Need for Ray Tracing

Ice Sculptures, Fairbanks, AK, 2002

(Slides adapted from Amitabh Varshney)

Ray-Tracing

- Trace rays of light (assume geometric optics)
- A very powerful general rendering model
- Can be used for:
  - Scan-conversion
  - Visibility determination
  - Global illumination
  - Anti-aliasing

Ray Tracing

- Used in pre-rendered images
- Movies
  - Blue Moon Rendering Tools (bmrt.org) has a ray tracer that has been used in several films: A Bug's Life, Stuart Little, Hollow Man, Swordfish,…

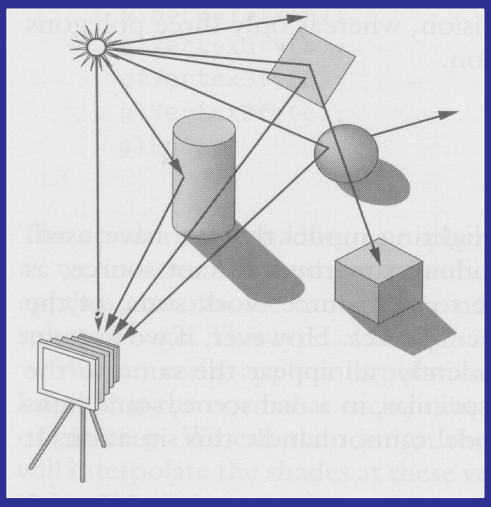
Morning by Horvatth Szabolcs

Ray Traced Images

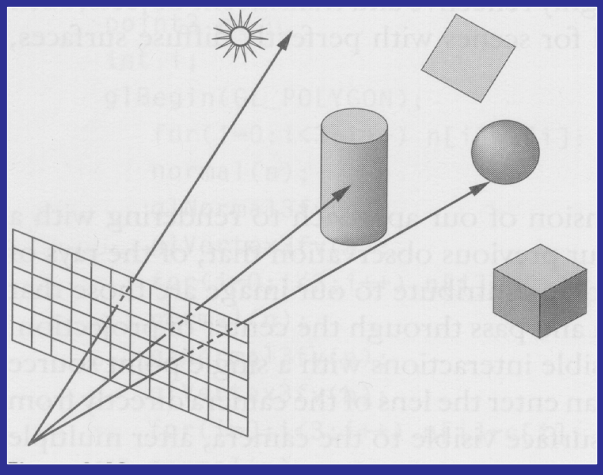
- Internet Ray Tracing Competition (irtc.org)

Small World by Stephen M. Farrell

Forward Ray-Tracing

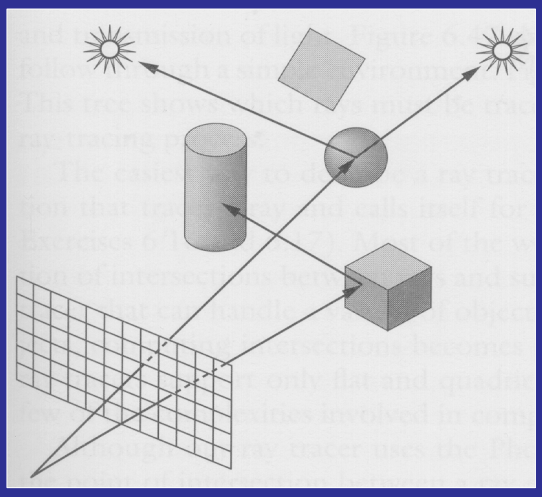


Backward Ray-Tracing



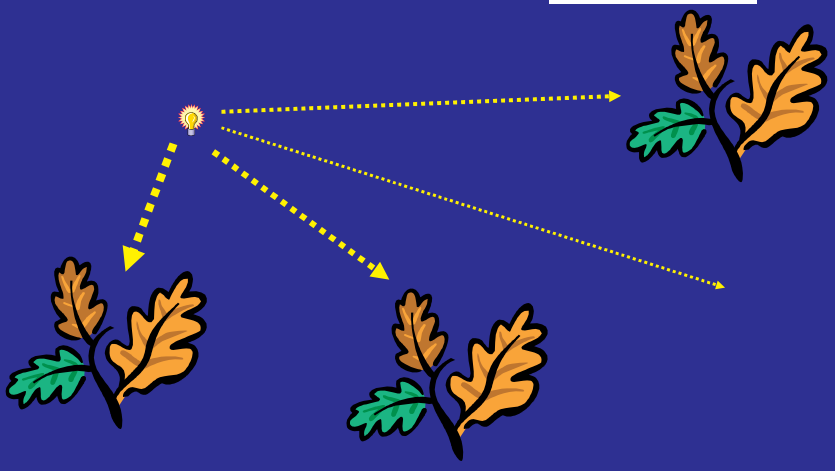
Primary Rays

First-Order Reflections

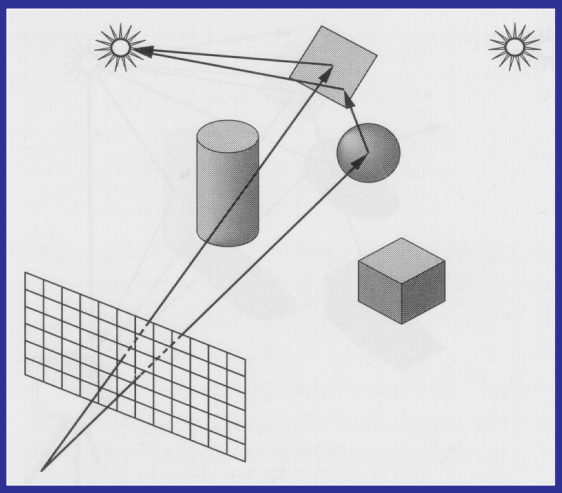


Secondary Rays: One bounce

- Intensity drops off with distance.
- With square of distance: $\frac{1}{d^2}$
- To simulate effects of non-point sources: $\frac{1}{a_0 + a_1 d + a_2 d^2}$



Second-Order Reflections

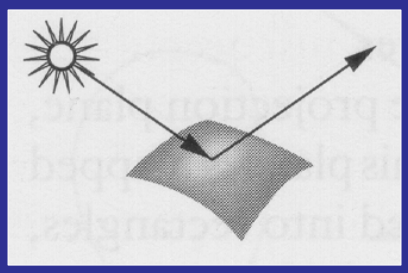


Tertiary Rays

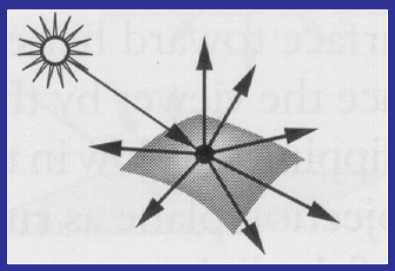
Recursive Ray-Tracing

- Depth of the ray-tracing tree is arbitrary
- Need some termination criteria, say depth 6
- Can introduce several global illumination effects:
  - Reflection, Refraction, Shadows, Transparency, …

Reflections

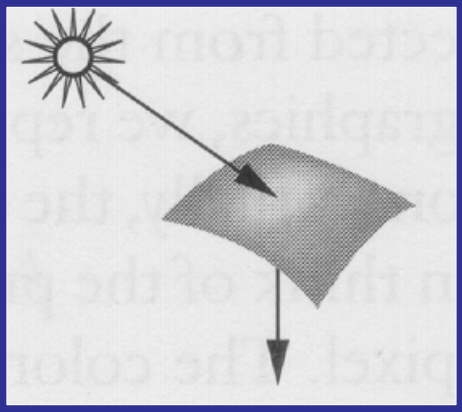


Specular

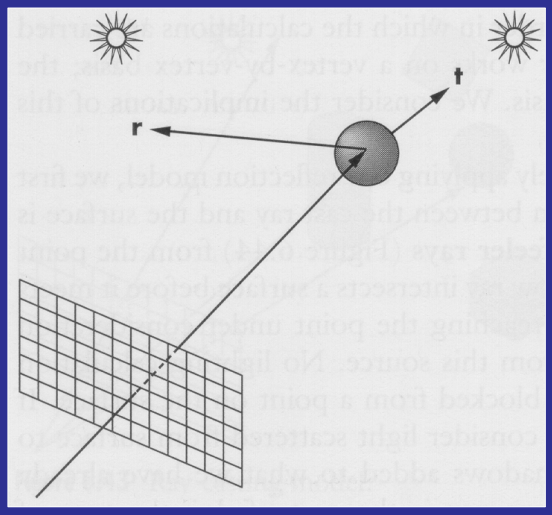


Diffuse / General

Refraction



Reflections and Refraction



Ray-Tracing

- Most common ray-tracers have three new rays per intersection point:
  - Reflection ray
  - Refraction ray
  - Shadow ray
- Most of the time is spent in intersection computations
- This models many effects, but fails to capture some interreflections.

Ray-Sphere Intersections

- Equation of the ray (parametric form):

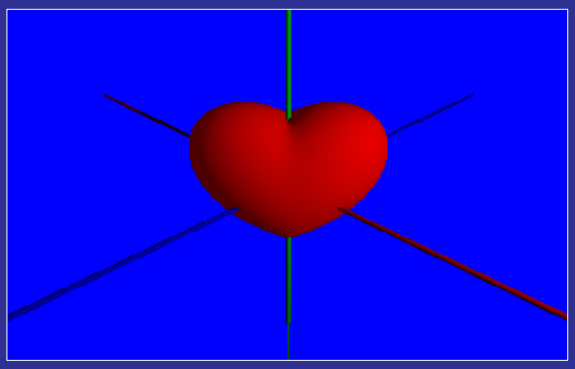
  $p(t) = p_o + t\,(p_1 - p_o)$
- Equation of the sphere (implicit form):

  $(x - c_x)^2 + (y - c_y)^2 + (z - c_z)^2 = r^2$
- Substitute parametric equation into implicit equation:

  $(x_o + t(x_1 - x_o) - c_x)^2 + (y_o + t(y_1 - y_o) - c_y)^2 + (z_o + t(z_1 - z_o) - c_z)^2 = r^2$

  $\alpha\, t^2 + \beta\, t + \gamma = 0$
- Solving the quadratic equation:
  - Imaginary solution: no ray-sphere intersection
  - Unique solution: tangential ray-sphere intersection
  - Two real solutions: ray shoots through the sphere
- Similarly for most implicit surfaces: torus, cylinder, heart, …

A Ray-traced Implicit Heart



$(2x^2 + y^2 + z^2 - 1)^3 - (0.1\, x^2 + y^2)\, z^3 = 0$

Image courtesy, Dan Skarda and Tomas Bily

Ray-Triangle Intersections

- Equation of the ray (parametric form):

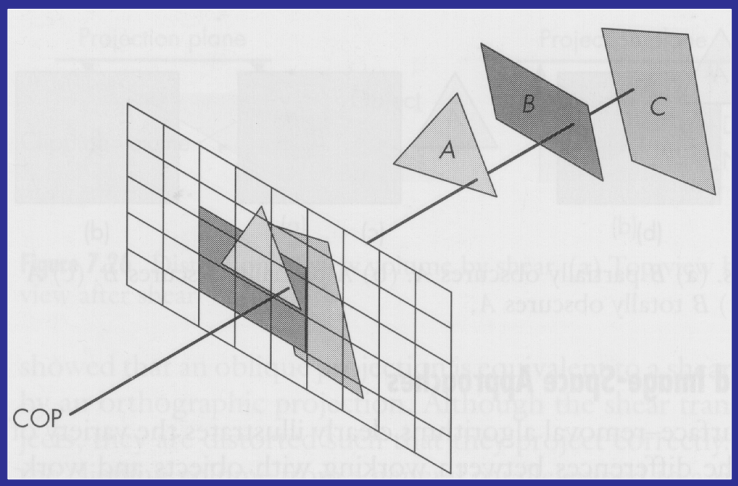
  $p(t) = p_o + t(p_1 - p_o)$
- Equation of the plane (implicit form):

  $ax + by + cz + d = 0$
- Substitute parametric equation into implicit equation:

  $a(x_o + t(x_1 - x_o)) + b(y_o + t(y_1 - y_o)) + c(z_o + t(z_1 - z_o)) + d = 0$

  $\alpha t + \beta = 0$
- On getting the intersection point, need to check whether it lies inside the triangle
- Project to the principal plane (x = 0 or y = 0 or z = 0) based on direction of the triangle normal and use any of the point in polygon tests discussed in the polygon scan conversion lecture.

Implicit Visibility Determination



Antialiasing and Ray Tracing

- Single-sample per pixel
  - May cause aliasing artifacts
  - Reflections/refractions can cause high frequencies even if objects are smooth and low frequency
- Super Sampling
  - Shoot multiple rays per pixel: regular grid, jittering, Poisson disk sampling
  - Average them: weighted/unweighted
  - Adaptive: If high variation amongst supersampled rays per pixel, shoot more

Distribution Ray Tracing

- Also called *distributed* ray tracing (Cook 1986)
- Take multiple samples and average them for:
  - Blurred reflections (distribute reflected rays)
  - Convincing translucency (distribute refracted rays)
  - Soft shadows (distribute shadow rays)
  - Stochastic anti-aliasing (distribute primary rays over image)
  - Motion blur (distribute primary rays over time)
  - Depth of field effects (distribute primary rays across a lens)
  - Area light sources (distribute samples from area lights)

Accelerating Ray-Tracing

- Reduce ray-object intersection tests
- Efficiently leap empty space
- Spatial Hierarchies
  - Binary Trees, Quad Trees, Octrees
  - BSP Trees
- Bounding Volume Hierarchies
  - AABBs (axis-aligned bounding boxes)
  - OBBs (oriented bounding boxes)
  - Bounding spheres

Ellipsoid Hierarchy