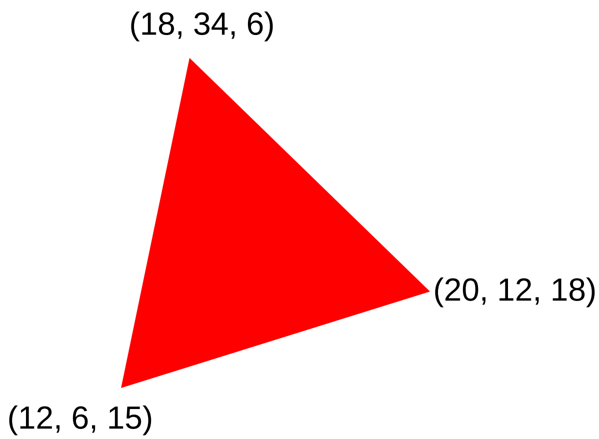
New Way: Vertex Representation and Storage

- We have declare vertex lists, edge lists and arrays
- But vertex data usually passed to OpenGL in array with specific structure
- We now study that structure….

Vertex Attributes

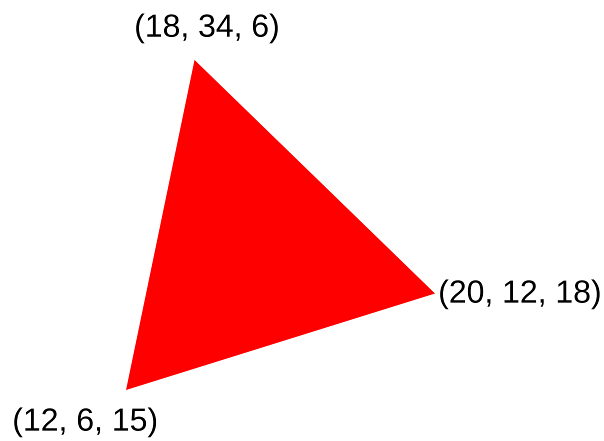


- Vertices can have attributes
  - Position (e.g 20, 12, 18)
  - Color (e.g. red)
  - Normal (x,y,z)
  - Texture coordinates

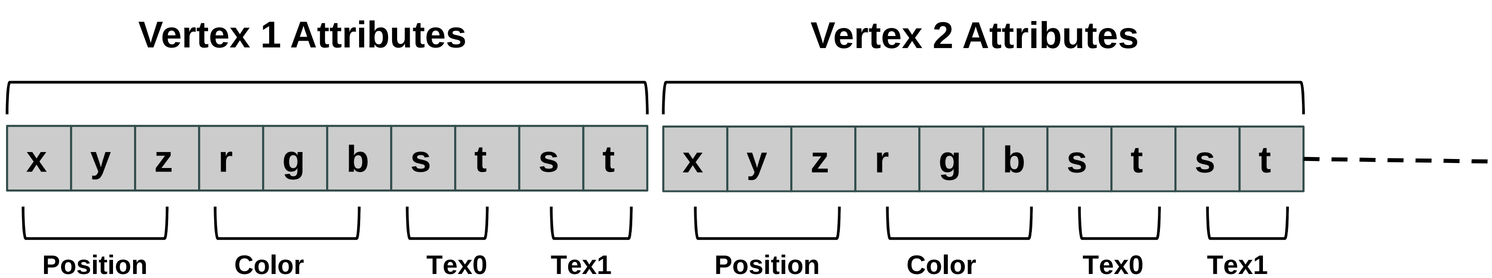
Vertex Arrays

- **Previously:** OpenGL provided a facility called ***vertex arrays*** for storing rendering data
- Six types of arrays were supported initially
  - Vertices
  - Colors
  - Color indices
  - Normals
  - Texture coordinates
  - Edge flags
- Now vertex arrays can be used for **any attributes**

Vertex Attributes

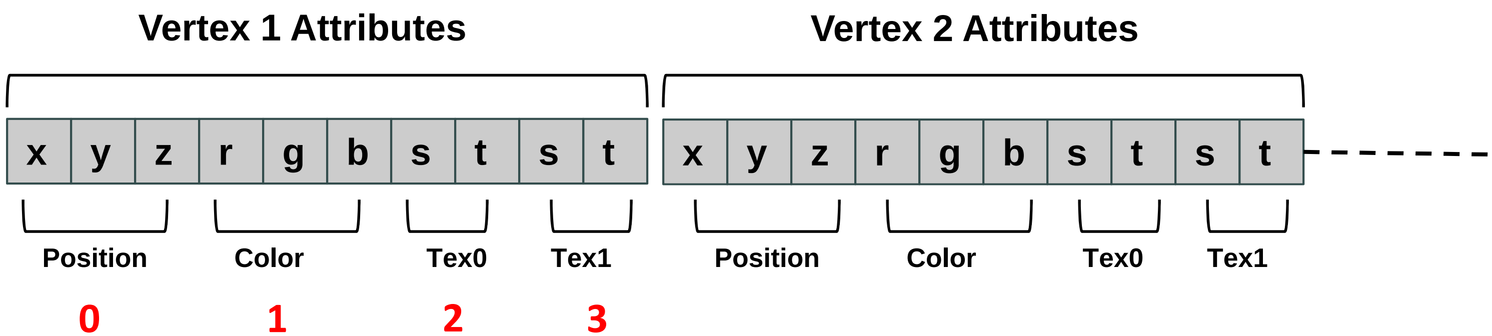


- Store vertex attributes in single Array (array of structures)



Declaring Array of Vertex Attributes

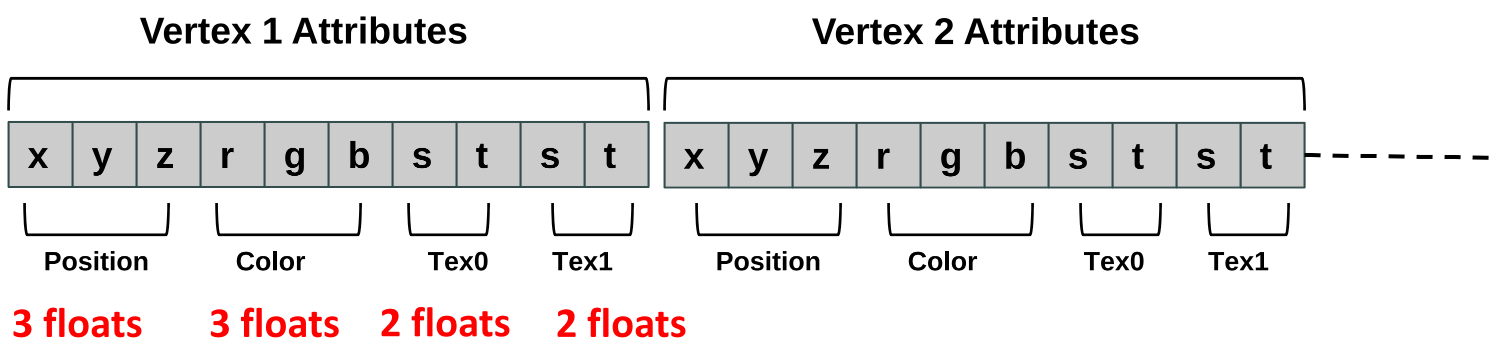
- Consider the following array of vertex attributes



- So we can define attribute positions (per vertex)

```
#define VERTEX_POS_INDEX          0
#define VERTEX_COLOR_INDEX        1
#define VERTEX_TEXCOORD0_INDX     2
#define VERTEX_TEXCOORD1_INDX     3
```

Declaring Array of Vertex Attributes

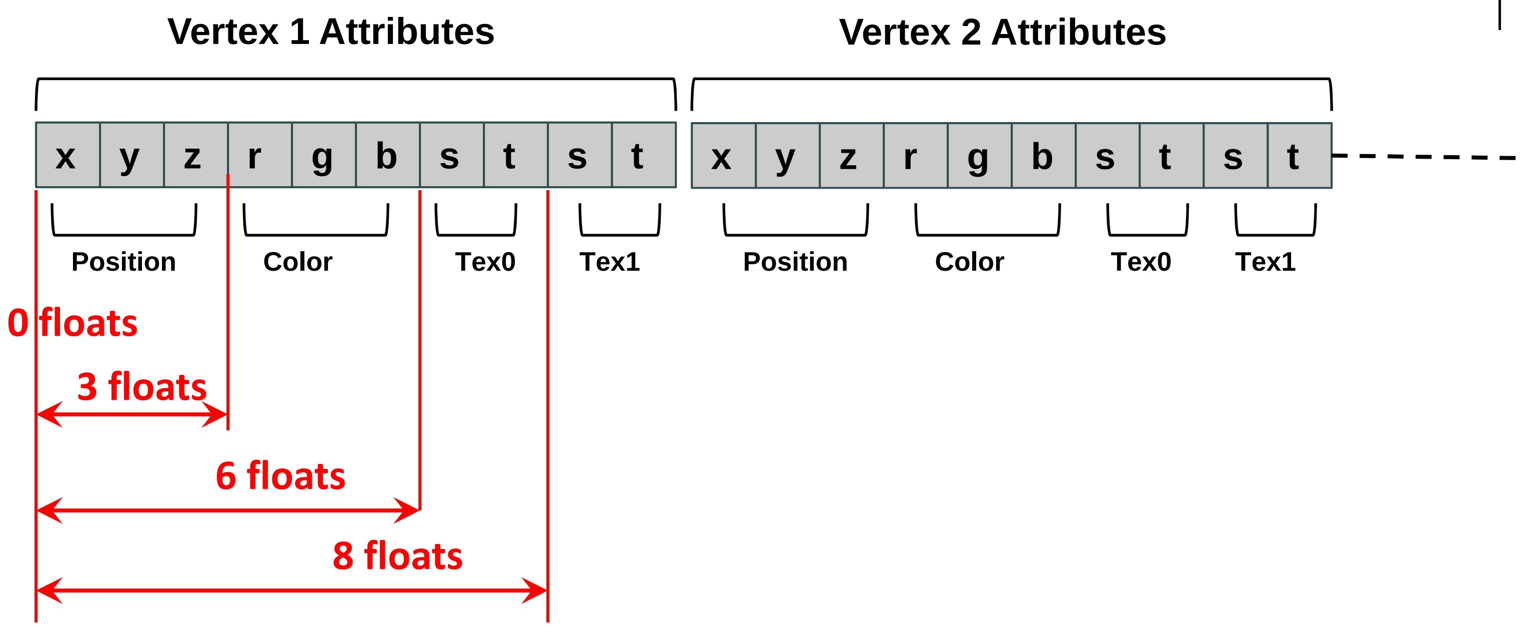


- Also define number of floats (storage) for each vertex attribute

```
#define VERTEX_POS_SIZE             3    // x, y and z
#define VERTEX_COLOR_SIZE           3    // r, g and b
#define VERTEX_TEXCOORD0_SIZE       2    // s and t
#define VERTEX_TEXCOORD1_SIZE       2    // s and t

#define VERTEX_ATTRIB_SIZE    VERTEX_POS_SIZE + VERTEX_COLOR_SIZE + \
                              VERTEX_TEXCOORD0_SIZE + \
                              VERTEX_TEXCOORD1_SIZE
```

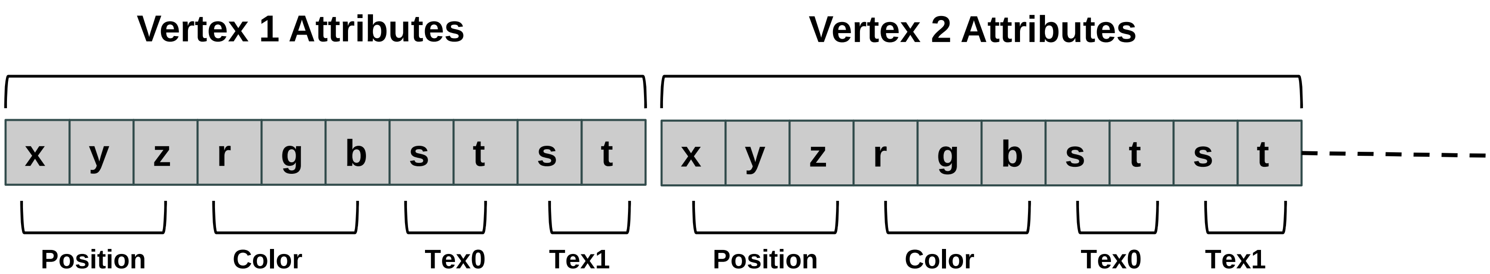
Declaring Array of Vertex Attributes



- Define offsets (# of floats) of each vertex attribute from beginning

```
#define VERTEX_POS_OFFSET           0
#define VERTEX_COLOR_OFFSET         3
#define VERTEX_TEXCOORD0_OFFSET     6
#define VERTEX_TEXCOORD1_OFFSET     8
```

Allocating Array of Vertex Attributes



- Allocate memory for entire array of vertex attributes

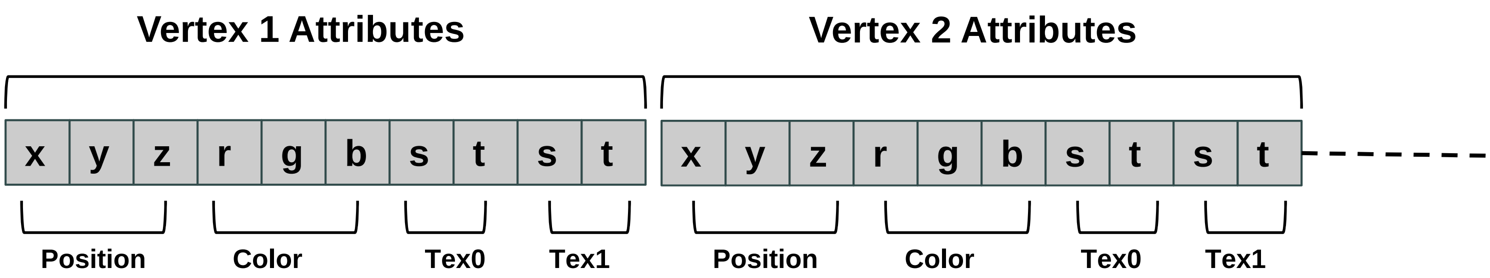
Recall

```
#define VERTEX_ATTRIB_SIZE    VERTEX_POS_SIZE + VERTEX_COLOR_SIZE + \
                              VERTEX_TEXCOORD0_SIZE + \
                              VERTEX_TEXCOORD1_SIZE
```

```
float *p = malloc(numVertices * VERTEX_ATTRIB_SIZE * sizeof(float));
```

Allocate memory for all vertices

Specifying Array of Vertex Attributes



- **glVertexAttribPointer** used to specify vertex attributes
- Example: to specify vertex position attribute

Position 0

3 values (x, y, z)

```
glVertexAttribPointer(VERTEX_POS_INDX, VERTEX_POS_SIZE,
                      GL_FLOAT, GL_FALSE,
                      VERTEX_ATTRIB_SIZE * sizeof(float), p);
```

Data should not Be normalized

Data is floats

Stride: distance between consecutive vertices

Pointer to data

```
glEnableVertexAttribArray(0);
```

- `do same for normal, tex0 and tex1`

Computer Graphics (CS 4731)
Lecture 8: Building 3D Models & Introduction to Transformations

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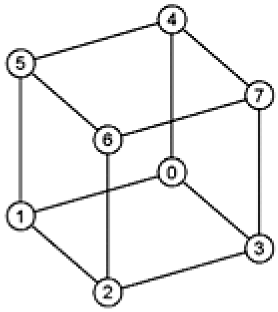
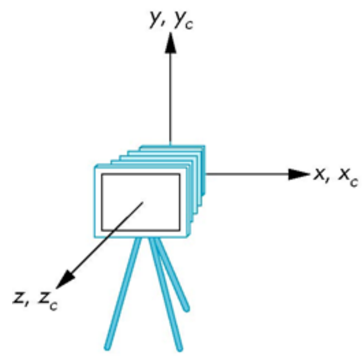
Full Example: Rotating Cube in 3D

- **Desired Program behaviour:**
  - Draw colored cube
  - Continuous rotation about X,Y or Z axis
    - Idle function called repeatedly when nothing to do
    - Increment angle of rotation in idle function
  - Use 3-button mouse to change direction of rotation
    - Click left button -> rotate cube around X axis
    - Click middle button -> rotate cube around Y axis
    - Click right button -> rotate cube around Z axis



- Use default camera
  - If we don't set camera, we get a default camera
  - Located at origin and points in the negative z direction

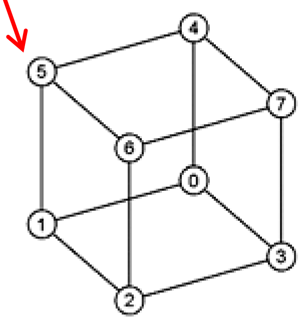


(a)

Cube Vertices

Declare array of (x,y,z,w) vertex positions
for a unit cube centered at origin
(Sides aligned with axes)

```
point4 vertices[8] = {
0  point4( -0.5, -0.5,  0.5, 1.0 ),
1  point4( -0.5,  0.5,  0.5, 1.0 ),
2  point4(  0.5,  0.5,  0.5, 1.0 ),
3  point4(  0.5, -0.5,  0.5, 1.0 ),
4  point4( -0.5, -0.5, -0.5, 1.0 ),
5  point4( -0.5,  0.5, -0.5, 1.0 ),
6  point4(  0.5,  0.5, -0.5, 1.0 ),
7  point4(  0.5, -0.5, -0.5, 1.0 )
};
```



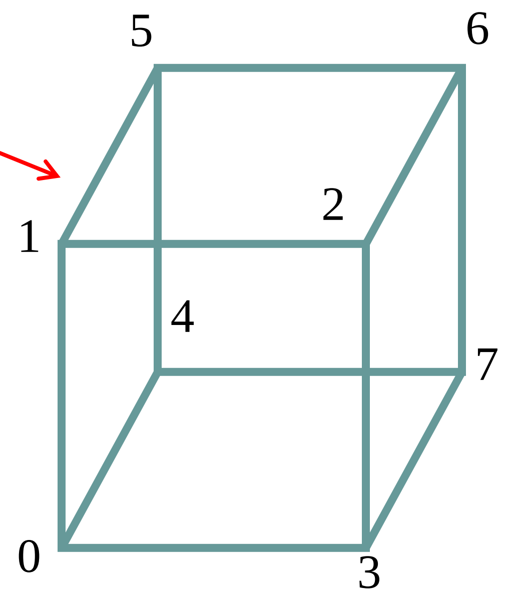

```
color4 vertex_colors[8] = {
    color4( 0.0, 0.0, 0.0, 1.0 ),  // black
    color4( 1.0, 0.0, 0.0, 1.0 ),  // red
    color4( 1.0, 1.0, 0.0, 1.0 ),  // yellow
    color4( 0.0, 1.0, 0.0, 1.0 ),  // green
    color4( 0.0, 0.0, 1.0, 1.0 ),  // blue
    color4( 1.0, 0.0, 1.0, 1.0 ),  // magenta
    color4(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

Declare array of vertex colors
(set of RGBA colors vertex can have)

Color Cube

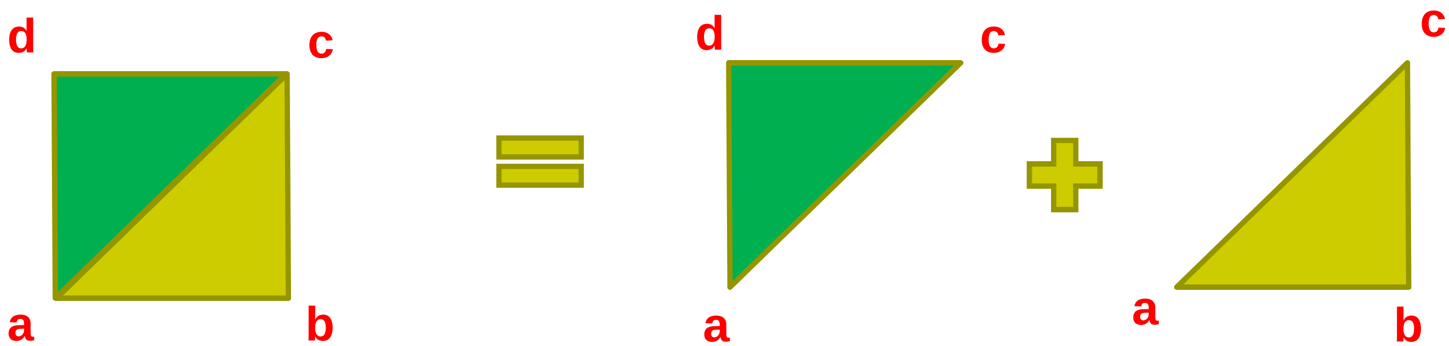
```
// generate 6 quads,
// sides of cube

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 );
}
```

```
point4 vertices[8] = {
  0 point4( -0.5, -0.5,  0.5, 1.0 ),
  1 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 ),
  4 point4( -0.5, -0.5, -0.5, 1.0 ),
  5 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 )
};
```



Function **quad** is
Passed vertex indices

Quad Function




```
// quad generates two triangles (a,b,c) and (a,c,d) for each face
// and assigns colors to the vertices

int Index = 0;  // Index goes 0 to 5, one for each vertex of face

void quad( int a, int b, int c, int d )
{
 0  colors[Index] = vertex_colors[a]; points[Index] = vertices[a]; Index++;
 1  colors[Index] = vertex_colors[b]; points[Index] = vertices[b]; Index++;
 2  colors[Index] = vertex_colors[c]; points[Index] = vertices[c]; Index++;
 3  colors[Index] = vertex_colors[a]; points[Index] = vertices[a]; Index++;
 4  colors[Index] = vertex_colors[c]; points[Index] = vertices[c]; Index++;
 5  colors[Index] = vertex_colors[d]; points[Index] = vertices[d]; Index++;
}
```

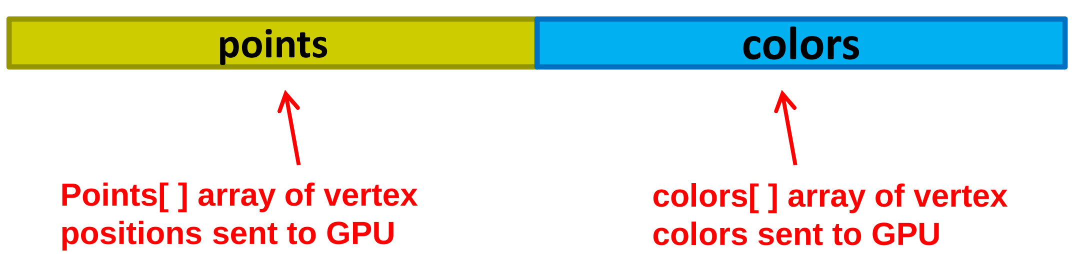
quad 0 = points[0 - 5]
quad 1 = points[6 – 11]
quad 2 = points [12 – 17] …etc

Points[ ] array to be Sent to GPU

Read from appropriate index of unique positions declared

Initialization I

```
void init()
{
    colorcube(); // Generates cube data in application using quads

    // Create a vertex array object
    GLuint vao;
    glGenVertexArrays ( 1, &vao );
    glBindVertexArray ( vao );

    // Create a buffer object and move data to GPU
    GLuint buffer;
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof(points) +
                                     sizeof(colors), NULL, GL_STATIC_DRAW );
```



Initialization II

Send points[ ] and colors[ ] data to GPU separately using **`glBufferSubData`**

```
glBufferSubData( GL_ARRAY_BUFFER, 0, sizeof(points), points );
glBufferSubData( GL_ARRAY_BUFFER, sizeof(points), sizeof(colors), colors );
```


```
// Load vertex and fragment shaders and use the resulting shader program
GLuint program = InitShader( "vshader36.glsl", "fshader36.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)) );
```

Specify vertex data

Specify color data

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

Want to Connect rotation variable theta in program to variable in shader

Display Callback

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

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

    glutSwapBuffers();
}
```

Draw series of triangles forming cube

Mouse Callback

```
…
enum { Xaxis = 0, Yaxis = 1, Zaxis = 2, NumAxes = 3 };


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;
        }
    }
}
```

Select axis (x,y,z) to rotate around
Using mouse click

Idle Callback

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

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

    glutPostRedisplay();
}
```

The idle( ) function is called whenever nothing to do

Use it to increment rotation angle in steps of theta = 0.01 around currently selected axis

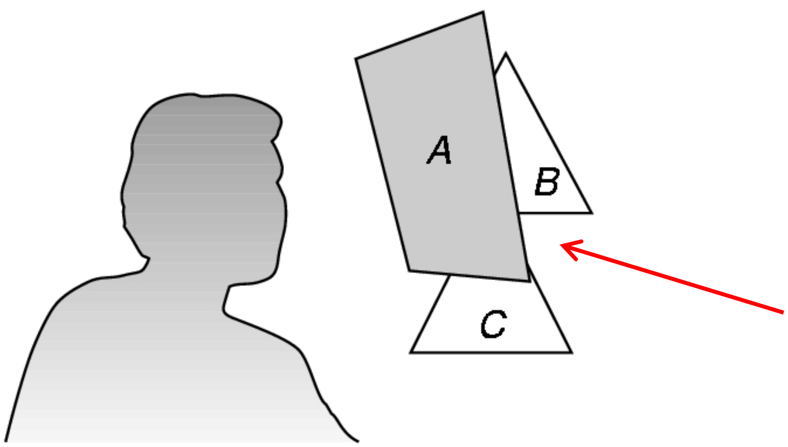
```
void main( void ){
  ………
  glutIdleFunc( idle );
  ………
}
```

Note: still need to:

- Apply rotation by (theta) in shader

Hidden-Surface Removal

- We want to see only surfaces in front of other surfaces
- OpenGL uses *hidden-surface* technique called the ***z-buffer*** algorithm
- Z-buffer uses distance from viewer (depth) to determine closer objects
- Objects rendered so that only front objects appear in image



If overlap,
Draw face **A** (front face)
Do not draw faces **B** and **C**

Using OpenGL's *z*-buffer algorithm

- Z-buffer uses an extra buffer, (the z-buffer), to store depth information as geometry travels down the pipeline
- 3 steps to set up Z-buffer:
  1. In **`main( )`** function

     ```
     glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH)
     ```

  2. Enabled in **`init( )`** function

     ```
     glEnable(GL_DEPTH_TEST)
     ```

  3. Clear depth buffer whenever we clear screen

     ```
     glClear(GL_COLOR_BUFFER_BIT | DEPTH_BUFFER_BIT)
     ```

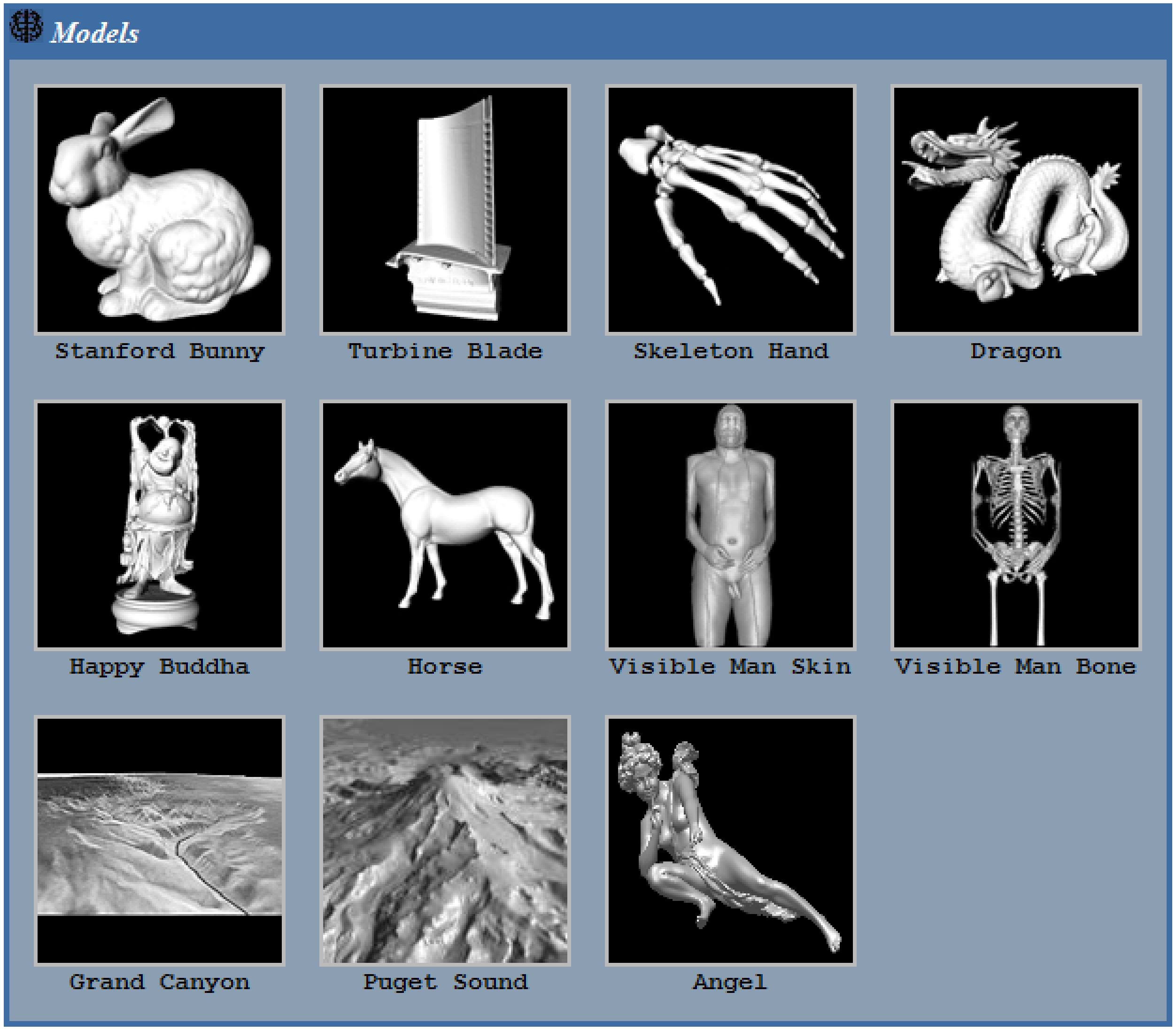
3D Mesh file formats

- 3D meshes usually stored in 3D file format
- Format defines how vertices, edges, and faces are declared
- Over 400 different file formats
- **Polygon File Format (PLY)** used a lot in graphics
- Originally PLY was used to store 3D files from 3D scanner
- We can get PLY models from web to work with
- We will use PLY files in this class

Sample PLY File

```
ply
format ascii 1.0
comment this is a simple file
obj_info any data, in one line of free form text element vertex 3
property float x
property float y
property float z
element face 1
property list uchar int vertex_indices
end_header
-1 0 0
0 1 0
1 0 0
3 0 1 2
```

Georgia Tech Large Models Archive



Stanford 3D Scanning Repository

Lucy: 28 million faces

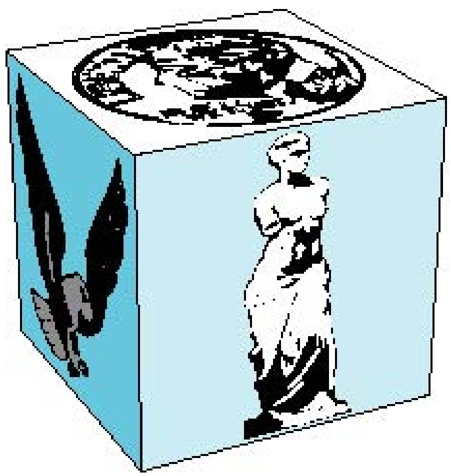
Happy Buddha: 9 million faces

Introduction to Transformations

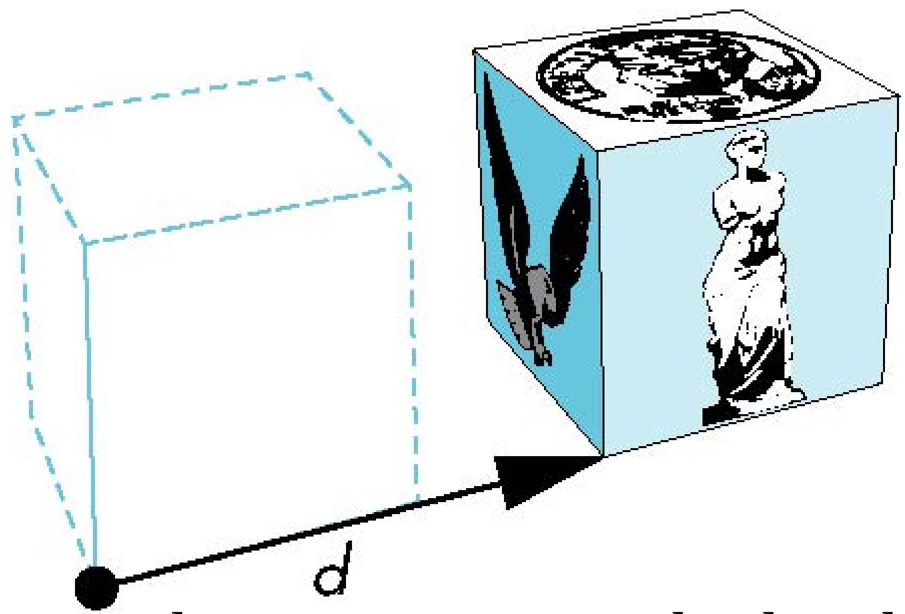
- May also want to transform objects by changing its:
  - Position (translation)
  - Size (scaling)
  - Orientation (rotation)
  - Shapes (shear)

Translation

- Move each vertex by **same** distance $\mathbf{d} = (\mathbf{d}_x, \mathbf{d}_y, \mathbf{d}_z)$



object



translation: every point displaced by same vector

Scaling

Expand or contract along each axis (fixed point of origin)

$x' = s_x x$
$y' = s_y y$
$z' = s_z z$

$$\mathbf{p}' = \mathbf{S}\mathbf{p}$$

where

$$\mathbf{S} = \mathbf{S}(s_x, s_y, s_z)$$