Ray-Tracing

Figure 1: Reflection test: (left) with environment map. (right) with environment map and ray-traced interreflections.

[Pixar: Ray Tracing for the Movie 'Cars'
http://graphics.pixar.com/library/RayTracingCars/paper.pdf]

Ray-tracing Overview

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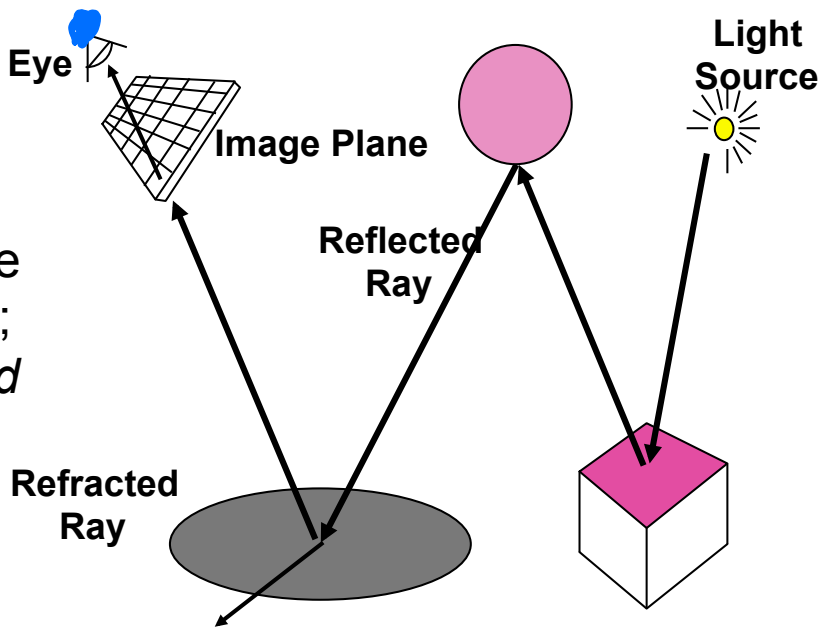
- handles multiple inter-reflections of light
- partly physics-based: geometric optics
- well suited to transparent and reflective objects

Trace light path from the eye backwards(!) into the scene; *recursively apply to reflected and refracted rays.*



Ray-Tracing

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```
raytrace( ray )  {
    find closest intersection: P
    colour_local = (0,0,0);
    if visible(P,L)                          // cast shadow ray
          colour_local = Phong(N,L,rayDir)
    colour_reflect = raytrace( reflected_ray )    // if reflective
    colour_refract = raytrace( refracted_ray )    // if refractive
    colour = k1*colour_local +
             k2*colour_reflect +
             k3*colour_refract
    return( colour )
}
```

- "raycasting" : only cast first ray from eye

R = reflected
T = transmitted ("refracted")

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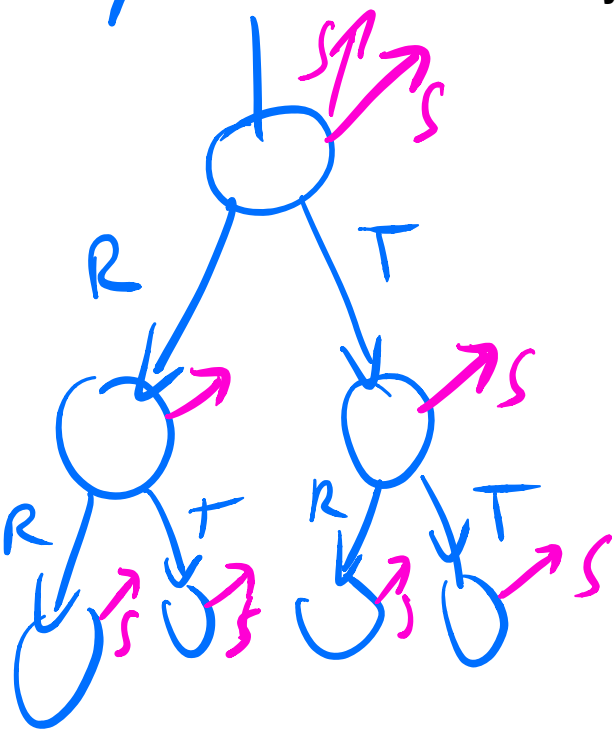
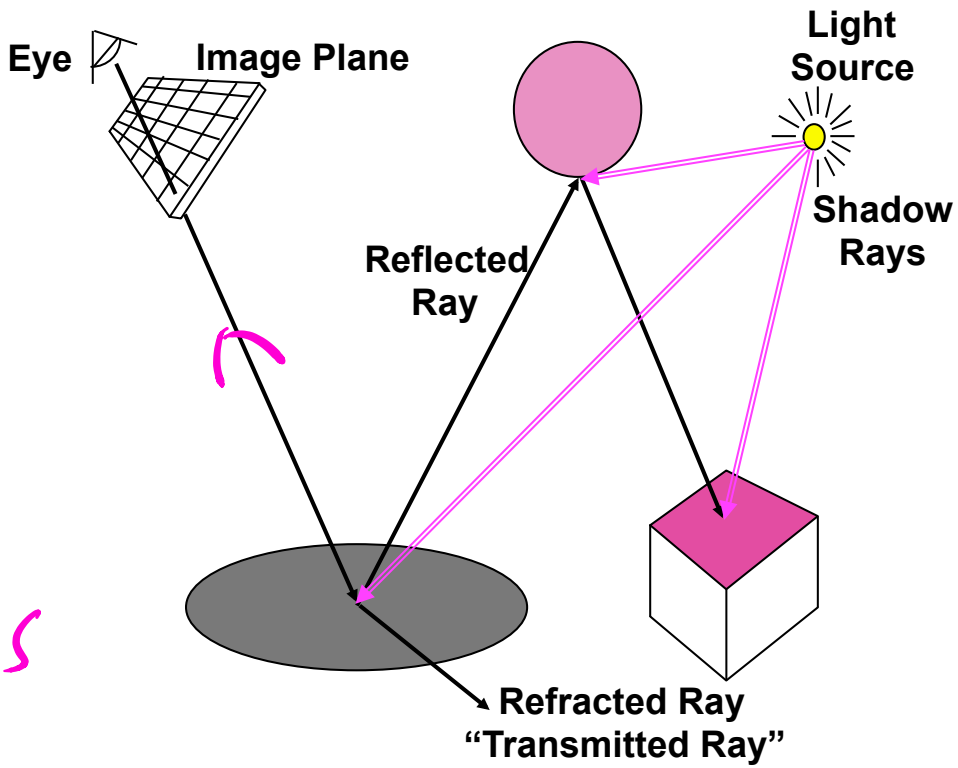
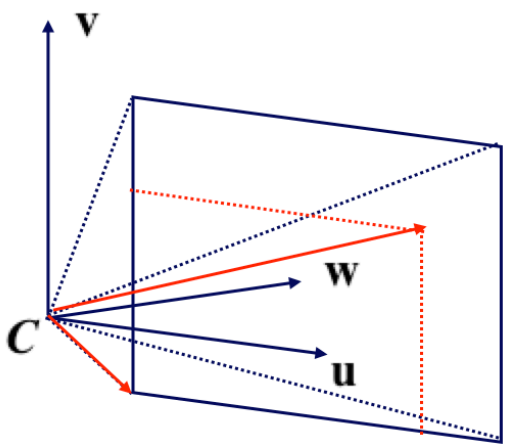
Ray Tree





Ray Generation & Termination

- distance to image plane: d
- image resolution (in pixels): N_x, N_y
- image plane dimensions: $left, right, top, bot$
- pixel i, j



$$P_{0,0} = C + d\,\vec{w} + left\,\vec{u} + bot\,\vec{v}$$

$$P_{i,j} = P_{0,0} + i\Delta u\,\vec{u} + j\Delta v\,\vec{v}$$

where

$$\Delta u = (right - left) / N_x$$

$$\Delta v = (top - bot) / N_y$$

Ray Termination

- ray hits a diffuse object
- ray exits the scene
- when exceeding max recursion depth
- when final contribution will be too small

Ray-Sphere & Ray-Triangle Intersections

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Ray

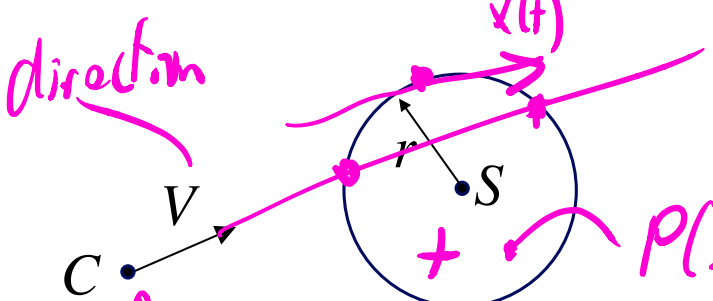
$$\mathrm{R}_{i,j}(t) = C + t \cdot (P_{i,j} - C)$$
$$= \vec{C} + t \cdot \vec{\mathbf{v}}_{i,j}$$

$$x(t) = C_x + V_x t$$
$$y(t) = C_y + V_y t$$
$$z(t) = C_z + V_z t$$

pixel(i,j)

Sphere $F(x,y,z) = r^2 - (x - S_x)^2 - (y - S_y)^2 - (z - S_z)^2 = 0$

x(t) y(t) z(t)



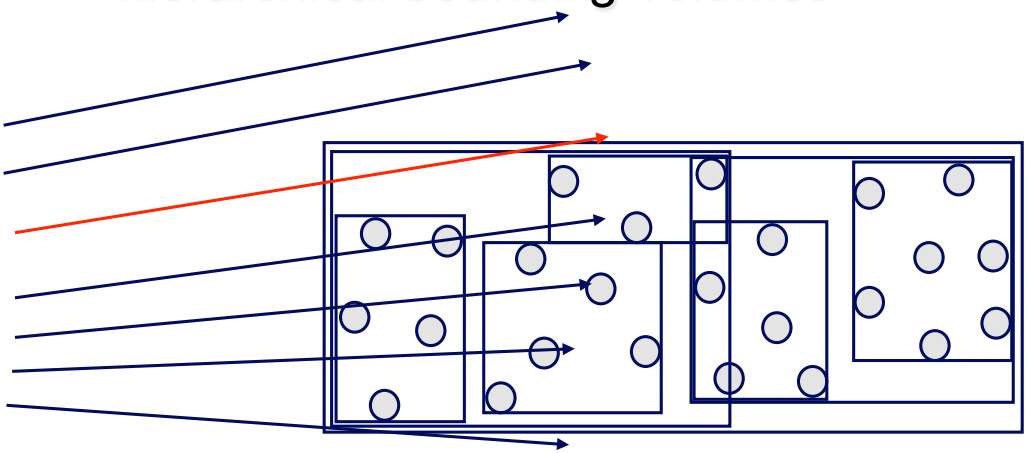
P(x,y,z)

after substitution quadratic eqn in t

misses! $b^2 - 4ac < 0$

Ray-Tracing: Optimizations

- process rays in parallel (multi-core, GPU, …)
- efficient ray-object culling
  - hierarchical bounding volumes



Ray-Triangle Intersections

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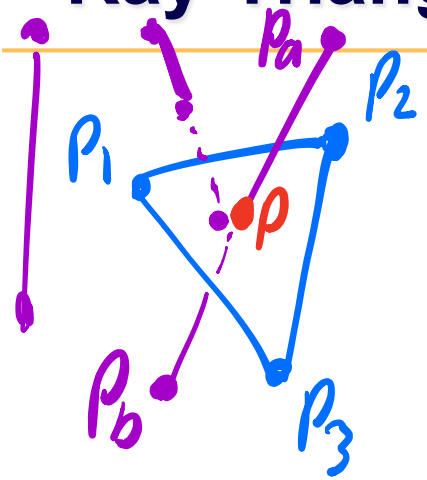

$$p(\alpha,\beta) = \alpha p_1 + \beta p_2 + (1-\alpha-\beta) p_3$$

$$= p_3 + \alpha(p_1 - p_3) + \beta(p_2 - p_3)$$

$$p(t) = p_a + t(p_b - p_a)$$

At intersection $p(\alpha,\beta) = p(t)$

$$p_3 + \alpha(p_1 - p_3) + \beta(p_2 - p_3) = p_a + t(p_b - p_a)$$

$$\alpha(p_1 - p_3) + \beta(p_2 - p_3) - t(p_b - p_a) = p_a - p_3$$

$$\begin{bmatrix} | & | & | \\ p_1 - p_3 & p_2 - p_3 & p_a - p_b \\ | & | & | \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \\ t \end{bmatrix} = \begin{bmatrix} | \\ p_a - p_3 \\ | \end{bmatrix}$$

then test:

$0 \le \alpha \le 1$

$0 \le \beta \le 1$

$0 \le 1-\alpha-\beta \le 1$

$0 \le t \le 1$