

Ray Tracing

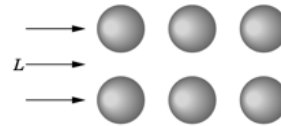
Ray Casting
Shadow Rays
Reflection and Transmission
[Ch. 13.2 - 13.3]

Jernej Barbic
University of Southern California

1

Local Illumination

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



2

Global Illumination

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



3

Object Space:

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

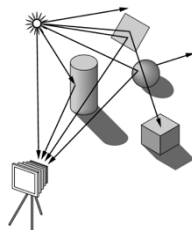
Image Space:

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

4

First idea: Forward Ray Tracing

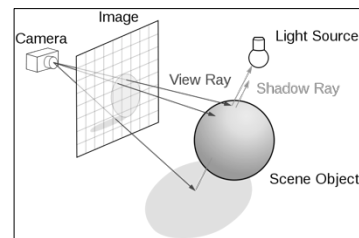
- Shoot (many) light rays from each light source
- Rays bounce off the objects
- Simulates paths of photons
- Problem: many rays will miss camera and not contribute to image!
- This algorithm is not practical



5

Backward Ray Tracing

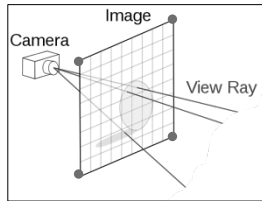
- Shoot one ray from camera through each pixel in image plane



6

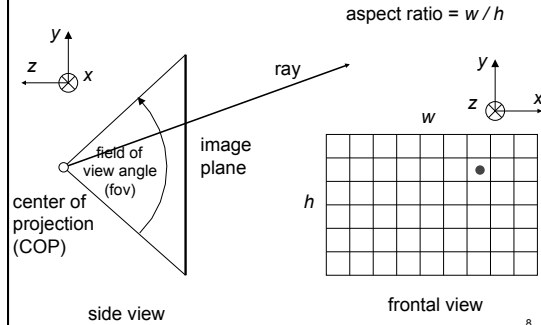
Generating Rays

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



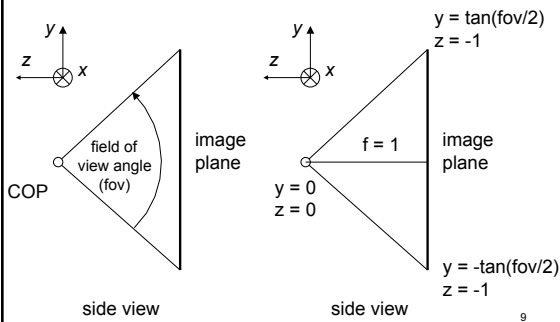
7

Generating Rays



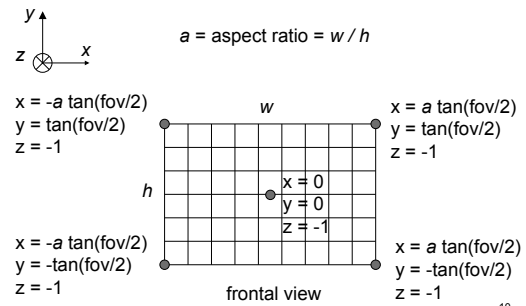
8

Generating Rays



9

Generating Rays

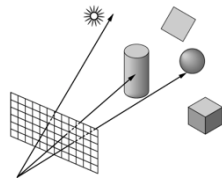


10

Determining Pixel Color

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

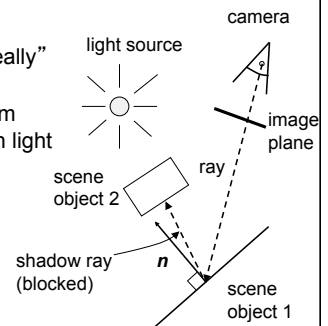
Steps (3) and (4) require recursion.



11

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

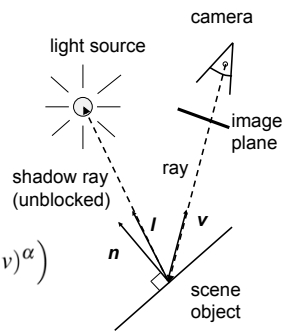


12

Phong Model

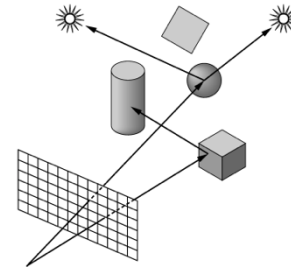
- If shadow ray can reach to the light, apply a standard Phong model

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



13

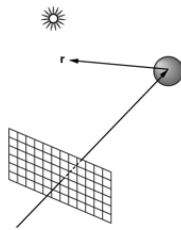
Where is Phong model applied in this example? Which shadow rays are blocked?



14

Reflection Rays

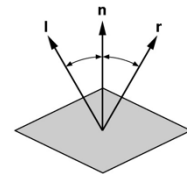
- For specular component of illumination
- Compute reflection ray (recall: backward!)
- Call ray tracer recursively to determine color



15

Angle of Reflection

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



16

Reflections Example

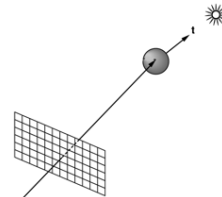


www.yafaray.org

17

Transmission Rays

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



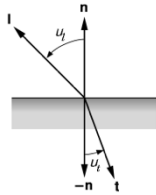
18

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
 - n_i = index for upper material
 - n_t = index for lower material

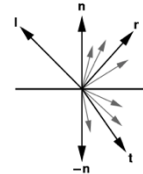
$$\frac{\sin(u_i)}{\sin(u_t)} = \frac{n_t}{n_i} = \eta$$



19

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)



20

Transmission + Translucency Example



www.povray.org

21

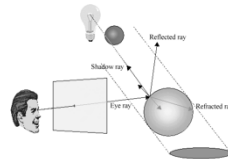
The Ray Casting Algorithm

- 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

22

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



23

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

24

Raytracing Example I



www.yafaray.org

25

Raytracing Example II



www.povray.org

26

Raytracing Example III



www.yafaray.org

27

Raytracing Example IV



www.povray.org

28

Summary

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

- Next lecture: Geometric queries

29