University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

Tamara Munzner

Shading, Advanced Rendering

Week 7, Wed Feb 28

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

Reading for Today and Tomorrow

- FCG Chap 10 Ray Tracing
  - only 10.1-10.7
- FCG Chap 25 Image-Based Rendering

News

- extra lab coverage: TAs available to answer questions
  - Wed 2-3, 5-6 (Matt)
  - Thu 11-2 (Matt)
  - Thu 3:30-5:30 (Gordon)
  - Fri 2-5 (Gordon)

News

- Project 2
  - rolling ball mode should rotate around center of world, not center of camera
    - corrected example binary will be posted soon

News

- Homework 2 Q9 was underconstrained
  - "Sketch what the resulting image would look like with an oblique angle of 70 degrees"
- add: and a length of .7 for lines perpendicular to the image plane
- question is now extra credit

Final Correction/Clarification: 3D Shear

- general shear $shear(hxy, hxz, hyx, hyz, hzx, hzy) = \begin{bmatrix} 1 & hyx & hzx & 0 \\ hxy & 1 & hzy & 0 \\ hxz & hyz & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
- "x-shear" usually means shear along x in direction of some other axis
  - **correction: not** shear along some axis in direction of x
  - to avoid ambiguity, always say "shear along <axis> in direction of <axis>"

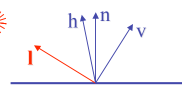
$$shearAlongXinDirectionOfY(h) = \begin{bmatrix} 1 & h & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad shearAlongXinDirectionOfZ(h) = \begin{bmatrix} 1 & 0 & h & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$shearAlongYinDirectionOfX(h) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ h & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad shearAlongYinDirectionOfZ(h) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & h & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$shearAlongZinDirectionOfX(h) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ h & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad shearAlongZinDirectionOfY(h) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & h & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Correction/Review: Reflection Equations

- Blinn improvement



$$\mathbf{I}_{specular} = \mathbf{k}_s \mathbf{I}_{light} (\mathbf{h} \bullet \mathbf{n})^{n_{shiny}}$$

$$\mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$

- full Phong lighting model
  - combine ambient, diffuse, specular components

$$\mathbf{I}_{total} = \mathbf{k}_a \mathbf{I}_{ambient} + \sum_{i=1}^{\#lights} \mathbf{I}_i (\mathbf{k}_d (\mathbf{n} \bullet \mathbf{l}_i) + \mathbf{k}_s (\mathbf{v} \bullet \mathbf{r}_i)^{n_{shiny}})$$

  - don't forget to normalize all vectors: n,l,r,v,h

Review: Lighting

- lighting models
- ambient
  - normals don't matter
- Lambert/diffuse
  - angle between surface normal and light
- Phong/specular
  - surface normal, light, and viewpoint

Review: Shading Models

- flat shading
  - compute Phong lighting once for entire polygon
- Gouraud shading
  - compute Phong lighting at the vertices and interpolate lighting values across polygon

Shading

Phong Shading

- linearly interpolating surface normal across the facet, applying Phong lighting model at every pixel
  - same input as Gouraud shading
  - pro: much smoother results
  - con: considerably more expensive

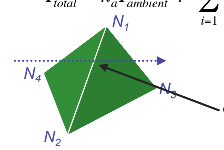
- **not** the same as Phong lighting
  - common confusion
  - Phong lighting: empirical model to calculate illumination at a point on a surface

Phong Shading

- linearly interpolate the vertex normals
  - compute lighting equations at each pixel
  - can use specular component

$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{\#lights} I_i \left(k_d (\mathbf{n} \cdot \mathbf{l}_i) + k_s (\mathbf{v} \cdot \mathbf{r}_i)^{n_{shiny}} \right)$$

remember: normals used in diffuse and specular terms



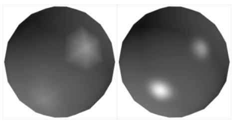
discontinuity in normal's rate of change harder to detect

Phong Shading Difficulties

- computationally expensive
  - per-pixel vector normalization and lighting computation!
  - floating point operations required
- lighting after perspective projection
  - messes up the angles between vectors
  - have to keep eye-space vectors around
- no direct support in pipeline hardware
  - but can be simulated with texture mapping

Shading Artifacts: Silhouettes

- polygonal silhouettes remain

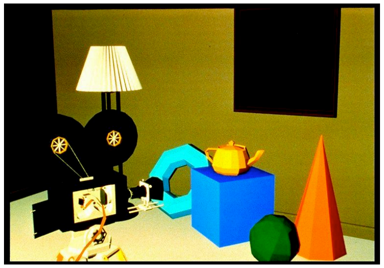


Gouraud *Phong*

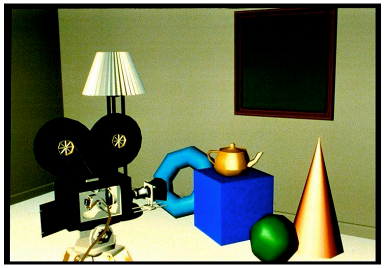
Shading Models Summary

- flat shading
  - compute Phong lighting once for entire polygon
- Gouraud shading
  - compute Phong lighting at the vertices and interpolate lighting values across polygon
- Phong shading
  - compute averaged vertex normals
  - interpolate normals across polygon and perform Phong lighting across polygon

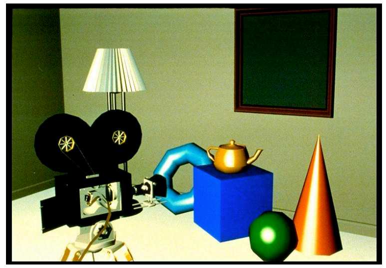
Shutterbug: Flat Shading



Shutterbug: Gouraud Shading

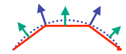


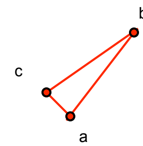
Shutterbug: Phong Shading



Reminder: Computing Normals

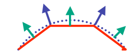
- per-vertex normals by interpolating per-facet normals
  - OpenGL supports both
- computing normal for a polygon

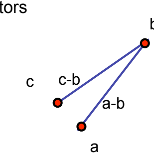




Reminder: Computing Normals

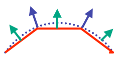
- per-vertex normals by interpolating per-facet normals
  - OpenGL supports both
- computing normal for a polygon
  - three points form two vectors

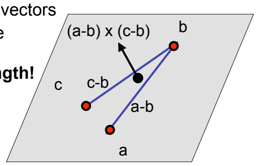




Reminder: Computing Normals

- per-vertex normals by interpolating per-facet normals
  - OpenGL supports both
- computing normal for a polygon
  - three points form two vectors
  - cross: normal of plane gives direction
  - **normalize to unit length!**
  - which side is up?
    - convention: points in counterclockwise order





Specifying Normals

- OpenGL state machine
  - uses last normal specified
  - if no normals specified, assumes all identical
- per-vertex normals

```
glNormal3f(1,1,1);
glVertex3f(3,4,5);
glNormal3f(1,1,0);
glVertex3f(10,5,2);
```

- per-face normals

```
glNormal3f(1,1,1);
glVertex3f(3,4,5);
glVertex3f(10,5,2);
```

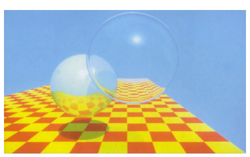

Advanced Rendering

Global Illumination Models

- simple lighting/shading methods simulate local illumination models
  - no object-object interaction
- global illumination models
  - more realism, more computation
  - leaving the pipeline for these two lectures!
- approaches
  - ray tracing
  - radiosity
  - photon mapping
  - subsurface scattering

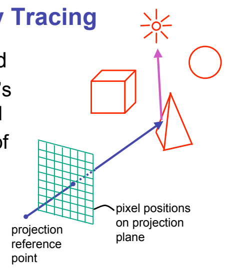
Ray Tracing

- simple basic algorithm
- well-suited for software rendering
- flexible, easy to incorporate new effects
  - Turner Whitted, 1990



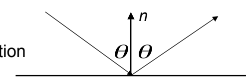
Simple Ray Tracing

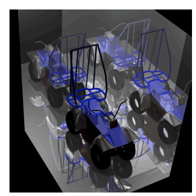
- view dependent method
  - cast a ray from viewer's eye through each pixel
  - compute intersection of ray with first object in scene
  - cast ray from intersection point on object to light sources

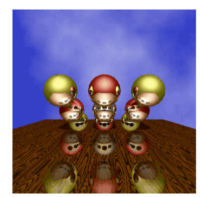


Reflection

- mirror effects
  - perfect specular reflection

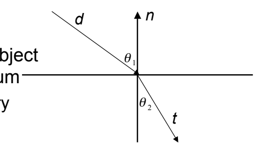


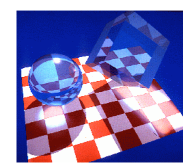




Refraction

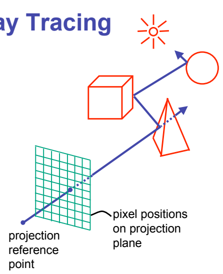
- happens at interface between transparent object and surrounding medium
  - e.g. glass/air boundary
- Snell's Law
  - $c_1 \sin\theta_1 = c_2 \sin\theta_2$
  - light ray bends based on refractive indices c_1, c_2





Recursive Ray Tracing

- ray tracing can handle
  - reflection (chrome/mirror)
  - refraction (glass)
  - shadows
- spawn secondary rays
  - reflection, refraction
    - if another object is hit, recurse to find its color
  - shadow
    - cast ray from intersection point to light source, check if intersects another object



Basic Algorithm

```
for every pixel p_i {
    generate ray r from camera position through pixel p_i
    for every object o in scene {
        if ( r intersects o )
          compute lighting at intersection point, using local
          normal and material properties; store result in p_i
        else
          p_i= background color
    }
}
```

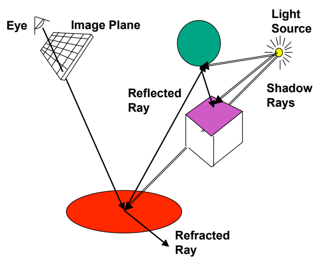

Basic Ray Tracing Algorithm

```
RayTrace(r,scene)
obj := FirstIntersection(r,scene)
if (no obj) return BackgroundColor;
else begin
    if ( Reflect(obj) ) then
      reflect_color := RayTrace(ReflectRay(r,obj));
    else
      reflect_color := Black;
   if ( Transparent(obj) ) then
      refract_color := RayTrace(RefractRay(r,obj));
    else
      refract_color := Black;
  return Shade(reflect_color,refract_color,obj);
end;
```


Algorithm Termination Criteria

- termination criteria
  - no intersection
  - reach maximal depth
    - number of bounces
  - contribution of secondary ray attenuated below threshold
    - each reflection/refraction attenuates ray

Ray Tracing Algorithm



Ray-Tracing Terminology

- terminology:
  - primary ray: ray starting at camera
  - shadow ray
  - reflected/refracted ray
  - ray tree: all rays directly or indirectly spawned off by a single primary ray
- note:
  - need to limit maximum depth of ray tree to ensure termination of ray-tracing process!

Ray Tracing

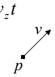
- issues:
  - generation of rays
  - intersection of rays with geometric primitives
  - geometric transformations
  - lighting and shading
  - efficient data structures so we don't have to test intersection with *every* object

Ray - Object Intersections

- inner loop of ray-tracing
  - must be extremely efficient
- solve a set of equations
  - ray-sphere
  - ray-triangle
  - ray-polygon

Ray - Sphere Intersection

- ray: $x(t) = p_x + v_x t,\; y(t) = p_y + v_y t,\; z(t) = p_z + v_z t$

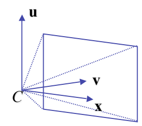


- unit sphere: $x^2 + y^2 + z^2 = 1$
- quadratic equation in t:

$$\begin{aligned} 0 &= (p_x + v_x t)^2 + (p_y + v_y t)^2 + (p_z + v_z t)^2 - 1 \\ &= t^2(v_x^2 + v_y^2 + v_z^2) + 2t(p_x v_x + p_y v_y + p_z v_z) \\ &\quad + (p_x^2 + p_y^2 + p_z^2) - 1 \end{aligned}$$

Ray Generation

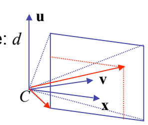
- camera coordinate system
  - origin: C (camera position)
  - viewing direction: $\mathbf{v}$
  - up vector: $\mathbf{u}$
  - x direction: $\mathbf{x} = \mathbf{v} \times \mathbf{u}$
- note:
  - corresponds to viewing transformation in rendering pipeline
  - like gluLookAt



Ray Generation

- other parameters:
  - distance of camera from image plane: d
  - image resolution (in pixels): w, h
  - left, right, top, bottom boundaries in image plane: l, r, t, b
- then:
  - lower left corner of image: $O = C + d\cdot\mathbf{v} + l\cdot\mathbf{x} + b\cdot\mathbf{u}$
  - pixel at position i, j ($i=0..w-1, j=0..h-1$):

$$\begin{aligned} P_{i,j} &= O + i\cdot\frac{r-l}{w-1}\cdot\mathbf{x} - j\cdot\frac{t-b}{h-1}\cdot\mathbf{u} \\ &= O + i\cdot\Delta x\cdot\mathbf{x} - j\cdot\Delta y\cdot\mathbf{y} \end{aligned}$$



Ray Generation

- ray in 3D space:

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

where $t = 0\ldots\infty$

Ray Tracing

- issues:
  - generation of rays
  - intersection of rays with geometric primitives
  - geometric transformations
  - lighting and shading
  - efficient data structures so we don't have to test intersection with *every* object

Ray Intersections

- task:
  - given an object o, find ray parameter t, such that $\mathbf{R}_{i,j}(t)$ is a point on the object
    - such a value for t may not exist
  - intersection test depends on geometric primitive

Ray Intersections: Spheres

- spheres at origin
  - implicit function

$$S(x,y,z): x^2 + y^2 + z^2 = r^2$$

  - ray equation

$$R_{i,j}(t) = C + t\cdot\mathbf{v}_{i,j} = \begin{pmatrix} c_x \\ c_y \\ c_z \end{pmatrix} + t\cdot\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \begin{pmatrix} c_x + t\cdot v_x \\ c_y + t\cdot v_y \\ c_z + t\cdot v_z \end{pmatrix}$$

Ray Intersections: Spheres

- to determine intersection:
  - insert ray $\mathbf{R}_{i,j}(t)$ into $S(x,y,z)$:

$$(c_x + t\cdot v_x)^2 + (c_y + t\cdot v_y)^2 + (c_z + t\cdot v_z)^2 = r^2$$

  - solve for t (find roots)
    - simple quadratic equation

Ray Intersections: Other Primitives

- implicit functions
  - spheres at arbitrary positions
    - same thing
  - conic sections (hyperboloids, ellipsoids, paraboloids, cones, cylinders)
    - same thing (all are quadratic functions!)
- polygons
  - first intersect ray with plane
    - linear implicit function
  - then test whether point is inside or outside of polygon (2D test)
  - for convex polygons
    - suffices to test whether point in on the correct side of every boundary edge
    - similar to computation of outcodes in line clipping (upcoming)

Credits

- some of raytracing material from Wolfgang Heidrich
- http://www.ugrad.cs.ubc.ca/~cs314/WHmay2006/