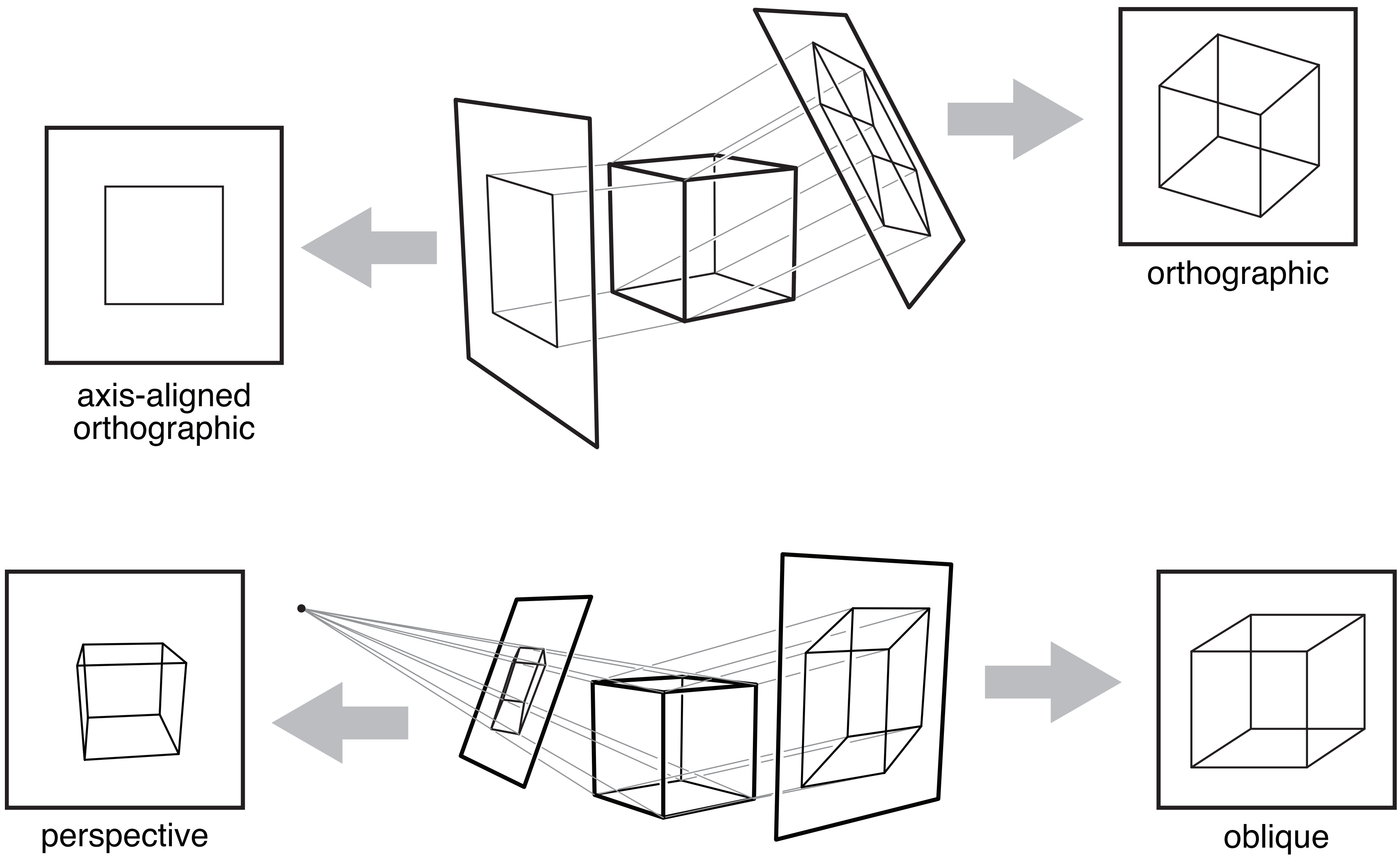
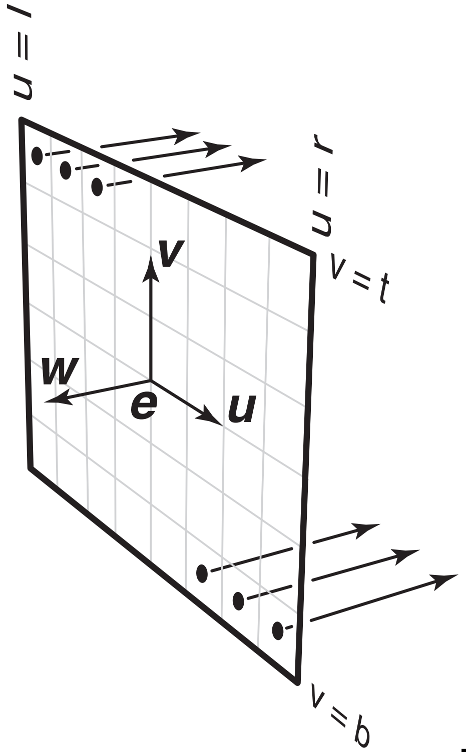
Basic Ray Tracing

CMSC 435/634

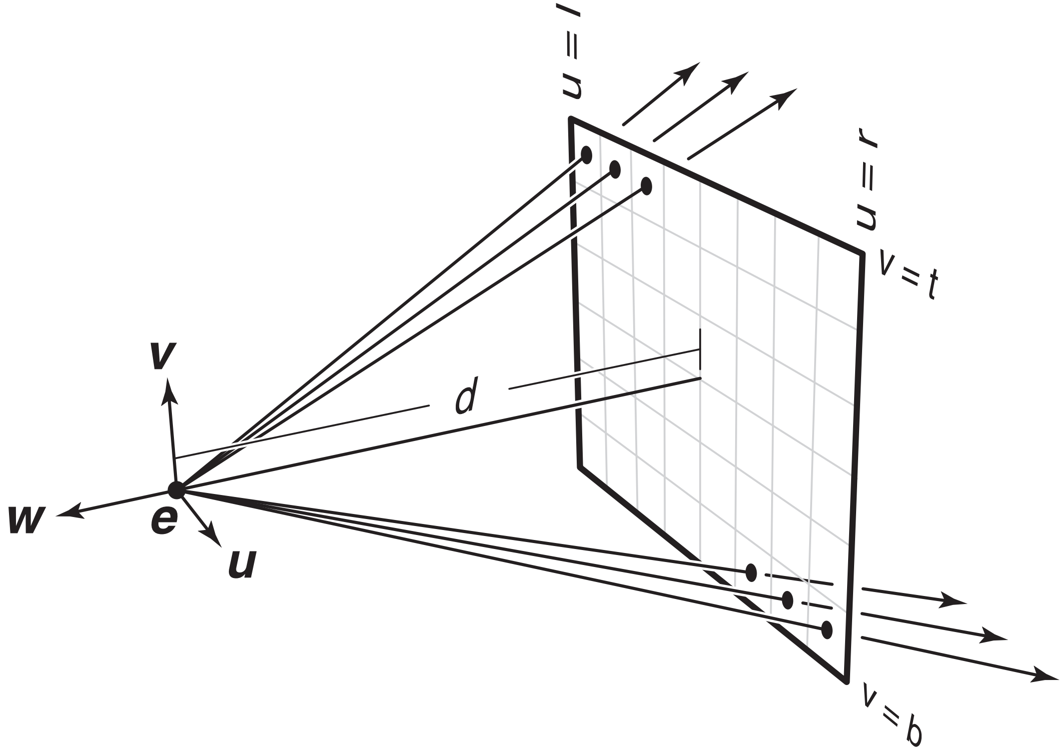
Projections



Computing Viewing Rays



Parallel projection
same direction, different origins



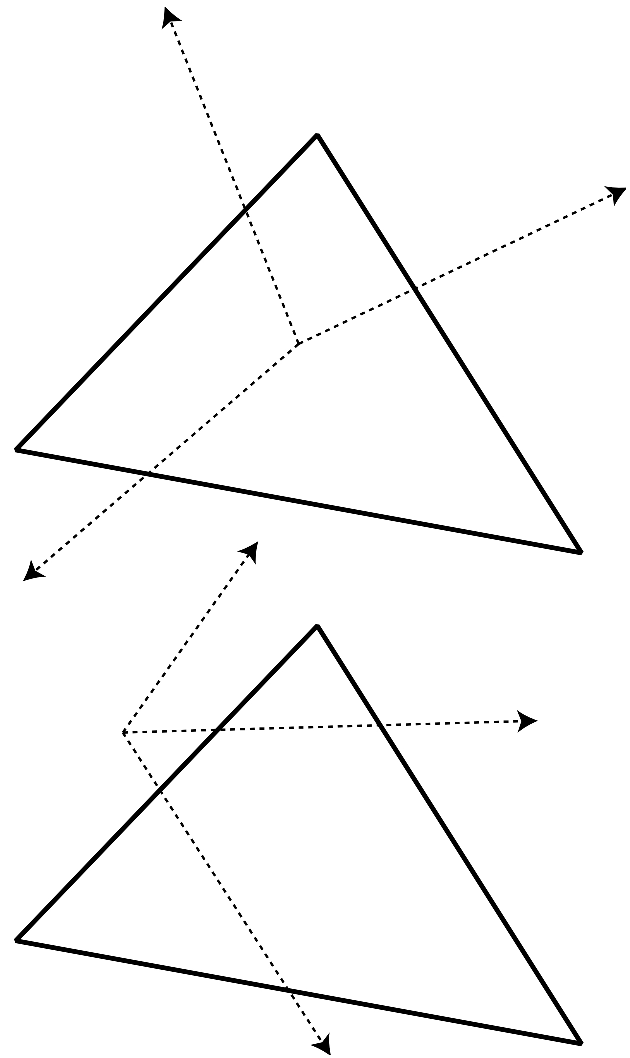
Perspective projection
same origin, different directions

Ray-Triangle Intersection

```
boolean raytri (ray r, vector p0, p1, p2, interval [t0,t1] )
{
    compute t
    if (( t < t0 ) or (t > t1))
        return ( false )
    compute γ
    if ((γ < 0 ) or (γ > 1))
        return ( false )
    compute β
    if ((β < 0 ) or (β+γ > 1))
        return ( false )
   return true
}
```

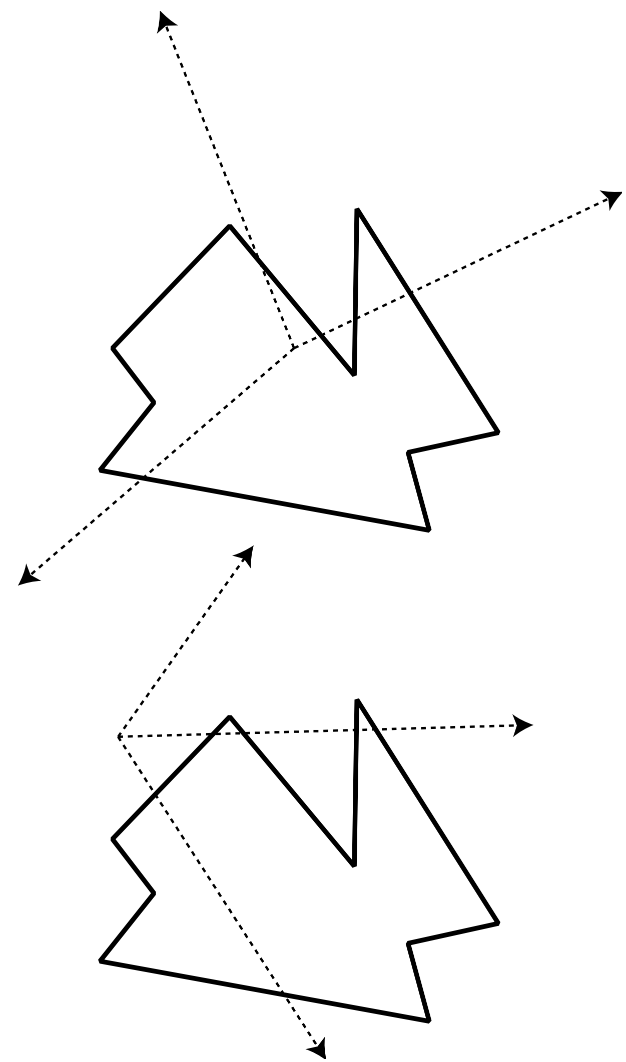
Point in Polygon?

- Is P in polygon?
- Cast ray from P to infinity
  - 1 crossing = inside
  - 0, 2 crossings = outside

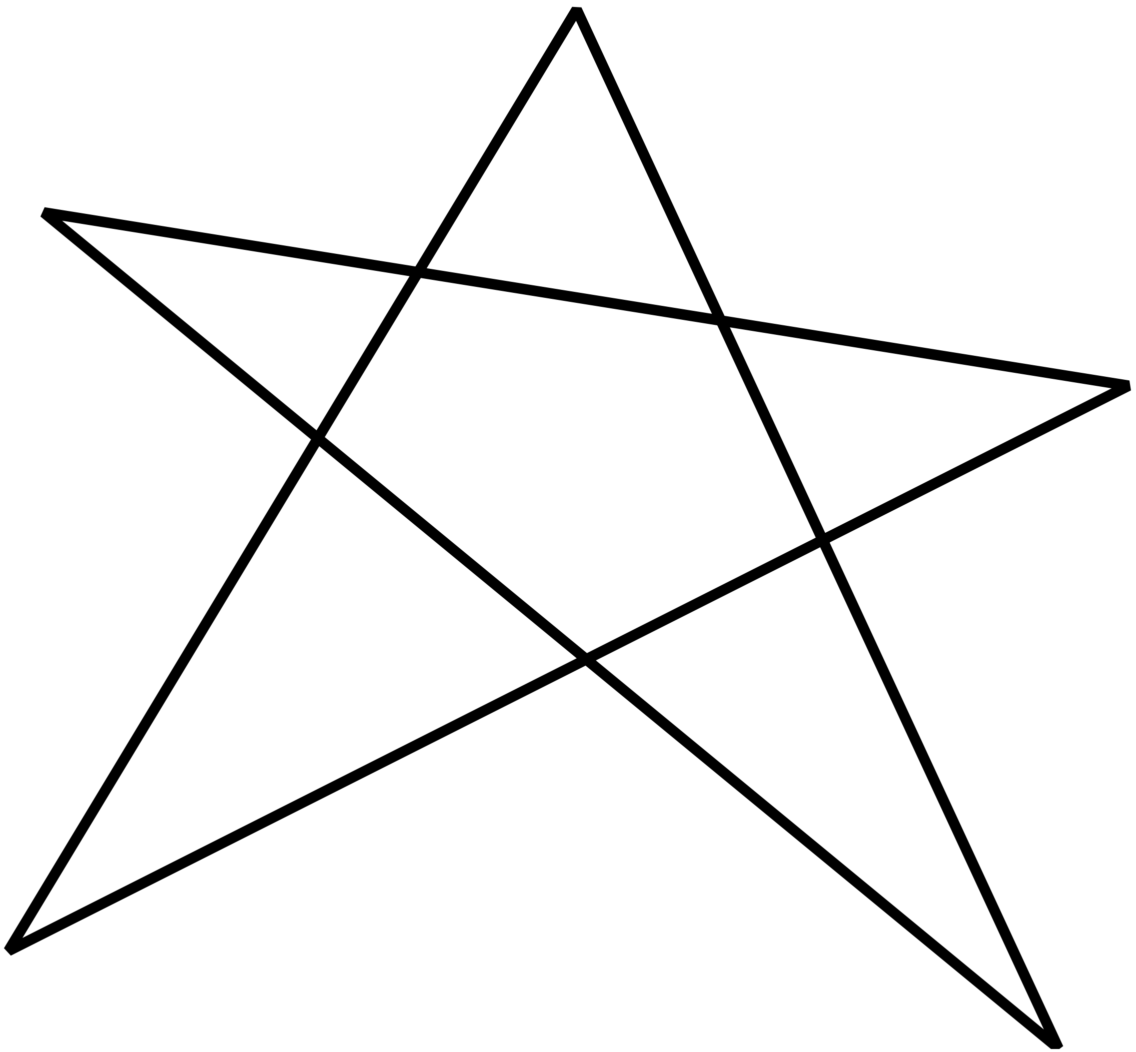


Point in Polygon?

- Is P in concave polygon?
- Cast ray from P to infinity
  - Odd crossings = inside
  - Even crossings = outside



What Happens?



Raytracing Characteristics

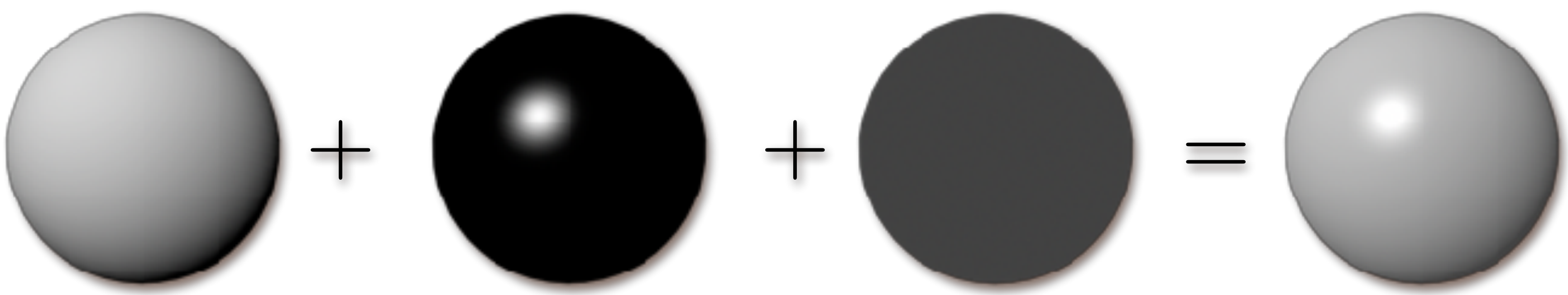
- Good
  - Simple to implement
  - Minimal memory required
  - Easy to extend
- Bad
  - Aliasing
  - Computationally intensive
    - Intersections expensive (75-90% of rendering time)
    - Lots of rays

Basic Illumination Concepts

- Terms
  - Illumination: calculating light intensity at a point (object space; equation) based loosely on physical laws
  - Shading: algorithm for calculating intensities at pixels (image space; algorithm)
- Objects
  - Light sources: light-emitting
  - Other objects: light-reflecting
- Light sources
  - Point (special case: at infinity)
  - Area

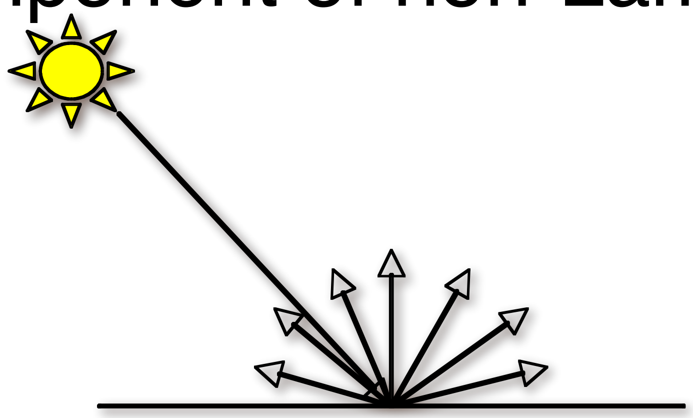
A Simple Model

- Approximate BRDF as sum of
  - A diffuse component
  - A specular component
  - A “ambient” term



Diffuse Component

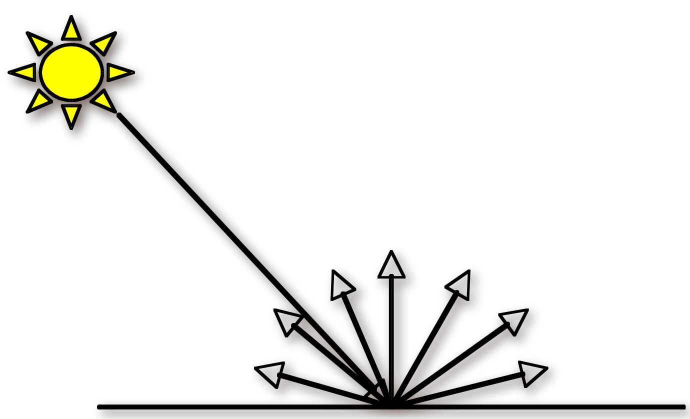
- Lambert's Law
  - Intensity of reflected light proportional to cosine of angle between surface and incoming light direction
  - Applies to "diffuse," "Lambertian," or "matte" surfaces
  - Independent of viewing angle
- Use as a component of non-Lambertian surfaces



Diffuse Component

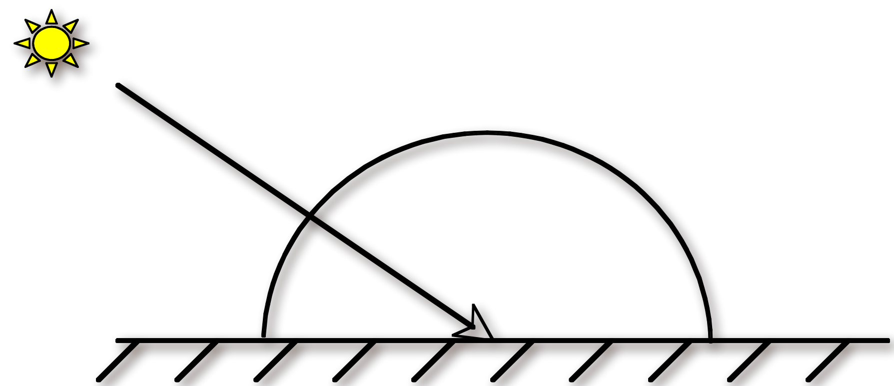
$$k_d \boldsymbol{I}(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})$$

$$\max(k_d \boldsymbol{I}(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}), 0)$$

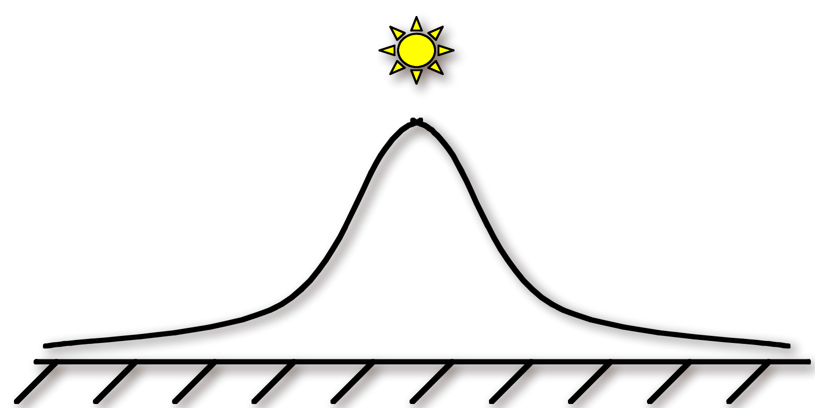


Diffuse Component

- Plot light leaving in a given direction:

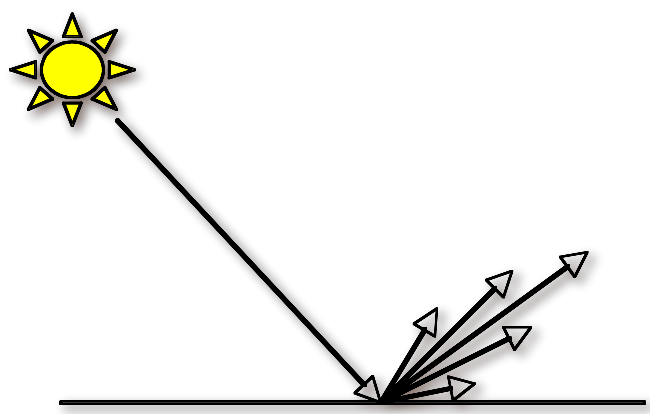


- Plot light leaving from each point on surface



Specular Component

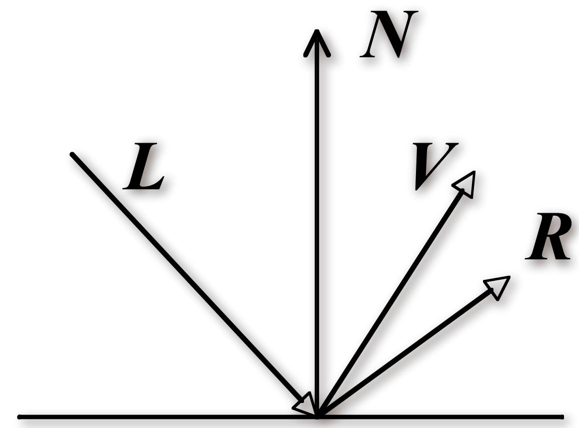
- Specular component is a mirror-like reflection
- Phong Illumination Model
  - A reasonable approximation for some surfaces
  - Fairly cheap to compute
- Depends on view direction

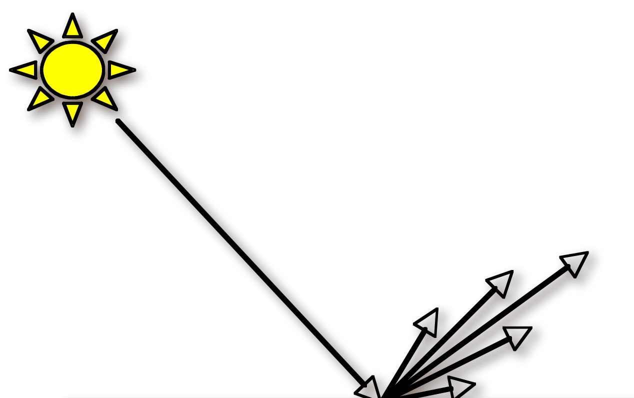


Specular Component

$$k_s I(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}})^p$$

$$k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$

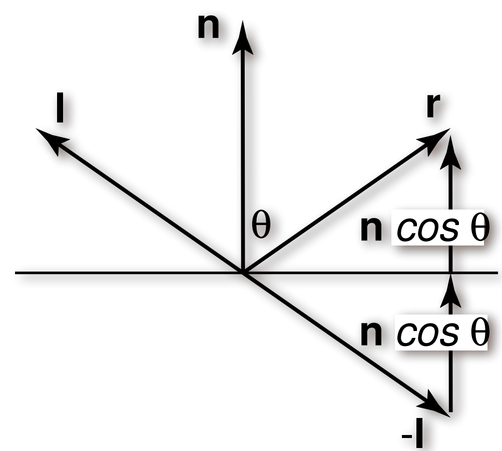




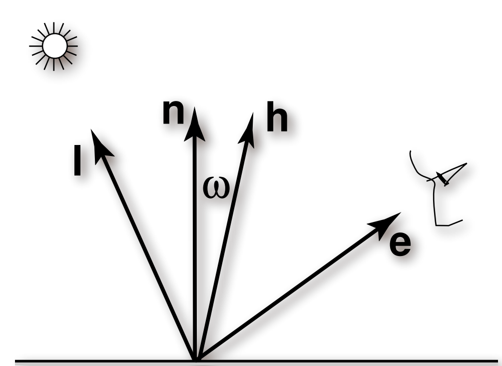
Specular Component

- Computing the reflected direction

$$\hat{\mathbf{r}} = -\hat{\mathbf{l}} + 2(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$

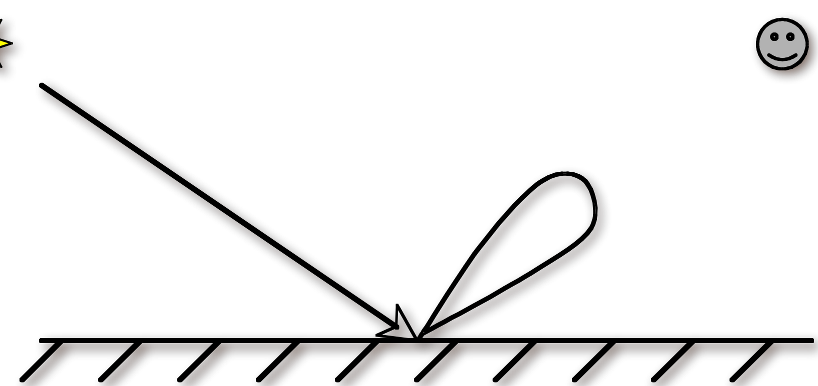


$$\hat{\mathbf{h}} = \frac{\hat{\mathbf{l}} + \hat{\mathbf{v}}}{||\hat{\mathbf{l}} + \hat{\mathbf{v}}||}$$

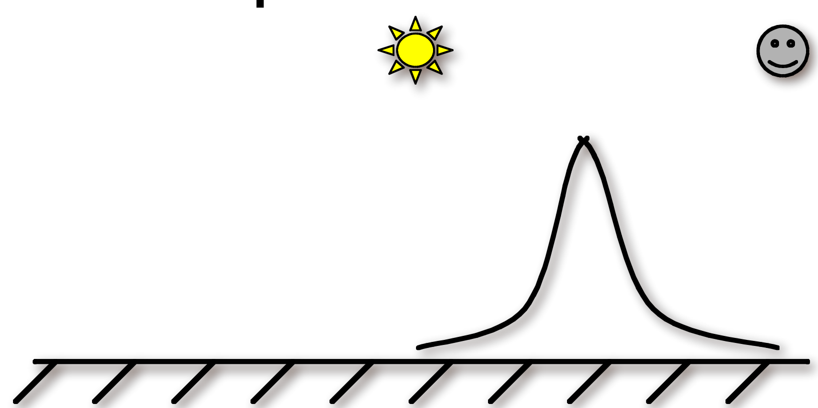


Specular Component

- Plot light leaving in a given direction:

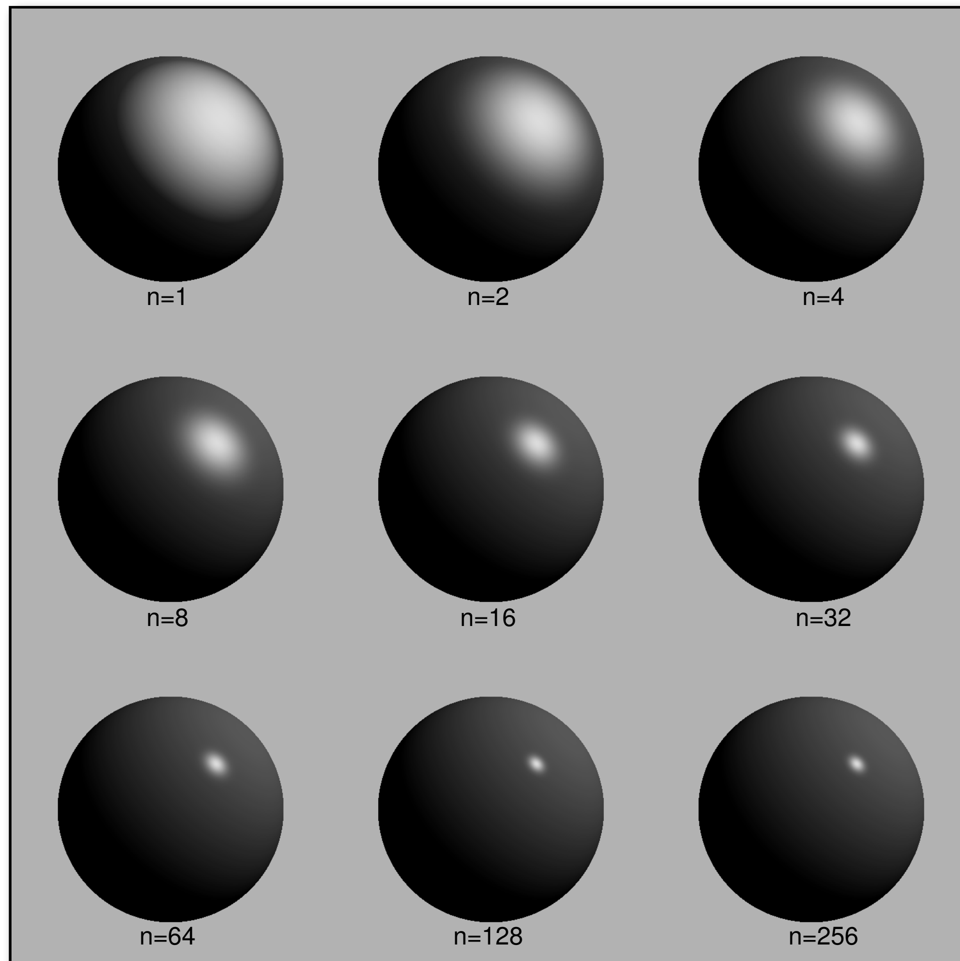


- Plot light leaving from each point on surface



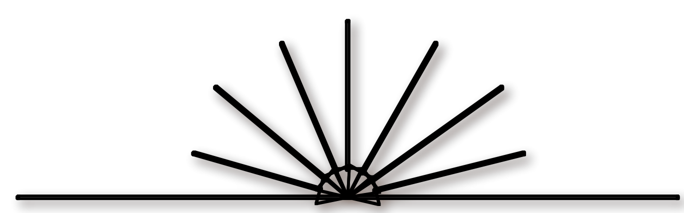
Specular Component

- Specular exponent sometimes called “roughness”



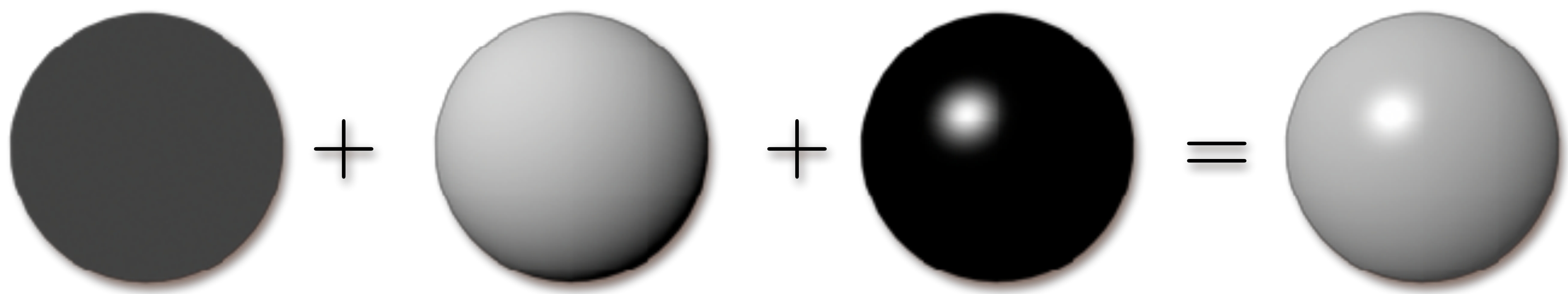
Ambient Term

- Really, its a cheap hack
- Accounts for “ambient, omnidirectional light”
- Without it everything looks like it’s in space



Summing the Parts

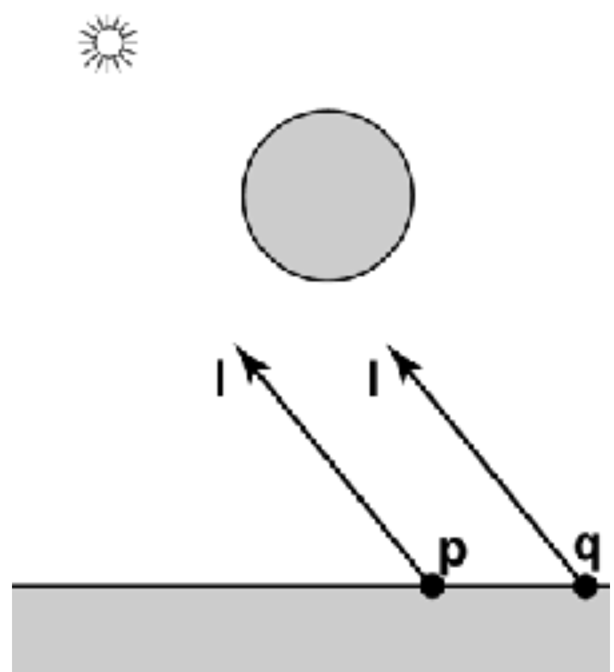
$$R = k_a I + k_d I \max(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}, 0) + k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$



- Recall that the $k_?$ are by wavelength
  - RGB in practice
- Sum over all lights

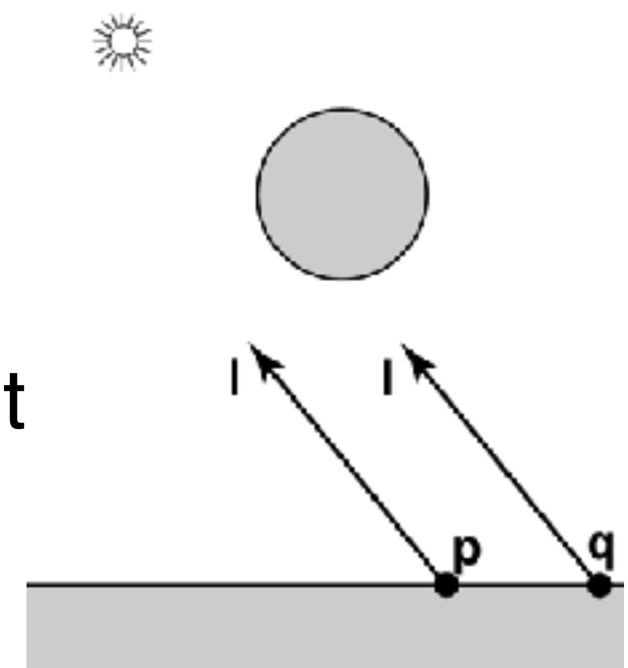
Shadows

- What if there is an object between the surface and light?

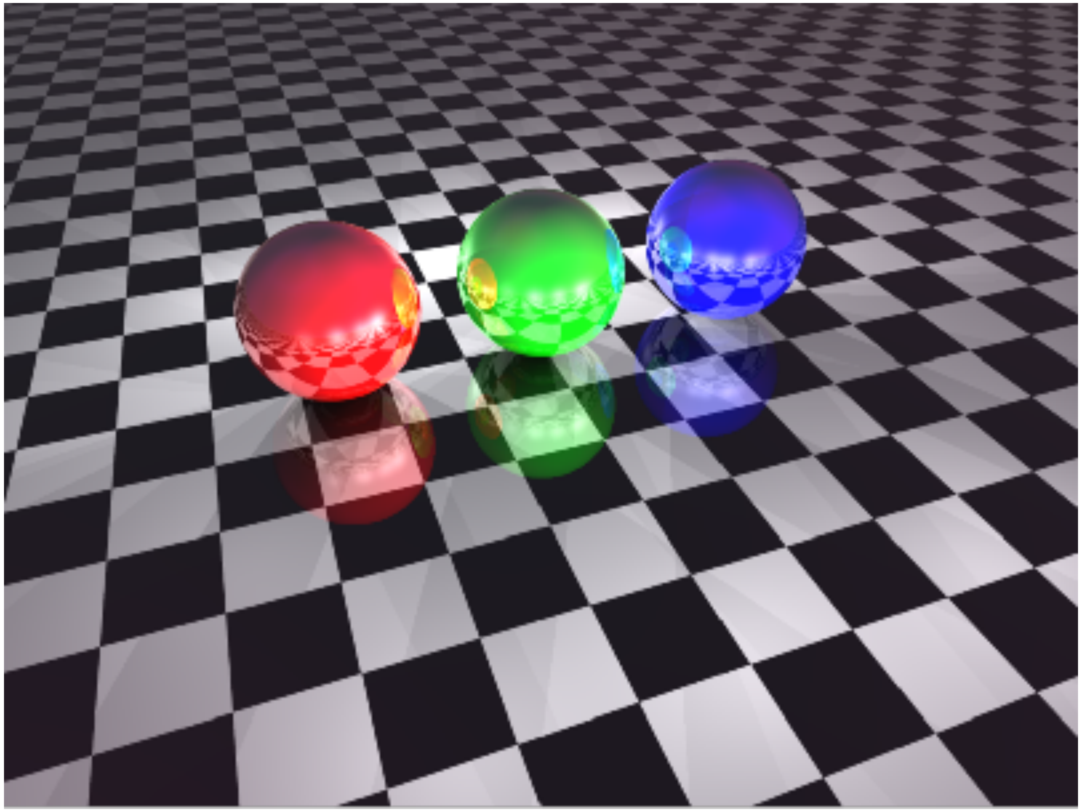


Ray Traced Shadows

- Trace a ray
  - Start = point on surface
  - End = light source
  - t=0 at Surface, t=1 at Light
  - "Bias" to avoid *surface acne*
- Test
  - Bias ≤ t ≤ 1 = shadow
  - t < Bias or t > 1 = use this light



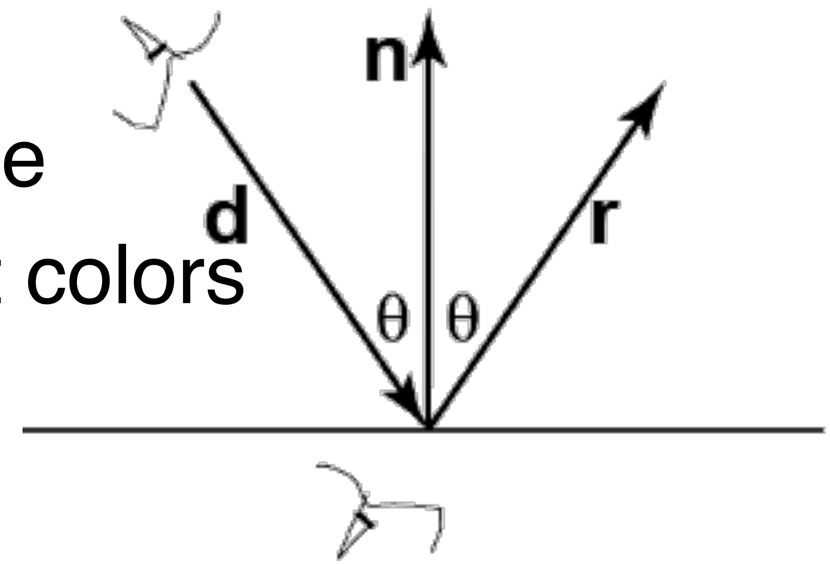
Mirror Reflection



The Dark Side of the Trees - Gilles Tran,
Spheres - Martin K. B.

Ray Tracing Reflection

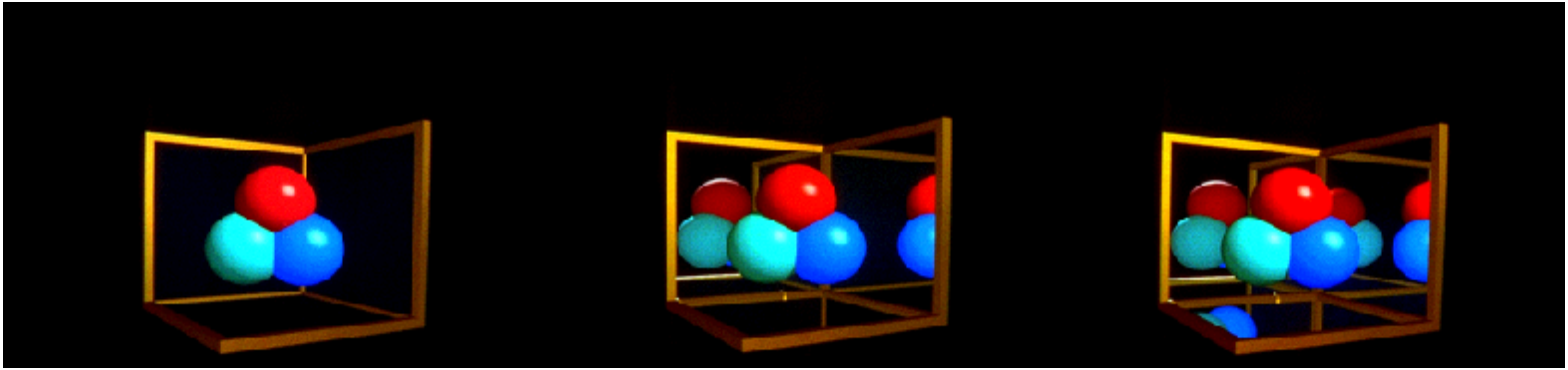
- Viewer looking in direction ***d*** *sees whatever the viewer "below" the surface sees looking in direction* ***r***
- In the real world
  - Energy loss on the bounce
  - Loss different for different colors



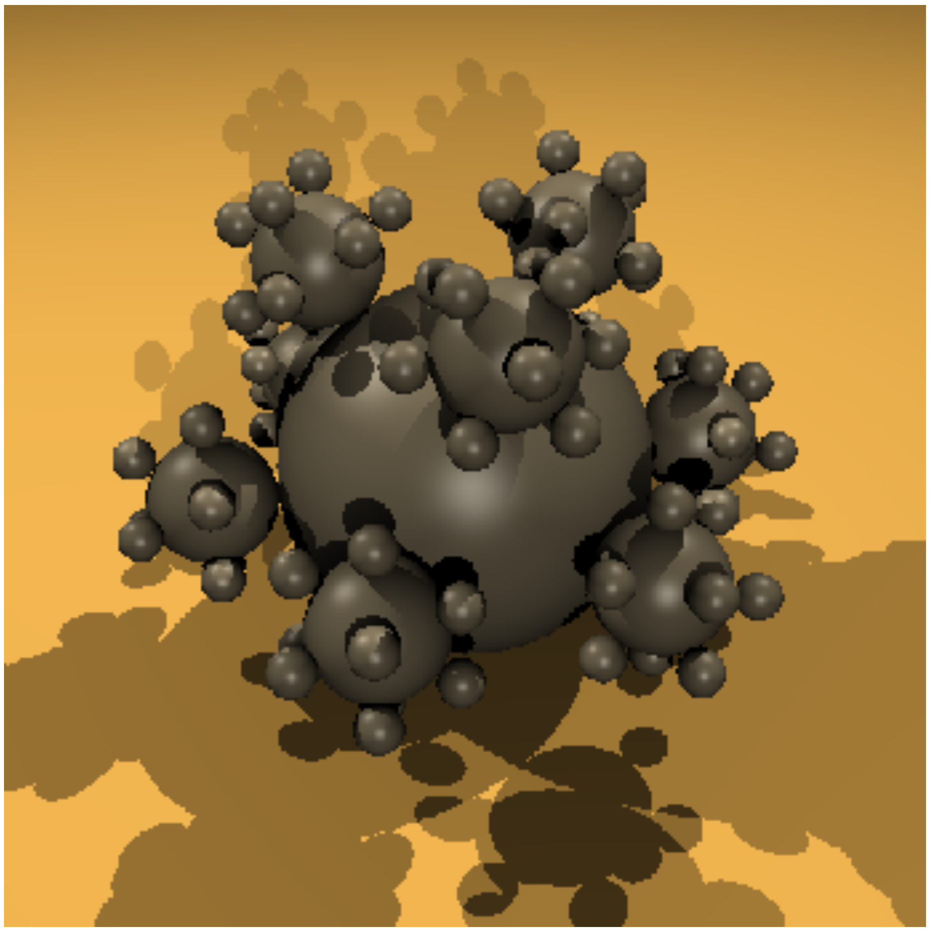
- New ray
  - Start on surface, in reflection direction

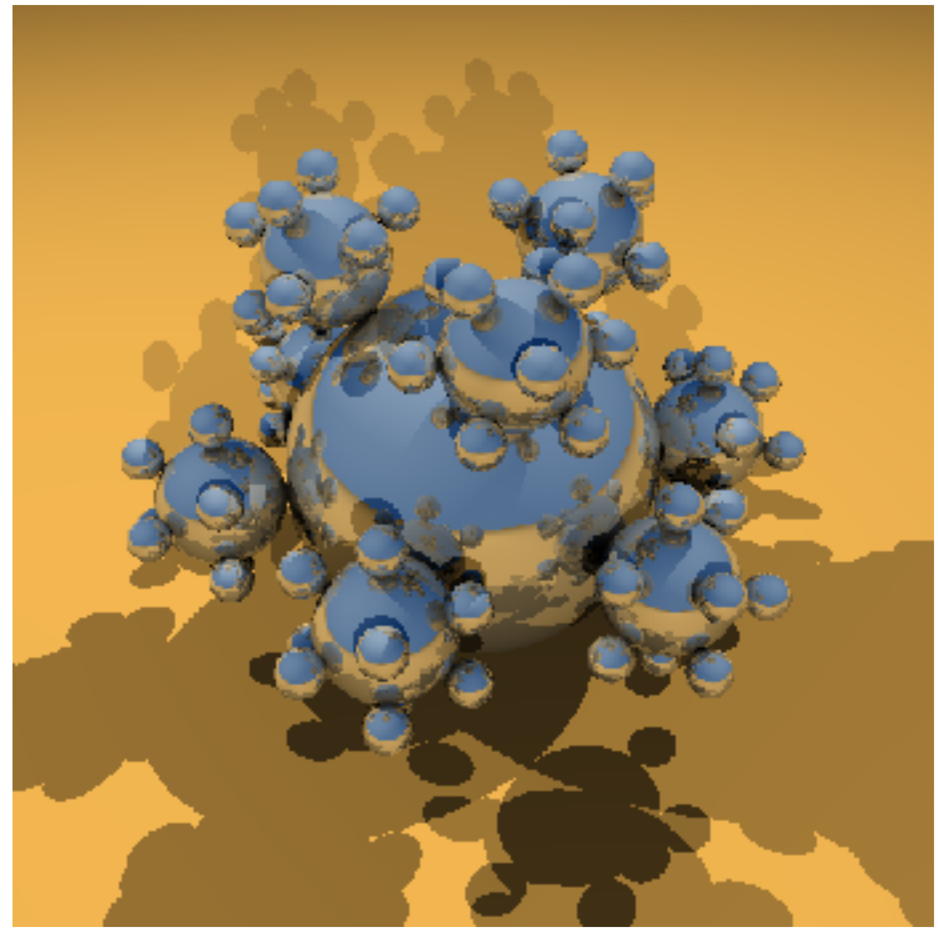
Ray Traced Reflection

- Avoid looping forever
  - Stop after *n* bounces
  - Stop when contribution to pixel gets too small



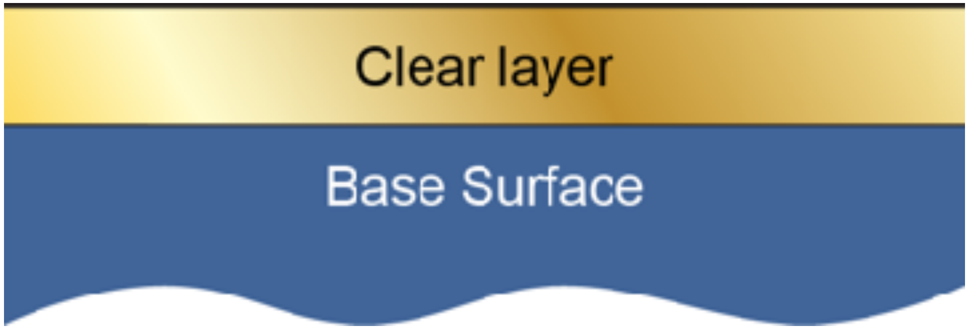
Specular vs. Mirror Reflection

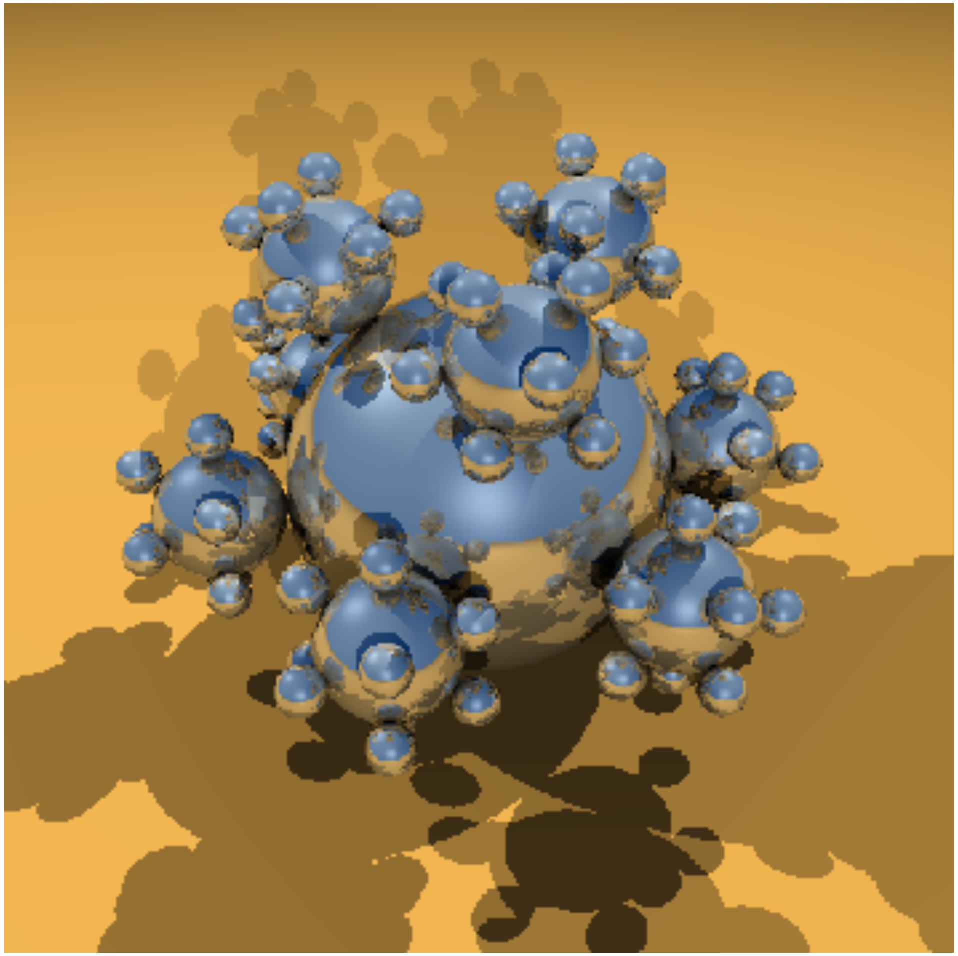




Combined Specular & Mirror

- Many surfaces have both

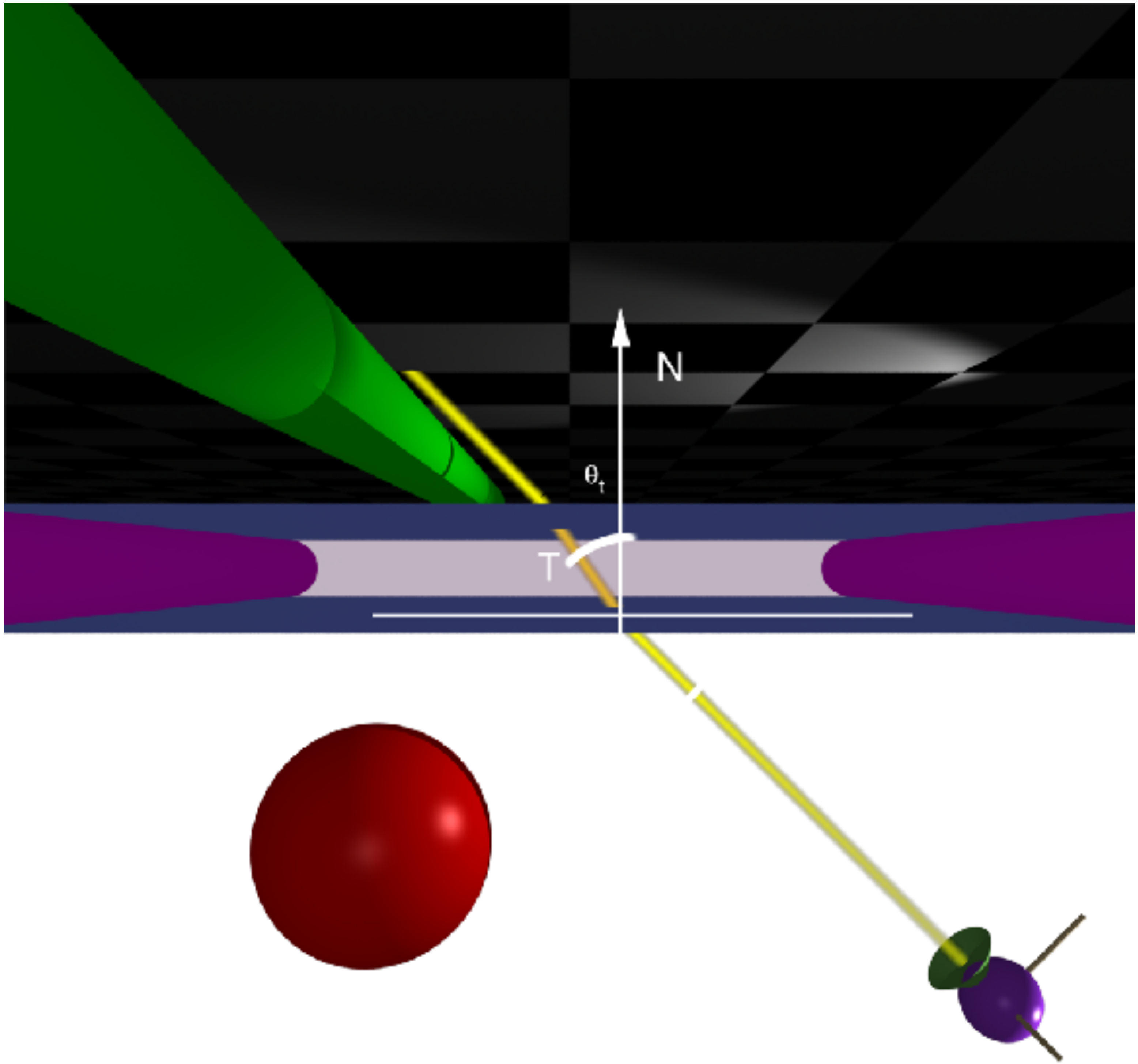




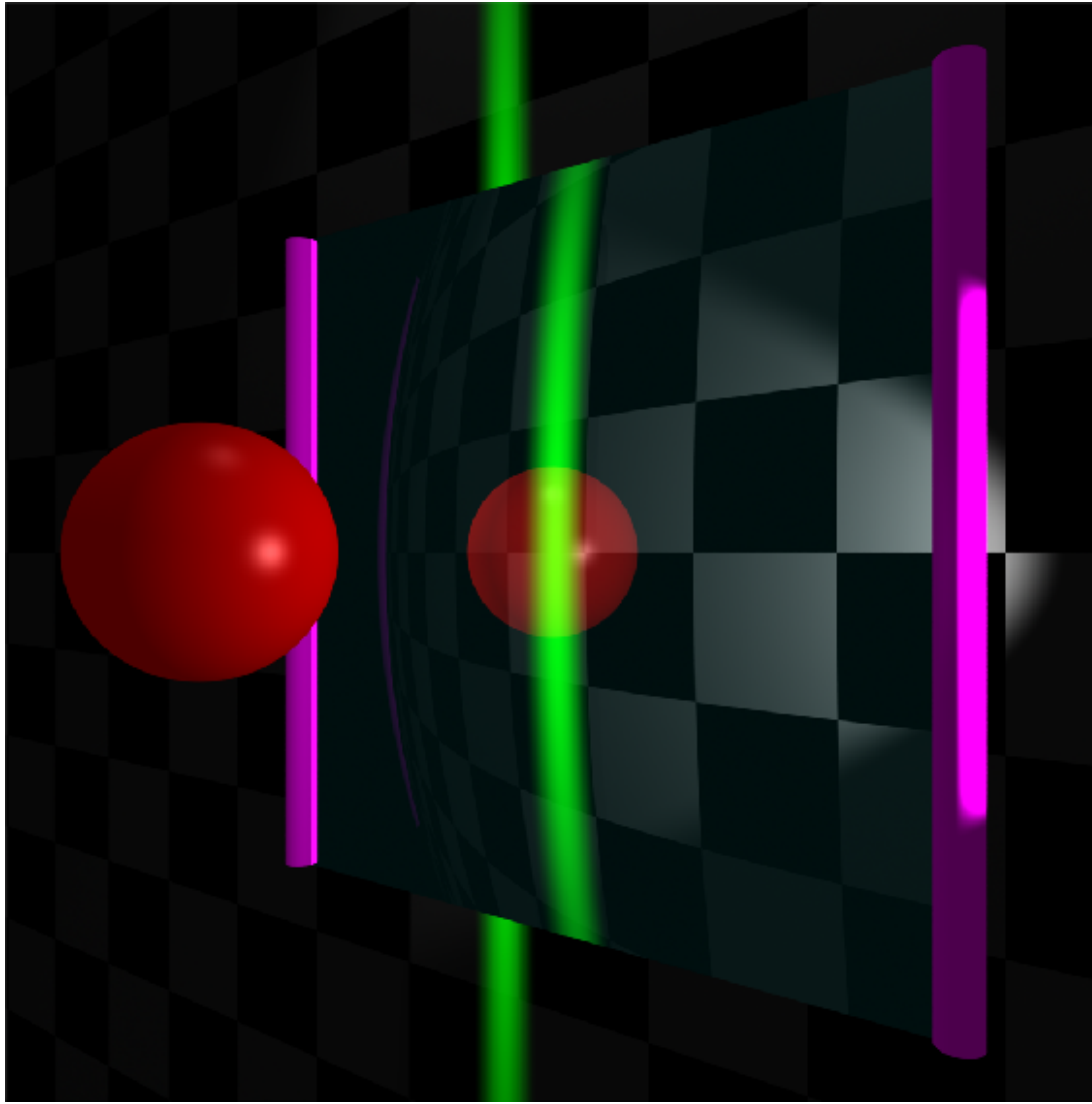
Refraction


Refraction
No Refraction

Top



Front



Calculating Refraction Vector

- Snell's Law

$$n_v \sin\theta_v = n_t \sin\theta_t$$

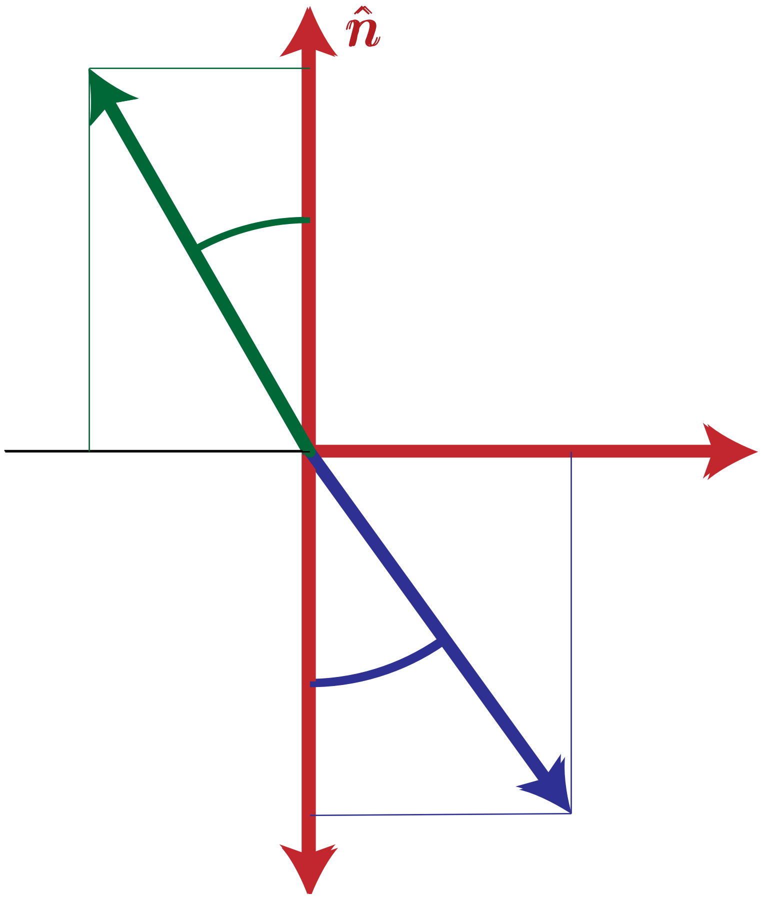
- In terms of θ_t

$$\hat{t} = \hat{m}\sin\theta_t - \hat{n}\cos\theta_t$$

- $\hat{m}$ term

$$\hat{m} = (\hat{n}(\hat{n}\cdot\hat{v}) - \hat{v})/\sin\theta_v$$

$$\begin{aligned}\hat{m}\sin\theta_t \\ &= (\hat{n}(\hat{n}\cdot\hat{v}) - \hat{v})\sin\theta_t/\sin \\ &= (\hat{n}(\hat{n}\cdot\hat{v}) - \hat{v})\, n_v/n_t\end{aligned}$$



Calculating Refraction Vector

- Snell's Law

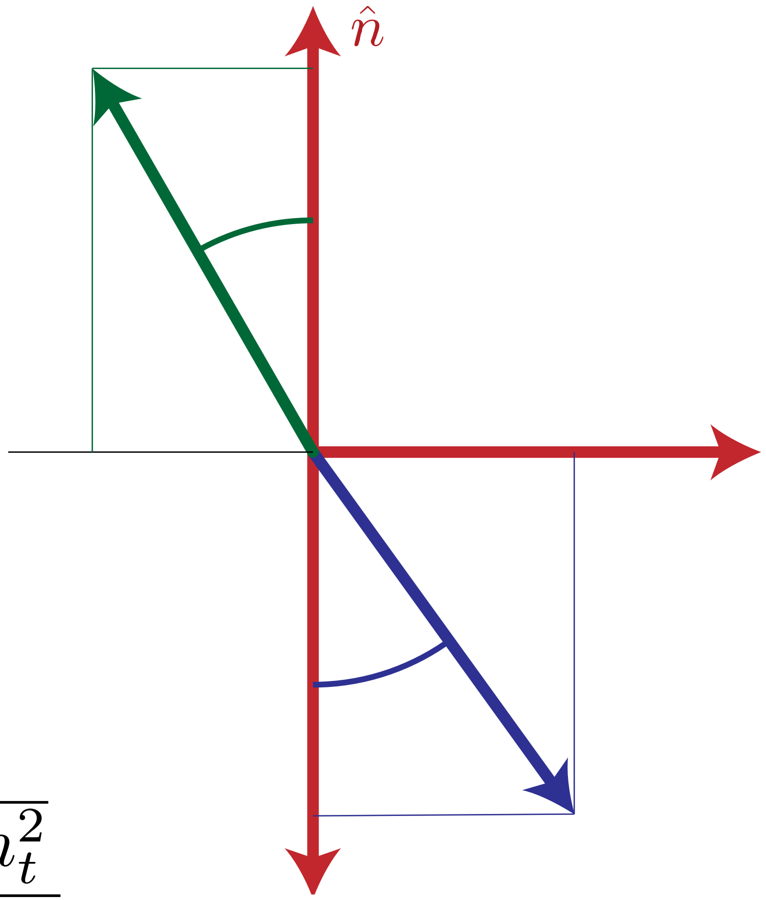
$$n_v \sin\theta_v = n_t \sin\theta_t$$

- In terms of θ_t

$$\hat{t} = \hat{m}\sin\theta_t - \hat{n}\cos\theta_t$$

- $\hat{n}$ term

$$\begin{aligned}
-\hat{n}\cos\theta_t &\\
&= -\hat{n}\sqrt{1-\sin^2\theta_t}\\
&= -\hat{n}\sqrt{1-\sin^2\theta_v\, n_v^2/n_t^2}\\
&= -\hat{n}\sqrt{1-(1-\cos^2\theta_v)\, n_v^2/n_t^2}\\
&= -\hat{n}\sqrt{1-(1-(\hat{n}\cdot\hat{v})^2)\, n_v^2/n_t^2}
\end{aligned}$$



Calculating Refraction Vector

- Snell's Law

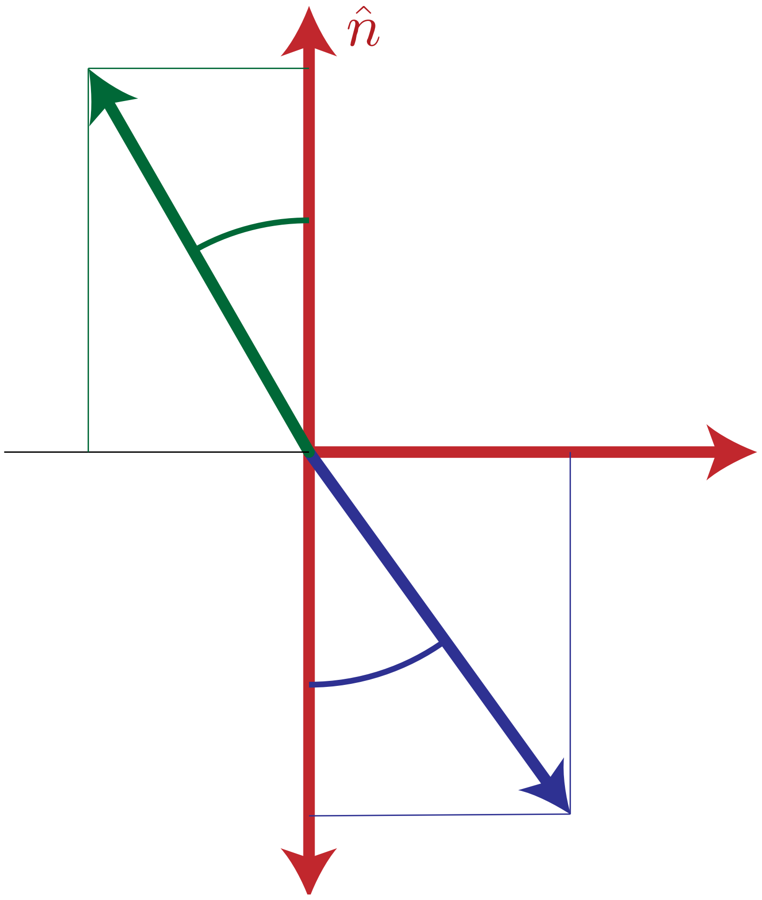
$$n_v \sin\theta_v = n_t \sin\theta_t$$

- In terms of θ_t

$$\hat{t} = \hat{m}\sin\theta_t - \hat{n}\cos\theta_t$$

- In terms of $\hat{n}$ and $\hat{v}$

$$\hat{t} = (\hat{n}(\hat{n}\cdot\hat{v}) - \hat{v})n_v/n_t$$
$$-\hat{n}\sqrt{1-(1-(\hat{n}\cdot\hat{v})^2)\,n_v^2/n_t^2}$$



Alpha Blending

- How much makes it through
- α = opacity
  - How much of foreground color 0-1
- 1-α = transparency
  - How much of background color
- Foreground*α + Background*(1-α)

Refraction and Alpha

- Refraction = what direction
- α = how much
  - Often approximate as a constant
  - Better: Use Fresnel

$$F = \frac{1}{2}\left(\frac{n_v\ \hat{n}\cdot\hat{r} + n_t\ \hat{n}\cdot\hat{t}}{n_v\ \hat{n}\cdot\hat{r} - n_t\ \hat{n}\cdot\hat{t}}\right)^2 + \frac{1}{2}\left(\frac{n_v\ \hat{n}\cdot\hat{t} + n_t\ \hat{n}\cdot\hat{r}}{n_v\ \hat{n}\cdot\hat{t} - n_t\ \hat{n}\cdot\hat{r}}\right)^2$$

  - Schlick approximation

$$F_0 = (n_v - n_t)^2/(n_v + n_t)^2$$
$$F \approx F_0 + (1 - F_0)(1 - \hat{n}\cdot\hat{v})^5$$

Full Ray-Tracing

- For each pixel
  - Compute ray direction
  - Find closest surface
  - For each light
    - Shoot shadow ray
    - If not shadowed, add direct illumination
  - Shoot ray in reflection direction
  - Shoot ray in refraction direction

Dielectric

```
if (p is on a dielectric) then
    r = reflect (d, n)
    if (d.n < 0) then
          refract (d, n , n, t)
          c = -d.n
          kr = kg = kb = 1
    else
          kr = exp(-alphar * t)
          kg = exp(-alphag * t)
          kb = exp(-alphab * t)
          if (refract(d, -n, 1/n t) then
               c = t.n
          else
               return k * color(p+t*r)
    R0 = (n-1)^2 / (n+1)^2
    R = R0 + (1-R0)(1 - c)^5
    return k(R color(p + t*r) + (1-R)color(p+t*t)
```

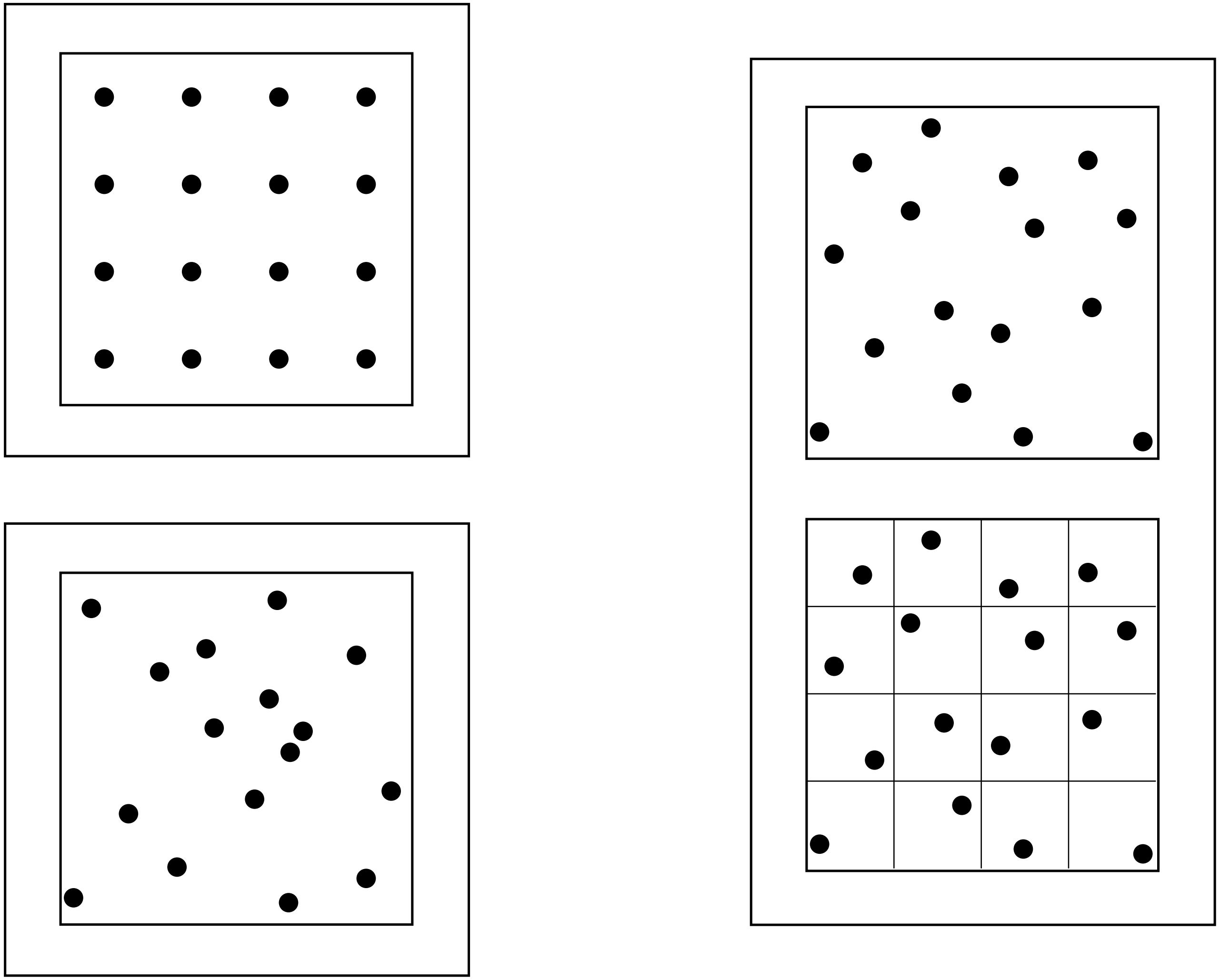
Distribution Ray Tracing

Distribution Ray Tracing

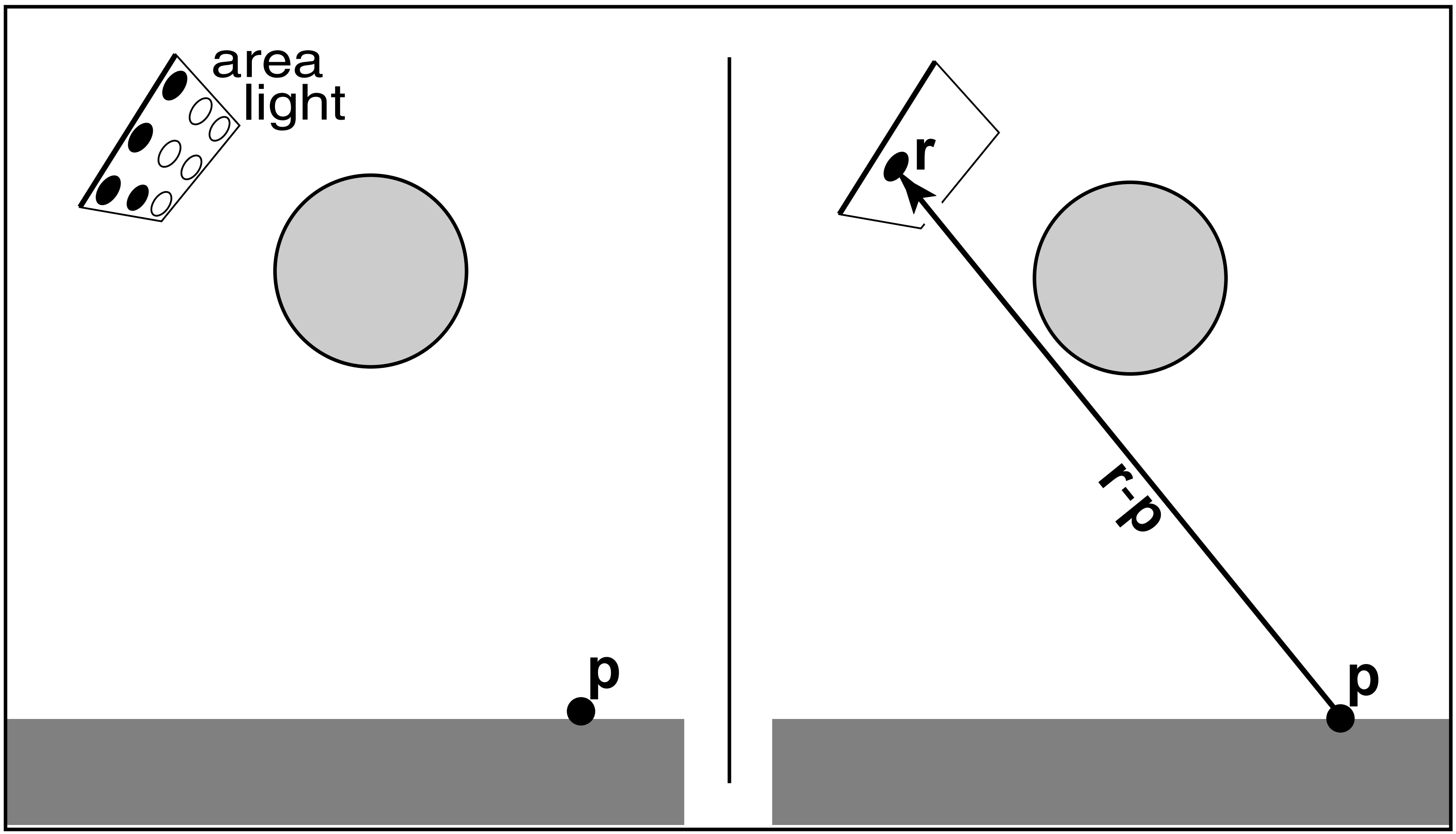
- Anti-aliasing
- Soft Shadows
- Depth of Field
- Glossy Reflection
- Motion Blur

- Turns Aliasing into Noise

Sampling



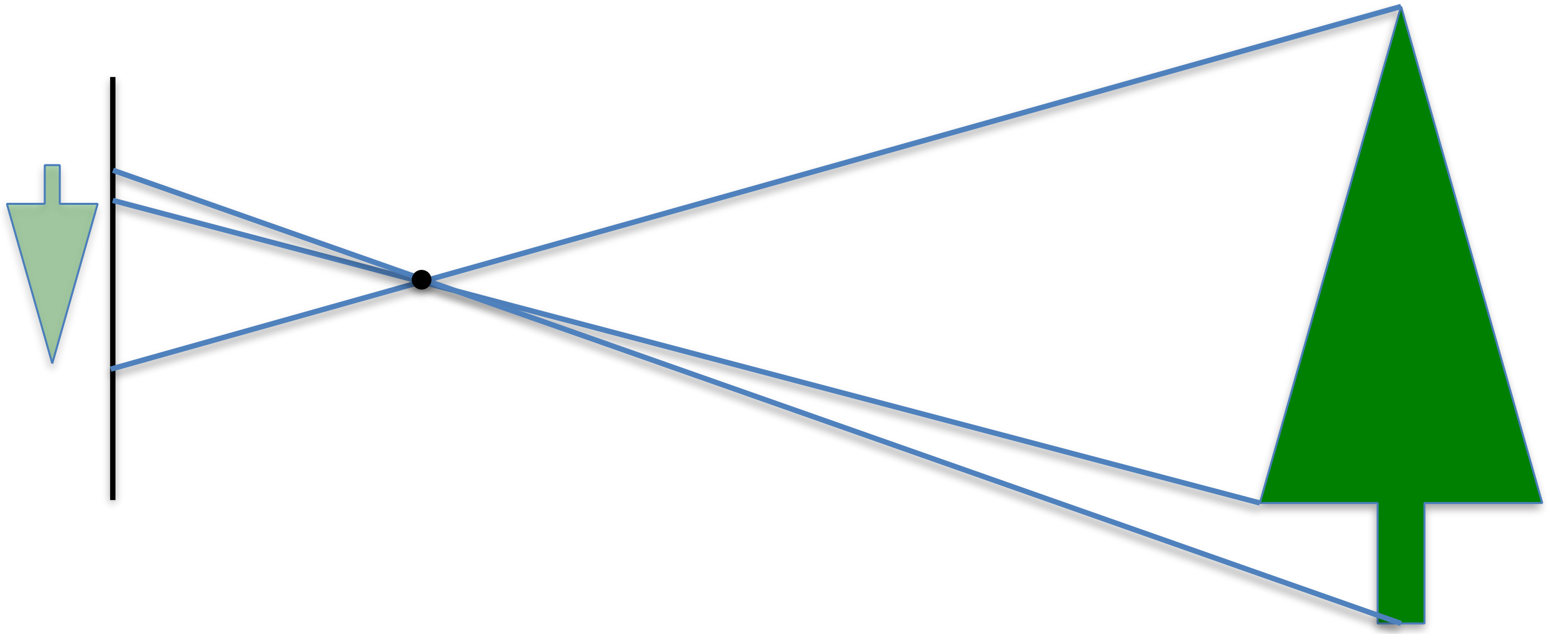
Soft Shadows



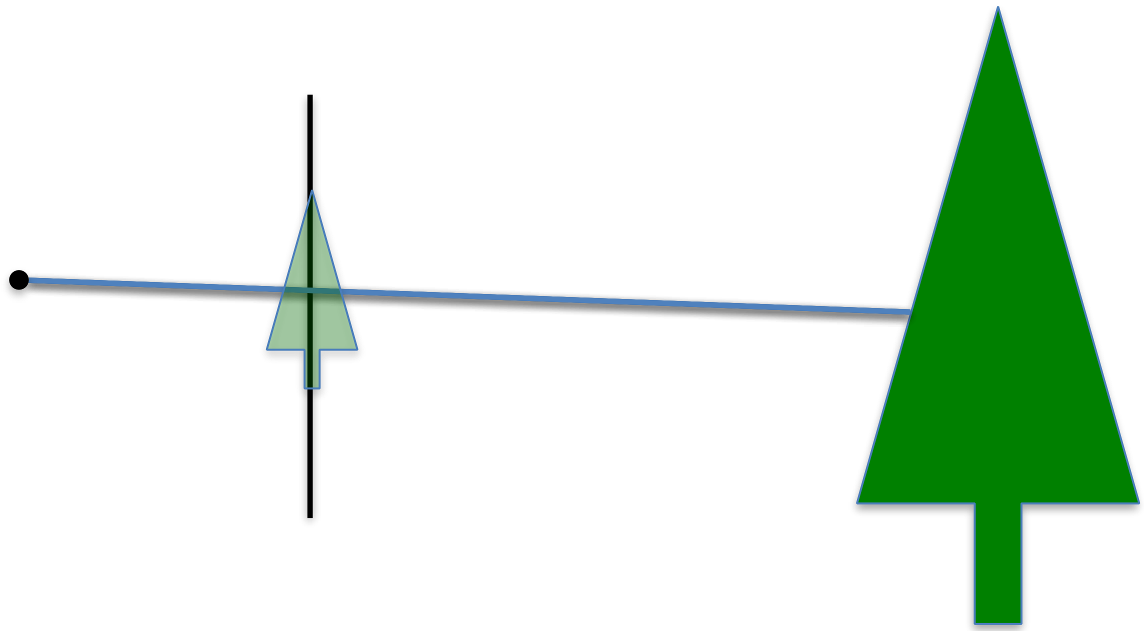
Depth of Field

Soler et al., Fourier Depth of Field, ACM TOG v28n2, April 2009

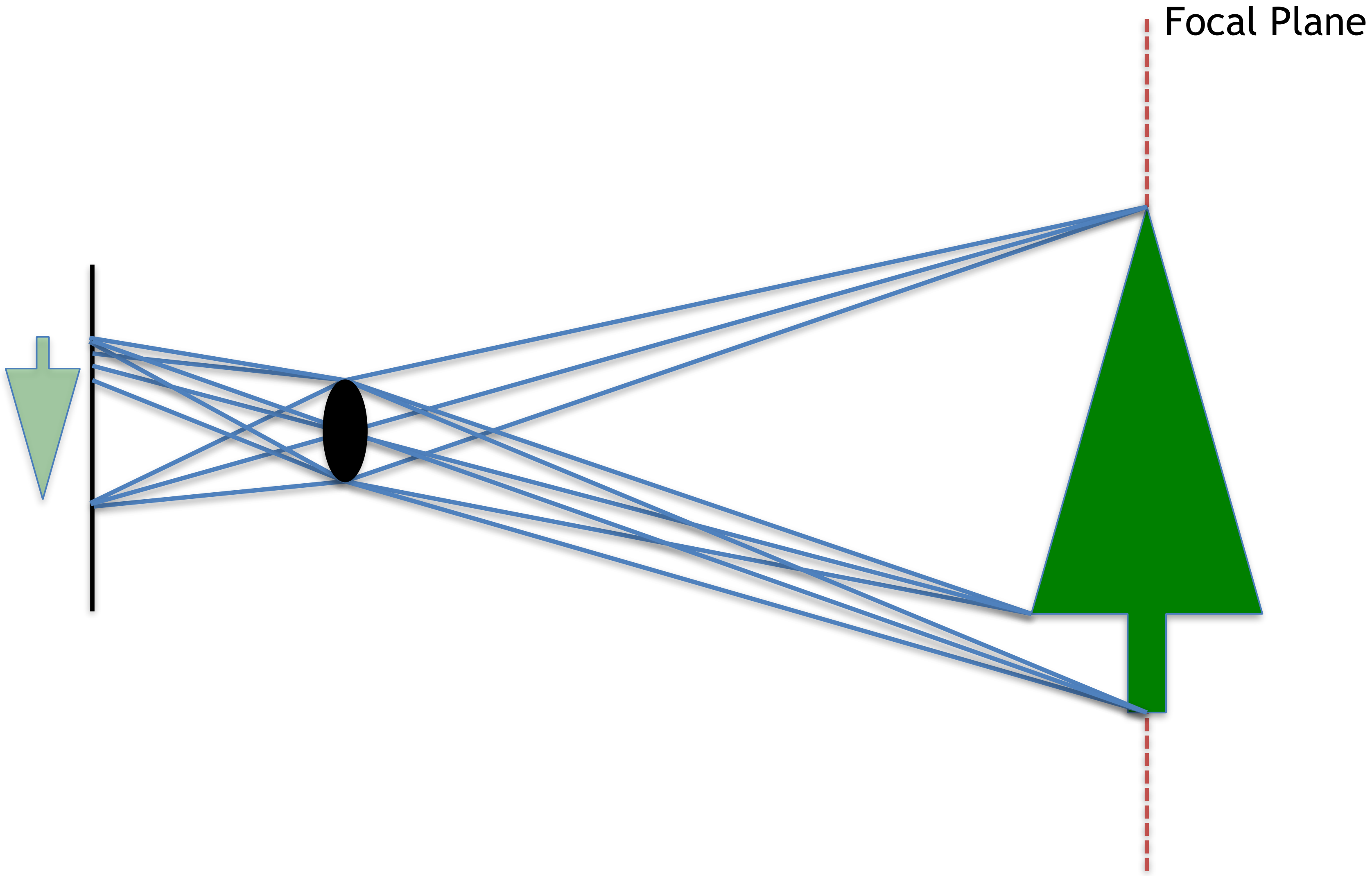
Pinhole Lens



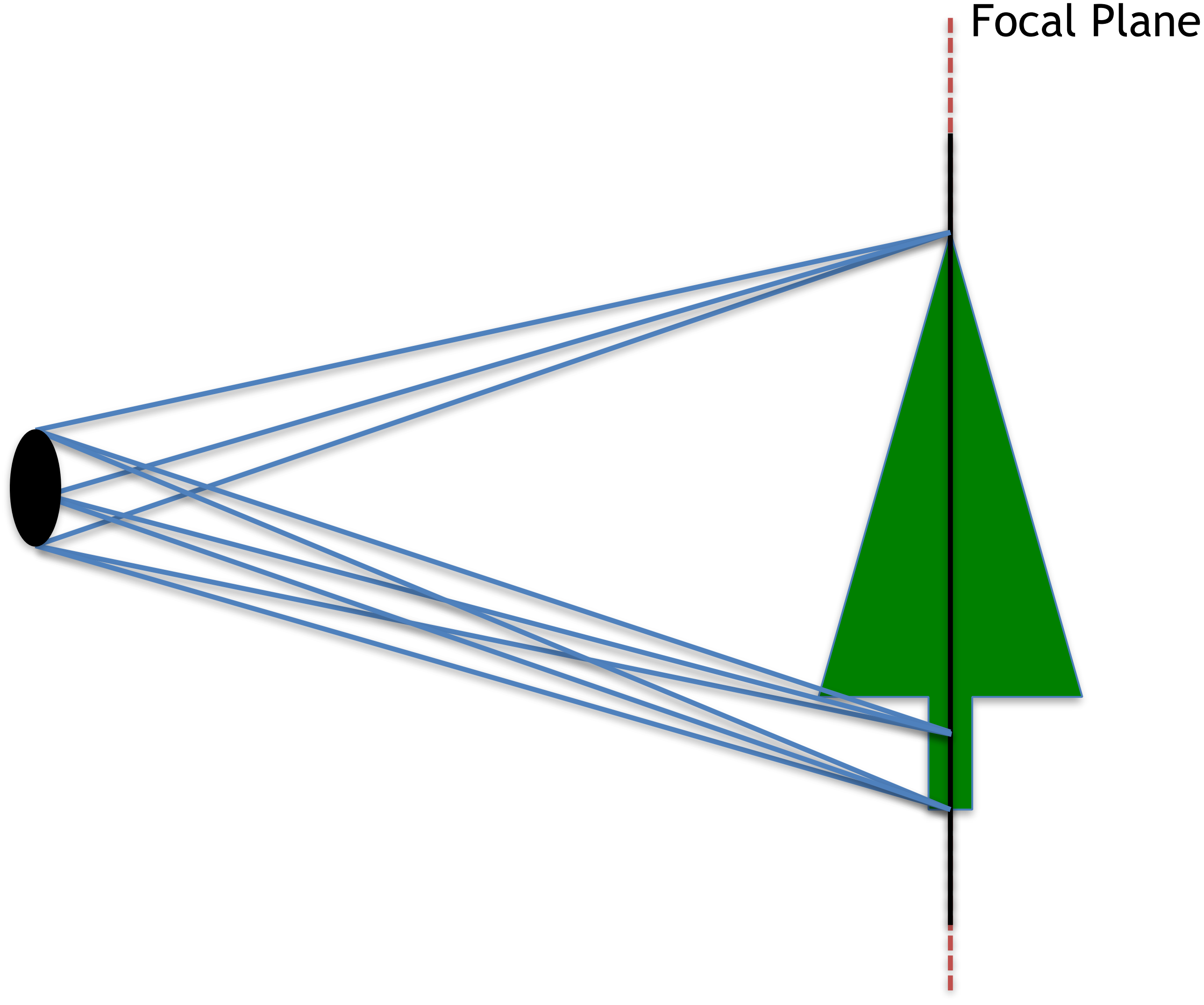
Lens Model



Real Lens



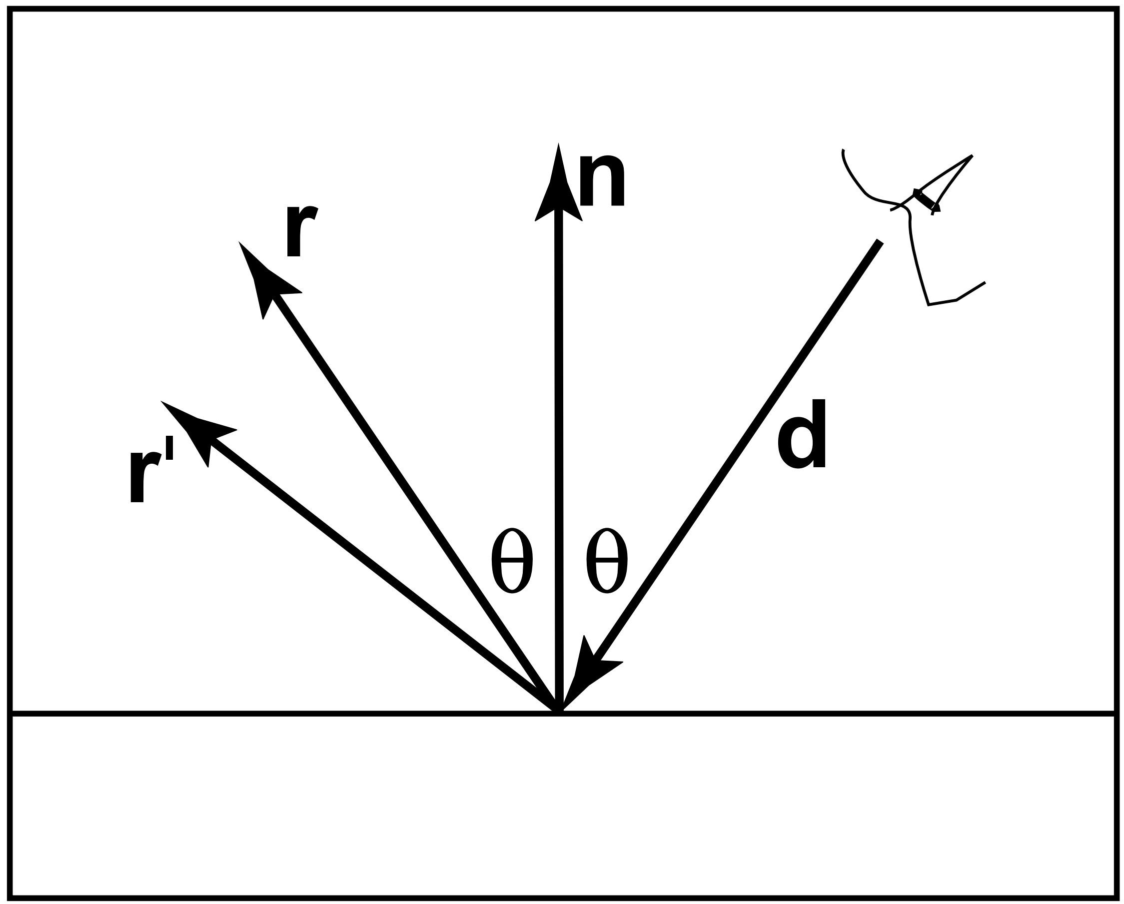
Lens Model



Ray Traced DOF

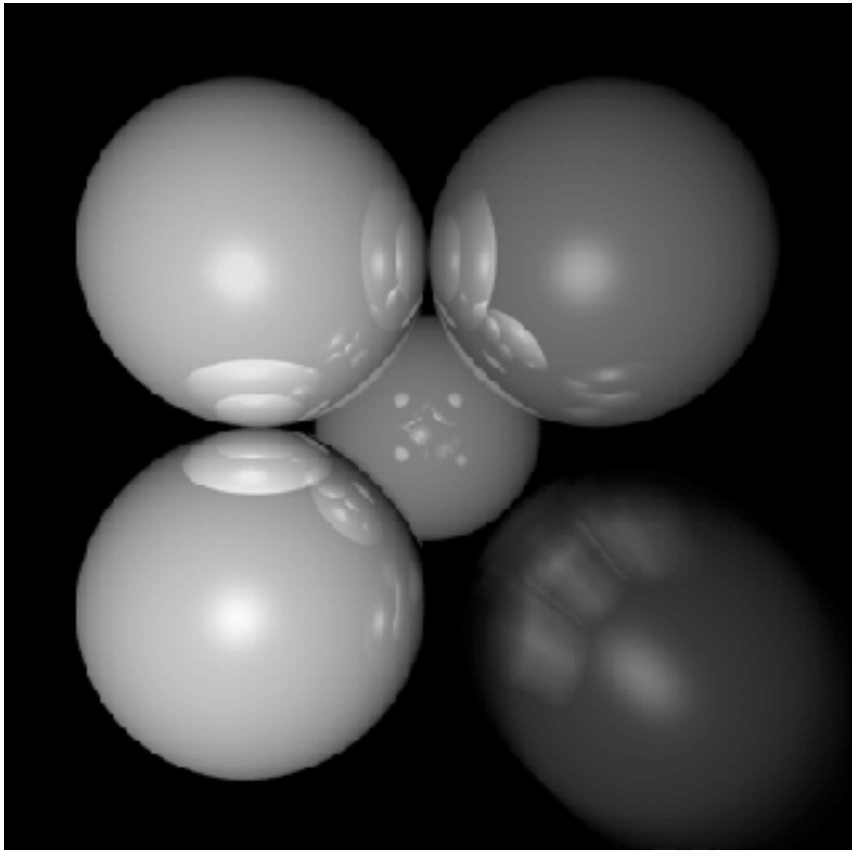
- Move image plane out to focal plane
- Jitter start position within lens aperture
  - Smaller aperture = closer to pinhole
  - Larger aperture = more DOF blur

Glossy Reflection



Motion Blur

- Things move while the shutter is open



Ray Traced Motion Blur

- Include information on object motion
- Spread multiple rays per pixel across time