# Building Models

CS 537 Interactive Computer Graphics
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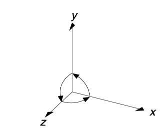
# Objectives

- Introduce simple data structures for building polygonal models
  - Vertex lists
  - Edge lists

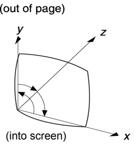



# Representation of 3D Transformations

- *Z* axis represents depth
- Right Handed System
  - When looking "down" at the origin, positive rotation is CCW




- Left Handed System
  - When looking "down", positive rotation is in CW
  - More natural interpretation for displays, big *z* means "far"

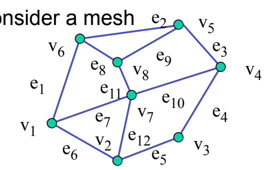






# Representing a Mesh

- Consider a mesh




- There are 8 nodes and 12 edges
  - 5 interior polygons
  - 6 interior (shared) edges
- Each vertex has a location $v_i = (x_i\ y_i\ z_i)$




# Simple Representation

- Define each polygon by the geometric locations of its vertices
- Leads to OpenGL code such as

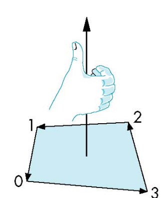
```
vertex[i] = vec3(x1, y1, z1);
vertex[i+1] = vec3(x6, y6, z6);
vertex[i+2] = vec3(x7, y7, z7);
i+=3;
```

- Inefficient and unstructured
  - Consider moving a vertex to a new location
  - Must search for all occurrences




# Inward and Outward Facing Polygons

- The order $\{v_1, v_6, v_7\}$ and $\{v_6, v_7, v_1\}$ are equivalent in that the same polygon will be rendered by OpenGL but the order $\{v_1, v_7, v_6\}$ is different
- The first two describe *outwardly facing* polygons
- Use the *right-hand rule* = counter-clockwise encirclement of outward-pointing normal
- OpenGL can treat inward and outward facing polygons differently



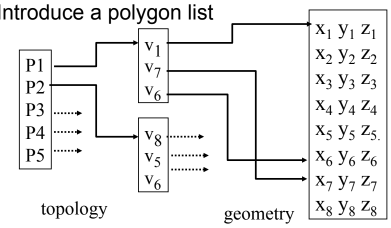
## Geometry vs Topology

- Generally it is a good idea to look for data structures that separate the geometry from the topology
  - Geometry: locations of the vertices
  - Topology: organization of the vertices and edges
  - Example: a polygon is an ordered list of vertices with an edge connecting successive pairs of vertices and the last to the first
  - Topology holds even if geometry changes



## Vertex Lists

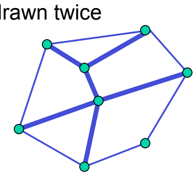
- Put the geometry in an array
- Use pointers from the vertices into this array
- Introduce a polygon list






## Shared Edges

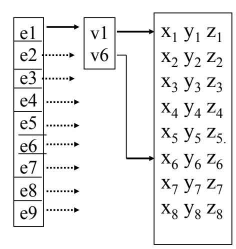
- Vertex lists will draw filled polygons correctly but if we draw the polygon by its edges, shared edges are drawn twice

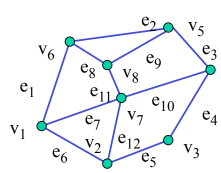


- Can store mesh by *edge list*



## Edge List




Note polygons are not represented



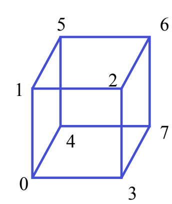
## Rotating Cube

- Full example
- Model Colored Cube
- Use 3 button mouse to change direction of rotation
- Use idle function to increment angle of rotation



## Draw cube from faces

```
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 );
    quad( 5, 4, 0, 1 );
}
```




Note that vertices are ordered so that we obtain correct outward facing normals

## Cube Vertices

```
// Vertices of a unit cube centered at origin
//  sides aligned with axes
point4 vertices[8] = {
    point4( -0.5, -0.5,  0.5, 1.0 ),
    point4( -0.5,  0.5,  0.5, 1.0 ),
    point4(  0.5,  0.5,  0.5, 1.0 ),
    point4(  0.5, -0.5,  0.5, 1.0 ),
    point4( -0.5, -0.5, -0.5, 1.0 ),
    point4( -0.5,  0.5, -0.5, 1.0 ),
    point4(  0.5,  0.5, -0.5, 1.0 ),
    point4(  0.5, -0.5, -0.5, 1.0 )
};
```



## Colors

```
// RGBA colors
color4 vertex_colors[8] = {
    color4( 0.0, 0.0, 0.0, 1.0 ),  // black
    color4( 1.0, 0.0, 0.0, 1.0 ),  // red
    color4( 1.0, 1.0, 0.0, 1.0 ),  // yellow
    color4( 0.0, 1.0, 0.0, 1.0 ),  // green
    color4( 0.0, 0.0, 1.0, 1.0 ),  // blue
    color4( 1.0, 0.0, 1.0, 1.0 ),  // magenta
    color4( 1.0, 1.0, 1.0, 1.0 ),  // white
    color4( 0.0, 1.0, 1.0, 1.0 )   // cyan
};
```



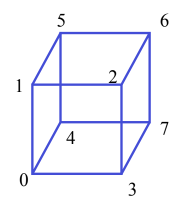
## Quad Function

```
// quad generates two triangles for each face and assigns colors
//    to the vertices
int Index = 0;
void quad( int a, int b, int c, int d )
{
    colors[Index] = vertex_colors[a]; points[Index] = vertices[a]; Index++;
    colors[Index] = vertex_colors[b]; points[Index] = vertices[b]; Index++;
    colors[Index] = vertex_colors[c]; points[Index] = vertices[c]; Index++;
    colors[Index] = vertex_colors[a]; points[Index] = vertices[a]; Index++;
    colors[Index] = vertex_colors[c]; points[Index] = vertices[c]; Index++;
    colors[Index] = vertex_colors[d]; points[Index] = vertices[d]; Index++;
}
```



## Color Cube

```
// 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 );
    quad( 5, 4, 0, 1 );
}
```






## Initialization I

```
void
init()
{
    colorcube();

    // Create a vertex array object

    GLuint vao;
    glGenVertexArrays ( 1, &vao );
    glBindVertexArray ( vao );
```



## Initialization II

```
// Create and initialize a buffer object
    GLuint buffer;
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof(points) +
      sizeof(colors), NULL, GL_STATIC_DRAW );
    glBufferSubData( GL_ARRAY_BUFFER, 0,
       sizeof(points), points );
    glBufferSubData( GL_ARRAY_BUFFER, sizeof(points),
       sizeof(colors), colors );
// Load shaders and use the resulting shader program
    GLuint program = InitShader( "vshdrcube.glsl", "fshdrcube.glsl" );
    glUseProgram( program );
```

## Initialization III

```
// set up vertex arrays
   GLuint vPosition = glGetAttribLocation( program, "vPosition" );
   glEnableVertexAttribArray( vPosition );
   glVertexAttribPointer( vPosition, 4, GL_FLOAT, GL_FALSE, 0,
                 BUFFER_OFFSET(0) );

   GLuint vColor = glGetAttribLocation( program, "vColor" );
   glEnableVertexAttribArray( vColor );
   glVertexAttribPointer( vColor, 4, GL_FLOAT, GL_FALSE, 0,
                 BUFFER_OFFSET(sizeof(points)) );

   Glint thetaLoc = glGetUniformLocation( program, "theta" );
```



## Display Callback

```
void
display( void )
{
   glClear( GL_COLOR_BUFFER_BIT
                    | GL_DEPTH_BUFFER_BIT );

   glUniform3fv( thetaLoc, 1, theta );
   glDrawArrays( GL_TRIANGLES, 0, NumVertices );

   glutSwapBuffers();
}
```



## OpenGL code

- Remember that matrices are column major order in GLSL, so …

Transpose your matrices when sending them to the shaders!

```
glUniformMatrix4fv(matrix_loc, 1, GL_TRUE,
                         model_view);
```



## Mouse Callback

```
void
mouse( int button, int state, int x, int y )
{
   if ( state == GLUT_DOWN ) {
      switch( button ) {
         case GLUT_LEFT_BUTTON:    axis = Xaxis;  break;
         case GLUT_MIDDLE_BUTTON:  axis = Yaxis;  break;
         case GLUT_RIGHT_BUTTON:   axis = Zaxis;  break;
      }
   }
}
```



## Idle Callback

```
void
idle( void )
{
   theta[axis] += 0.01;

   if ( theta[axis] > 360.0 ) {
      theta[axis] -= 360.0;
   }

   glutPostRedisplay();
}
```



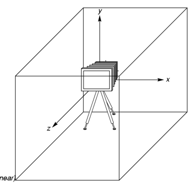
## Transforming Each Vertex

```
in vec4 vPosition, vColor;
out vec4 color;
uniform mat4 rot;

void main()
{
  gl_Position = rot * vPosition;
  color = vColor;
}
```

## OpenGL Default View Volume

- The default viewing volume is a box centered at the origin with sides of length 2
- (-1,-1,-1) ➔ (1,1,1)
- All geometry in box is parallel-projected into the z=0 plane!
- Then rendered






## Go to Assignment 4



## Assignment 4 Suggestions

- Define cube geometry and color in init()
- Keyboard callback
  - Figures out how to change transformation values
  - Calculates new transformation matrix, that includes scale, rotation and translation, and sends it the GPU via a uniform variable
  - Calls glutPostRedisplay()
- Display function draws cube
- Vertex shader applies transformation matrix to vertices



## Classical Viewing



## Objectives

- Introduce the classical views
- Compare and contrast image formation by computer with how images have been formed by architects, artists, and engineers
- Learn the benefits and drawbacks of each type of view



## Classical Viewing

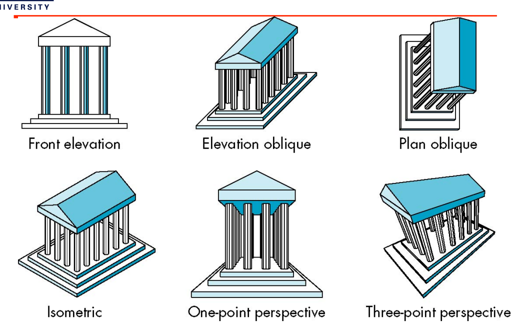
- Viewing requires three basic elements
  - One or more objects
  - A viewer with a projection surface
  - Projectors that go from the object(s) to the projection surface
- Classical views are based on the relationship among these elements
  - The viewer picks up the object and orients it how she would like to see it
- Each object is assumed to constructed from flat *principal faces*
  - Buildings, polyhedra, manufactured objects

## Planar Geometric Projections

- Standard projections project onto a plane
- Projectors are lines that either
  - converge at a center of projection
  - are parallel
- Such projections preserve lines
  - but not necessarily angles
- Nonplanar projections are needed for applications such as map construction



## Classical Projections



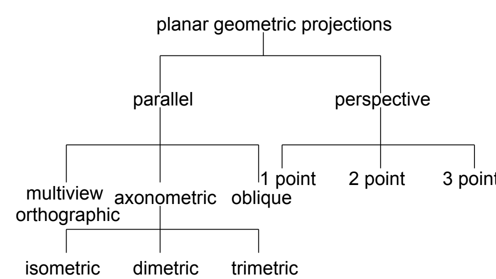



## Perspective vs Parallel

- Computer graphics treats all projections the same and implements them with a single pipeline
- Classical viewing developed different techniques for drawing each type of projection
- Fundamental distinction is between parallel and perspective viewing even though mathematically parallel viewing is the limit of perspective viewing

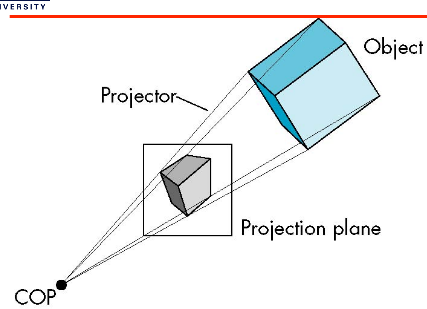


## Taxonomy of Planar Geometric Projections



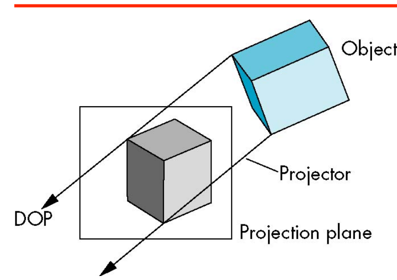



## Perspective Projection



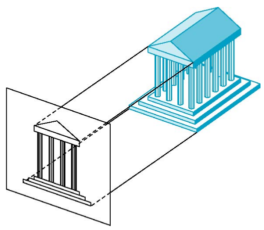



## Parallel Projection



## Orthographic Projection

Projectors are orthogonal to projection surface



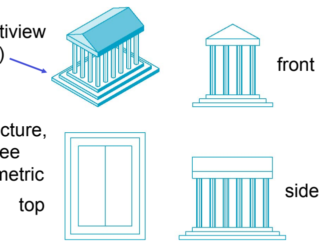


## Multiview Orthographic Projection

- Projection plane parallel to principal face
- Usually form front, top, side views

isometric (not multiview orthographic view)

in CAD and architecture, we often display three multiviews plus isometric






## Advantages and Disadvantages

- Preserves both distances and angles
  - Shapes preserved
  - Can be used for measurements
    - Building plans
    - Manuals
- Cannot see what object really looks like because many surfaces hidden from view
  - Often we add the isometric

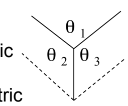


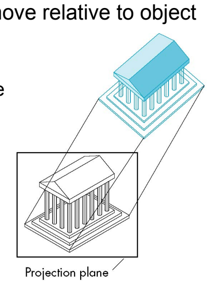
## Axonometric Projections

Allow projection plane to move relative to object

classify by how many angles of a corner of a projected cube are the same

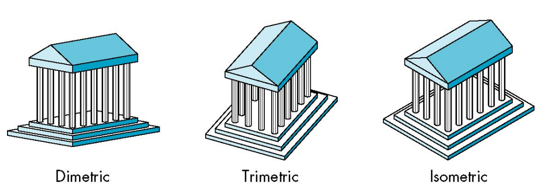
none: trimetric
two: dimetric
three: isometric






## Types of Axonometric Projections



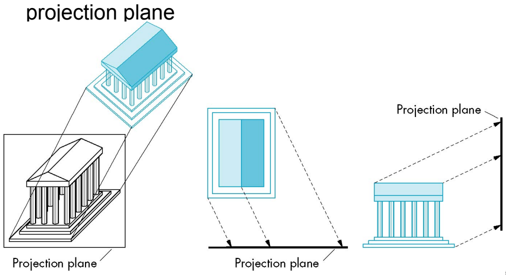



## Advantages and Disadvantages

- Lines are scaled (*foreshortened*) but can find scaling factors
- Lines preserved but angles are not
  - Projection of a circle in a plane not parallel to the projection plane is an ellipse
- Can see three principal faces of a box-like object
- Some optical illusions possible
  - Parallel lines appear to diverge
- Does not look real because far objects are scaled the same as near objects
- Used in CAD applications

## Oblique Projection

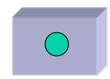
Arbitrary relationship between projectors and projection plane






## Advantages and Disadvantages

- Can pick the angles to emphasize a particular face
  - Architecture: plan oblique, elevation oblique
- Angles in faces parallel to projection plane are preserved while we can still see "around" side

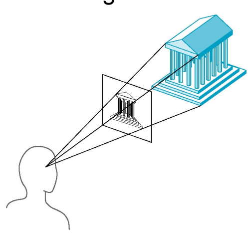


- In physical world, cannot create with simple camera; possible with bellows camera or special lens (architectural)



## Perspective Projection

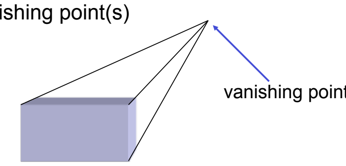
Projectors coverge at center of projection





## Vanishing Points

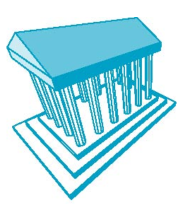
- Parallel lines (not parallel to the projection plan) on the object converge at a single point in the projection (the *vanishing point*)
- Drawing simple perspectives by hand uses these vanishing point(s)






## Three-Point Perspective

- No principal face parallel to projection plane
- Three vanishing points for cube





## Two-Point Perspective

- One principal direction parallel to projection plane
- Two vanishing points for cube

## One-Point Perspective

- One principal face parallel to projection plane
- One vanishing point for cube



## Advantages and Disadvantages

- Objects further from viewer are projected smaller than the same sized objects closer to the viewer (*diminution*)
  - Looks realistic
- Equal distances along a line are not projected into equal distances (*nonuniform foreshortening*)
- Angles preserved only in planes parallel to the projection plane
- More difficult to construct by hand than parallel projections (but not more difficult by computer)



## Taxonomy of Planar Geometric Projections