

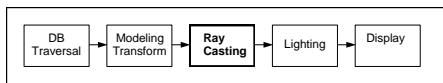
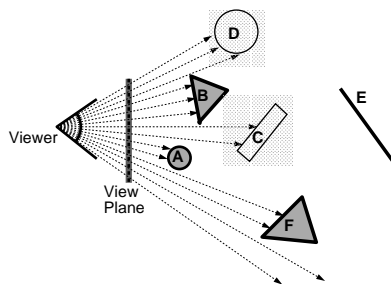
# Ray Tracing

Thomas A. Funkhouser

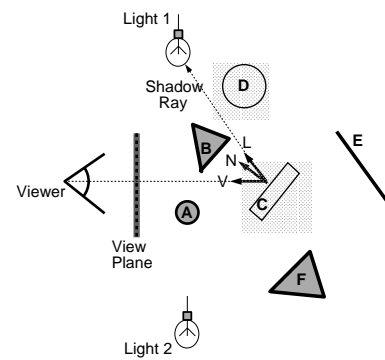
## Overview

- ◆ Ray casting revisited
- ◆ Recursive ray tracing
- ◆ Ray-surface intersections
- ◆ Acceleration techniques
- ◆ Sampling

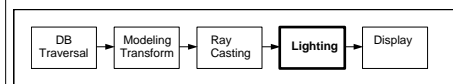
## Ray Casting



## Ray Casting



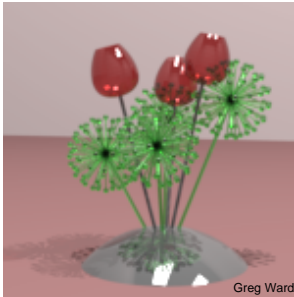
$$I = I_E + K_A I_A + \sum_i (K_D (N \cdot L_i) + K_S (V \cdot R_i)^n) S_i I_i$$



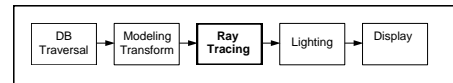
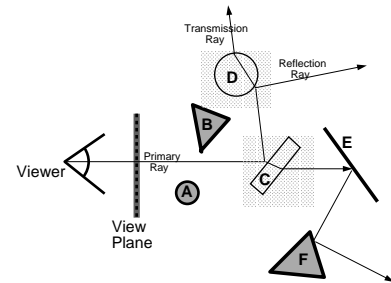
## Ray Tracing

### ♦ Goal

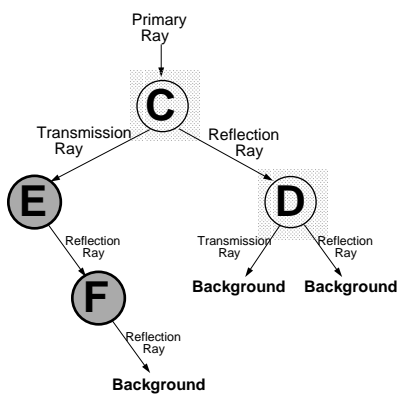
- Simulate indirect illumination



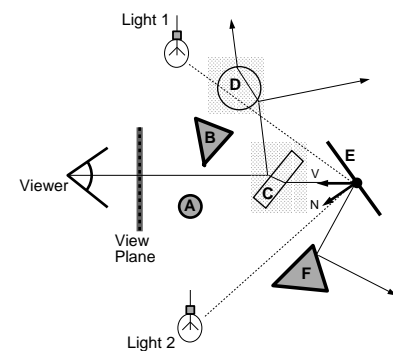
## Recursive Ray Tracing



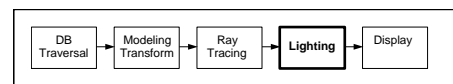
## Ray Tracing Tree



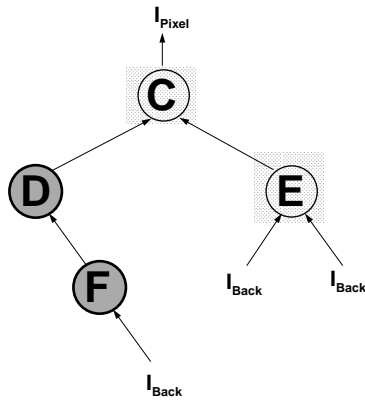
## Ray Tracing Lighting



$$I = I_E + K_A I_A + \sum_{L_i} (K_D (N \cdot L_i) + K_S (V \cdot R_i)^n) S_i I_{L_i} + K_S I_R + K_T I_T$$



## Ray Tracing Lighting



$$I = I_E + K_A I_A + \sum_{L_i} (K_D (N \cdot L_i) + K_S (V \cdot R_i)^n) S_i I_{L_i} + K_S I_R + K_T I_T$$

## Ray Intersections

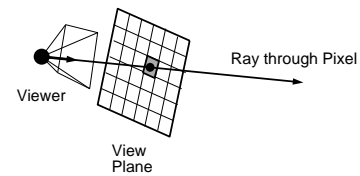
### ♦ Ray representation:

$$P = P_0 + tV$$

$$t \geq 0$$



### ♦ Ray through a pixel:



## Ray-Sphere Intersection

### ♦ Algebraic solution:

$$\text{Ray: } P = P_0 + tV$$

$$\text{Sphere: } |P - O|^2 - r^2 = 0$$

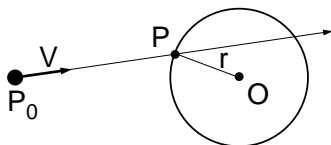
$$\text{substitute: } |P_0 + tV - O|^2 - r^2 = 0$$

$$\text{solve } At^2 + Bt + C = 0$$

$$\text{where } A = 1$$

$$B = 2 V \cdot (P_0 - O)$$

$$C = |P_0 - O|^2 - r^2$$



## Ray-Sphere Intersection

### ♦ Geometric solution:

$$L = O - P_0$$

$$t_{ca} = L \cdot V$$

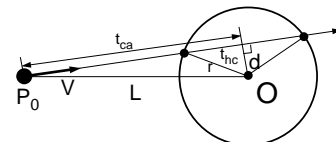
if  $(t_{ca} < 0)$  then no intersection

$$d = L \cdot L - t_{ca}^2$$

if  $(d > r^2)$  then no intersection

$$t_{hc} = \sqrt{r^2 - d^2}$$

$$t = t_{ca} - t_{hc} \text{ AND } t_{ca} + t_{hc}$$

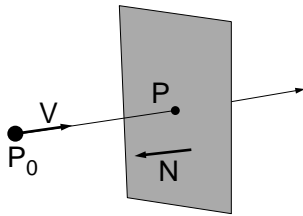


## Ray-Plane Intersection

Ray:  $P = P_0 + tV$   
Plane:  $P \cdot N + D = 0$

substitute:  $(P_0 + tV) \cdot N + D = 0$

solution:  $t = -(P_0 \cdot N + D) / (V \cdot N)$



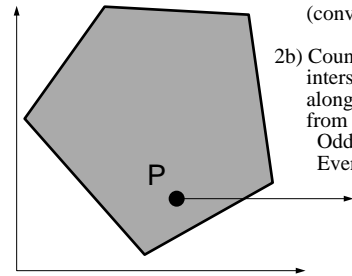
## Ray-Polygon Intersection

1)  $P = \text{ray-plane intersection}$

2) Check if polygon contains  $P$

2a) Check if  $P$  is on left-side of each edge (convex only)

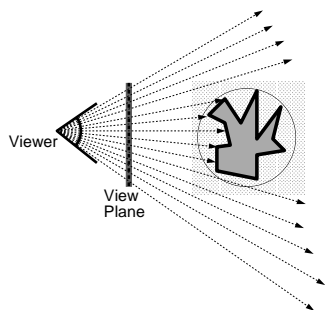
2b) Count edge intersections along any ray from point:  
Odd: inside  
Even: outside



## Ray Tracing Acceleration

### ◆ Bounding volumes

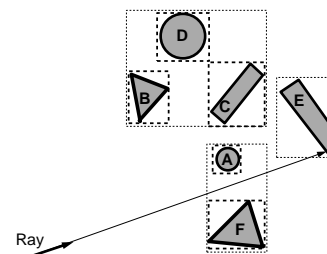
- Check simple bounding volume for ray-surface intersections before checking complex shapes



## Ray Tracing Acceleration

### ◆ Bounding volume hierarchies

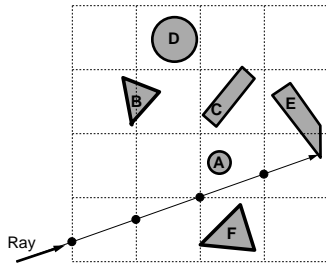
- Construct and check hierarchical bounding volumes



## Ray Tracing Acceleration

### ♦ Spatial data structures

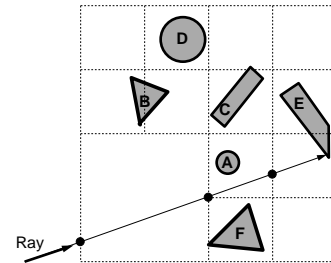
- Uniform Grids:



## Ray Tracing Acceleration

### ♦ Spatial data structures

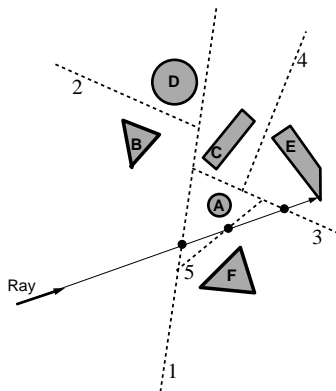
- Octrees:



## Ray Tracing Acceleration

### ♦ Spatial data structures

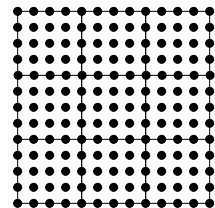
- BSP trees:



## Antialiasing

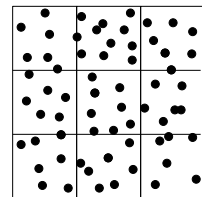
### ♦ Supersampling

- Multiple, evenly spaced samples per pixel



### ♦ Adaptive sampling

- Randomized, directed samples



## Summary

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- ◆ Ray casting
- ◆ Recursive ray tracing
- ◆ Ray trees
- ◆ Ray-surface intersections
- ◆ Spatial Subdivisions
- ◆ Antialiasing