

Computer Graphics (Fall 2008)

COMS 4160, Lecture 15: 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

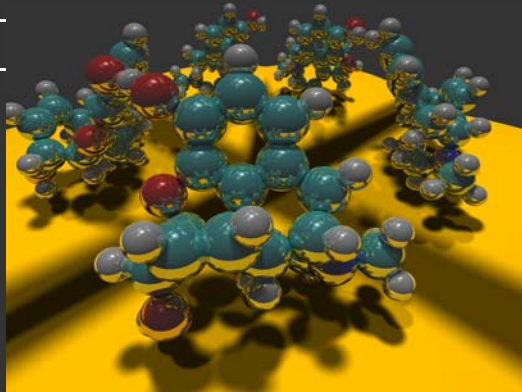


Image courtesy Paul Heckbert 1983

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

Outline

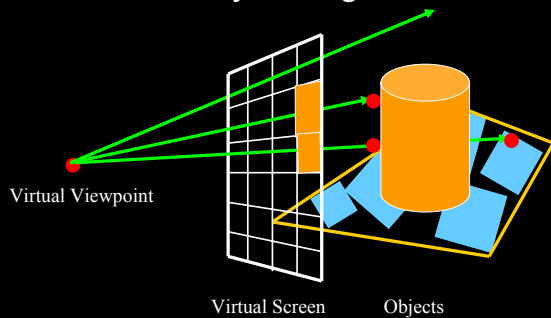
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Ray Casting

- 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 traces start at objects, find the nearest object, light it (OpenGLs)

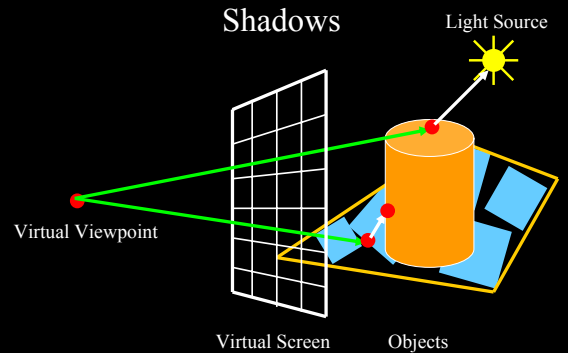
Comparison to hardware scan-line

- 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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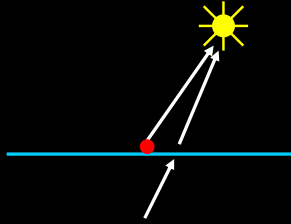
Shadows



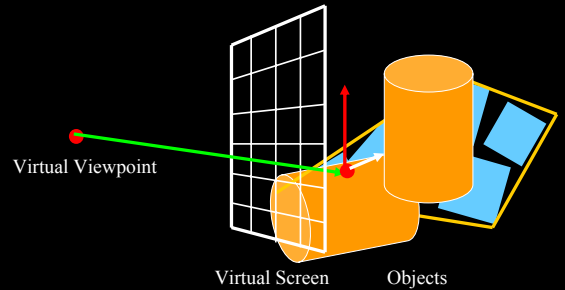
Shadow ray to light is behind the object's shadow 10.5 in textbook

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

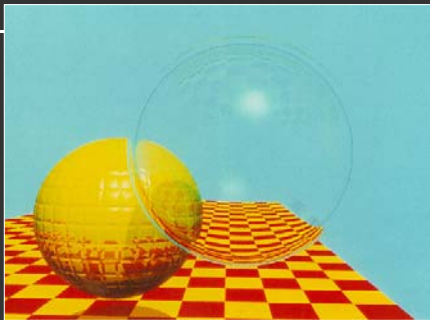
For each pixel

- 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

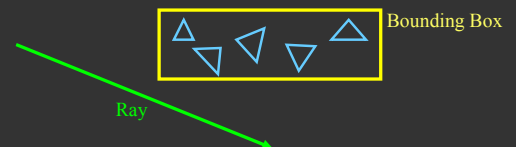
- Fewer Rays
 - Adaptive sampling, depth control
- Generalized Rays
 - Beam tracing, cone tracing, pencil tracing etc.
- Faster Intersections
 - Optimized Ray-Object Intersections
 - *Fewer Intersections*

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

Acceleration Structures

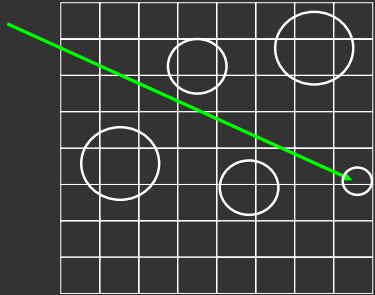
Bounding boxes (possibly hierarchical)

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>

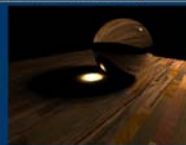
Ring - Stencil Routing



Cornell Box - Bitonic Sort



Glass Ball - Stencil Routing



Cornell Box - Increased Search Radius

