CSCI 420 Computer Graphics

Lecture 15

Ray Tracing

Ray Casting

Shadow Rays

Reflection and Transmission

[Ch. 13.2 - 13.3]

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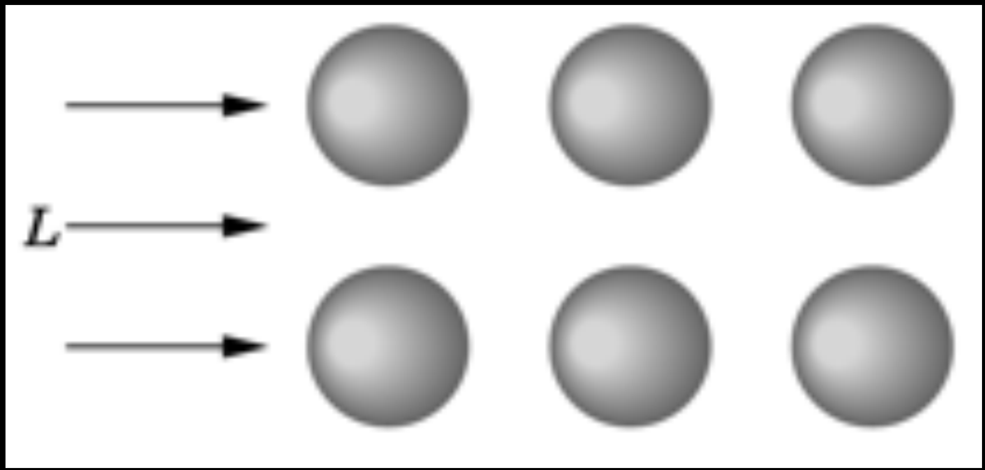
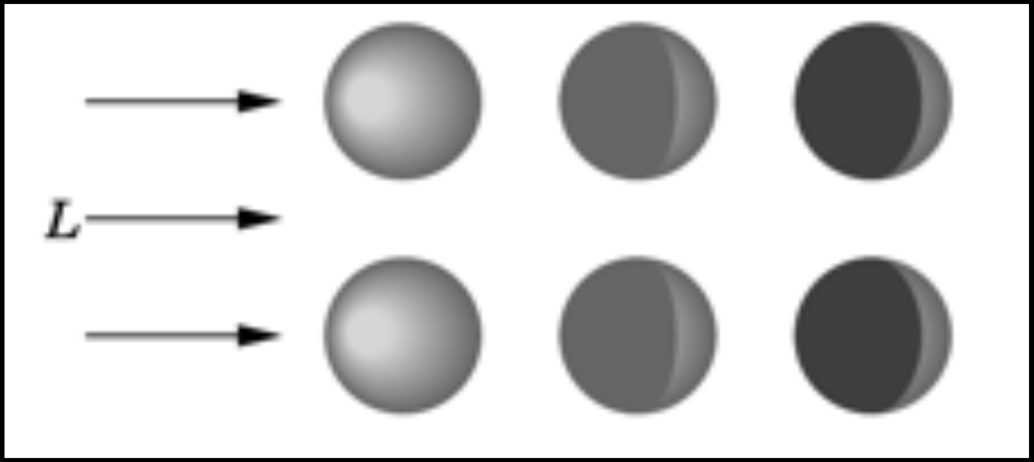
Local Illumination

- 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 interreflections)
- Photon mapping
- Precomputed Radiance Transfer (PRT)



Object Space:

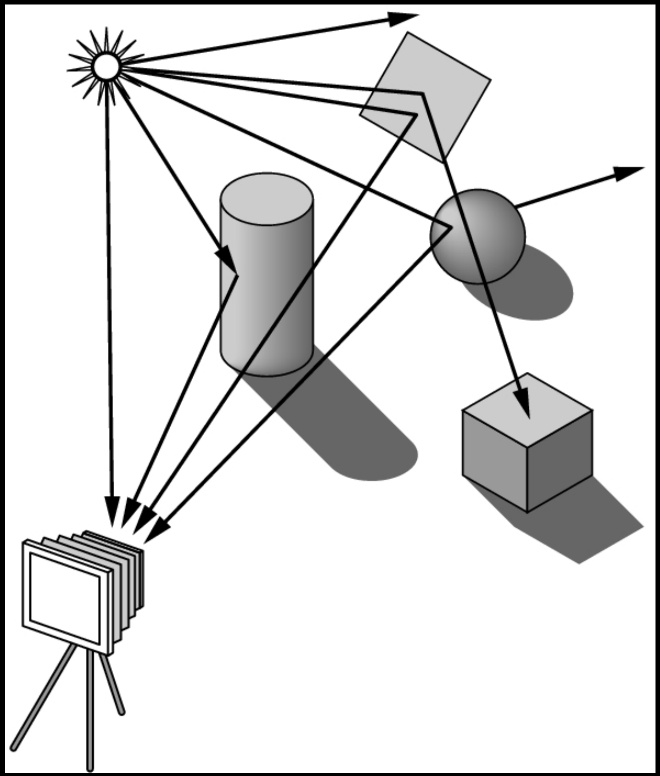
- Graphics pipeline: for each object, render
  - Efficient pipeline architecture, real-time
  - Difficulty: object interactions (shadows, reflections, etc.)

Image Space:

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

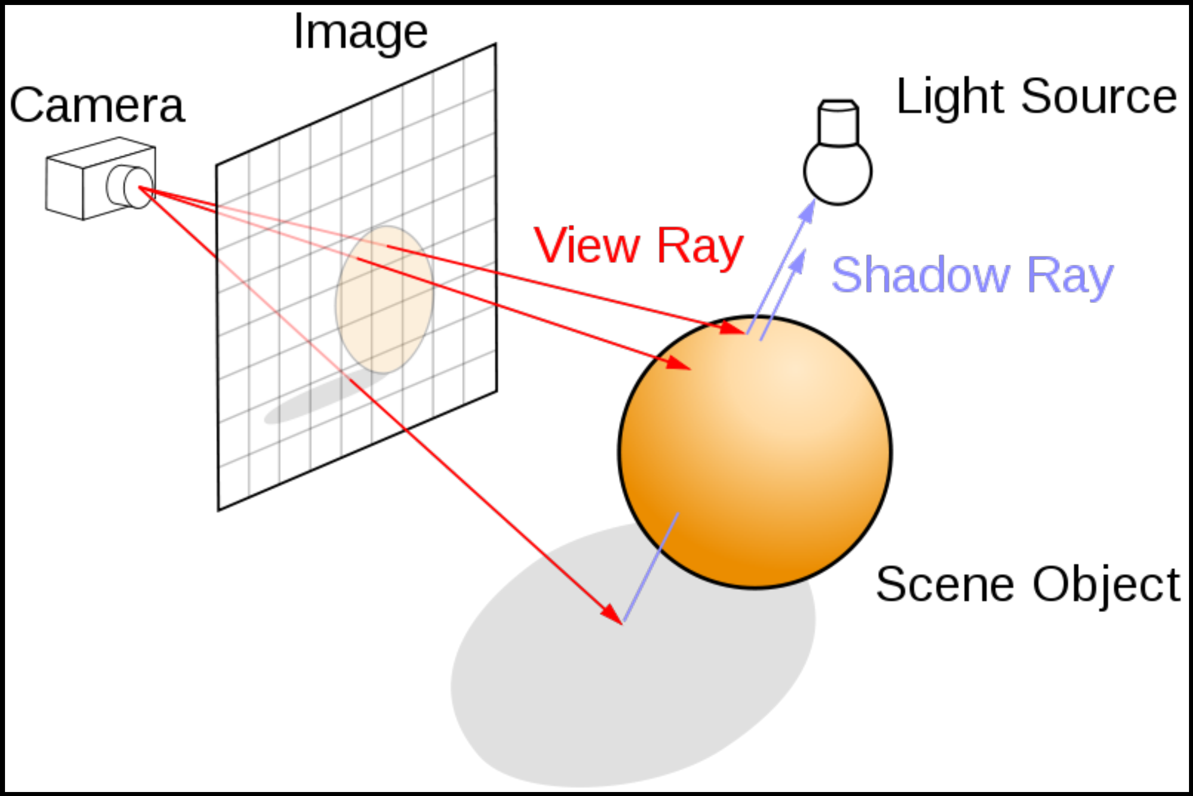
First idea: Forward Ray Tracing

- 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



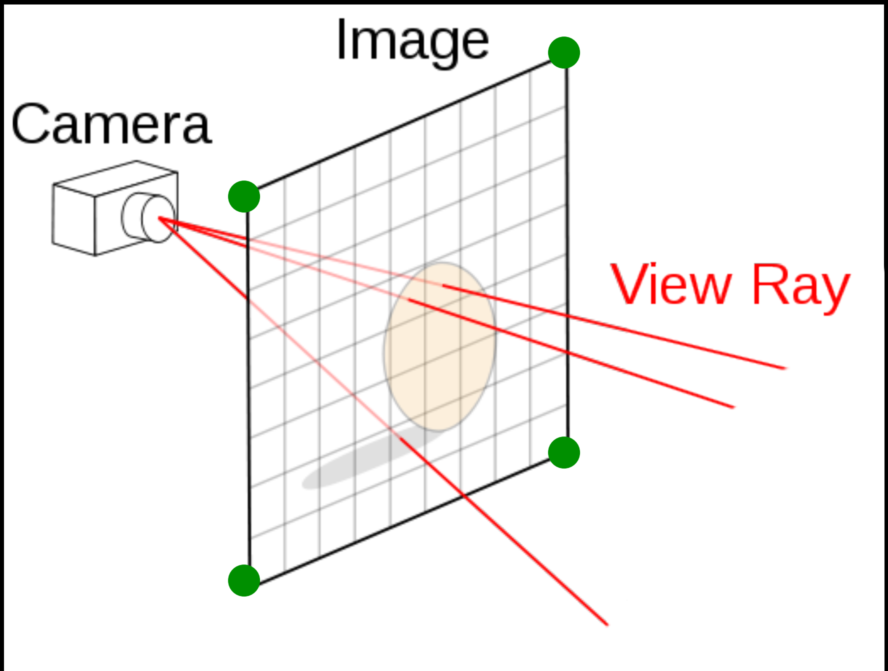
Backward Ray Tracing

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

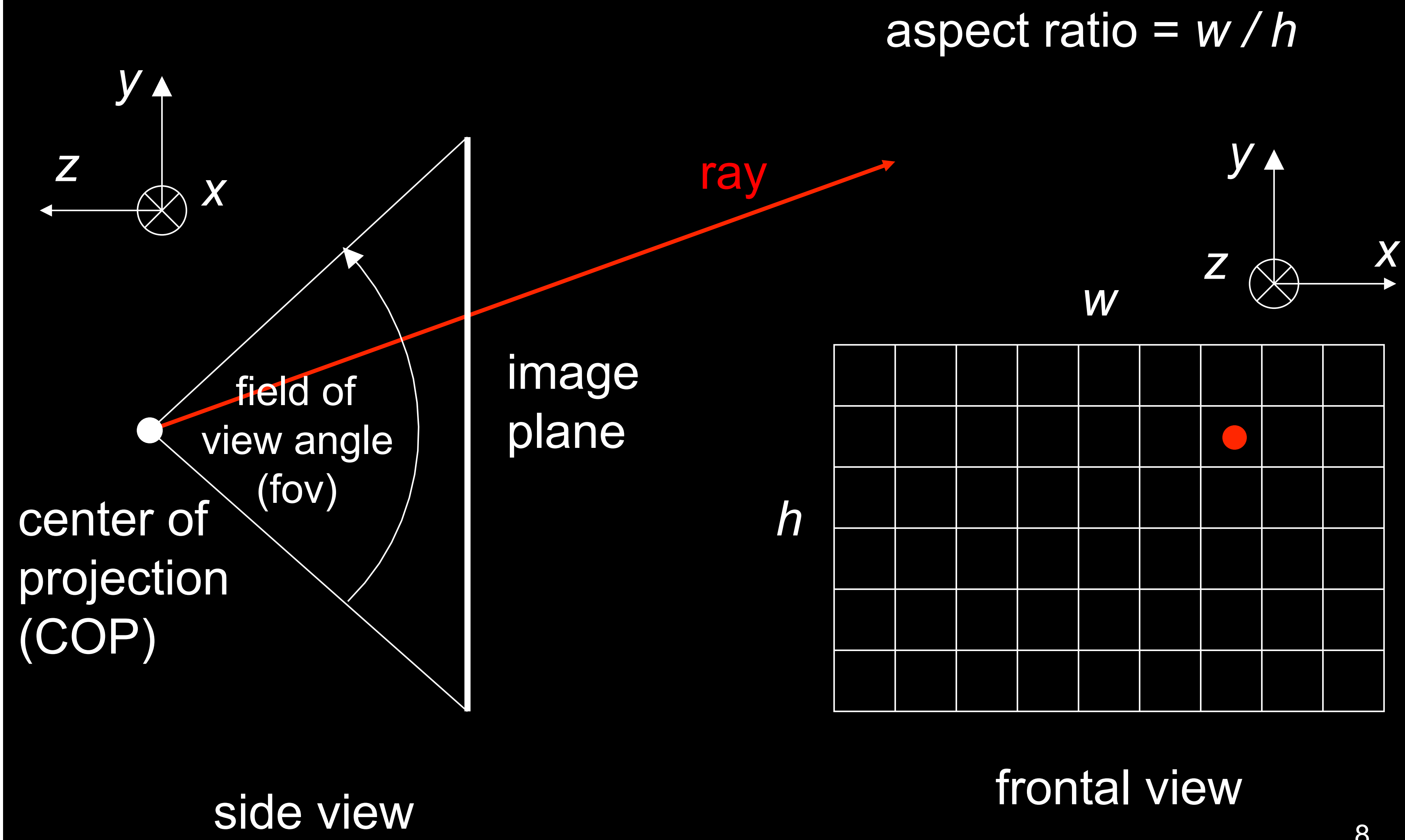


Generating Rays

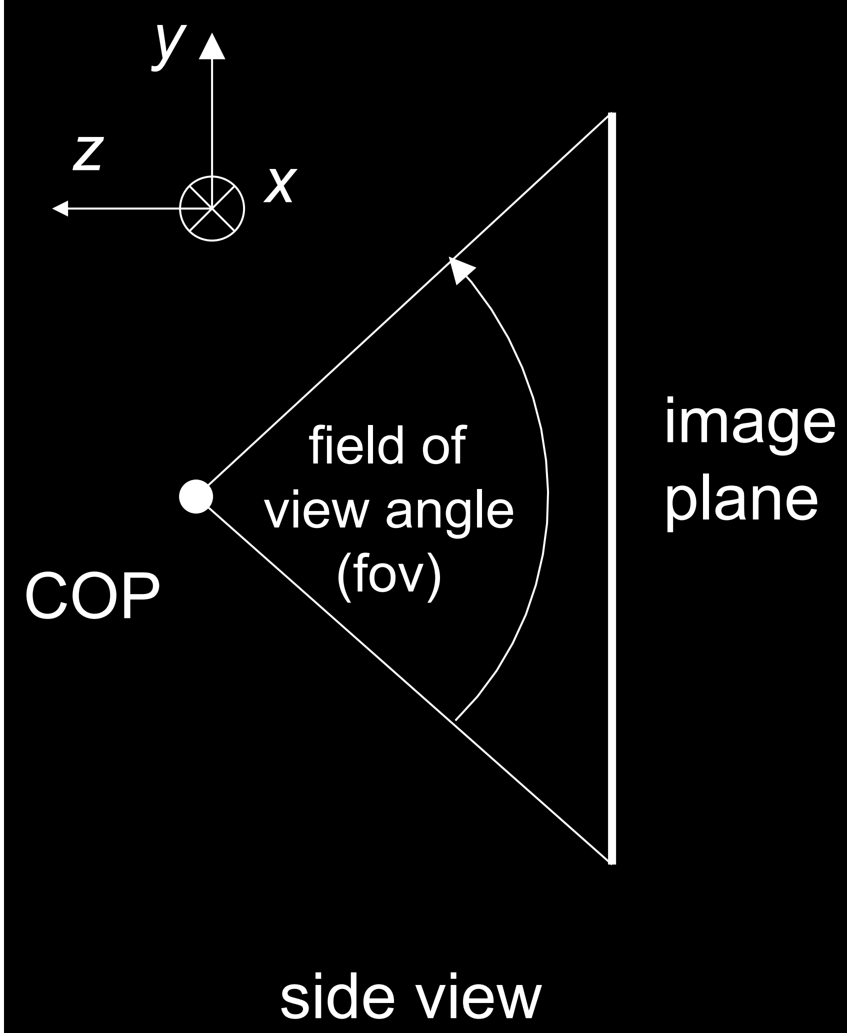
- Camera is at (0,0,0) and points in the negative z-direction
- Must determine coordinates of image corners in 3D

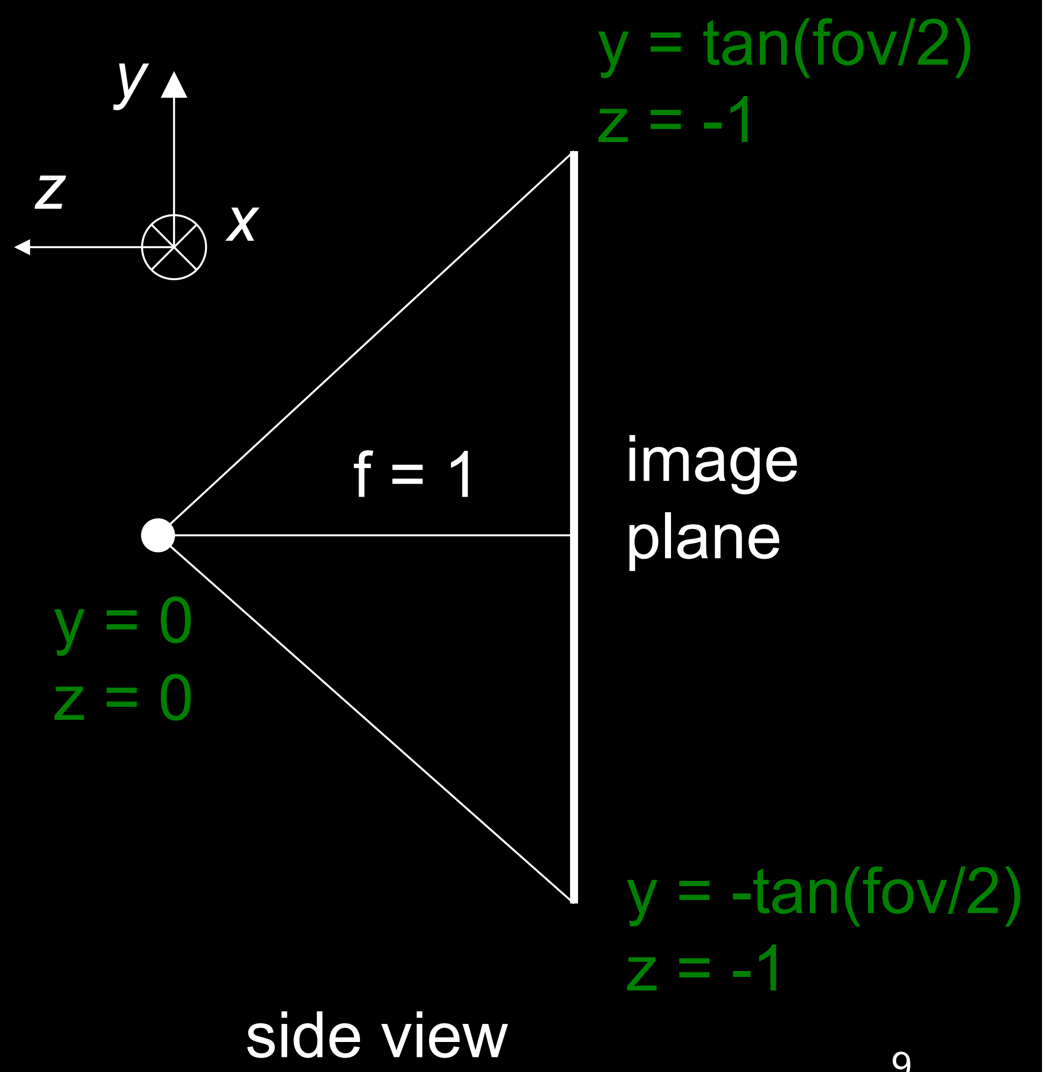


Generating Rays

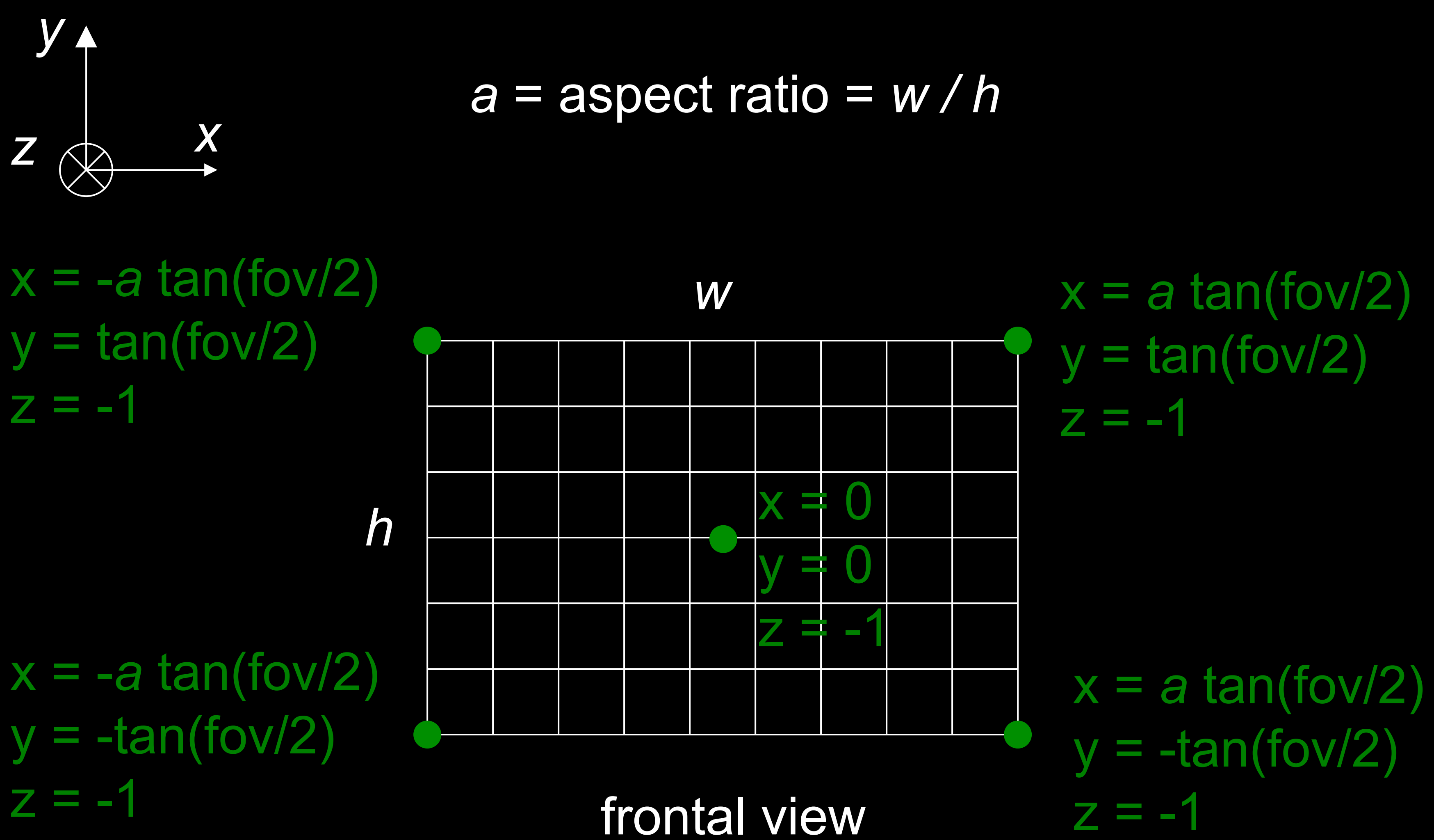


Generating Rays





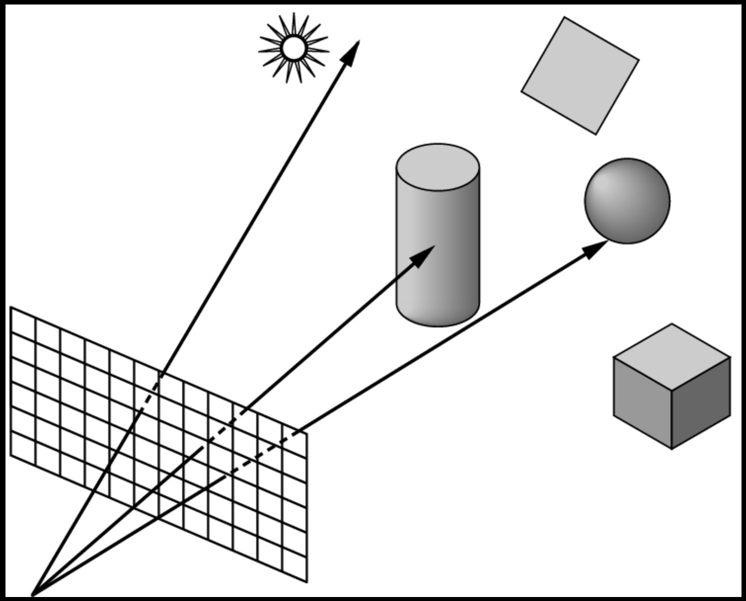
Generating Rays



Determining Pixel Color

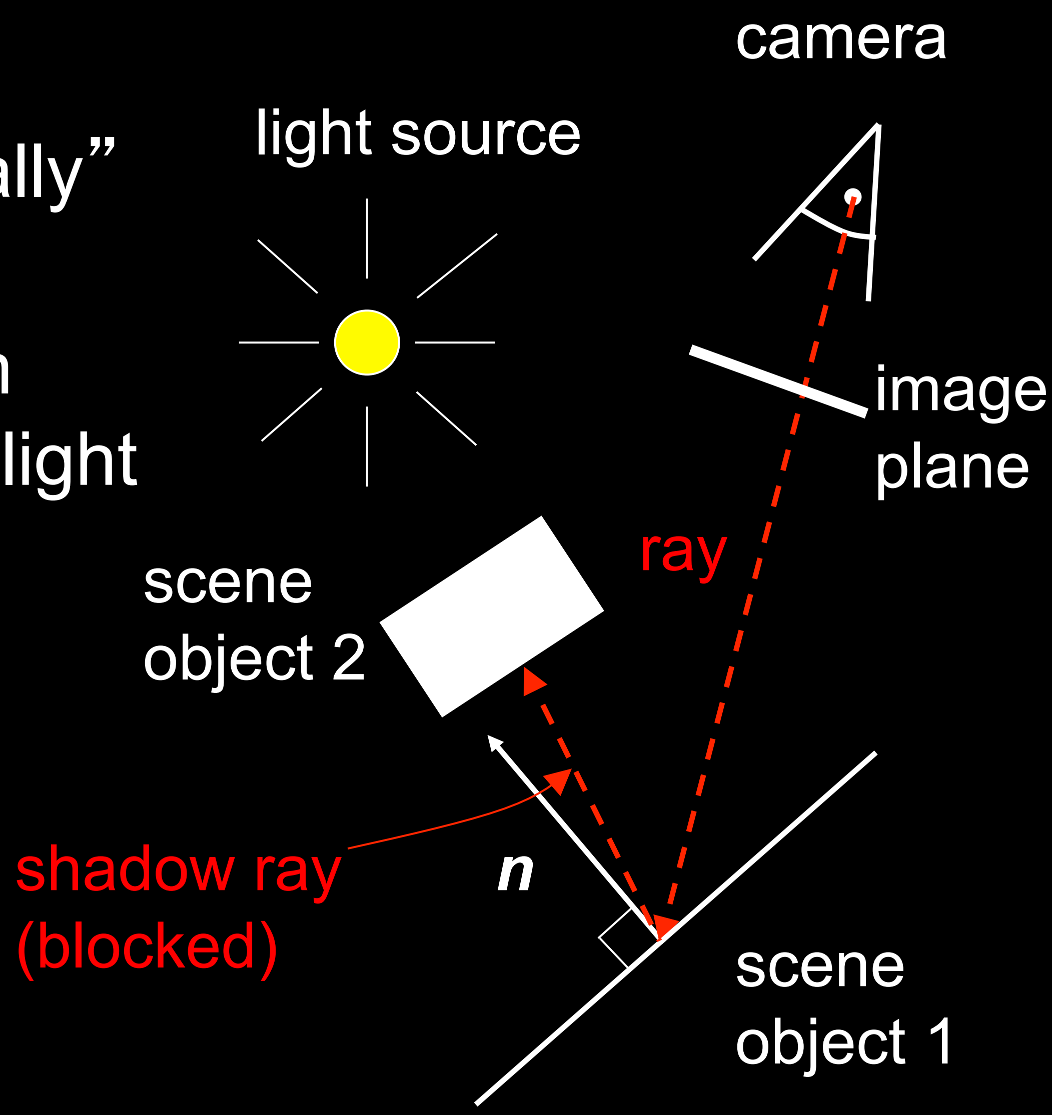
1. Phong model (local as before)
2. Shadow rays
3. Specular reflection
4. Specular transmission

Steps (3) and (4) require recursion.



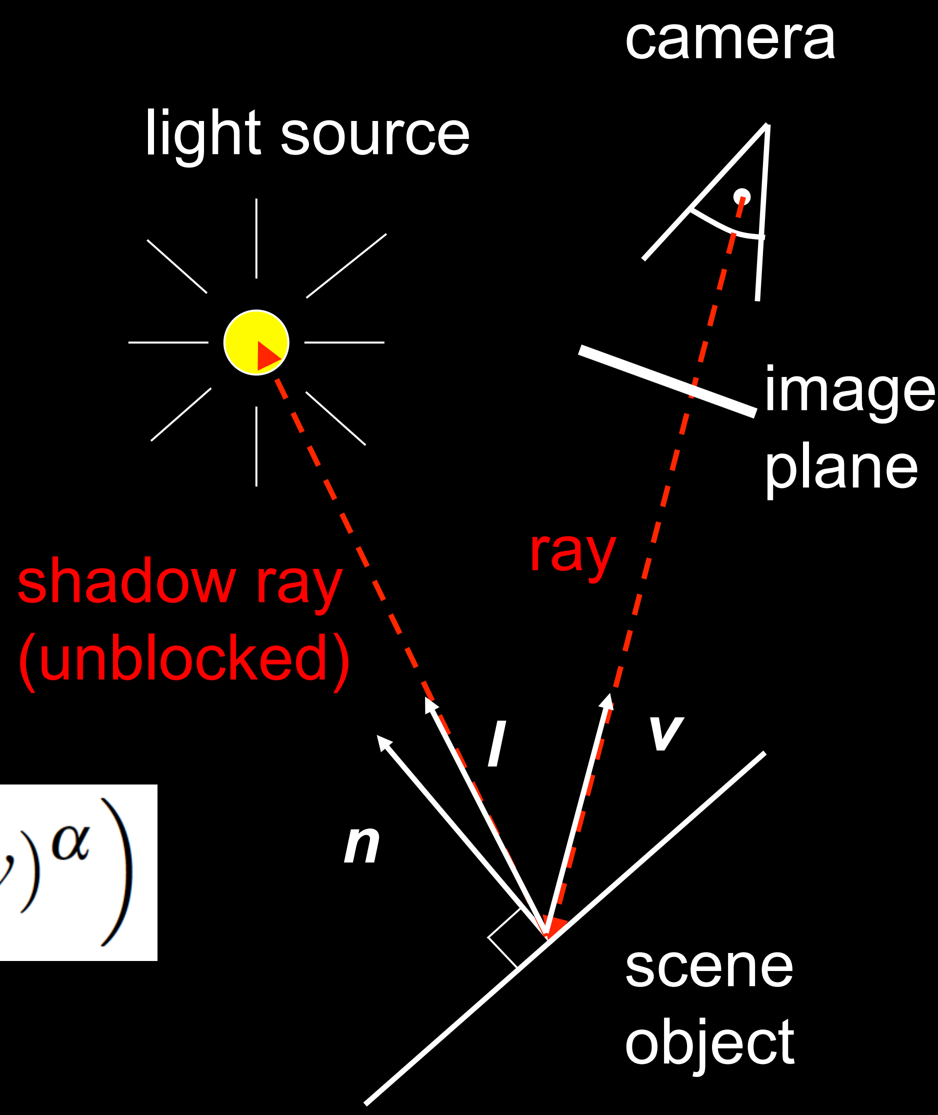
Shadow Rays

- 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



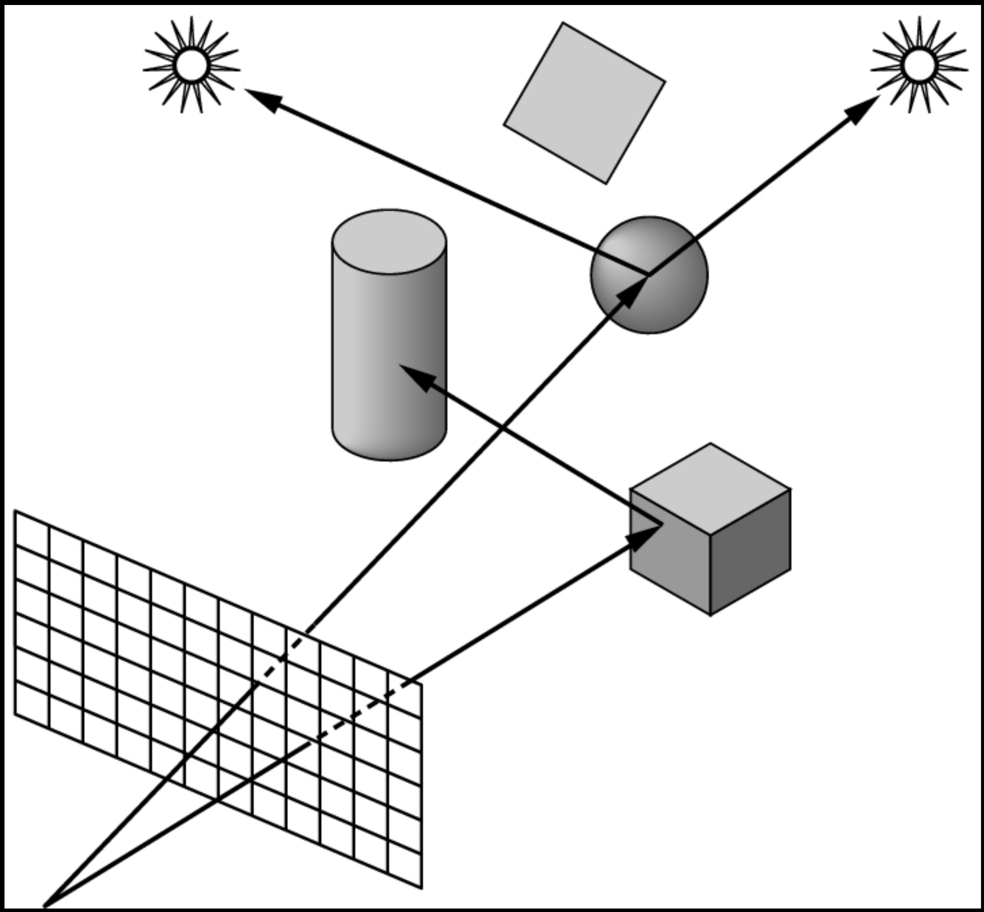
Phong Model

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



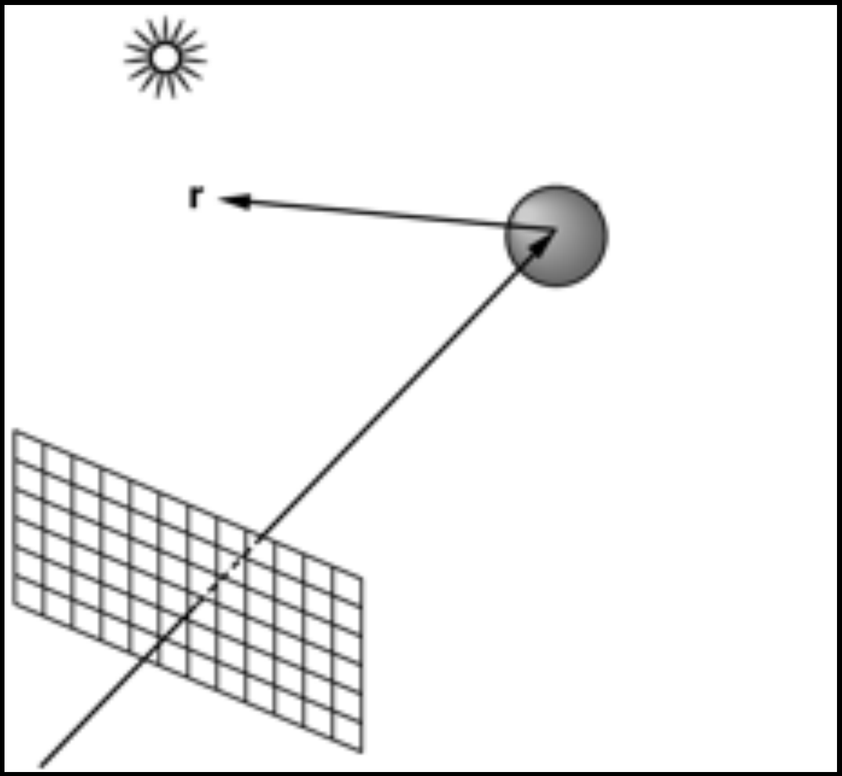
$$I = L\left(k_d(l \cdot n) + k_s(r \cdot v)^{\alpha}\right)$$

Where is Phong model applied in this example?
Which shadow rays are blocked?



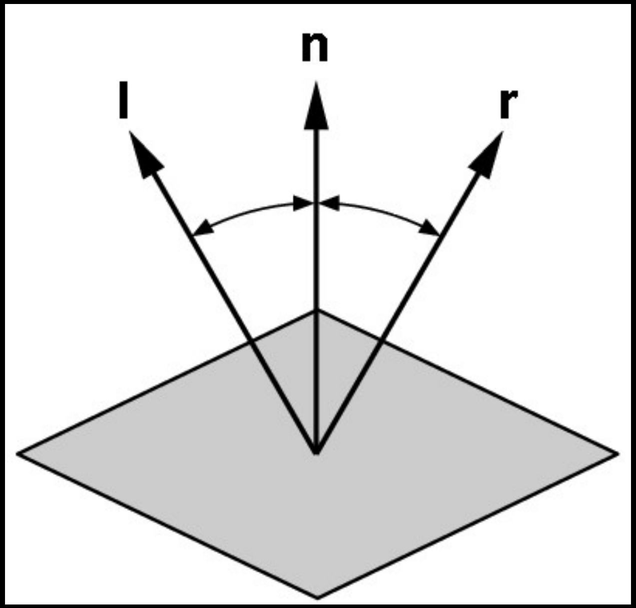
Reflection Rays

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

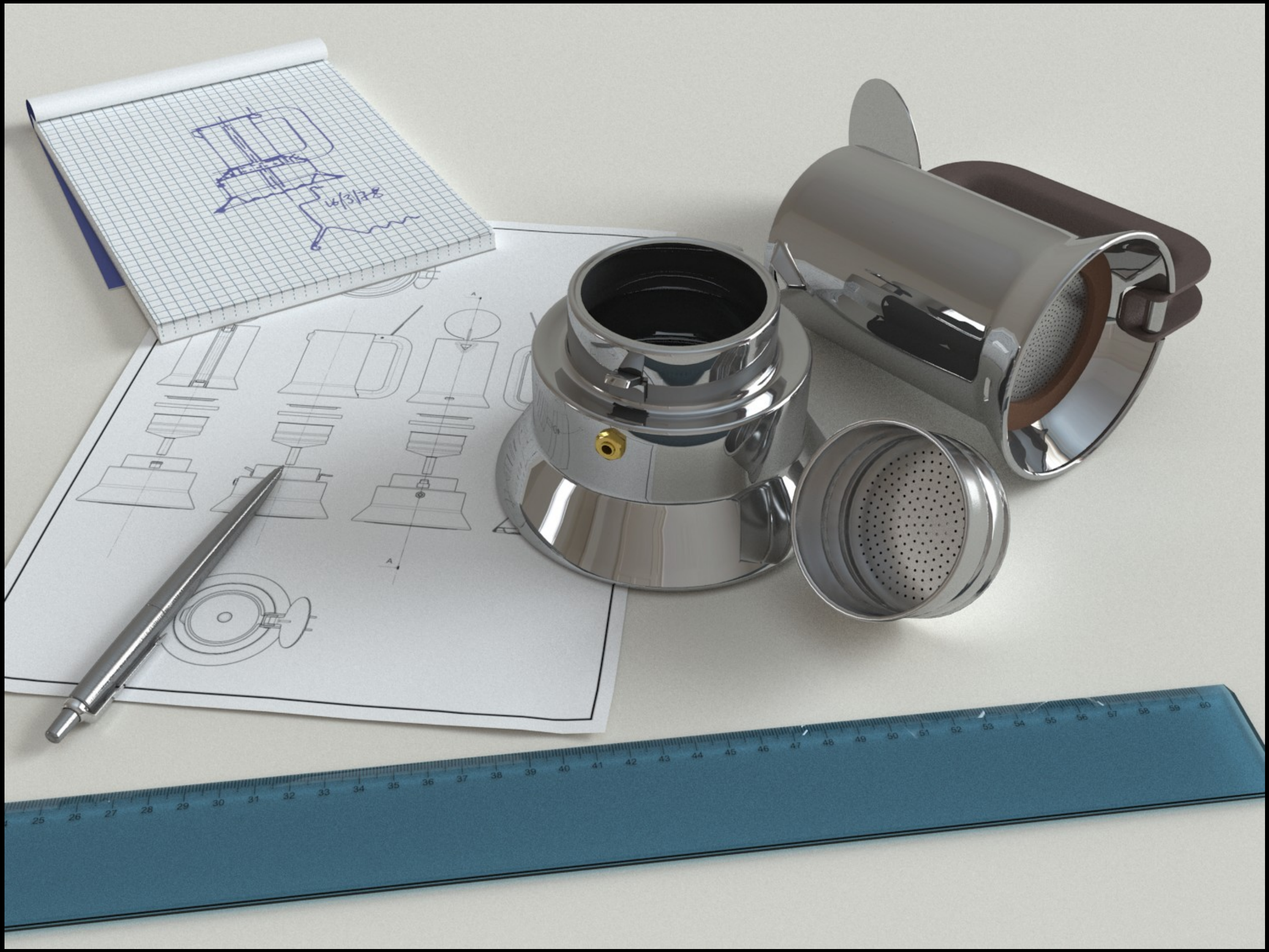


Angle of Reflection

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



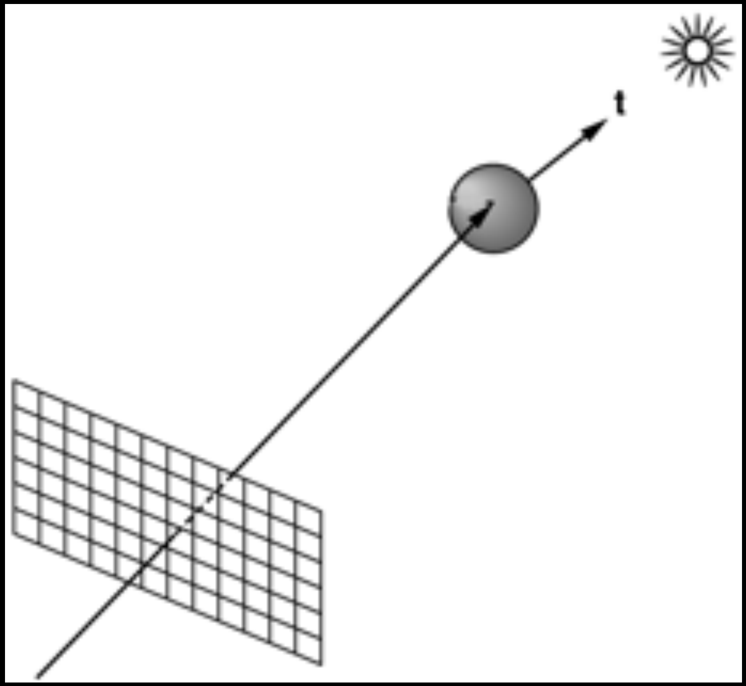
Reflections Example



www.yafaray.org

Transmission Rays

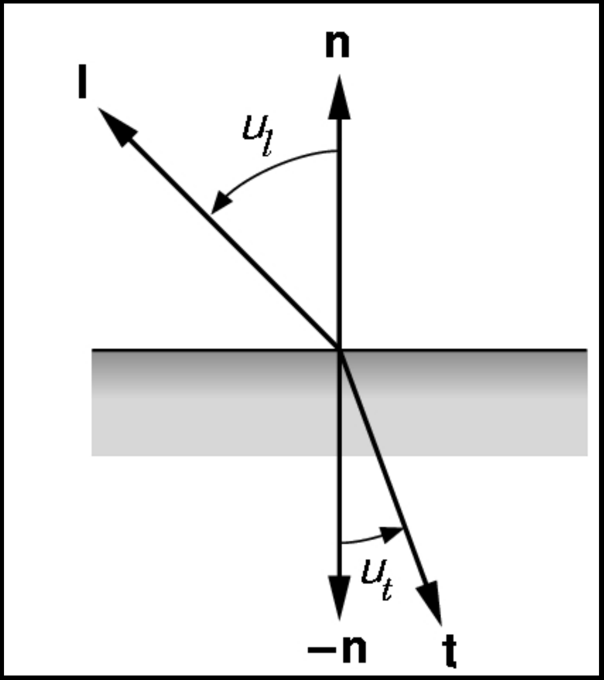
- Calculate light transmitted through surfaces
- Example: water, glass
- Compute transmission ray
- Call ray tracer recursively to determine color



Transmitted Light

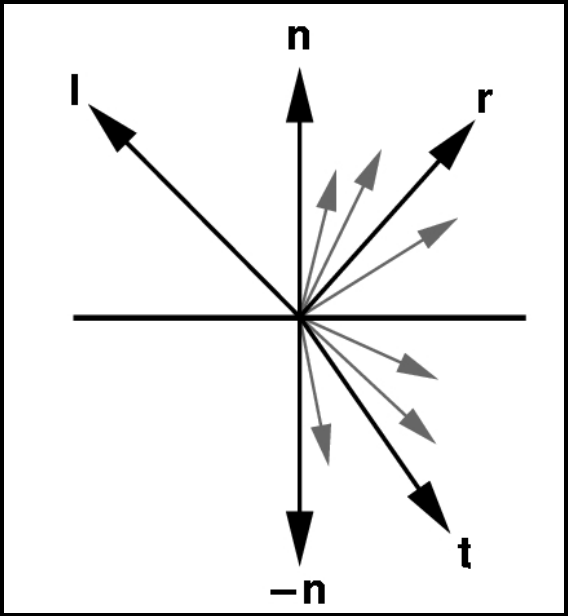
- Index of refraction is speed of light, relative to speed of light in vacuum
  - Vacuum: 1.0 (per definition)
  - Air: 1.000277 (approximate to 1.0)
  - Water: 1.33
  - Glass: 1.49
- Compute t using Snell's law
  - η_l = index for upper material
  - η_t = index for lower material

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



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

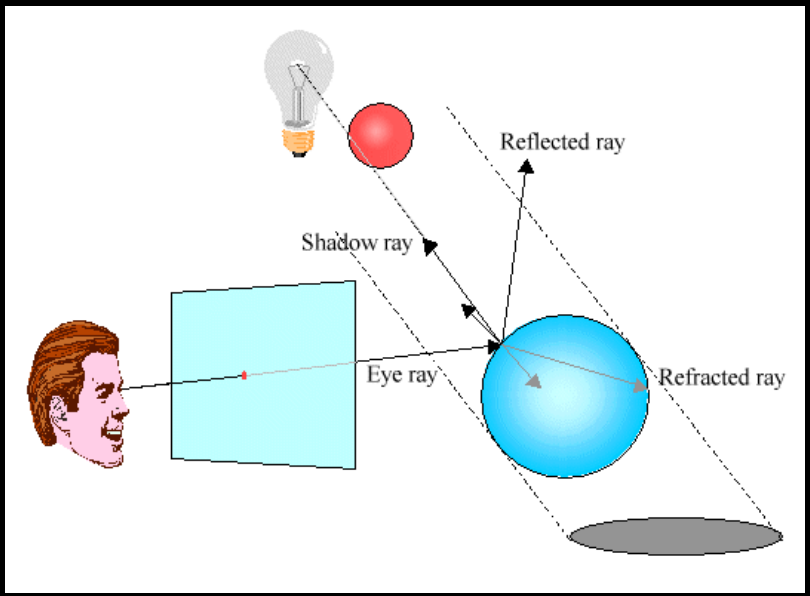
- Simplest case of ray tracing

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 (per pixel parallelism, not pipeline parallelism)
  - Aliasing
  - Inter-object diffuse reflections require many bounces

Raytracing Example I

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Raytracing Example II

www.povray.org

Raytracing Example III

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Raytracing Example IV

www.povray.org

Summary

- Ray Casting
- Shadow Rays and Local Phong Model
- Reflection
- Transmission

- Next lecture: Geometric queries