Sept

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WARNING

CS 460/560

Computer Graphics

Professor Richard Eckert

Lecture # 24

May 7, 2001

Lecture 24

- Final Exam
- Photorealism
  - Ray Tracing
  - Texture Mapping
  - Radiosity
- Fractals

Final Exam

- Friday, May 11, 2001
- EB - J23 / J15
  - (our classrooms)
- 8:30-10:30 A.M.
- Open Books and Notes

Final Exam Topics

- 3D Polygon Mesh Model Data Structures (Points, Polygon lists)
- 3D Viewing Transformation (4-parameter viewing setup)
- Projection Transformations (perspective, parallel)
- Window-to-Viewport Transformation
- Back-Face Culling
- Z-Buffer Hidden Surface Removal Algorithm
- Depth Sort Hidden Surface Removal Algorithm
- Illumination and Reflection (ambient, diffuse, specular)
- The Phong Illumination/Reflection Model
- Flat shading (data structures, parameters)
- Interpolated shading (Gouraud)
- Ray Tracing

Ray Tracing

- See CS-460/560 Notes at:

http://www.cs.binghamton.edu/~reckert/460/raytrace.htm

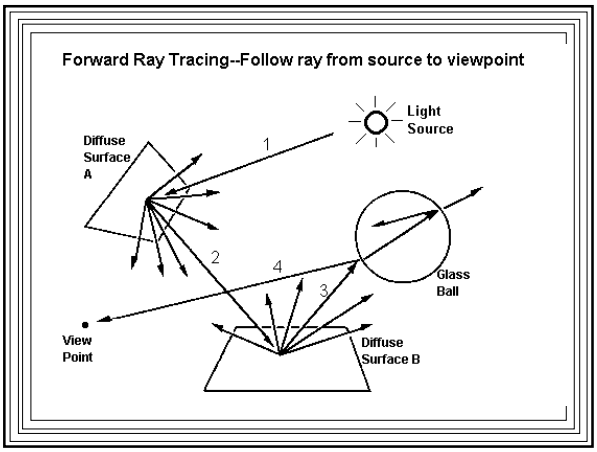
http://www.cs.binghamton.edu/~reckert/460/texture.htm

- Persistence of Vision Ray Tracer (free):

  http://povray.org/

Ray Tracing

- What is seen by viewer depends on:
  - rays of light that arrive at his/her eye
- So to get “correct” results:
  - Follow all rays of light from all light sources
  - Each time one hits an object, compute the reflected color/intensity
  - Store results for those that go through projection plane pixels into observer’s eye
  - Paint each pixel in the resulting color

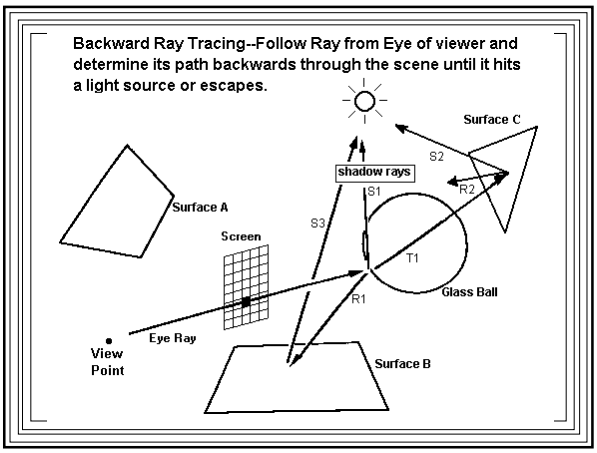


Forward Ray Tracing

- Infinite number of rays from each source
- At each intersection with an object
  - could have an infinite number of reflected rays
- Completely intractable
- Would take geological times to compute

Backward Ray Tracing

- Look only at rays observer sees
- Follow rays backwards from eye point through pixels on screen
- Check if they intersect objects
  - If so, can intersection point see a light source?
    - If so, compute intensity of reflected light
    - If not, point is in the shadow
  - If object has reflectivity/transparency
    - Follow reflected/transmission rays



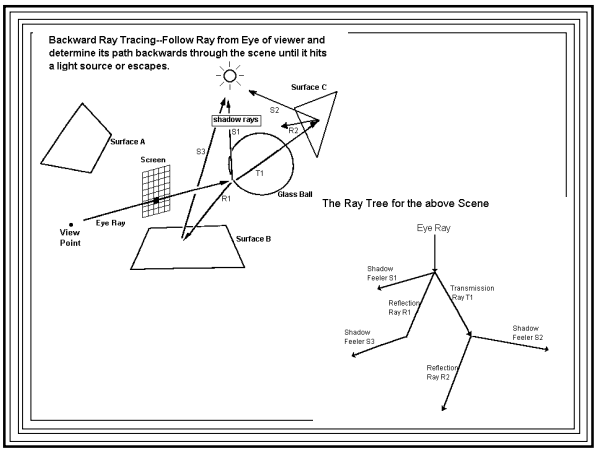
Simple Ray Tracing

Set up scene (position objects and light sources)
For each pixel on screen
  Form eye ray--vector from viewpoint through pixel
  For each object in scene
    If object is intersected by eye ray & is closest,
      Store intersection point & object ID
  Apply illumination model to closest intersection point
  Plot pixel in resulting color

- (Another way of doing hidden surface Removal)
- Difficulty is getting intersection points for complex objects

Recursive Ray Tracing

- Good for scenes with lots of specular reflection and transparency
- Also gives shadows automatically
- At each intersection point send out:
  - Shadow feeler rays toward light sources
  - Reflection rays in ideal reflection direction
  - Transmission rays in refraction direction
- Treat last two as eye rays
- Recursive algorithm



Recursive Ray Tracing Algorithm

depth = 0
for each pixel (x,y)
  Calculate direction from eyepoint to pixel
  TraceRay (eyepoint, direction, depth, *color)
  FrameBuf [x,y] = color

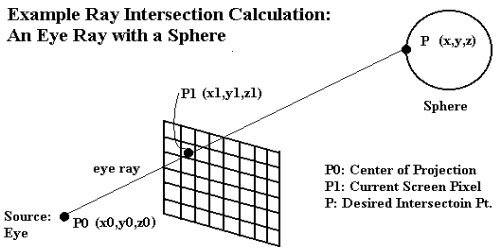
```
TraceRay (start_pt, direction_vector, recur_depth, *color)
  if (recur_depth > MAXDEPTH)    color = Background_color
  else
    // Intersect ray with all objects
    // Find intersection point that is closest to start_point
    if (no intersection)    color = Background_color
    else
      // Send out shadow rays toward light sources
      local_color = contribution of illumination model at int. pt.
      // Calculate direction of reflection ray
      TraceRay (int_pt, refl_dir., depth+1, *refl_color)
      // Calculate direction of transmitted ray
      TraceRay (int_pt., trans_dir., depth+1, *trans_color)
      color = Combine (local_color, refl_color, trans_color)
```

Combining Color from Reflection Ray

- Add attenuated reflected color to local color:

  color = local_color + k * refl_color
  - here refl_color is color returned by reflection ray
  - local_color is color computed by illumination at intersection point
  - k is the attenuation factor (<1)

Ray Tracing Intersection Calculations



Parametric Equations for Eye Ray:

$x = x0 + (x1-x0)*t = x0 + \Delta x*t$
$y = y0 + (y1-y0)*t = y0 + \Delta y*t$
$z = z0 + (z1-z0)*t = z0 + \Delta z*t$

Equation of a sphere of radius r, centered at (a,b,c)

$(x-a)^2 + (y-b)^2 + (z-c)^2 = r^2$

Substitute ray parametric equations:

$(x0+\Delta x*t-a)^2 + (y0+\Delta y*t-b)^2 + (z0+\Delta z*t-c)^2 = r^2$

Rearrange terms:

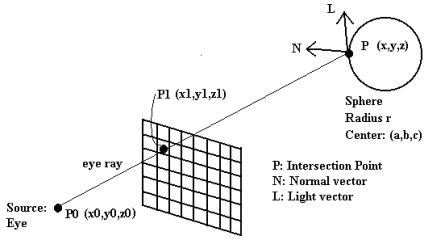
$(\Delta x^2+\Delta y^2+\Delta z^2)t^2 + 2[\Delta x(x0-a)+\Delta y(y0-b)+\Delta z(z0-c)]t$
$+(x0-a)^2 + (y0-b)^2 + (z0-c)^2 - r^2 = 0$

This is a quadratic in parameter t

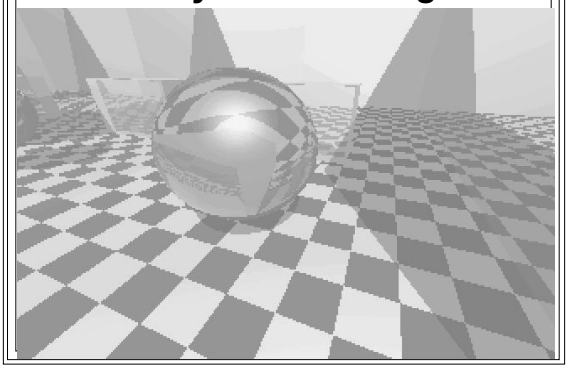
- Solution(s): value(s) of t where ray intersects sphere
- Three cases
  - No real roots ==> no intersection point
  - 1 real root ==> ray grazes sphere
  - 2 real roots ==> ray passes thru sphere
    - Select smaller t (closer to source)

Sphere Normal Computation

- To apply illumination model at intersection point P, need surface normal
- Can show: N = ((x-a)/r, (y-b)/r, (z-c)/r)



A Ray-Traced Image



Disadvantages of Ray Tracing

- Extremely compute intensive
  - But there are several acceleration techniques
- Bad for scenes with lots of diffuse reflection
  - But can be combined with other algorithms that handle diffuse reflection well
- Prone to aliasing
  - One sample per pixel
    - can give ugly artifacts
  - But there are anti-aliasing techniques

A 3-D Ray Tracing Animation Applet

- M.S. Project (Brian Maltzan
- http://members.nbci.com/bmaltzan/sim/

Persistence of Vision Ray Tracer

- POVRay free software
- Lots of capabilities
- Great for playing around with ray tracing
  - http://povray.org/

Pattern/Texture Mapping

- Adding details or features to surfaces
  - (variations in color or texture)

Surface Detail Polygons

- Good only for Polygon-based Scenes
  - e.g., doors, windows on side of house
- Associate Surface-Detail Polygons with each polygon in scene
- When shading base polygon:
  - use surface-detail polygons' material properties

General Texture Mapping

- Pattern Mapping Technique
  - Modulate surface color calculated by reflection model according to a pattern defined by a texture function
    - ("wrap" pattern around surface)
    - 2-D Texture function: T(u,v)
      - Could be a digitized image
      - Or a procedurally-defined pattern

Inverse Pixel Mapping (Screen Scanning)

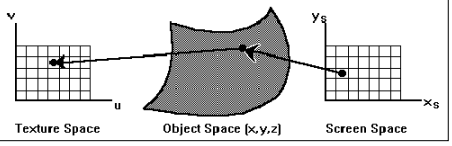
For each pixel on screen (xs, ys)

Compute pt (x,y,z) on closest surface projecting to pixel (e.g., ray tracing)

Determine color (e.g., apply illumination/reflection model)

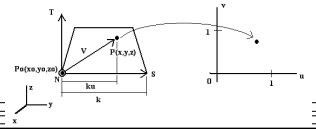
Compute (u,v) corresponding to (x,y,z) (inverse mapping)

Modulate color of (xs,ys) according to value of T(u,v) at (u,v)

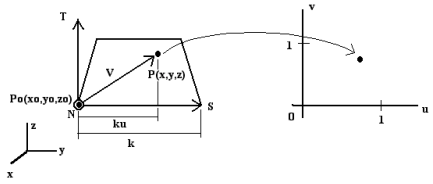


Ex: Screen Scanning a Polygon

- Choose axis S (unit vector) along a polygon edge
  - will align with u-axis in texture space
- Choose a polygon vertex Po(xo,yo,zo)
  - will correspond to origin in texture space
- Choose a scaling factor k
  - k = max dimension of polygon
    - 0-k in object space --> 0-1 in texture space
- Want to map point P(x,y,z) on polygon to (u,v)



- Construct V = P - Po
- V.S = k*u, projection of P onto S
- So u = V.S/k
- Choose orthogonal axis T in polygon plane (T=NxS)
- v=V.T/k



Radiosity Methods

- Two kinds of illumination at each reflective surface
  - Local: from point source
  - Global: light reflected from other surfaces in scene
  - Ray tracing handles specularly reflected global illumination
    - But not diffusely reflected global illumination

Radiosity Approach

- Compute global illumination
- All light energy coming off a surface is the sum of:
  - Light emitted by the surface
  - Light from other surfaces reflected off the surface
  - Divide scene into patches that are perfect diffuse reflectors...
    - Reflected light is non-directional
  - and/or emitters

- Radiosity (B):
  - Total light energy per unit area leaving a surface patch per unit time--sum of emitted and reflected energy (Brightness)
- Emission (E):
  - Energy per unit area emitted by the surface itself per unit time (Surfaces having nonzero E are light sources)

- Reflectivity (ρ):
  - Fraction of light reflected from a surface (a number between 0 and 1)
- Form Factor (Fij):
  - Fraction of light energy leaving patch i which arrives at patch j
    - Function only of geometry of environment

- Conservation of energy for patch i:
  - Total energy out = Energy emitted + Sum of energy from other patches reflected by patch i:

$$Bi*Ai = Ei*Ai + \rho_i * \sum_j Bj*Aj*Fji$$

$$Bi = Ei + \rho_i * \sum_j (Bj*Aj/Ai)*Fji$$

- Principle of Reciprocity for Form Factors
  - Reversing role of emitters and receivers:
    - Fraction of energy emitted by one and received by other would be same as fraction of energy going the other way
    - Fij*Ai = Fji*Aj ==> Fji = (Ai/Aj) Fij
    - So:

      $B_i = E_i + \rho_i * \Sigma B_j * F_{ij}$

      $B_i - \rho_i * \Sigma B_j * F_{ij} = E_i$
    - Need to solve this system of equations for the radiosities Bi

Radiosity -- Matrix Formulation and Solution

Assume N patches

$F_{ii} = 0$ – Patch I receives no energy from itself

Rearranging and writing out the Radiosity equation:

$$\begin{bmatrix} 1 & -\rho_1 F_{12} & -\rho_1 F_{13} & \cdots & -\rho_1 F_{1N} \\ -\rho_2 F_{21} & 1 & -\rho_2 F_{23} & \cdots & -\rho_2 F_{2N} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ -\rho_N F_{N1} & -\rho_N F_{N2} & -\rho_N F_{N3} & \cdots & 1 \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \cdots \\ \cdots \\ B_N \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ \cdots \\ \cdots \\ E_N \end{bmatrix}$$

This is the matrix equation: M B = E

The E_i and ρ_i are known, and the form factors F_{ij} can be calculated so that the matrix elements M_{ij} can be determined. Since the ρ_i and F_{ij} are all less than or equal to zero, matrix M is diagonally dominant, so the Gauss-Seidel iteration method is guaranteed to converge after a few iterations.

Gauss-Seidel Solution

$$B_1 + M_{12}B_2 + \cdots + M_{1N}B_N = E_1$$
$$M_{21}B_1 + B_2 + \cdots + M_{2N}BN = E_2$$
$$\cdots\cdots$$
$$M_{i1}B_1 + M_{i2}B_2 + \cdots + B_i + \cdots + M_{iN}B_N = E_i$$
$$\cdots\cdots$$

Initial guess: $B_i^{(0)} = E_i$

Next iteration $B_i^{(1)} = E_i - (M_{i1}B_1^{(0)} + \cdots + M_{i,i-1}B_{i-1}^{(0)} + \cdots + M_{i,i+1}^{(0)} + \cdots + M_{iN}B_N^{(0)})$

Continue iterating until all the difference between $B_i^{(k+1)}$ and $B_i^{(k)}$ is small enough for all patches

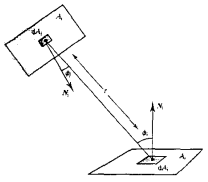
Notice that for each patch i we are "gathering" radiosity from all the other patches

Thus the scene is not finished until we have processed all patches--very time consuming.

Problem: getting form factors

Computing Form Factors

Form Factor Determination



The form factor F_{ij} from patch i to patch j is obtained in principle by by integrating over both patches:

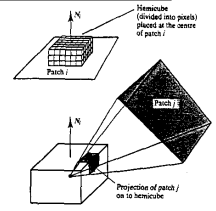
$$F_{A_i A_j} = F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\phi_i \cos\phi_j}{\pi r^2} dA_j \, dA_i$$

But this is very difficult.

$\Delta FF = \Sigma (\cos \phi_i \cos \phi_j \Delta A_j) / (\pi r^2)$, approx.

Hemicube Approximation

The Hemicube Approximation



Calculate and store the delta form factors for each element of the hemicube.

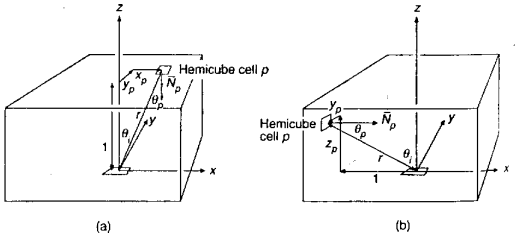
$$F_{ij} = \sum_q \Delta F_q$$

To calculate the form factor F_{ij}, build a hemicube centered on patch i and sum the delta form factors for those elements of the hemicube to which patch j projects.

Hemicube Pixel Computations

a. $\Delta F = \Delta A/[\pi*(x^2 + y^2 + 1)^2]$

b. $\Delta F = z*\Delta A/[\pi*(y^2+z^2+1)^2]^2$



Hemicube Form Factor Algorithm

Compute & strore all hemicube delta FormFactors: ΔFF[k]

Zero all the Fij

For all patches i

  Place unit hemicube at center of patch i

  For each patch j (j <> i)

    For each "pixel" k on hemicube

      If line from origin thru pixel intersects patch j

        Fij = Fij + ΔFF[k]

Radiosity Summary

- Good for scenes with lots of diffuse reflection
- Not good for scenes with lots of specular reflection
  - Complementary to Ray Tracing
  - But can be combined with Ray Tracing
- Very computationally intensive
  - Can take very long times for complex scenes
    - but once patch intensities are computed, scene "walkthroughs" are fast
  - Gauss-Seidel is very memory intensive
  - There are other approaches
    - Progressive Refinement