Computer Graphics (Fall 2004)

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

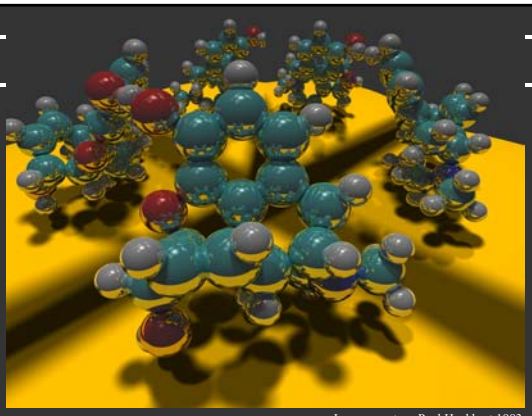

Image courtesy Paul Heckbert 1983

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

Demo applet: http://www.cs.berkeley.edu/~efros/java/tracer/tracer.html

Outline

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

Section 9 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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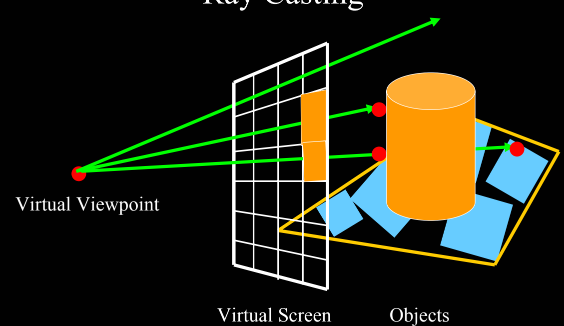
Ray Casting

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 9.1-9.2 in text (we show visually, omitting math)

Ray Casting



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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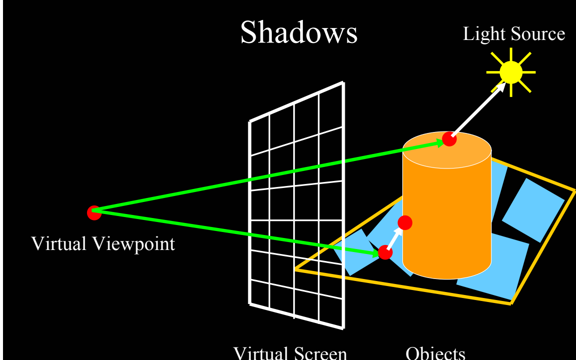
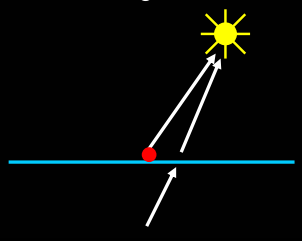
Shadows



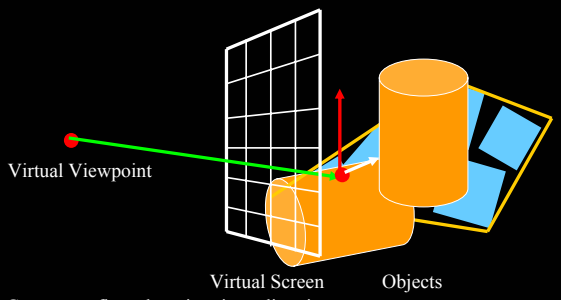
9.5 in textbook

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

9.6 in textbook

Recursive Ray Tracing

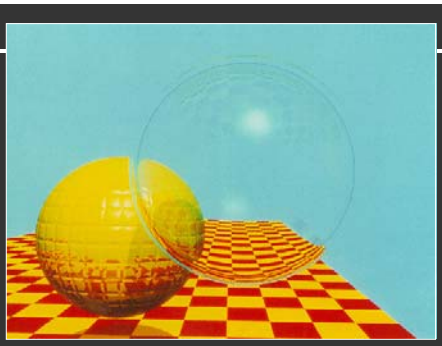
For each pixel

- 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 9.4 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 (9.11)
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 9.3

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 9.8 of text

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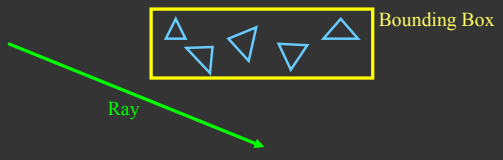
Acceleration

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

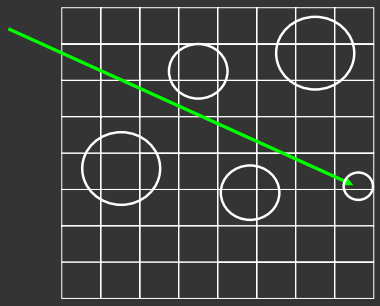
Acceleration Structures

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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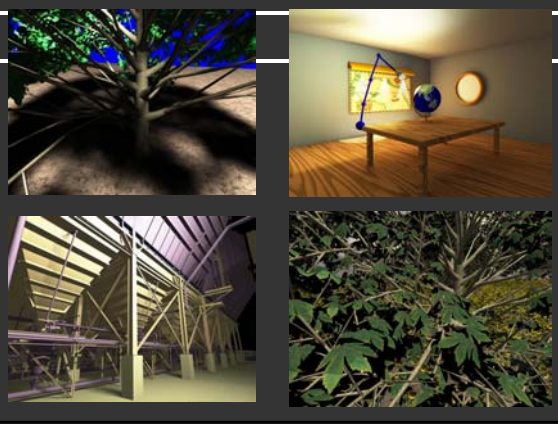
Interactive Raytracing

- 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