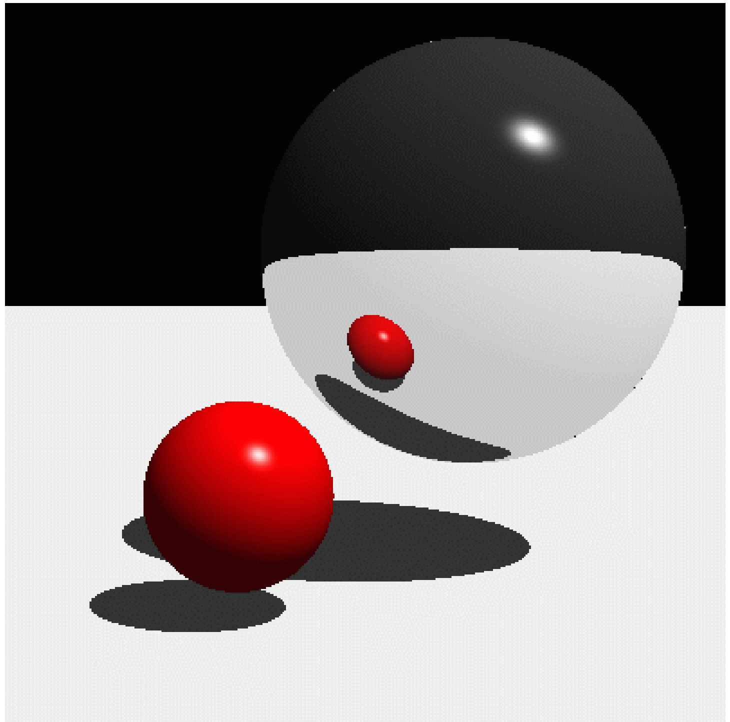
- Recursive Ray Tracing



Mirror Reflection

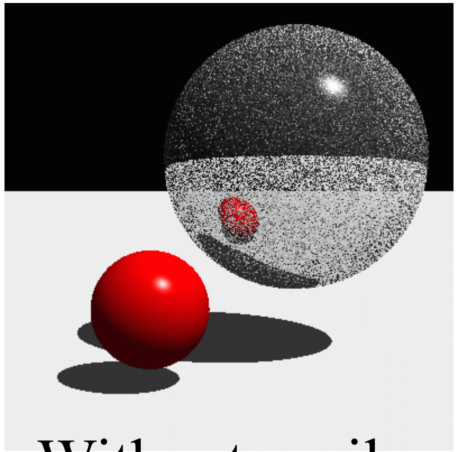
- Compute mirror contribution
- Cast ray in direction symmetric wrt normal
- Multiply by reflection coefficient (color)



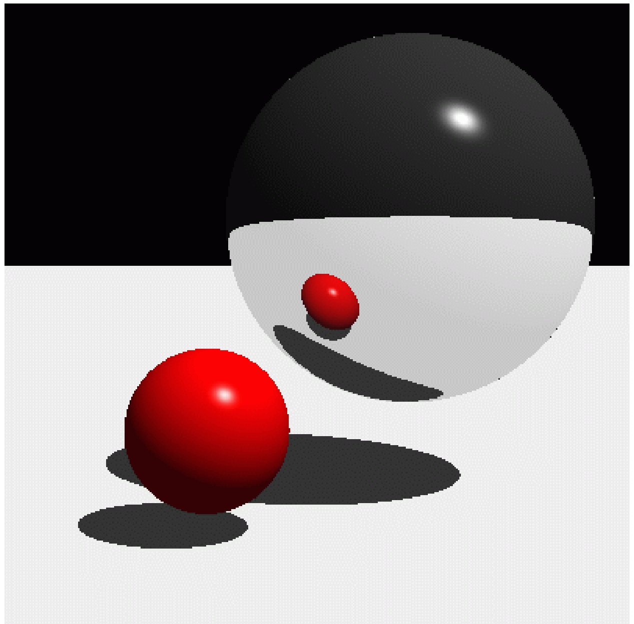


Mirror Reflection

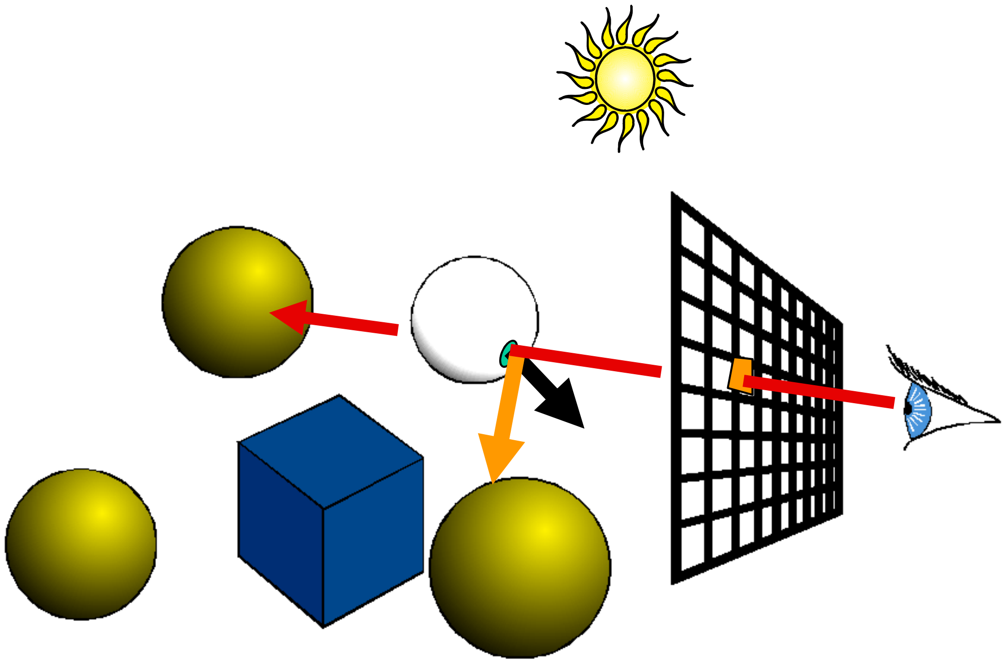
- Don’t forget to add epsilon to the ray



Without epsilon

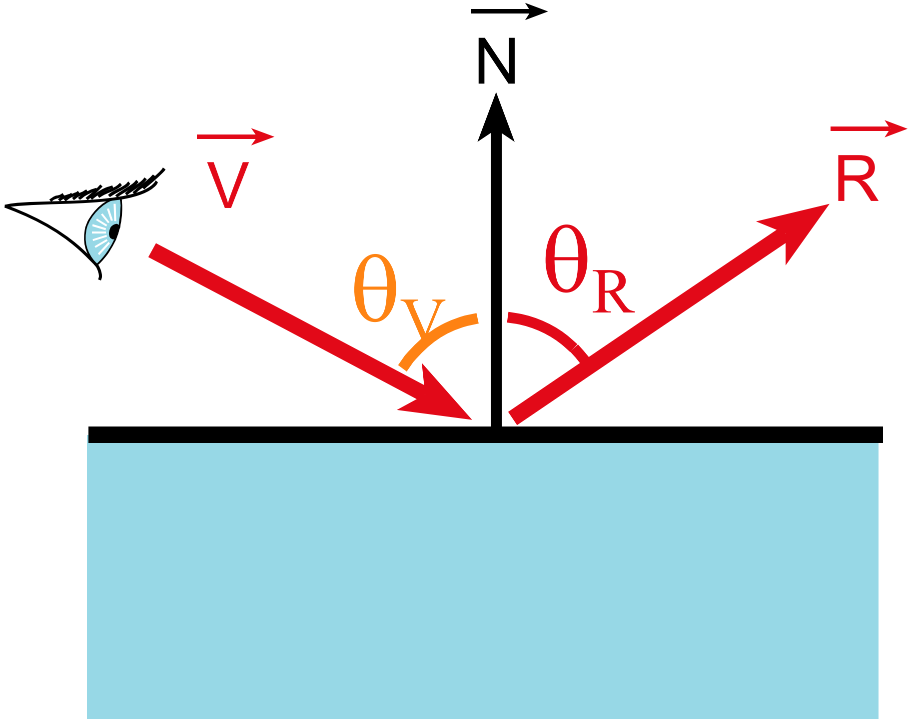


With epsilon



Reflection

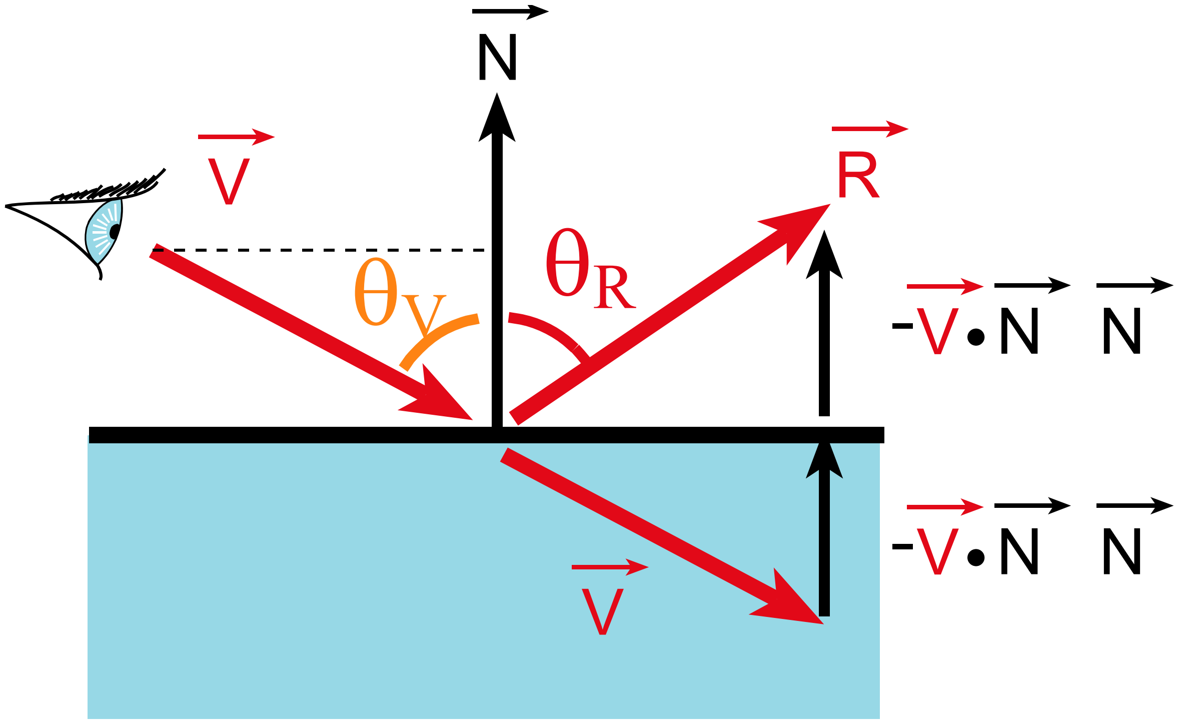
- Reflection angle = view angle



Reflection

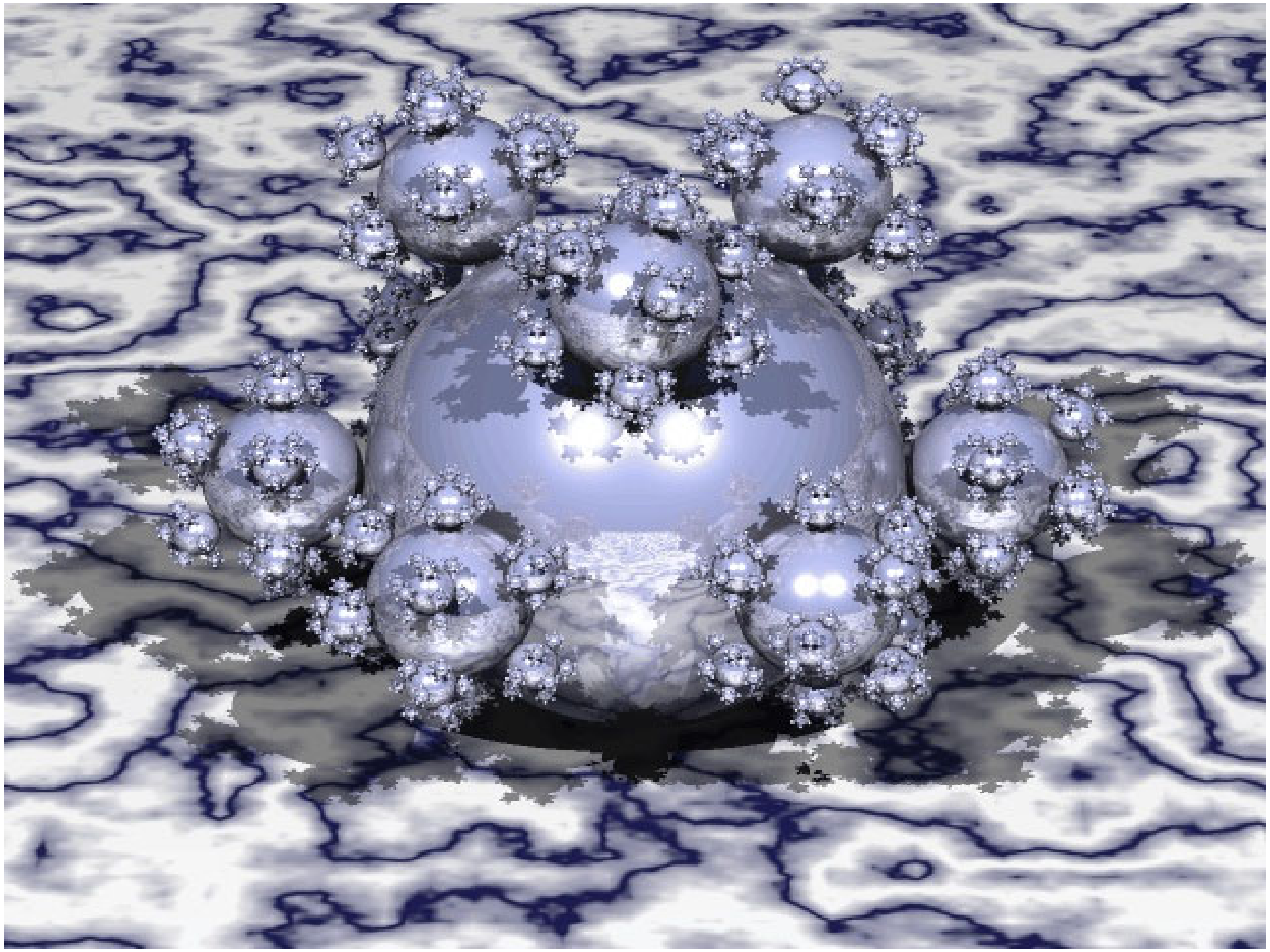
- Reflection angle = view angle

$$\vec{R} = \vec{V} - 2\left(\vec{V} \bullet \vec{N}\right)\vec{N}$$



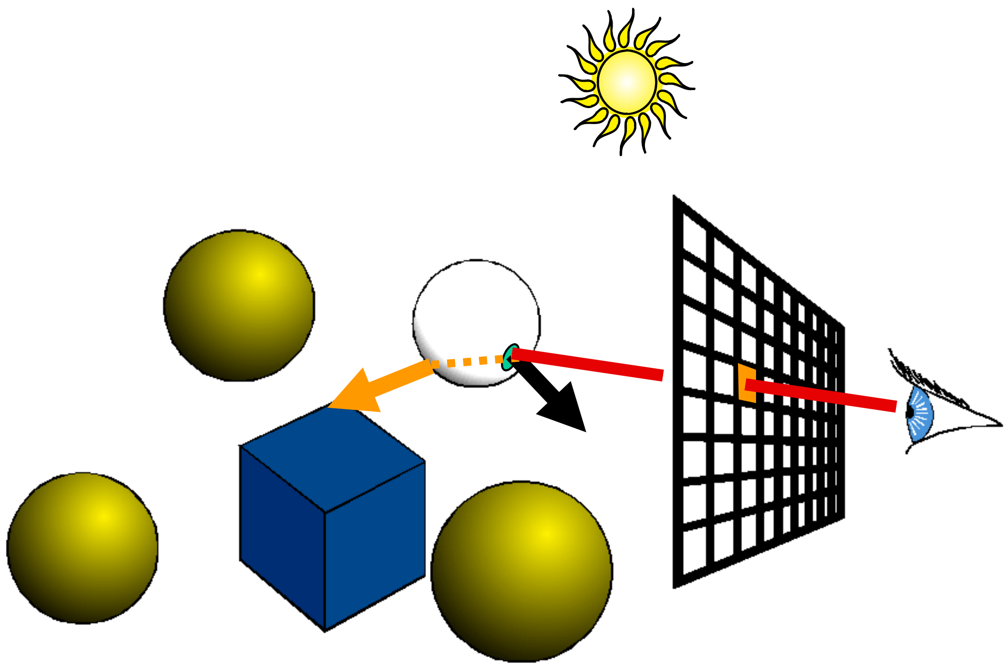
Questions?

- Image by Henrik Wann Jensen



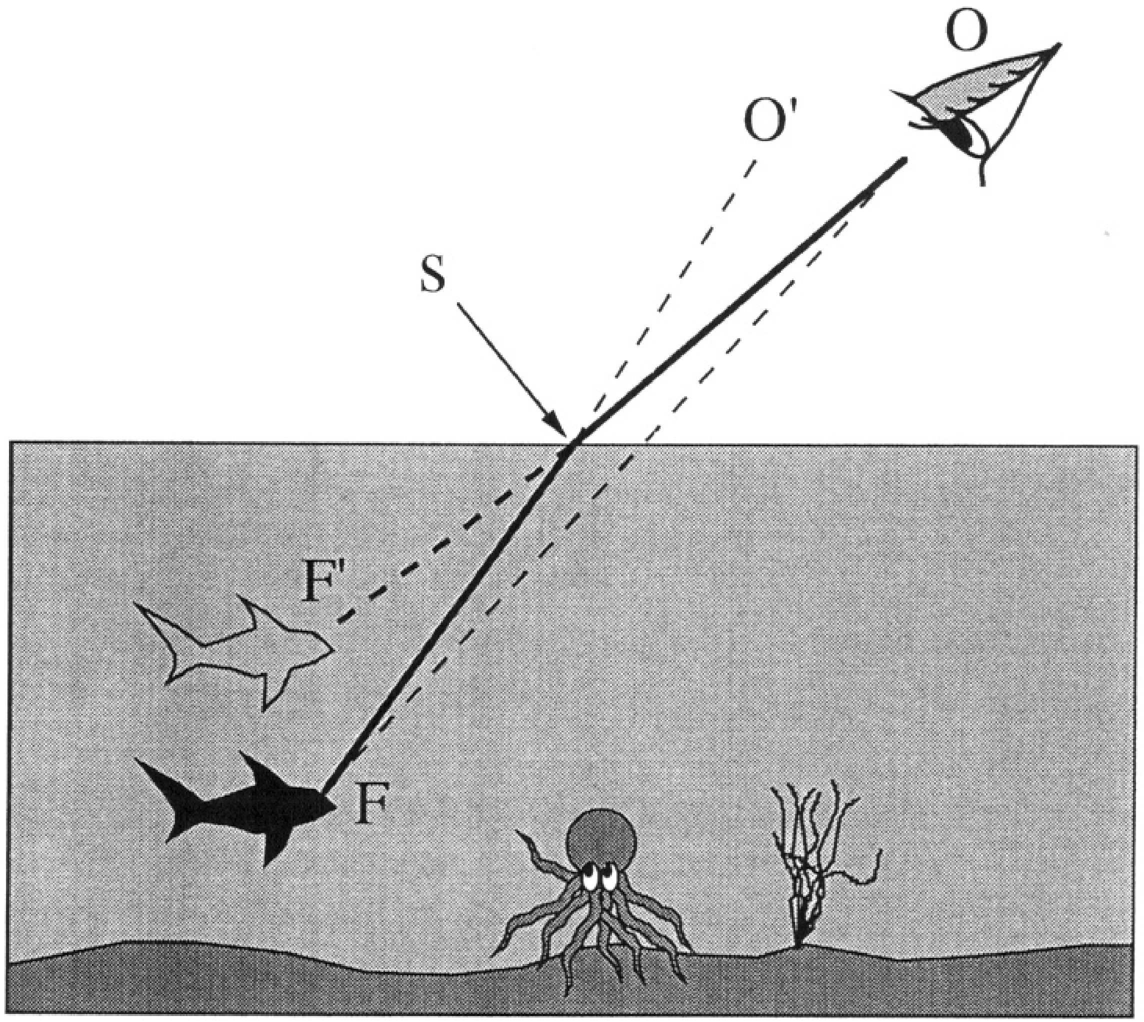
Transparency

- Compute transmitted contribution
- Cast ray in refracted direction
- Multiply by transparency coefficient (color)



Qualitative refraction

- From “Color and Light in Nature” by Lynch and Livingston



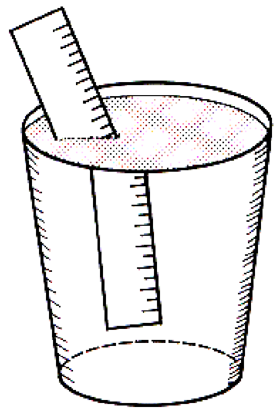
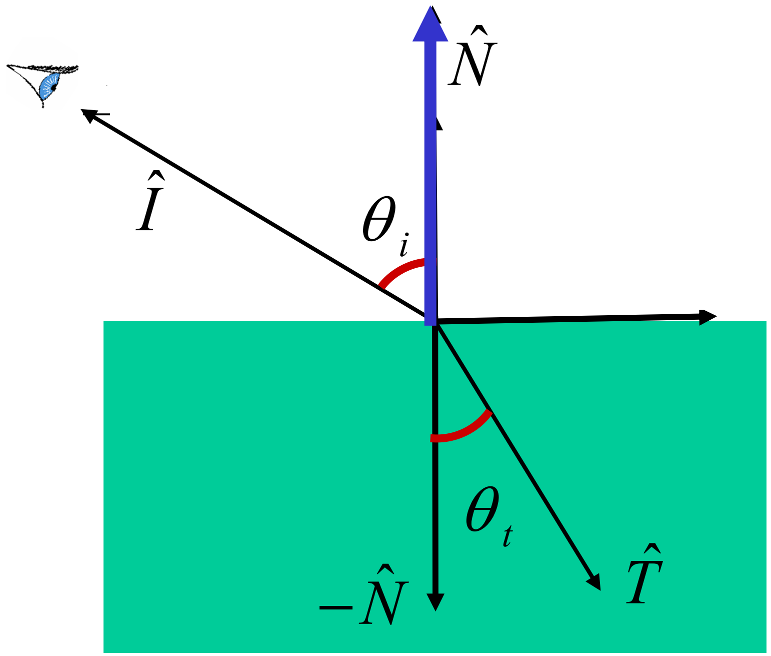


Fig. 9. Refraction causes the ruler to appear bent in a glass of water.

Refraction

Snell-Descartes Law

$$\frac{\sin\,\theta_i}{\sin\,\theta_t} = \frac{\eta_t}{\eta_i} = \eta_r$$



Note that I is the negative of the incoming ray

Total internal reflection

- From "Color and Light in Nature" by Lynch and Livingstone

Fig. 3.7A The optical manhole. From under water, the entire celestial hemisphere is compressed into a circle only 97.2° across. The dark boundary defining the edges of the manhole is not sharp due to surface waves. The rays are analogous to the crepuscular type seen in hazy air, Section 1.9. (Photo by D. Granger)

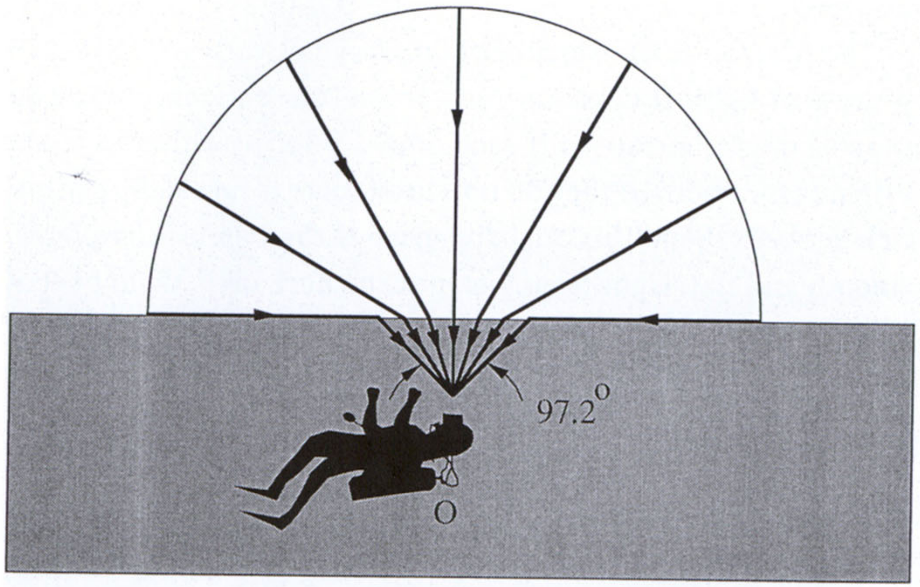
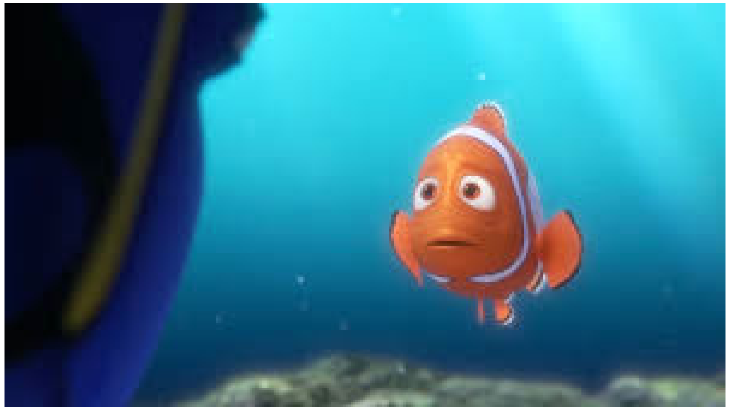


Fig. 3.7B The optical manhole. Light from the horizon (angle of incidence = 90°) is refracted downward at an angle of 48.6°. This compresses the sky into a circle with a diameter of 97.2° instead of its usual 180°.


From the Creators of MONSTERS, INC.
There are 3.7 trillion fish in the ocean.*
They're looking for one.
Disney · PIXAR
FINDING
NEMO
May 30
findingnemo.com
WALT DISNEY PICTURES PRESENTS A PIXAR ANIMATION STUDIOS FILM




E DEEP

Wavelength

- Refraction is wavelength-dependent
- Newton's experiment
- Usually ignored in graphics

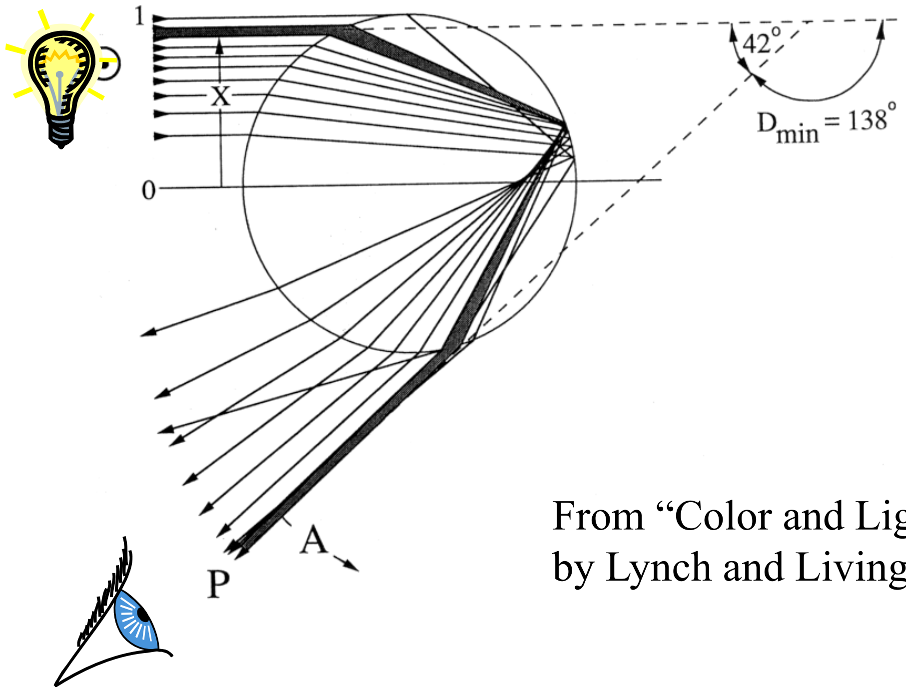
Pink Floyd, *The Dark Side of the Moon*

Pittoni, 1725, Allegory to Newton

Rainbow

- Refraction depends on wavelength
- Rainbow is caused by refraction+internal reflection+refraction
- Maximum for angle around 42 degrees

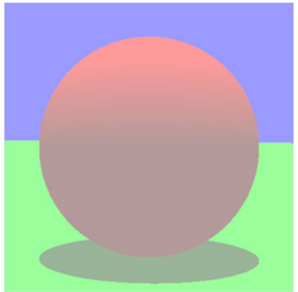
Digression



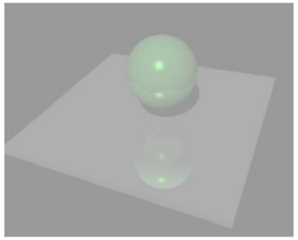
From "Color and Light in Nature" by Lynch and Livingstone

Overview of today

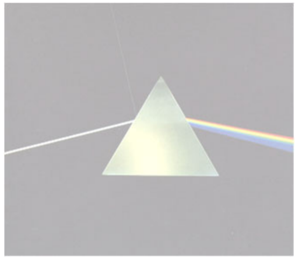
- Shadows



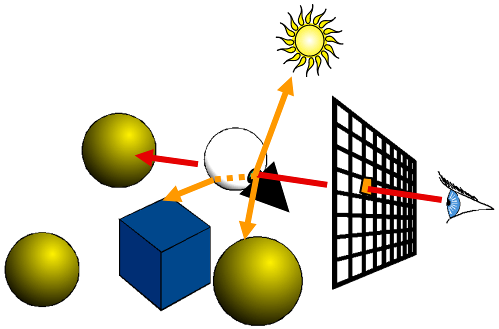
- Reflection



- Refraction



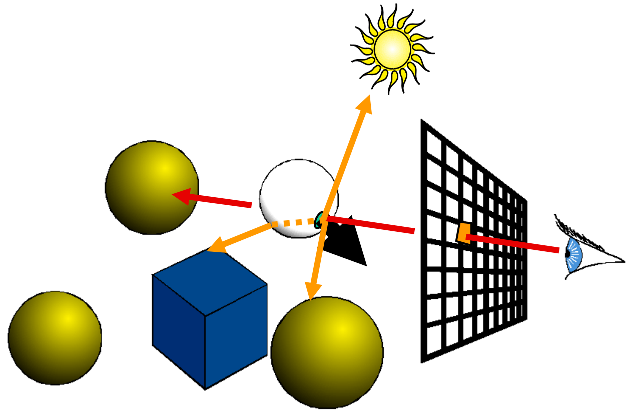
- Recursive Ray Tracing



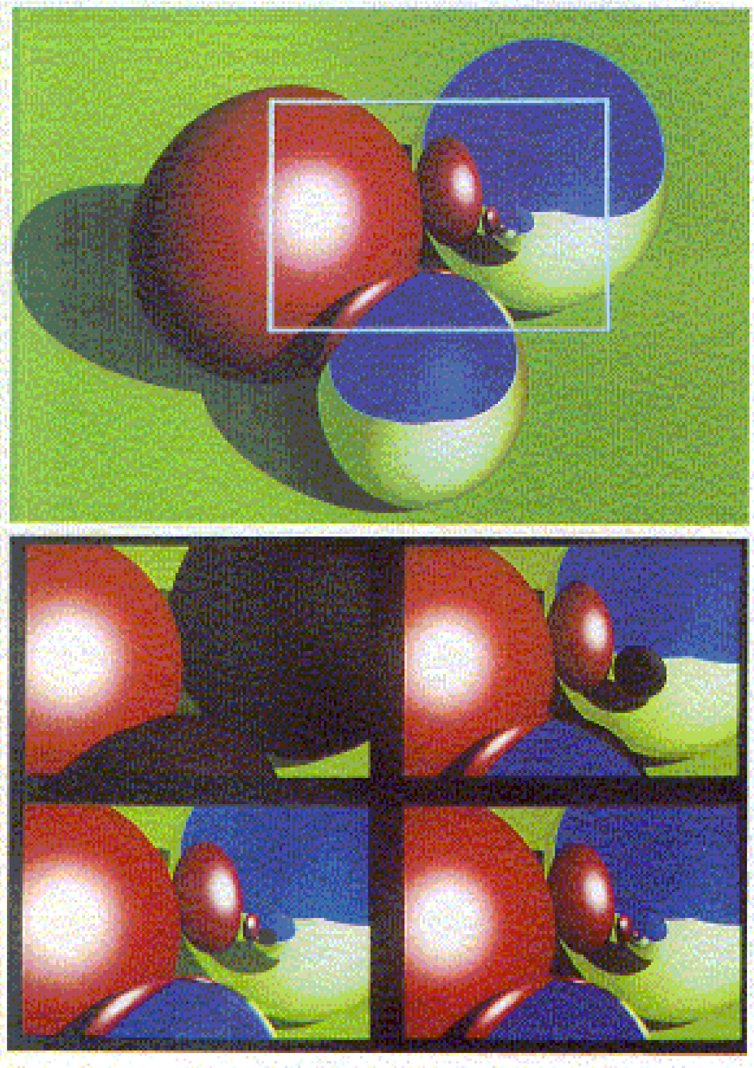
Recap: Ray Tracing

traceRay

- **Intersect all objects**
- **Ambient shading**
- **For every light**
  - **Shadow ray**
  - **shading**
- **If mirror**
  - **Trace reflected ray**
- **If transparent**
  - **Trace transmitted ray**



The depth of reflection

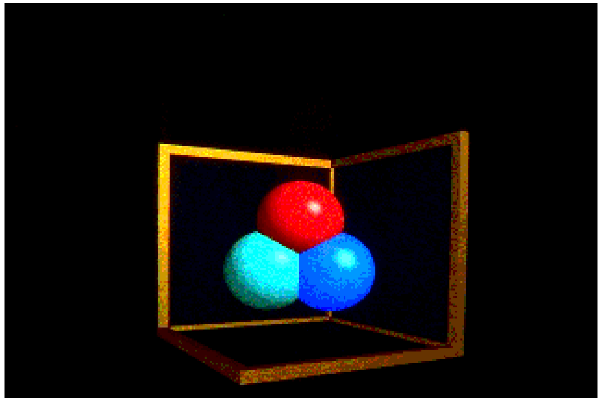
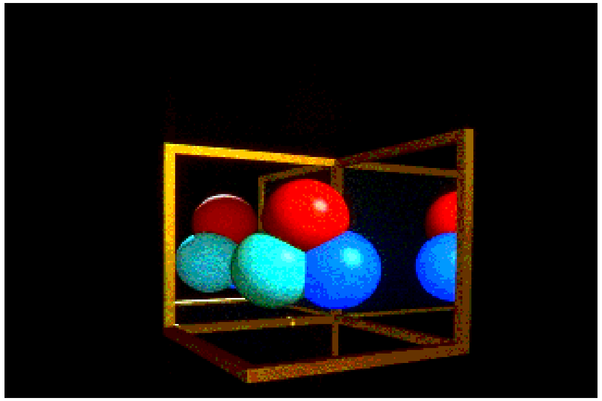
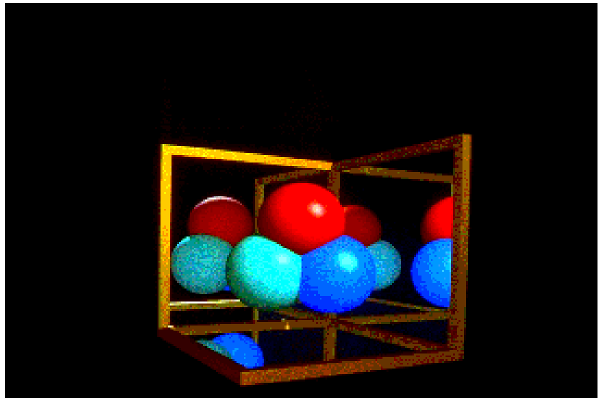


Avoiding infinite recursion

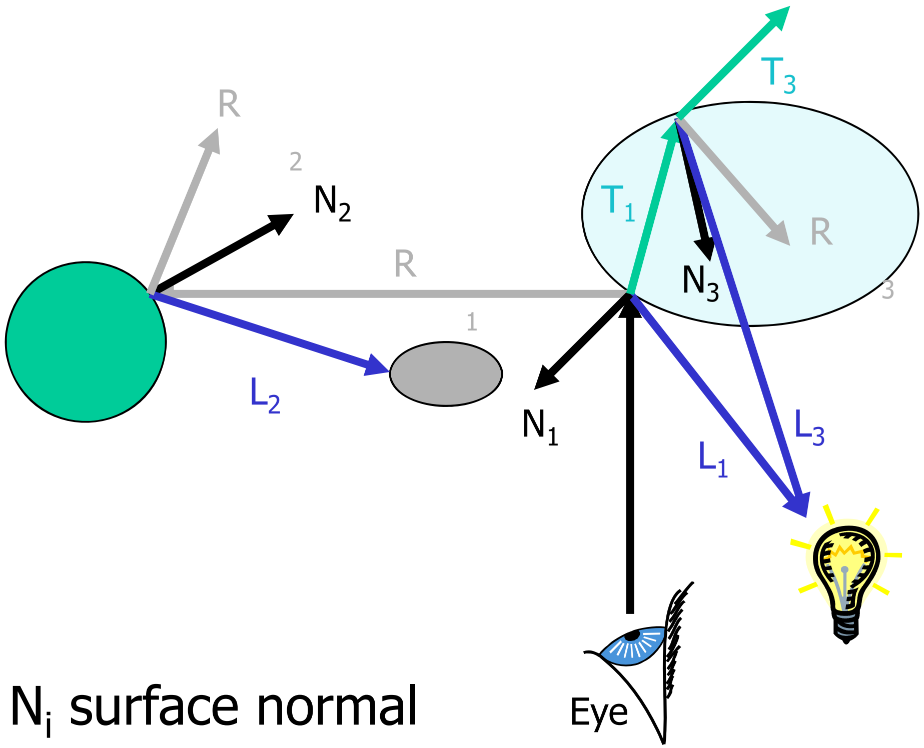
Stopping criteria:

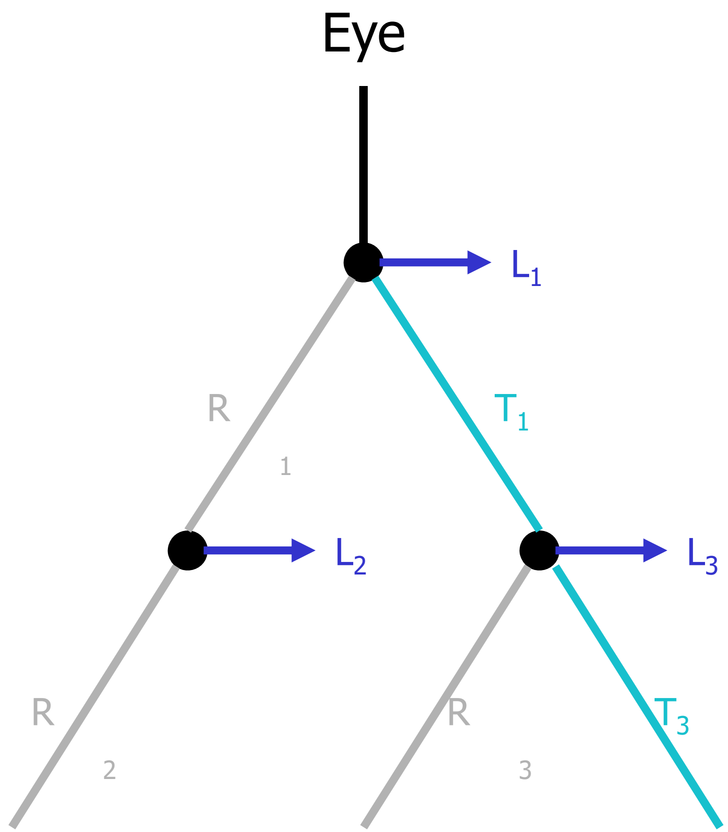
- Recursion depth
  - Stop after a number of bounces
- Ray contribution
  - Stop if transparency/transmitted attenuation becomes too small

Usually do both

The Ray Tree





N_i surface normal

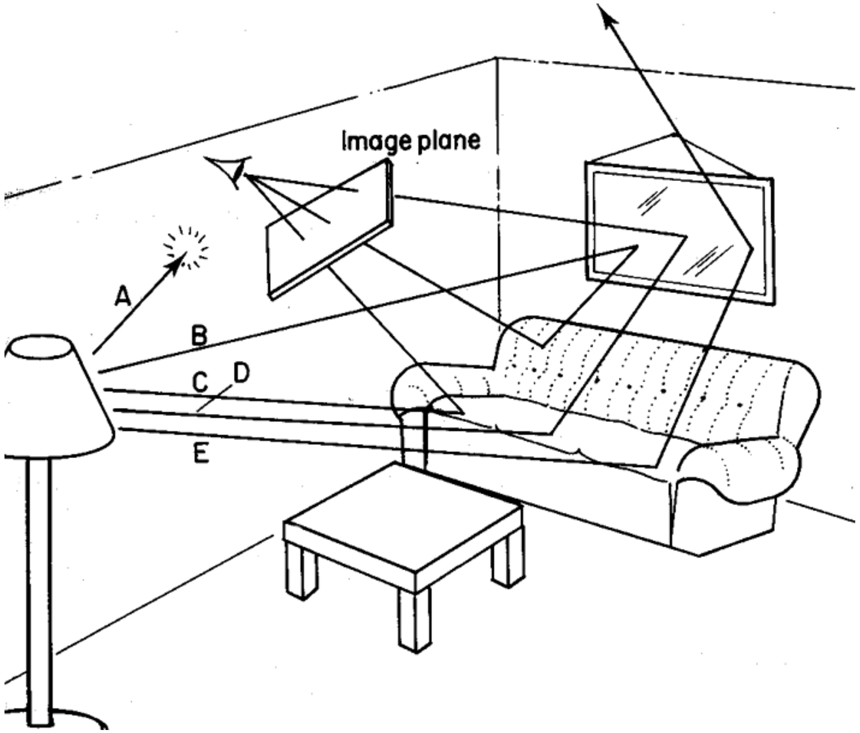
R_i reflected ray

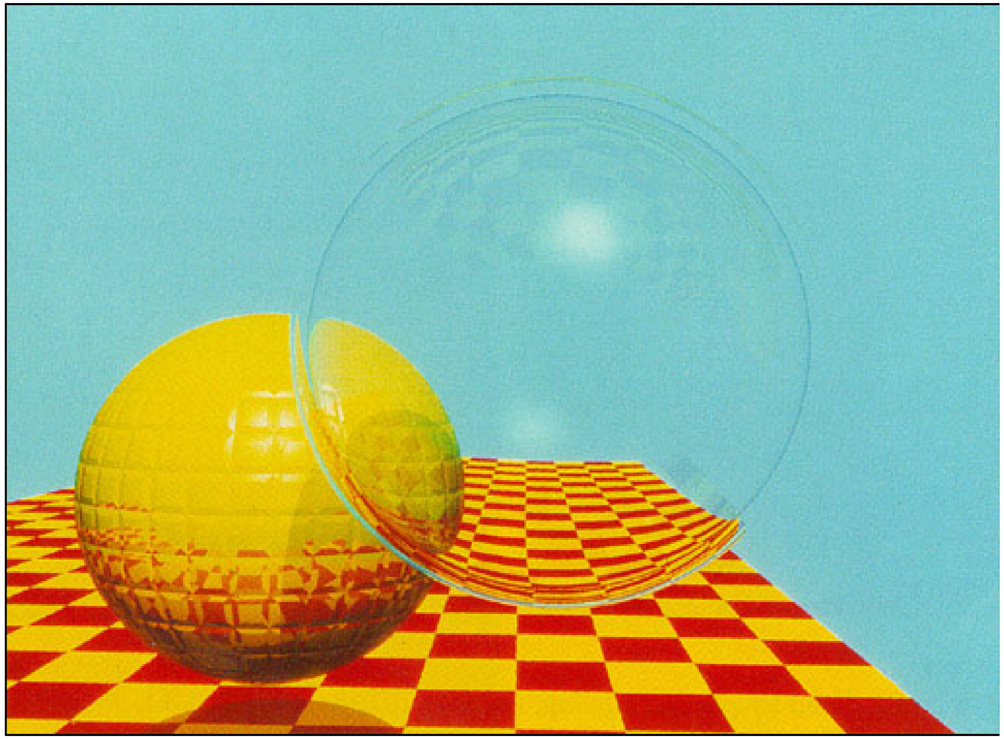
L_i shadow ray

T_i transmitted (refracted) ray

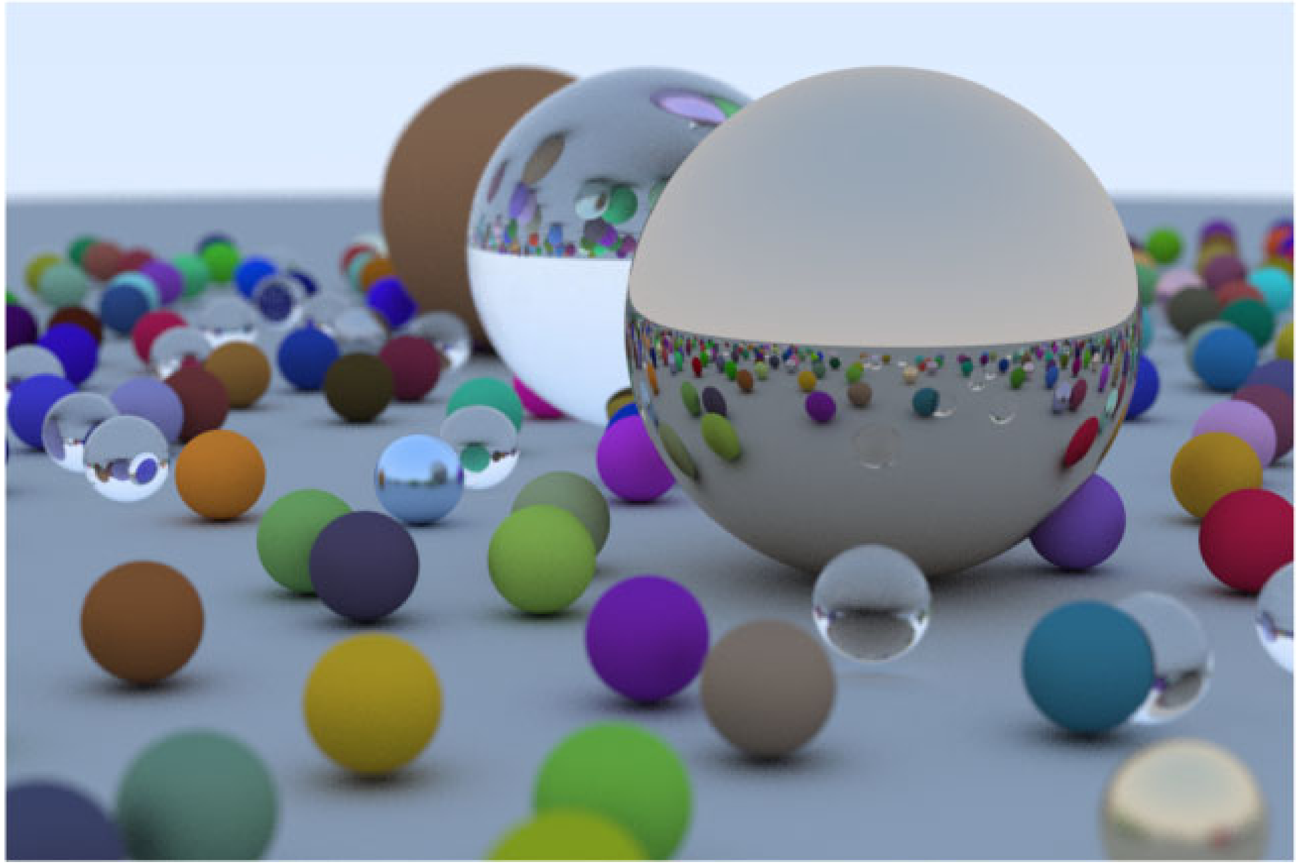
Ray Tracing History

- Ray Casting: Appel, 1968
- CSG and quadrics: Goldstein & Nagel 1971
- Recursive ray tracing: Whitted, 1980



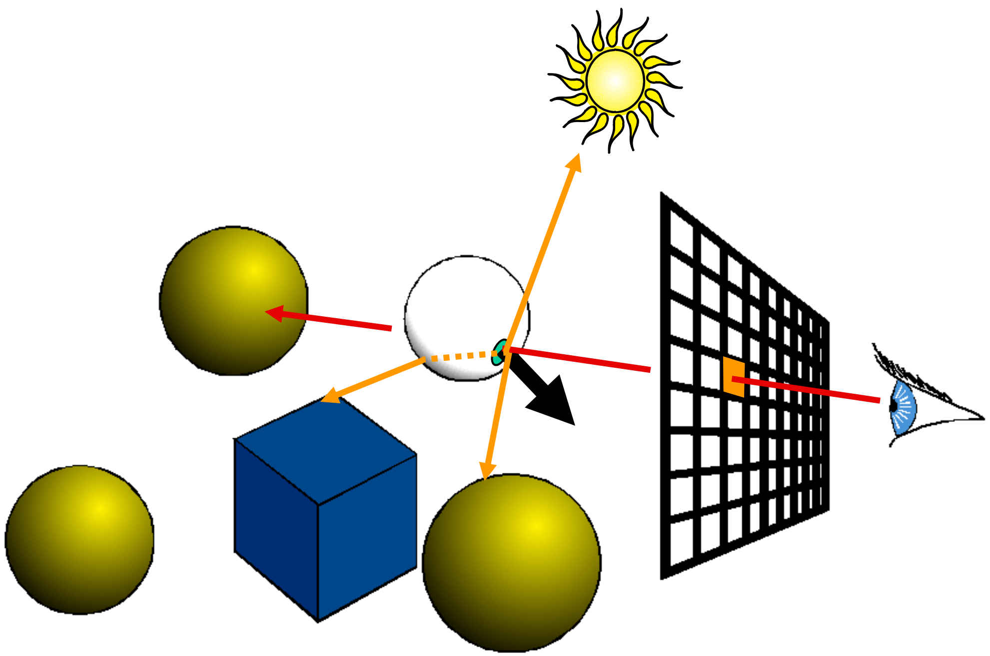


Mirror morphine This scene is composed entirely of spheres: the 40-sphere morphine molecule is tucked in the corner between two large mirrored balls and the yellow ground ball. The image was calculated at a resolution of 2048 × 2048 with 10 levels of reflections, 3 × 3 supersampling, and analytic penumbra calculations (not probabilistic methods), in 8 days of VAX 11/780 time. For a discussion of shadows and penumbrae, see Section 5.1. (Copyright © Paul Heckbert, NYIT, 1983)



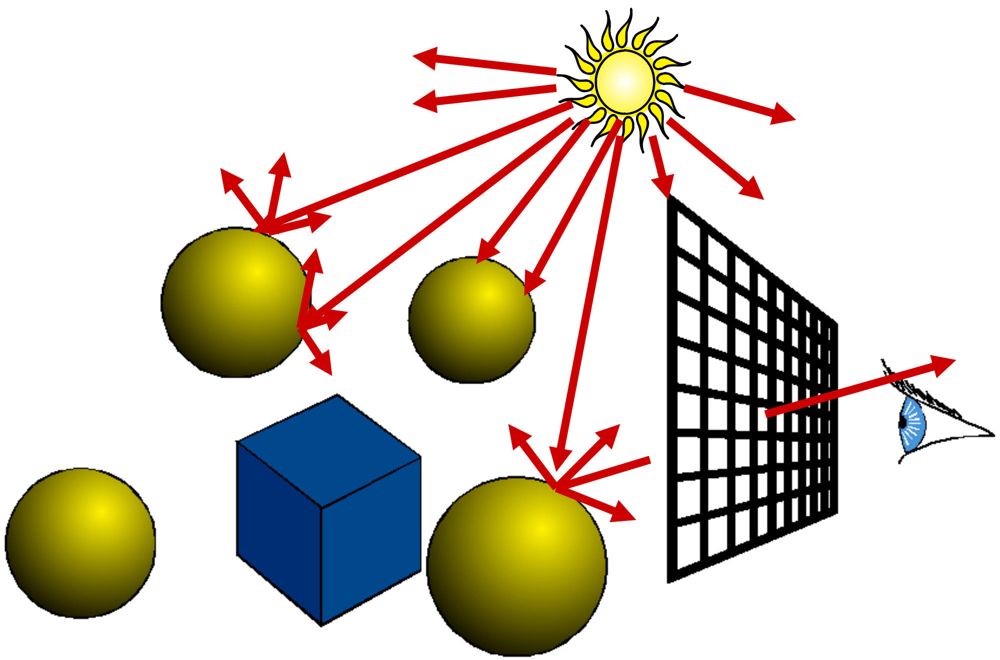
Does Ray Tracing simulate physics?

- Photons go from the light to the eye, not the other way
- What we do is backward ray tracing



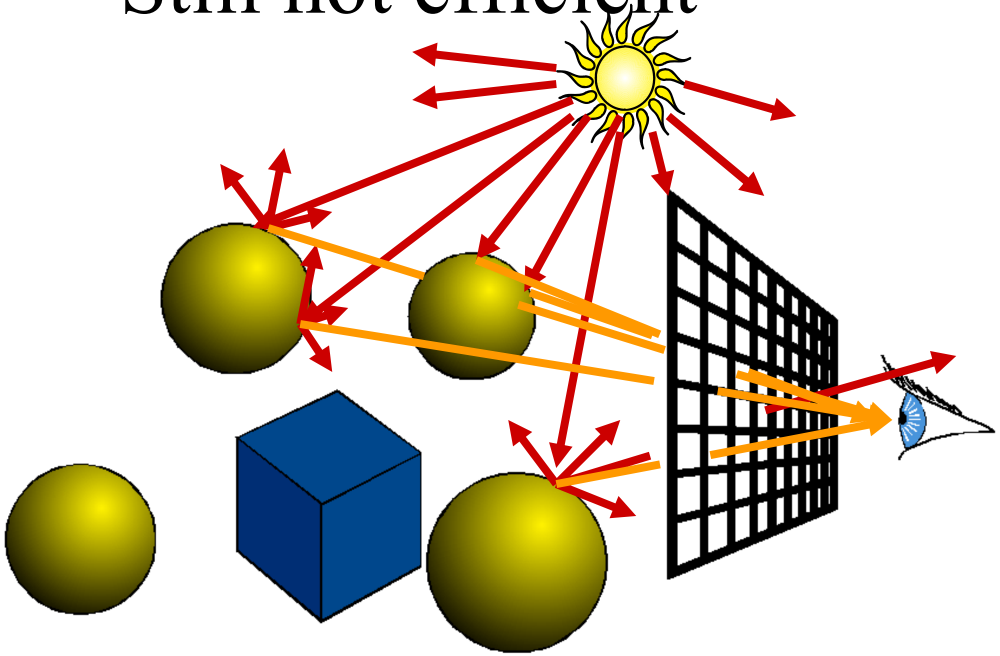
Forward ray tracing

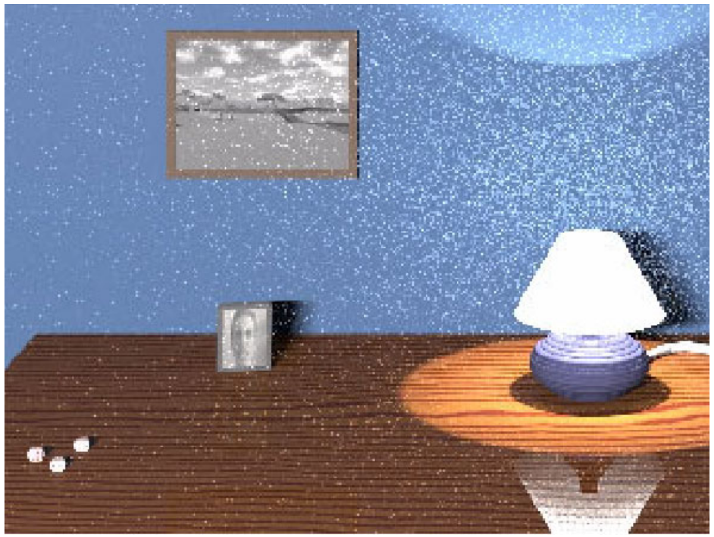
- Start from the light source
- But low probability to reach the eye
  - What can we do about it?



Forward ray tracing

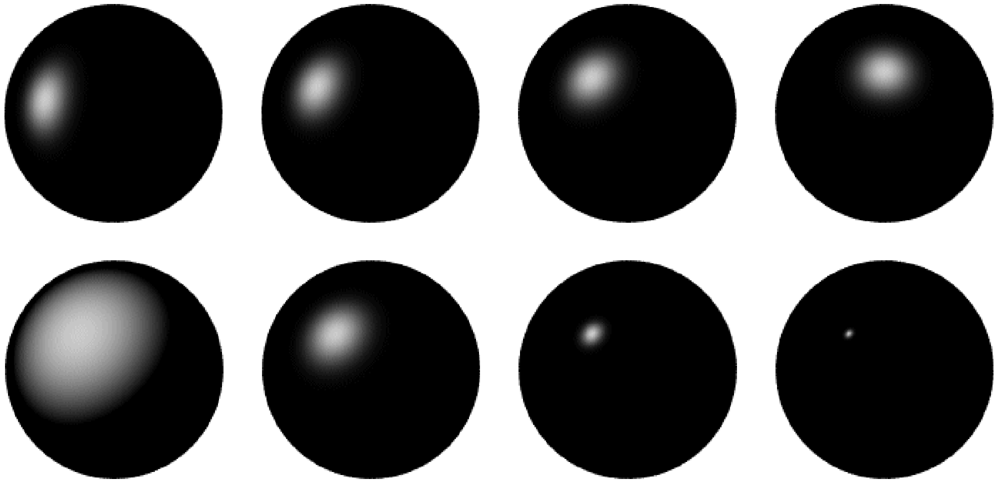
- Start from the light source
- But low probability to reach the eye
  - What can we do about it?
  - Always send a ray to the eye
- Still not efficient

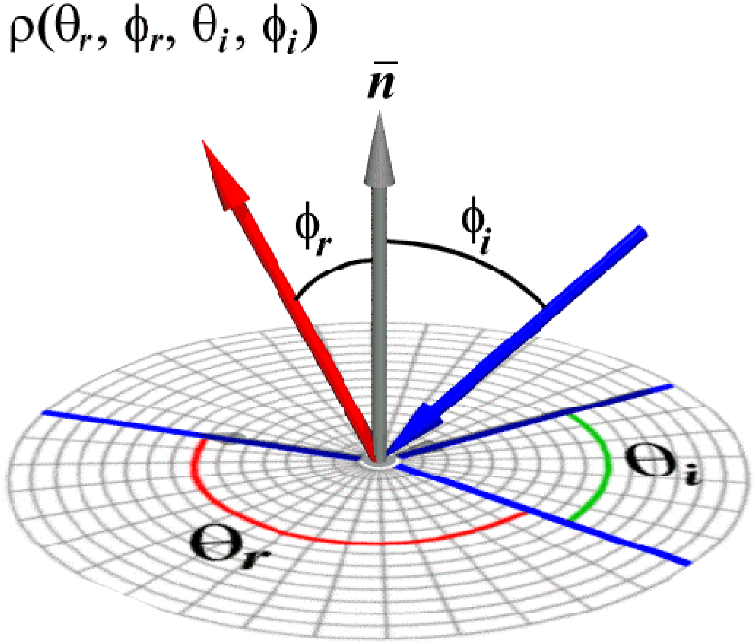




BRDF

- Reflectance properties, shading and BRDF

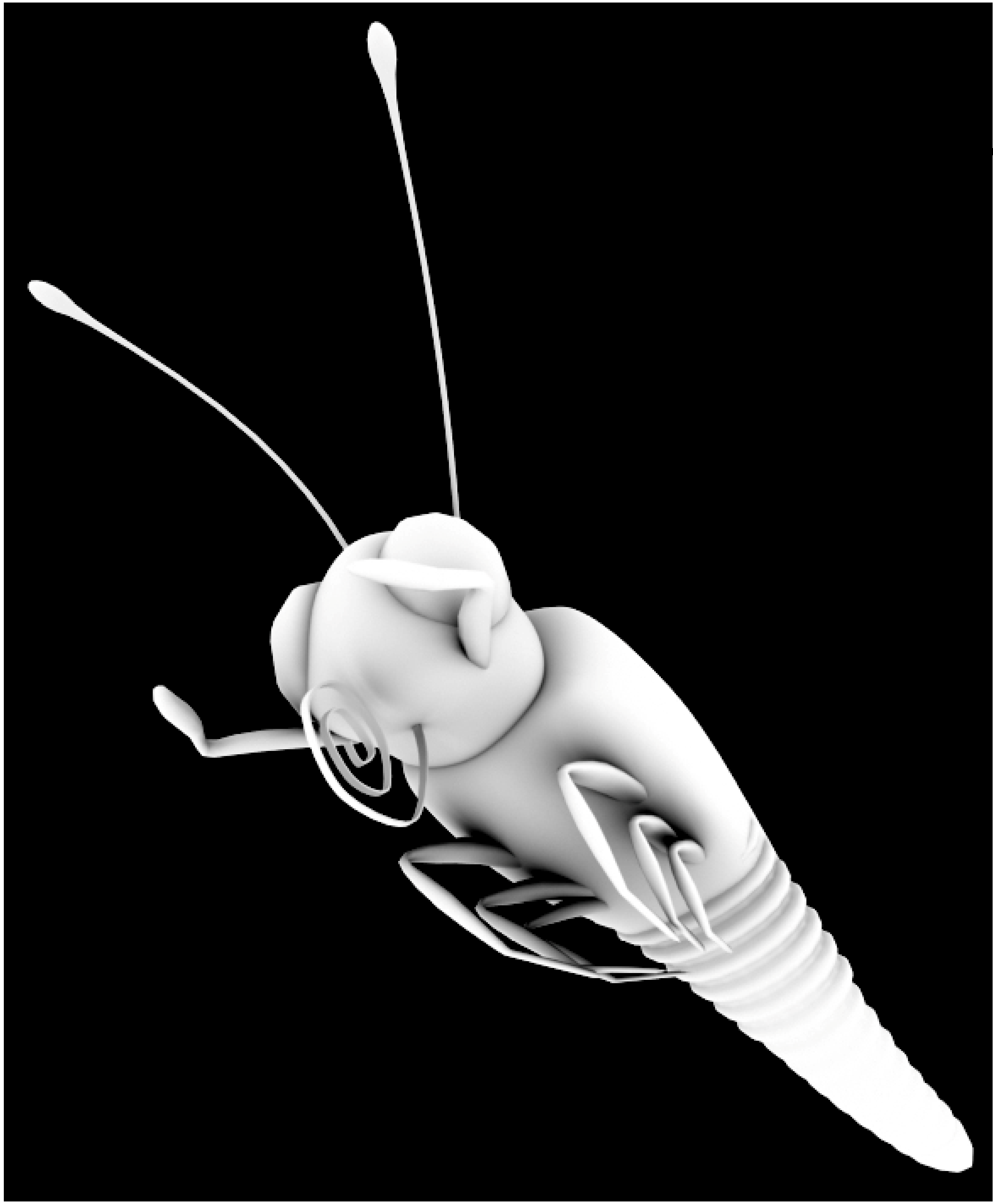




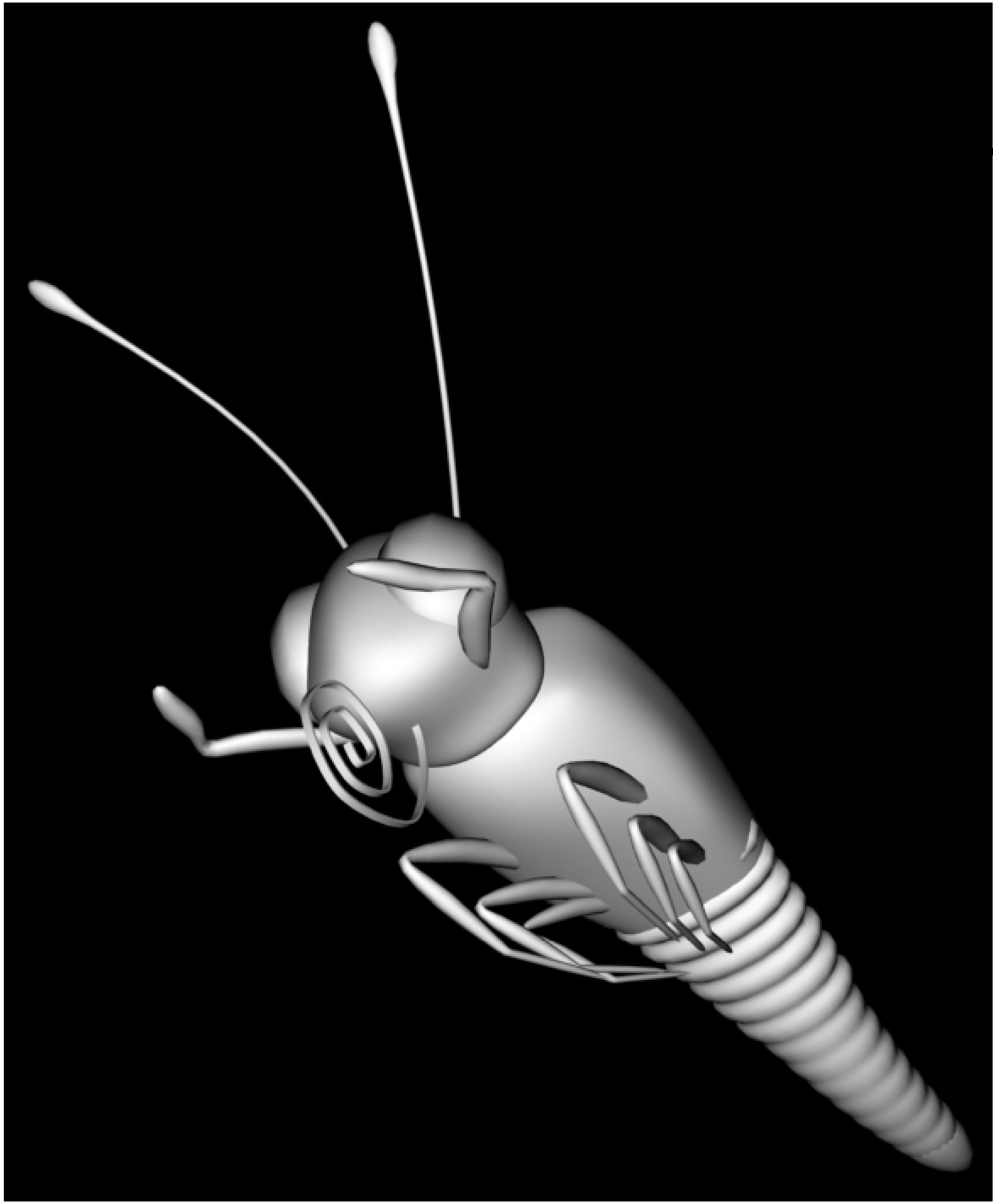
Material


Fire within
Magicka
Gold
Aurora
Glass
Blue Steel
Rubber
Pearl
Gemstone
Polished metal
Gear Freak

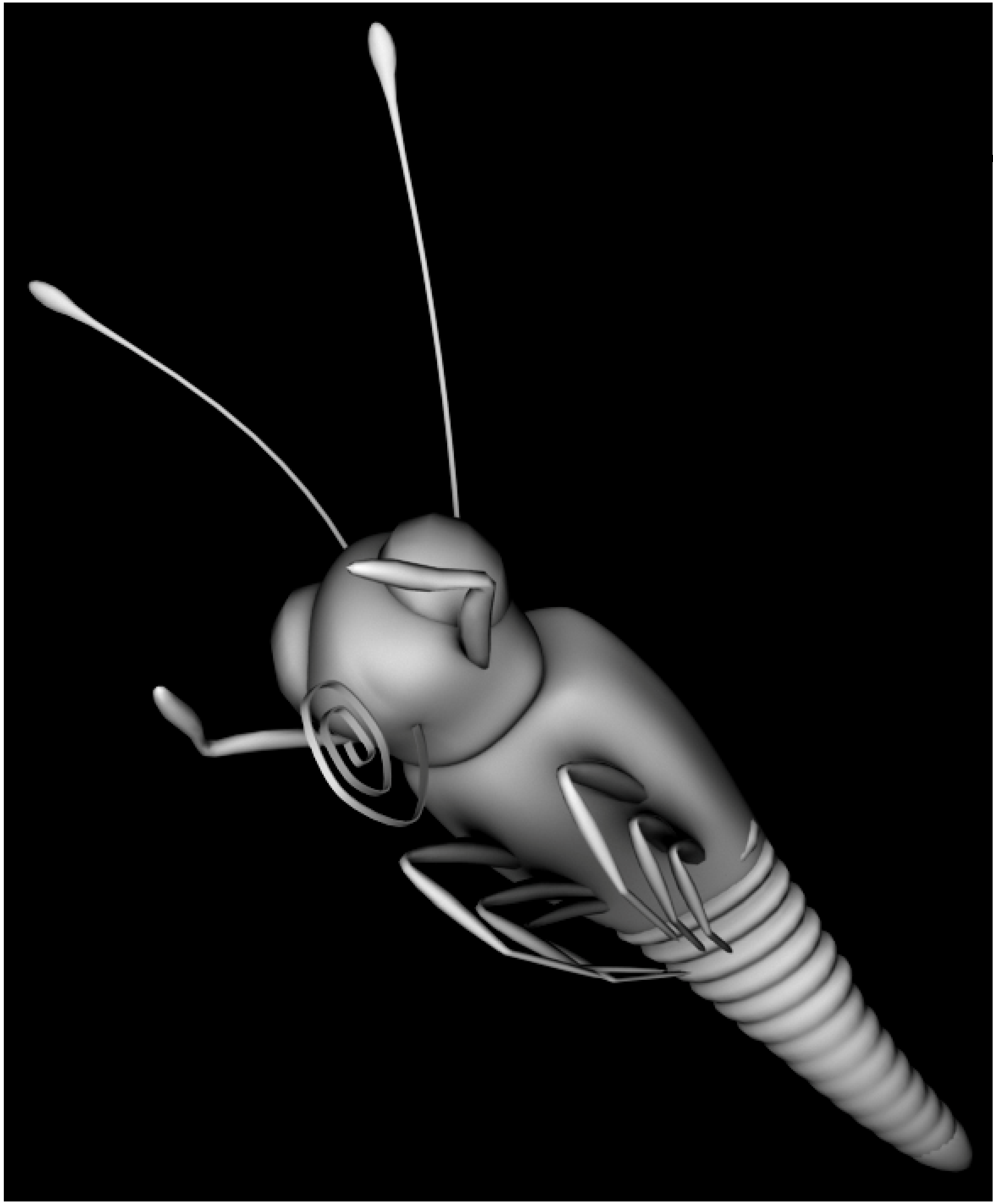
Ambient Occlusion



Ambient Occlusion

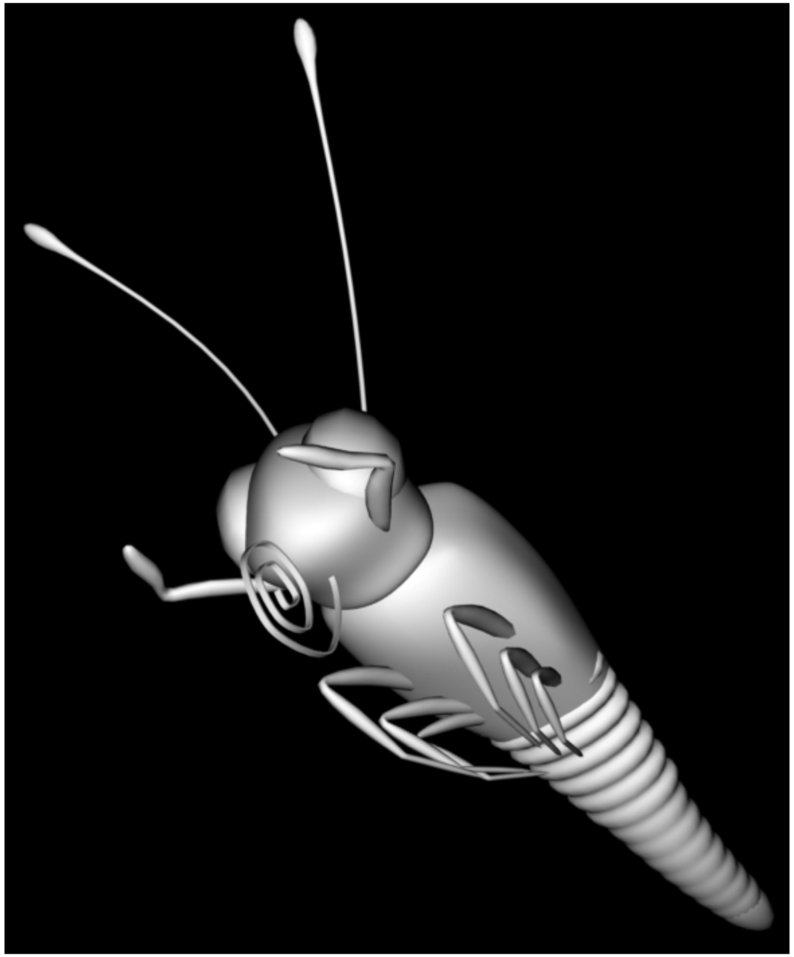


Diffuse Only

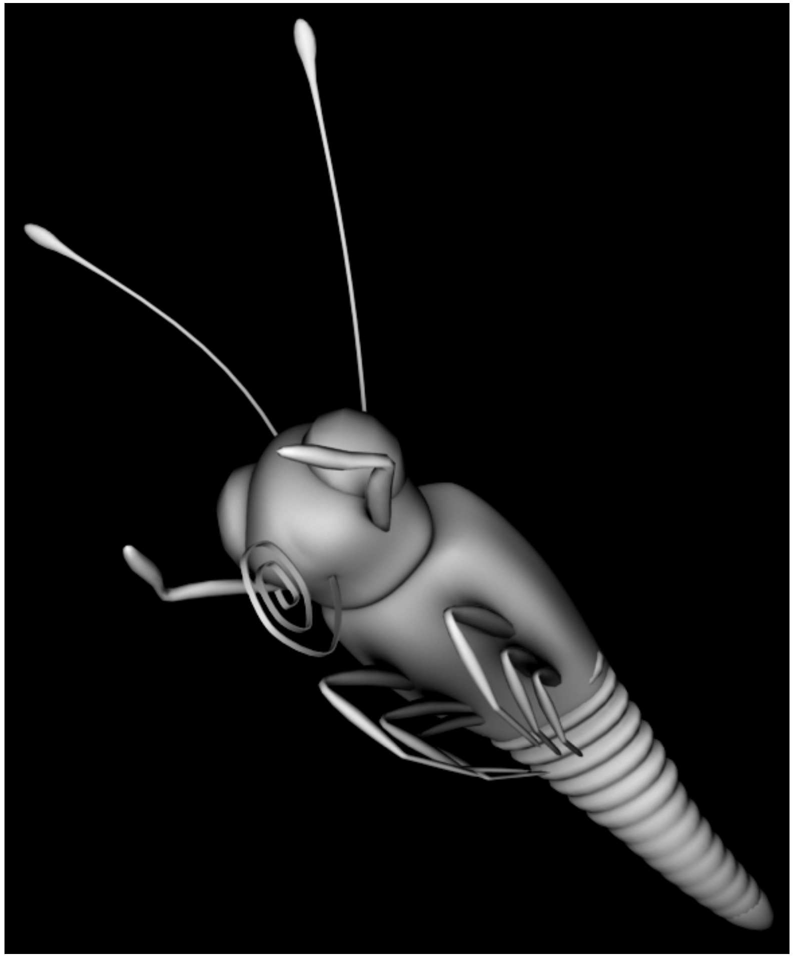


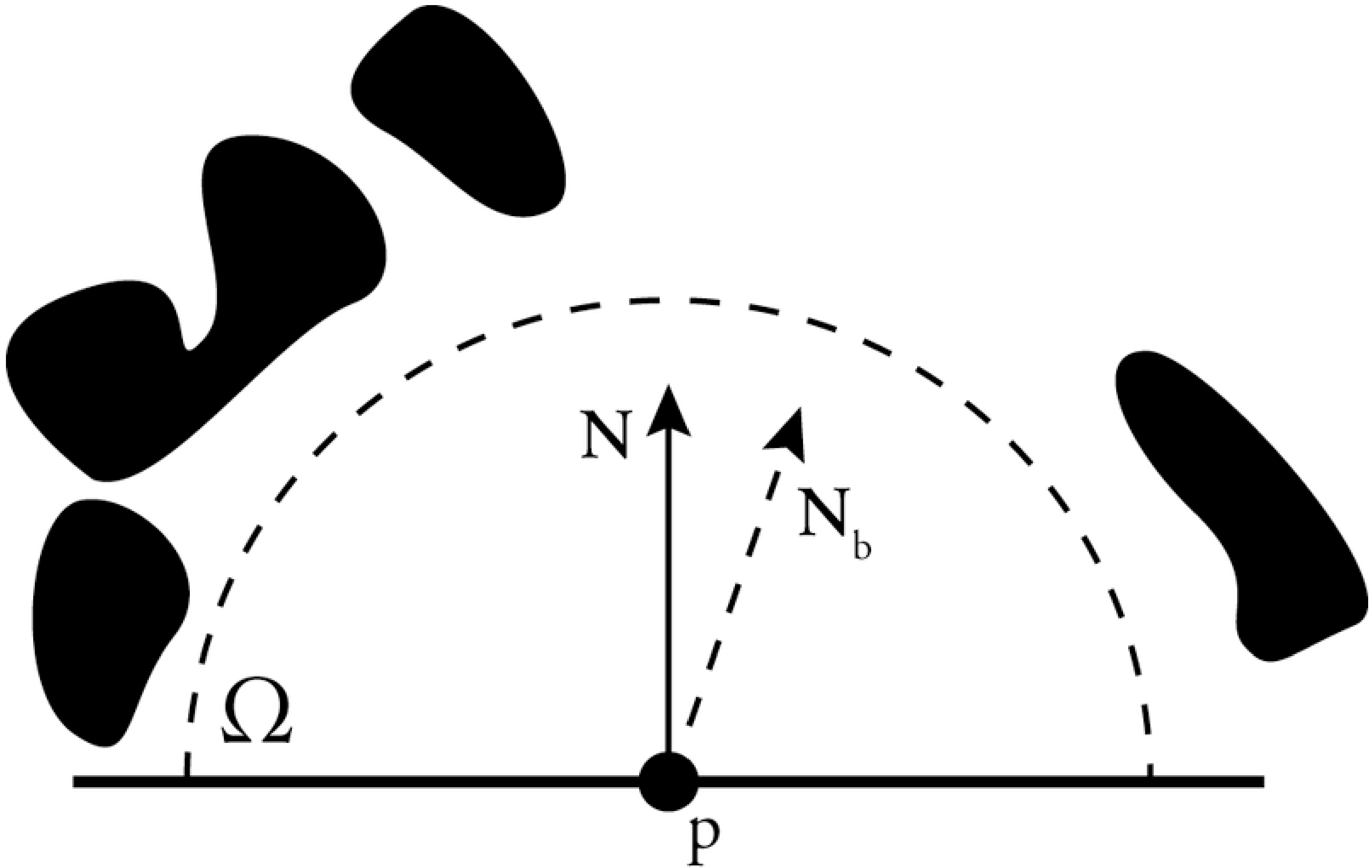
Diffuse and Ambient

Diffuse Only



Diffuse and Ambient




N
N_b
Ω
p