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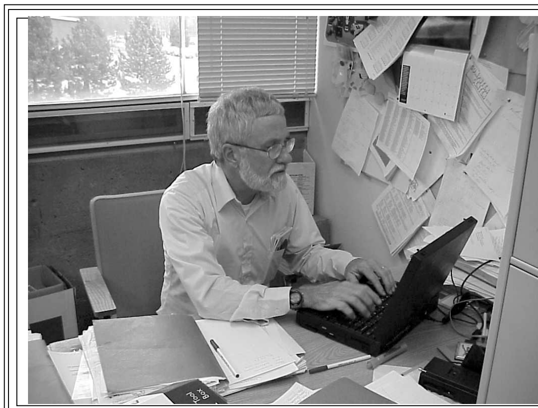
CS 460/560

Computer Graphics

Professor Richard Eckert

Lecture # 23

May 2, 2001



Lecture 23

- 3D Graphics using OpenGL
  - Illumination and Shading
- Hidden Surface Removal Revisited
  - Depth Sort
- Shadows

Illumination & Reflection in OpenGL

- Uses the Phong Illumination/Reflection Model

Final Phong Illumination/Reflection Model Result (Single Light Source)

- Three color intensity equations:

I(r,g,b) = Ambient + Point Diffuse + Point Specular

I(r,g,b) = kd(r,g,b)*Ia
+ Ip*kd(r,g,b)*(N.L)
+ Ip*ks*$(R.V)^n$

Illumination & Reflection in OpenGL

- Define Light Sources
- Define Material Properties
- Define Normal Vectors
- Specify Shading Model
- Enable Depth Testing (Z-Buffer)

Defining a Light Source

- Set up Arrays of lighting values

```
GLfloat ambLight0[ ] = {0.3f, 0.3f, 0.3f, 1.0f}; // R,G,B,α
GLfloat diffLight0[ ] = {0.5f, 0.5f, 0.5f, 1.0f};
GLfloat specLight0[ ] = {0.0f, 0.0f, 0.0f, 1.0f};
GLfloat posnLight0[ ] = {1.0f, 1.0f, 1.0f, 0.0f); // x,y,z,w
```

- Pass Arrays to OpenGL

```
glLightfv(GL_LIGHT0, GL_AMBIENT, ambLight0);
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffLight0);
glLightfv(GL_LIGHT0, GL_SPECULAR, specLight0);
glLightfv(GL_LIGHT0, GL_POSITION, posnLight0);
```

Enabling a Light Source

- Turning on the light source

```
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
```

Material Reflection Properties

- Set up Material Arrays
  - ambient/diffuse reflection coefficients

    GLfloat mat_ambdiff[ ] = {0.0f, 0.7f, 0.0f, 1.0f};
  - specular reflection coefficient

    GLfloat mat_spec[ ] = {1.0f, 1.0f, 1.0f, 1.0f};
- Pass Material Arrays to OpenGL

```
glMaterialfv(GL_FRONT,
   GL_AMBIENT_AND_DIFFUSE,
   mat_ambdiff);
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_spec);
glMaterialf(GL_FRONT, GL_SHININESS, 20.0f);
```

Defining Normals

- Must compute normals for all polygons
- OpenGL has no function to do that
  - So write your own
- Assume the result is:

  double n[3];
- Use this when you define the polygon

```
glBegin(GL_POLYGON)
    glNormal3f((GLfloat)n[0], (GLfloat)n[1], (GLfloat)n[2]);
    // glVertex3f() calls here for polygon vertices
glEnd();
```

Specify a Shading Model & Enable Depth Testing

```
glShadeModel(GL_FLAT);  // use GL_SMOOTH
   for Gouraud shading
glEnable(GL_DEPTH_TEST);
glClear (GL_COLOR_BUFFER_BIT |
   GL_DEPTH_BUFFER_BIT);
      // clear frame buffer and z-buffer
```

Some sample code (view class: OnDraw)

```
glShadeModel(GL_SMOOTH);
glEnable(GL_DEPTH_TEST);
glClearColor(1.0f, 1.0f, 1.0f, 1.0f);
glClear(GL_COLOR_BUFFER_BIT |GL_DEPTH_BUFFER_BIT);
glMatrixMode(GL_MODELVIEW);  glLoadIdentity();
glMaterialfv(GL_FRONT, GL_AMBIENT_AND_DIFFUSE,mat_ambdiff);
glMaterialfv(GL_FRONT, GL_SPECULAR, mat_spec);
glMaterialf(GL_FRONT, GL_SHININESS, 20.0f);
glLightfv(GL_LIGHT0, GL_AMBIENT, ambLight0);
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffLight0);
glLightfv(GL_LIGHT0, GL_SPECULAR, specLight0);
glLightfv(GL_LIGHT0, GL_POSITION, posnLight0);
glEnable(GL_LIGHTING); glEnable(GL_LIGHT0);
DrawCube();
glFlush();
```

Code from DrawCube() function

```
glTranslatef(0.0f, 0.0f, -3.0f);    // position cube
glRotatef(20.0f, 1.0f, 0.0f, 0.0f);
glRotatef(20.0f, 0.0f, 1.0f, 0.0f);
// Draw the polygons of the cube, only one face given here:
double p1[] = {-0.5, 0.5, 0.5}; double p2[] = {-0.5, -0.5, 0.5};
double p3[] = {0.5, -0.5, 0.5}; double n[3];
CalcNormal(p1, p2, p3, n);
glBegin(GL_POLYGON); // only 1 face here, other 5 must be defined
      glNormal3f((GLfloat)n[0], (GLfloat)n[1], (GLfloat)n[2]);
      glVertex3f(-0.5f, 0.5f, 0.5f);
      glVertex3f(-0.5f, -0.5f, 0.5f);
      glVertex3f(0.5f, -0.5f, 0.5f);
      glVertex3f(0.5f, 0.5f, 0.5f);
glEnd();
```

Code from CalcNormal(double *p1, double *p2, double *p3, double *n)

```
// Form two vectors from the points.
double a[3], b[3];
a[0] = p2[0] - p1[0];    a[1] = p2[1] - p1[1];    a[2] = p2[2] - p1[2];
b[0] = p3[0] - p1[0];    b[1] = p3[1] - p1[1];    b[2] = p3[2] - p1[2];
// Calculate the cross product of the two vectors.
n[0] = a[1] * b[2] - a[2] * b[1];
n[1] = a[2] * b[0] - a[0] * b[2];
n[2] = a[0] * b[1] - a[1] * b[0];
// Normalize the new vector.
double length = sqrt(n[0]*n[0]+n[1]*n[1]+n[2]*n[2]);
n[0] = n[0] / length;
n[1] = n[1] / length;
n[2] = n[2] / length;
```

Back to Hidden Surface Removal

- The Depth Sort Technique

Depth Sort Hidden Surface Removal

- Basic Idea
  - Order Polygons according to how far away from observer
  - Then “paint” them into picture, farthest first, closest last
    - Far surfaces overwritten by near surfaces
  - The way artists sometimes paint scenes

Algorithm

1. Remove back faces (preprocessing step)
2. Decompose remaining polygons into triangles
   - Depth determination easiest for triangles
3. Sort triangles into depth order
4. Apply Painters Algorithm

The Depth Sort (step 3)

For each triangle

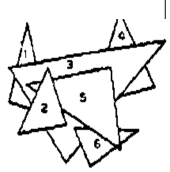
Create a linked list with pointers to all triangles in front of the triangle

And a counter of all triangles in back of the triangle

Gives an array of linked lists

An Example

triangle	counter	list
1	0	3 5 2
2	3	
3	2	2 5 6
4	0	3 5
5	4	2
6	1	5



Painter’s Algorithm (step 4)

Repeat

Go through array & draw any triangle whose counter = 0 // it’s the farthest

Decrement counter of all triangles in list of drawn triangle // since there’s 1 less in back

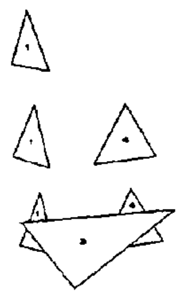
Mark counter of drawn triangle as finished

Until all triangles have been drawn

Painter's Algorithm in Action (A)

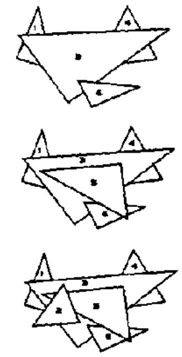
Triangle	List	Counters	Counters after
1 draw	3 5 2	0	•
2		3	2
3	2 5 6	2	1
4	3 5	0	0
5	2	4	3
6	5	1	1
1	3 5 2	•	•
2		2	2
3	2 5 6	1	0
4 draw	3 5	0	•
5	2	3	2
6	5	1	1
1	3 5 2	•	•
2		2	1
3 draw	2 5 6	0	•
4	3 5	•	•
5	2	2	1
6	5	1	0

Picture



Painter's Algorithm in Action (B)

1	3 5 2	•	•
2		1	1
3	2 5 6	•	•
4	3 5	•	•
5	2	1	0
6 draw	5	0	•
1	3 5 2	•	•
2		1	0
3	2 5 6	•	•
4	3 5	•	•
5 draw	2	0	•
6	5	•	•
1	3 5 2	•	•
2 draw		0	•
3	2 5 6	•	•
4	3 5	•	•
5	2	•	•
6	5	•	•

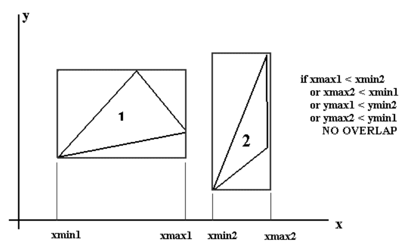


Depth Sort (Step 3) Details

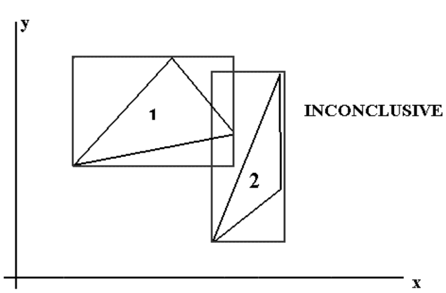
```
Initialize all triangle counters to 0
for i = 1 to n-1
    for j = i+1 to n
        if triangles i & j "overlap"
            if triangle j is "in front of" triangle i
                add triangle j to i's list
                ctr[j]++
            else
                add triangle i to j's list
                ctr[i]++
```

Determine if Triangles "overlap"

1. Mini-max test (inexpensive)
   - look at containing rectangles
   - if rectangles don't overlap, triangles don't

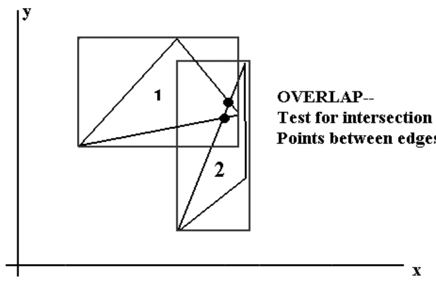


But if rectangles overlap, triangles may not



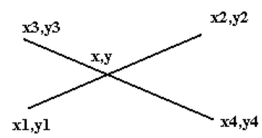
2. So check for intersections of pairs of edges
   - we're working with x-y projections
   - if projected edges intersect, triangles overlap
   - 9 tests in all
   - Can use parametric equations of edges to look for intersections

2. Test for Intersection Points between Edges



OVERLAP--
Test for intersection
Points between edges

Can Use Parametric Equations



x=x1+(x2-x1)t
y=y1+(y2-y1)t

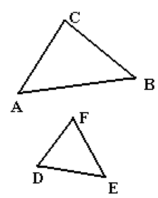
x=x3+(x4-x3)s
y=y3+(y4-y3)s

Equate & solve for s & t
If 0<=t<=1
& 0<=s<=1
the edges intersect

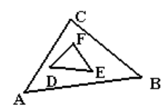
3. But if there are no intersections, triangles still could overlap

- One triangle's projection could contain the other's
- So test for containment

3. Test for Containment

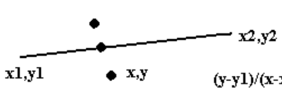


D,E,F not on same side
of AB as C ==>
DEF not contained in ABC



D on same side of BC as A
E on same side of BC as A
F on same side of BC as A
D on same side of AC as B
E on same side of AC as B
F on same side of AC as B
D on same side of AB as C
E on same side of AB as C
F on same side of AB as C
==> DEf is contained in ABC

Which Side of a Line is a Point on



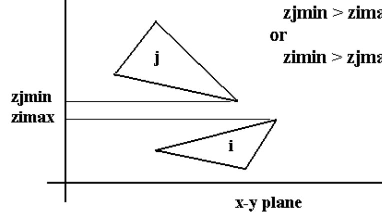
(y-y1)/(x-x1) = (y2-y1)/(x2-x1): on line
Or: (x-x1)(y2-y1) - (y-y1)(x2-x1) = 0

f(x,y) = (x-x1)(y2-y1) - (y-y1)(x2-x1)
f(x,y) = 0 ==> (x,y) on line
f(x,y) < 0 ==> (x,y) on one side of line
f(x,y) > 0 ==> (x,y) on other side of line

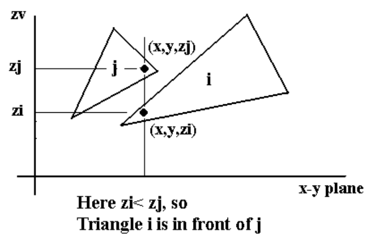
Determine which Triangle "in front"

1. Mini-max test
   - if all zv's of i's vertices < all zv's of j's, then i is in front of j

i in front of j if:
zjmin > zimax
or
zimin > zjmax

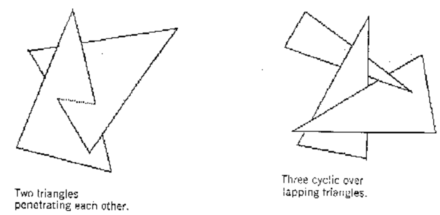


2. If test 1 inconclusive, find a point with same x,y on overlapping triangle projections & compute z for each
   - Triangle with smaller z is in front



Algorithm won't work for some cases

- Inter-penetrating triangles
- Cyclic overlapping triangles
- So decompose triangles into smaller ones

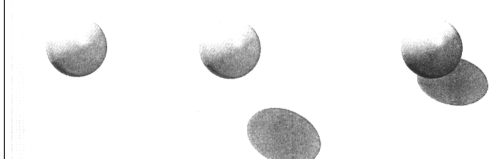


Performance of Depth Sort

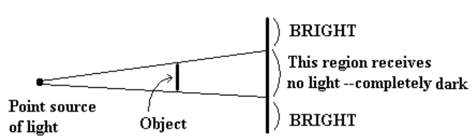
- Depends on number of polygons
- More polygons means slower
- And it's worse than linear

Shadows

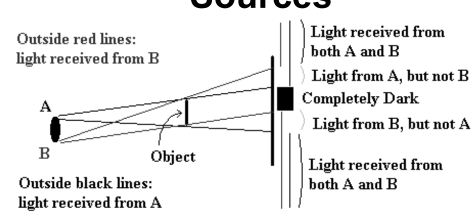
- Very important to our perception of depth
- Shadow position/orientation give information as to how objects relate to each other in space



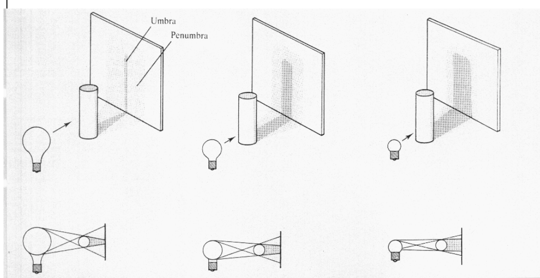
Sharp Shadows from Point Sources



Soft Shadows from Extended Sources



Umbra: central area that receives no light (complete shadow)
Penumbra: areas in partial shadow (receive light from part of source)



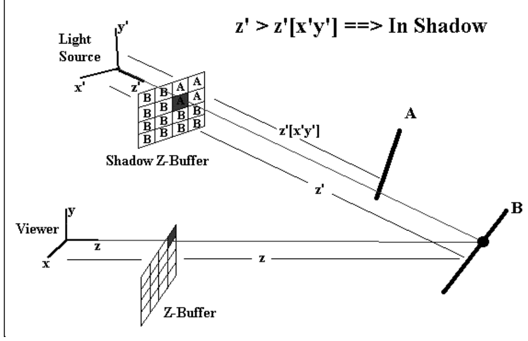
Shadows from Point Sources

- Look at shadows from point sources
- If a point is in shadow, set Phong Ip to 0
  - Source gets no light from point source
  - So no reflection from point source
  - Still must include ambient term
- Lots of algorithms
- One of simplest: Shadow Z-Buffer

Shadow Z-Buffer Algorithm

- A two-stage process
  1. Take source as viewpoint & compute depths
     - Store results in shadow Z-buffer Z'[x'y']
     - Each Z'[x',y'] will contain distance of closest surface to light source
  2. Normal Z-Buffer rendering
     - But if (x,y) is closest (visible), transform to light space coordinates (x',y',z')
     - If z' > Z'[x',y'] point is in shadow
       - Some object is closer to light & will block it
       - So only include ambient term in computation

Shadow Z-Buffer



Set up shadow Z-buf Z'[x',y'] using coordinate system whose origin is at light source

```
Z-buf[x,y]=infinity for all x,y
for each polygon
    for each pixel x,y
        calculate z
        if z < Z-buf[x,y]
            transform x,y,z to light coord space x',y',z'
            if z' > Z'[x',y']
                reduce intensity (include only ambient)
            Z-buf[x,y]=z; fb[x,y]=intensity
```