# CS6533/CS4533 Lecture 6 Slides/Notes

**Sample Code for Shader-Based OpenGL, Sphere Rolling Transformations in HW2, Polygon Scan Conversion (Handouts, Notes)**

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- Discussed the sample code ``Handout: rotoate-cube-new.cpp'' (posted at ``https://cse.engineering.nyu.edu/cs653/'' under `Handout: rotate-cube-new.cpp ("Rotate-Cube-New.tar.gz") '. You should download the source code and play with it. Use it as a starting point for HW2.

- Some screen shots of the sample code discussions with annotations are listed below.

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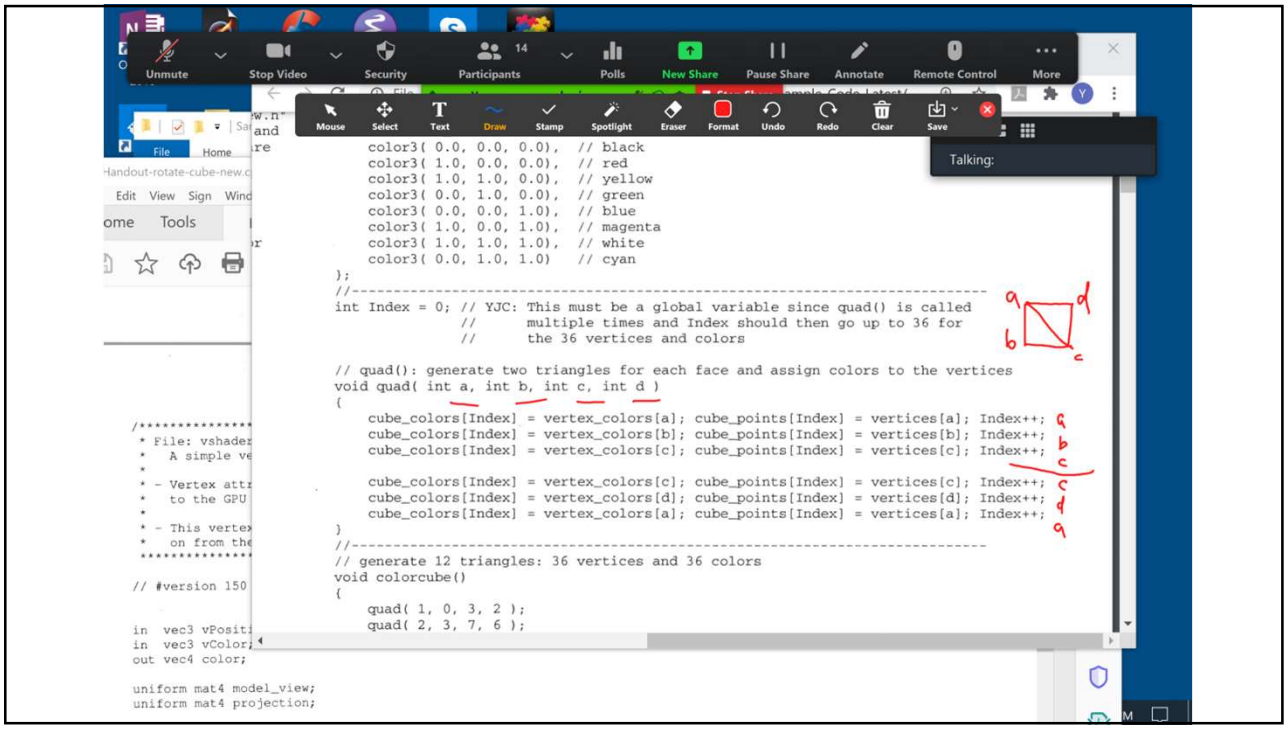
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Talking:
color3( 0.0, 0.0, 0.0), // black
color3( 1.0, 0.0, 0.0), // red
color3( 1.0, 1.0, 0.0), // yellow
color3( 0.0, 1.0, 0.0), // green
color3( 0.0, 0.0, 1.0), // blue
color3( 1.0, 0.0, 1.0), // magenta
color3( 1.0, 1.0, 1.0), // white
color3( 0.0, 1.0, 1.0) // cyan
};
int Index = 0; // YJC: This must be a global variable since quad() is called
// multiple times and Index should then go up to 36 for
// the 36 vertices and colors
// quad(): generate two triangles for each face and assign colors to the vertices
void quad( int a, int b, int c, int d )
{
cube_colors[Index] = vertex_colors[a]; cube_points[Index] = vertices[a]; Index++;
cube_colors[Index] = vertex_colors[b]; cube_points[Index] = vertices[b]; Index++;
cube_colors[Index] = vertex_colors[c]; cube_points[Index] = vertices[c]; Index++;
cube_colors[Index] = vertex_colors[c]; cube_points[Index] = vertices[c]; Index++;
cube_colors[Index] = vertex_colors[d]; cube_points[Index] = vertices[d]; Index++;
cube_colors[Index] = vertex_colors[a]; cube_points[Index] = vertices[a]; Index++;
}
// generate 12 triangles: 36 vertices and 36 colors
void colorcube()
{
quad( 1, 0, 3, 2 );
quad( 2, 3, 7, 6 );
in vec3 vPositi
in vec3 vColor;
out vec4 color;
uniform mat4 model_view;
uniform mat4 projection;

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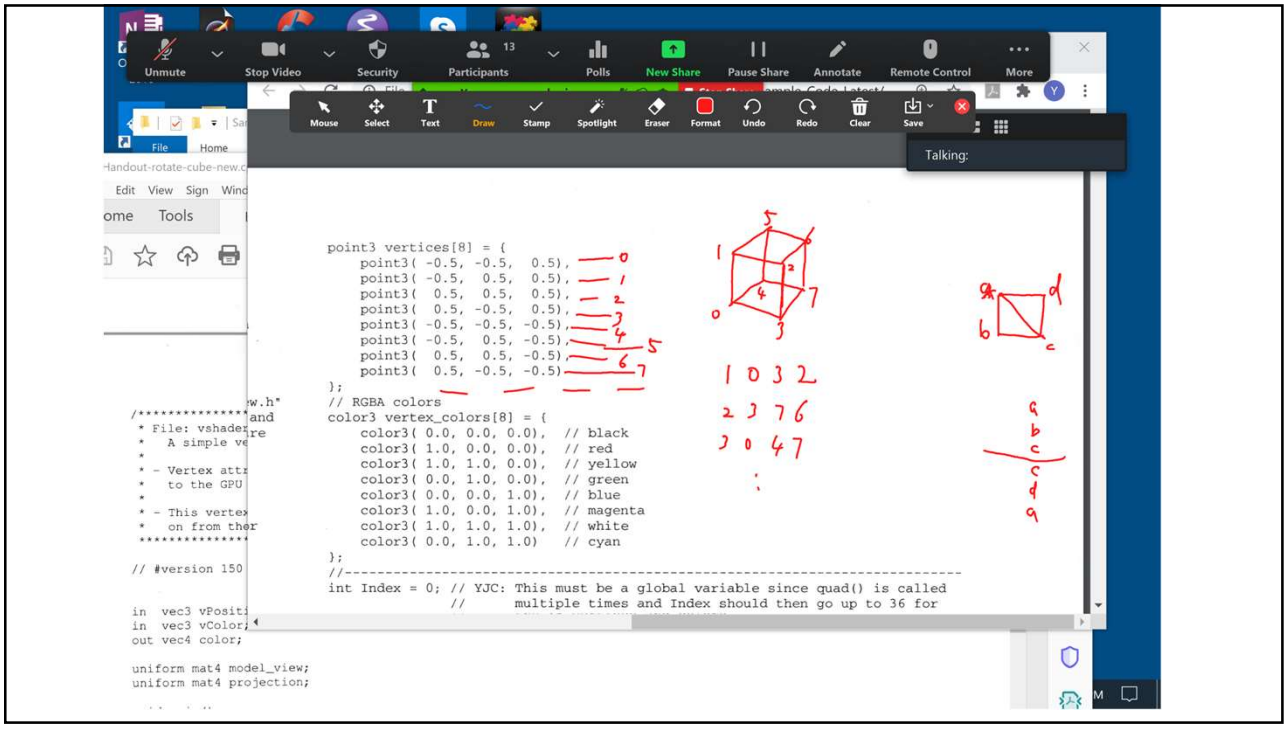
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Talking:
point3 vertices[8] = {
point3( -0.5, -0.5, 0.5),
point3( -0.5, 0.5, 0.5),
point3( 0.5, 0.5, 0.5),
point3( 0.5, -0.5, 0.5),
point3( -0.5, -0.5, -0.5),
point3( -0.5, 0.5, -0.5),
point3( 0.5, 0.5, -0.5),
point3( 0.5, -0.5, -0.5)
};
// RGBA colors
color3 vertex_colors[8] = {
color3( 0.0, 0.0, 0.0), // black
color3( 1.0, 0.0, 0.0), // red
color3( 1.0, 1.0, 0.0), // yellow
color3( 0.0, 1.0, 0.0), // green
color3( 0.0, 0.0, 1.0), // blue
color3( 1.0, 0.0, 1.0), // magenta
color3( 1.0, 1.0, 1.0), // white
color3( 0.0, 1.0, 1.0) // cyan
};
int Index = 0; // YJC: This must be a global variable since quad() is called
// multiple times and Index should then go up to 36 for
1 0 3 2
2 3 7 6
3 0 4 7

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```
                        //      the 36 vertices and colors

            // quad(): generate two triangles for each face and assign colors to the vertices
            void quad( int a, int b, int c, int d )
            {
                cube_colors[Index] = vertex_colors[a]; cube_points[Index] = vertices[a]; Index++;
                cube_colors[Index] = vertex_colors[b]; cube_points[Index] = vertices[b]; Index++;
                cube_colors[Index] = vertex_colors[c]; cube_points[Index] = vertices[c]; Index++;

                cube_colors[Index] = vertex_colors[c]; cube_points[Index] = vertices[c]; Index++;
                cube_colors[Index] = vertex_colors[d]; cube_points[Index] = vertices[d]; Index++;
                cube_colors[Index] = vertex_colors[a]; cube_points[Index] = vertices[a]; Index++;
            }
            //----------------------------------------------------------------------------
            // generate 12 triangles: 36 vertices and 36 colors
            void colorcube()
            {
                quad( 1, 0, 3, 2 );
                quad( 2, 3, 7, 6 );
                quad( 3, 0, 4, 7 );
                quad( 6, 5, 1, 2 );
                quad( 4, 5, 6, 7 );
 'A'            quad( 5, 4, 0, 1 );
            }
'C'         //-----------------------------
r 'F'       // generate 2 triangles: 6 vertices and 6 colors
            void floor()
angle)      {
                floor_colors[0] = vertex_colors[3]; floor_points[0] = vertices[3];
                floor_colors[1] = vertex_colors[0]; floor_points[1] = vertices[0];
                floor_colors[2] = vertex_colors[4]; floor_points[2] = vertices[4];

                floor_colors[3] = vertex_colors[4]; floor_points[3] = vertices[4];
```

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```
            //----------------------------------------------------------------------------
            // generate 12 triangles: 36 vertices and 36 colors
            void colorcube()
            {
                quad( 1, 0, 3, 2 );
                quad( 2, 3, 7, 6 );
                quad( 3, 0, 4, 7 );
                quad( 6, 5, 1, 2 );
                quad( 4, 5, 6, 7 );
 'A'            quad( 5, 4, 0, 1 );
            }
'C'         //-----------------------------
r 'F'       // generate 2 triangles: 6 vertices and 6 colors
            void floor()
angle)      {
                floor_colors[0] = vertex_colors[3]; floor_points[0] = vertices[3];
                floor_colors[1] = vertex_colors[0]; floor_points[1] = vertices[0];
                floor_colors[2] = vertex_colors[4]; floor_points[2] = vertices[4];

                floor_colors[3] = vertex_colors[4]; floor_points[3] = vertices[4];
                floor_colors[4] = vertex_colors[7]; floor_points[4] = vertices[7];
                floor_colors[5] = vertex_colors[3]; floor_points[5] = vertices[3];
            }
            //----------------------------------------------------------------------------
ngle)       // OpenGL initialization
            void init()
            {
                colorcube();
```

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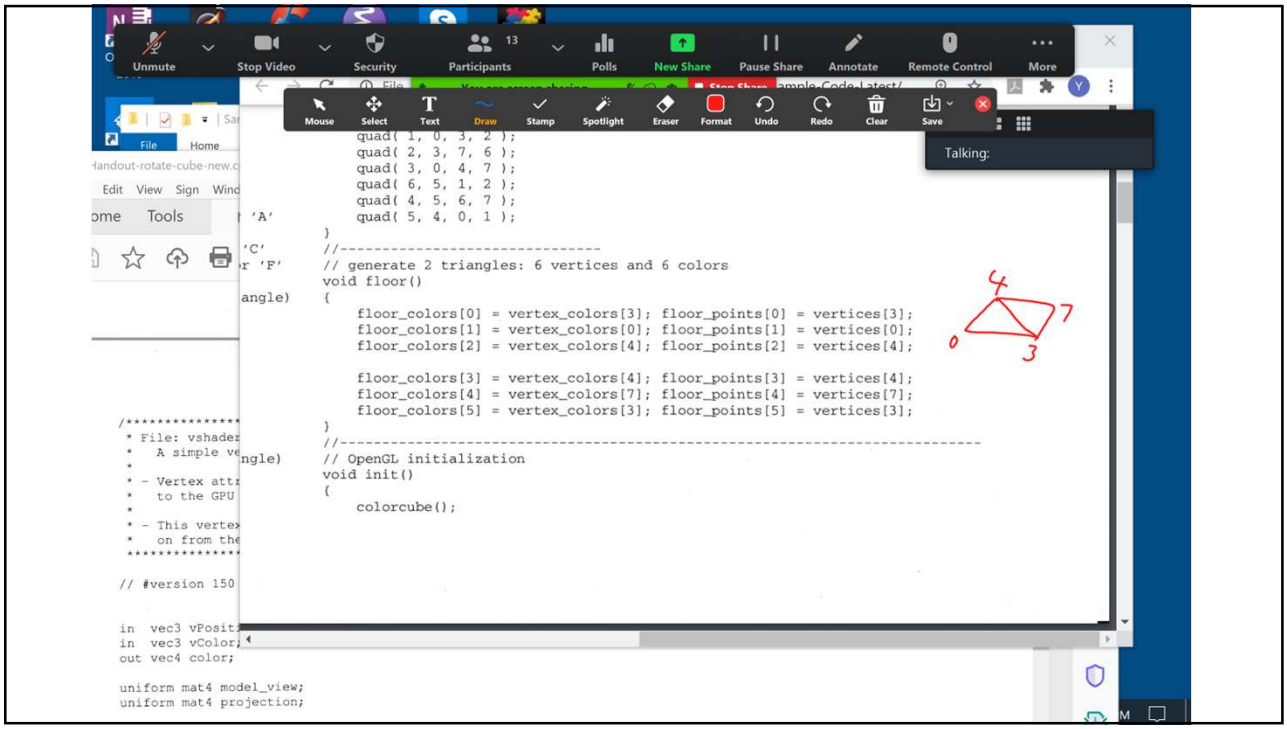
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Talking:
quad( 1, 0, 3, 2 );
quad( 2, 3, 7, 6 );
quad( 3, 0, 4, 7 );
quad( 6, 5, 1, 2 );
quad( 4, 5, 6, 7 );
quad( 5, 4, 0, 1 );
}
//----------
// generate 2 triangles: 6 vertices and 6 colors
void floor()
{
floor_colors[0] = vertex_colors[3]; floor_points[0] = vertices[3];
floor_colors[1] = vertex_colors[0]; floor_points[1] = vertices[0];
floor_colors[2] = vertex_colors[4]; floor_points[2] = vertices[4];
floor_colors[3] = vertex_colors[4]; floor_points[3] = vertices[4];
floor_colors[4] = vertex_colors[7]; floor_points[4] = vertices[7];
floor_colors[5] = vertex_colors[3]; floor_points[5] = vertices[3];
}
//----------
// OpenGL initialization
void init()
{
colorcube();
4
7
0
3
// #version 150
in vec3 vPosit
in vec3 vColor;
out vec4 color;
uniform mat4 model_view;
uniform mat4 projection;

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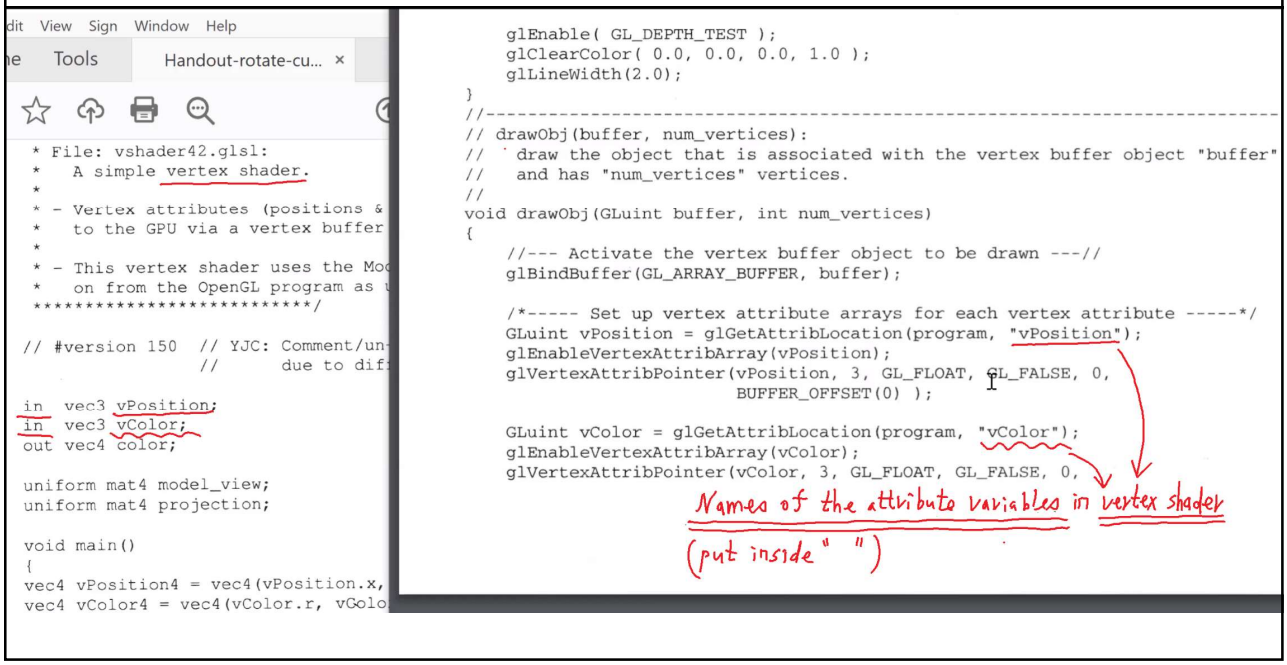
Tools
Handout-rotate-cu...
* File: vshader42.glsl:
* A simple vertex shader.
* - Vertex attributes (positions &
* to the GPU via a vertex buffer
* - This vertex shader uses the Mod
* on from the OpenGL program as u
// #version 150 // YJC: Comment/un
// due to dif
in vec3 vPosition;
in vec3 vColor;
out vec4 color;
uniform mat4 model_view;
uniform mat4 projection;
void main()
{
vec4 vPosition4 = vec4(vPosition.x,
vec4 vColor4 = vec4(vColor.r, vGolo
glEnable( GL_DEPTH_TEST );
glClearColor( 0.0, 0.0, 0.0, 1.0 );
glLineWidth(2.0);
}
// drawObj(buffer, num_vertices):
// draw the object that is associated with the vertex buffer object "buffer"
// and has "num_vertices" vertices.
void drawObj(GLuint buffer, int num_vertices)
{
//--- Activate the vertex buffer object to be drawn ---//
glBindBuffer(GL_ARRAY_BUFFER, buffer);
/*----- Set up vertex attribute arrays for each vertex attribute -----*/
GLuint vPosition = glGetAttribLocation(program, "vPosition");
glEnableVertexAttribArray(vPosition);
glVertexAttribPointer(vPosition, 3, GL_FLOAT, GL_FALSE, 0,
BUFFER_OFFSET(0) );
GLuint vColor = glGetAttribLocation(program, "vColor");
glEnableVertexAttribArray(vColor);
glVertexAttribPointer(vColor, 3, GL_FLOAT, GL_FALSE, 0,
Names of the attributes variables in vertex shader
(put inside " ")

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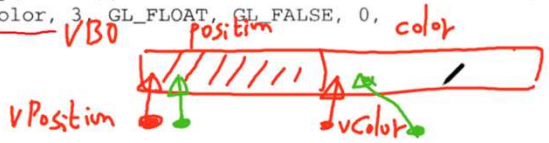
```
    program = InitShader("vshader42.glsl", "fshader42.glsl");

    glEnable( GL_DEPTH_TEST );
    glClearColor( 0.0, 0.0, 0.0, 1.0 );
    glLineWidth(2.0);

//----------------------------------------------------------------------------
// drawObj(buffer, num_vertices):
//   draw the object that is associated with the vertex buffer object "buffer"
//   and has "num_vertices" vertices.
//
void drawObj(GLuint buffer, int num_vertices)

    //--- Activate the vertex buffer object to be drawn ---//
    glBindBuffer(GL_ARRAY_BUFFER, buffer);

    /*----- Set up vertex attribute arrays for each vertex attribute -----*/
    GLuint vPosition = glGetAttribLocation(program, "vPosition");
    glEnableVertexAttribArray(vPosition);
    glVertexAttribPointer(vPosition, 3, GL_FLOAT, GL_FALSE, 0,
                          BUFFER_OFFSET(0) );

    GLuint vColor = glGetAttribLocation(program, "vColor");
    glEnableVertexAttribArray(vColor);
    glVertexAttribPointer(vColor, 3, GL_FLOAT, GL_FALSE, 0,

#endif
#if 1 // The fo
      // Commer
      // gives
  //
  // The set-up
      mv = mv *
  //
  // The set-up
  //  mv = Tran
  //
  //
  // The set-up
  //     Incorr
  //  mv = Tran
  //
  //
#endif
#if 0  // The f
       // Comme
```





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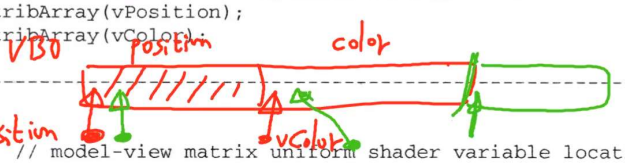
```
        {
            colorcube();
```

```
                                BUFFER_OFFSET(sizeof(point3) * num_vertices) );
          // the offset is the (total) size of the previous vertex attribute array(s)

            /* Draw a sequence of geometric objs (triangles) from the vertex buffer
               (using the attributes specified in each enabled vertex attribute array) */
            glDrawArrays(GL_TRIANGLES, 0, num_vertices);

ay()        /*--- Disable each vertex attribute array being enabled ---*/
            glDisableVertexAttribArray(vPosition);
            glDisableVertexAttribArray(vColor);
        }
        //----------------------------------------------------------------------------
        void display( void )
        {
          GLuint  model_view;  // model-view matrix uniform shader variable location
          GLuint  projection;  // projection matrix uniform shader variable location
```

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```
/*----- Set Up the Model-View matrix for the cube -----*/
#if 0 // The following is to verify the correctness of the function NormalMatrix():
      // Commenting out Rotate() and un-commenting mat4WithUpperLeftMat3()
      // gives the same result.
      mv = mv * Translate(0.0, 0.5, 0.0) * Scale (1.4, 1.4, 1.4)
             * Rotate(angle, 0.0, 0.0, 2.0);
           // * mat4WithUpperLeftMat3(NormalMatrix(Rotate(angle, 0.0, 0.0, 2.0), 1));
#endif
#if 1 // The following is to verify that Rotate() about (0,2,0) is RotateY():
      // Commenting out Rotate() and un-commenting RotateY()
      // gives the same result.
  //
  // The set-up below gives a new scene (scene 2), using Correct LookAt().
     mv = mv * Translate(0.0, 0.5, 0.0) * Scale (1.4, 1.4, 1.4)
             * Rotate(angle, 0.0, 2.0, 0.0);
           // * RotateY(angle);
  //
  // The set-up below gives the original scene (scene 1), using Correct LookAt().
  //  mv = Translate(0.0, 0.5, 0.0) * mv * Scale (1.4, 1.4, 1.4)
  //                * Rotate(angle, 0.0, 2.0, 0.0);
  //              // * RotateY(angle);
  //
  // The set-up below gives the original scene (scene 1), when using previously
  //     Incorrect LookAt() (= Translate(1.0, 1.0, 0.0) * correct LookAt() )
  //  mv = Translate(-1.0, -0.5, 0.0) * mv * Scale (1.4, 1.4, 1.4)
  //                * Rotate(angle, 0.0, 2.0, 0.0);
  //              // * RotateY(angle);
  //
#endif
#if 0  // The following is to verify that Rotate() about (3,0,0) is RotateX():
       // Commenting out Rotate() and un-commenting RotateX()
```

model-view matrix mv is set as mv ← LookAt( )* Scale( )* Rotate( ):

① First apply Rotate( ) to objects

② Then apply Scale( ) to objs

These are all in the (world frame)

③ Finally apply LookAt( ) to change to (eye frame)

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# Transformations for Sphere Rolling in HW2

- Discussed how to do transformations for sphere rolling --- there are two transformations: rotation & translation. They have to match each other (rotation amount corresponds to the distance of translation) to produce the sphere rolling effect.
- Discussed HW2 part (c): Treat each rotation segment (sphere center going from A to B, from B to C, from C to A) independently (see next slides).
- HW2 part (d) (correct rolling transition): build on top of part (c) (see the slide "HW2 Part (d)" below).

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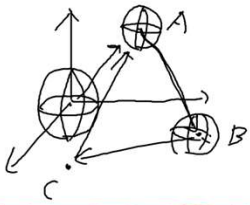
HW2: Part (c) Sphere Rolling.




Initial Sol.: Treat each rolling segment independently.


1. Rotate (angle, $V_x$, $V_y$, $V_z$)
(in degrees) Rotation axis vector

$\vec{AB}$: B − A. $\vec{OY} = (0,1,0)$

Suppose $\vec{AB} = (1,2,3)$ x) $\vec{AB} = (1,2,3)$

$\vec{OY} \times \vec{AB} = (3,0,-1) = (V_x, V_y, V_z)$

($\vec{AB} \times \vec{OY}$ is wrong: rotating backwards)

* $\vec{OY} = (0,1,0)$: normal vector to the ground.
$\vec{OY} \perp$ ground.
* Rotation axis vector $(V_x, V_y, V_z)$ is $\perp$ to both $\vec{OY}$ & $\vec{AB}$
$\Rightarrow (V_x, V_y, V_z) = \vec{OY} \times \vec{AB}$.

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(Input sphere is centered at the origin)

2. Translate ($T_x$, $T_y$, $T_z$)


$(T_x, T_y, T_z) = \vec{OA} + d \cdot \frac{\vec{AB}}{|\vec{AB}|}$ → length 1

eg. $\vec{AB} = (1,2,3)$ $\frac{\vec{AB}}{|\vec{AB}|} = \frac{(1,2,3)}{\sqrt{1^2+2^2+3^2}} = \left(\frac{1}{\sqrt{14}}, \frac{2}{\sqrt{14}}, \frac{3}{\sqrt{14}}\right)$

$\frac{360}{2\pi r} = \frac{\text{angle}}{d} \Rightarrow d = \text{angle} \cdot \frac{2\pi r}{360}$ $(r = 1)$

* Applying to the sphere:
① Rotate( )
② Translate( )
③ LookAt( )
(in this order)

* angle:
* Global variable, initially 0
* In each frame, increase its value by some fixed amount.

Note: 1. Use the variable "angle" to control both Rotate( ) and Translate( ) so that they match each other to produce the sphere rolling effect.

2. When angle > 360. do we reset angle ← 0 ? Ans: No (angle ← 0 ⇒ d = 0 This puts the sphere back to center at A.)

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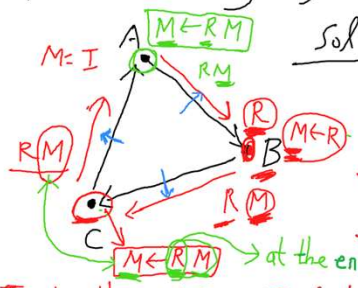
## HW2 Part (d): Fix the issue of incorrect Rolling Segment Transition.




Sol: Use a matrix M to maintain the accumulated rotation (amount) up to the end of the previous rolling segment.

Initially: $M \leftarrow I$ (identity matrix)

* Update M each time when changing the rolling segment

① M
② Rotate( )
③ Translate( )
④ LookAt( )

Rolling as in part (c) ("independently along the current seg.")

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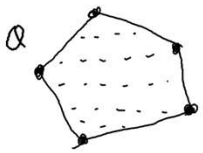
## Scan-Conversion of Polygons

Purpose: Display filled polygons.




* Use Bresenham's Alg. to draw the boundary edges of the polygon Q

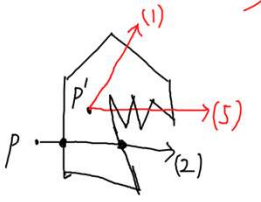
First Issue: Given the boundary, decide the interior of the polygon Q

(1) Odd-Even test
(2) Winding test

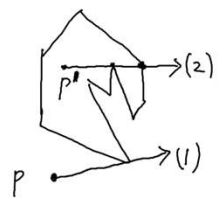
(For a pt p decide whether p is inside or outside Q)

(1) Odd-Even test:

Draw a ray from p to infinity. count # intersections between the ray and the boundary: odd: p is inside; even: p is outside




Issue: What if the ray goes thru a vertex? Degenerate cases! Singularity

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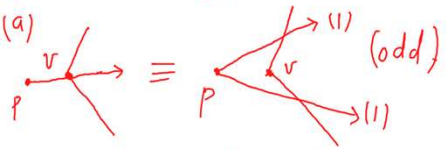
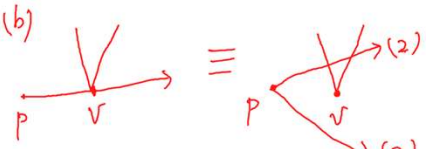
Solution : The perturbation idea:

(a)

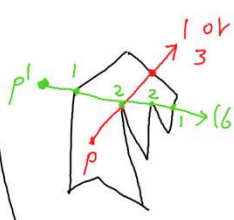



For vertex v where its 2 edges are on both sides of the ray ⇒ 1 intersection.

(b)




Both edges of v are on the same side of the ray. (even) ⇒ 0 or 2 intersections




1 or odd. 3 p is inside. ok.

(6) even. p' is outside. ok

(2) Winding Test (see next).

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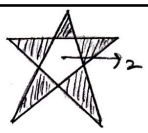


How about  ?

(2) Winding test


point P

① any ray $\overrightarrow{PQ}$ to infinity, not going thru any vertex

② $d'$: rotate $\overrightarrow{PQ}$ counter clock wise by 90°

③ Trace all edges of the polygon by following the edges to enclose the polygon ⇒ each edge is assigned a direction.

④ For each edge $e$ crossed by $\overrightarrow{PQ}$, project $e$ along $d'$: same as $d'$: +1, opposite to $d'$: -1 — once

Sum ≠ 0 : P is inside

= 0 : outside

eg: $e_1$ : -1

$e_2$ : -1

Sum = -2 ∴ P is inside

#

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Next: How do we fill the interior of a polygon?

M1: Flood Fill: ① Pick a seed pt s inside the polygon

② grow untill hitting the boundary.

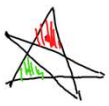

* Finding a seed s:

Lowest vertex v  go along the right edge e of v

Pick a pt to the left of e.



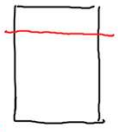
* If the polygon boundary crosses itself. then we need a seed in each region.

eg. 

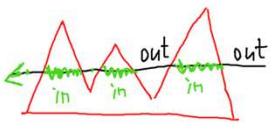
For a simple polygon (boundary never crosses) a single seed is enough.

M2: Scan-line Algorithm.

Def: Scan line: A horizontal line of pixels that goes thru the frame buffer end to end

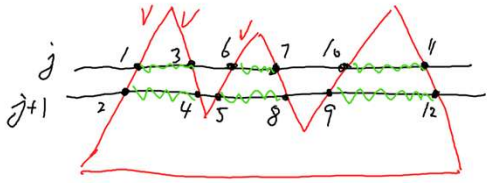


* Use odd-even test



* For each scan line, maintain a list of intersections with the polygon boundary sorted left-to-right:

⇒ Use y-x algorithm:

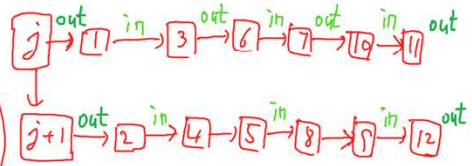



① Create a bucket for each scan line.

② Process each edge, put the intersections with the scan lines to the corresponding buckets. (when drawing each pt on the edge, its y-value indicates the scan line intersected)

(scan lines are ordered by y-values)

③ Each pt is inserted to the bucket by insertion sort according to the x-value. (left → right)




Q: In step ②, if we instead process each scan line and try to find its intersections with edges, ?

Ans: Correct, but inefficient.
Need to check each edge, but may find No intersection. (wasted ops)

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