

## Ray Tracing

(Slides with help of Vivek Puri)

## Outline

- Introduction
- Concept
- Ray Object Intersections
  - Sphere
  - Plane
  - Polygon
  - Box
  - Quadrics

## Ray Tracing..?

- Method for producing visual images constructed in 3D computer graphics environments, with more photorealism than ray casting or scanline rendering techniques
- Works by tracing a path from an imaginary eye through each pixel in a virtual screen, accumulating the contribution of each light in the scene
- As each ray is cast from the eye, it is tested for intersection versus objects within the scene

## Ray Casting Vs Ray Tracing..?

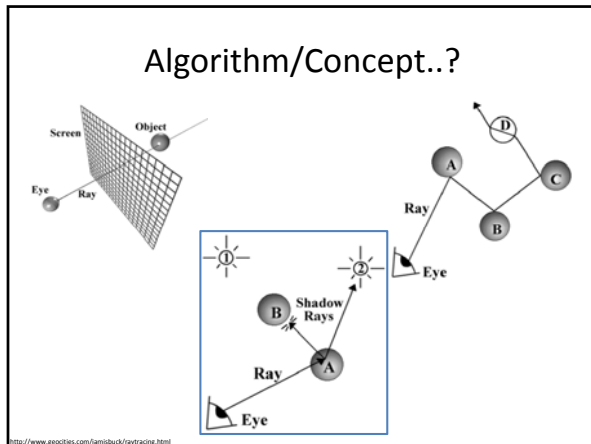
- Idea behind ray casting is to shoot rays from the eye, one per pixel, and find the closest object blocking the path of that ray
- Rays are not traced further from the first intersection

## Advantages

- Realistic simulation of lighting
- Effects such as reflections and shadows are a natural result
- Simple to implement
- Impressive results

## Disadvantages

- Performance
- Requires implementation of close approximation to the physical equations of light to be photorealistic



### The Big Picture..!!

- A primary ray is shot through each pixel and tested for intersection against all objects in the scene.
  - S : Shadow Rays
  - T : Refracted/Transmitted Rays
  - R : Reflected Rays
- Obvious efficiency bottleneck
  - Each secondary ray is tested against all the objects in the scene.

### Ray Object Intersections

- A ray is defined as
  - $R_0 = [x_0, y_0, z_0]$  - origin of ray
  - $R_d = [x_d, y_d, z_d]$  - direction of ray

Then, a set of points on the ray are defined as

$$R(t) = R_0 + R_d * t \quad \text{where } t > 0.0$$

If  $R_d$  is normalized, then  $t$  equals the distance of the ray from origin in World Coordinates,

### Ray Sphere Intersection

- Sphere is defined by its center ( $S_c = [x_c, y_c, z_c]$ ) and radius  $S_r$

Thus, the equation of Sphere

$$(x-x_c)^2 + (y-y_c)^2 + (z-z_c)^2 = S_r^2$$

Substitute equation of ray and solve quadratic eqn for  $t$ ,

- If discriminant  $< 0 \Rightarrow$  No intersection
- If discriminant  $\geq 0 \Rightarrow$  Intersection. Smaller  $t$  gives the nearest intersection point

### Ray Plane Intersection

- Plane is defined by  $Ax+By+Cz+D=0$

Substitute the equation for ray and solve for  $t$ ,

$$t = -(AX_0 + BY_0 + CZ_0 + D) / (AX_d + BY_d + CZ_d)$$

$$= -(P_n \cdot R_0 + D) / (P_n \cdot R_d)$$

where  $P_n$  is normal unit vector

If  $P_n \cdot R_d = 0 \Rightarrow$  Ray is parallel to the plane

If  $P_n \cdot R_d > 0 \Rightarrow$  Normal of plane points away from the ray

If  $t < 0 \Rightarrow$  Ray intersects plane behind origin

If  $t > 0 \Rightarrow$  Substitute  $t$  in equation for intersection point

### Ray Polygon Intersection

- Check whether the ray intersects the polygon plane
- Calculate the point of intersection
- Check whether the point is within the polygon. **How?**
  - Cross products
  - Shoot a ray from the point and count edges crossed, if odd then inside
  - .....

### Ray Box Intersection

- Transform box vertices ( $V_i$ ) to align with the coordinate axes
- Solve for intersection with  $x_{\min}$  and  $x_{\max}$  planes; similarly solve for Y and Z.
- Check for common interval or intersection
  - If,  $\max(t_{\min}) \leq \min(t_{\max})$
  - Then,  $t_0 = \max(t_{\min})$
  - $t_1 = \min(t_{\max})$

### Ray Quadric Intersection

- Class of quadrics (surfaces that can be defined by a quadratic equation) include cylinders, cones, ellipsoids, paraboloids, etc
- The general quadric surface equation is  
 $Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Iz + J = 0$
- Substitute the equation of ray, we get the form,  
 $A_q t^2 + B_q t + C_q = 0$
- Solve for  $t$