CSCI 420 Computer Graphics
Lecture 15

Ray Tracing

Ray Casting
Shadow Rays
Reflection and Transmission
[Angel Ch. 11]

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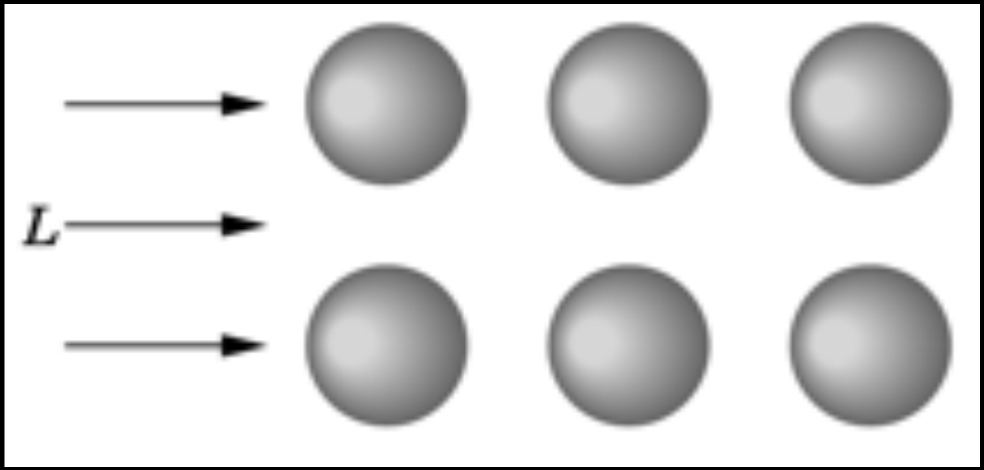
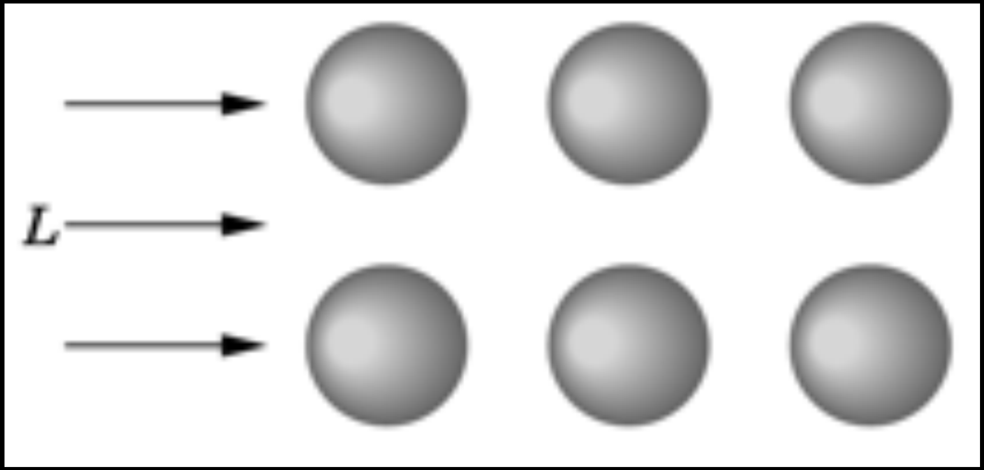
Local Illumination

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



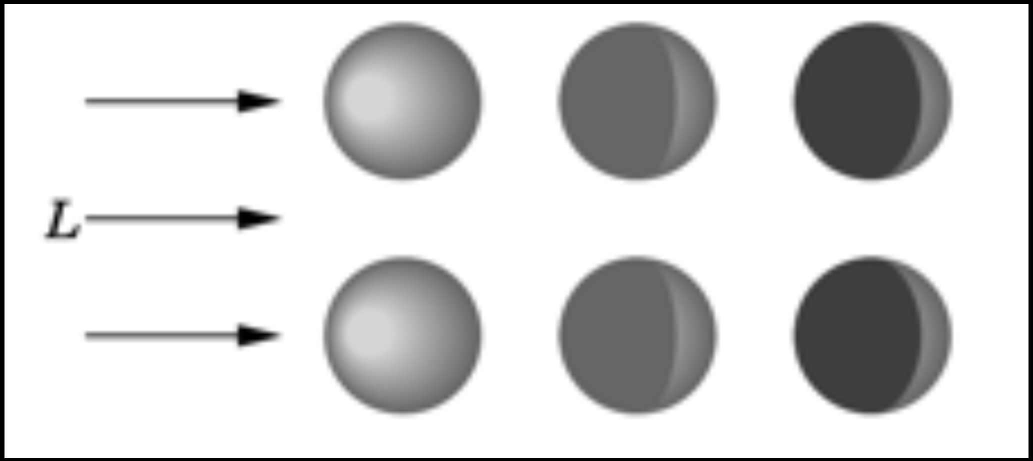
Local Illumination

- Each vertex shader runs independently
- Each fragment shader runs independently
- We have some interaction when depth buffering happens.
- All other object interactions require some kind of hack.



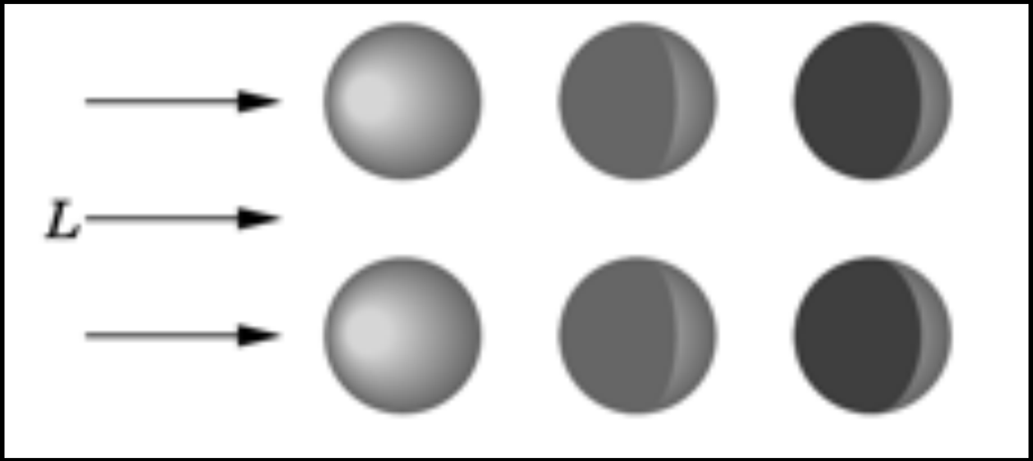
Global Illumination

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



Global Illumination

- In the real world...
  - Surfaces obstruct light.
  - Surfaces reflect light onto other surfaces.
  - Surfaces scatter light.



Object Space:

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

Image Space:

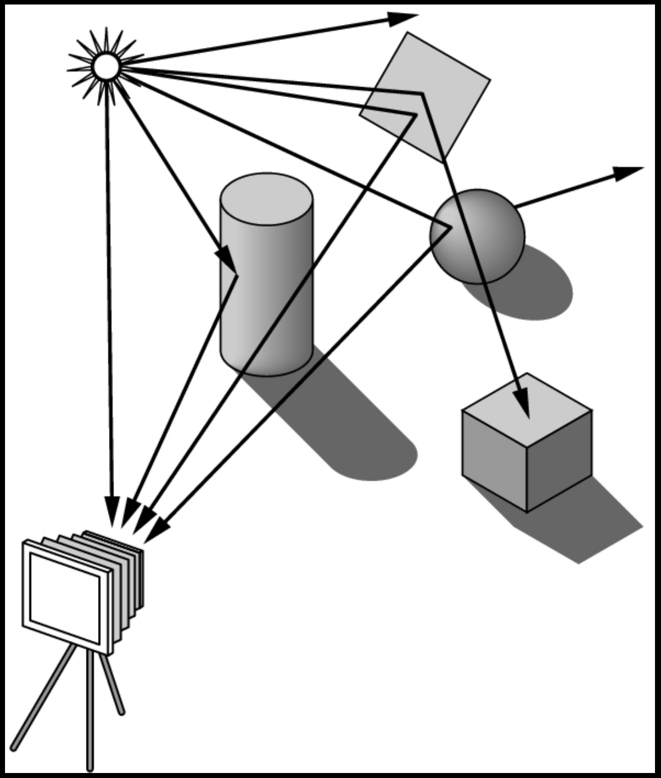
- Ray tracing: for each pixel, determine color
  - Pixel-level parallelism
  - Difficulty: very intensive computation, usually off-line

So let's simulate physics!

- Simulating physics is what computers are for!
- Physically trace every single ray of light.
- All light comes from light sources.
- Light that makes it to the camera film eventually gets written into the output image.

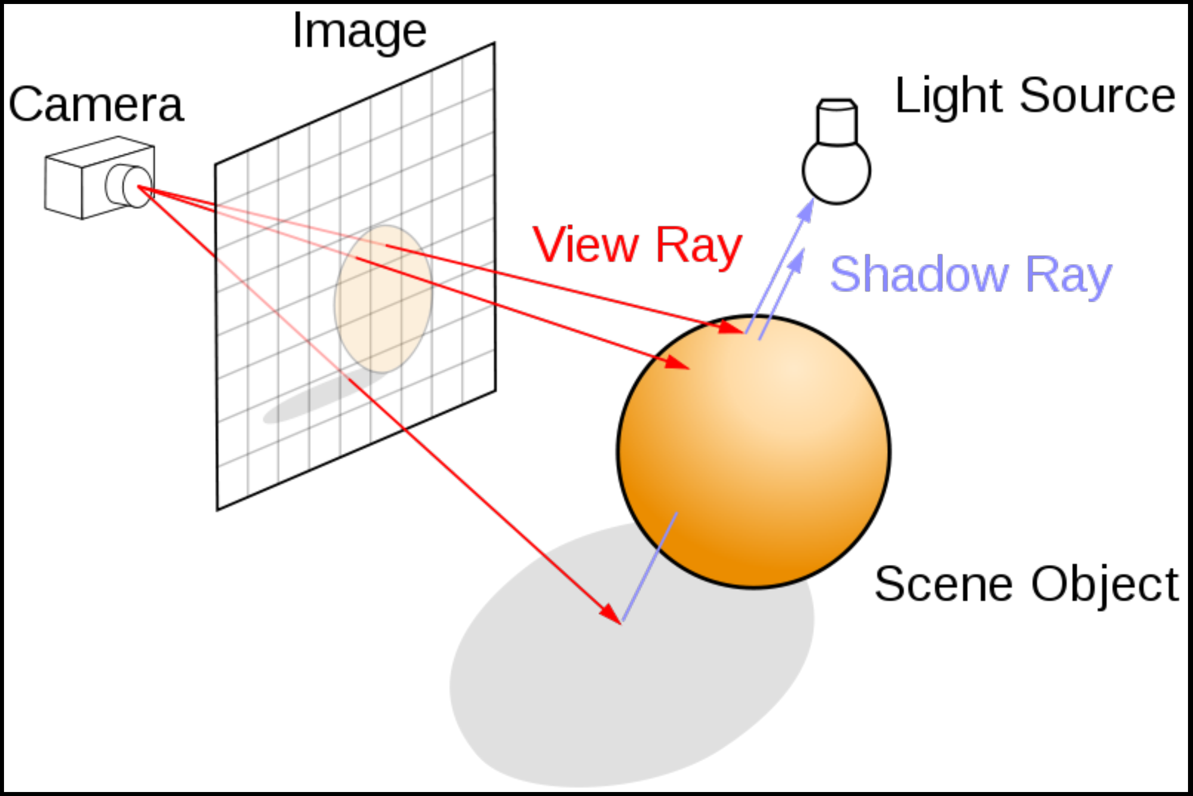
First idea: Forward Ray Tracing

- 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
  - Really, really not practical.



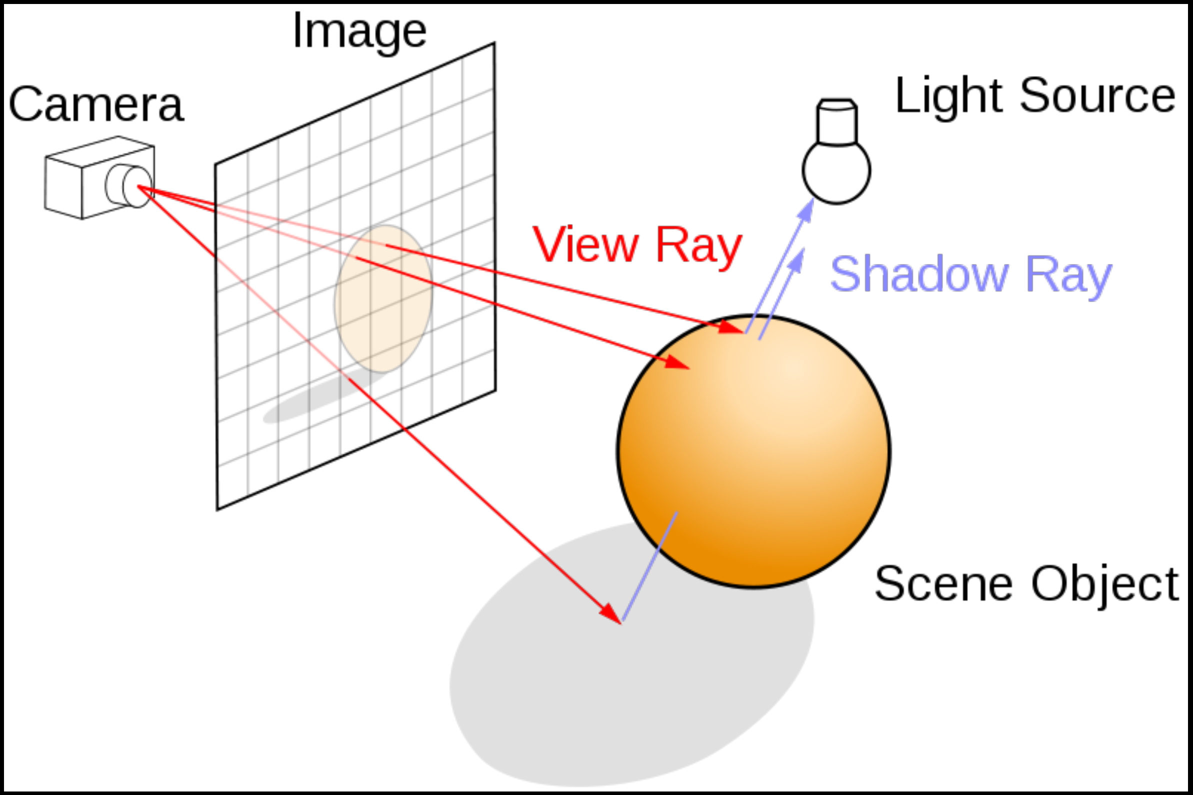
Backward Ray Tracing

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



Backward Ray Tracing

- Shoot one ray from camera through each pixel in image plane
  - ...what's the physical problem here?



Backward Ray Tracing

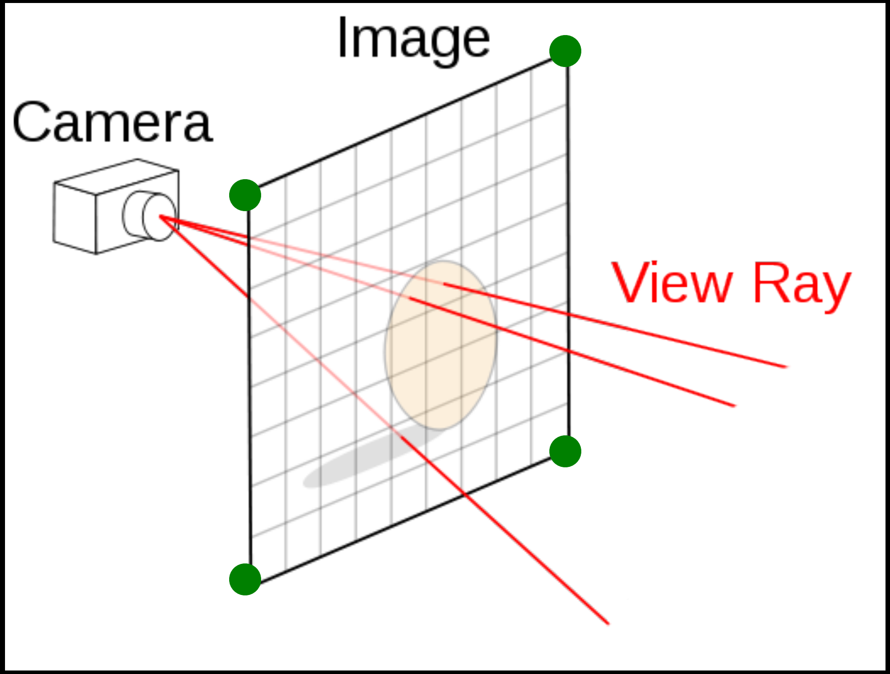
- Shoot one ray from camera through each pixel in image plane
  - ...what's the physical problem here?
  - ...if we actually simulated every single backward ray correctly, this would also not be computationally practical.
  - In practice, we simulate only up to a certain amount of bounces.

How does backward ray tracing work?

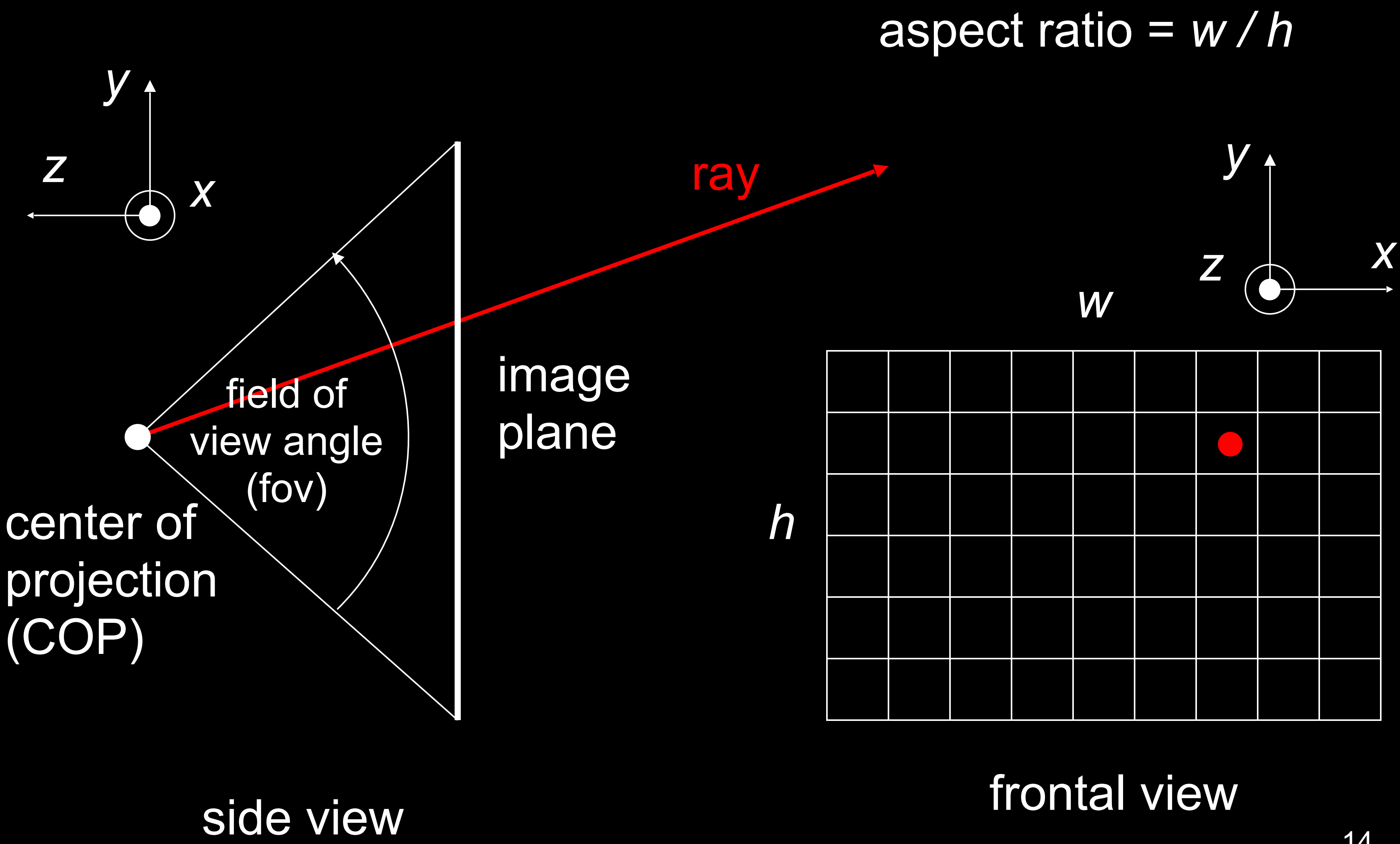
- You will implement a basic backward ray tracing renderer in your homework.
- This is an algorithm that requires almost no libraries, hardware, etc...
  - Unlike OpenGL
  - You only need to be able to write to an image file as output.

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



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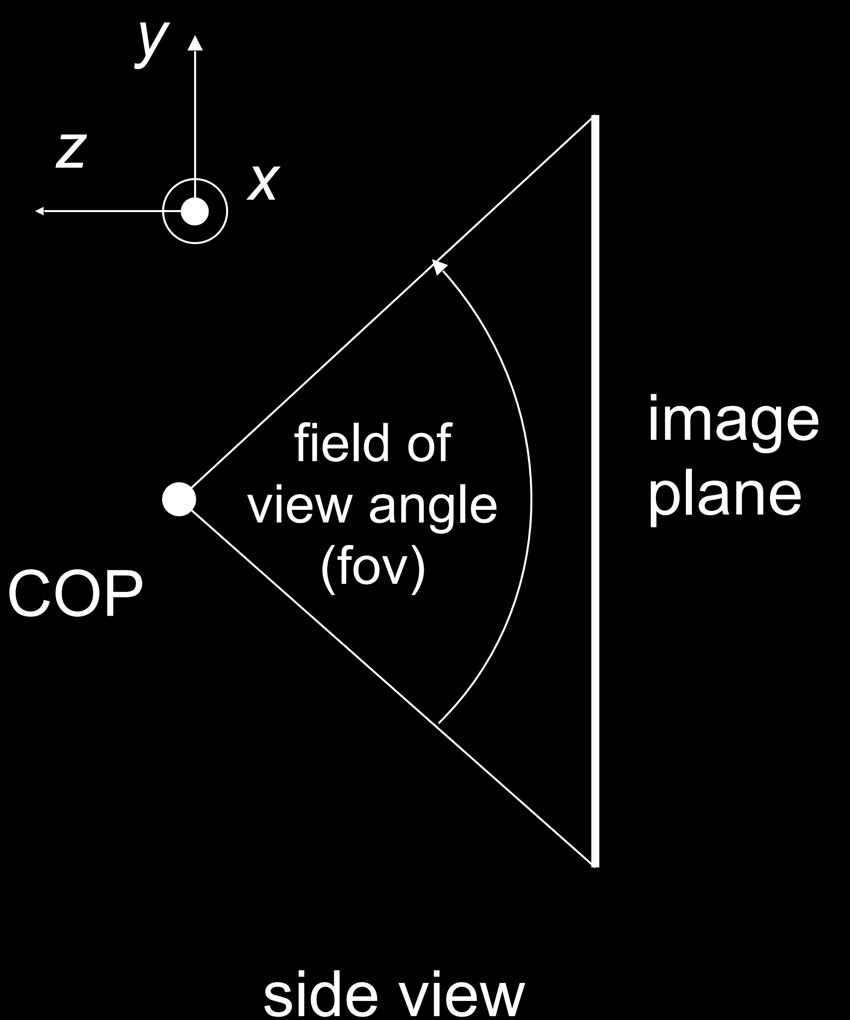
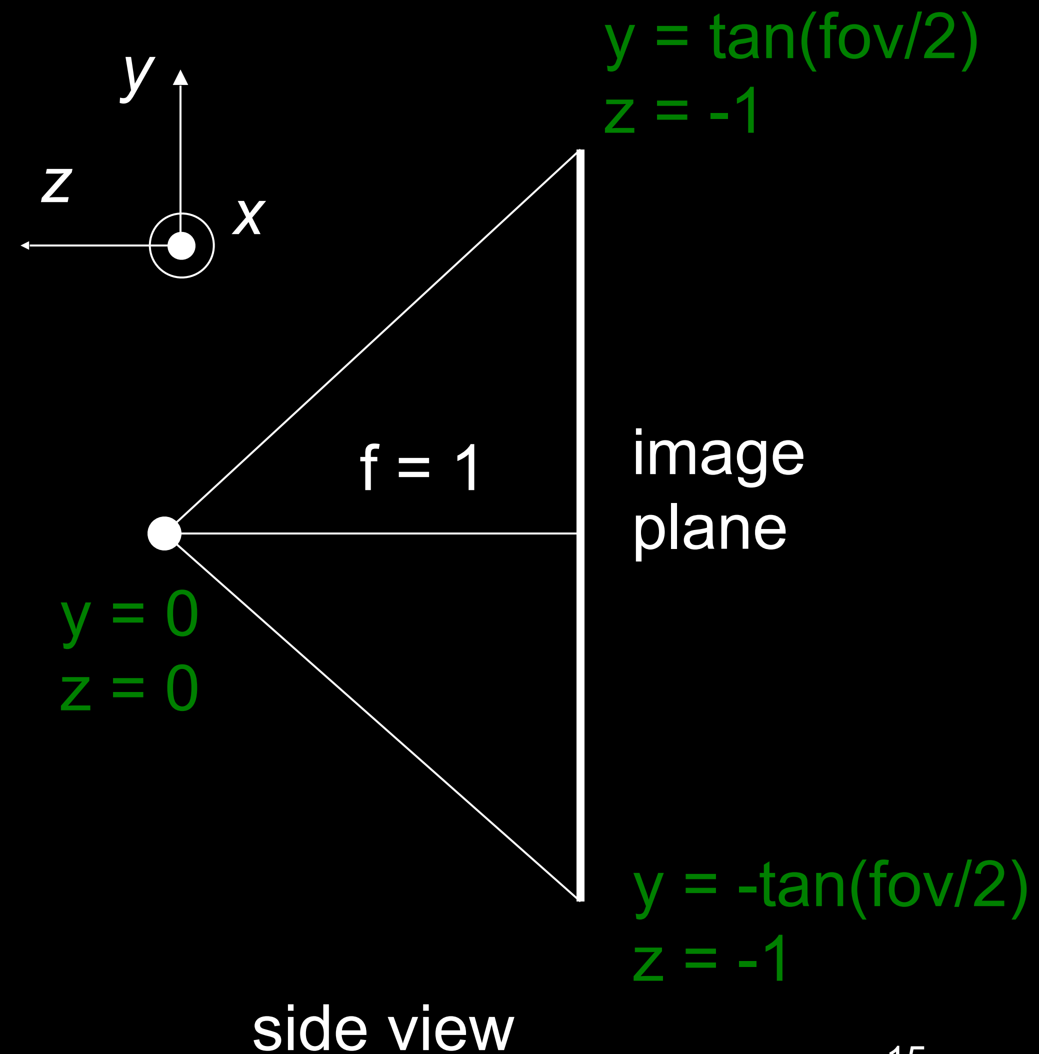
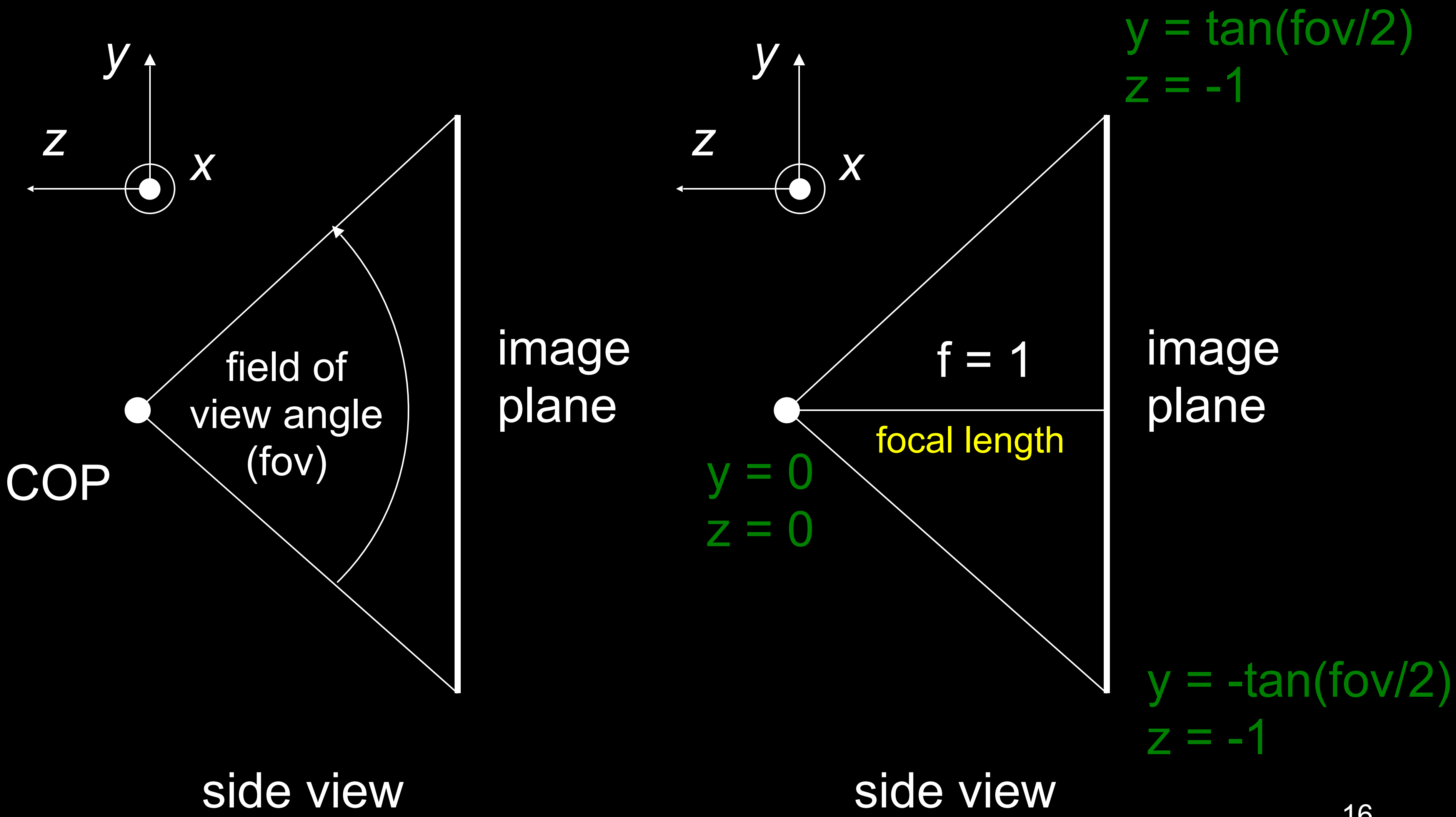
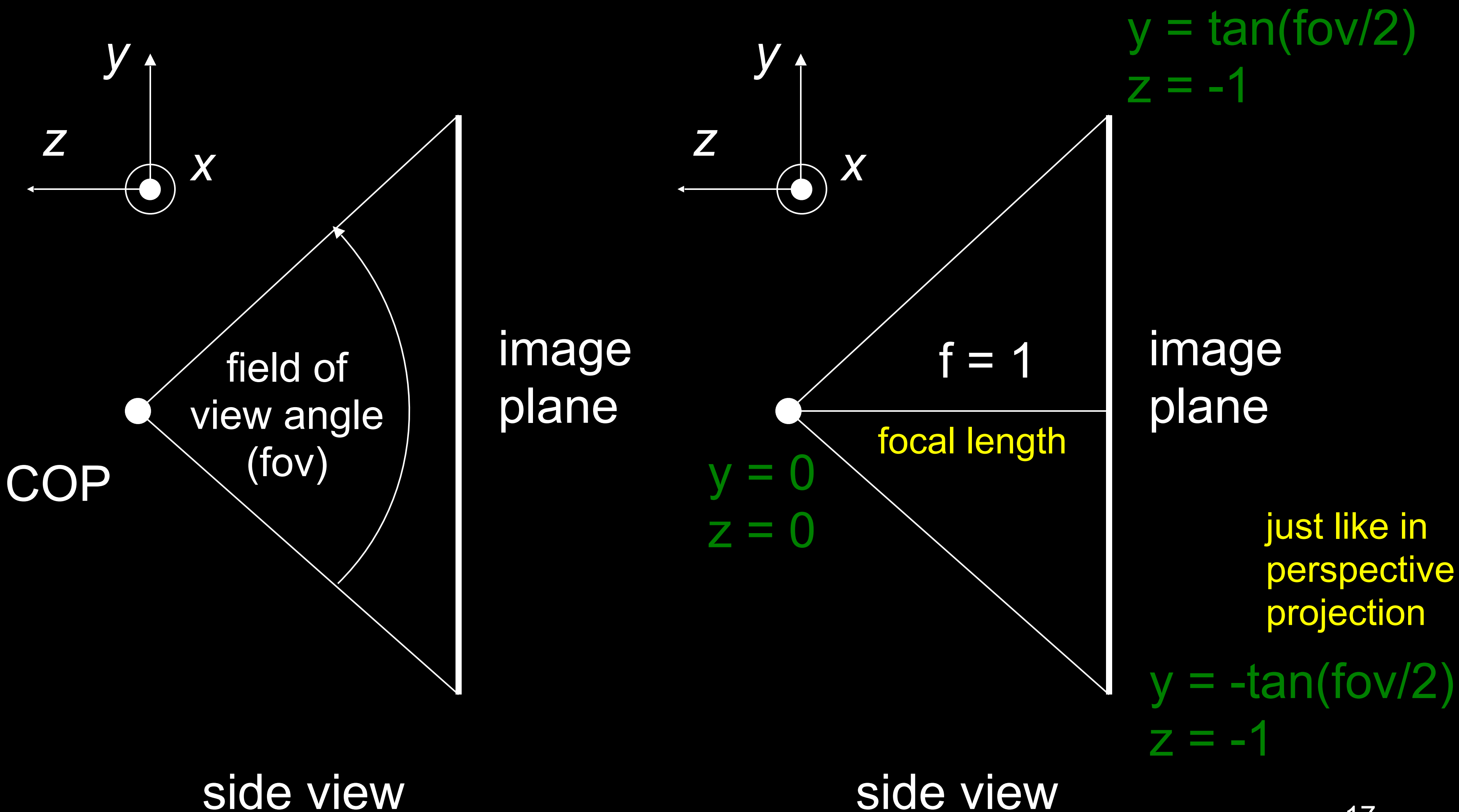




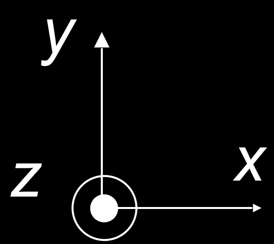
Generating Rays



Generating Rays



Generating Rays



a = aspect ratio = w / h

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

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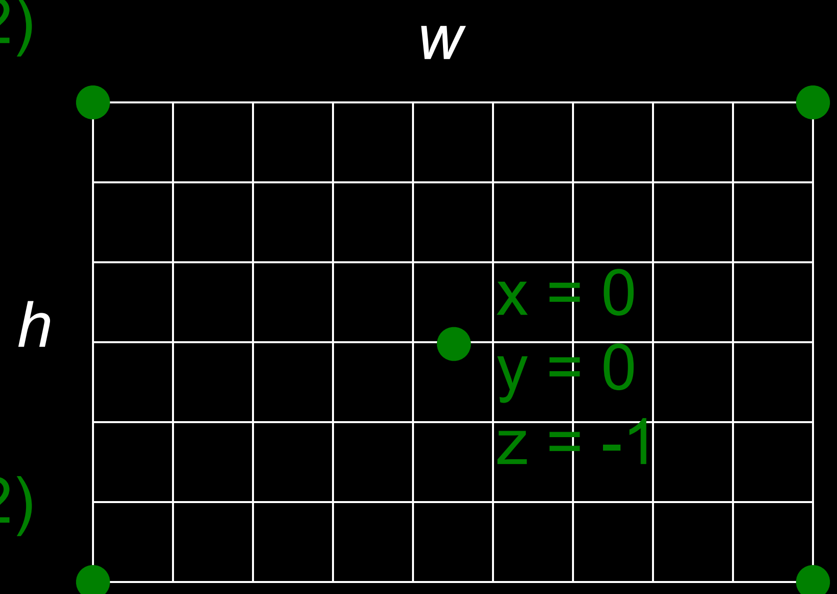

$x = -a \tan(fov/2)$
$y = -\tan(fov/2)$
$z = -1$

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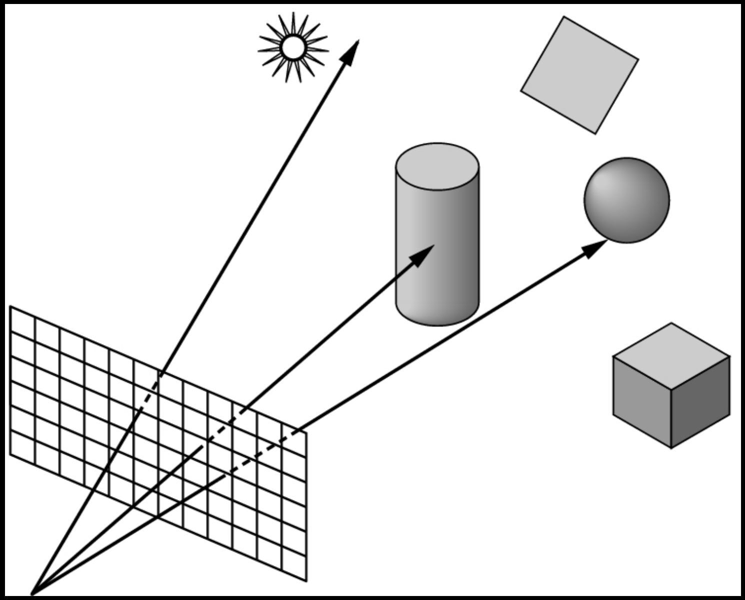
frontal view

Determining Pixel Color

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

Steps (3) and (4) require recursion.



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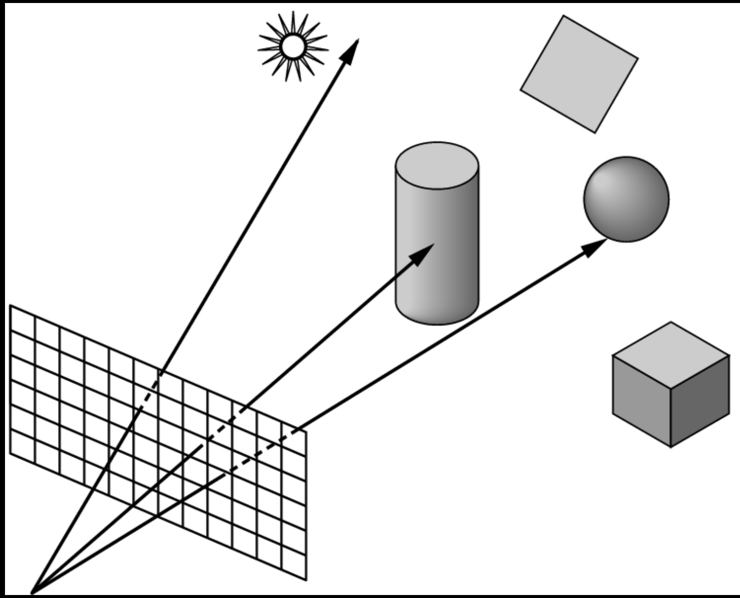


Later:

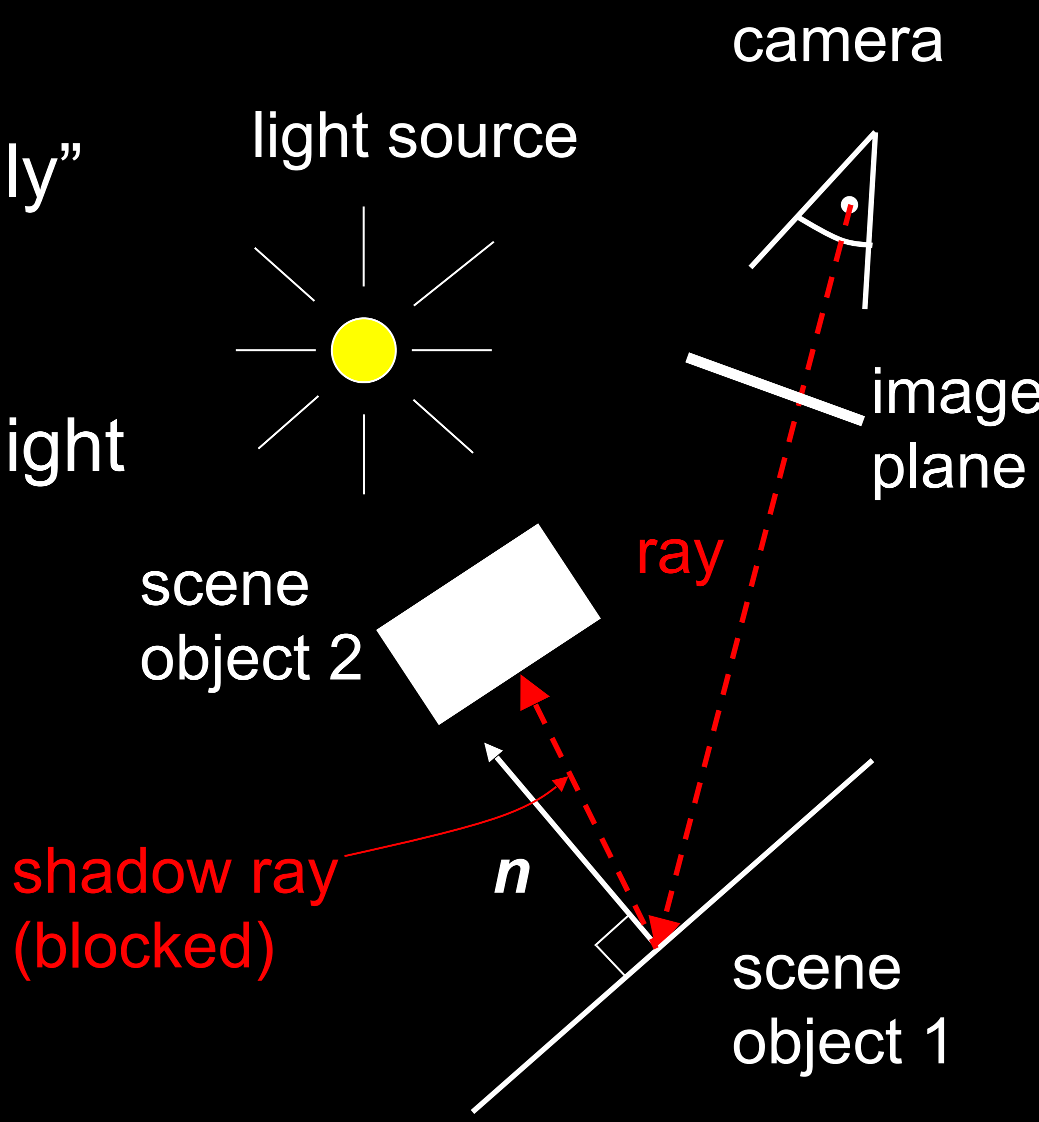
5. Metallic reflection
6. Scattering (subsurface)

Shadow Rays

- Previously, in local OpenGL illumination...
- At every point, we loop through all lights and add their contribution with the Blinn/Phong lighting model.
- But now that we raytrace, we can check whether each light *actually* hits the point we are drawing.

Shadow Rays

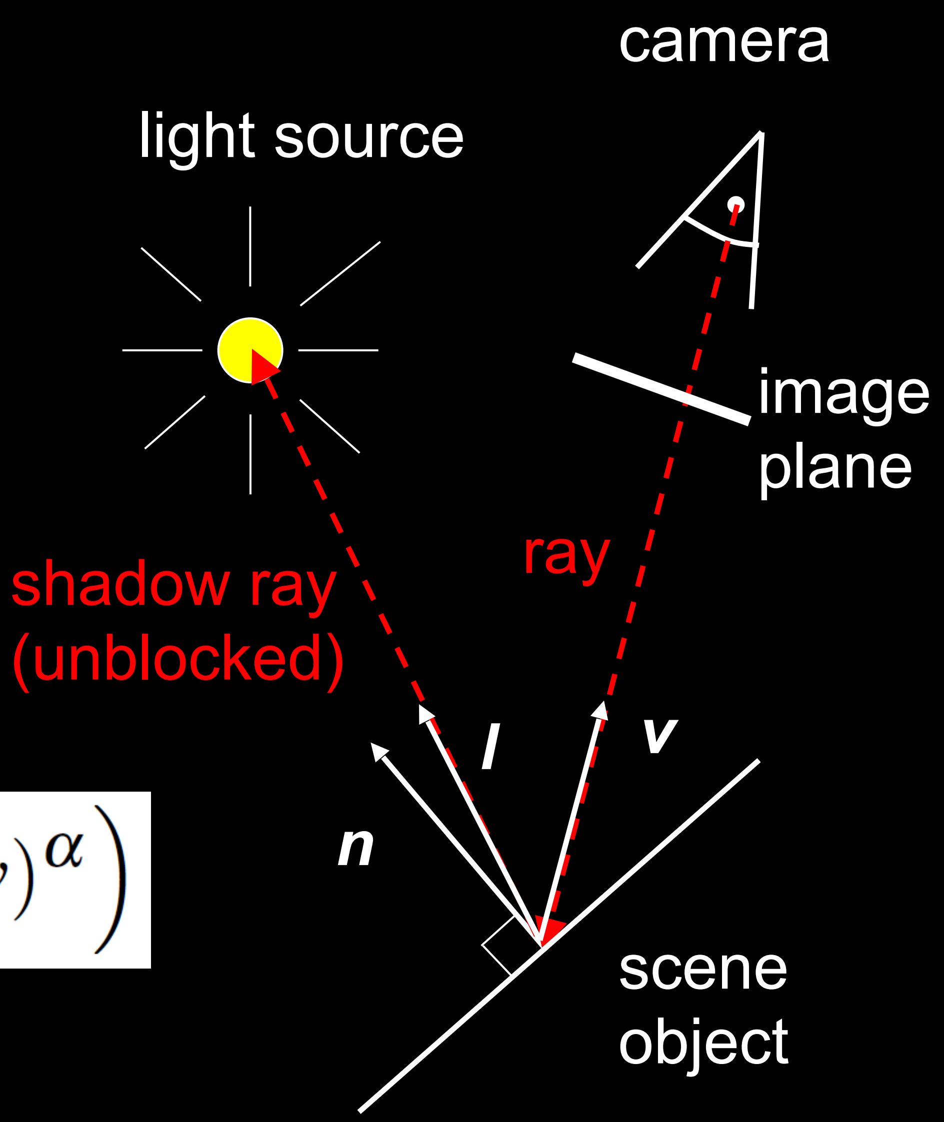
- Determine if light “really” hits surface point
- Cast shadow ray from surface point to each light
- If shadow ray hits opaque object, no contribution from that light
- This is essentially improved diffuse reflection



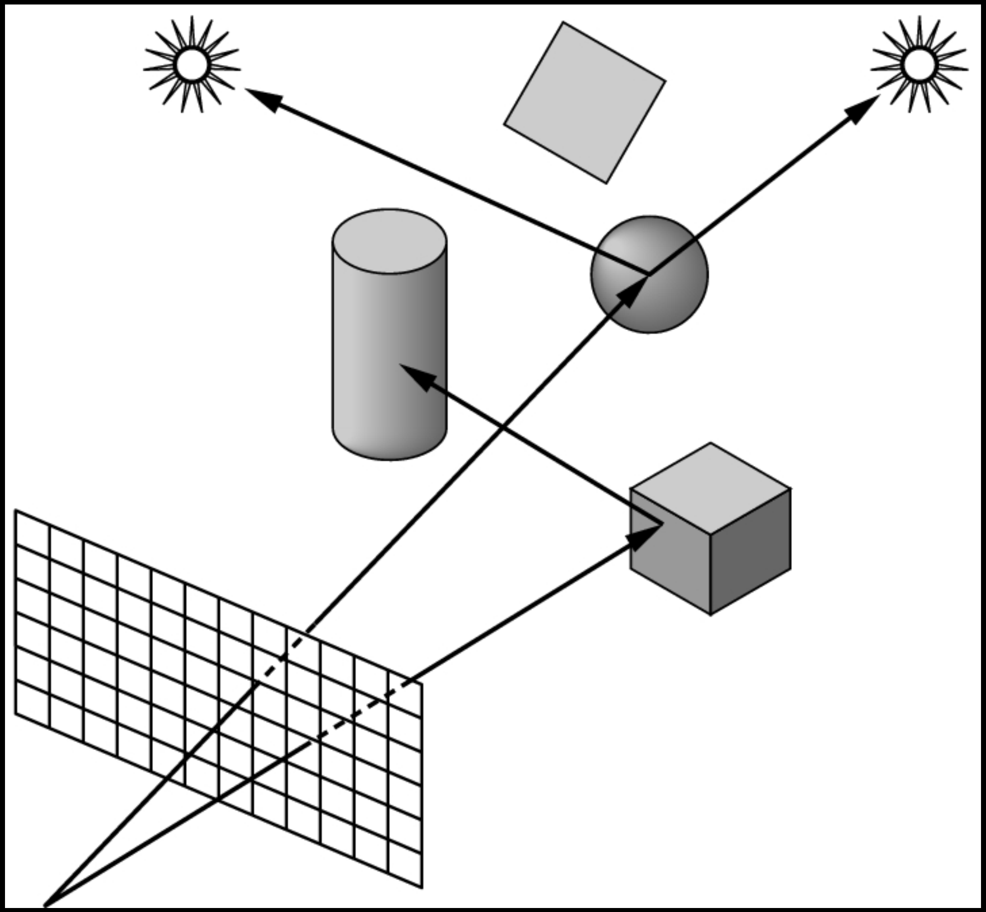
Phong Model

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

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

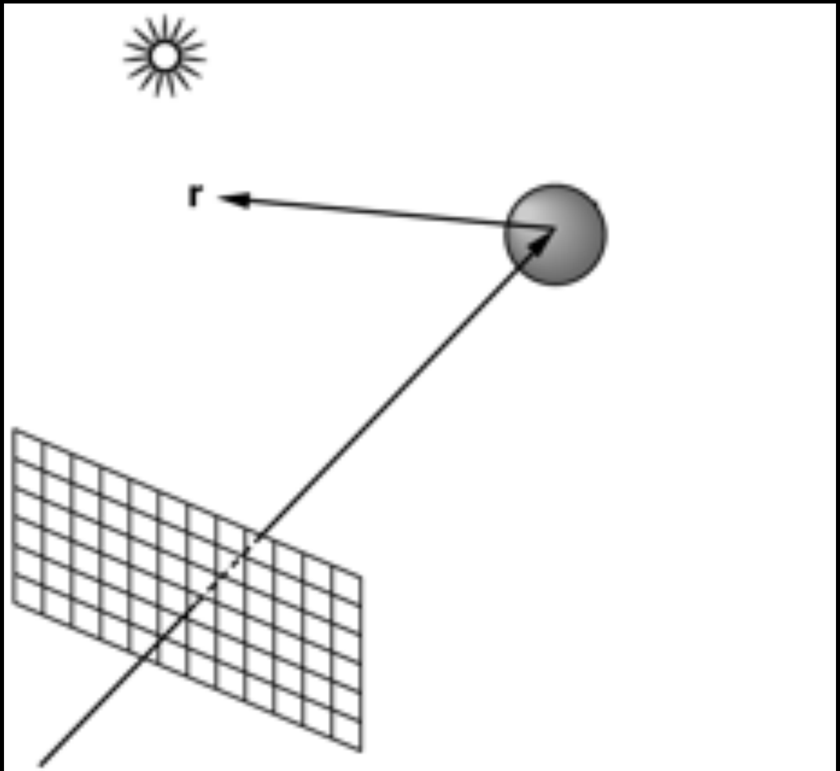


Where is Phong model applied
in this example?
Which shadow rays are blocked?



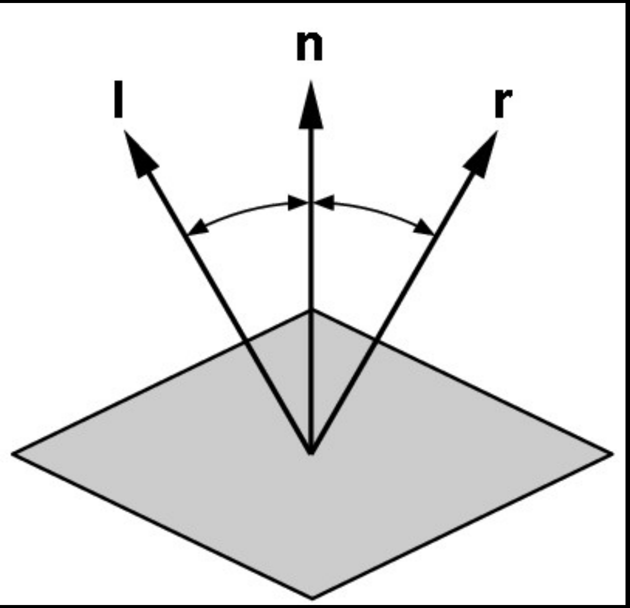
Reflection Rays

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

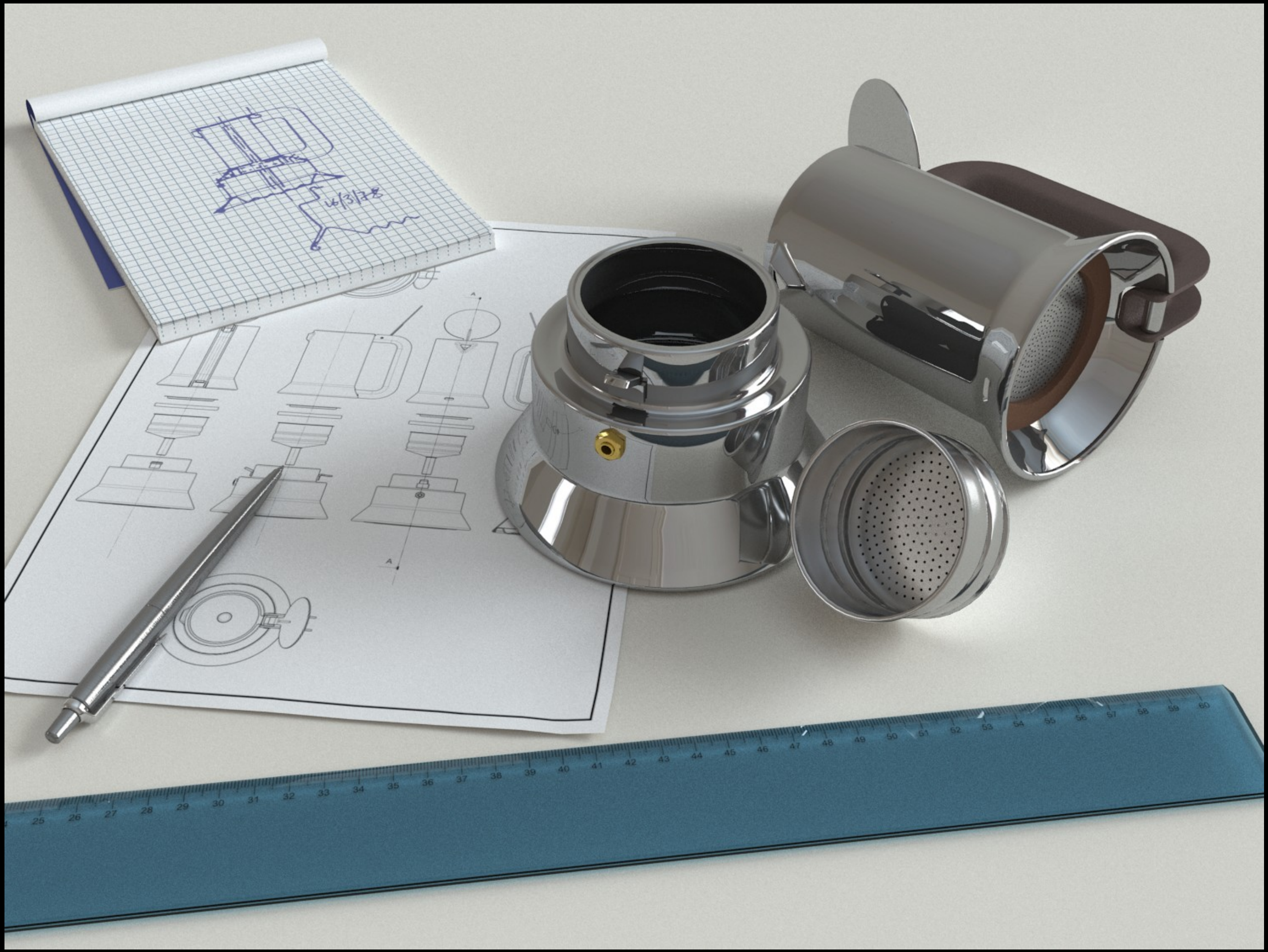


Angle of Reflection

- 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



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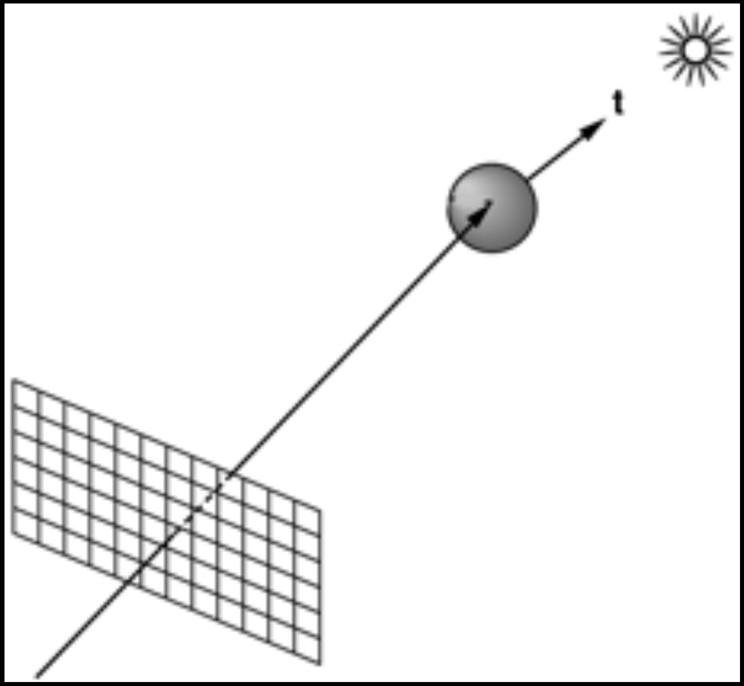
Transmission Rays

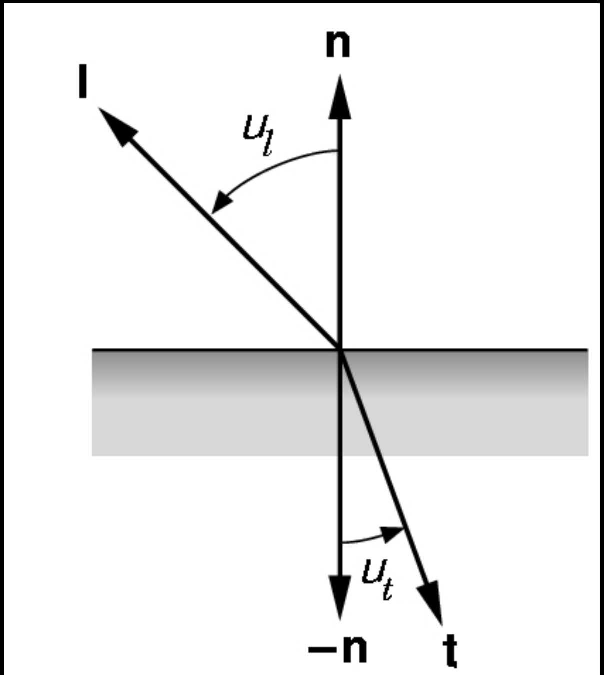
- Calculate light transmitted through surfaces
- Example: water, glass
- Compute transmission ray
- Call ray tracer recursively to determine color



Transmitted Light

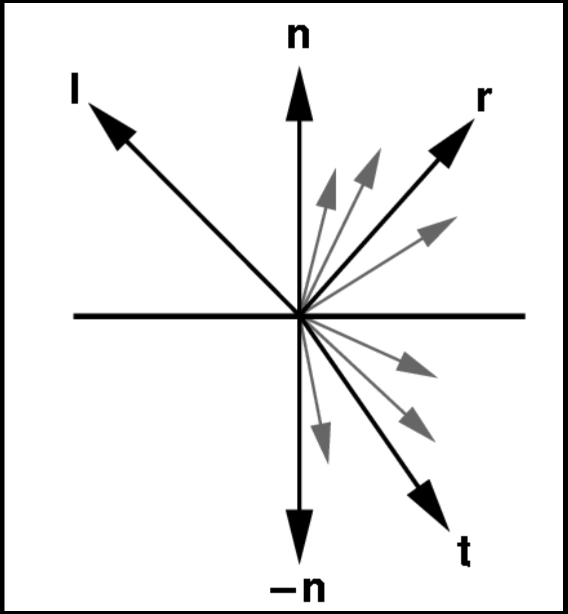
- Index of refraction is speed of light, relative to speed of light in vacuum
  - Vacuum: 1.0 (per definition)
  - Air: 1.000277 (approximate to 1.0)
  - Water: 1.33
  - Glass: 1.49
- Compute t using Snell's law
  - η_l = index for upper material
  - η_t = index for lower material

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



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

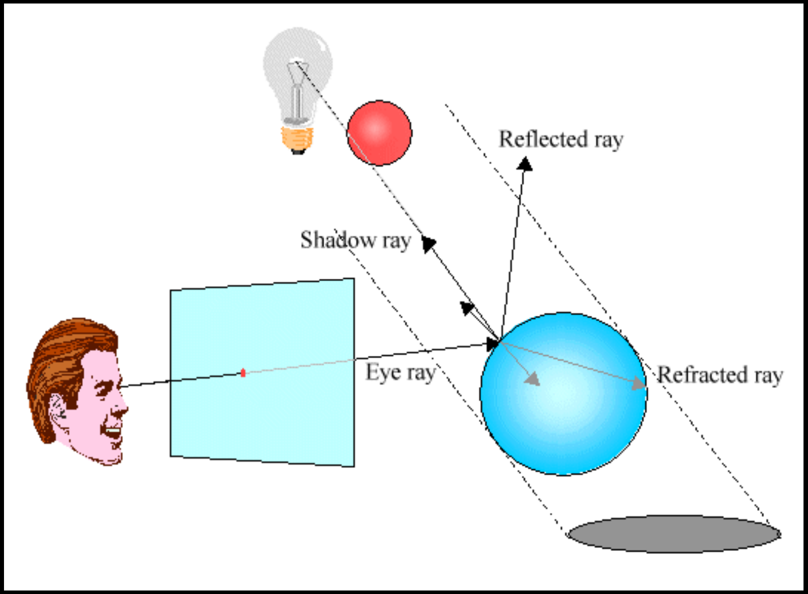
- Simplest case of ray tracing

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 (per pixel parallelism, not pipeline parallelism)
  - 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