Johns Hopkins
Engineering for Professionals

605.767 Applied Computer Graphics

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Module 2A
Ray Tracing

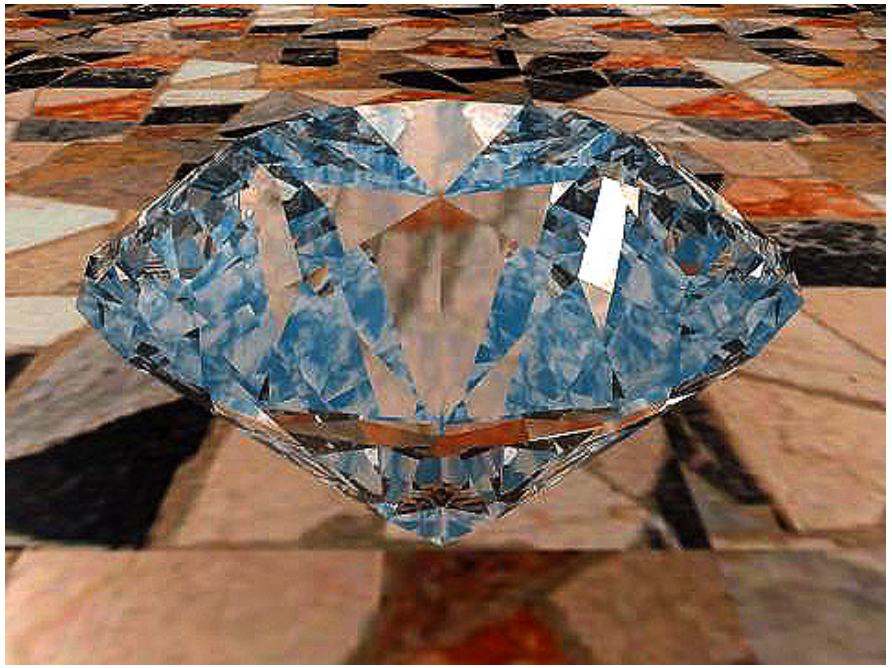
Ray Tracing

- Introduction
- Ray casting
  - Basic algorithms
- Phong-based local reflection / illumination model
  - Review
- Recursive ray tracing
  - Basic method
  - Reflections
  - Transparency
  - Shadows
- Limitations of basic ray tracer

Outline

- Discuss ray casting
  - Basic program structure
  - Finding intersections
- Review Phong illumination / reflection model
- Examine a recursive ray tracer
  - Basic program structure
  - Reflection
  - Refraction (transparency)
  - Shadows
  - Efficiency considerations
- Next week
  - Extending the reflection model
  - Adding textures
  - Anti-aliasing and other improvements

Ray Tracing



Images created with Okino's multi-threaded ray tracer in the NuGraf rendering System
http://www.okino.com/mainpic4.htm

Ray Tracing Introduction

- Ray tracing concept comes from study of geometric optics
  - Rene Descartes used ray tracing techniques to describe the shape of a rainbow
    - Experimental observations of a spherical glass filled with water
    - Treatise in 1637
- Ray tracing usage in computer graphics
  - Appel (1968) and Goldstein and Nagel (1971)
    - Ray casting for visible surface determination
  - Kay 1979 and Whitted 1980
    - First ray tracing model that traced beyond the first ray-object intersection
    - Incorporated shadows, reflection, and refraction
  - Extensive research in the 1980s
  - Produced realistic images for the time but was very costly
  - Early research dealt with efficiency
    - At the time many ray-traced images took hours or even days to produce

Ray Tracing

- Recursive ray-tracing produces a single framework that incorporates
  - Hidden surface removal
  - Shadow computation
  - Light reflection
  - Light refraction
  - Global specular interaction
    - Multiple reflections
- Advantages
  - Partial solution to the global illumination problem
  - Produces realistic images
  - Strength is ability to deal with specular interactions between objects
- Disadvantages
  - High processing overhead
  - Not well suited to global diffuse reflections

Basic Algorithm

- Ray tracing works in object space (world coordinates)
- Basic ray-tracing algorithm
  - Trace a ray from the eye through the center of each pixel in the image plane
  - If the ray intersects an object, perform **local** calculations to determine color due to direct illumination
    - Light from sources directly reflected from the surface
  - If the object is partially reflective or transparent the color will also include a contribution from reflected and transmitted rays
    - Trace rays **backwards** from the intersect point
    - May involve further tracing of rays at other intersections of objects
  - Ray trace (single ray) terminates when no objects are intersected or so many prior intersections have been found that the color contribution is likely to be negligible
    - Depth of the ray trace

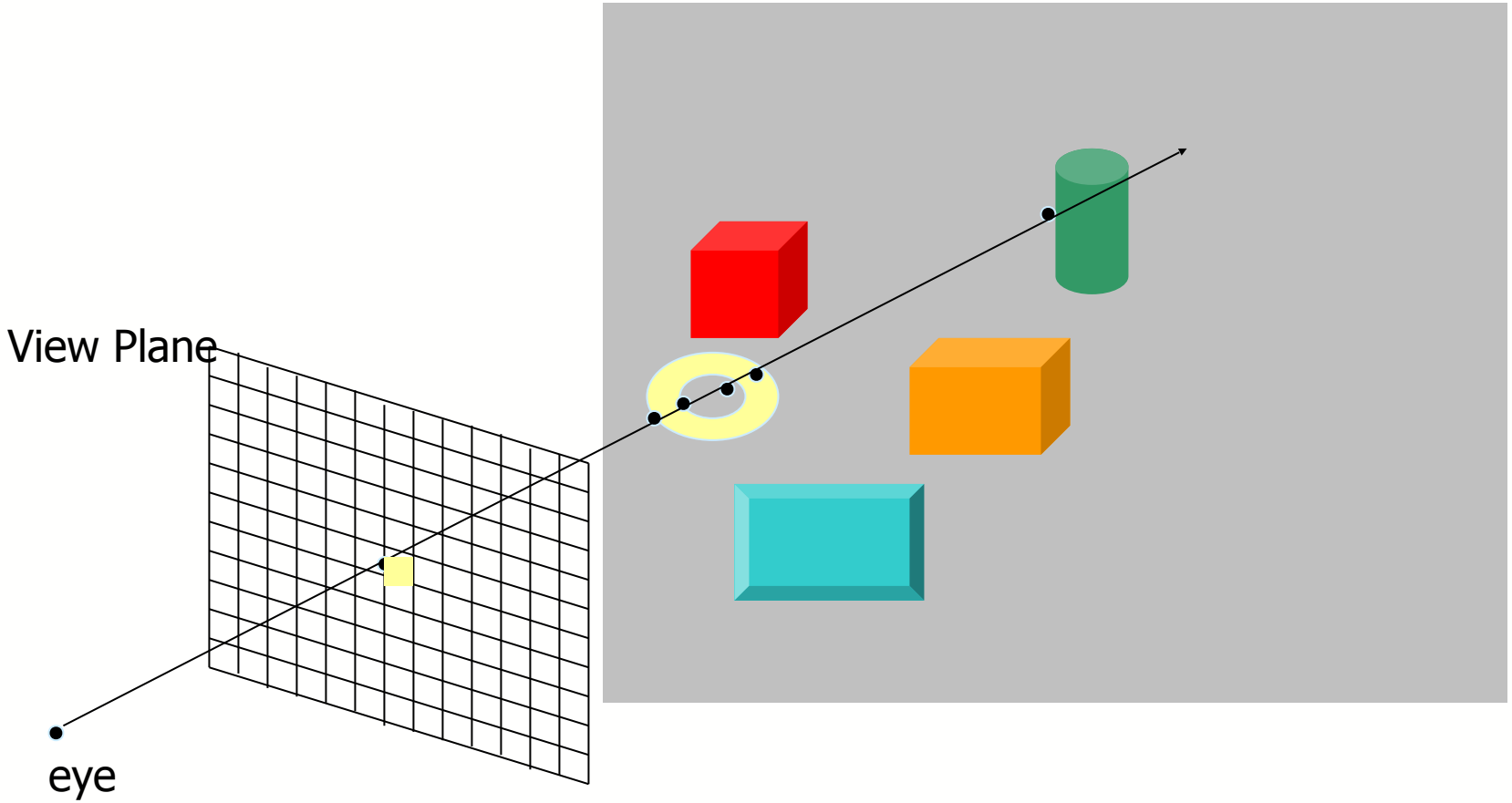
Simplifying Assumptions of Basic Algorithm

- Ray is considered to be infinitely thin
  - Reflection and refraction occur without any spreading
- Reflecting or refracting interface is considered perfectly smooth
  - Gives recursive ray-traced images a unique signature - they usually consist of shiny objects exhibiting multiple sharp reflections
    - Does not occur in reality (except in a room of mirrors!) with undiminished sharpness because rays are spread when reflected and refracted
- Rays are traced backwards
  - The reverse direction of light propagation
  - Only interested in a fixed number of rays
    - Those that pass through the view plane
  - Tracing from light sources would involve an infinite number of rays
    - Though there has been limited work to create a backwards ray tracer
      - Traces rays in the direction of light propagation
        - Backwards from traditional ray tracing

Ray Casting

- Ray casting is considered a visible surface determination method
  - Can also be used to determine surface visibility and color
  - Ray casting is often used as a volume rendering technique
    - Also as a technique for rendering Constructive Solid Geometry
- Method traces rays from the viewer's eye to objects in the scene
  - A center of projection (eye point) and an image/view plane is selected
  - Window on the image plane is divided into rectangular grid of pixels
    - At a desired image resolution
  - Project rays from the eye point through the pixel center into the scene
  - Pixel color is set to the color of the first intersection
- Ray tracing and ray casting are often used synonymously
  - Distinction
    - Ray tracing generally refers to a recursive ray tracing algorithm
    - Ray casting is not recursive

Ray Casting



Basic Structure of Ray Casting Application

```
Define objects
Define light sources
Set up the camera
for (int r = 0; r < nRows; r++)
{
   for (int c = 0; c < nCols; c++)
   {
        Build the ray through pixel rc
        Find intersections of this ray with objects in the scene
        Identify closest intersection in front of the eye
        Compute intersection point and normal at that intersection
        Find the color of light returning to the eye along the ray
           from the intersected object
        Set the pixel to that color
   }
}
```

Wolfenstein Ray Casting

- Ray casting was used in many early game engines, like Wolfenstein 3D, Doom, Duke Nukem
  - Uniform height walls
  - Ray was cast for each column
  - Vertical slice of wall texture was selected and scaled based on distance that ray intersects wall
- Enemy and other objects are transparent bitmaps

http://www.permadi.com/tutorial/raycast/rayc2.html