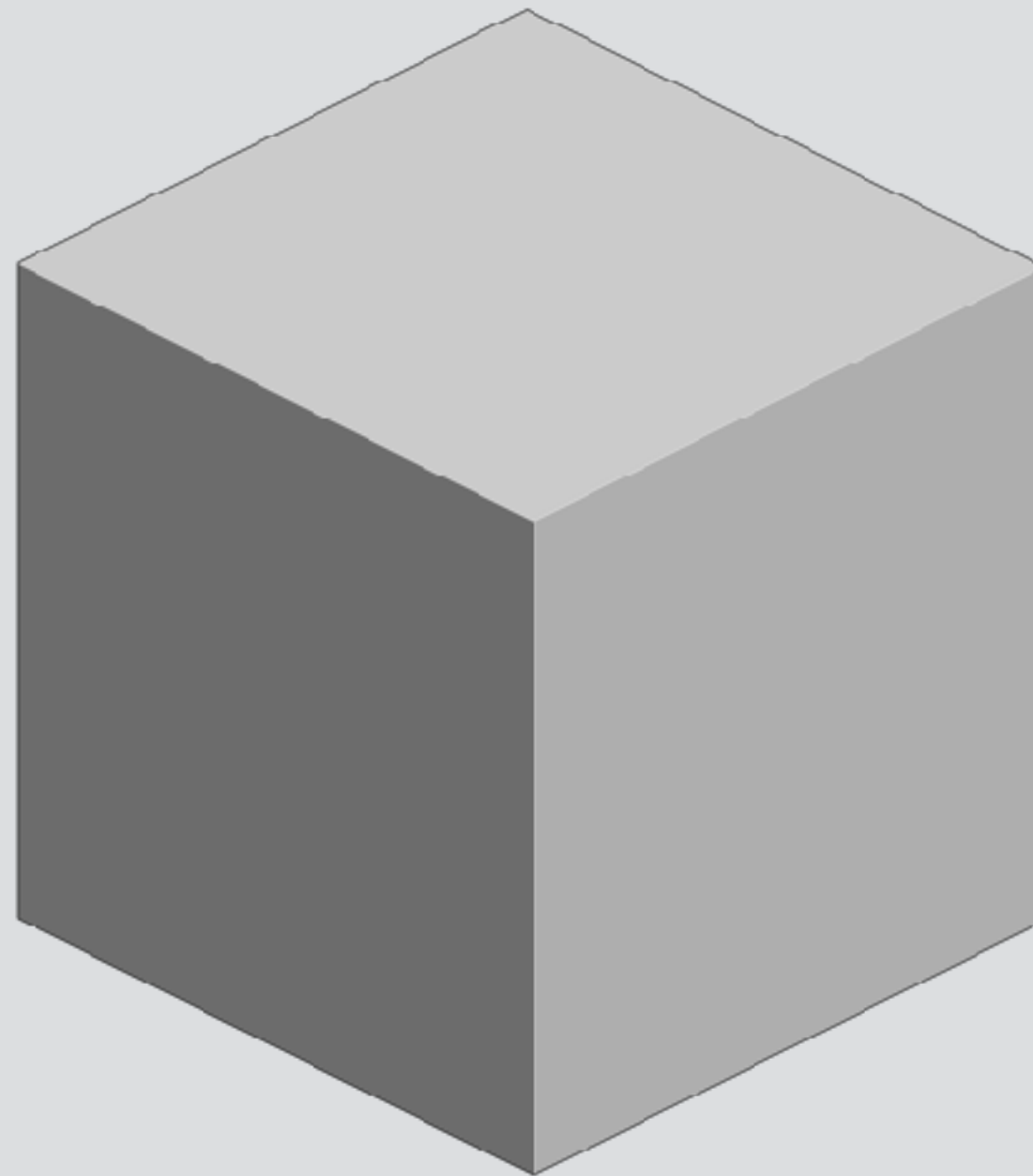


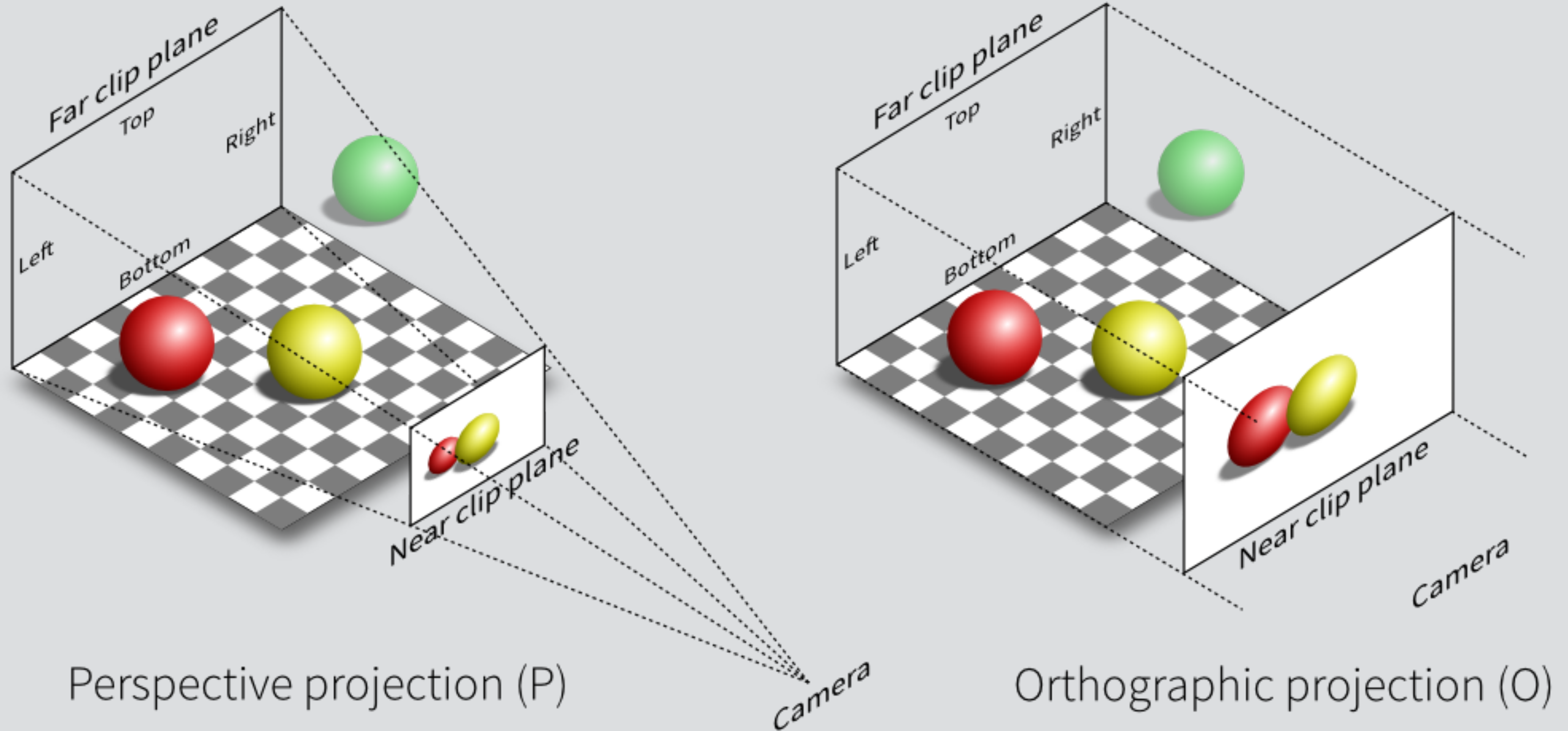
3D Graphics

Part 1



Perspective

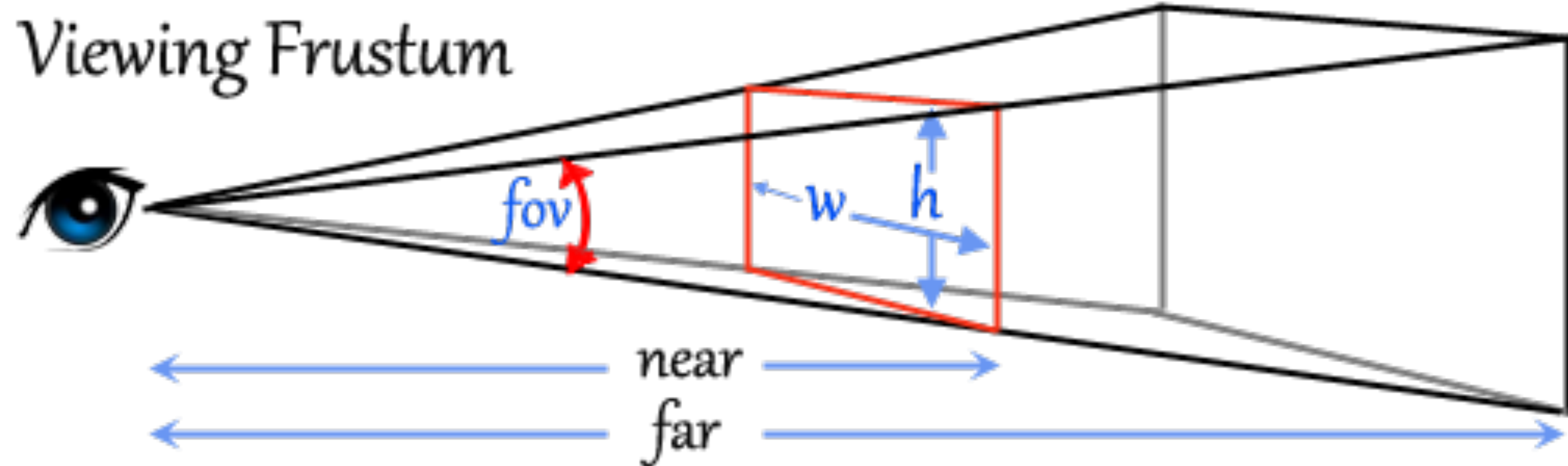
Perspective vs. Orthographic projection.

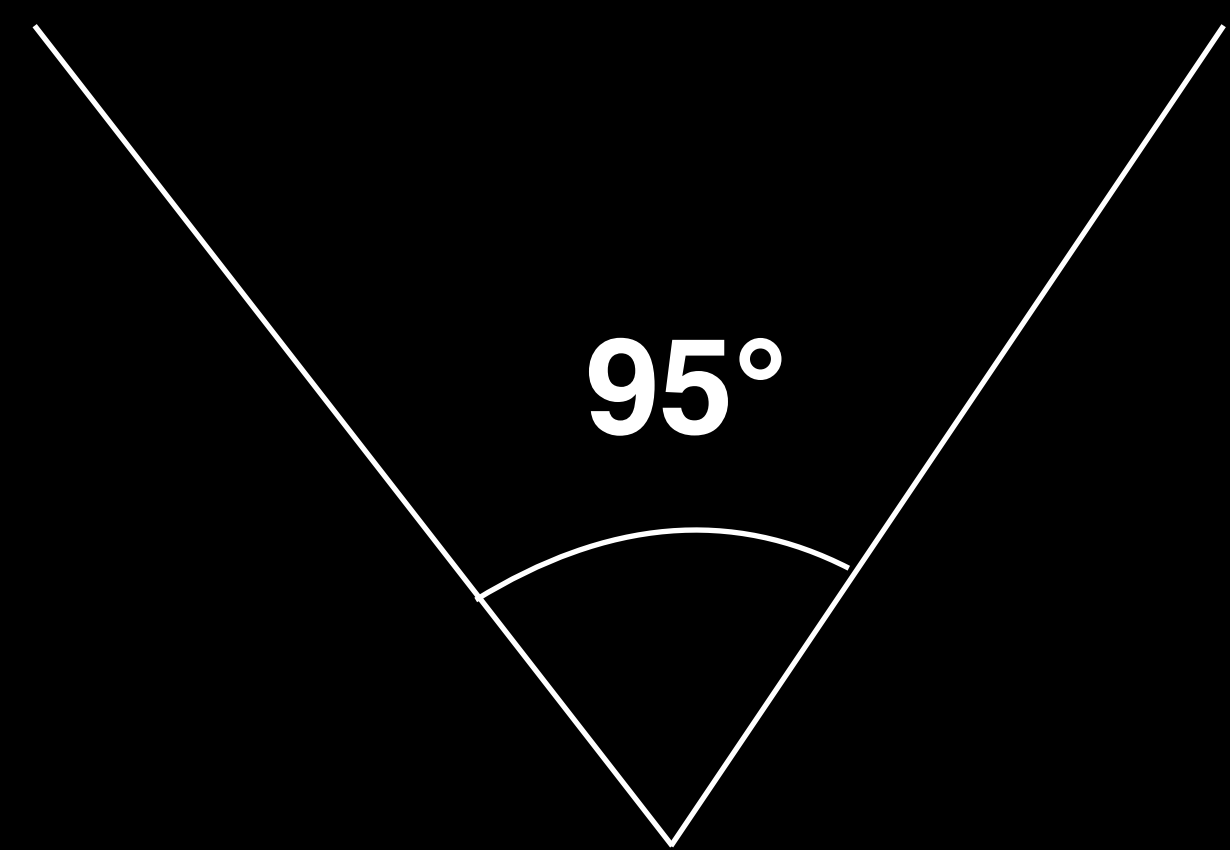
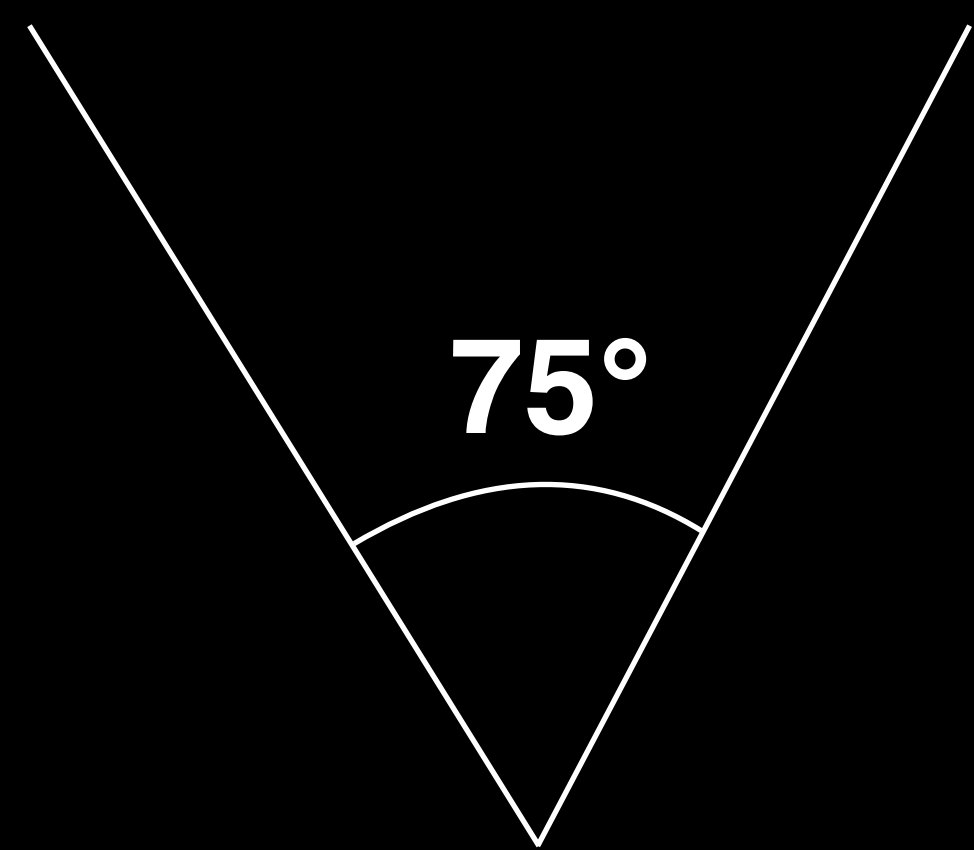
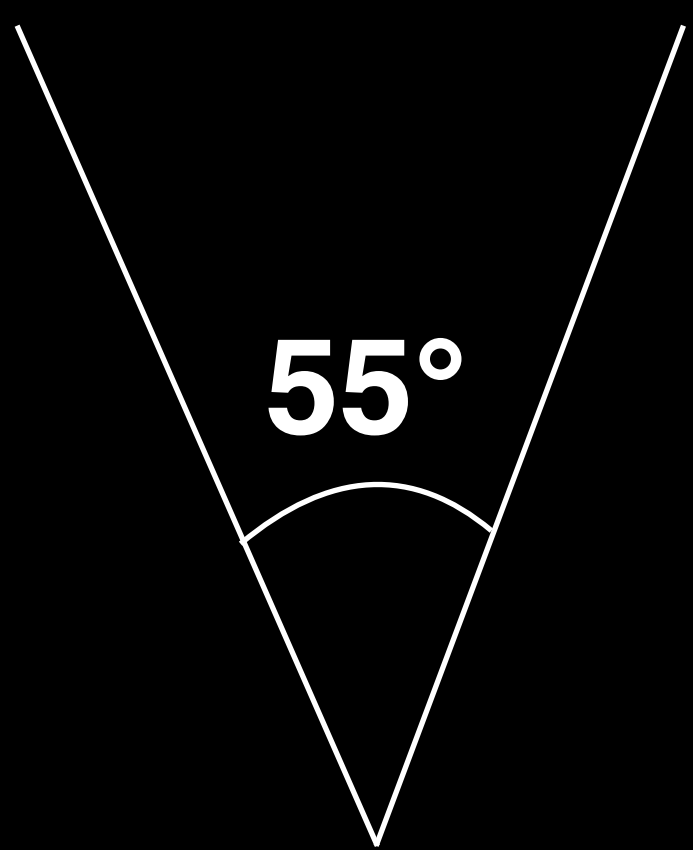


Orthographic projection matrix.

$$\begin{pmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{(r+l)}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{(t+b)}{t-b} \\ 0 & 0 & -\frac{2}{f-n} & -\frac{(f+n)}{f-n} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Building a perspective projection matrix.





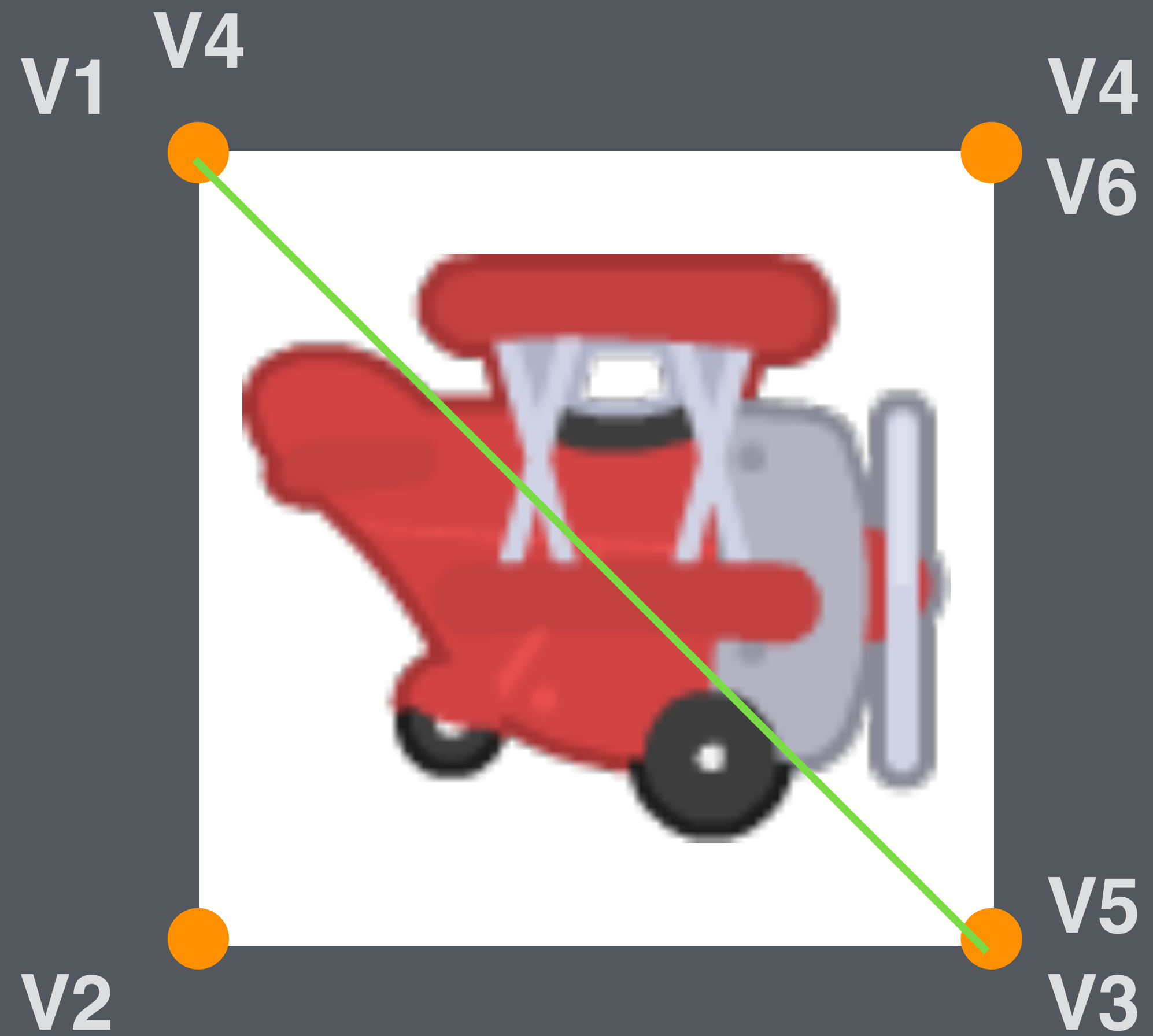
Perspective projection matrix.

$$P = \begin{bmatrix} \frac{\cot \frac{fovy}{2}}{aspect} & 0 & 0 & 0 \\ 0 & \cot \frac{fovy}{2} & 0 & 0 \\ 0 & 0 & \frac{n+f}{n-f} & \frac{2 * n * f}{n-f} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

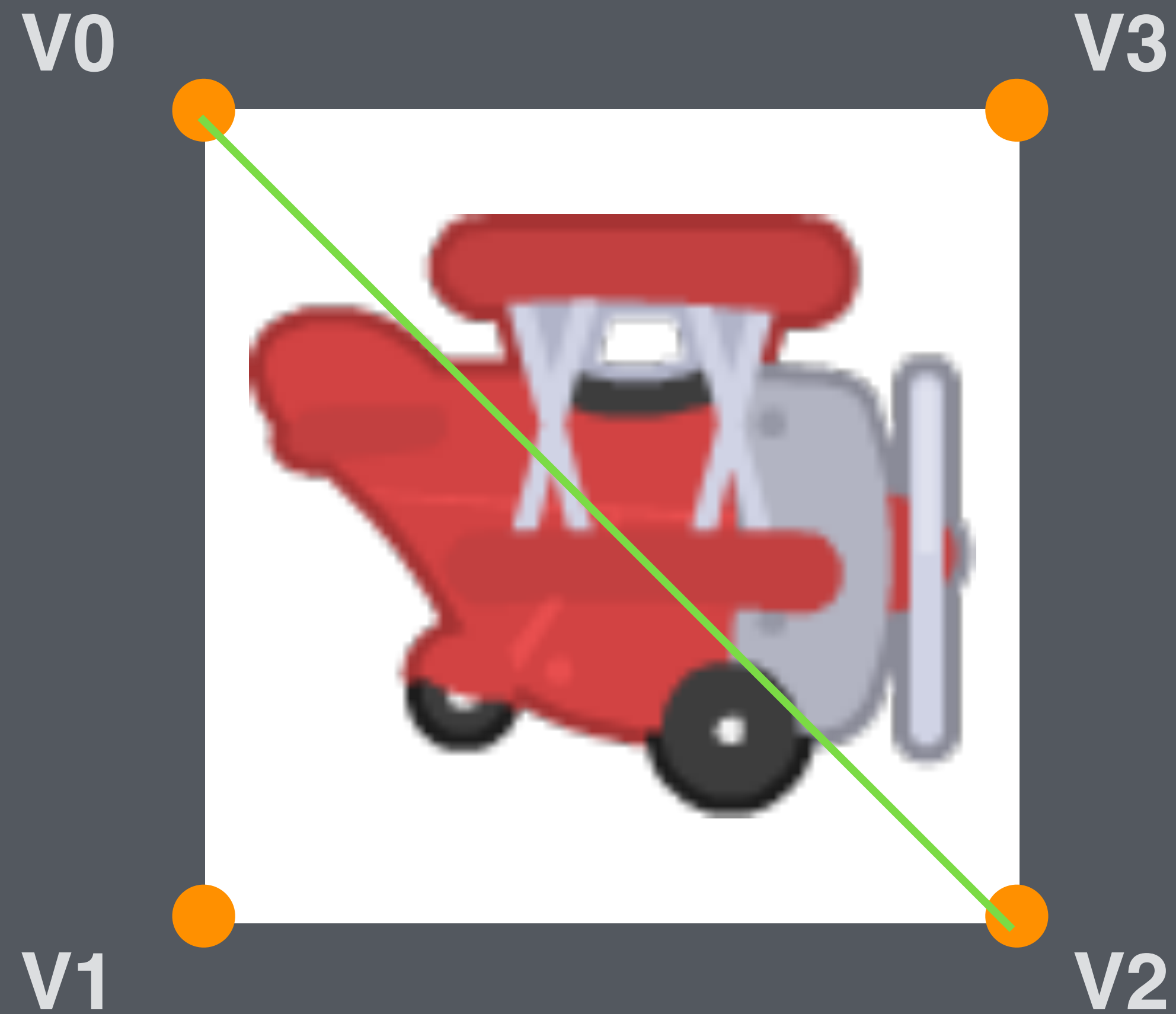

```
void Matrix::setPerspectiveProjection(float fov, float aspect,  
float zNear, float zFar) {  
  
    m[0][0] = 1.0f/tanf(fov/2.0)/aspect;  
    m[1][1] = 1.0f/tanf(fov/2.0);  
    m[2][2] = (zFar+zNear)/(zNear-zFar);  
    m[3][2] = (2.0f*zFar*zNear)/(zNear-zFar);  
    m[2][3] = -1.0f;  
    m[3][3] = 0.0f;  
}
```

Indexed drawing.

GL_TRIANGLES



GL_TRIANGLES



V0,V1,V2

V0,V2,V3


```
void glDrawElements (GLenum mode, GLsizei  
count, GLenum type, const GLvoid *indices);
```

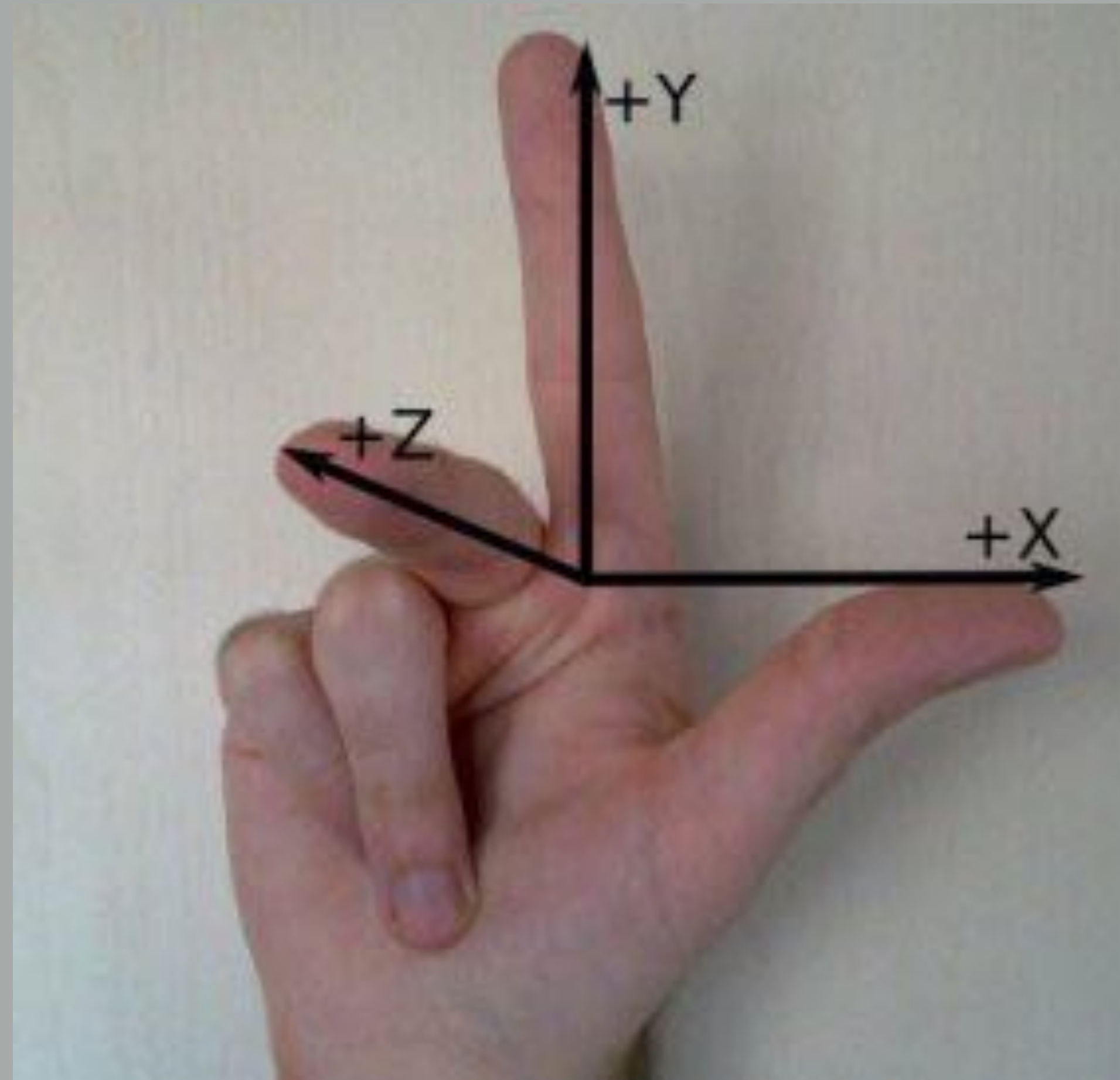
Draws vertices defined by glVertexPointer using a list of indices from that array.

```
std::vector<unsigned int> indices = {0,1,2,0,2,3};  
glDrawElements(GL_TRIANGLES, 6, GL_UNSIGNED_INT, indices.data());
```

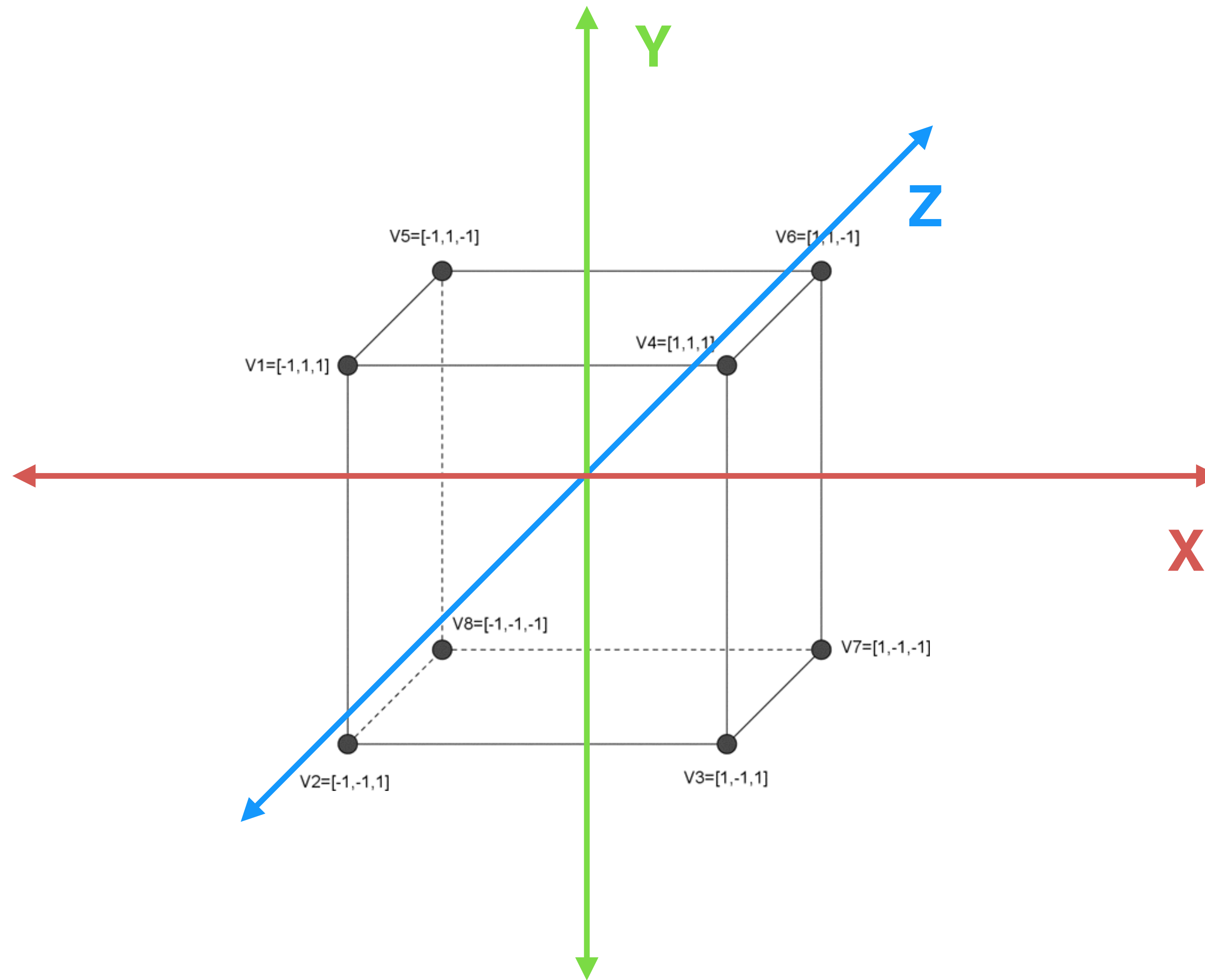
Drawing in 3D

It's the same as drawing in 2D!
We just need to specify 3 dimensions per vertex!

Right-handed coordinate system.



Drawing a cube.



```
float vertices[24] = {-1.0, -1.0, 1.0,
1.0, -1.0, 1.0,
1.0, 1.0, 1.0,
-1.0, 1.0, 1.0,
-1.0, -1.0, -1.0,
1.0, -1.0, -1.0,
1.0, 1.0, -1.0,
-1.0, 1.0, -1.0};
```

```
float colors[32] = {1.0f, 0.0f, 0.0f, 1.0,
0.0f, 1.0f, 0.0f, 1.0,
0.0f, 0.0f, 1.0f, 1.0,
1.0f, 1.0f, 0.0f, 1.0,
0.0f, 1.0f, 1.0f, 1.0,
1.0f, 0.0f, 1.0f, 1.0,
1.0f, 0.5f, 0.0f, 1.0,
1.0f, 0.0f, 0.5f, 1.0};
```

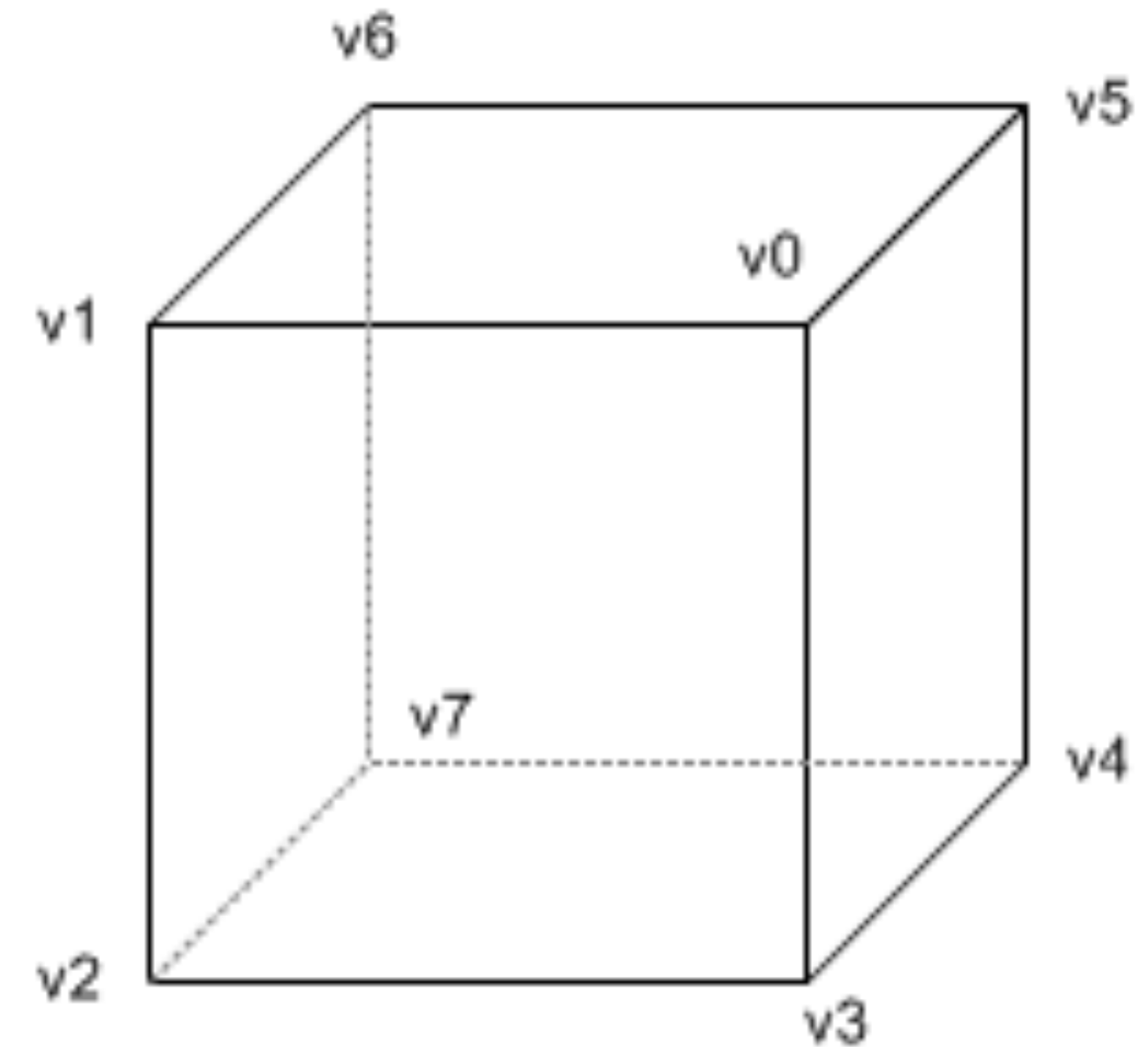
```
unsigned int indices[36] = {
0, 1, 2,
2, 3, 0,
3, 2, 6,
6, 7, 3,
7, 6, 5,
5, 4, 7,
4, 5, 1,
1, 0, 4,
4, 0, 3,
3, 7, 4,
1, 5, 6,
6, 2, 1};
```

```
glVertexAttribPointer(program.positionAttribute, 3, GL_FLOAT, false, 0, vertices);
glEnableVertexAttribArray(program.positionAttribute);
```

```
glVertexAttribPointer(colorAttribute, 4, GL_FLOAT, false, 0, colors);
glEnableVertexAttribArray(colorAttribute);
```

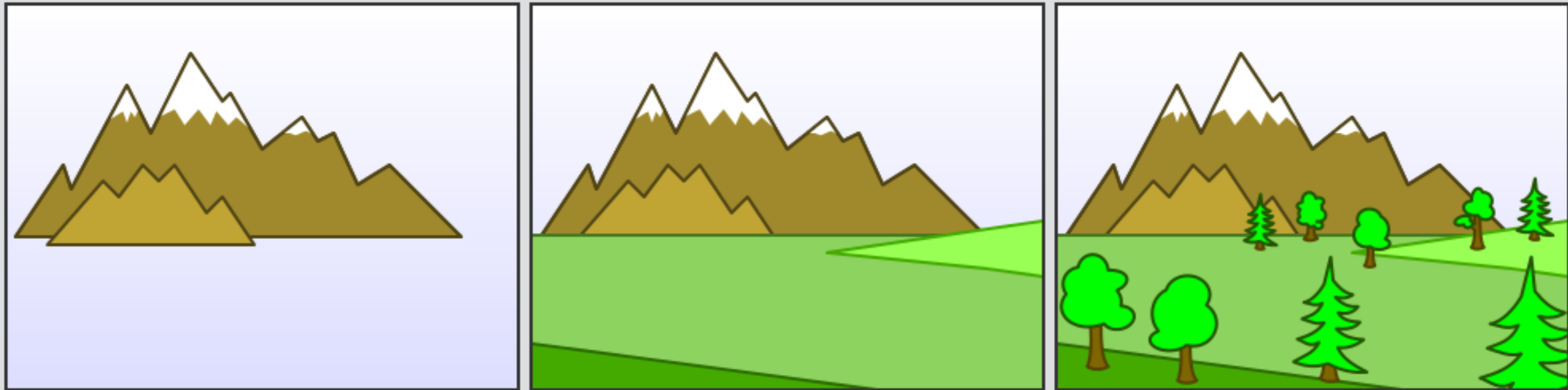
```
glDrawElements(GL_TRIANGLES, 36, GL_UNSIGNED_INT, indices);
```

3 DIMENSIONS PER VERTEX

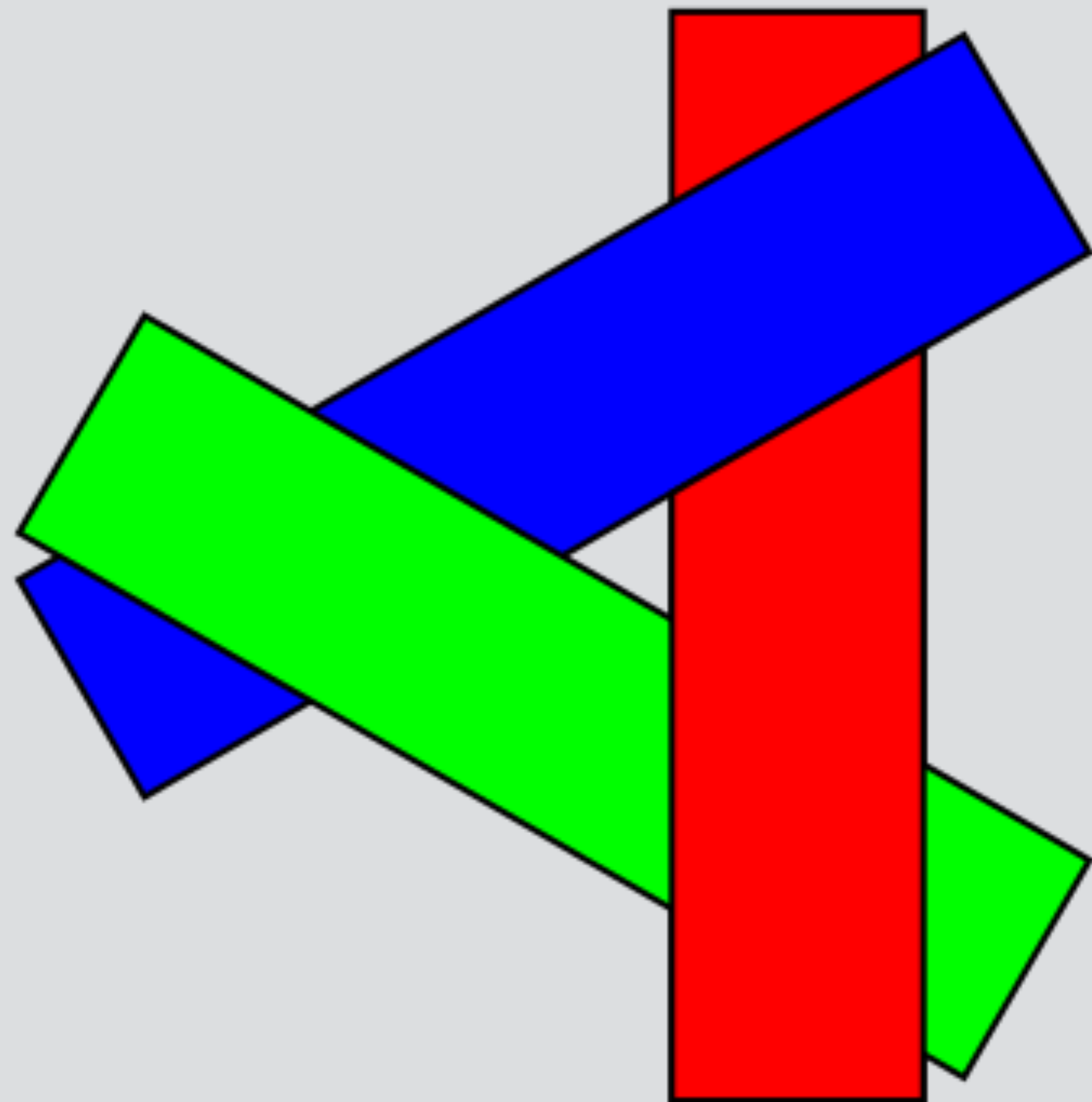


3 DIMENSIONS PER VERTEX

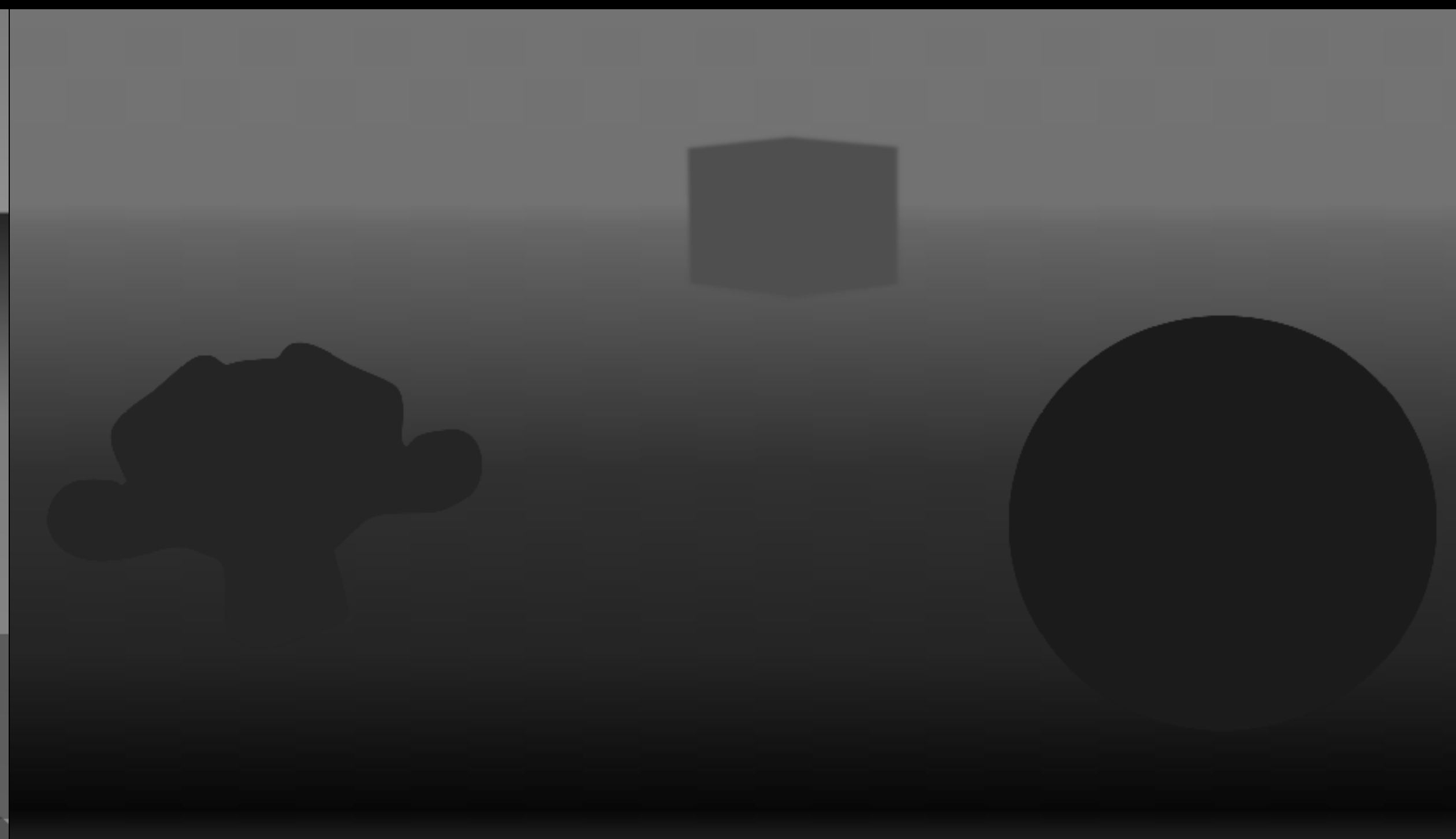
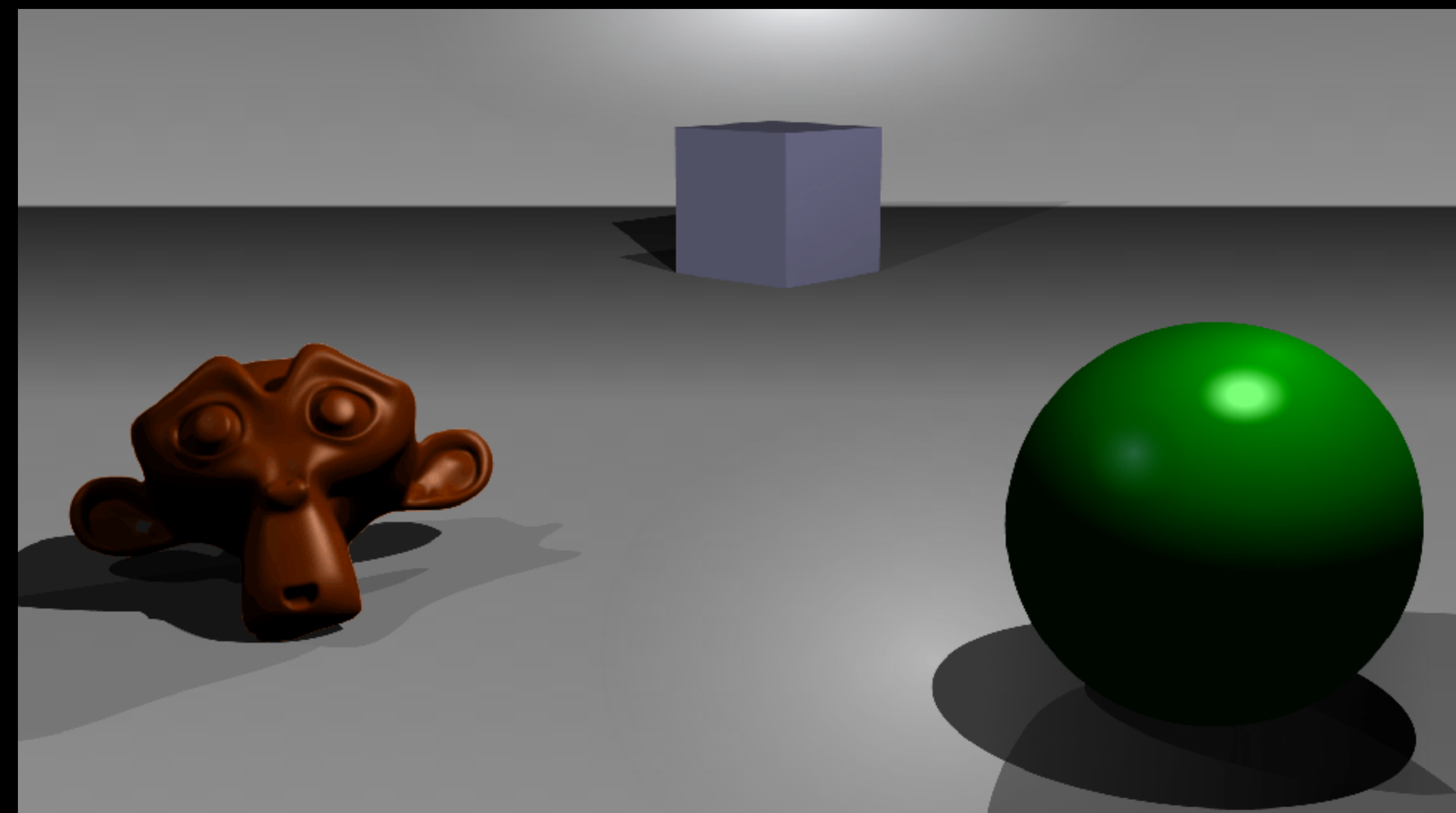
Painter's algorithm.



???



Z-Buffer



Enabling the Z-Buffer in OpenGL.


```
void glDepthMask (GLboolean flag);
```

Enables or disables depth buffer writing.

```
glDepthMask(GL_TRUE); // enable depth write  
glDepthMask(GL_FALSE); // disable depth write
```

```
void glEnable (GLenum capability);  
void glDisable (GLenum capability);
```

Enable or disable an OpenGL capability. Use GL_DEPTH_TEST to enable or disable depth test capability.

```
glEnable(GL_DEPTH_TEST); // enable depth testing  
glDisable(GL_DEPTH_TEST); // disable depth testing
```

```
void glDepthFunc (GLenum func);
```

Specifies the function used to compare each incoming pixel depth value with the depth value present in the depth buffer.

Can be one of the following:

GL_NEVER, GL_LESS, GL_EQUAL, GL_LEQUAL, GL_GREATER, GL_NOTEQUAL, GL_GEQUAL, and GL_ALWAYS

For example if the function is **GL_LEQUAL**, the pixel will only be drawn if its depth is **LESS THAN OR EQUAL** than the pixel's depth on the screen (most of the time we want this).

```
glDepthFunc(GL_LEQUAL); // only draw pixels that are closer or equal
```

Putting it together.

Enabling depth testing/writing for 3D.

```
glEnable(GL_DEPTH_TEST);  
glDepthFunc(GL_LEQUAL);  
glDepthMask(GL_TRUE);
```

Disabling depth testing and writing.

```
glDisable(GL_DEPTH_TEST);  
glDepthMask(GL_FALSE);
```

Clearing the depth buffer!

If using the depth buffer, we need to tell the OpenGL clear function to clear the depth buffer as well as the color buffer!

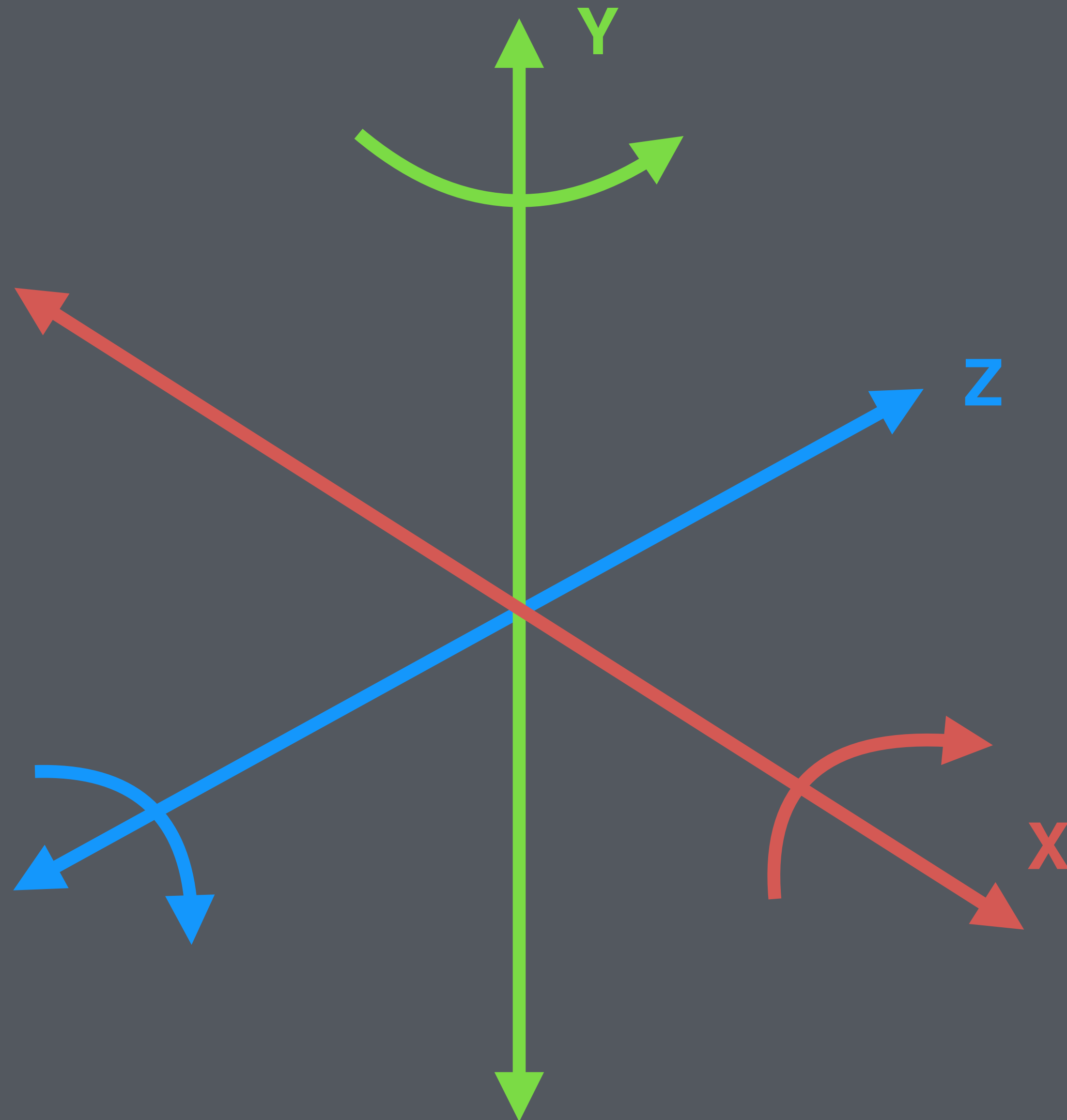
```
glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
```

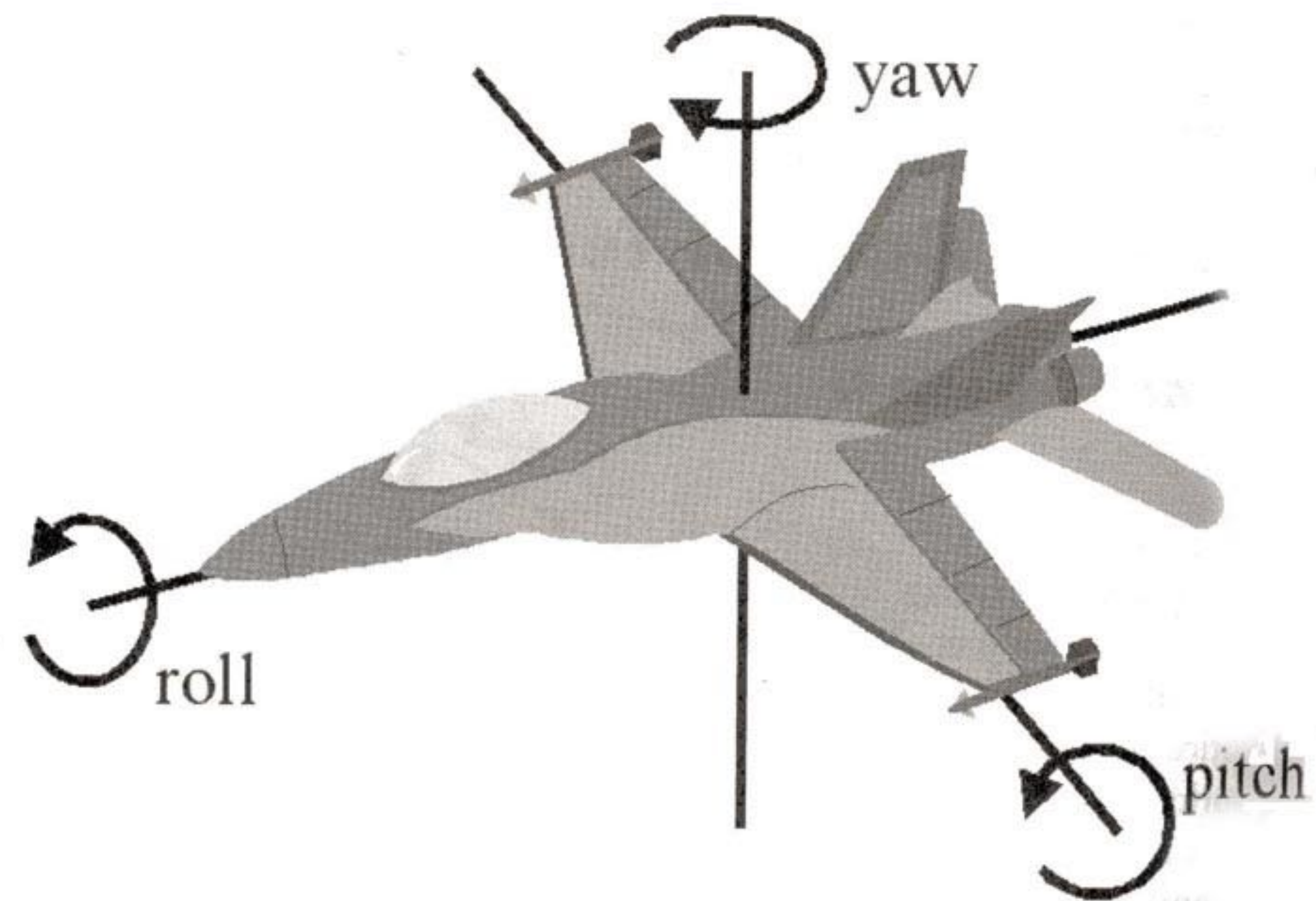
Texturing in 3D

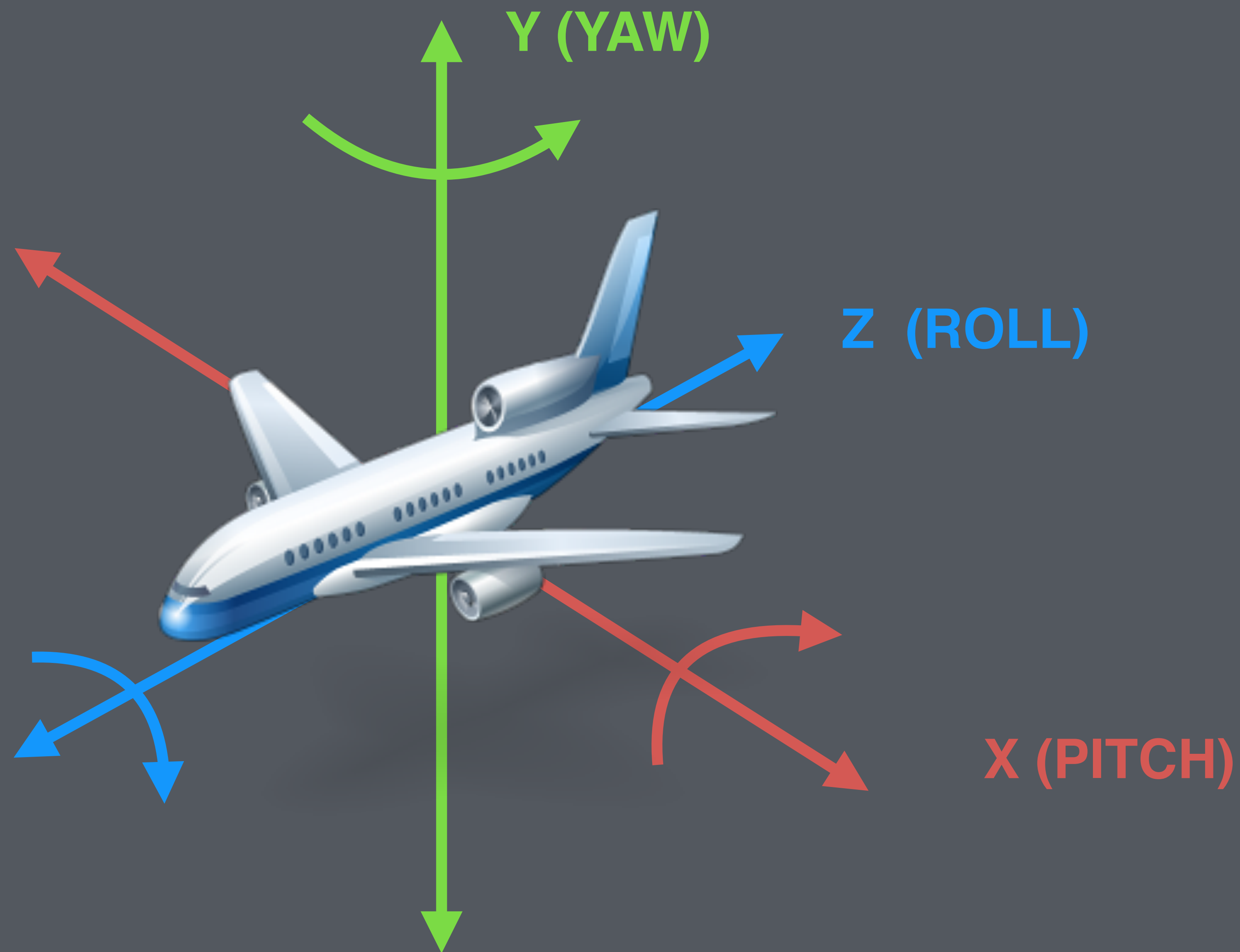


3D Entities

3 degrees of rotation.







```
class Entity {
public:

    Entity();
    void Update(float elapsed);
    void Render();
    void buildMatrix();

    void FixedUpdate();

    Matrix matrix;

    Vector position;
    Vector rotation;
    Vector scale;

    Vector velocity;
    Vector acceleration;

    unsigned int texture;
    std::vector<float> vertices;
    std::vector<float> uvs;

    bool visible;
    float friction;

};
```

Extending our entity class
into the **3rd dimension**.

$$\begin{array}{c}
 \text{X-Rotation in 3D} \\
 \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi & 0 \\ 0 & \sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{array}
 \begin{array}{c}
 \text{Z-Rotation in 3D} \\
 \begin{bmatrix} \cos\phi & -\sin\phi & 0 & 0 \\ \sin\phi & \cos\phi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{array}
 \begin{array}{c}
 \text{Scale in 3D} \\
 \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{array}
 (4 \times 4) * (4 \times 1) = (4 \times 1)$$

$$\begin{array}{c}
 \text{Y-Rotation in 3D} \\
 \begin{bmatrix} \cos\phi & 0 & \sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\phi & 0 & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{array}
 \begin{array}{c}
 \text{Translation in 3D} \\
 \begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{array}
 \begin{array}{c}
 \text{Matrix Multiplication} \\
 \begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{bmatrix}
 \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ q \end{bmatrix}
 \end{array}$$



3D Camera

Our view matrix needs to be
the inverse of the camera entity's matrix!

Mixing 2D and 3D

Rendering 3D, then 2D on top of it.

- Clear color and depth buffers
- Set perspective projection in projection matrix.
- Enable depth testing and writing
- Draw 3D scene
- Set orthographic projection in projection matrix
- Disable depth testing and writing
- Render 2D scene