Computer Graphics (Fall 2006)

COMS 4160, Lecture 21: Ray Tracing

http://www.cs.columbia.edu/~cs4160

Effects needed for Realism

- (Soft) Shadows
- Reflections (Mirrors and Glossy)
- Transparency (Water, Glass)
- Interreflections (Color Bleeding)
- Complex Illumination (Natural, Area Light)
- Realistic Materials (Velvet, Paints, Glass)
- And many more

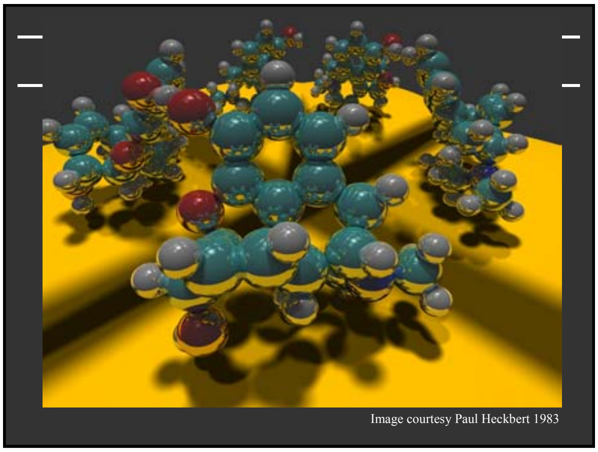

Image courtesy Paul Heckbert 1983

Ray Tracing

- Different Approach to Image Synthesis as compared to Hardware pipeline (OpenGL)
- Pixel by Pixel instead of Object by Object
- Easy to compute shadows/transparency/etc

Outline

- *History*
- Basic Ray Casting (instead of rasterization)
  - Comparison to hardware scan conversion
- Shadows / Reflections (core algorithm)
- Ray-Surface Intersection
- Optimizations
- Current Research

Section 10 in text

Ray Tracing: History

- Appel 68
- Whitted 80 [recursive ray tracing]
  - Landmark in computer graphics
- Lots of work on various geometric primitives
- Lots of work on accelerations
- Current Research
  - Real-Time raytracing (historically, slow technique)
  - Ray tracing architecture

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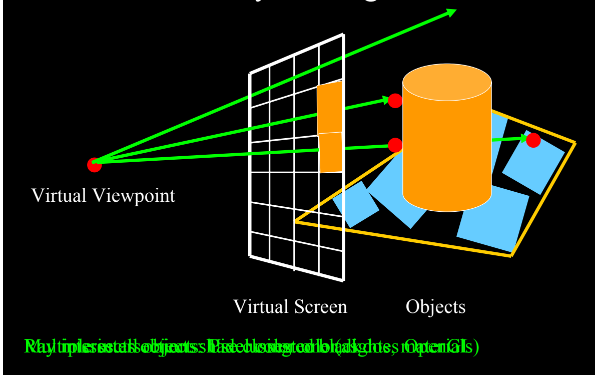
Ray Casting

Produce same images as with OpenGL

- Visibility per pixel instead of Z-buffer
- Find nearest object by shooting rays into scene
- Shade it as in standard OpenGL

Section 10.1-10.2 in text (we show visually, omitting math)

Ray Casting



Ray misses all objects: Pixel colored black
Ray intersects object: shade using color, lights, materials
Multiple intersections: Use closest one (as does OpenGL)

Comparison to hardware scan-line

- Per-pixel evaluation, per-pixel rays (not scan-convert each object). On face of it, costly
- But good for walkthroughs of extremely large models (amortize preprocessing, low complexity)
- More complex shading, lighting effects possible

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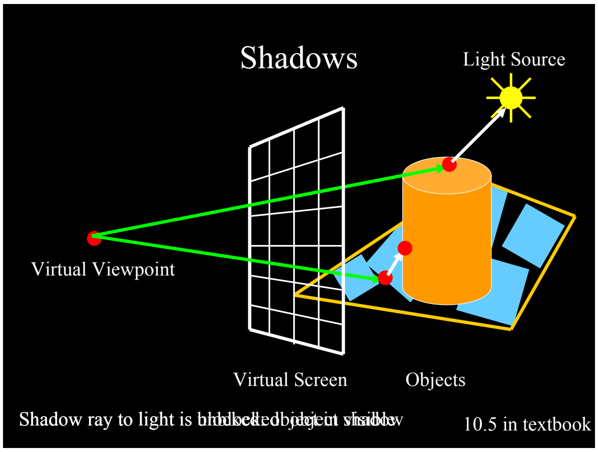
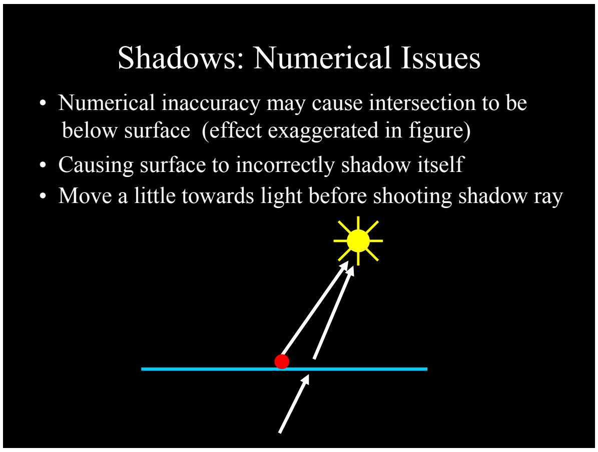
Shadows



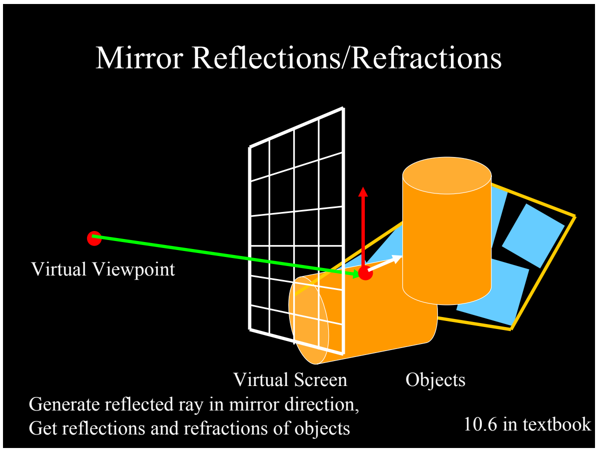
Shadow ray to light is unblocked: object visible
Shadow ray to light is blocked: object in shadow

10.5 in textbook



Shadows: Numerical Issues

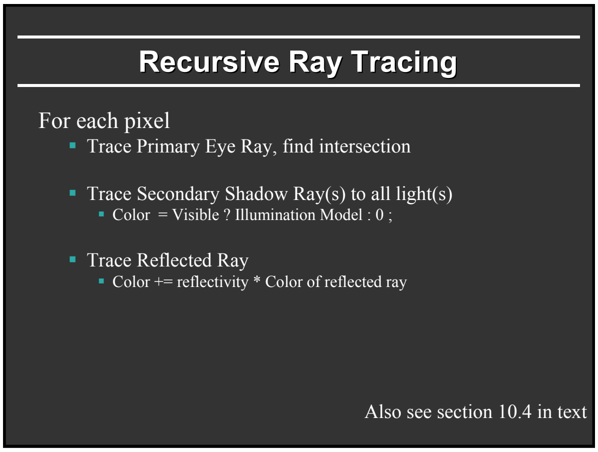
- Numerical inaccuracy may cause intersection to be below surface (effect exaggerated in figure)
- Causing surface to incorrectly shadow itself
- Move a little towards light before shooting shadow ray



Mirror Reflections/Refractions

Generate reflected ray in mirror direction,
Get reflections and refractions of objects

10.6 in textbook

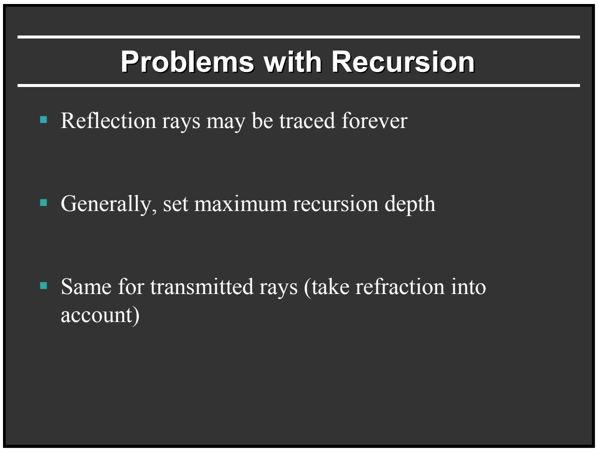


Recursive Ray Tracing

For each pixel

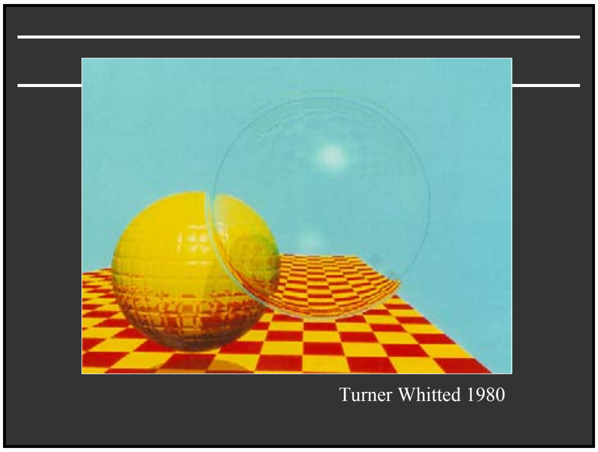
- Trace Primary Eye Ray, find intersection
- Trace Secondary Shadow Ray(s) to all light(s)
  - Color = Visible ? Illumination Model : 0 ;
- Trace Reflected Ray
  - Color += reflectivity * Color of reflected ray

Also see section 10.4 in text

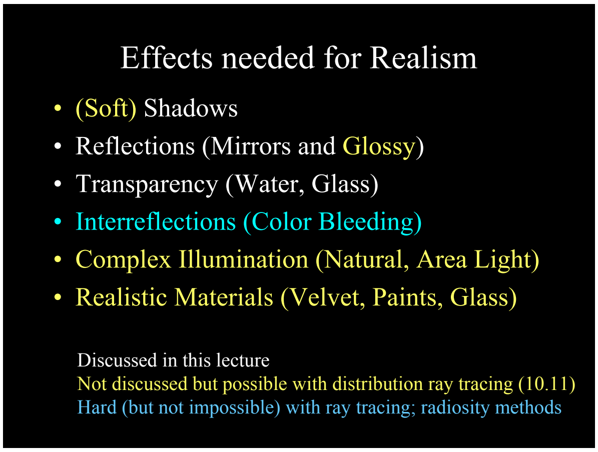


Problems with Recursion

- Reflection rays may be traced forever
- Generally, set maximum recursion depth
- Same for transmitted rays (take refraction into account)



Turner Whitted 1980



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Discussed in this lecture
Not discussed but possible with distribution ray tracing (10.11)
Hard (but not impossible) with ray tracing; radiosity methods

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Ray/Object Intersections

- Heart of Ray Tracer
  - One of the main initial research areas
  - Optimized routines for wide variety of primitives
- Various types of info
  - Shadow rays: Intersection/No Intersection
  - Primary rays: Point of intersection, material, normals
  - Texture coordinates
- Work out examples
  - Triangle, sphere, polygon, general implicit surface

Section 10.3

Ray-Tracing Transformed Objects

We have an optimized ray-sphere test

- But we want to ray trace an ellipsoid…

Solution: Ellipsoid transforms sphere

- Apply inverse transform to ray, use ray-sphere
- Allows for instancing (traffic jam of cars)

Mathematical details worked out in class

Section 10.8 of text

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Acceleration

Testing each object for each ray is slow

- Fewer Rays

  Adaptive sampling, depth control
- Generalized Rays

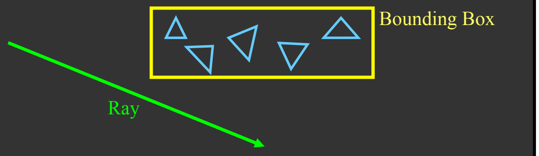
  Beam tracing, cone tracing, pencil tracing etc.
- Faster Intersections
  - Optimized Ray-Object Intersections
  - ***Fewer Intersections***

Section 10.9 goes into more detail, we just discuss some approaches at high level

Acceleration Structures

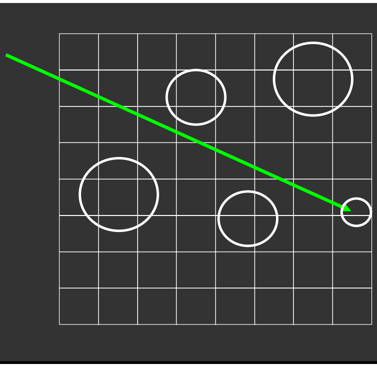
Bounding boxes (possibly hierarchical)

If no intersection bounding box, needn't check objects



Spatial Hierarchies (Oct-trees, kd trees, BSP trees)

Acceleration Structures: Grids



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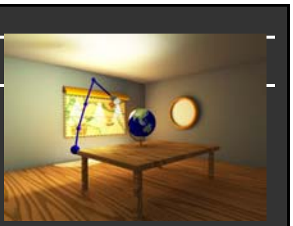
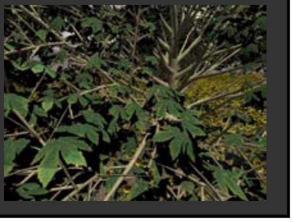
Interactive Raytracing

- Ray tracing historically slow
- Now viable alternative for complex scenes
  - Key is sublinear complexity with acceleration; need not process all triangles in scene
- Allows many effects hard in hardware
- OpenRT project real-time ray tracing (http://www.openrt.de)





Raytracing on Graphics Hardware

- Modern Programmable Hardware general streaming architecture
- Can map various elements of ray tracing
- Kernels like eye rays, intersect etc.
- In vertex or fragment programs
- Convergence between hardware, ray tracing

[Purcell et al. 2002, 2003]

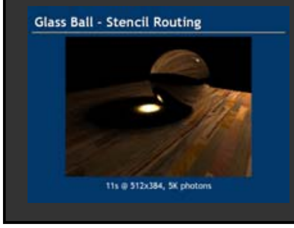
http://graphics.stanford.edu/papers/photongfx

Ring - Stencil Routing

8s @ 512x384, 16K photons

Cornell Box - Bitonic Sort

64s @ 512x512, 65K photons



Glass Ball - Stencil Routing

11s @ 512x384, 5K photons

Cornell Box - Increased Search Radius