7.2 Ray Tracing

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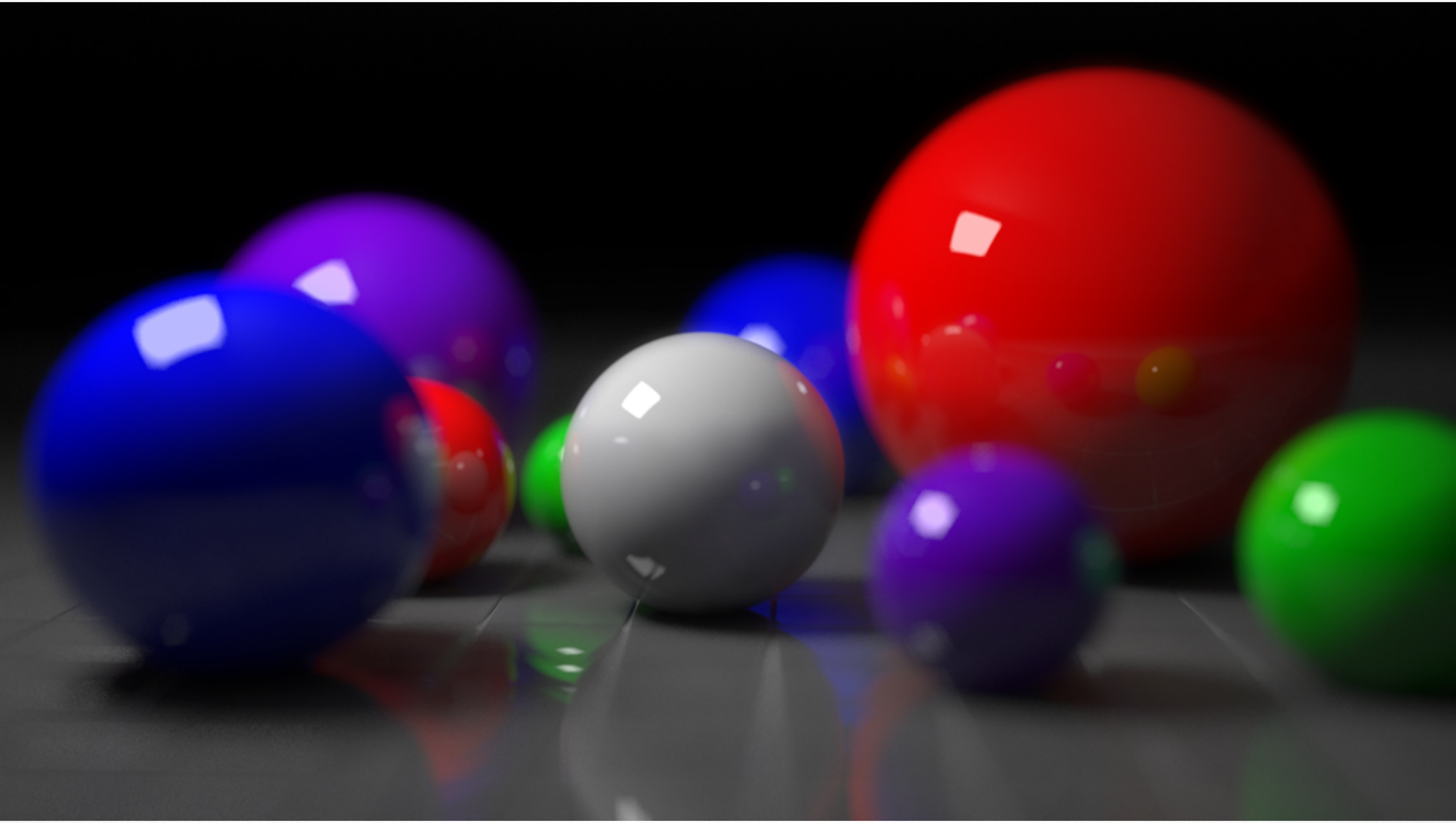
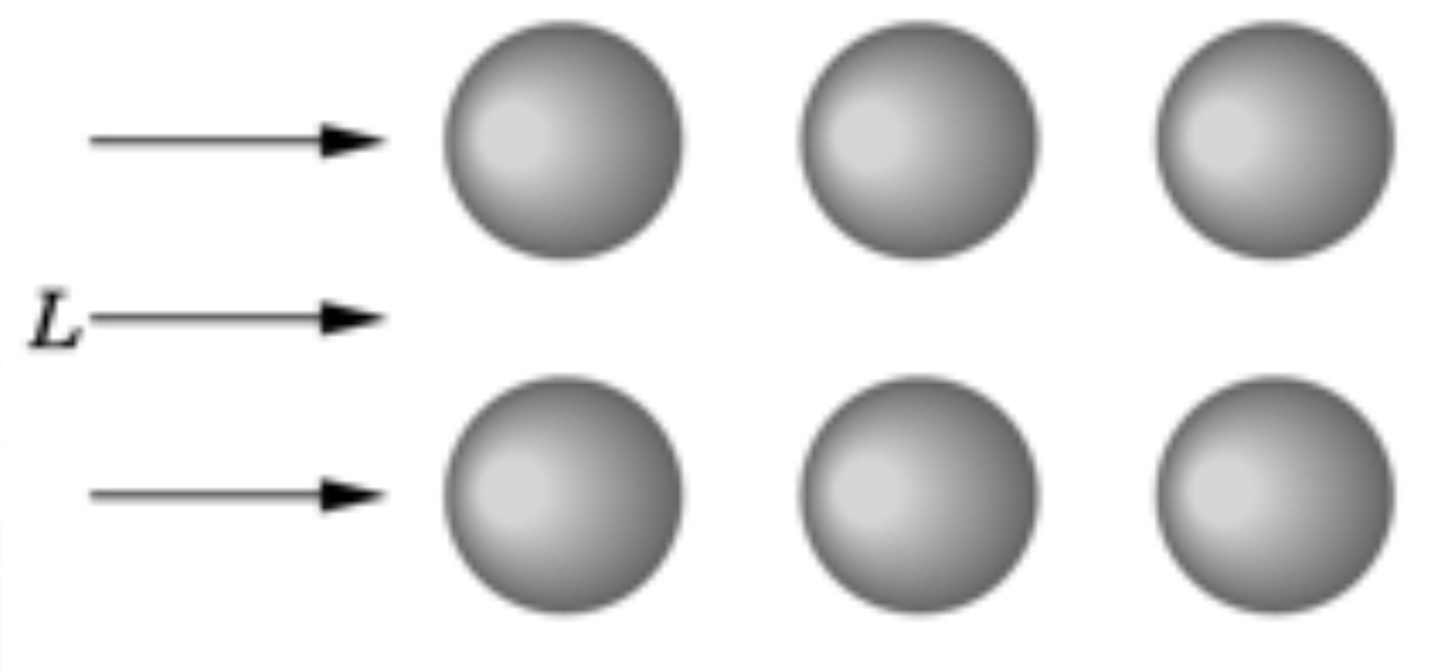
Motivation: Reflections

Motivation: Depth of Field



Local Illumination

- Object illuminations are independent
- No light scattering between objects
- No real shadows, reflection, transmission
- OpenGL pipeline uses this



Global Illumination

- Ray tracing (highlights, reflection, transmission)
- Radiosity (surface inter reflections)
- Photon mapping
- Precomputed Radiance Transfer (PRT)

Object Space

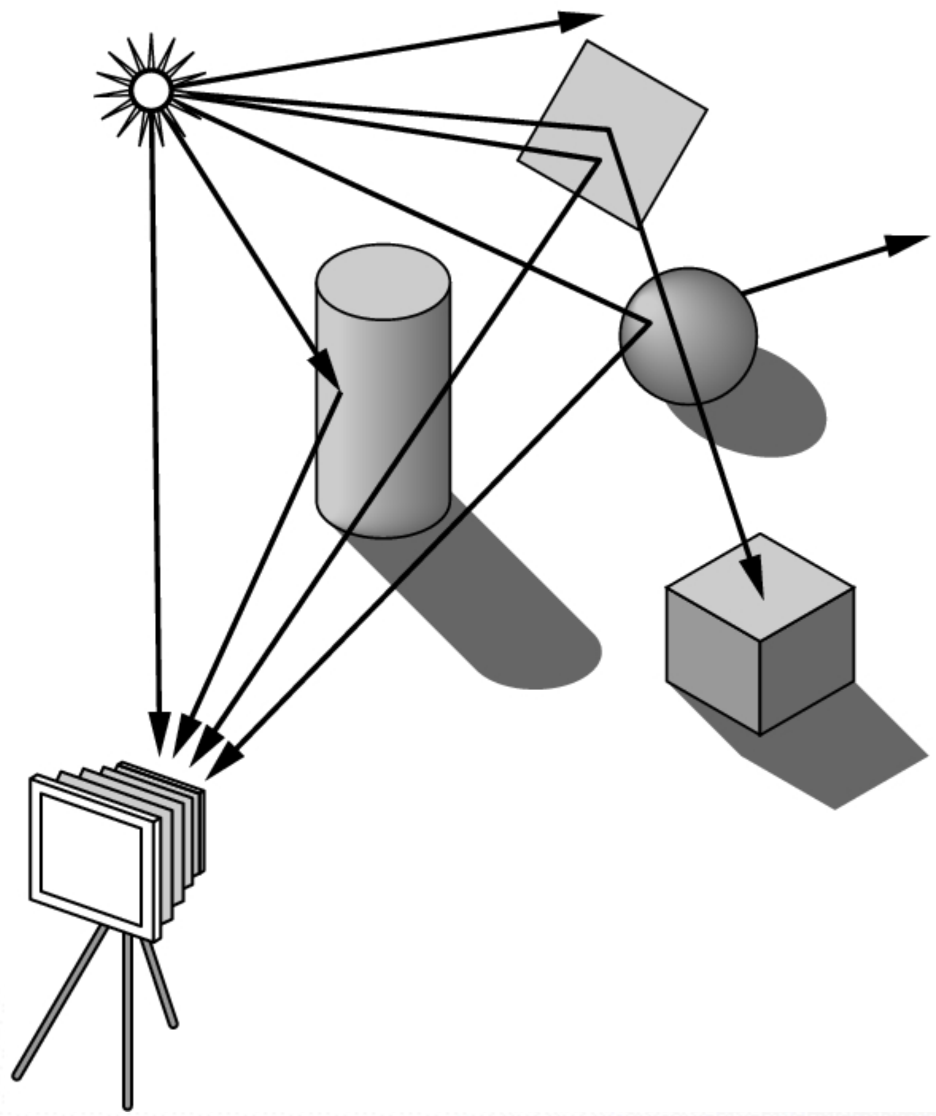
- Graphics pipeline: for each object, render
  - Efficient pipeline architecture, real-time
  - Difficulty: object interactions (shadows, reflections, etc.)

Image Space

- Ray tracing: for each pixel, determine color
  - Pixel-level parallelism
  - Difficulty: very intensive computation, usually off-line

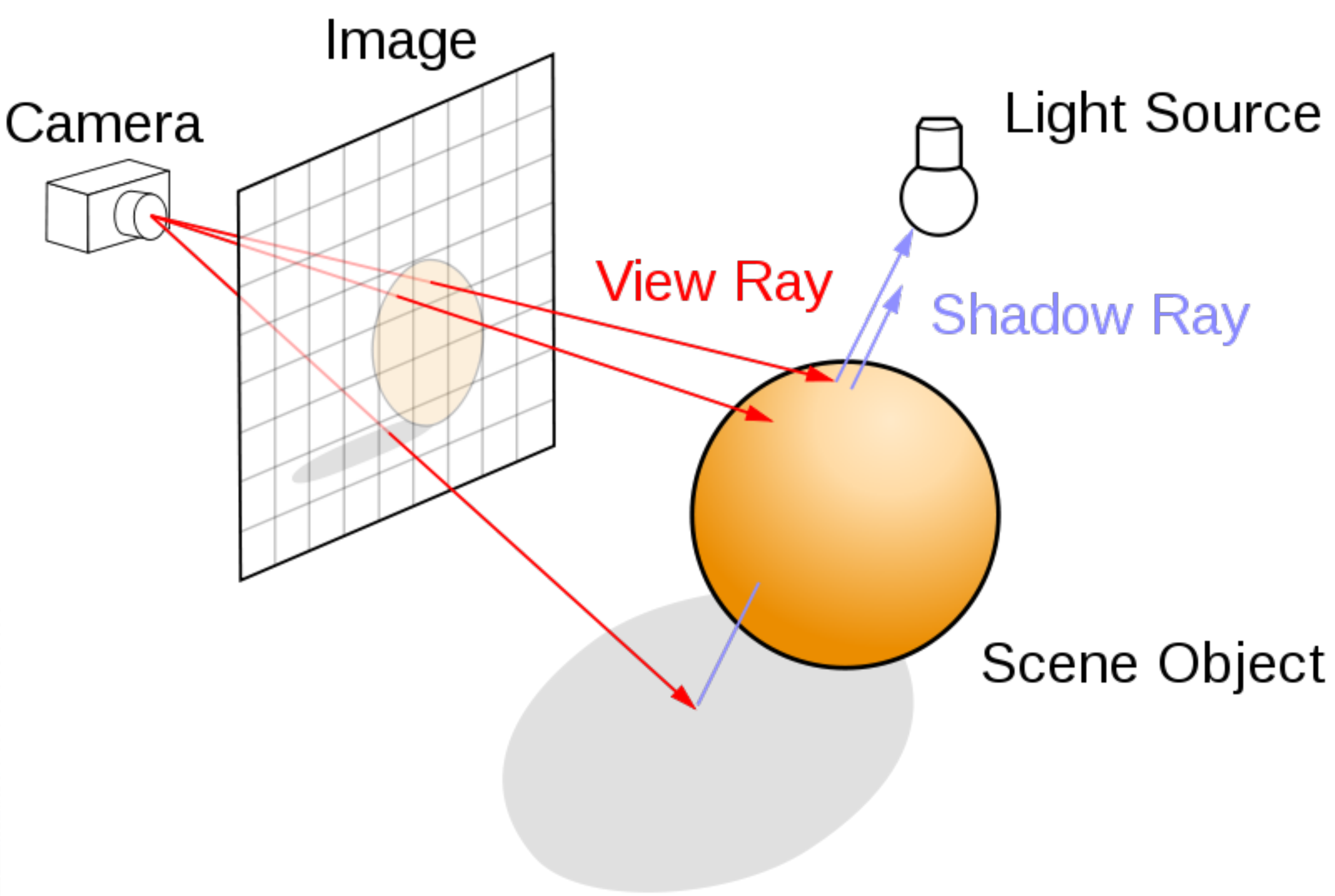
First idea: Forward Ray Tracing

- Shoot (many) light rays from each light source
- Rays bounce off the objects
- Simulates paths of photons
- Problem: many rays will
- miss camera and not contribute to image!
- This algorithm is not practical



Backward Ray Tracing

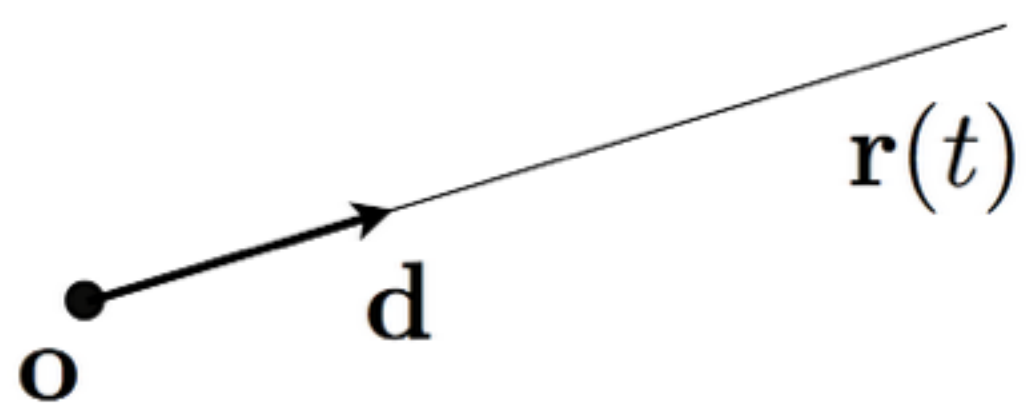
- Shoot one ray from camera through each pixel in image plane



Generating Rays

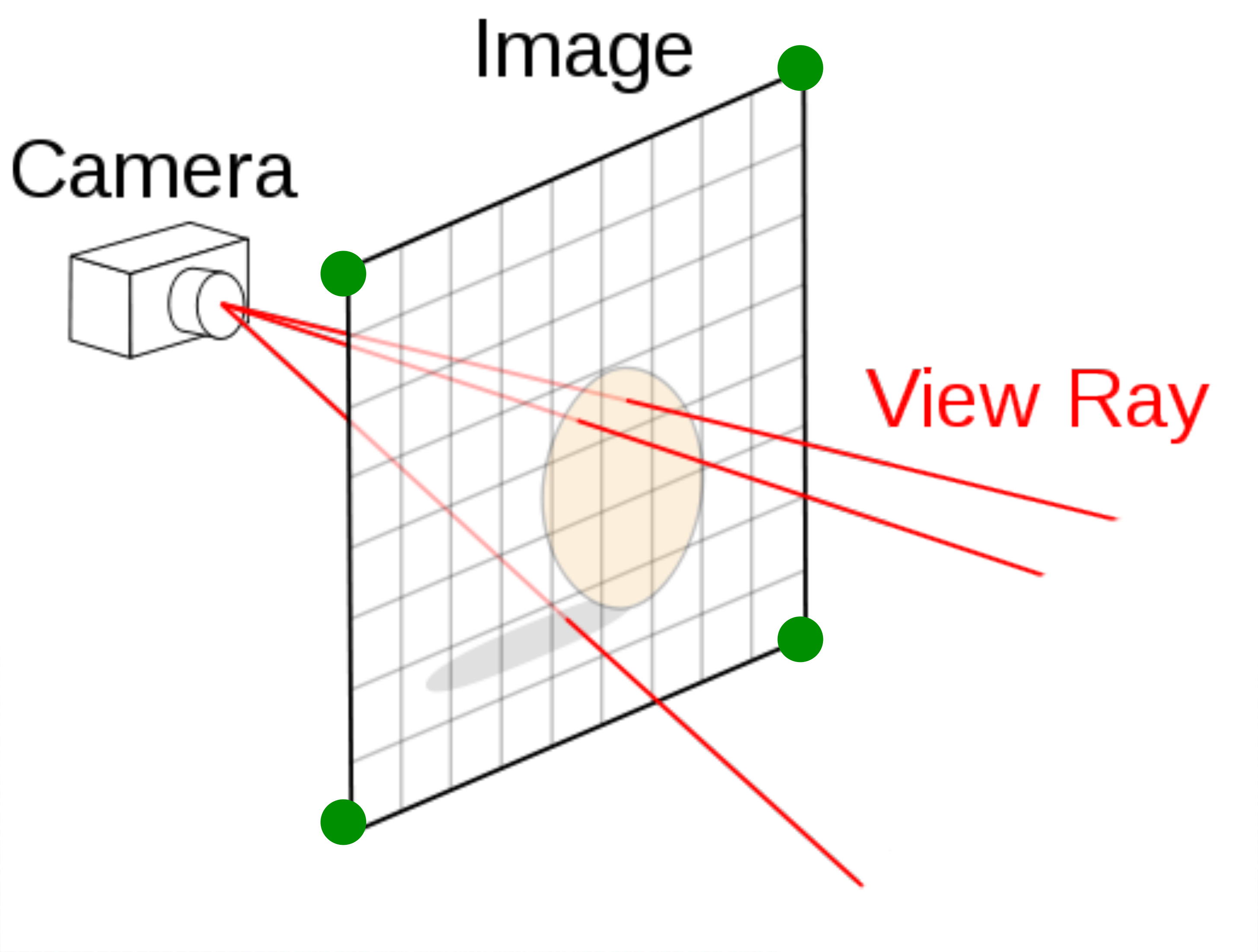
$$\mathbf{r}(t) = \mathbf{o} + t\mathbf{d}$$

ray origin direction

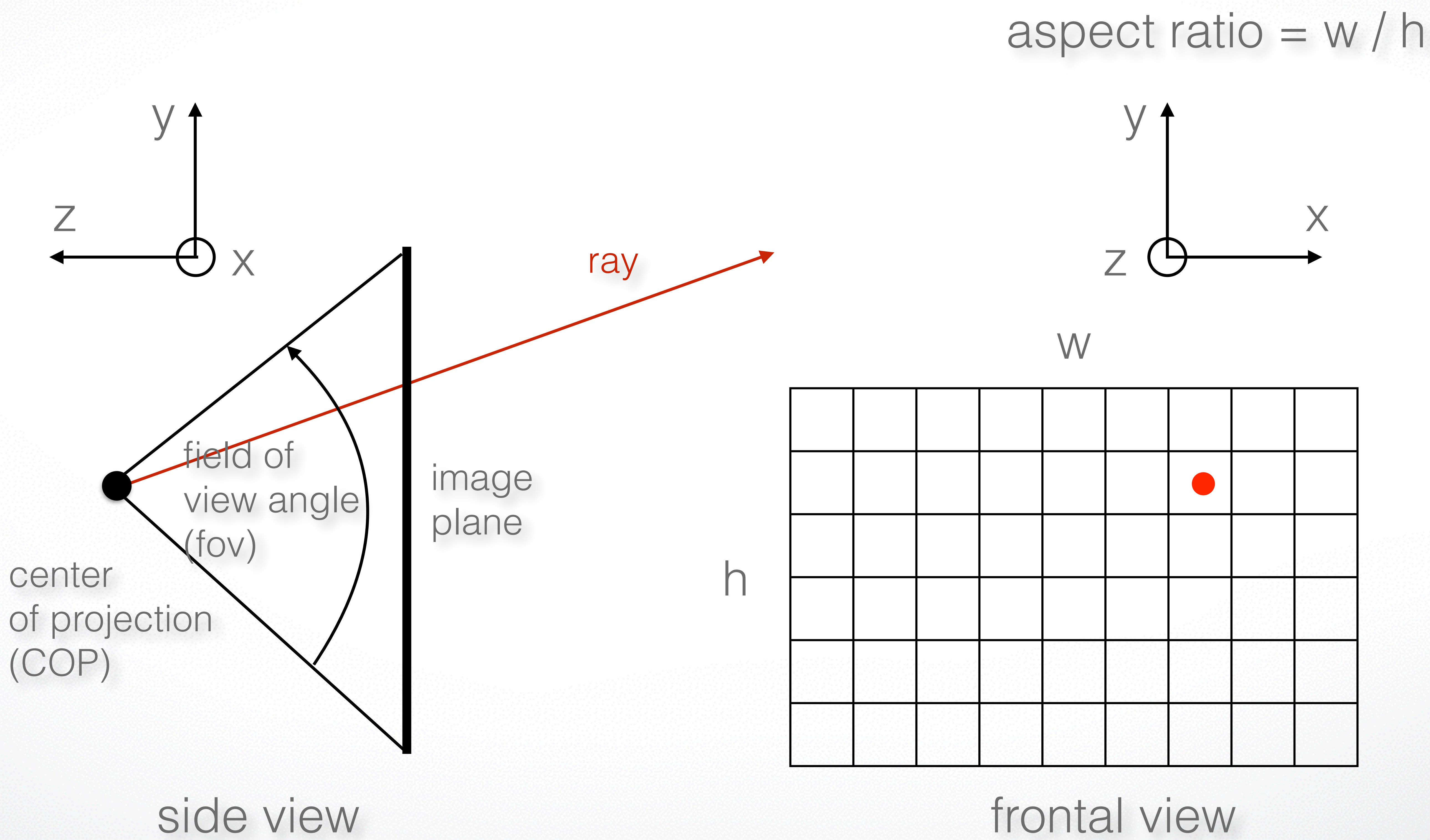


Generating Rays

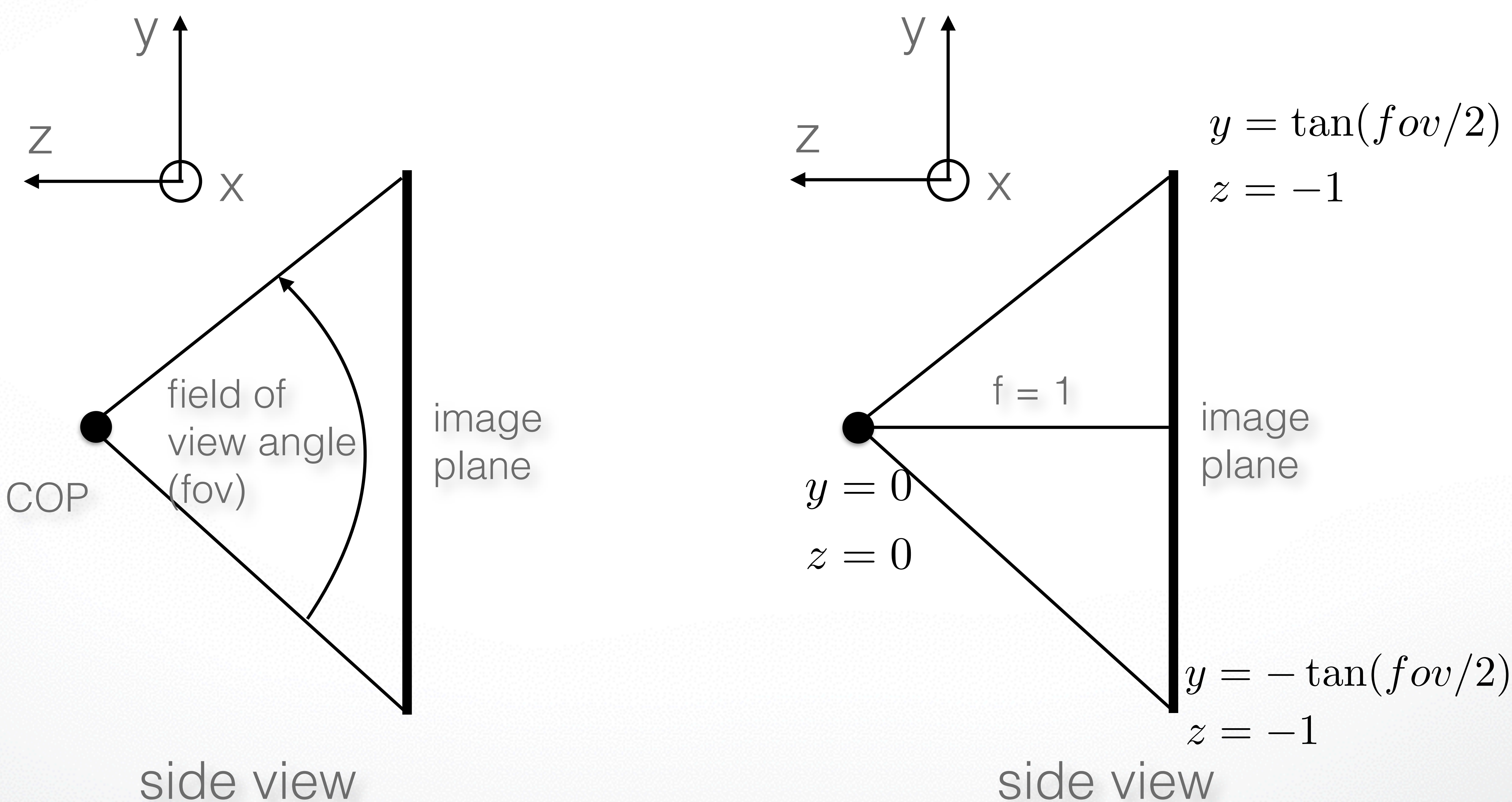
- Camera is at (0,0,0) and points in the negative z-direction
- Must determine coordinates of image corners in 3D



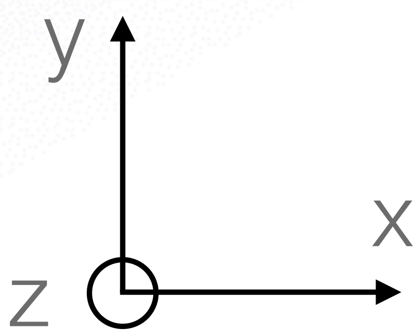
Generating Rays



Generating Rays



Generating Rays



a = aspect ratio = w / h

$x = -a\tan(fov/2)$
$y = \tan(fov/2)$
$z = -1$

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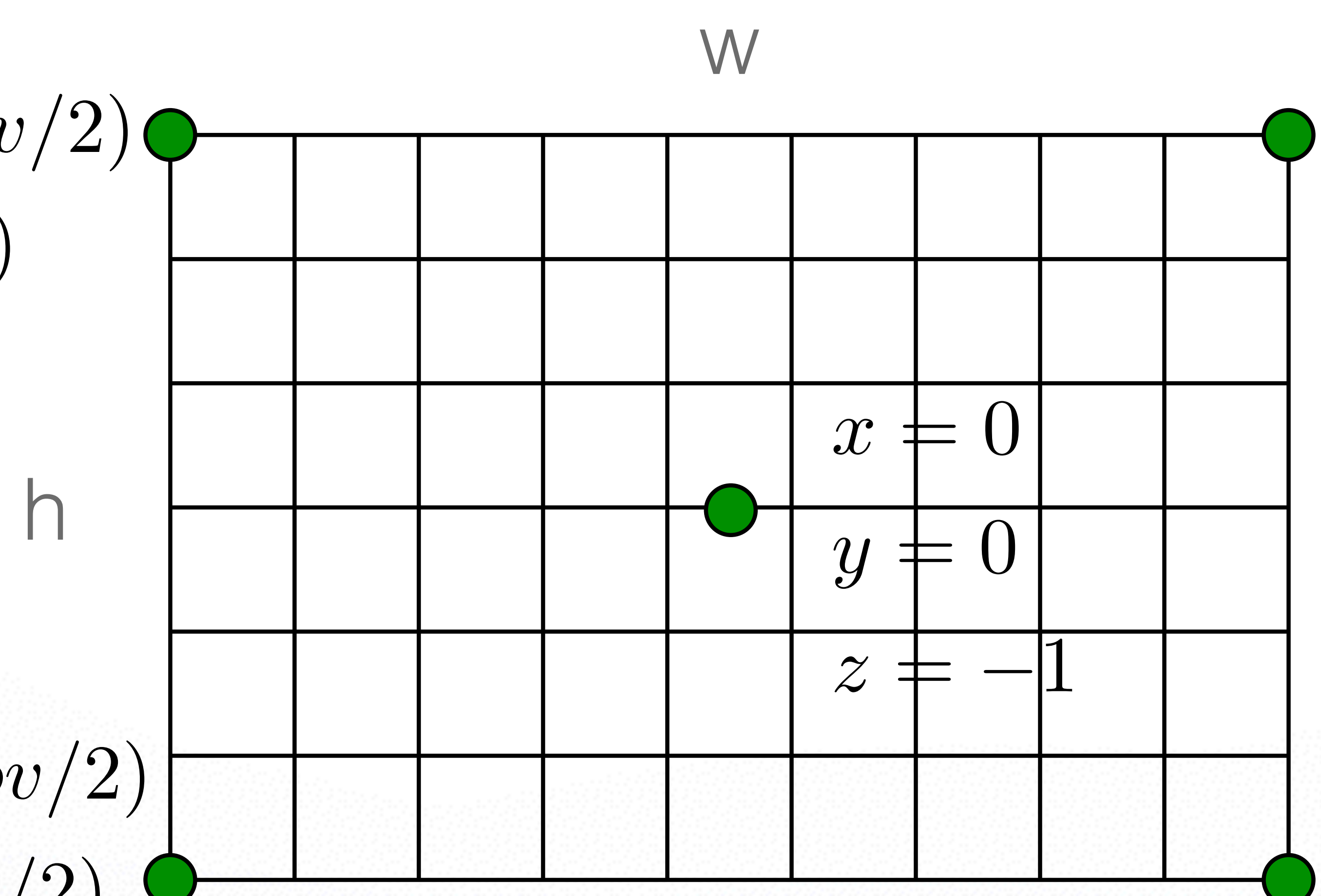

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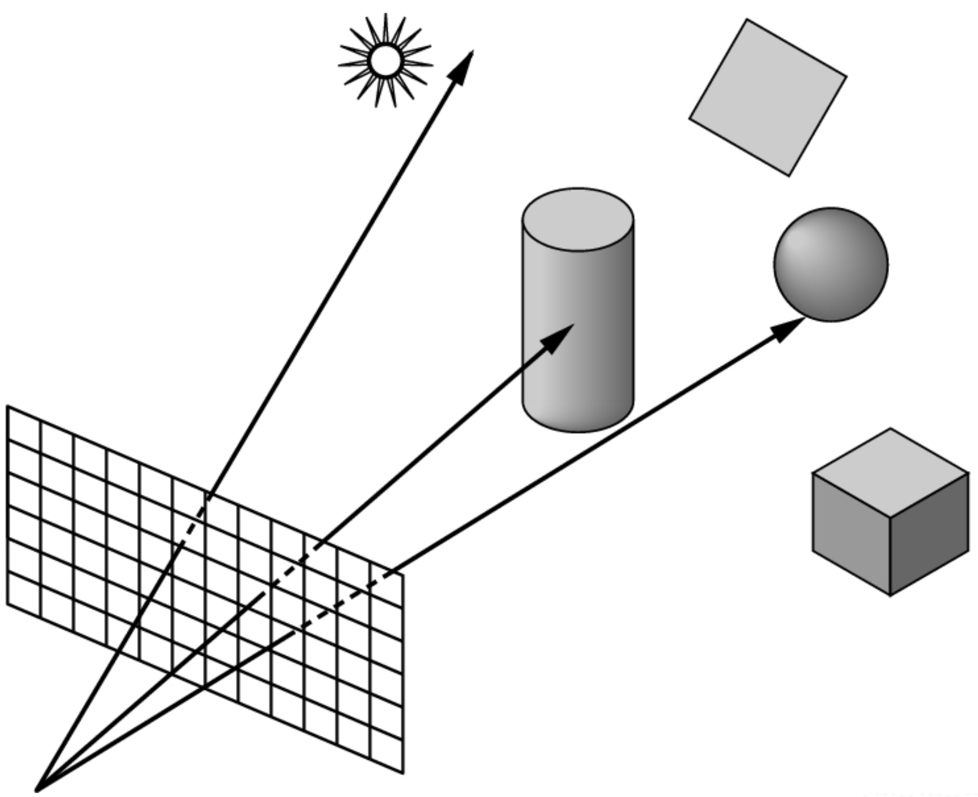
frontal view

Determining Pixel Color

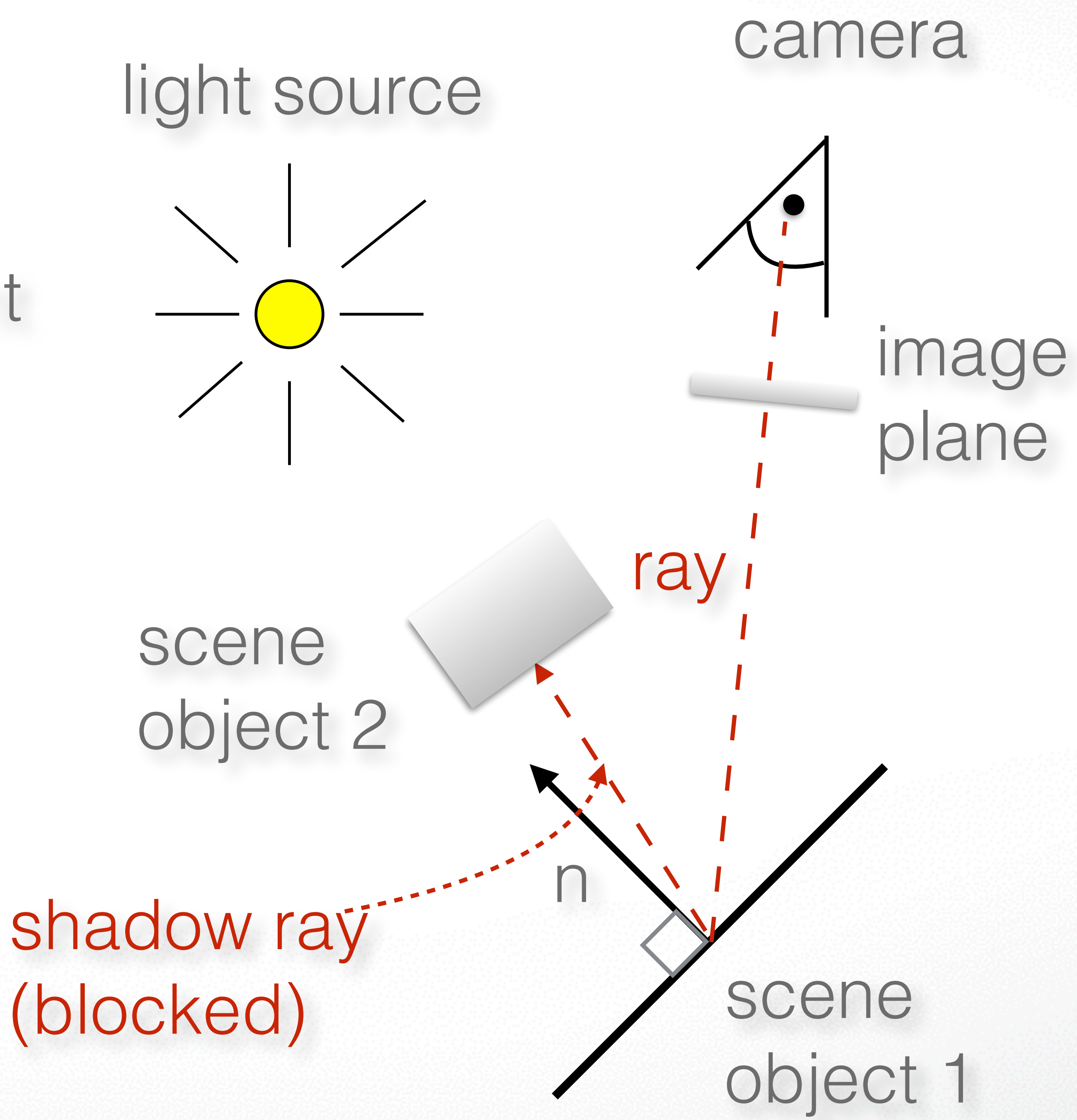
1. Phong model (local as before)
2. Shadow rays
3. Specular reflection
4. Specular transmission

Steps (3) and (4) require recursion.



Shadow Rays

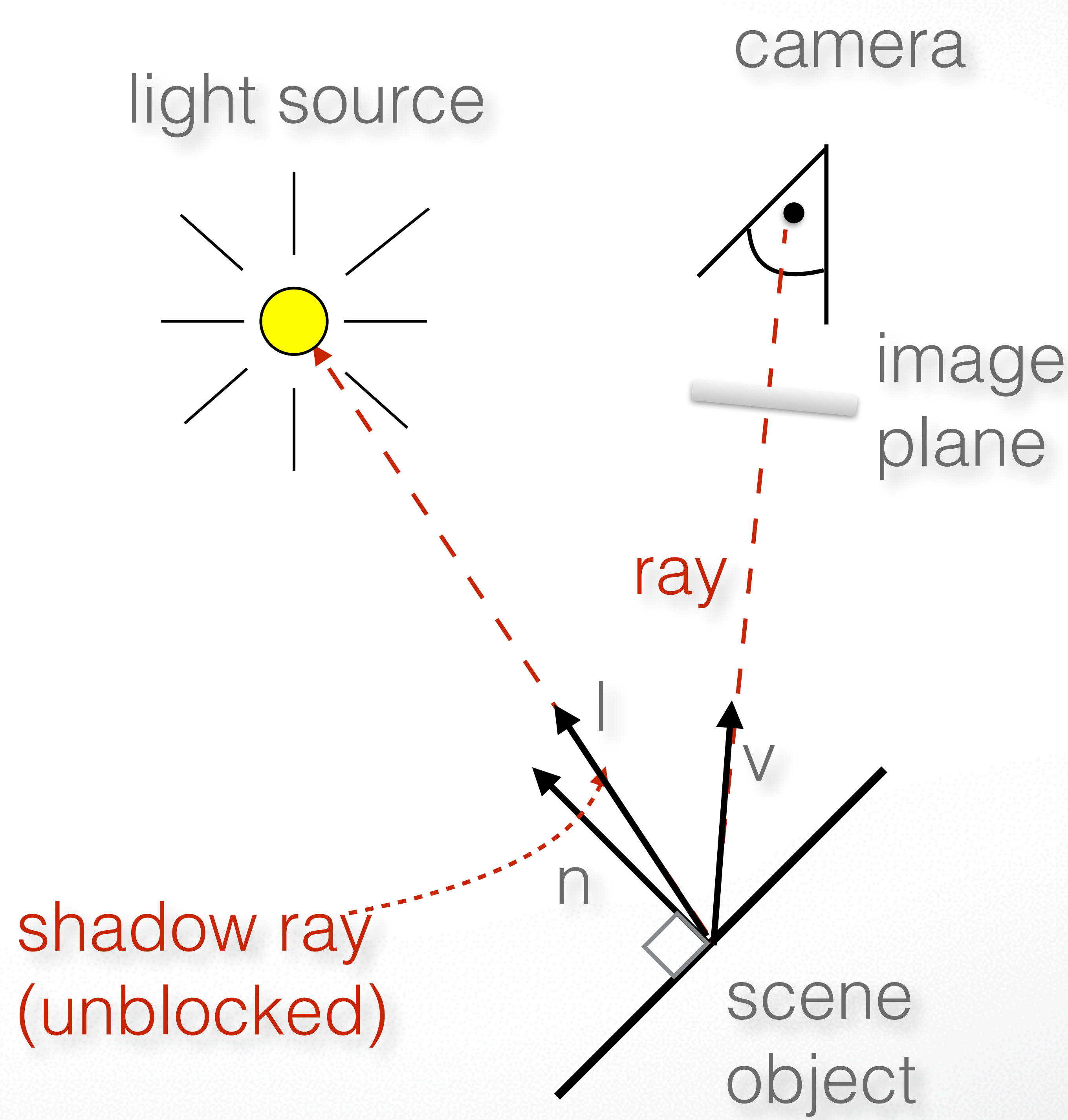
- Determine if light "really" hits surface point
- Cast shadow ray from surface point to each light
- If shadow ray hits opaque object, no contribution from that light
- This is essentially improved diffuse reflection



Phong Model

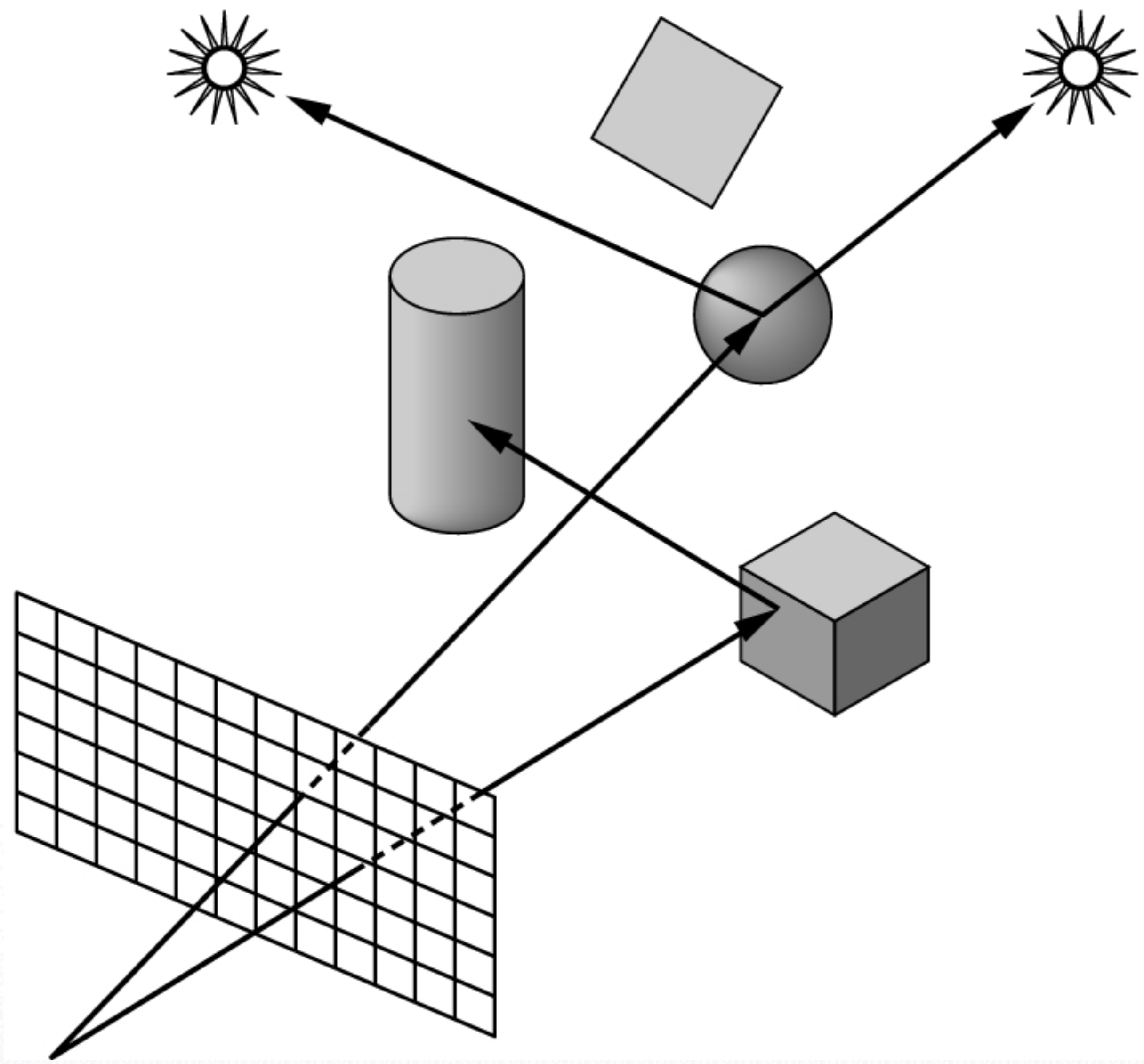
- If shadow ray can reach to the light, apply a standard Phong model

$$I = L\left(k_d(l \cdot n) + k_s(r \cdot v)^{\alpha}\right)$$



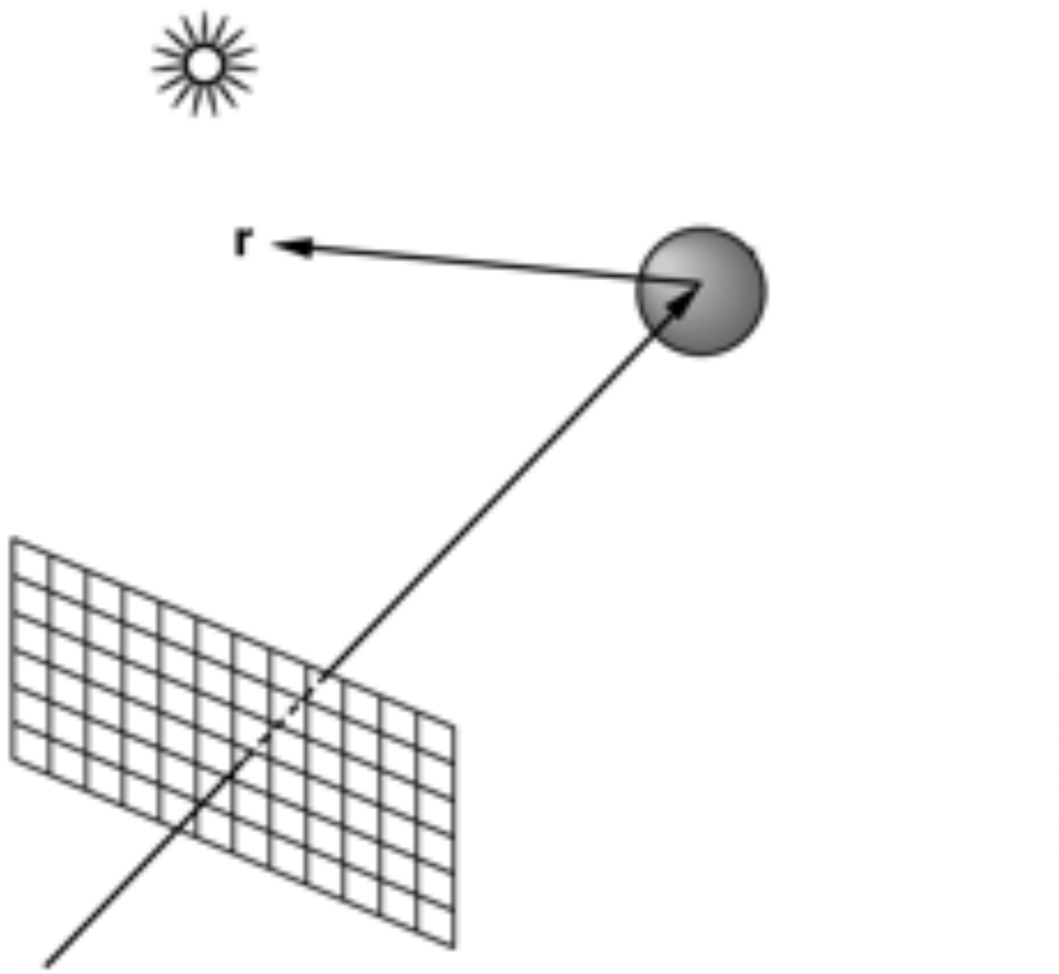
Where is Phong model applied in this example?

Which shadow rays are blocked?



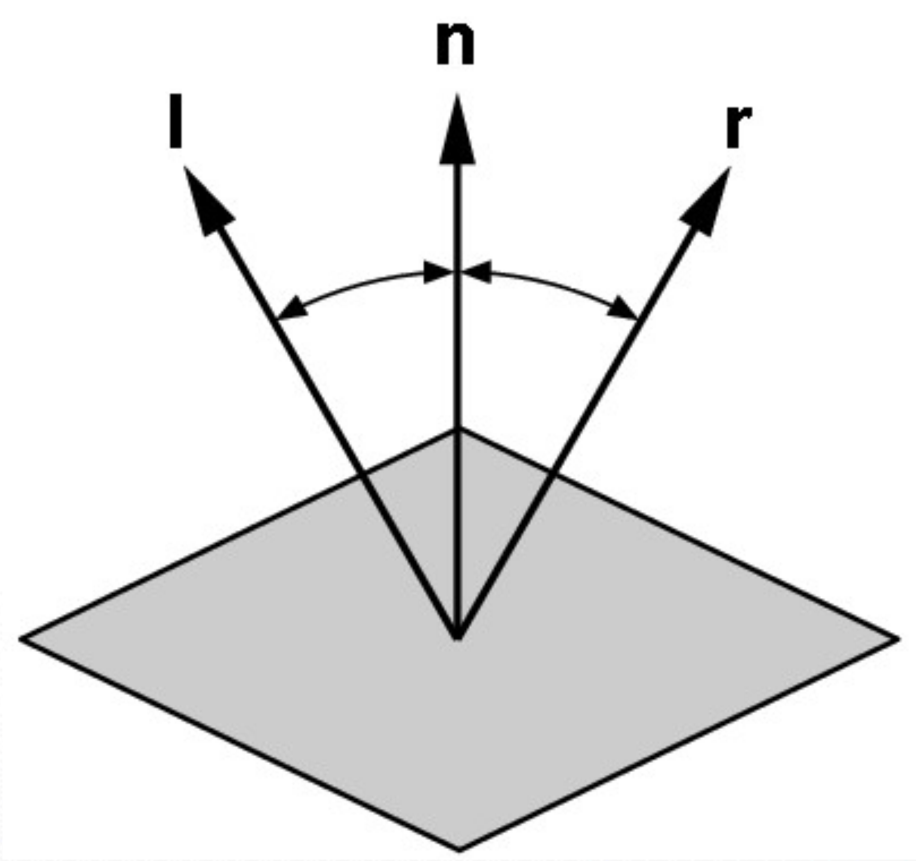
Reflection Rays

- For specular component of illumination
- Compute reflection ray (recall: backward!)
- Call ray tracer recursively to determine color

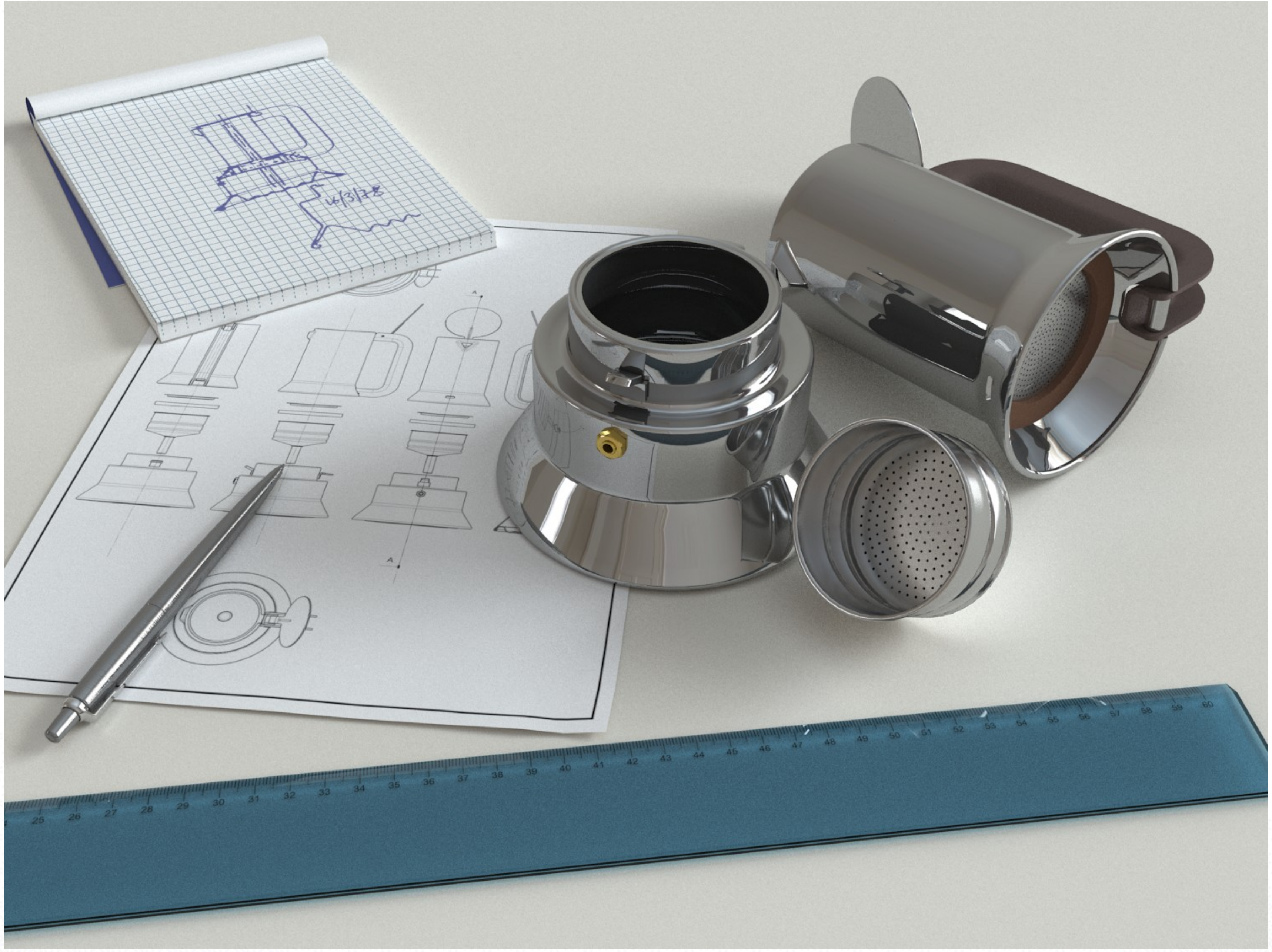


Angle of Reflection

- Recall: incoming angle = outgoing angle
- $r = 2(l \cdot n)n - l$
- Compute only for surfaces that are reflective



Reflections Example



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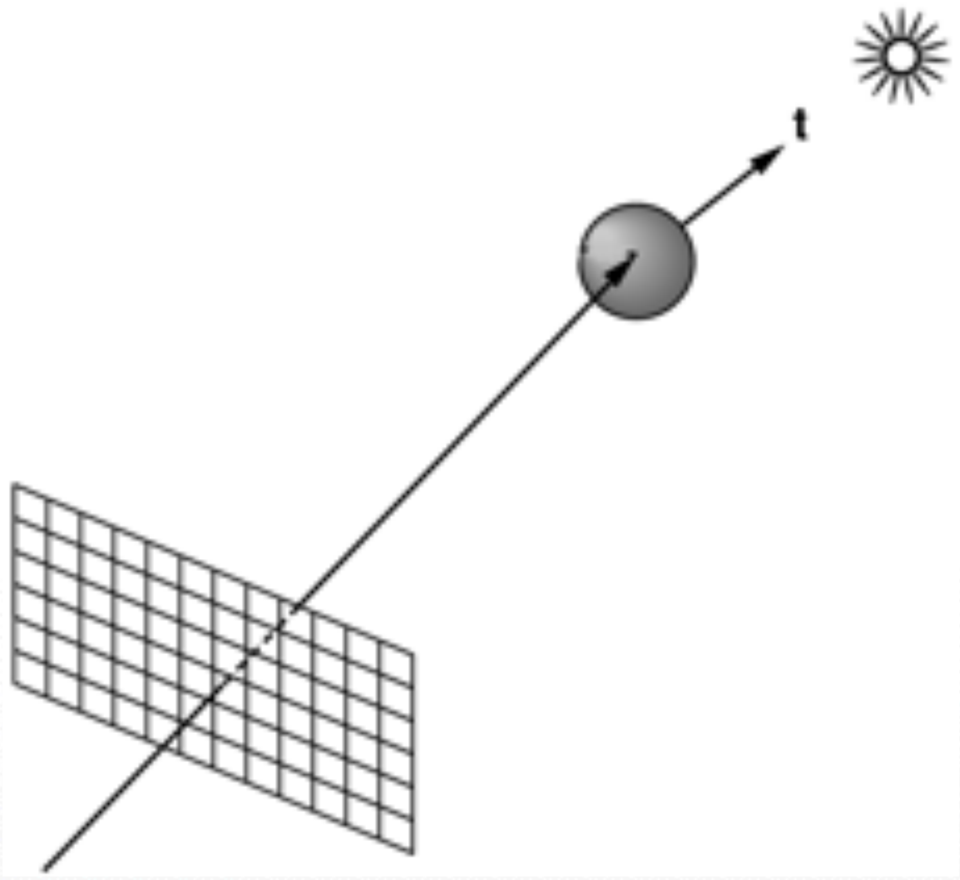
Transmission Rays

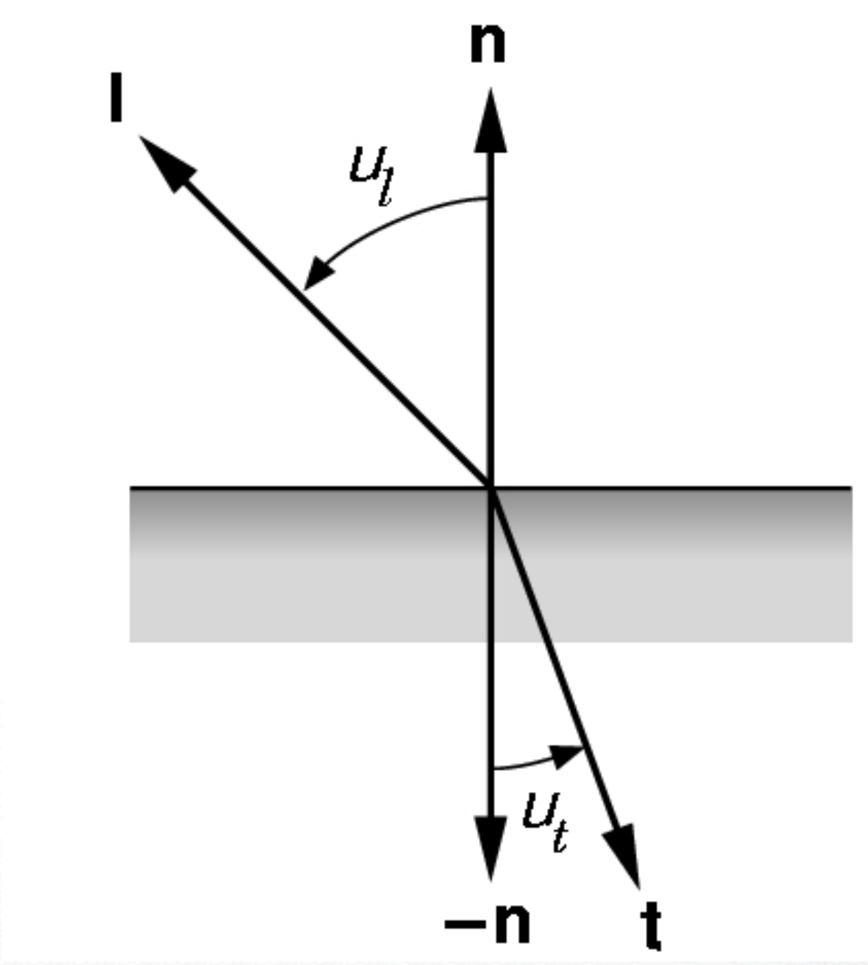
- Calculate light transmitted through surfaces
- Example: water, glass
- Compute transmission ray
- Call ray tracer recursively to determine color



Transmitted Light

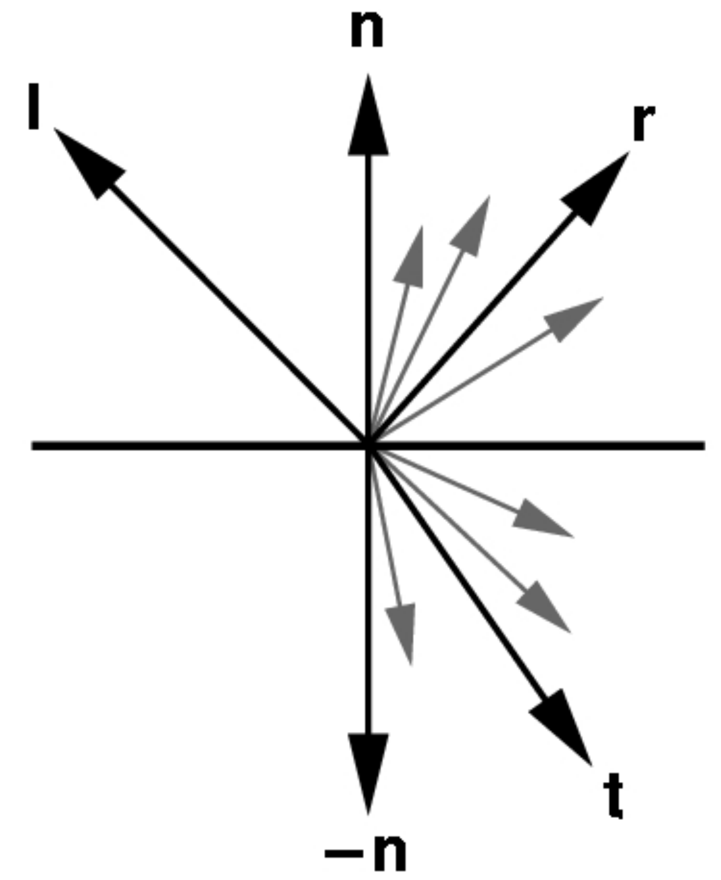
- Index of refraction is speed of light, relative to speed of light in vacuum
  - Vacuum: 1.0 (per definition)
  - Air: 1.000277 (approximate to 1.0)
  - Water: 1.33
  - Glass: 1.49
- Compute t using Snell's law
  - η_l = index for upper material
  - η_t = index for lower material

$$\frac{\sin(u_l)}{\sin(u_t)} = \frac{\eta_t}{\eta_l} = \eta$$



Translucency

- Most real objects are not transparent, but blur the background image
- Scatter light on other side of surface
- Use stochastic sampling (called distributed ray tracing)



Transmission + Translucency Example

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The Ray Casting Algorithm

- Simplest case of ray tracing

1. For each pixel (x,y), fire a ray from COP through (x,y)
2. For each ray & object, calculate closest intersection
3. For closest intersection point **p**

   - Calculate surface normal

   - For each light source, fire shadow ray

   - For each unblocked shadow ray, evaluate local Phong model for that light, and add the result to pixel color

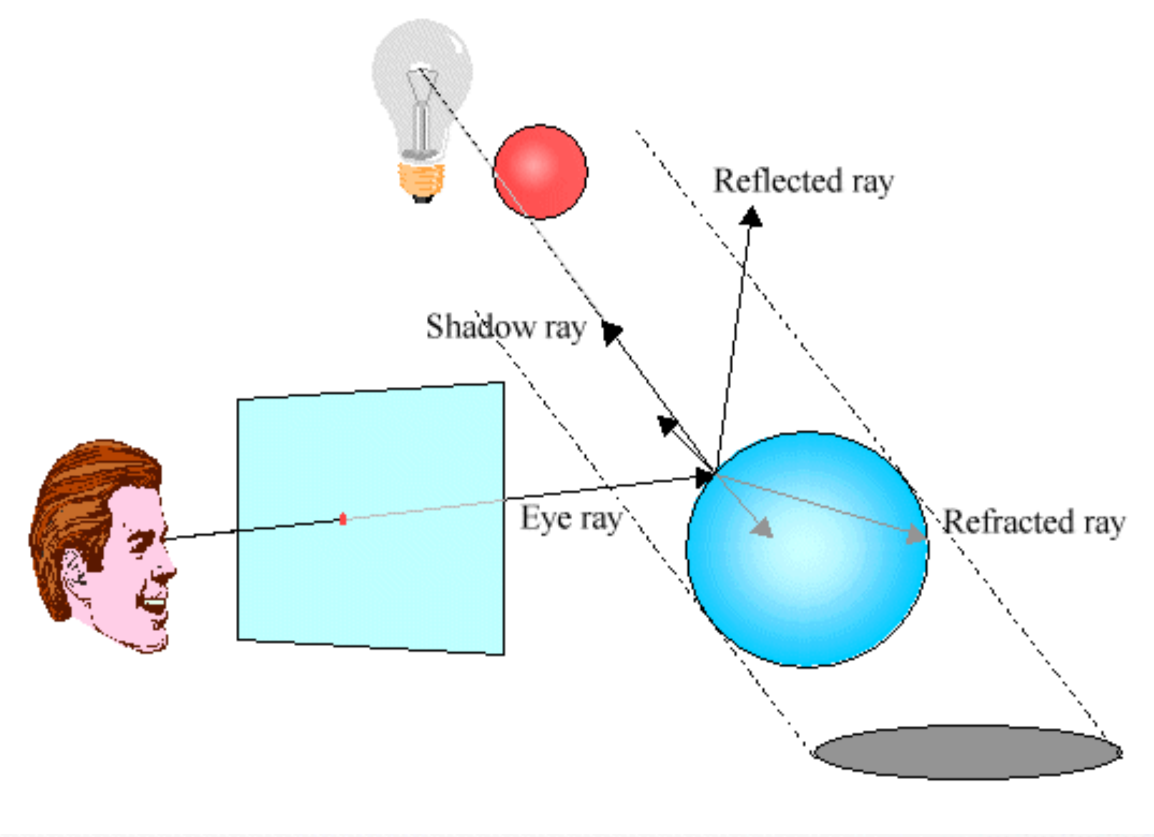
- Critical operations

  - Ray-surface intersections

  - Illumination calculation

Recursive Ray Tracing

- Also calculate specular component
  - Reflect ray from eye on specular surface
  - Transmit ray from eye through transparent surface
- Determine color of incoming ray by recursion
- Trace to fixed depth
- Cut off if contribution below threshold



Ray Tracing Assessment

- Global illumination method
- Image-based
- Pluses
  - Relatively accurate shadows, reflections, refractions
- Minuses
  - Slow (intersection computations)
  - Aliasing
  - Inter-object diffuse reflections require many bounces

Raytracing Example I

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Raytracing Example II

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Raytracing Example III

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Raytracing Example IV

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Summary

- Ray Casting
- Shadow Rays and Local Phong Model
- Reflection
- Transmission
- Next lecture: Geometric queries

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Thanks!