Recursive ray tracing (chapter 12)

- Pixel brightness =

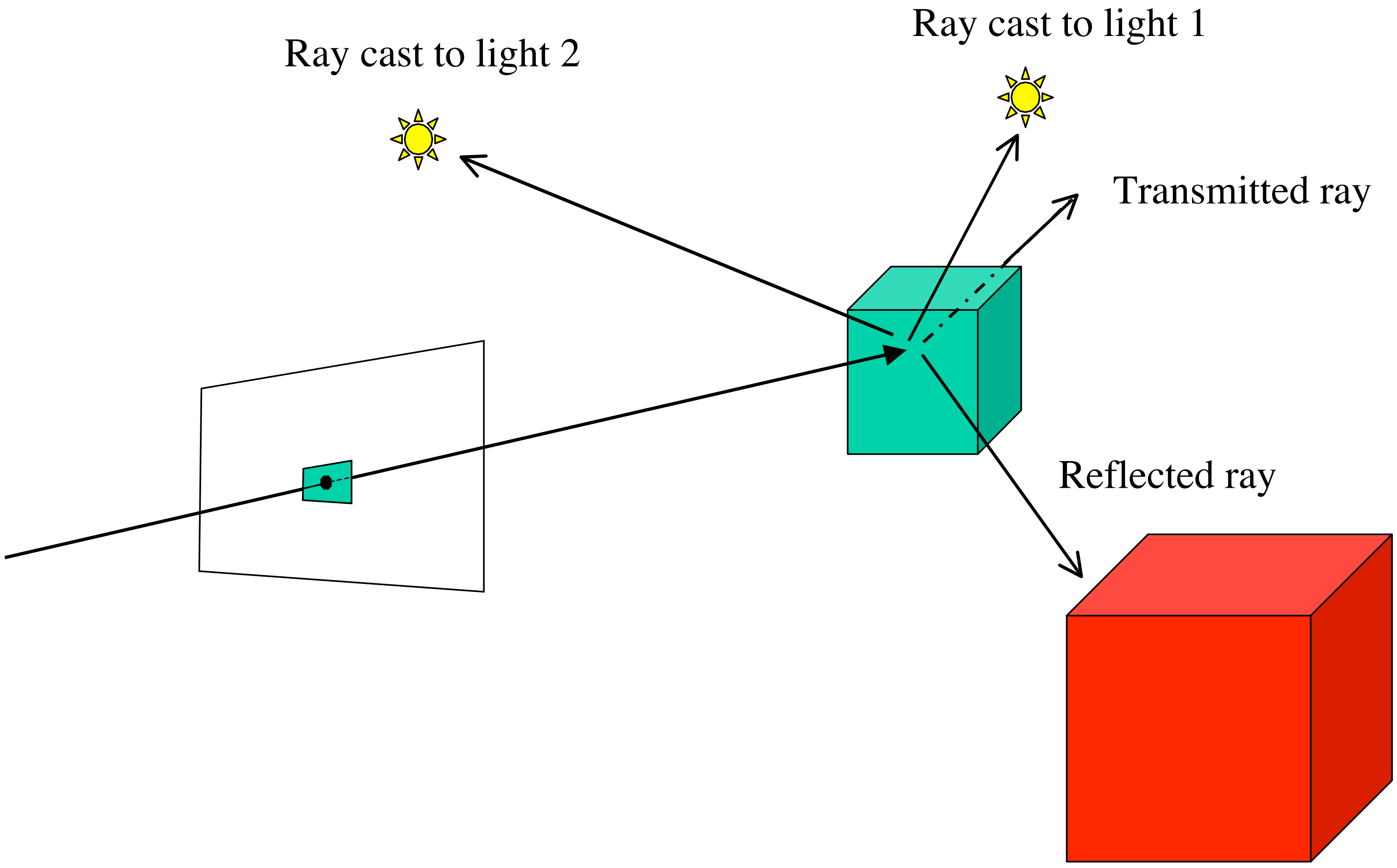
  radiance along ray to pinhole

  = $\square_d$(diffuse) +
  $\square_s$(reflected) +
  $\square_t$(transmitted)

- Diffuse component:
  - from sources alone (local shading model) typically Lambertian but could add a Phong type specular model
  - from global illumination model (usually just “ambient”)

- Reflected component is due to radiance along ray from intersection along mirror direction (often referred to as specular ray, but this is not to be confused with the specular lobe which might be added in as part of the diffuse component if it contributions from non-sources would be ignored--the usual case)

- Transmitted component is due to radiance along ray from intersection along transmitted direction


Ray cast to light 2
Ray cast to light 1
Transmitted ray
Reflected ray

Recursive ray tracing rendering algorithm

- Cast ray from pinhole (projection center) through pixel, determine nearest intersection
- Compute components by casting rays
  - to sources = shadow ray (and for specular lobe)
  - along reflected direction = reflected ray
  - along transmitted dir = refracted ray
- Each of the components has a weight
  - The main processes do not affect color much but a vector of weights for may be more convenient, or accurate depending on a color model
- Determine each component and add them up
- To determine some of the components, the ray tracer must be called **recursively**.

Recursive ray tracing rendering (cont)

- Reflections (at least need to be attenuated)--no perfect reflectors
- We must stop the recursion at some point
  - when contributions are too small
    - need to track the cumulative effect
  - typically also limit the depth explicitly

Mechanics

- Primary issue is intersection computations.
  - E.g. sphere, triangle.
- Polygon (see book chapter 1)
- Sphere (see book chapter 1)

Mechanics

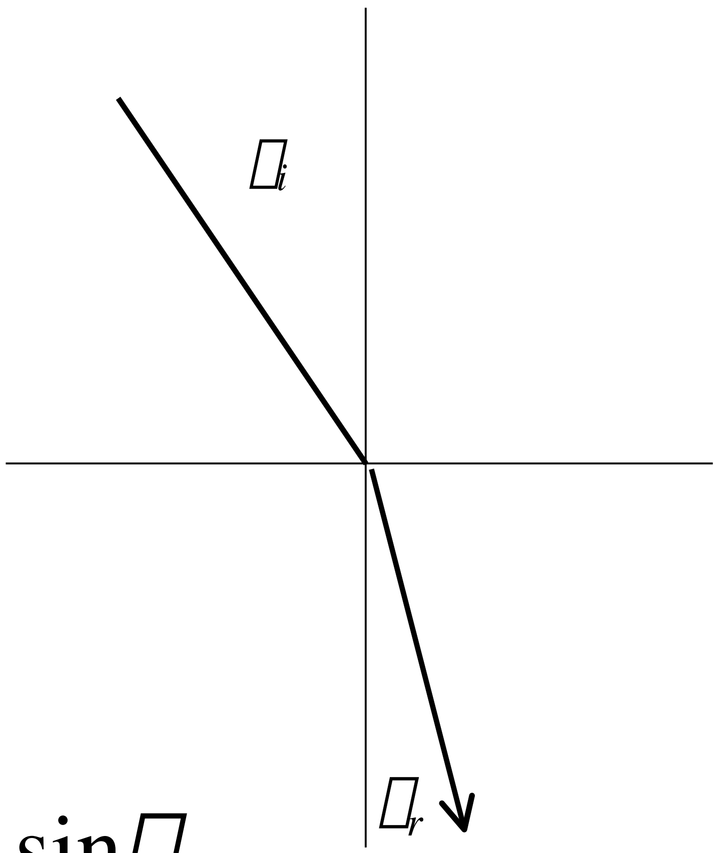
- Primary issue is intersection computations.
  - E.g. sphere, triangle.
- Polygon (see book page 461-2, handout for a better way)
- Sphere (see book page 460, or handout)

Refraction Details

Index of refraction, n, is the ratio of speed of light in a vacuum, to speed of light in medium.

Typical values:

water:	1.33
glass:	1.45-1.6
diamond:	2.2



$$n_i \sin\theta_i = n_r \sin\theta_r$$

Mechanics

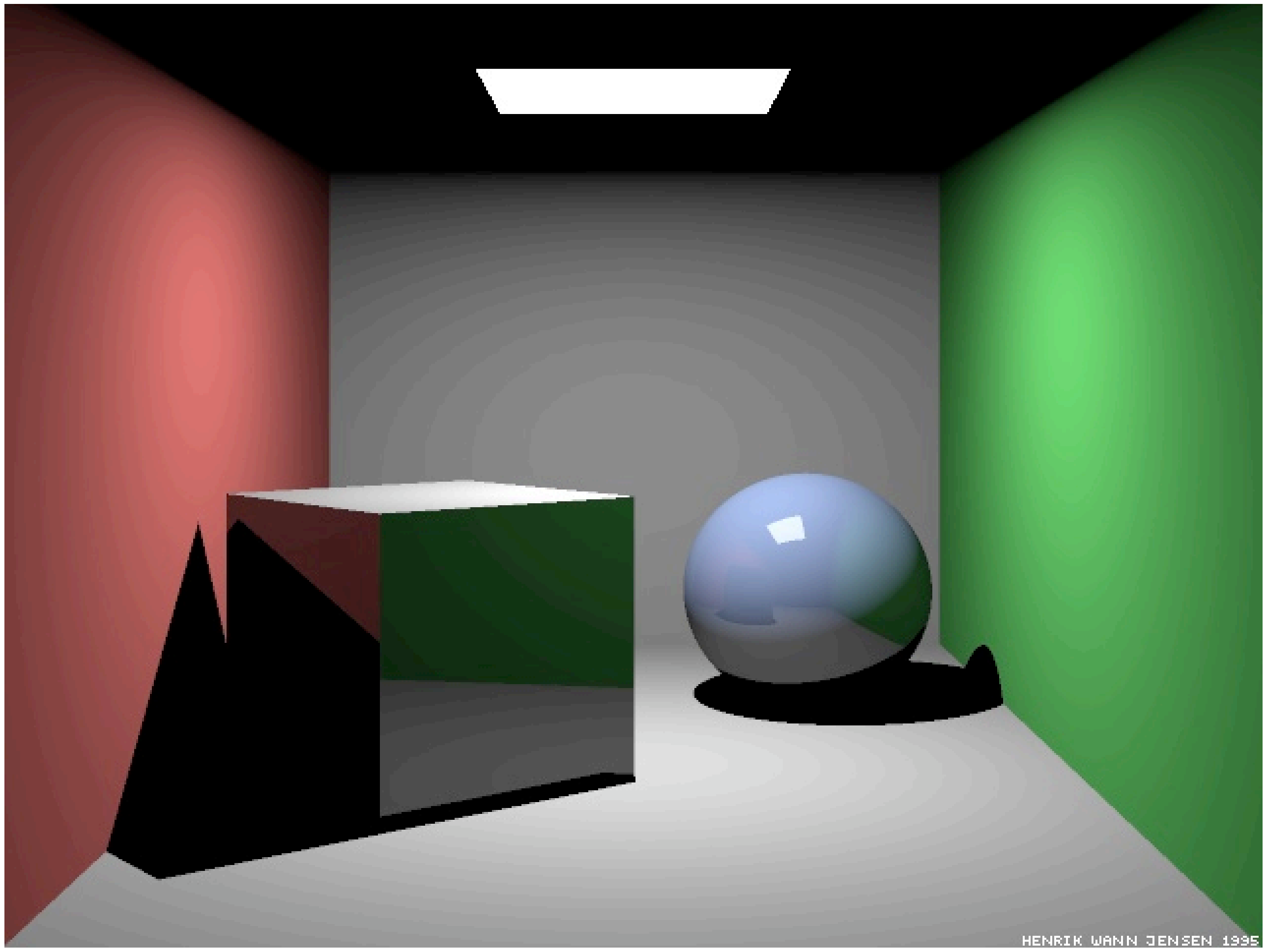
- Another issue is attenuation
- Reflection
- No perfect mirror, typically 95% attenuation at each bounce (or user controlled). If you allow 100% then have to track the depth!
- Absorption
  - Usually can ignore in air, but it depends on the application
  - Translucent absorption is exponential in depth

$$I = I_0 e^{\square\square d}$$

PCKTWTCH by Kevin Odhner, POVRay

©Steve Anger 1993
PHILCO
84
6Z4

6Z4.JPG - A Philco 6Z4 vacuum tube by Steve Anger



Ray-traced Cornell box, due to Henrik Jensen,
http://www.gk.dtu.dk/~hwj

Issues

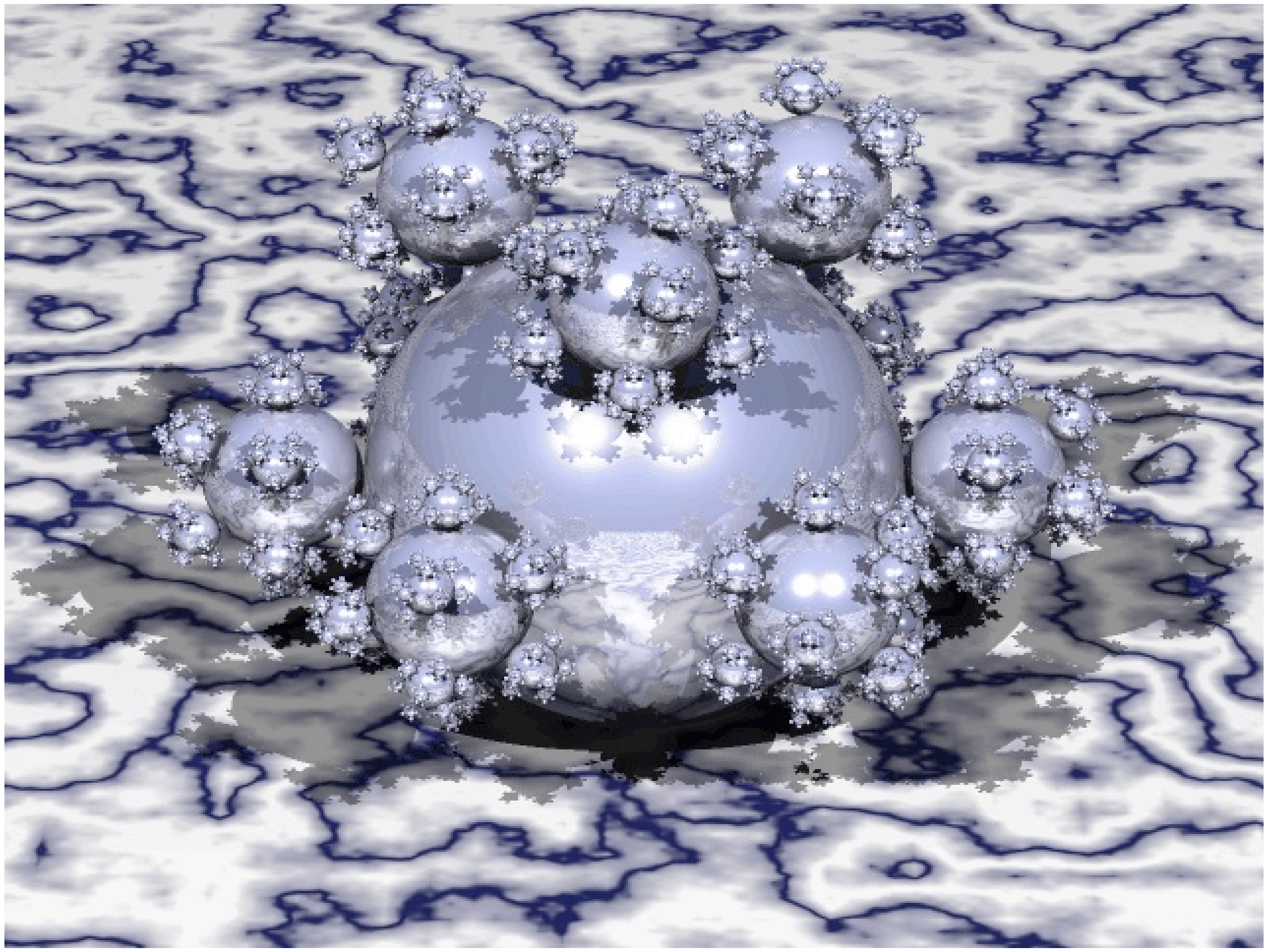
- Sampling (aliasing)
- Very large numbers of objects
  - Need making intersections efficient, exclude as much as possible using clever data structures
- Surface detail
  - bumps, texture, etc.
- Illumination effects
  - Caustics, specular to diffuse transfer
- Camera models

Sampling

- Simplest ray-tracer is one ray per pixel
  - This gives aliasing problems
- Solutions
  - Cast multiple rays per pixel, and use a weighted average
  - Rays can be on a uniform grid
  - It turns out to be better if they are “quite random” in position
    - “hard-core” Poisson model appears to be very good
    - different patterns of rays at each pixel

Efficiency - large numbers of objects

- Construct a space subdivision hierarchy of some form to make it easier to tell which objects a ray might intersect
- Uniform grid
  - easy, but many cells
- Bounding Spheres
  - easy intersections first
- Octtree
  - rather like a grid, but hierarchical
- BSP tree

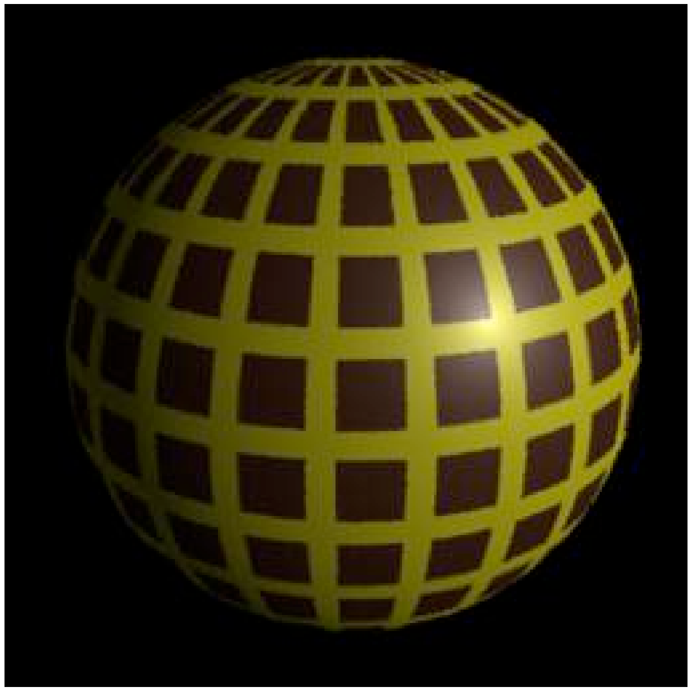


500,000 spheres, Henrik Jensen, http://www.gk.dtu.dk/~hwj

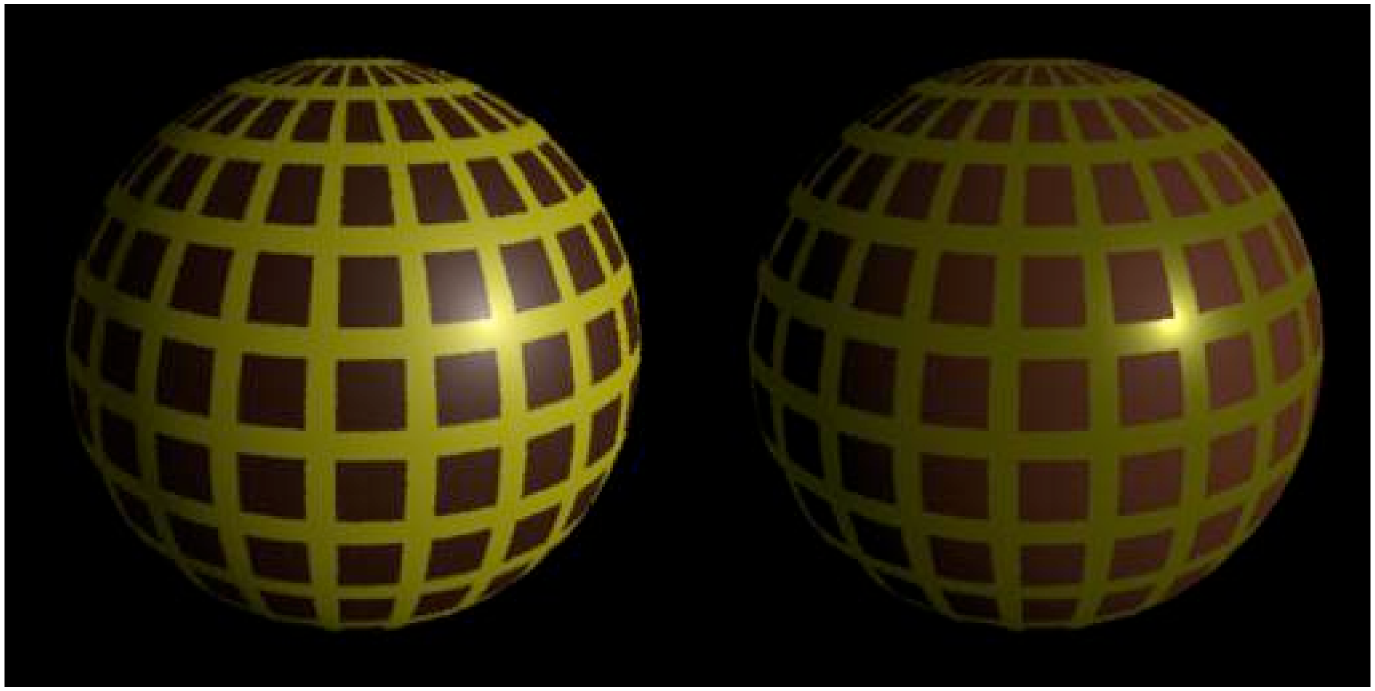
Surface detail

- Knowing the intersection point gives us a position in intrinsic coordinates on the surface
  - e.g. for a triangle, distance from two of three bounding planes
- This is powerful - we could attach some effect at that point

- Texture maps:
  - Make albedo (or color) a function of position in these coordinates
  - Rendering: when intersection is found, compute coordinates and get albedo from a map
  - This is not specific to ray-tracing



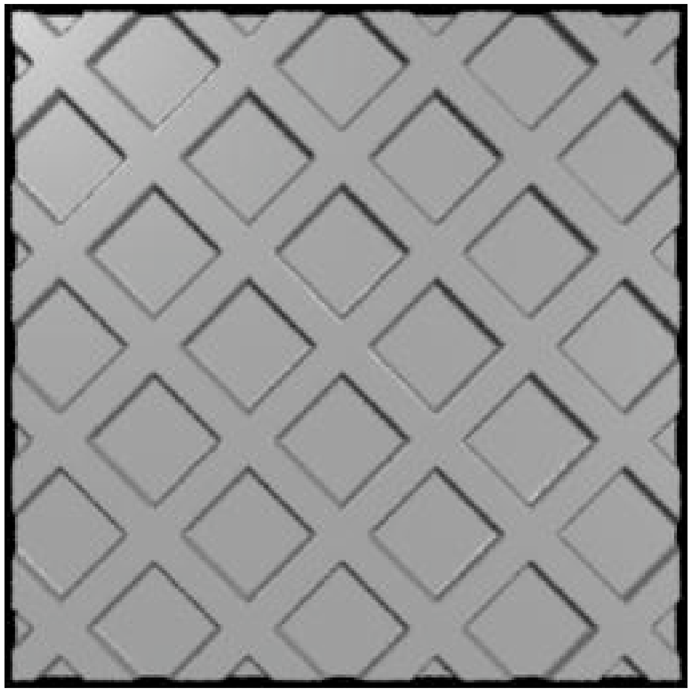
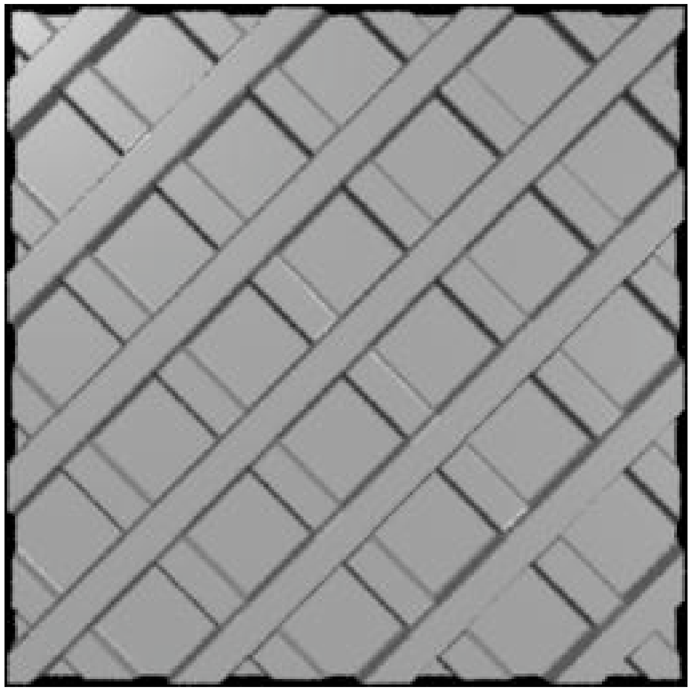
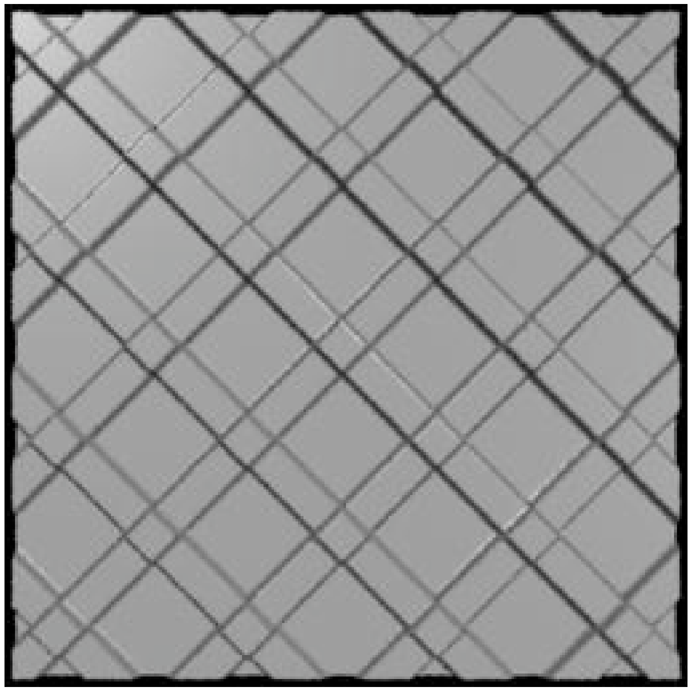
From RmanNotes
http://www.cgrg.ohio-state.edu/~smay/RManNotes/index.html



From RmanNotes
http://www.cgrg.ohio-state.edu/~smay/RManNotes/index.html

Surface detail, II

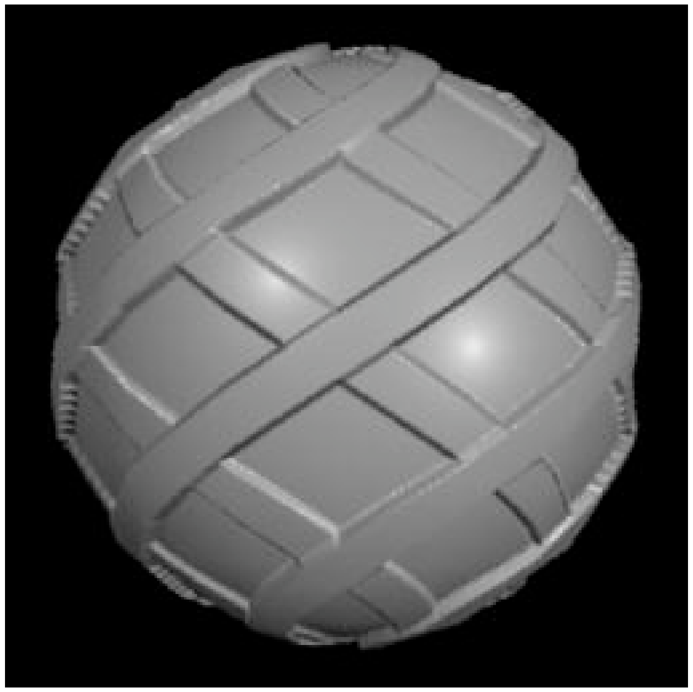
- Bumps
  - we assume that the surface has a set of bumps on it
    - e.g. the pores on an orange
  - these bumps are at a fine scale, so don't really affect the point of intersection, but do affect the normal
  - strategy:
    - obtain normal from "bump function"
    - shade using this modified normal
    - notice that some points on the surface may be entirely dark
    - bump maps might come from pictures (like texture maps)

From RmanNotes
http://www.cgrg.ohio-state.edu/~smay/RManNotes/index.html

Surface detail, III

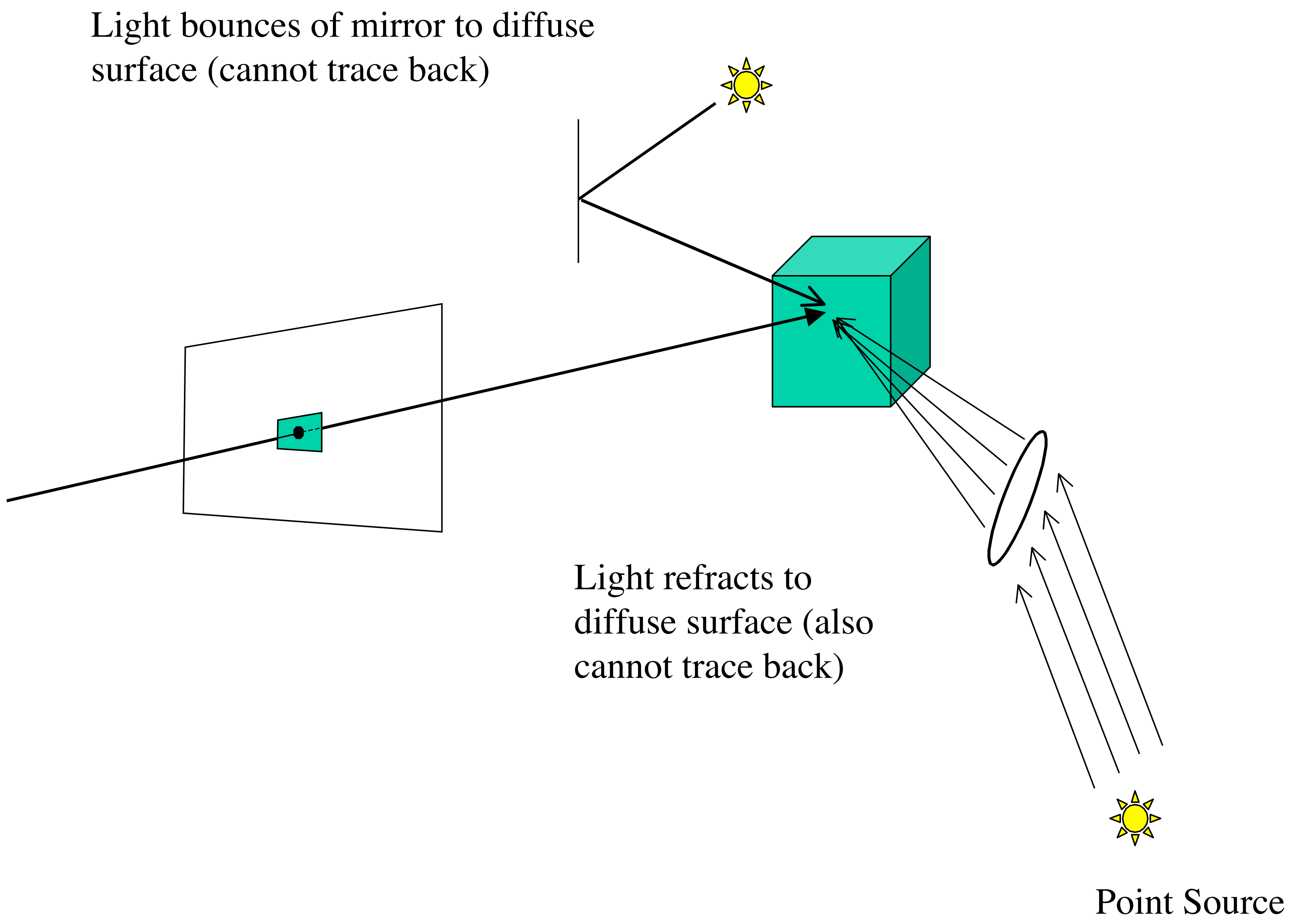
- A more expensive trick is to have a map which includes **displacements** as well
- Must be done **before** visibility



From RmanNotes
http://www.cgrg.ohio-state.edu/~smay/RManNotes/index.html

Illumination effects

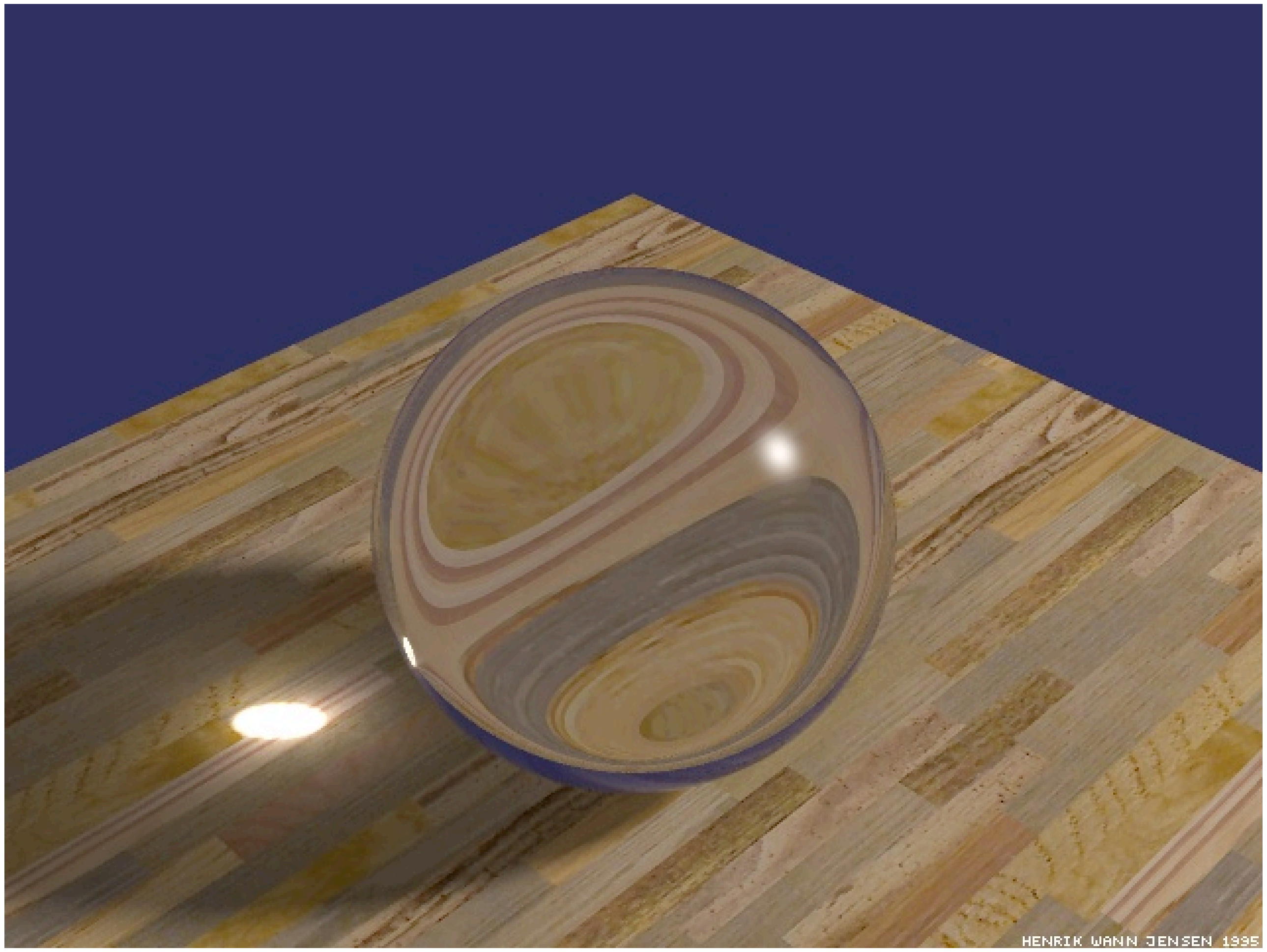
- Caustics:
  - refraction or reflection causes light to be “collected” in some regions.
- Specular-> diffuse transfer
  - source reflected in a mirror
- Can’t render this by tracing rays from the eye - how do they know how to get back to the source?


Light bounces of mirror to diffuse surface (cannot trace back)
Light refracts to diffuse surface (also cannot trace back)
Point Source

Illumination effects (cont)

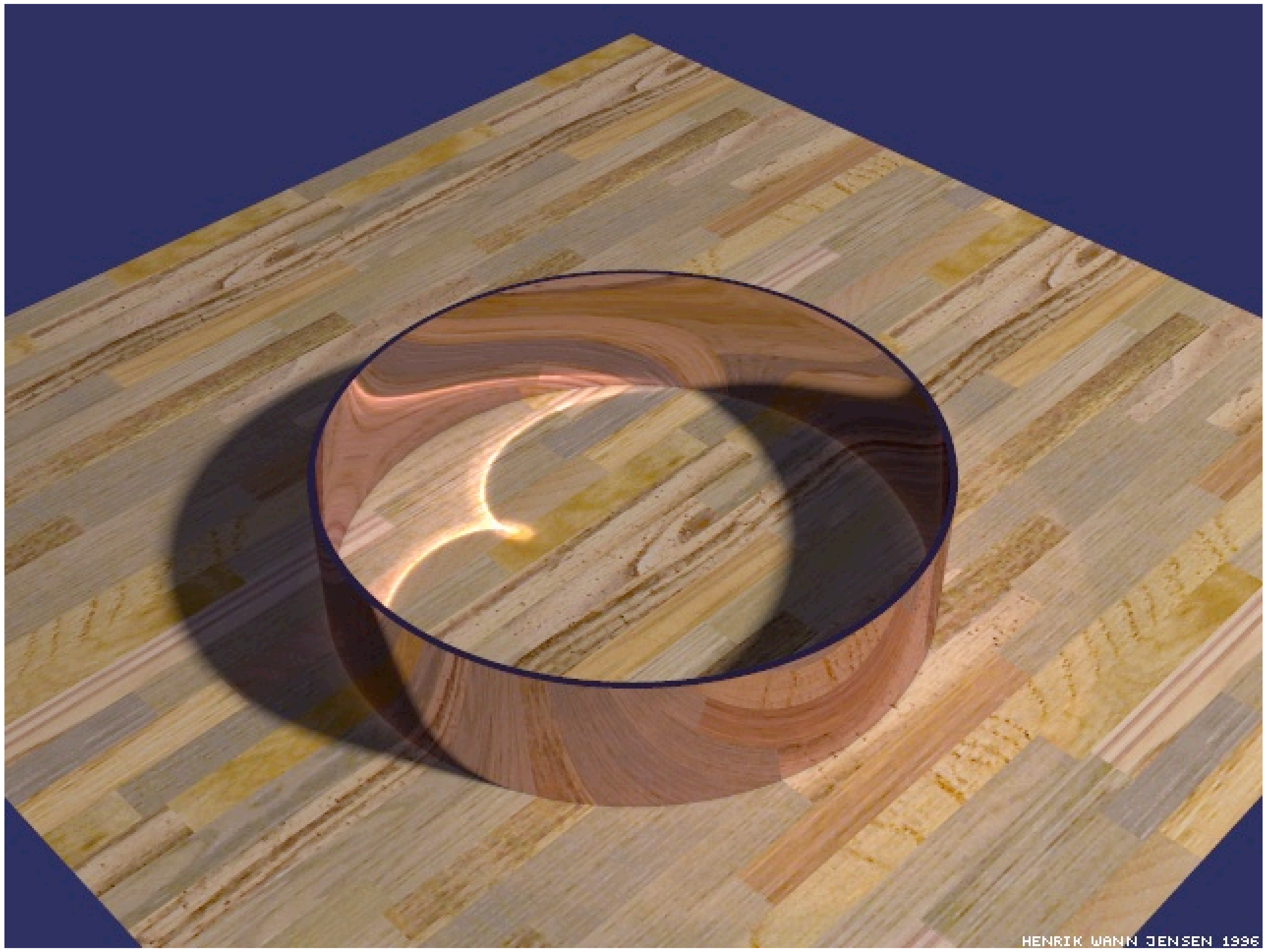
- To get the effect of light reflected and refracted from sources onto diffuse surfaces, trace rays from the light to the first diffuse surface
  - leave a note that illumination has arrived - an illumination map, or photon map
  - sometimes referred to as the forward ray
  - now retrieve this note by tracing eye rays
- Issues
  - efficiency (why trace rays to things that might be invisible?)
  - aliasing (rays are spread out by, say, curved mirrors)

Refraction caustic



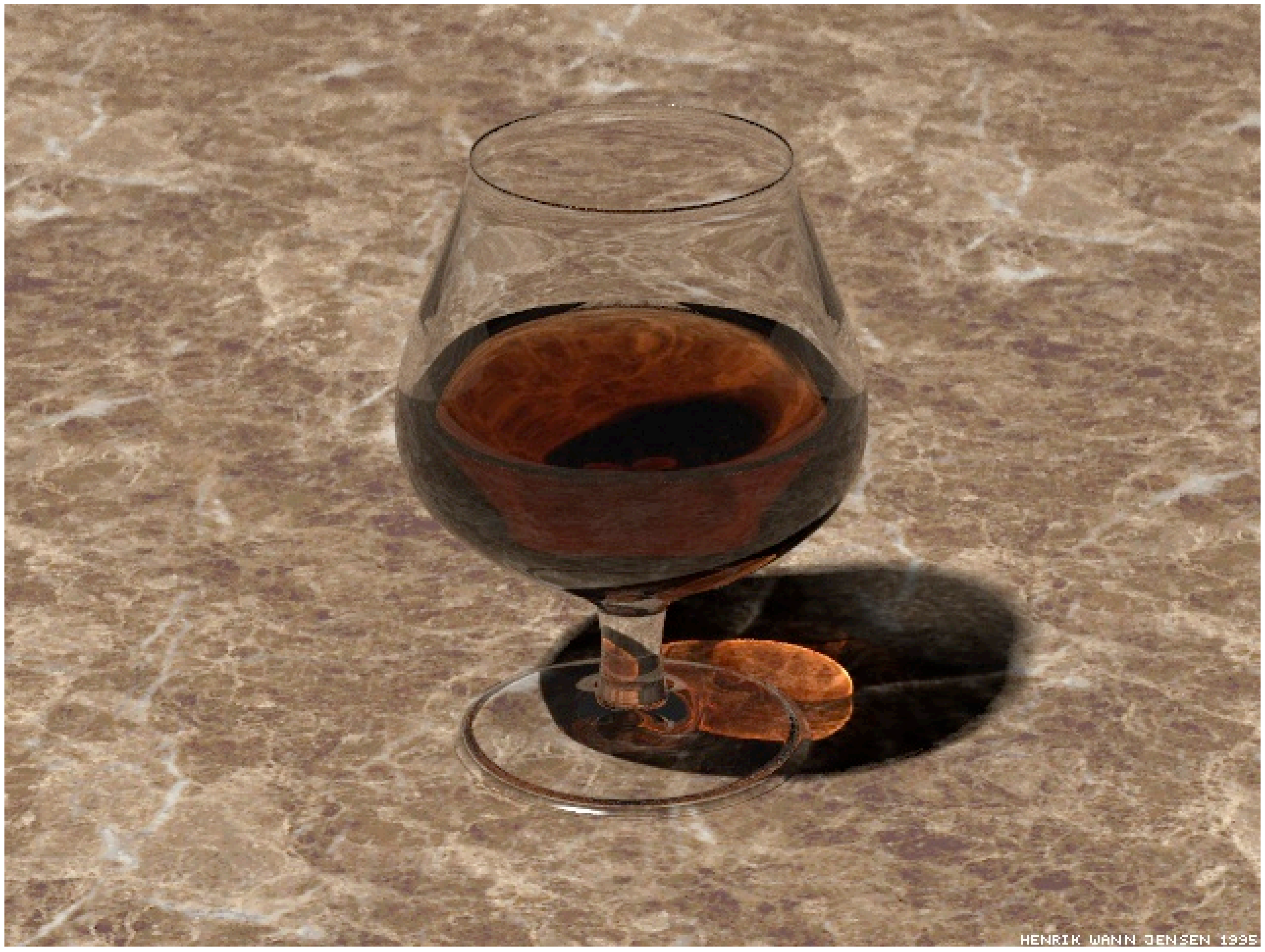
Henrik Jensen, http://www.gk.dtu.dk/~hwj

Reflection caustic



Henrik Jensen, http://www.gk.dtu.dk/~hwj

Refraction caustics

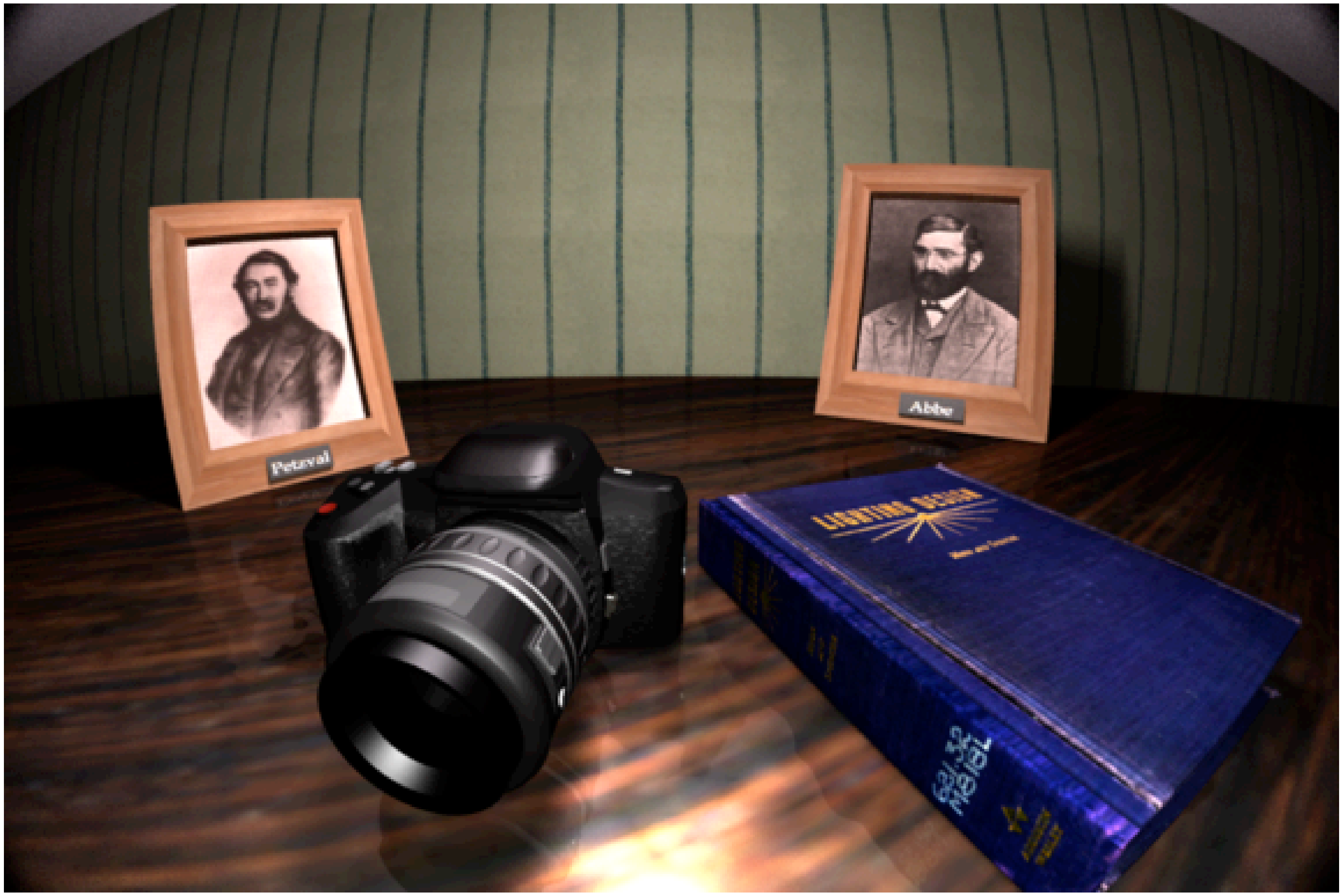


Henrik Jensen, http://www.gk.dtu.dk/~hwj

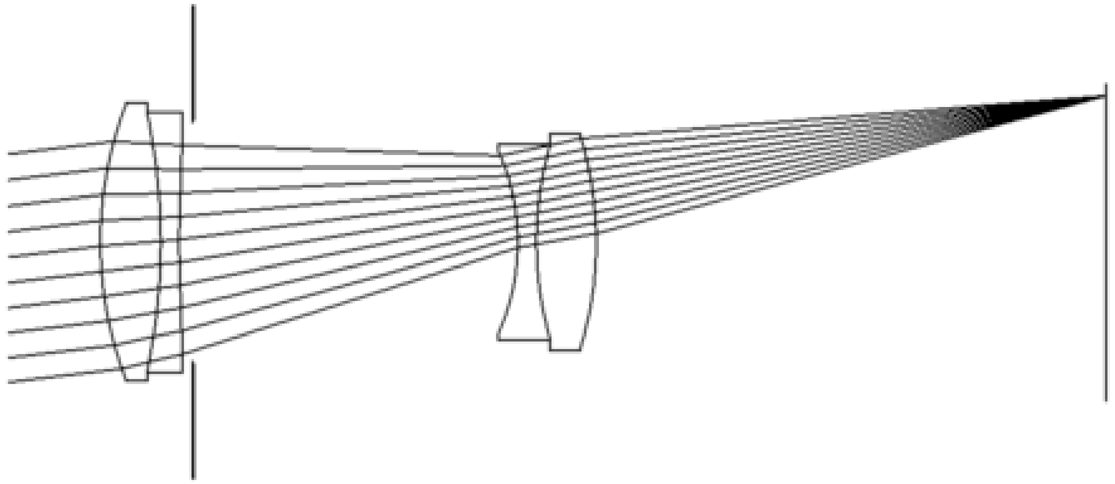
Lens Effects

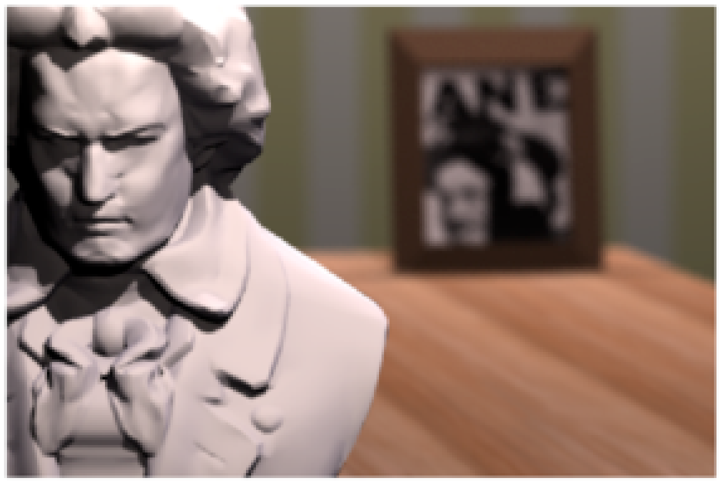
Note that a ray tracer very elegantly deals with the projection geometry that we struggled with in earlier lectures which was based on a very simple and “ideal” camera model

We can go further and introduce a more interesting or realistic camera model



from
A Realistic Camera Model for Computer Graphics
Craig Kolb, Don Mitchell, and Pat Hanrahan
Computer Graphics (Proceedings of SIGGRAPH '95), ACM SIGGRAPH, 1995, pp. 317-324





Note limited depth of field, just like a real lens

from
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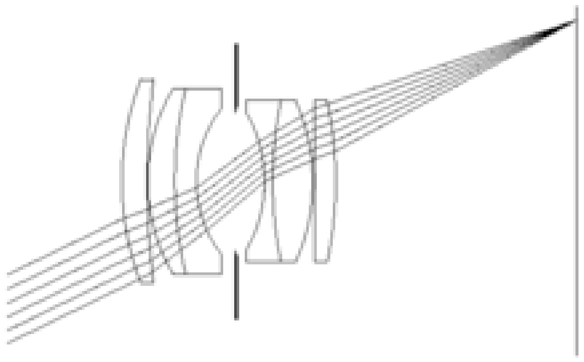

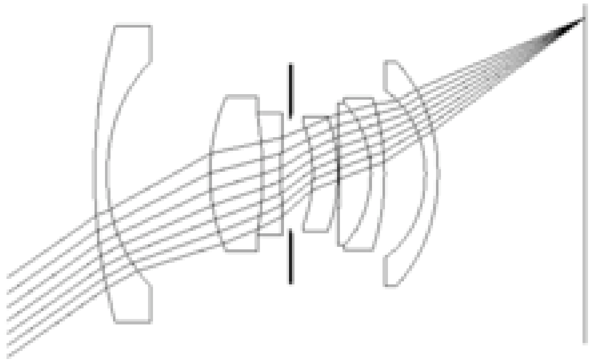

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