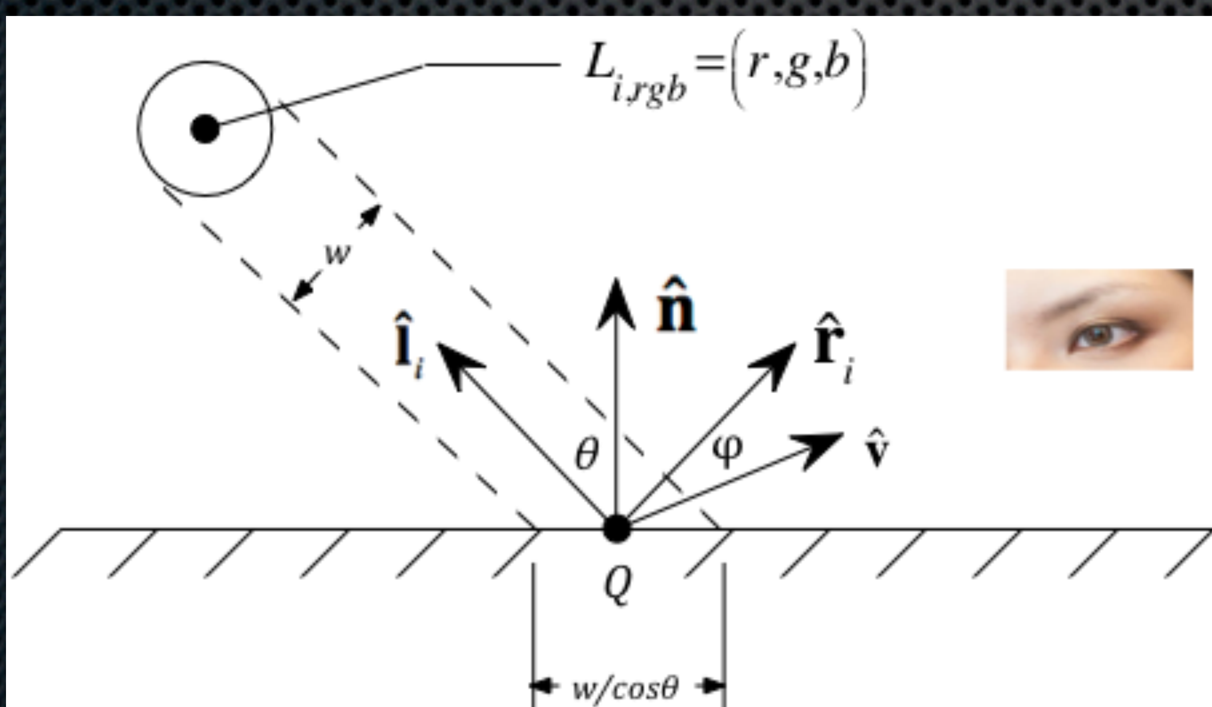
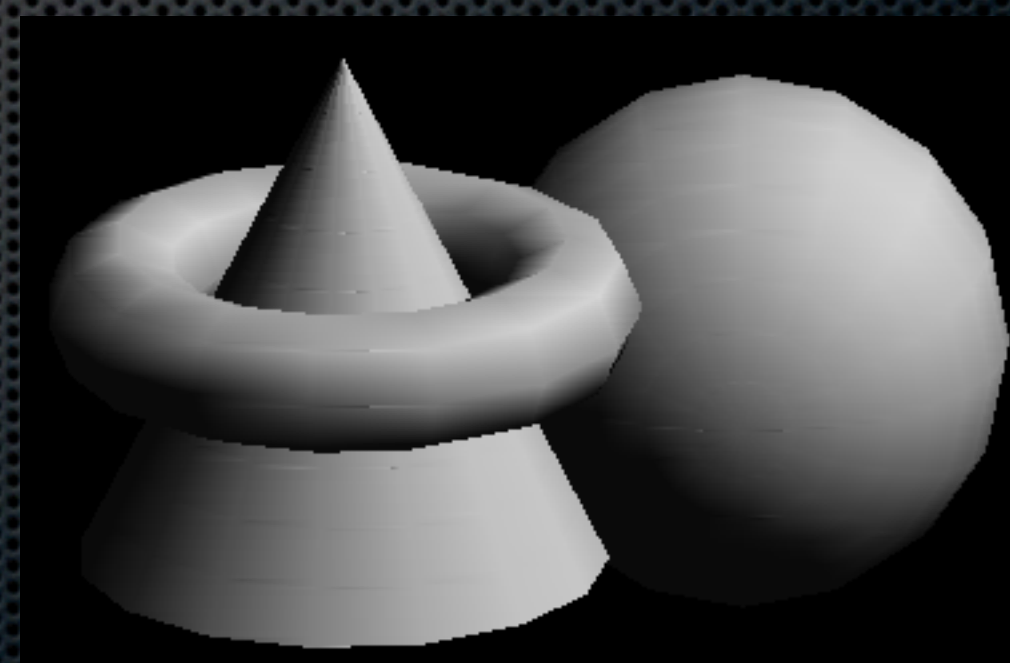
CMSC427 fall 2017
Global illumination – intro

Ray tracing and radiosity

So far – local illumination

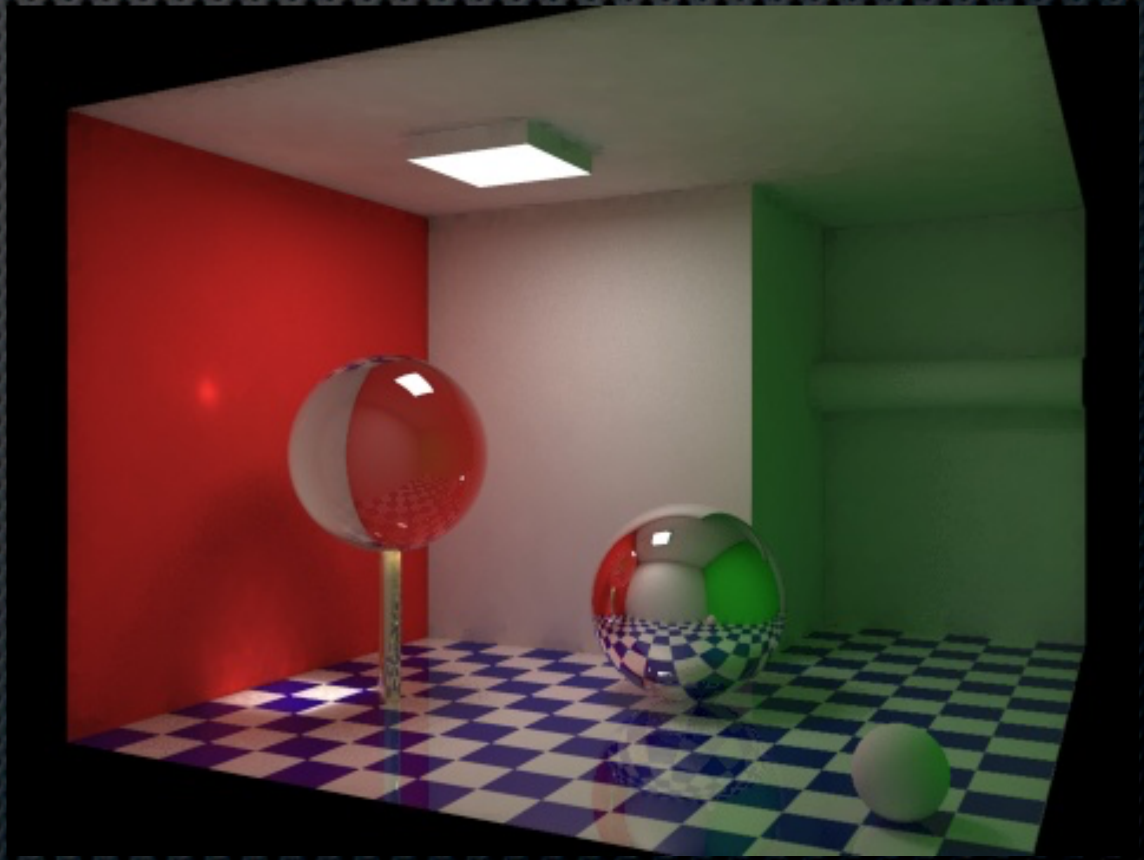
- One triangle, one light at a time
- Object rendering *into* image – what pixel sees me?
- Opaque surfaces
- No shadows, no crosstalk between facets





Now– global illumination +

- Scene oriented – consider all triangles and lights
- Image oriented rendering – what object can pixel see?
- Translucent and transparent surfaces, refraction
- Shadows, color bleeding



Ray Tracing and Radiosity

- General concepts
  - What advantages do they have?
  - How can you spot a ray-traced or radiositied image?
- How they work
  - Ray tracing overview
  - Radiosity overview
- Other approaches: path tracing, ray marching

Ray tracing

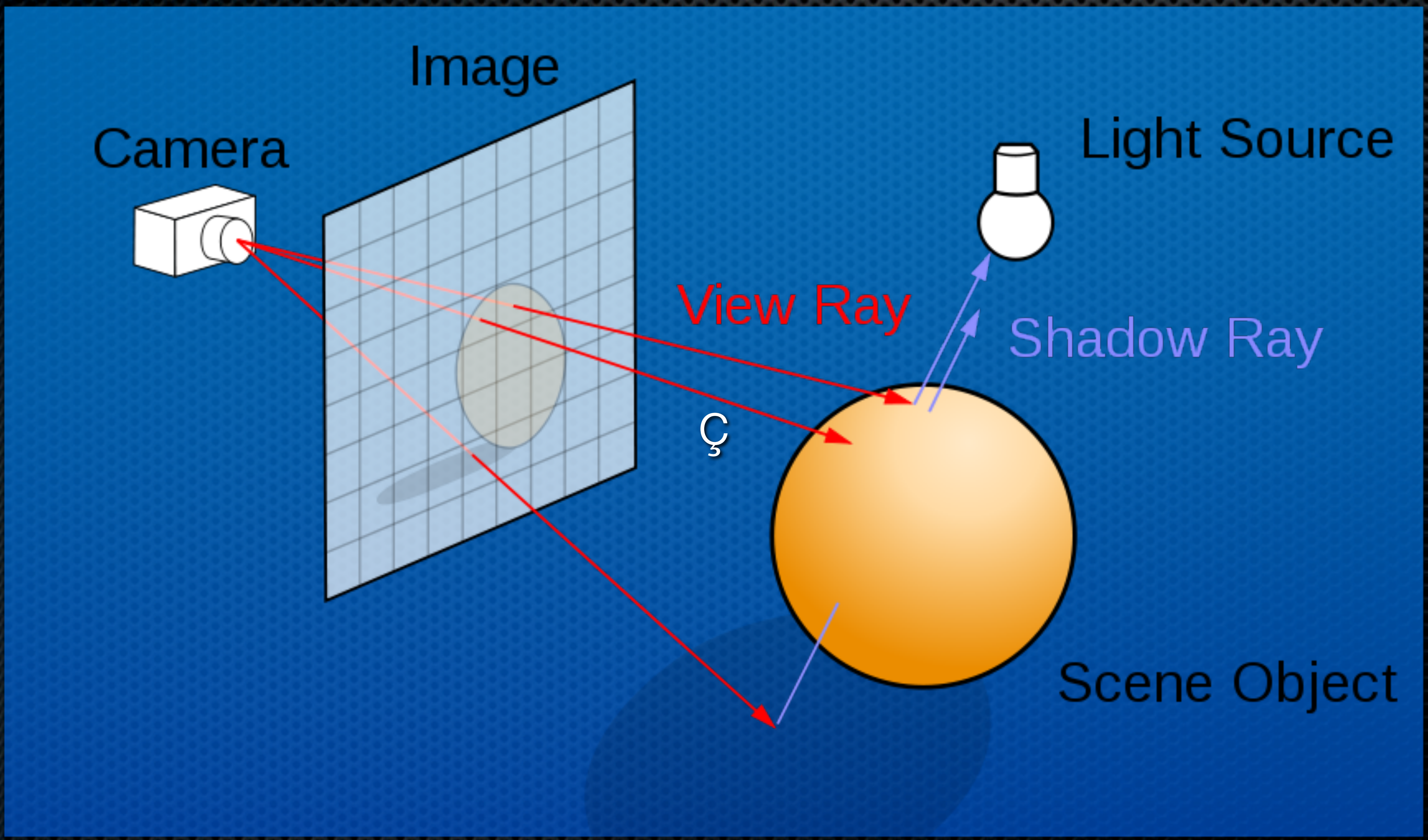
- Reflections, refractions
- Sharp shadows
- Partial physical model
- Point lights
- Tracing single rays

Radiosity

- Soft shadows
- Better physics
- Extended lights

- Integrating over extended areas

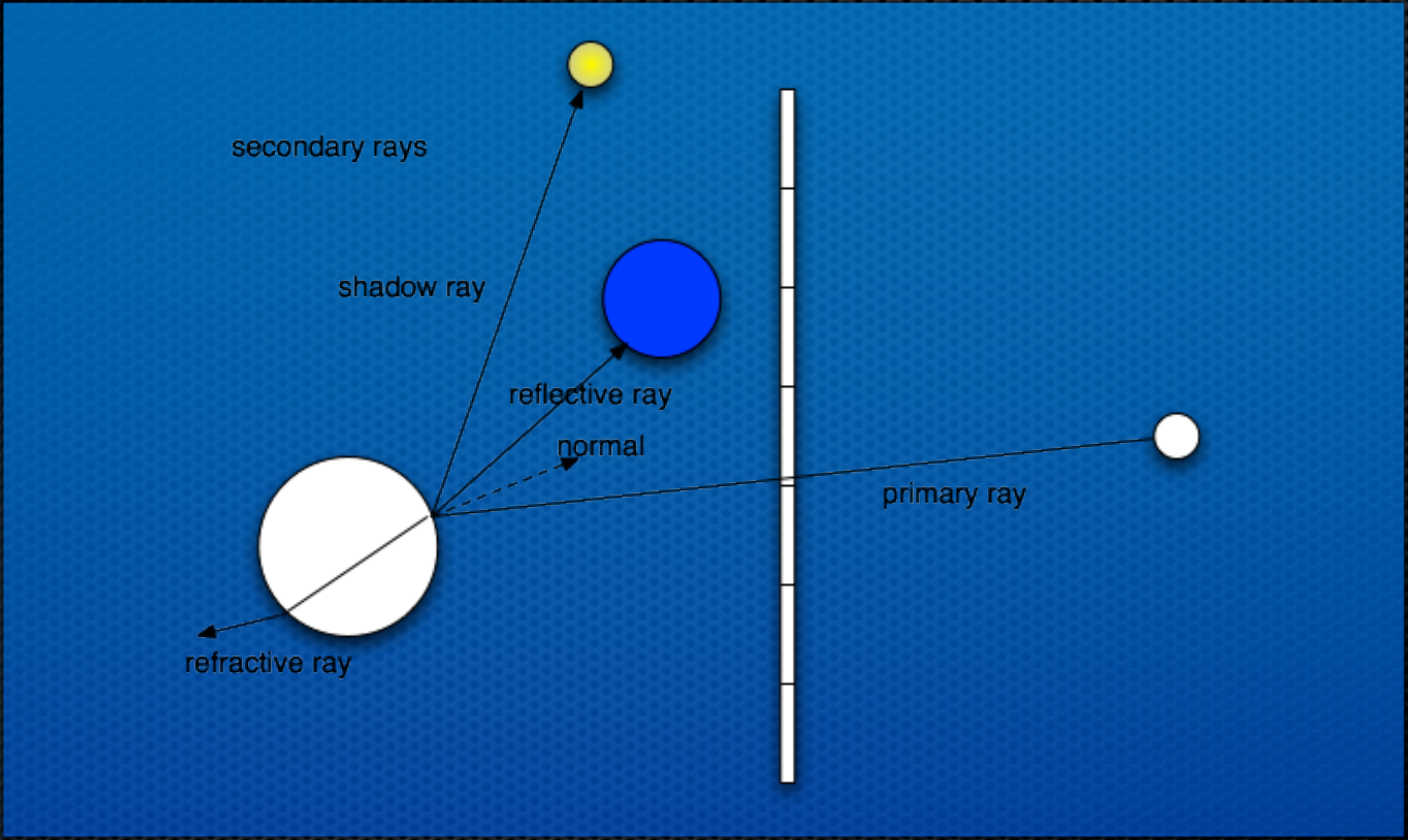
Ray tracing principles



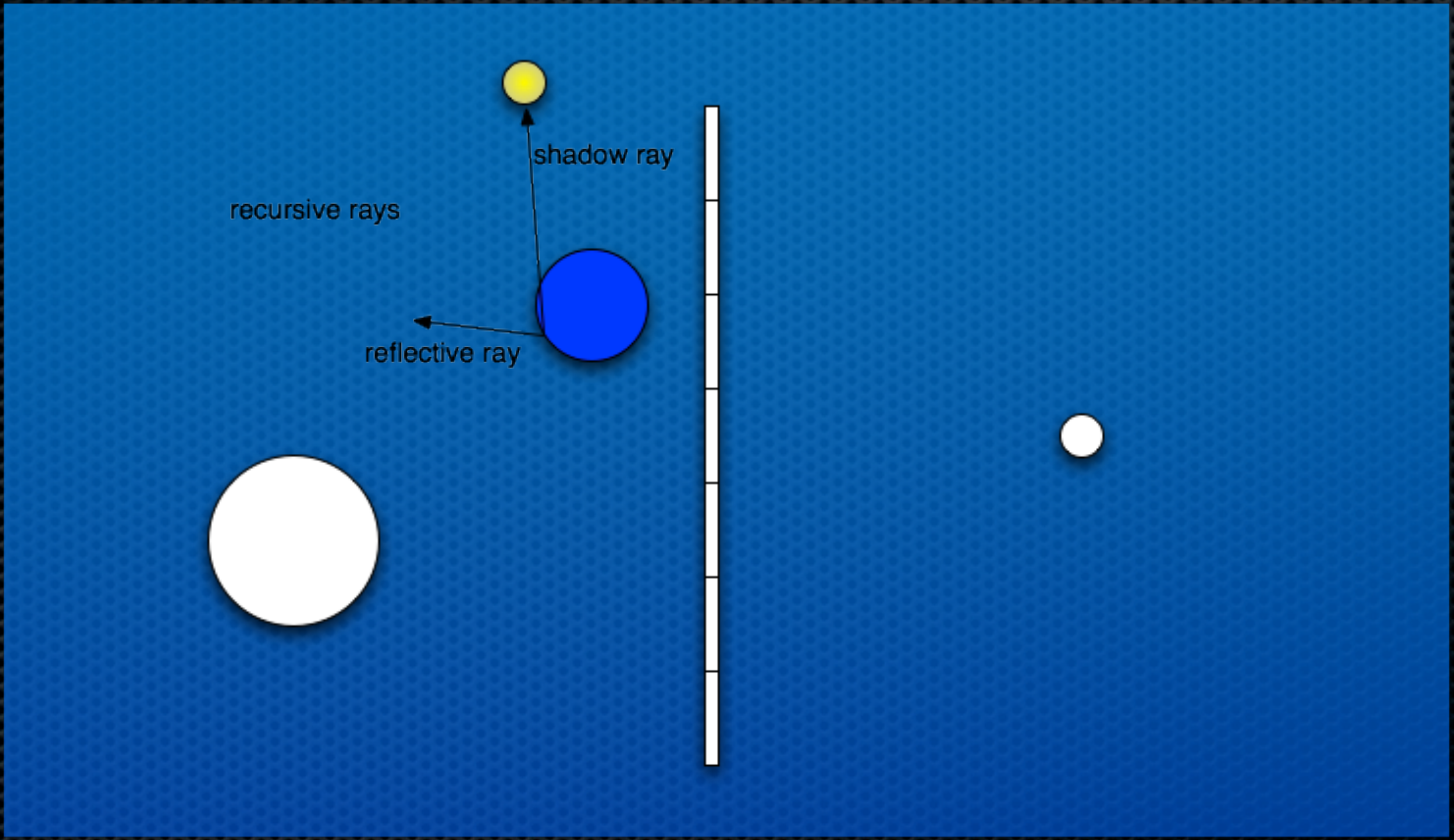
The Rays

- Concepts:
  - View (primary) ray
  - Secondary rays
    - Shadow ray (to all lights)
    - Reflection ray
    - Refraction ray

The rays again

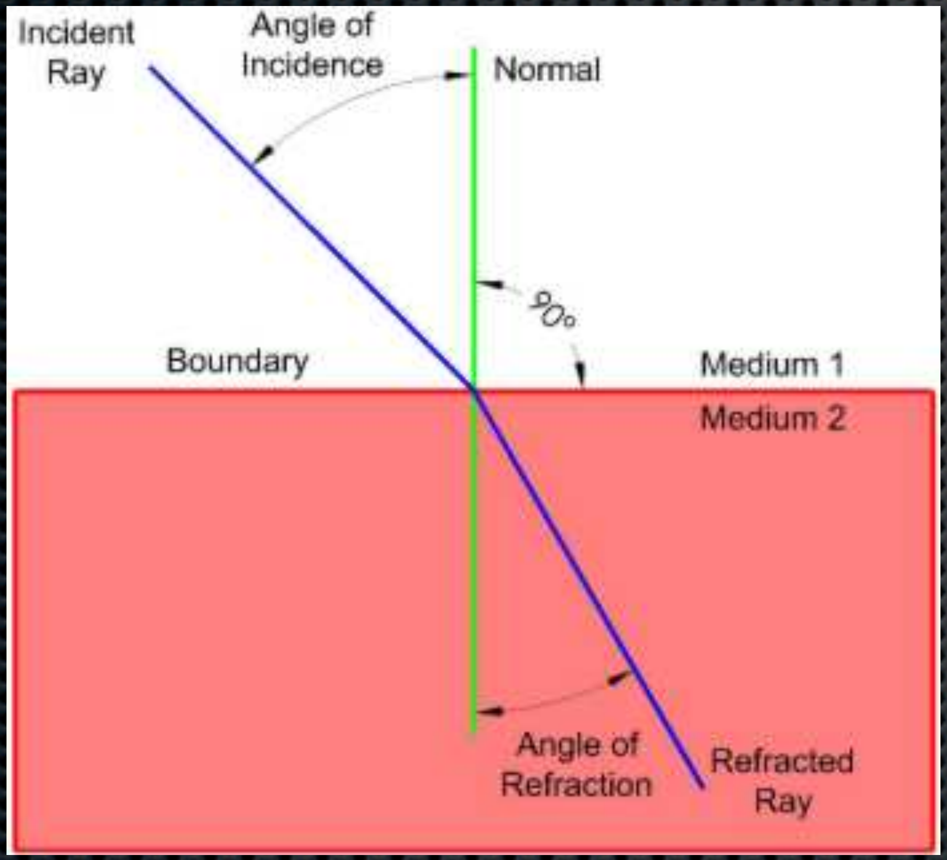


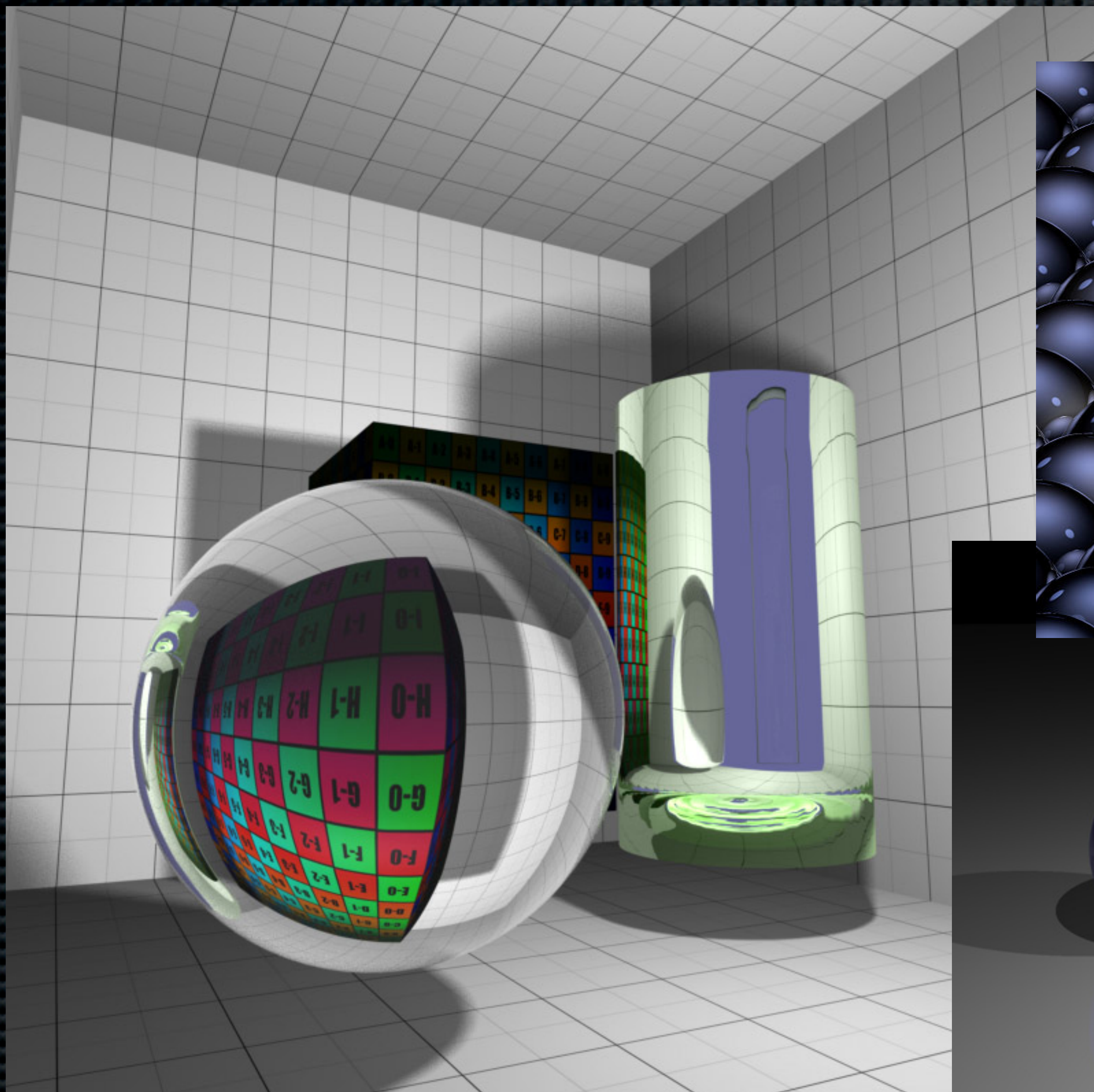
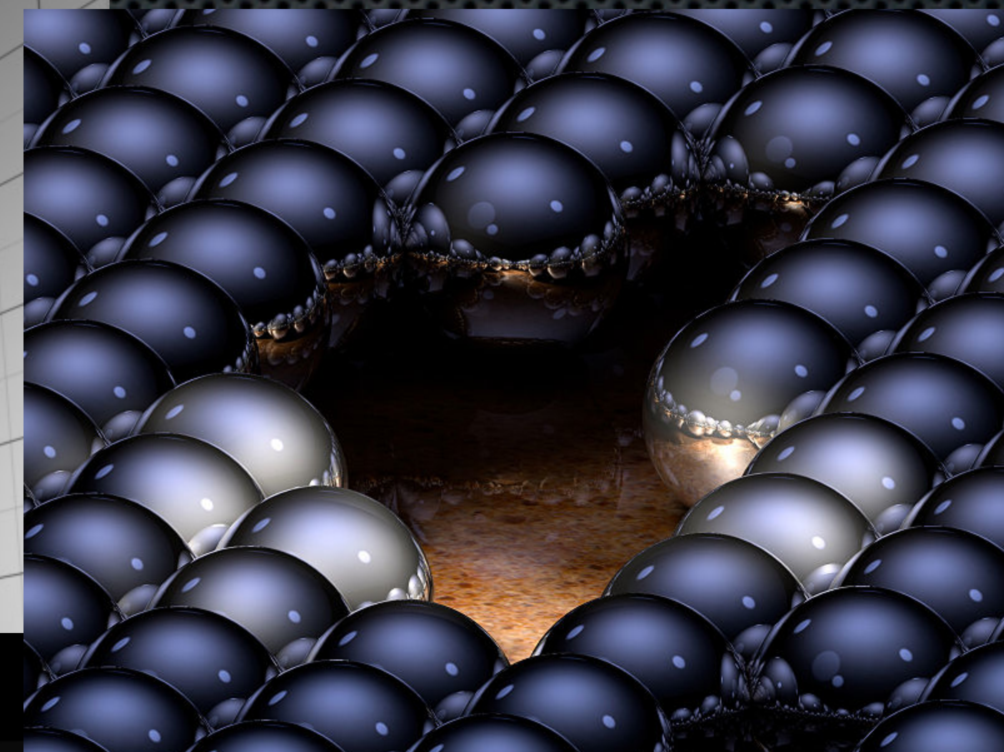
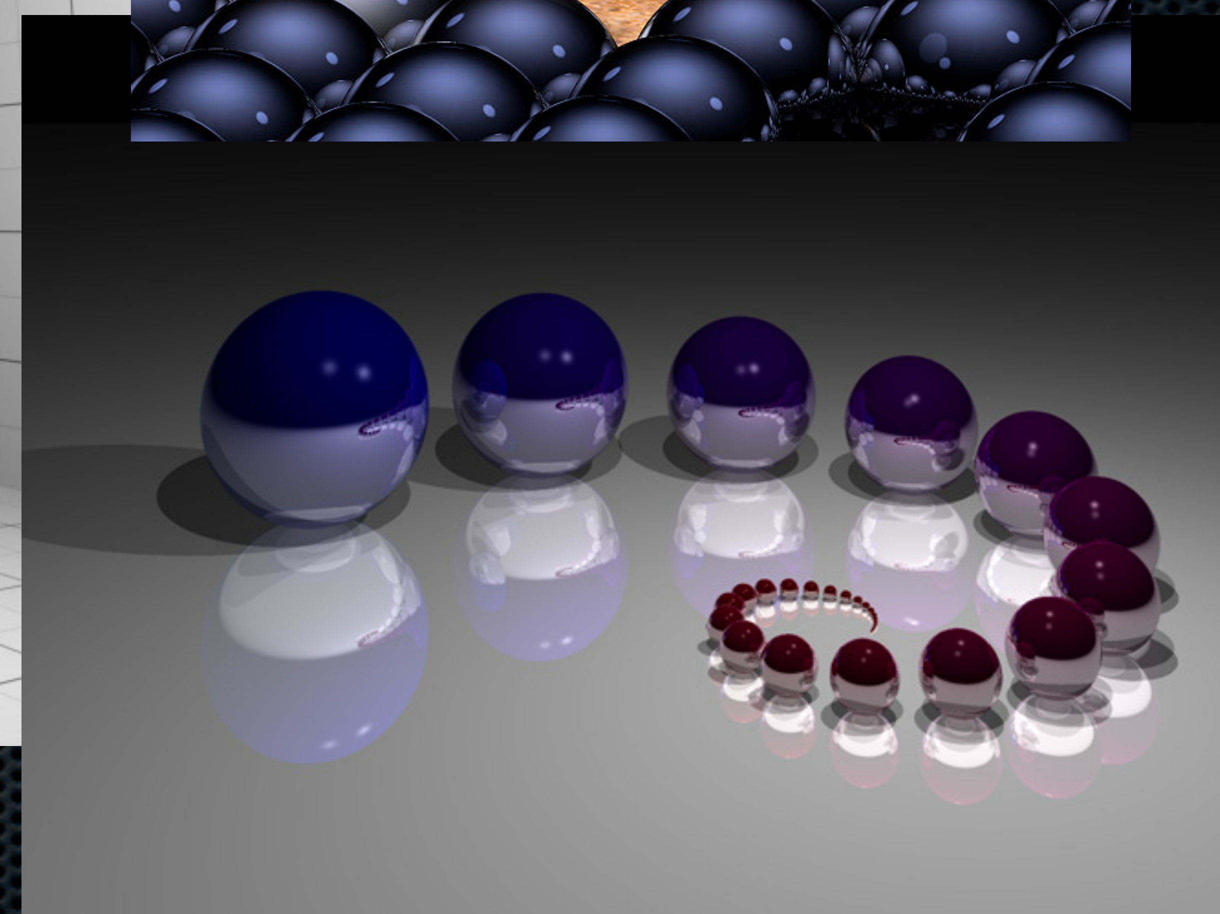
Recursive rays (rinse, repeat)



Refraction

- Depends on ratio of speed of light between two materials




Rasterized
Ray traced


Tweaking ray tracing

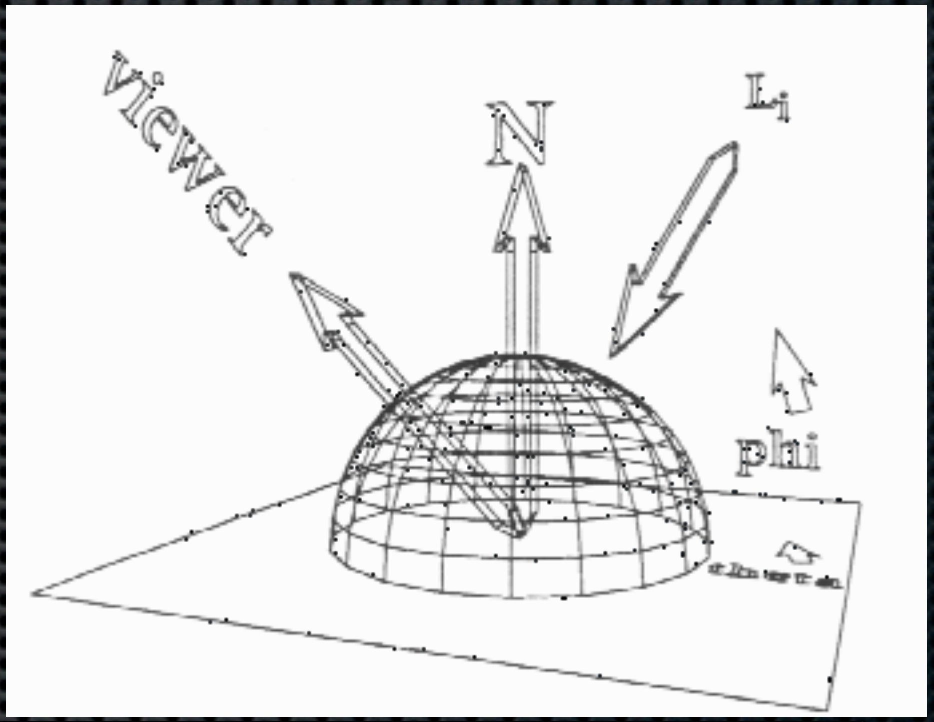
- One is not enough
  - One primary ray can “barely” miss an object
  - Stochastic or random ray tracing
    - multiple, random primary rays out of a pixel
- Speeding it up
  - Speed up intersection calculations by data structure

Radiosity principles

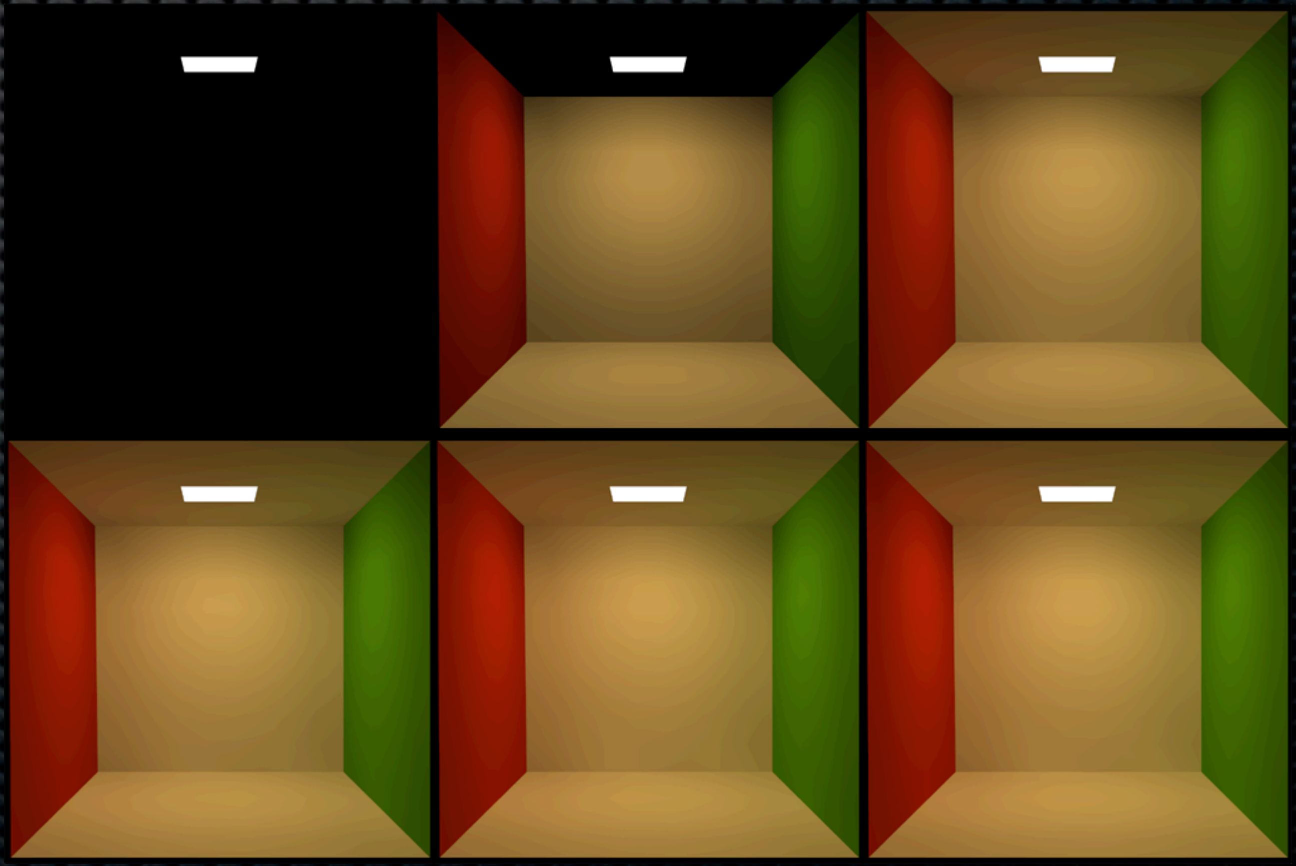
- Global vs. local computations

The Cornell box

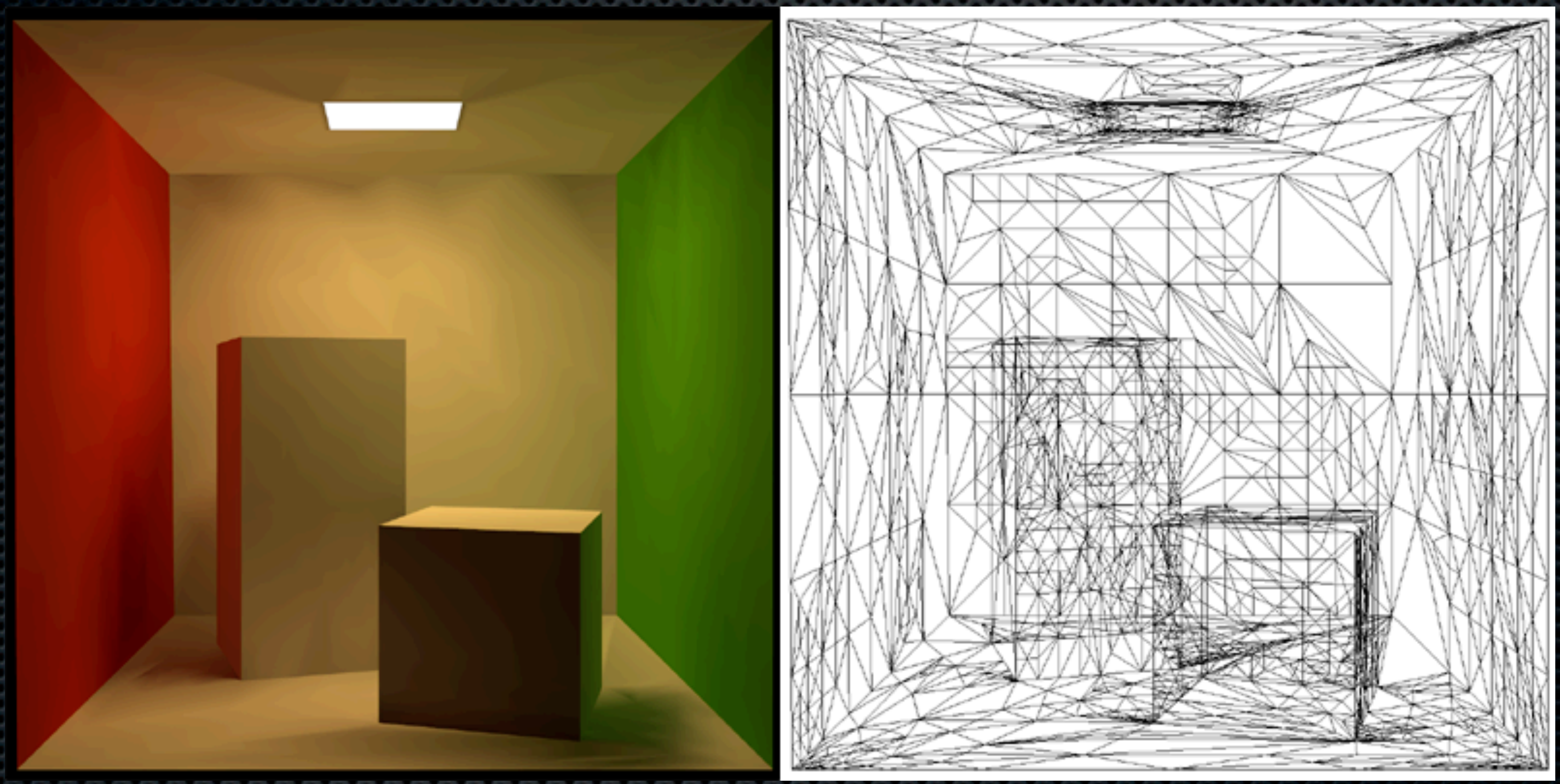
Radiosity vs. ray tracing



- Ray tracing - sample rays for each light, reflection and refraction
- Radiosity - integration over all rays on patch
- Iterate until light solutions are stable



Patch computations



Ray tracing details

- The basic recursive algorithm
- Casting the primary ray
- Intersecting with an object: sphere (circle), triangle
- Computing refraction ray

Ray tracing algorithm

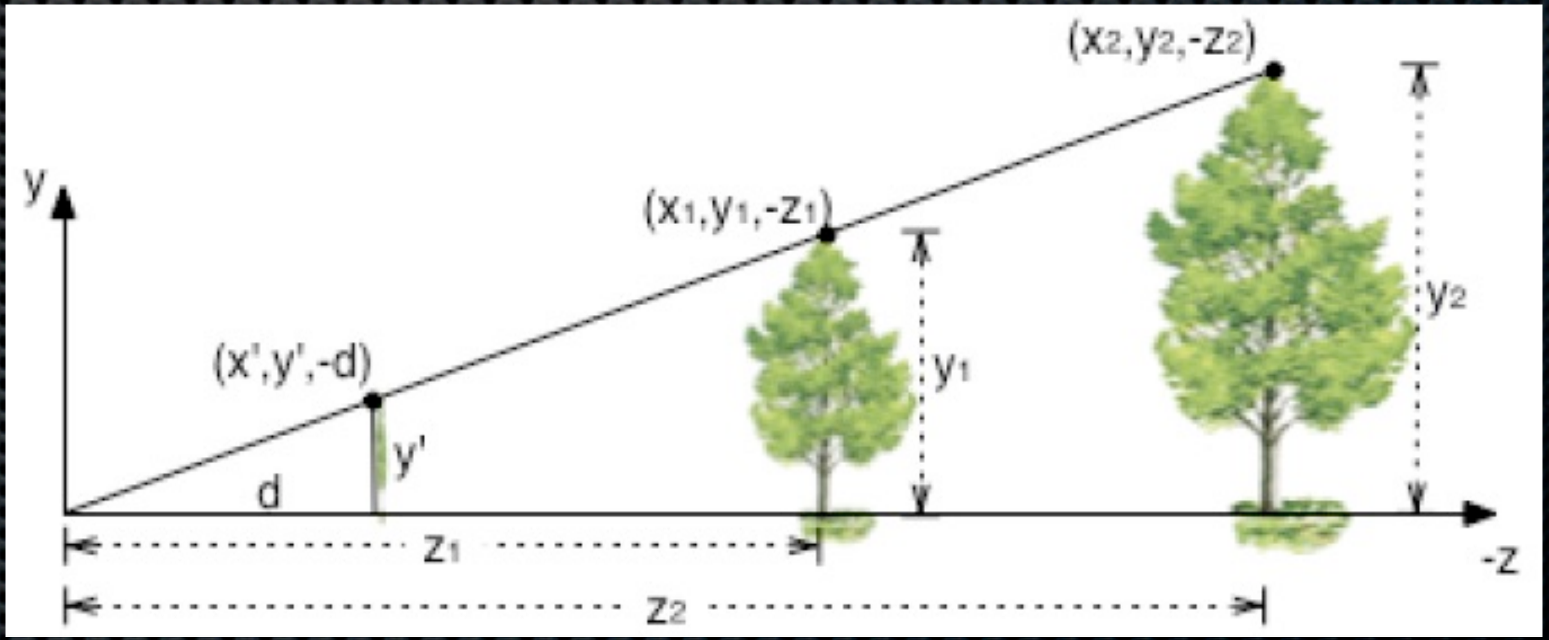
```
for (int j = 0; j < imageHeight; ++j) {
  for (int i = 0; i < imageWidth; ++i) {
    Ray primaryRay = new Ray(i,j);
    color[i][j] = rayTrace(primaryRay,0); }}

rayTrace(ray, generation)
    if (generation > maxGen) return backgrdColor;
    hitPt = intersect(ray, objectList);
    if (hitPt == null) return backgroundColor;
    c = accumulateLights(hitPt);
    if (reflective(hitPt)) {
        reflectRay = reflect(ray,hitPt)
        c += trace(reflectRay) }
    if (refractive(hitPt)) {
        refractRay = refract(ray,hitPt)
        c += trace(refractRay) }
    return c
```

Casting first ray

$p(t) = eye + t(imagePt - eye)$ **with t in [0,inf]**

imagePt is (x‘,y‘,-d), eye is at origin



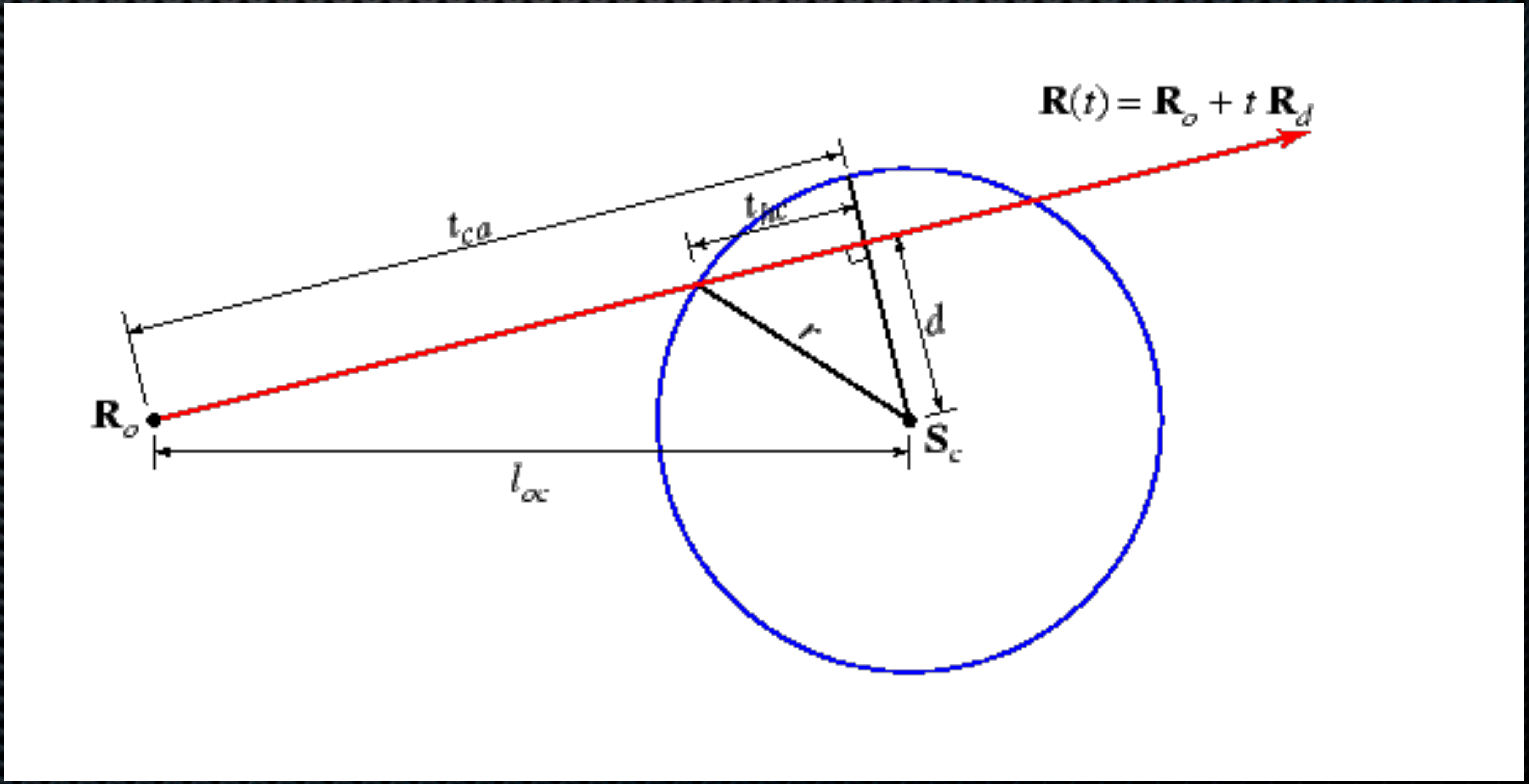
Intersecting with first object

For each object:

Compute hit time t when ray hits object

Find object with smallest t – that is hit point

Spheres are easiest!

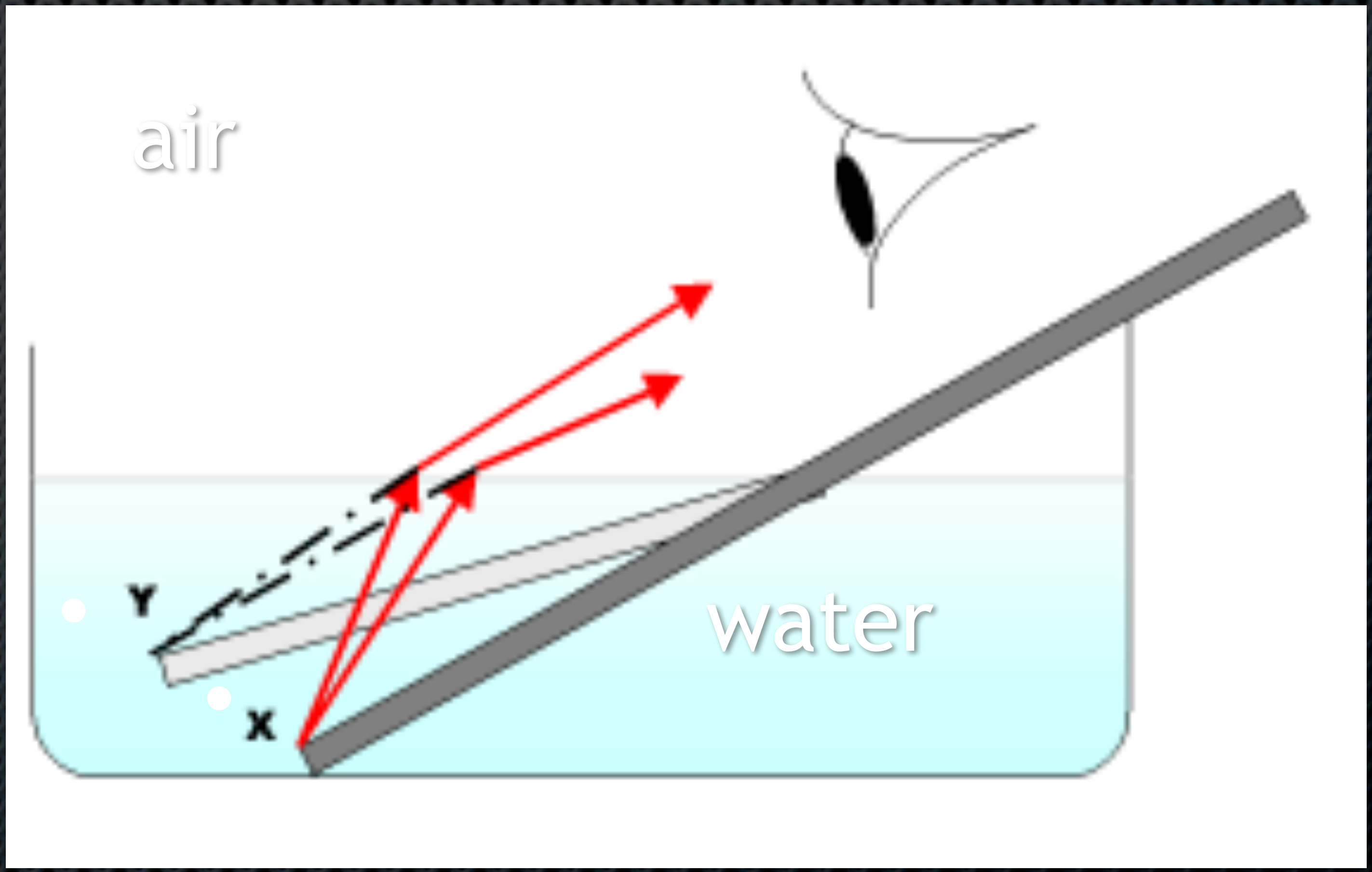


Reflection & refraction

Refraction

http://en.wikipedia.org/wiki/Refraction

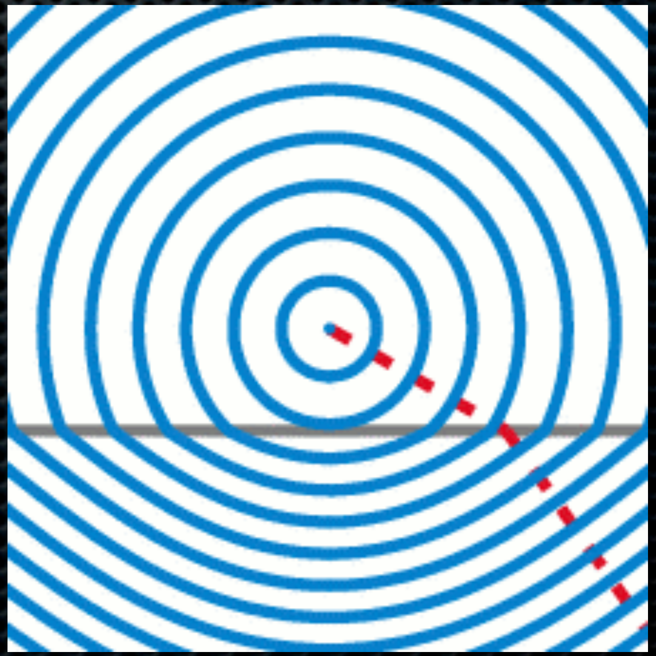
- Light rays that travel from one medium to an other are bent
- To the viewer, object at location x appears to be at location y



Index of refraction

http://en.wikipedia.org/wiki/Refractive_index

- Speed of light depends on medium
  - Speed of light in vacuum c
  - Speed of light in medium v
- Index of refraction $n=c/v$
  - Air 1.00029
  - Water 1.33
  - Acrylic glass 1.49
- "Change in phase velocity leads to bending of light rays"



Snell’s law

http://en.wikipedia.org/wiki/Snell's_law

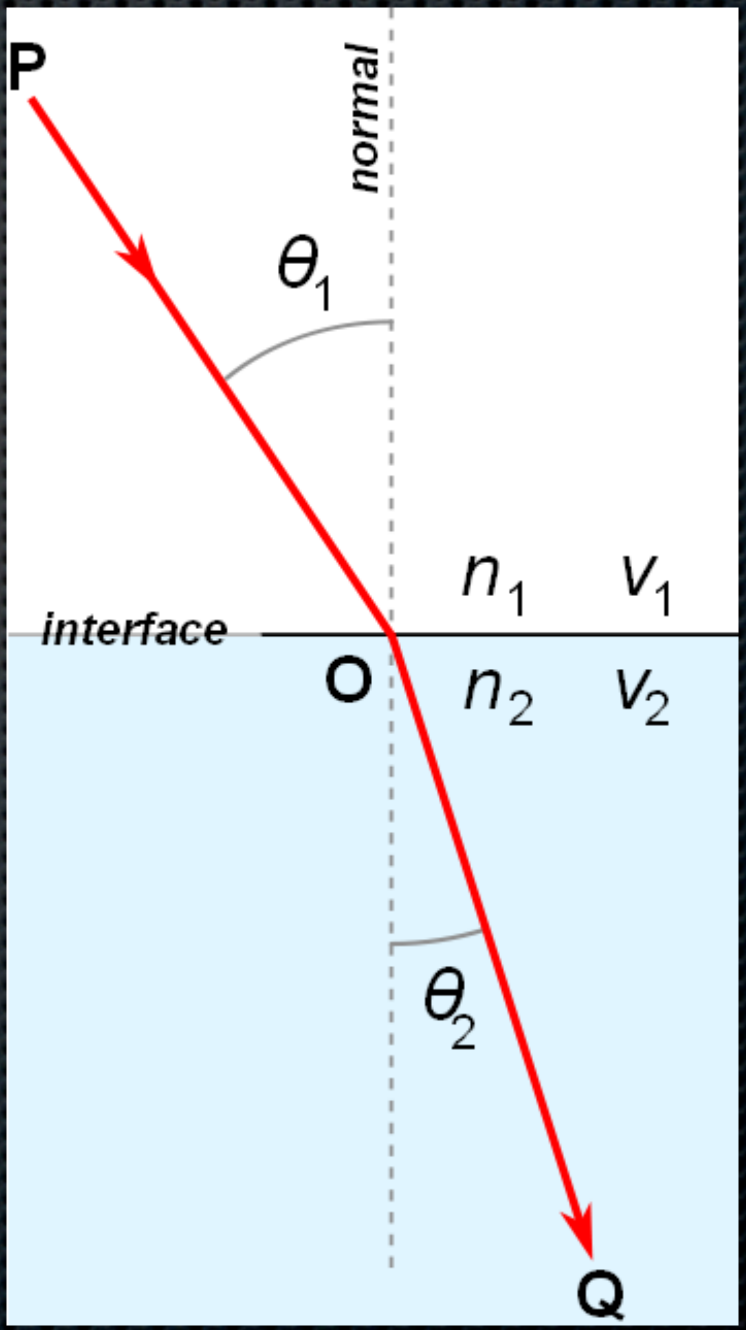
- Ratio of sines of angle of incidence θ_1 and refraction θ_2 is equal to opposite ratio of indices of refraction n_1, n_2

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

- Vector form in 3D

$$\mathbf{r} = \frac{n_1}{n_2}\mathbf{v} + \left(\frac{n_1}{n_2}\cos\theta_1 + \cos\theta_2\right)\mathbf{n}$$

- Viewing, refracted direction **v, r (P,Q)**
- Normal vector **n**



Total internal reflection

http://en.wikipedia.org/wiki/Total_internal_reflection

- Angle of refracted ray

$$\theta_2 = \arcsin\left(\theta_1 \frac{n_1}{n_2}\right)$$

- Critical angle

$$\theta_c = \frac{n_2}{n_1}$$

- If $\theta_1 = \theta_c$ we get $\theta_2 = \pi/2$ refracted ray is parallel to interface
- If $\theta_1 > \theta_c$ we have total internal reflection (light ray does not cross interface between media)

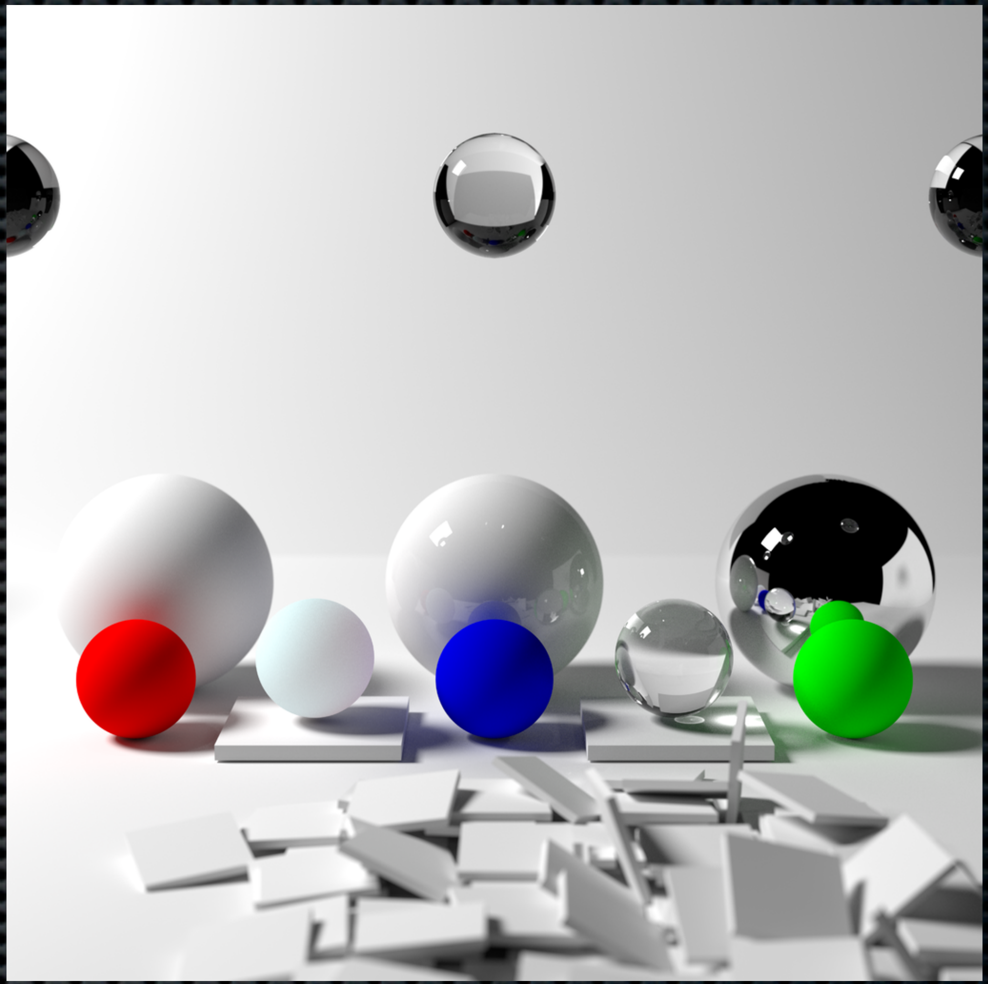
Fresnel equations

- Fresnel equations are relatively complex to evaluate
- In graphics, often use Schlick's approximation
  https://en.wikipedia.org/wiki/Schlick%27s_approximation
  - Ratio F between reflected and refracted light
  - Indices of refraction n_1, n_2

$$F = f + (1 - f)(1 - \mathbf{v} \cdot \mathbf{n})^5$$

$$f = \frac{\left(1.0 - \frac{n_1}{n_2}\right)^2}{\left(1.0 + \frac{n_1}{n_2}\right)^2}$$

Newer algorithms



- Path tracing
  - A multisampled, randomized version of ray tracing to approx. radiosity
- Ray marching
  - A "binary search" approach to finding the hit point for complex shapes when no closed form exists

This image is ...?