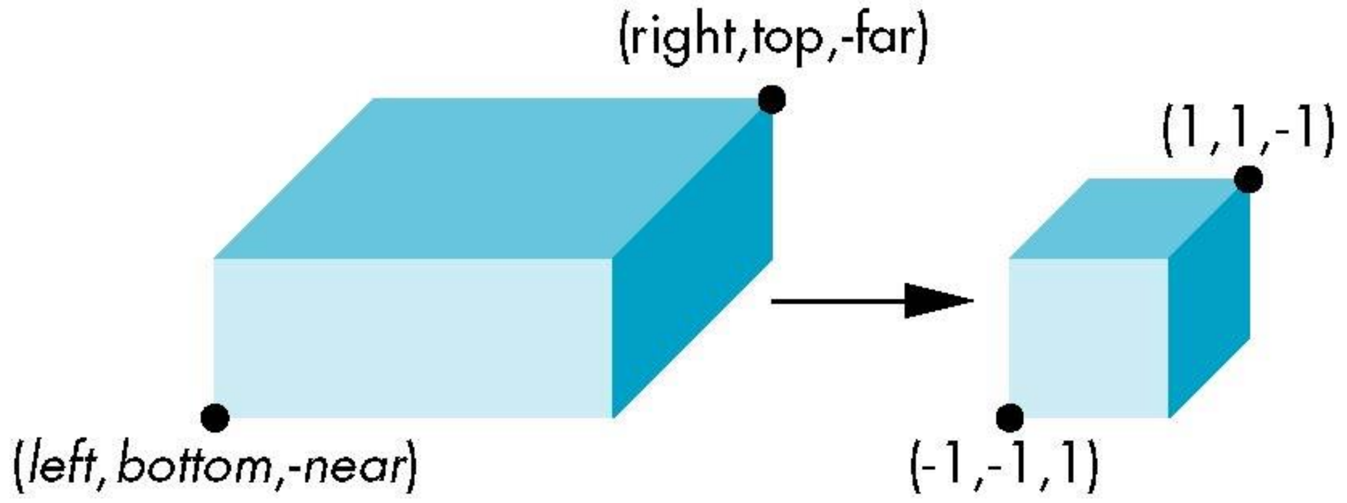
Viewing

9TH WEEK, 2022

Orthogonal Normalization

```
ortho(left,right,bottom,top,near,far)
```

- Normalization ⇒ find transformation to convert specified clipping volume to default



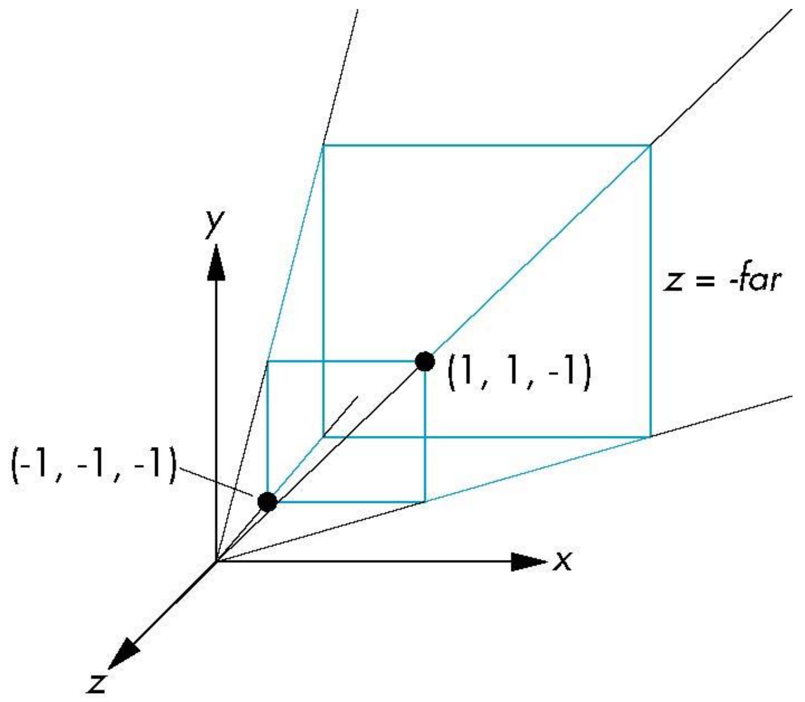
Orthogonal Matrix

- Two steps
  - Move center to origin: $T(-(left+right)/2, -(bottom+top)/2, (near+far)/2))$
  - Scale to have sides of length 2: $S(2/(left-right), 2/(top-bottom), 2/(near-far))$

$$\mathbf{P} = \mathbf{ST} = \begin{bmatrix} \frac{2}{right-left} & 0 & 0 & -\frac{right+left}{right-left} \\ 0 & \frac{2}{top-bottom} & 0 & -\frac{top+bottom}{top-bottom} \\ 0 & 0 & \frac{2}{near-far} & \frac{far+near}{far-near} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Simple Perspective

- Consider a simple perspective with the COP at the origin, the near clipping plane at $z = -1$, and a 90-degree field of view determined by the planes $x = \pm z$, $y = \pm z$



Perspective Matrices

- Simple projection matrix in homogeneous coordinates

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

- Note that this matrix is independent of the far clipping plane

Generalization

$$\mathbf{N} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \alpha & \beta \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

- after perspective division, the point (x, y, z, 1) goes to

$$x'' = x/z$$
$$y'' = y/z$$
$$z'' = -(\alpha+\beta/z)$$

- which projects orthogonally to the desired point regardless of α and β

Picking α and β

- If we pick: $\alpha = \dfrac{\text{near} + \text{far}}{\text{far} - \text{near}}$

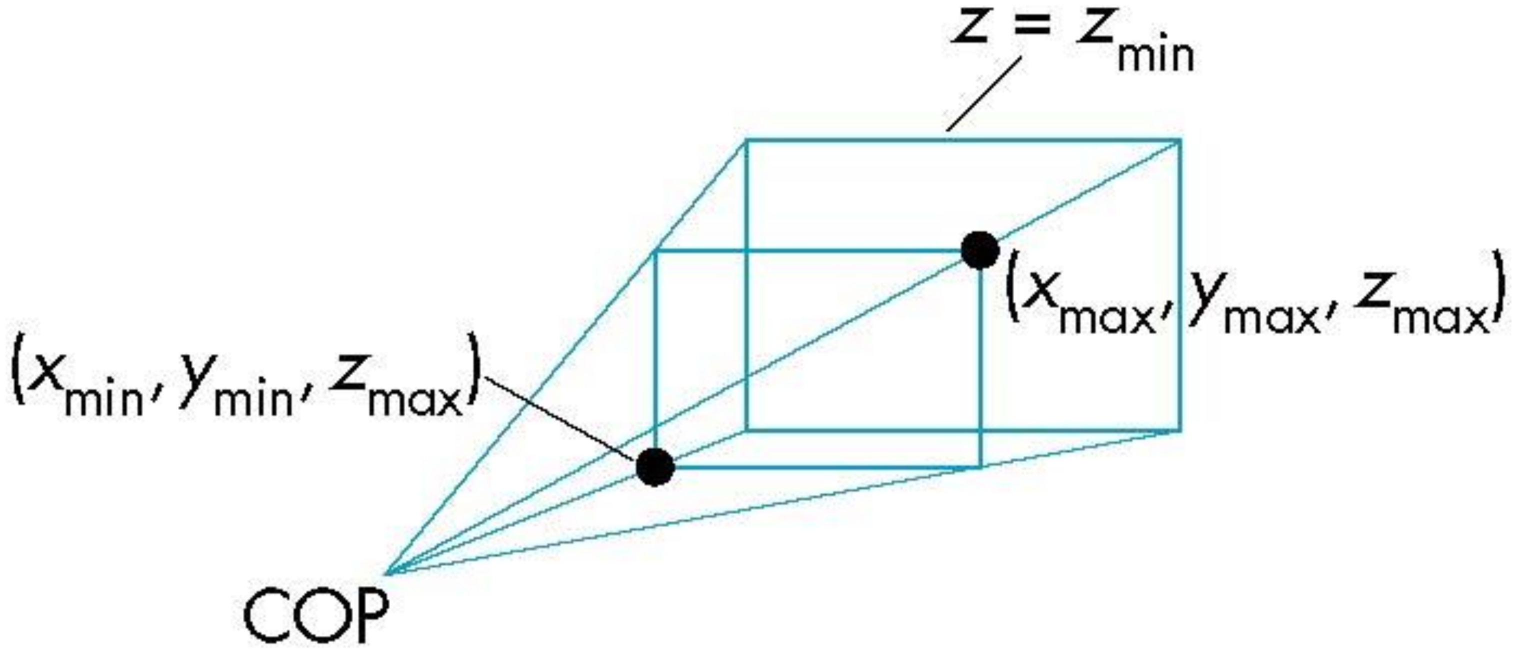
  $$\beta = \frac{2\text{near} * \text{far}}{\text{near} - \text{far}}$$

  - the near plane is mapped to $z = -1$
  - the far plane is mapped to $z = 1$
  - and the sides are mapped to $x = \pm 1$, $y = \pm 1$

- Hence the new clipping volume is the default clipping volume

WebGL Perspective

- **`gl.frustum`** allows for an unsymmetric viewing frustum (although **`gl.perspective`** does not)



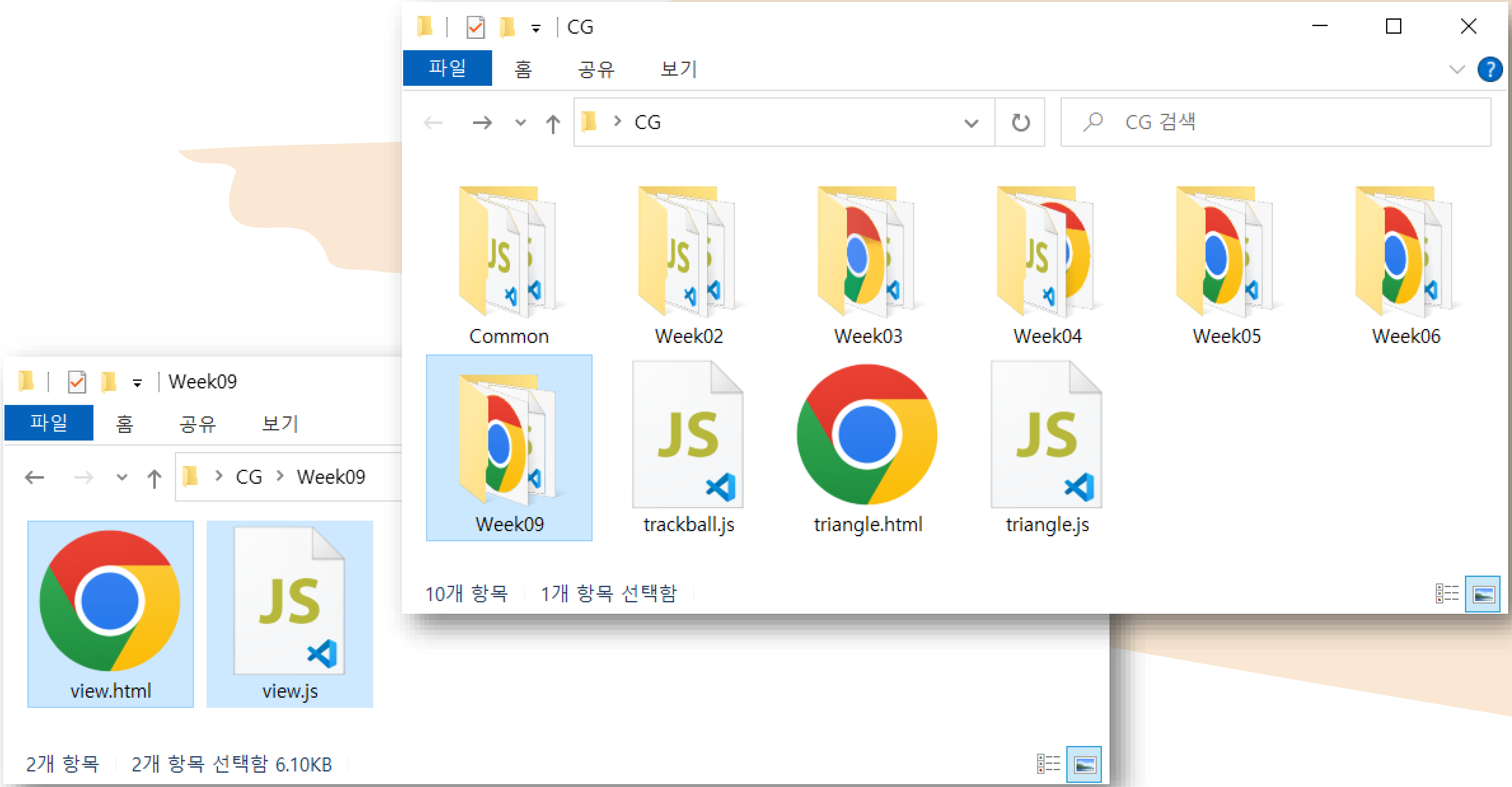
Perspective Matrices

- frustum

$$\mathbf{P} = \begin{bmatrix} \frac{2*near}{right-left} & 0 & \frac{right-left}{right-left} & 0 \\ 0 & \frac{2*near}{top-bottom} & \frac{top+bottom}{top-bottom} & 0 \\ 0 & 0 & -\frac{far+near}{far-near} & -\frac{2*\ far*near}{far-near} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

- perspective

$$\mathbf{P} = \begin{bmatrix} \frac{near}{right} & 0 & 0 & 0 \\ 0 & \frac{near}{top} & 0 & 0 \\ 0 & 0 & -\frac{far+near}{far-near} & -\frac{2*\ far*near}{far-near} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$



CG
파일
홈
공유
보기
CG
CG 검색
Common
Week02
Week03
Week04
Week05
Week06
Week09
trackball.js
triangle.html
triangle.js
10개 항목
1개 항목 선택함
Week09
파일
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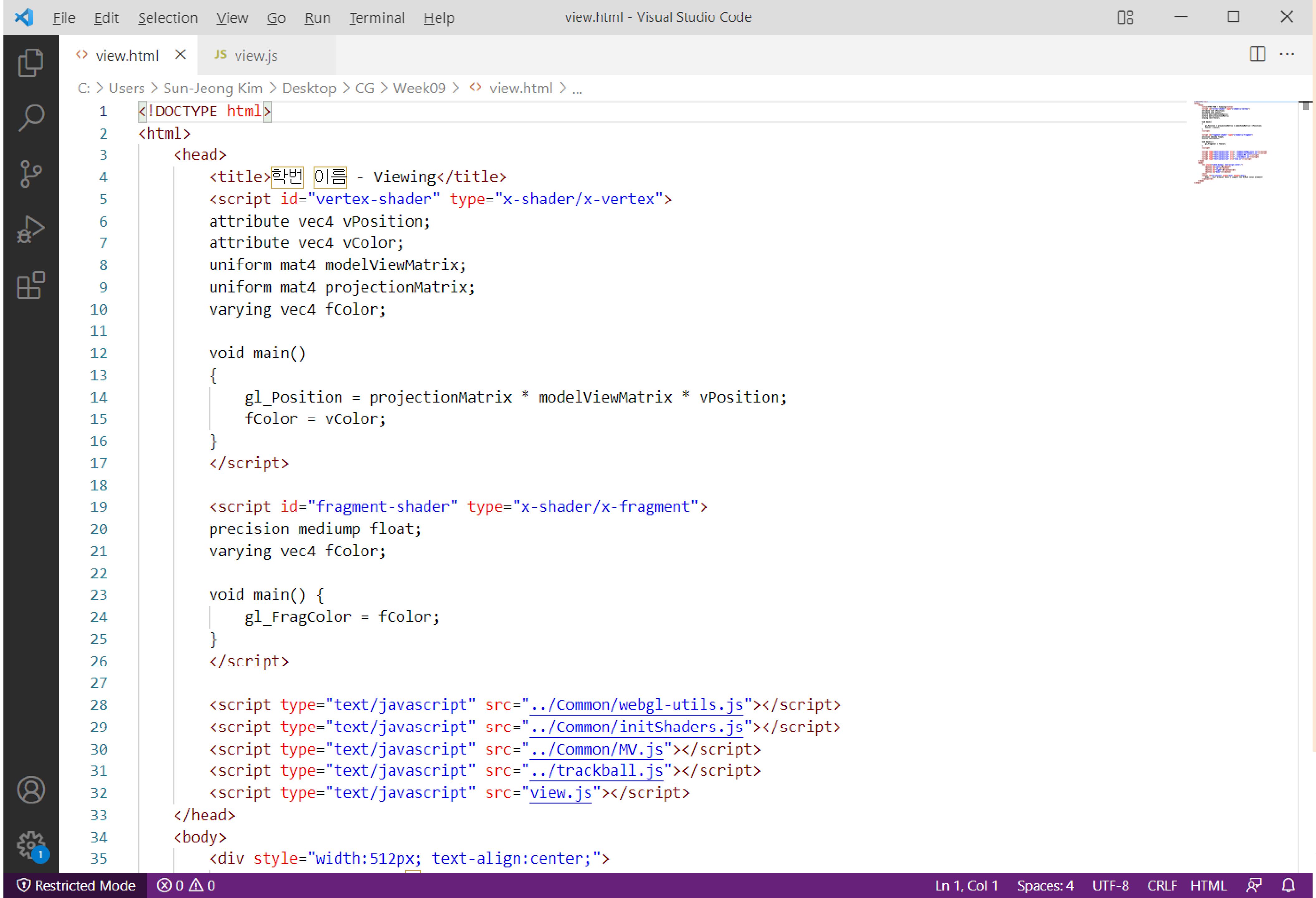
공유
보기
CG > Week09
view.html
view.js
2개 항목
2개 항목 선택함 6.10KB


File Edit Selection View Go Run Terminal Help
view.html - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.html > ...
Restricted Mode
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF HTML

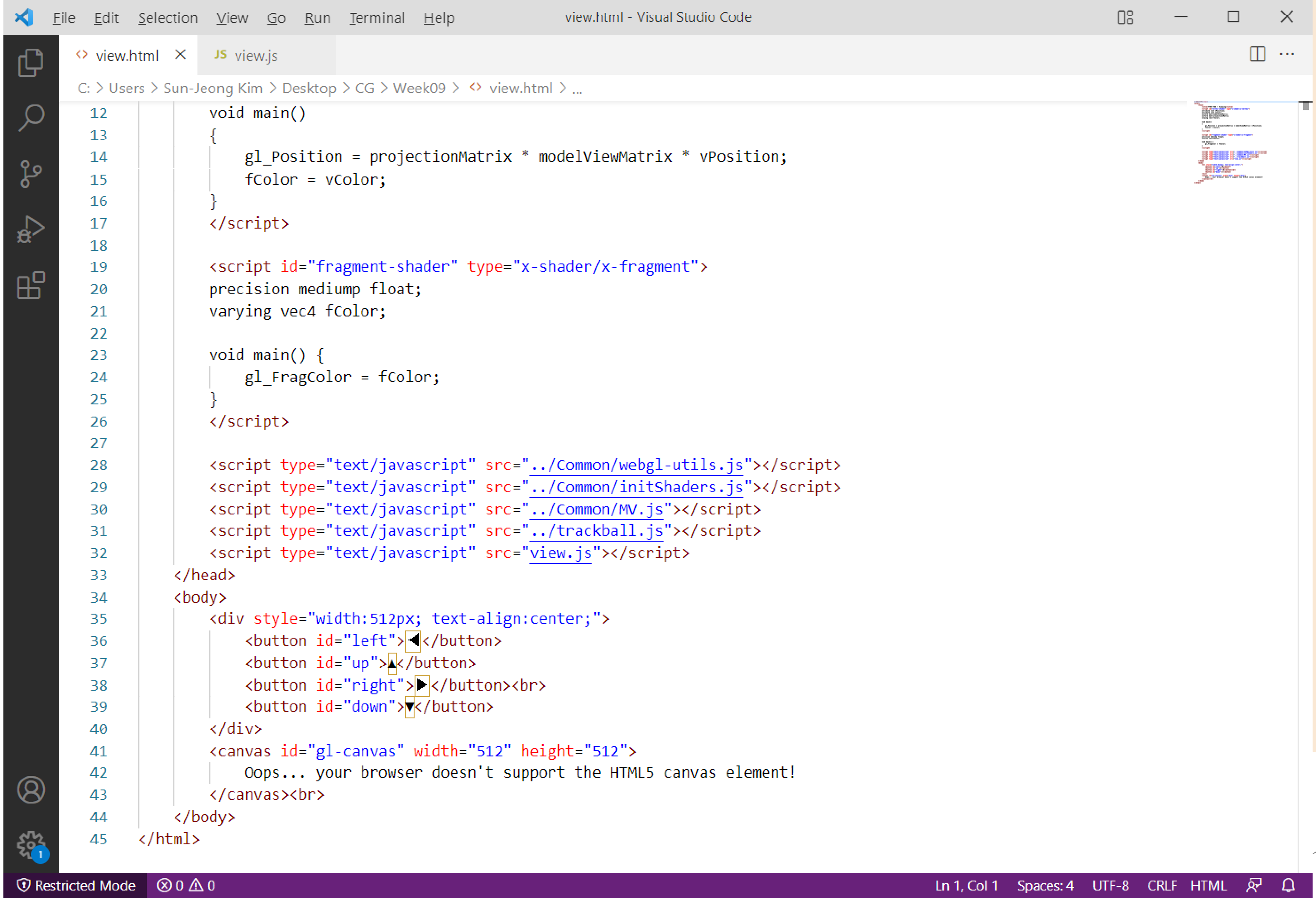
```html
<!DOCTYPE html>
<html>
    <head>
        <title>학번 이름 - Viewing</title>
        <script id="vertex-shader" type="x-shader/x-vertex">
        attribute vec4 vPosition;
        attribute vec4 vColor;
        uniform mat4 modelViewMatrix;
        uniform mat4 projectionMatrix;
        varying vec4 fColor;

        void main()
        {
            gl_Position = projectionMatrix * modelViewMatrix * vPosition;
            fColor = vColor;
        }
        </script>

        <script id="fragment-shader" type="x-shader/x-fragment">
        precision mediump float;
        varying vec4 fColor;

        void main() {
            gl_FragColor = fColor;
        }
        </script>

        <script type="text/javascript" src="../Common/webgl-utils.js"></script>
        <script type="text/javascript" src="../Common/initShaders.js"></script>
        <script type="text/javascript" src="../Common/MV.js"></script>
        <script type="text/javascript" src="../trackball.js"></script>
        <script type="text/javascript" src="view.js"></script>
    </head>
    <body>
        <div style="width:512px; text-align:center;">
```


File Edit Selection View Go Run Terminal Help
view.html - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.html > ...
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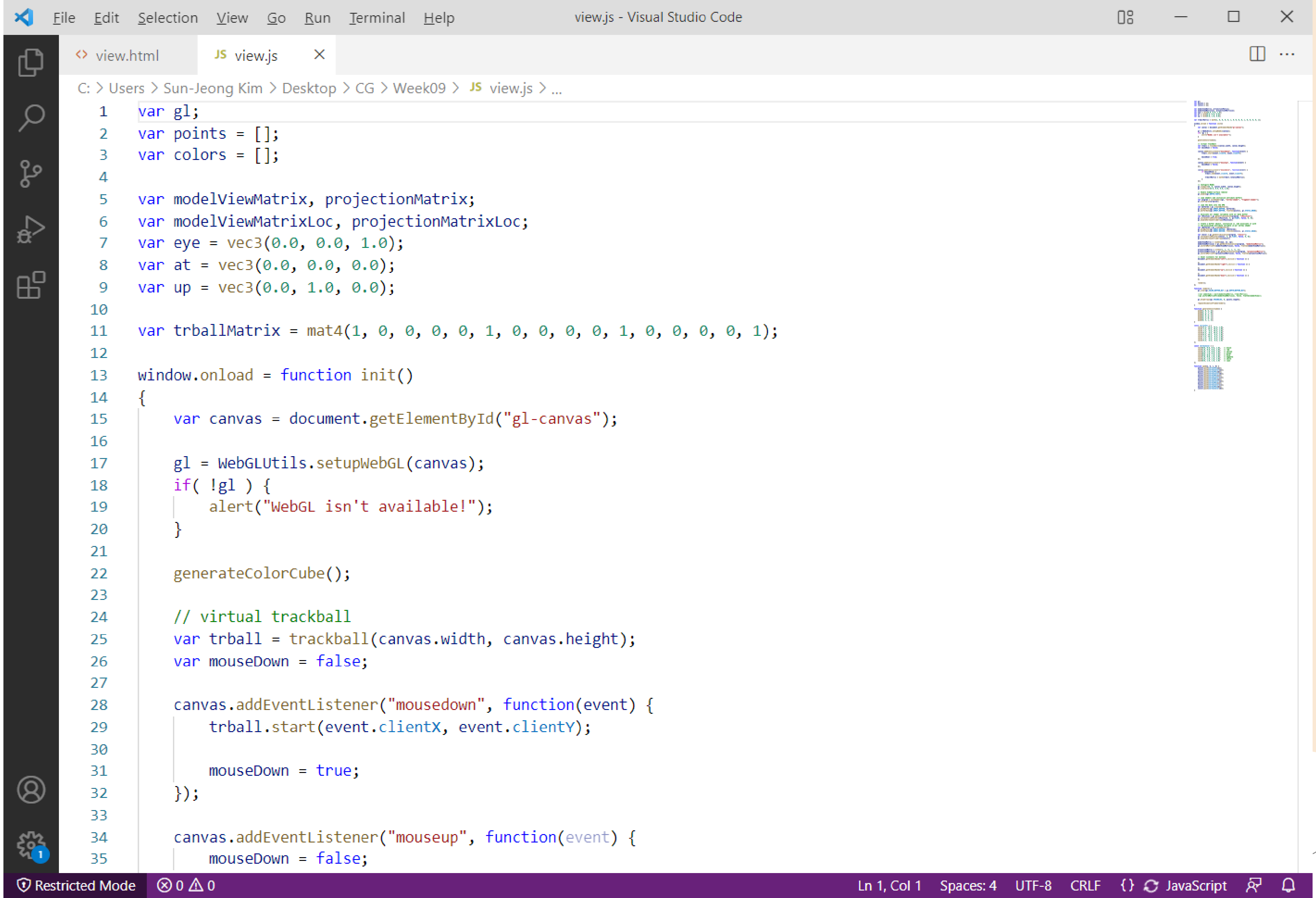
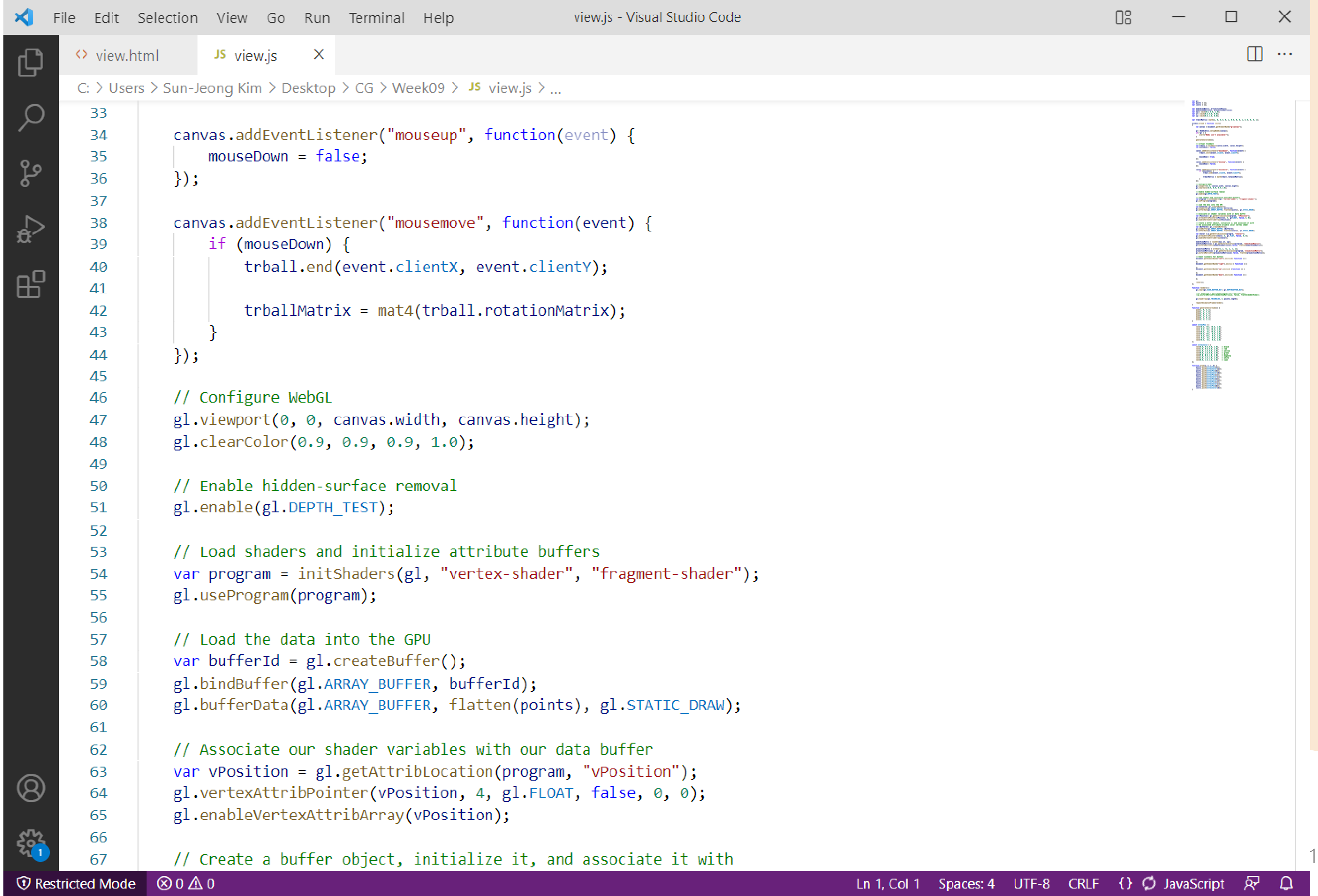
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF HTML

```
        void main()
        {
            gl_Position = projectionMatrix * modelViewMatrix * vPosition;
            fColor = vColor;
        }
        </script>

        <script id="fragment-shader" type="x-shader/x-fragment">
        precision mediump float;
        varying vec4 fColor;

        void main() {
            gl_FragColor = fColor;
        }
        </script>

        <script type="text/javascript" src="../Common/webgl-utils.js"></script>
        <script type="text/javascript" src="../Common/initShaders.js"></script>
        <script type="text/javascript" src="../Common/MV.js"></script>
        <script type="text/javascript" src="../trackball.js"></script>
        <script type="text/javascript" src="view.js"></script>
    </head>
    <body>
        <div style="width:512px; text-align:center;">
            <button id="left">◀</button>
            <button id="up">▲</button>
            <button id="right">▶</button><br>
            <button id="down">▼</button>
        </div>
        <canvas id="gl-canvas" width="512" height="512">
            Oops... your browser doesn't support the HTML5 canvas element!
        </canvas><br>
    </body>
</html>
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > ...
Restricted Mode
0 0
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF {} JavaScript

```
var gl;
var points = [];
var colors = [];

var modelViewMatrix, projectionMatrix;
var modelViewMatrixLoc, projectionMatrixLoc;
var eye = vec3(0.0, 0.0, 1.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);

var trballMatrix = mat4(1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1);

window.onload = function init()
{
    var canvas = document.getElementById("gl-canvas");

    gl = WebGLUtils.setupWebGL(canvas);
    if( !gl ) {
        alert("WebGL isn't available!");
    }

    generateColorCube();

    // virtual trackball
    var trball = trackball(canvas.width, canvas.height);
    var mouseDown = false;

    canvas.addEventListener("mousedown", function(event) {
        trball.start(event.clientX, event.clientY);

        mouseDown = true;
    });

    canvas.addEventListener("mouseup", function(event) {
        mouseDown = false;
```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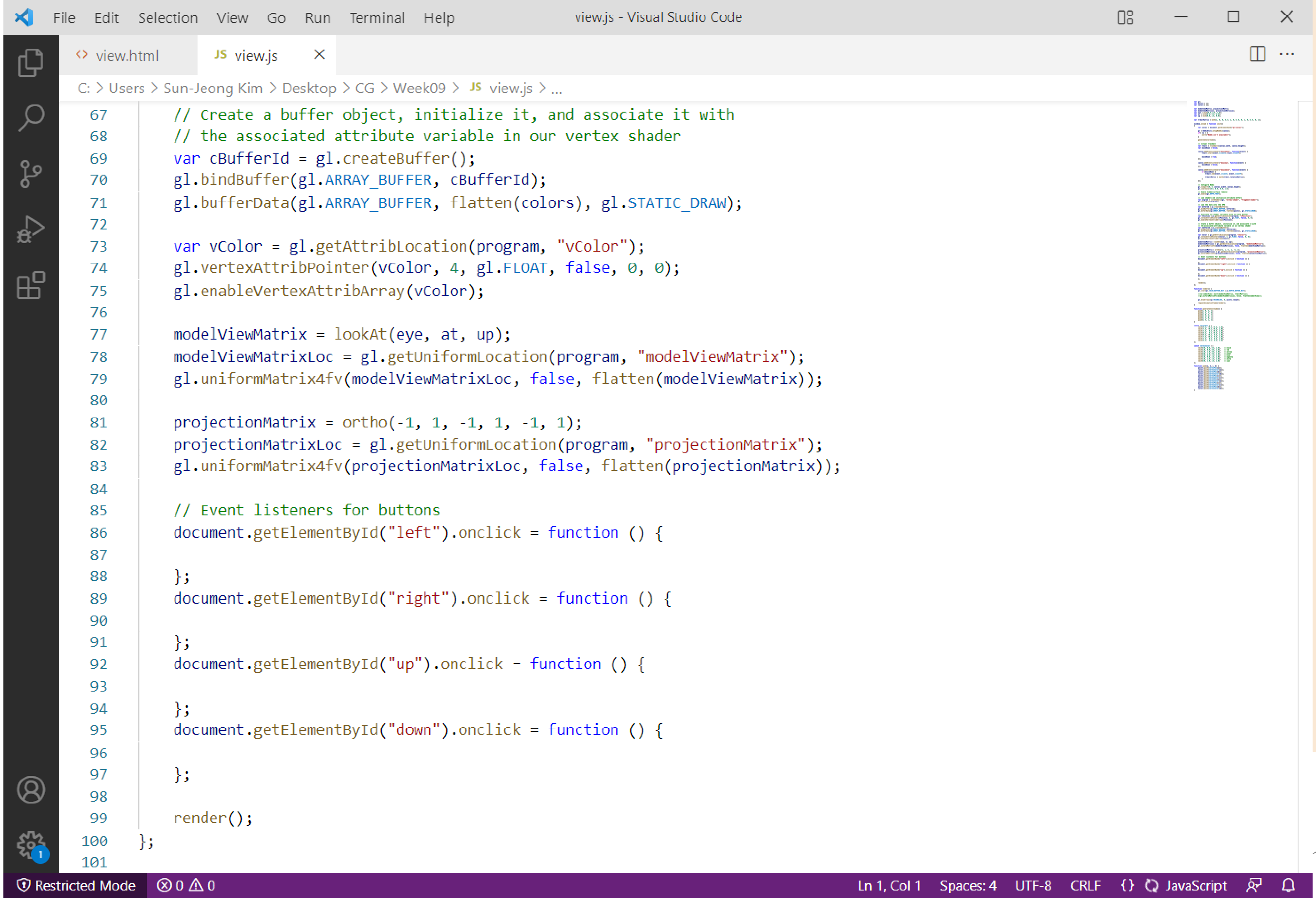
Restricted Mode
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF JavaScript

```

    canvas.addEventListener("mouseup", function(event) {
        mouseDown = false;
    });

    canvas.addEventListener("mousemove", function(event) {
        if (mouseDown) {
            trball.end(event.clientX, event.clientY);

            trballMatrix = mat4(trball.rotationMatrix);
        }
    });

    // Configure WebGL
    gl.viewport(0, 0, canvas.width, canvas.height);
    gl.clearColor(0.9, 0.9, 0.9, 1.0);

    // Enable hidden-surface removal
    gl.enable(gl.DEPTH_TEST);

    // Load shaders and initialize attribute buffers
    var program = initShaders(gl, "vertex-shader", "fragment-shader");
    gl.useProgram(program);

    // Load the data into the GPU
    var bufferId = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, bufferId);
    gl.bufferData(gl.ARRAY_BUFFER, flatten(points), gl.STATIC_DRAW);

    // Associate our shader variables with our data buffer
    var vPosition = gl.getAttribLocation(program, "vPosition");
    gl.vertexAttribPointer(vPosition, 4, gl.FLOAT, false, 0, 0);
    gl.enableVertexAttribArray(vPosition);

    // Create a buffer object, initialize it, and associate it with
```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view.js - Visual Studio Code
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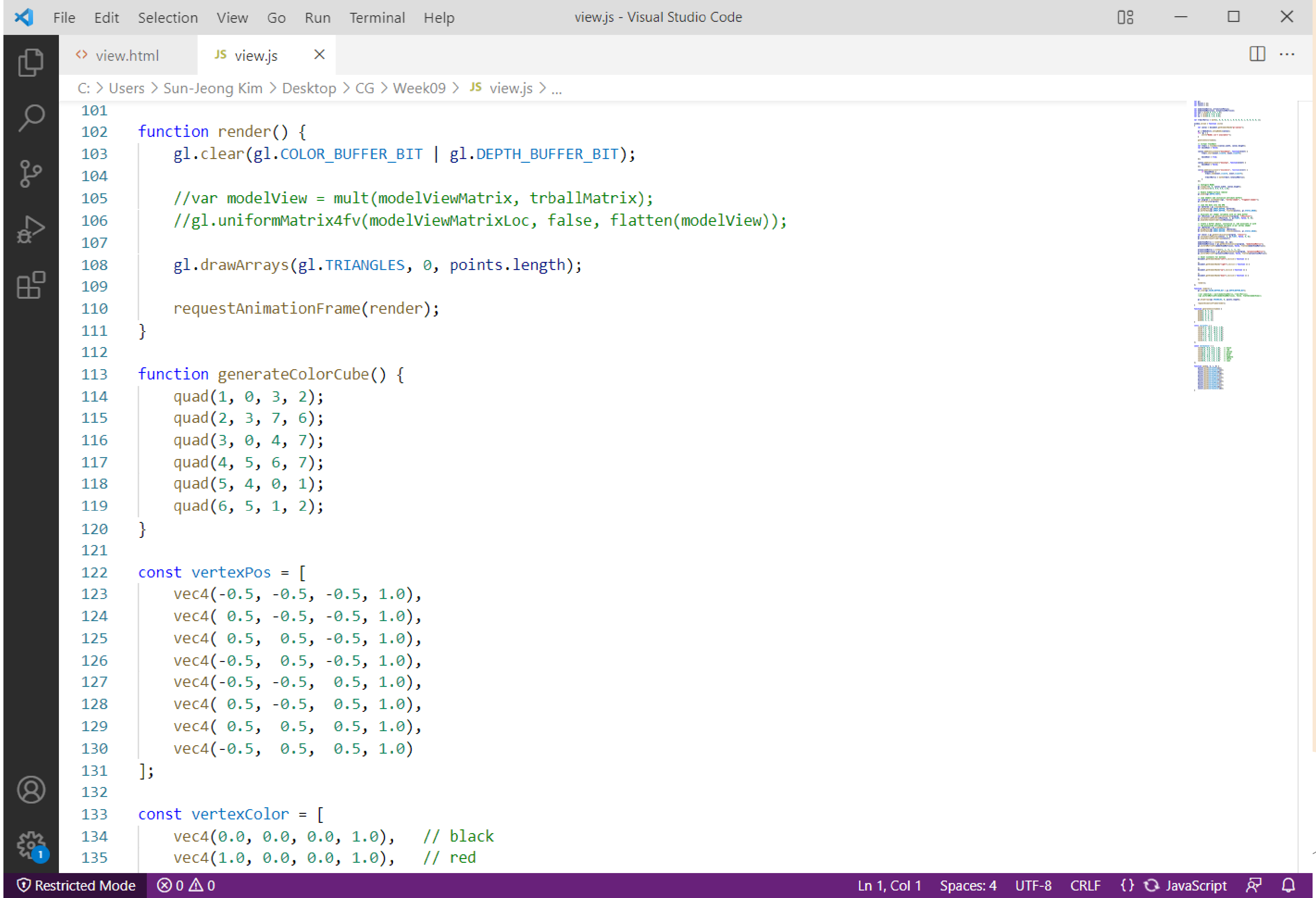
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF JavaScript

```javascript
    // Create a buffer object, initialize it, and associate it with
    // the associated attribute variable in our vertex shader
    var cBufferId = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, cBufferId);
    gl.bufferData(gl.ARRAY_BUFFER, flatten(colors), gl.STATIC_DRAW);

    var vColor = gl.getAttribLocation(program, "vColor");
    gl.vertexAttribPointer(vColor, 4, gl.FLOAT, false, 0, 0);
    gl.enableVertexAttribArray(vColor);

    modelViewMatrix = lookAt(eye, at, up);
    modelViewMatrixLoc = gl.getUniformLocation(program, "modelViewMatrix");
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelViewMatrix));

    projectionMatrix = ortho(-1, 1, -1, 1, -1, 1);
    projectionMatrixLoc = gl.getUniformLocation(program, "projectionMatrix");
    gl.uniformMatrix4fv(projectionMatrixLoc, false, flatten(projectionMatrix));

    // Event listeners for buttons
    document.getElementById("left").onclick = function () {

    };
    document.getElementById("right").onclick = function () {

    };
    document.getElementById("up").onclick = function () {

    };
    document.getElementById("down").onclick = function () {

    };

    render();
};
```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Restricted Mode
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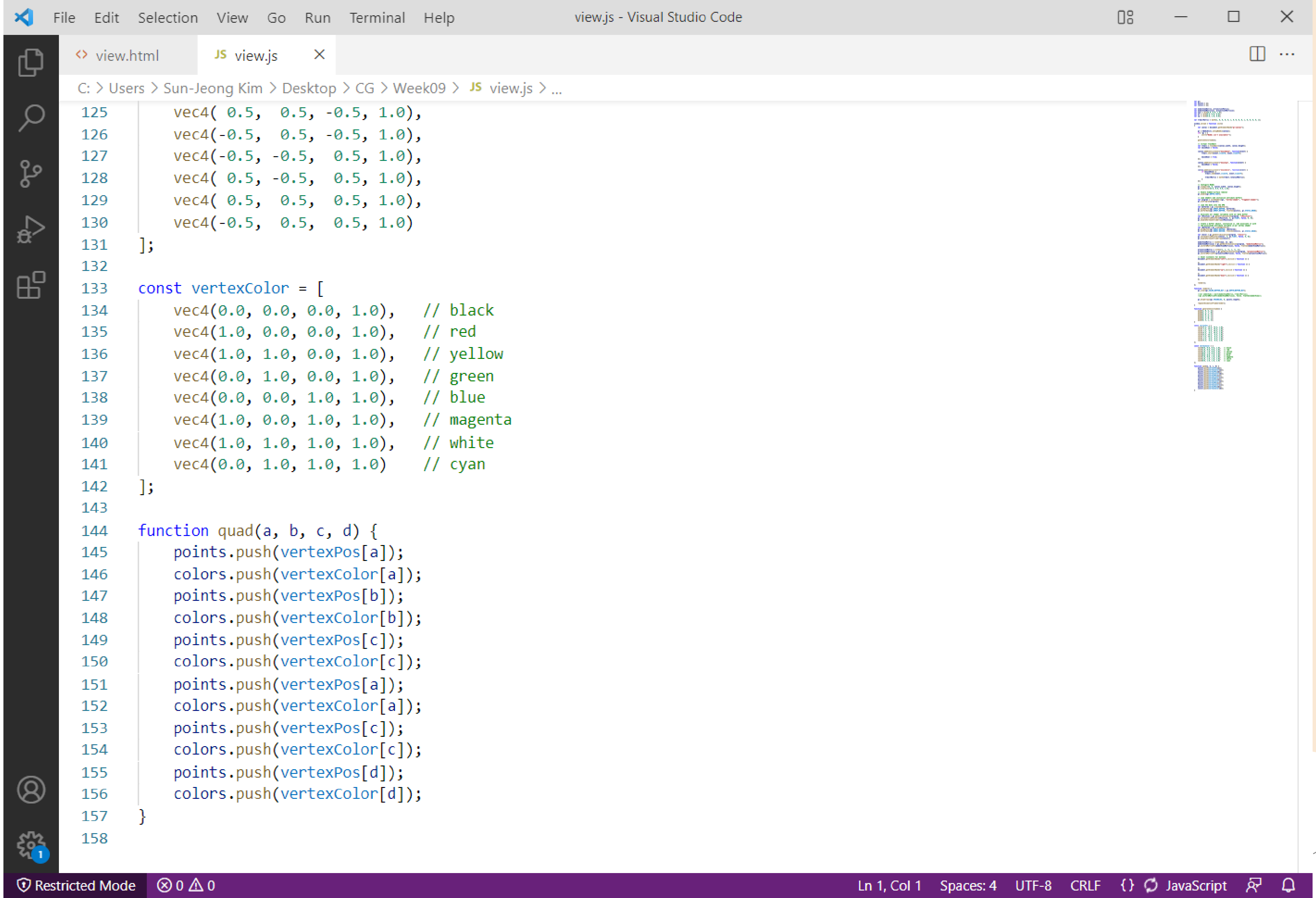
Ln 1, Col 1 Spaces: 4 UTF-8 CRLF JavaScript

```javascript

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    //var modelView = mult(modelViewMatrix, trballMatrix);
    //gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    gl.drawArrays(gl.TRIANGLES, 0, points.length);

    requestAnimationFrame(render);
}

function generateColorCube() {
    quad(1, 0, 3, 2);
    quad(2, 3, 7, 6);
    quad(3, 0, 4, 7);
    quad(4, 5, 6, 7);
    quad(5, 4, 0, 1);
    quad(6, 5, 1, 2);
}

const vertexPos = [
    vec4(-0.5, -0.5, -0.5, 1.0),
    vec4( 0.5, -0.5, -0.5, 1.0),
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
    vec4(-0.5, -0.5,  0.5, 1.0),
    vec4( 0.5, -0.5,  0.5, 1.0),
    vec4( 0.5,  0.5,  0.5, 1.0),
    vec4(-0.5,  0.5,  0.5, 1.0)
];

const vertexColor = [
    vec4(0.0, 0.0, 0.0, 1.0),    // black
    vec4(1.0, 0.0, 0.0, 1.0),    // red
```


view.js - Visual Studio Code
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view.js
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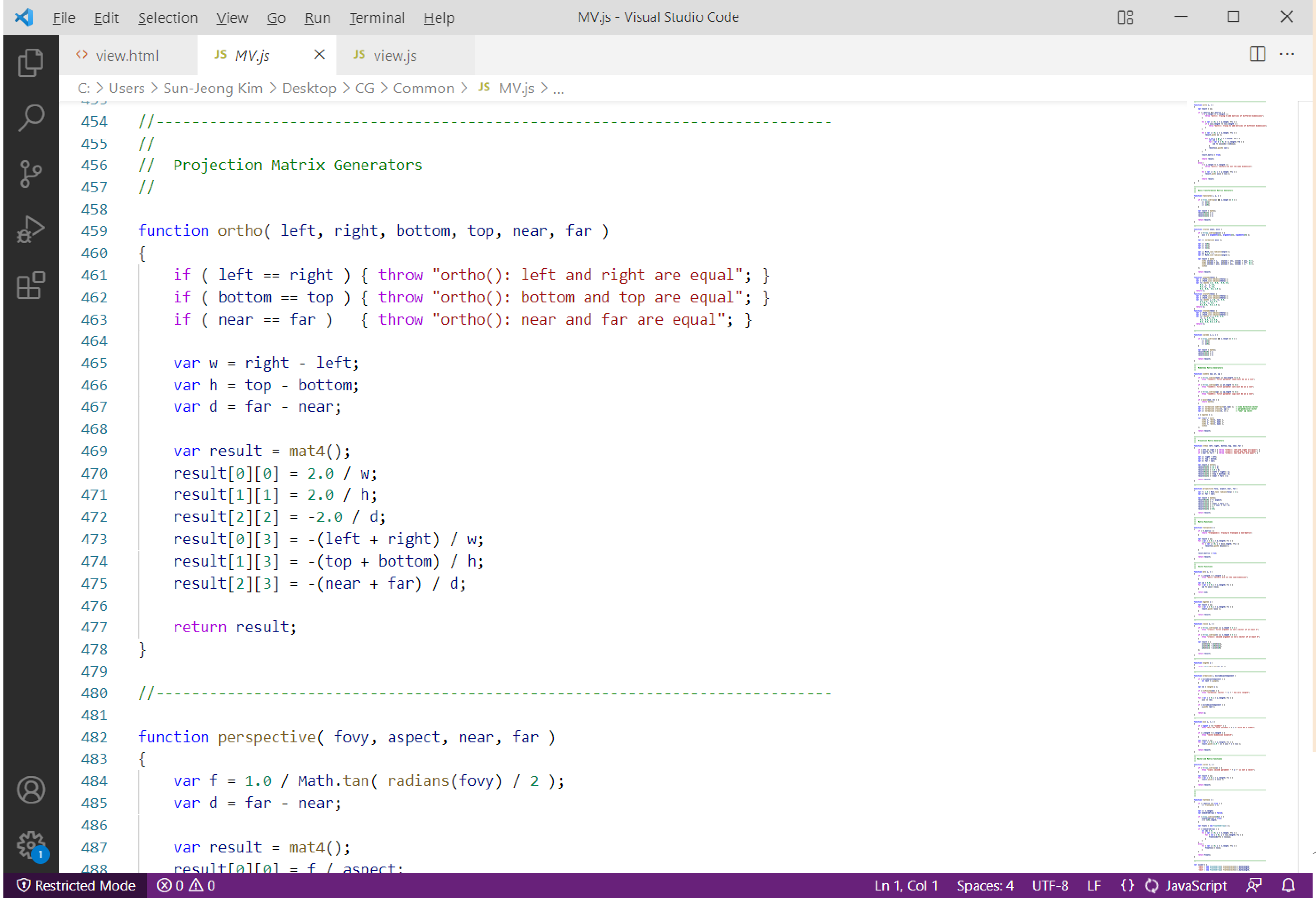
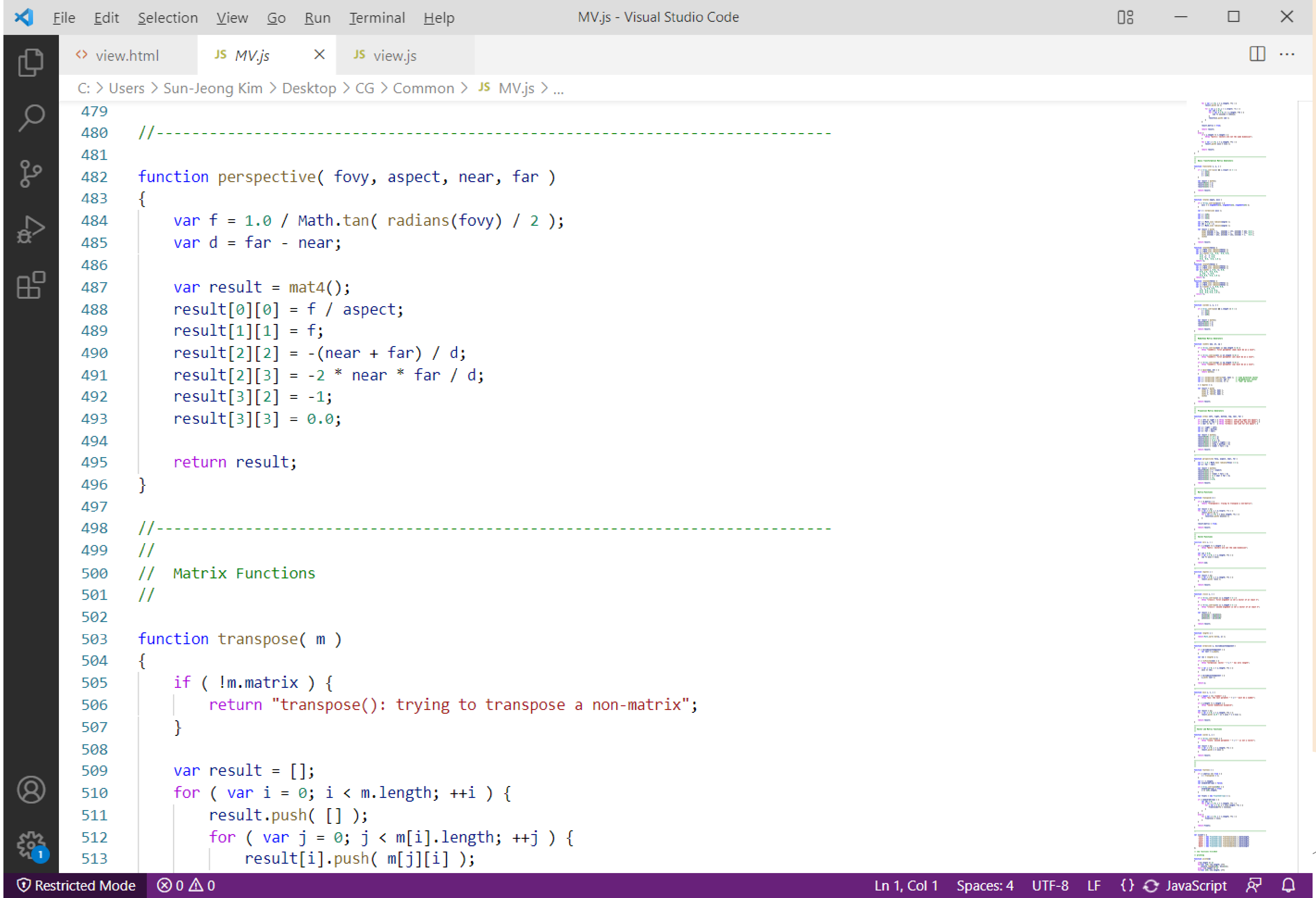
JavaScript

```
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
    vec4(-0.5, -0.5,  0.5, 1.0),
    vec4( 0.5, -0.5,  0.5, 1.0),
    vec4( 0.5,  0.5,  0.5, 1.0),
    vec4(-0.5,  0.5,  0.5, 1.0)
];

const vertexColor = [
    vec4(0.0, 0.0, 0.0, 1.0),   // black
    vec4(1.0, 0.0, 0.0, 1.0),   // red
    vec4(1.0, 1.0, 0.0, 1.0),   // yellow
    vec4(0.0, 1.0, 0.0, 1.0),   // green
    vec4(0.0, 0.0, 1.0, 1.0),   // blue
    vec4(1.0, 0.0, 1.0, 1.0),   // magenta
    vec4(1.0, 1.0, 1.0, 1.0),   // white
    vec4(0.0, 1.0, 1.0, 1.0)    // cyan
];

function quad(a, b, c, d) {
    points.push(vertexPos[a]);
    colors.push(vertexColor[a]);
    points.push(vertexPos[b]);
    colors.push(vertexColor[b]);
    points.push(vertexPos[c]);
    colors.push(vertexColor[c]);
    points.push(vertexPos[a]);
    colors.push(vertexColor[a]);
    points.push(vertexPos[c]);
    colors.push(vertexColor[c]);
    points.push(vertexPos[d]);
    colors.push(vertexColor[d]);
}
```


File Edit Selection View Go Run Terminal Help
MV.js - Visual Studio Code
view.html
MV.js
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Common > MV.js > ...
Restricted Mode
0 0
Ln 1, Col 1 Spaces: 4 UTF-8 LF {} JavaScript

```
//----------------------------------------------------------------------------
//
//  Projection Matrix Generators
//

function ortho( left, right, bottom, top, near, far )
{
    if ( left == right ) { throw "ortho(): left and right are equal"; }
    if ( bottom == top ) { throw "ortho(): bottom and top are equal"; }
    if ( near == far )   { throw "ortho(): near and far are equal"; }

    var w = right - left;
    var h = top - bottom;
    var d = far - near;

    var result = mat4();
    result[0][0] = 2.0 / w;
    result[1][1] = 2.0 / h;
    result[2][2] = -2.0 / d;
    result[0][3] = -(left + right) / w;
    result[1][3] = -(top + bottom) / h;
    result[2][3] = -(near + far) / d;

    return result;
}

//----------------------------------------------------------------------------

function perspective( fovy, aspect, near, far )
{
    var f = 1.0 / Math.tan( radians(fovy) / 2 );
    var d = far - near;

    var result = mat4();
    result[0][0] = f / aspect;
```


File Edit Selection View Go Run Terminal Help
MV.js - Visual Studio Code
view.html
MV.js
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Common > MV.js > ...
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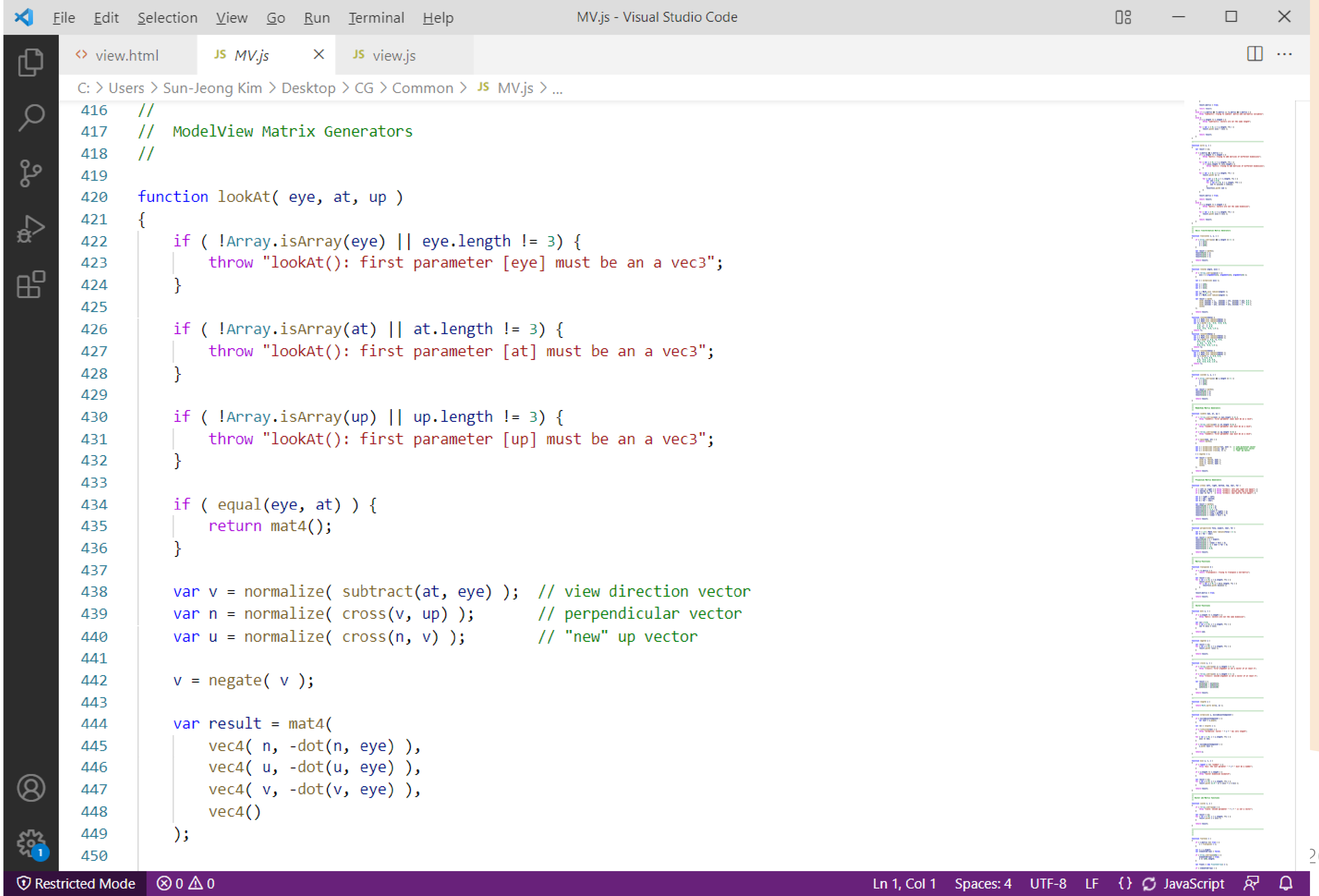
JavaScript

```javascript

//----------------------------------------------------------------------------

function perspective( fovy, aspect, near, far )
{
    var f = 1.0 / Math.tan( radians(fovy) / 2 );
    var d = far - near;

    var result = mat4();
    result[0][0] = f / aspect;
    result[1][1] = f;
    result[2][2] = -(near + far) / d;
    result[2][3] = -2 * near * far / d;
    result[3][2] = -1;
    result[3][3] = 0.0;

    return result;
}

//----------------------------------------------------------------------------
//
//  Matrix Functions
//

function transpose( m )
{
    if ( !m.matrix ) {
        return "transpose(): trying to transpose a non-matrix";
    }

    var result = [];
    for ( var i = 0; i < m.length; ++i ) {
        result.push( [] );
        for ( var j = 0; j < m[i].length; ++j ) {
            result[i].push( m[j][i] );
```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MV.js - Visual Studio Code
view.html
MV.js
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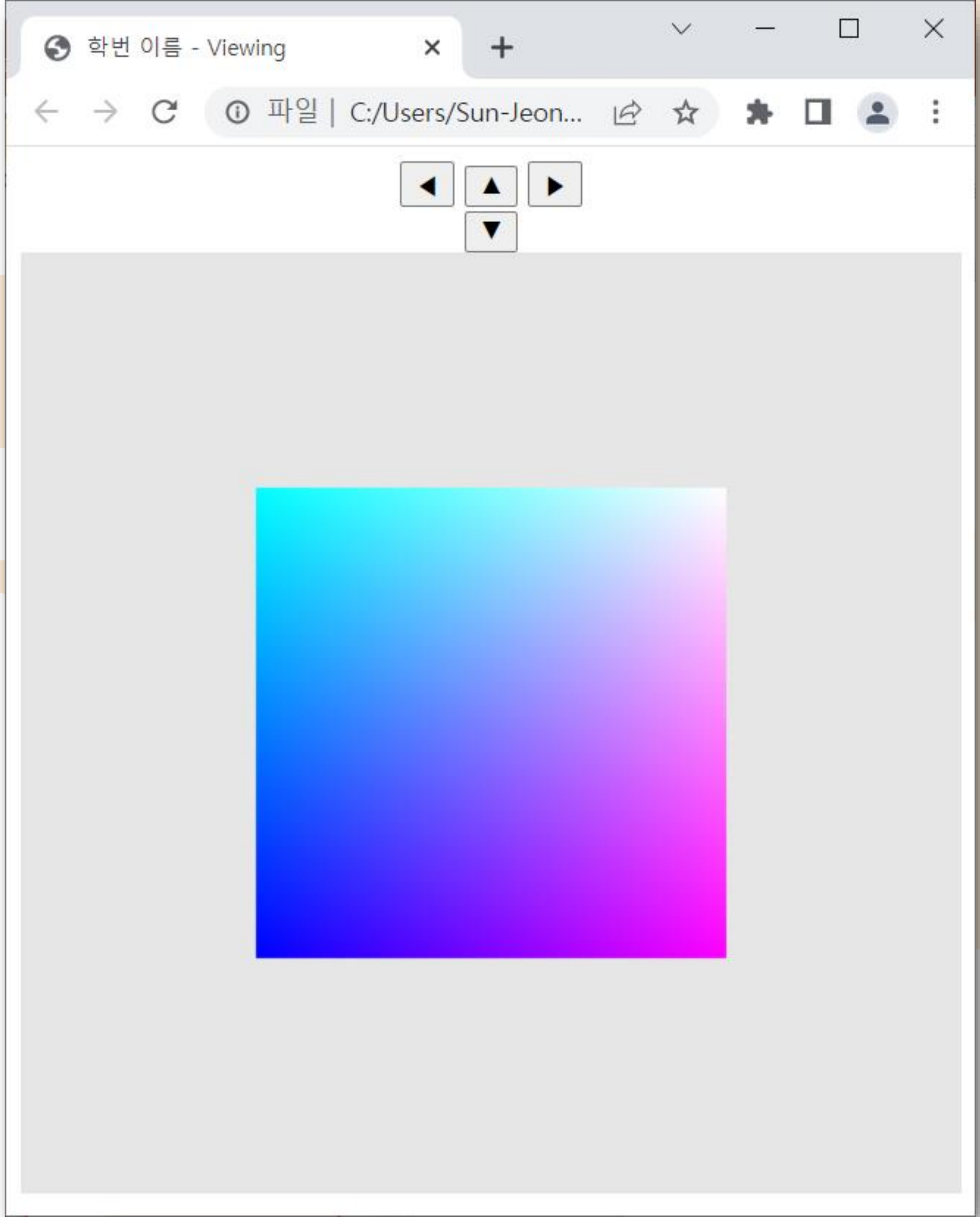
C: > Users > Sun-Jeong Kim > Desktop > CG > Common > MV.js > ...
Restricted Mode
Ln 1, Col 1
Spaces: 4
UTF-8
LF
JavaScript

```
//
//  ModelView Matrix Generators
//

function lookAt( eye, at, up )
{
    if ( !Array.isArray(eye) || eye.length != 3) {
        throw "lookAt(): first parameter [eye] must be an a vec3";
    }

    if ( !Array.isArray(at) || at.length != 3) {
        throw "lookAt(): first parameter [at] must be an a vec3";
    }

    if ( !Array.isArray(up) || up.length != 3) {
        throw "lookAt(): first parameter [up] must be an a vec3";
    }

    if ( equal(eye, at) ) {
        return mat4();
    }

    var v = normalize( subtract(at, eye) );  // view direction vector
    var n = normalize( cross(v, up) );       // perpendicular vector
    var u = normalize( cross(n, v) );        // "new" up vector

    v = negate( v );

    var result = mat4(
        vec4( n, -dot(n, eye) ),
        vec4( u, -dot(u, eye) ),
        vec4( v, -dot(v, eye) ),
        vec4()
    );

```


학번 이름 - Viewing
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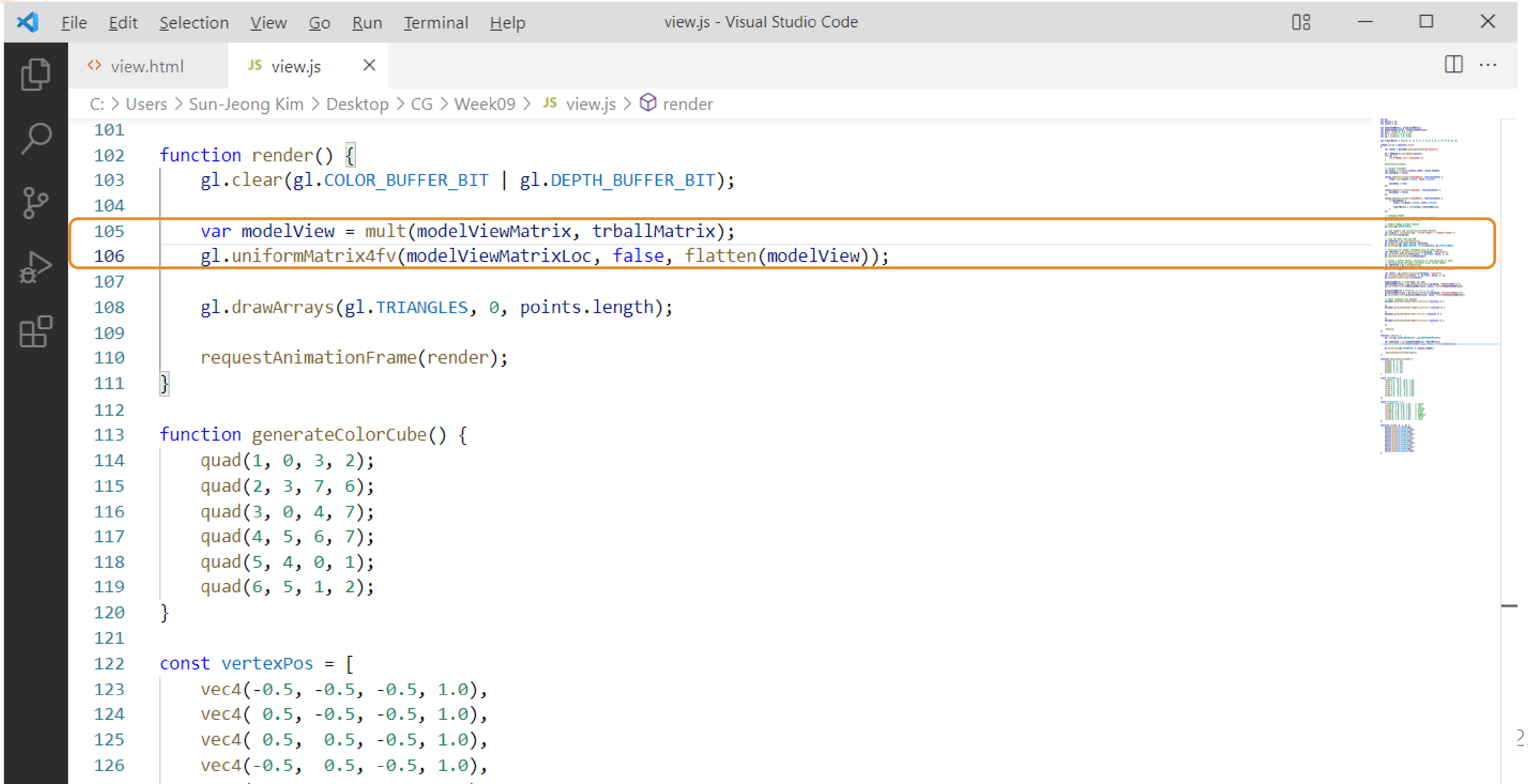
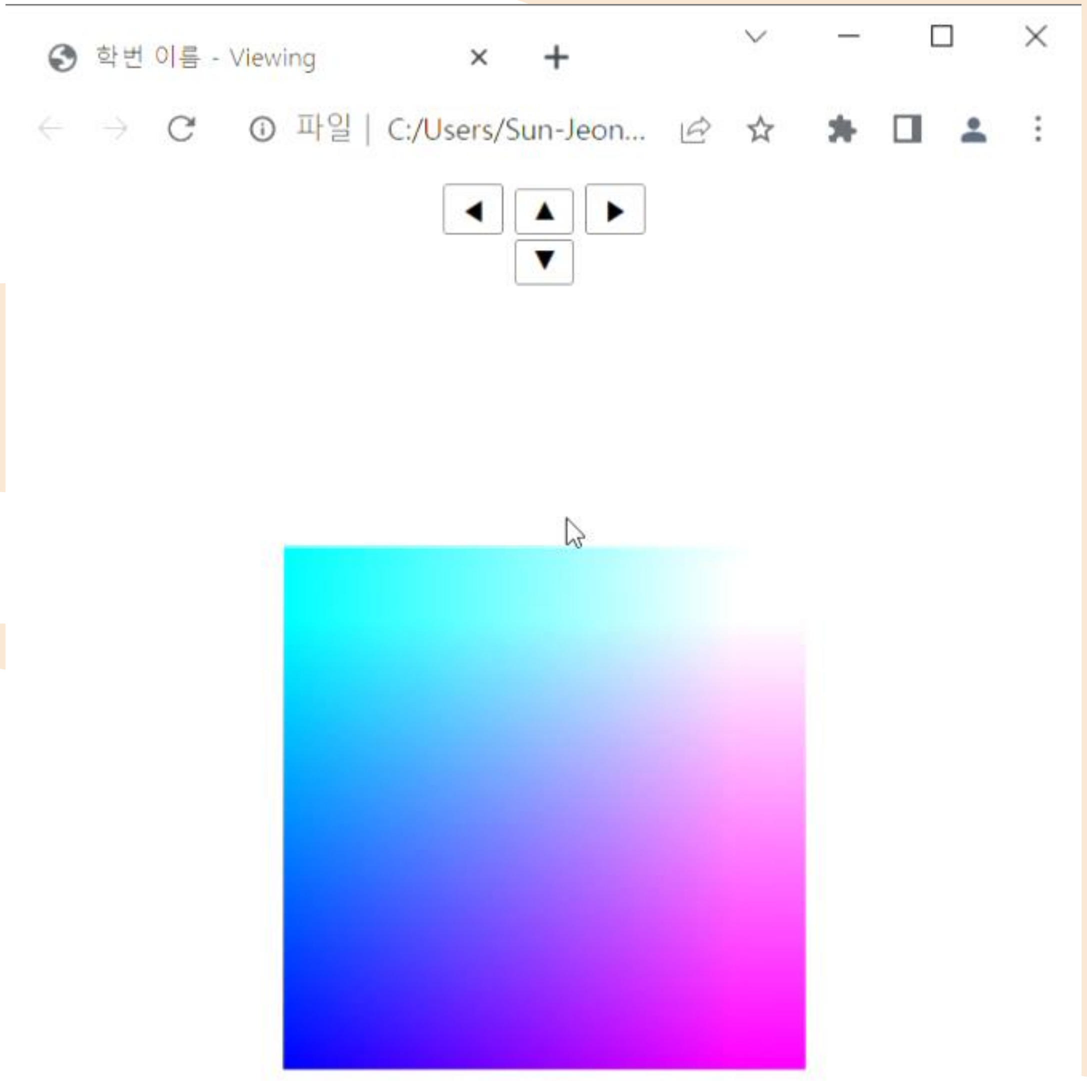
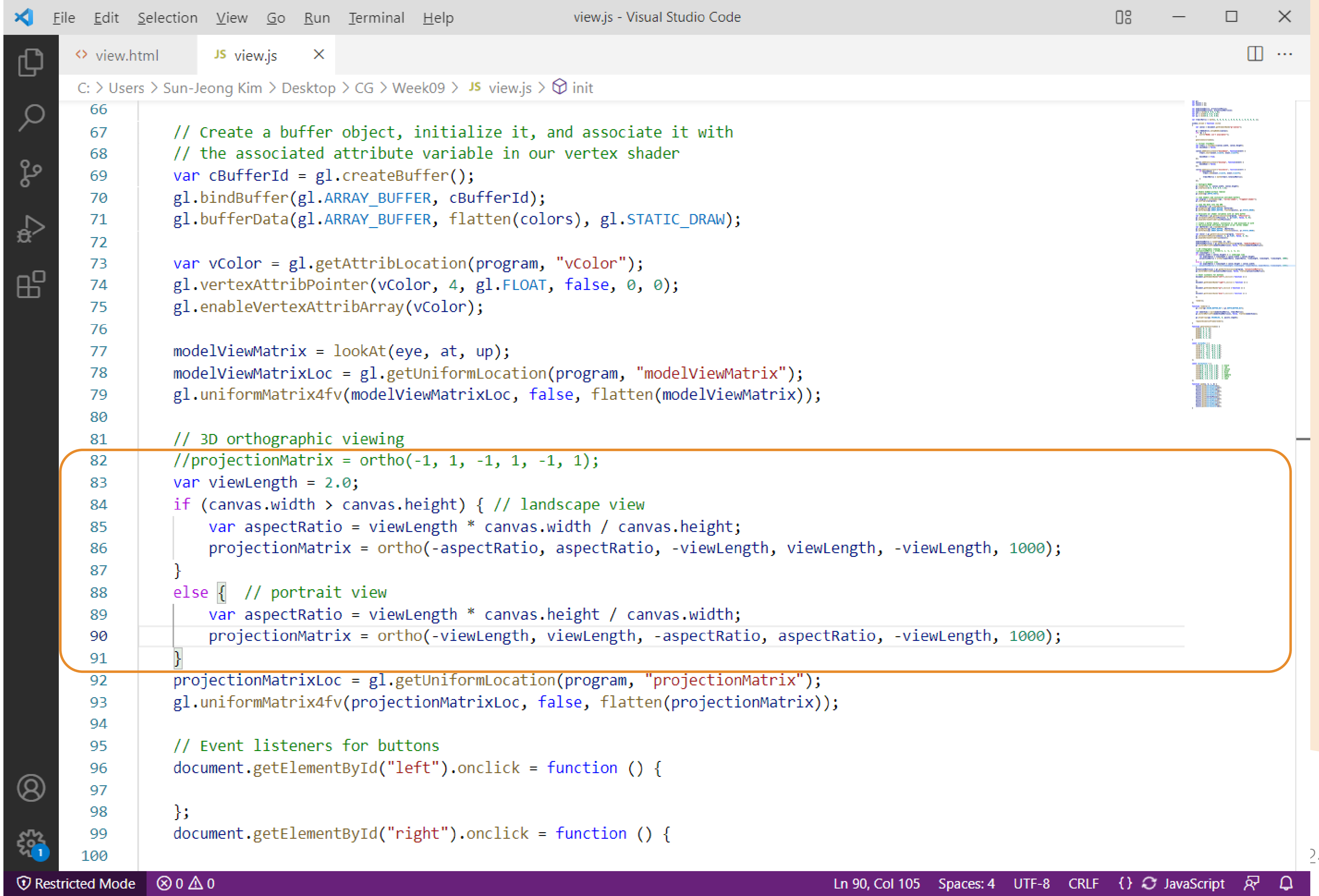
Rotation with a Quaternion

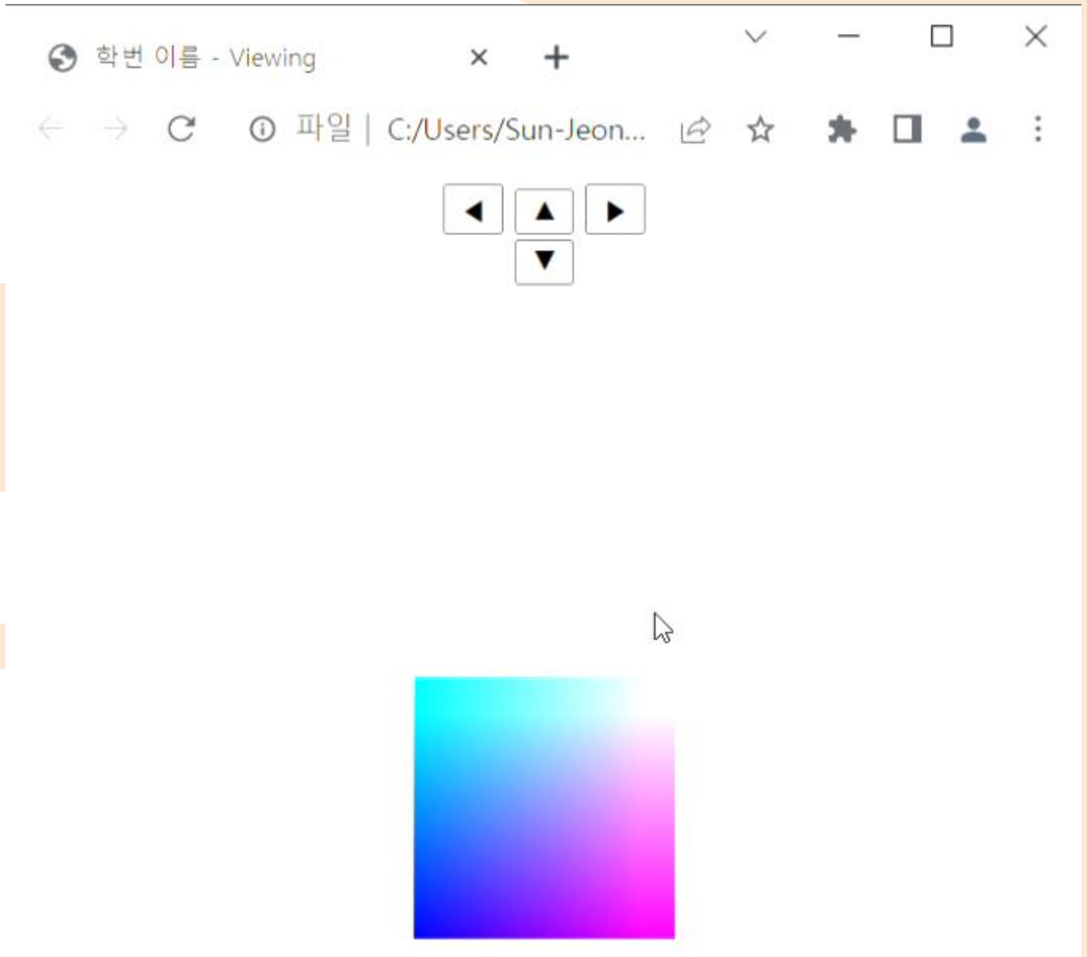

File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > render

```
function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    gl.drawArrays(gl.TRIANGLES, 0, points.length);

    requestAnimationFrame(render);
}

function generateColorCube() {
    quad(1, 0, 3, 2);
    quad(2, 3, 7, 6);
    quad(3, 0, 4, 7);
    quad(4, 5, 6, 7);
    quad(5, 4, 0, 1);
    quad(6, 5, 1, 2);
}

const vertexPos = [
    vec4(-0.5, -0.5, -0.5, 1.0),
    vec4( 0.5, -0.5, -0.5, 1.0),
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
```


학번 이름 - Viewing
파일 | C:/Users/Sun-Jeon...


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init
Restricted Mode
0 0
Ln 90, Col 105 Spaces: 4 UTF-8 CRLF JavaScript

```javascript

    // Create a buffer object, initialize it, and associate it with
    // the associated attribute variable in our vertex shader
    var cBufferId = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, cBufferId);
    gl.bufferData(gl.ARRAY_BUFFER, flatten(colors), gl.STATIC_DRAW);

    var vColor = gl.getAttribLocation(program, "vColor");
    gl.vertexAttribPointer(vColor, 4, gl.FLOAT, false, 0, 0);
    gl.enableVertexAttribArray(vColor);

    modelViewMatrix = lookAt(eye, at, up);
    modelViewMatrixLoc = gl.getUniformLocation(program, "modelViewMatrix");
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelViewMatrix));

    // 3D orthographic viewing
    //projectionMatrix = ortho(-1, 1, -1, 1, -1, 1);
    var viewLength = 2.0;
    if (canvas.width > canvas.height) { // landscape view
        var aspectRatio = viewLength * canvas.width / canvas.height;
        projectionMatrix = ortho(-aspectRatio, aspectRatio, -viewLength, viewLength, -viewLength, 1000);
    }
    else {  // portrait view
        var aspectRatio = viewLength * canvas.height / canvas.width;
        projectionMatrix = ortho(-viewLength, viewLength, -aspectRatio, aspectRatio, -viewLength, 1000);
    }
    projectionMatrixLoc = gl.getUniformLocation(program, "projectionMatrix");
    gl.uniformMatrix4fv(projectionMatrixLoc, false, flatten(projectionMatrix));

    // Event listeners for buttons
    document.getElementById("left").onclick = function () {

    };
    document.getElementById("right").onclick = function () {

```


학번 이름 - Viewing
파일 | C:/Users/Sun-Jeon...
◀
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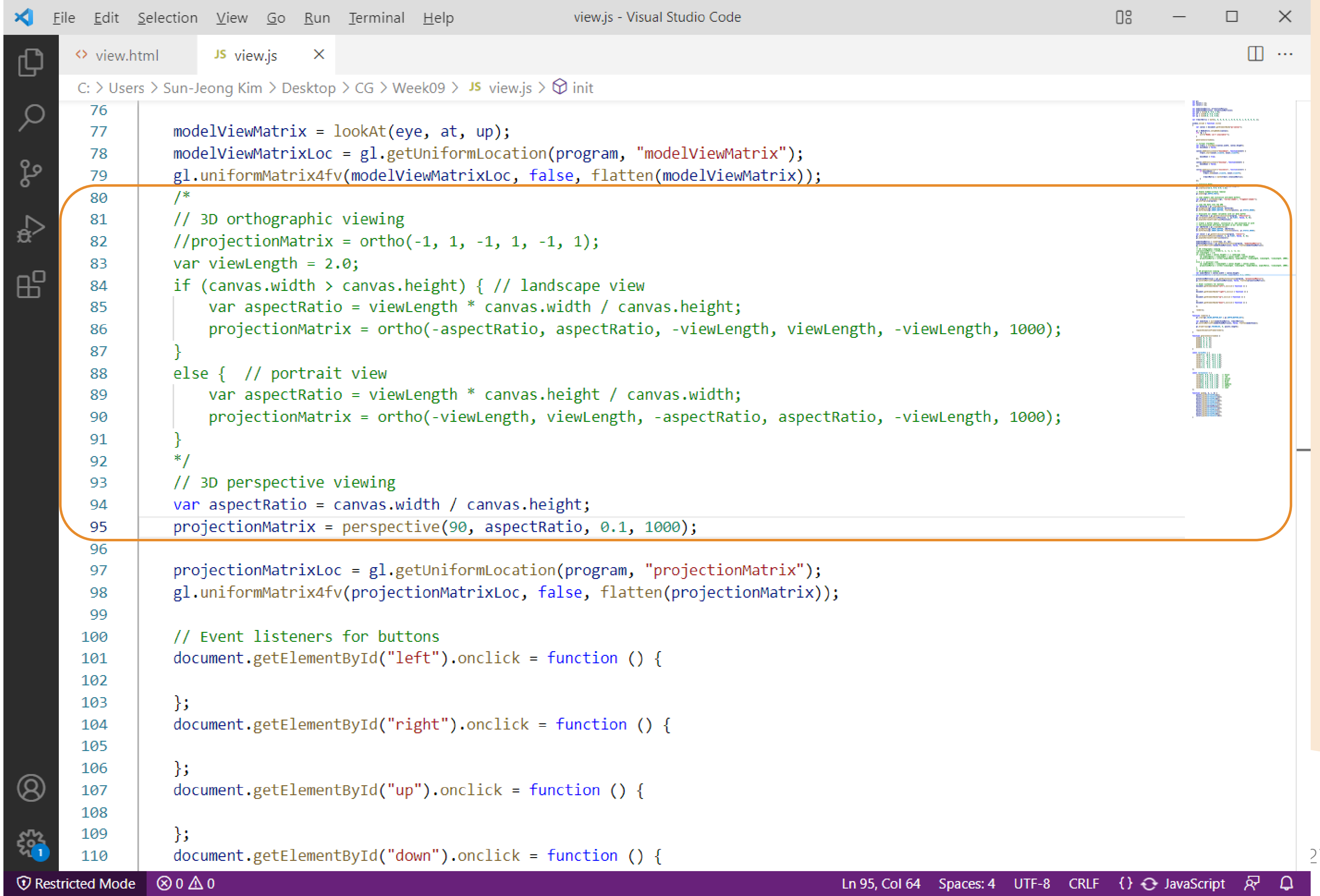
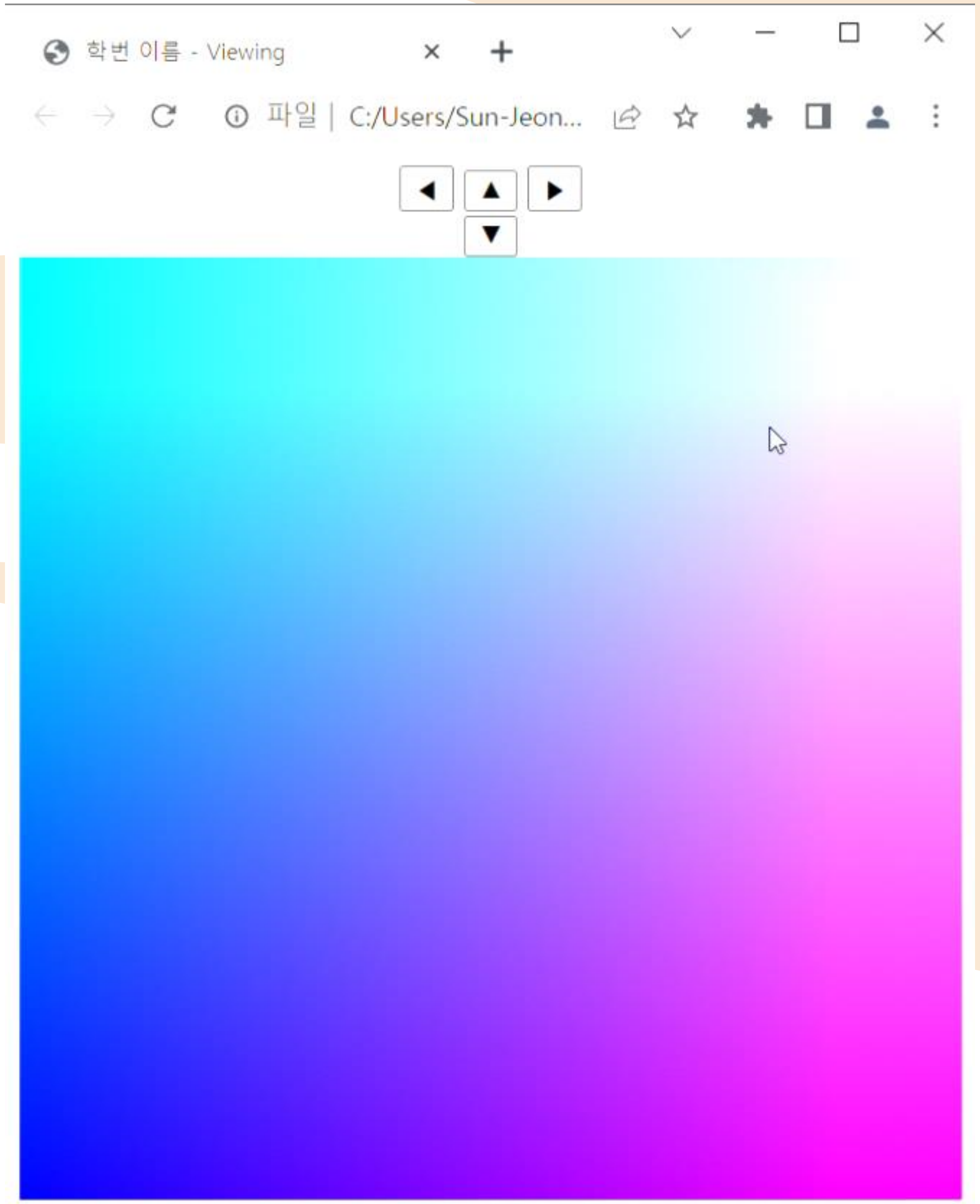
연습 문제 (1)

- ortho( ) 함수의 left, right, bottom, top의 값을 변경해보고, 그 의미를 파악해 보시오.
  - 예) viewLength = 1.0; 또는 viewLength = 3.0;


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init
Restricted Mode
Ln 95, Col 64 Spaces: 4 UTF-8 CRLF JavaScript

```javascript

    modelViewMatrix = lookAt(eye, at, up);
    modelViewMatrixLoc = gl.getUniformLocation(program, "modelViewMatrix");
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelViewMatrix));
    /*
    // 3D orthographic viewing
    //projectionMatrix = ortho(-1, 1, -1, 1, -1, 1);
    var viewLength = 2.0;
    if (canvas.width > canvas.height) { // landscape view
        var aspectRatio = viewLength * canvas.width / canvas.height;
        projectionMatrix = ortho(-aspectRatio, aspectRatio, -viewLength, viewLength, -viewLength, 1000);
    }
    else {  // portrait view
        var aspectRatio = viewLength * canvas.height / canvas.width;
        projectionMatrix = ortho(-viewLength, viewLength, -aspectRatio, aspectRatio, -viewLength, 1000);
    }
    */
    // 3D perspective viewing
    var aspectRatio = canvas.width / canvas.height;
    projectionMatrix = perspective(90, aspectRatio, 0.1, 1000);

    projectionMatrixLoc = gl.getUniformLocation(program, "projectionMatrix");
    gl.uniformMatrix4fv(projectionMatrixLoc, false, flatten(projectionMatrix));

    // Event listeners for buttons
    document.getElementById("left").onclick = function () {

    };
    document.getElementById("right").onclick = function () {

    };
    document.getElementById("up").onclick = function () {

    };
    document.getElementById("down").onclick = function () {
```



학번 이름 - Viewing
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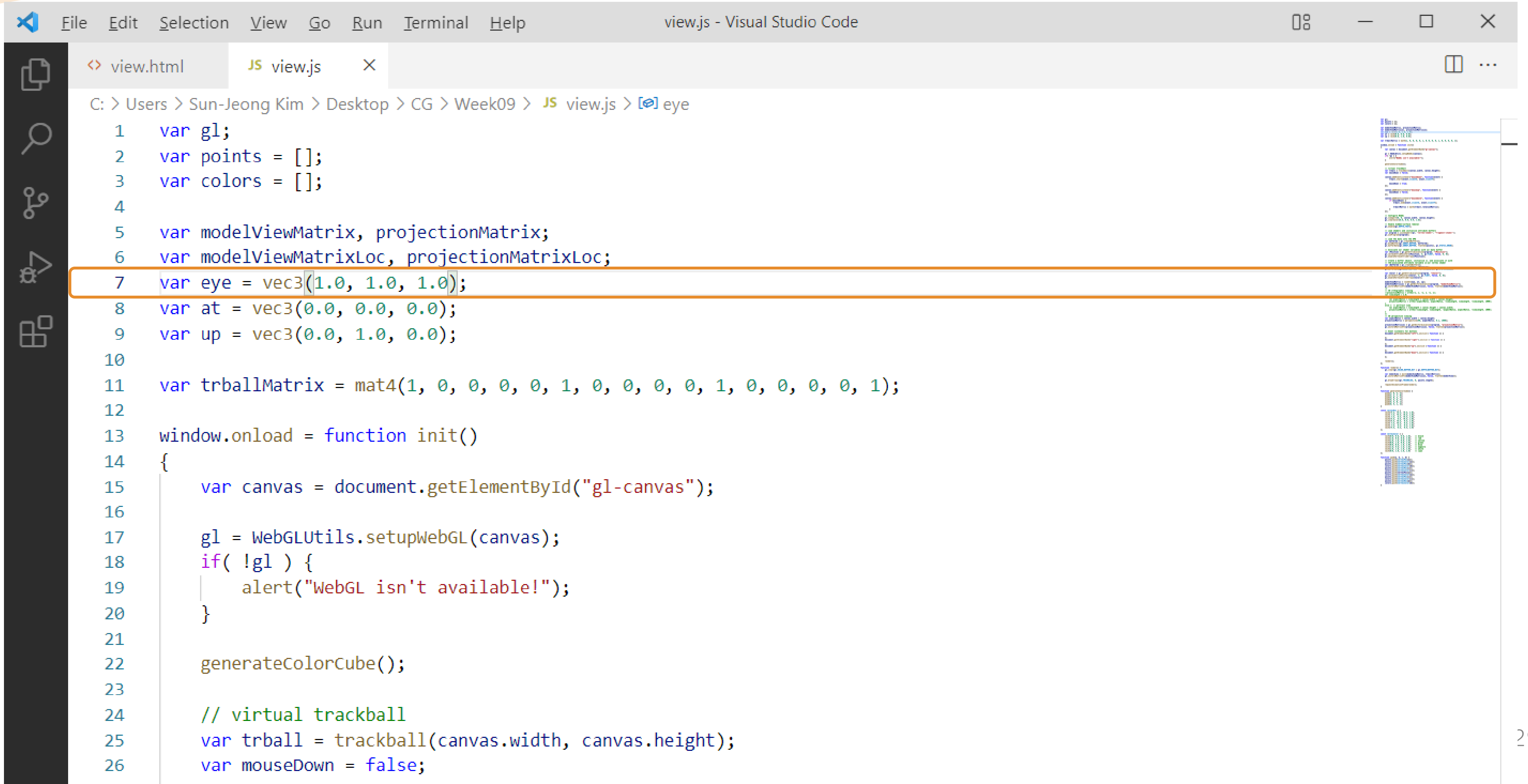
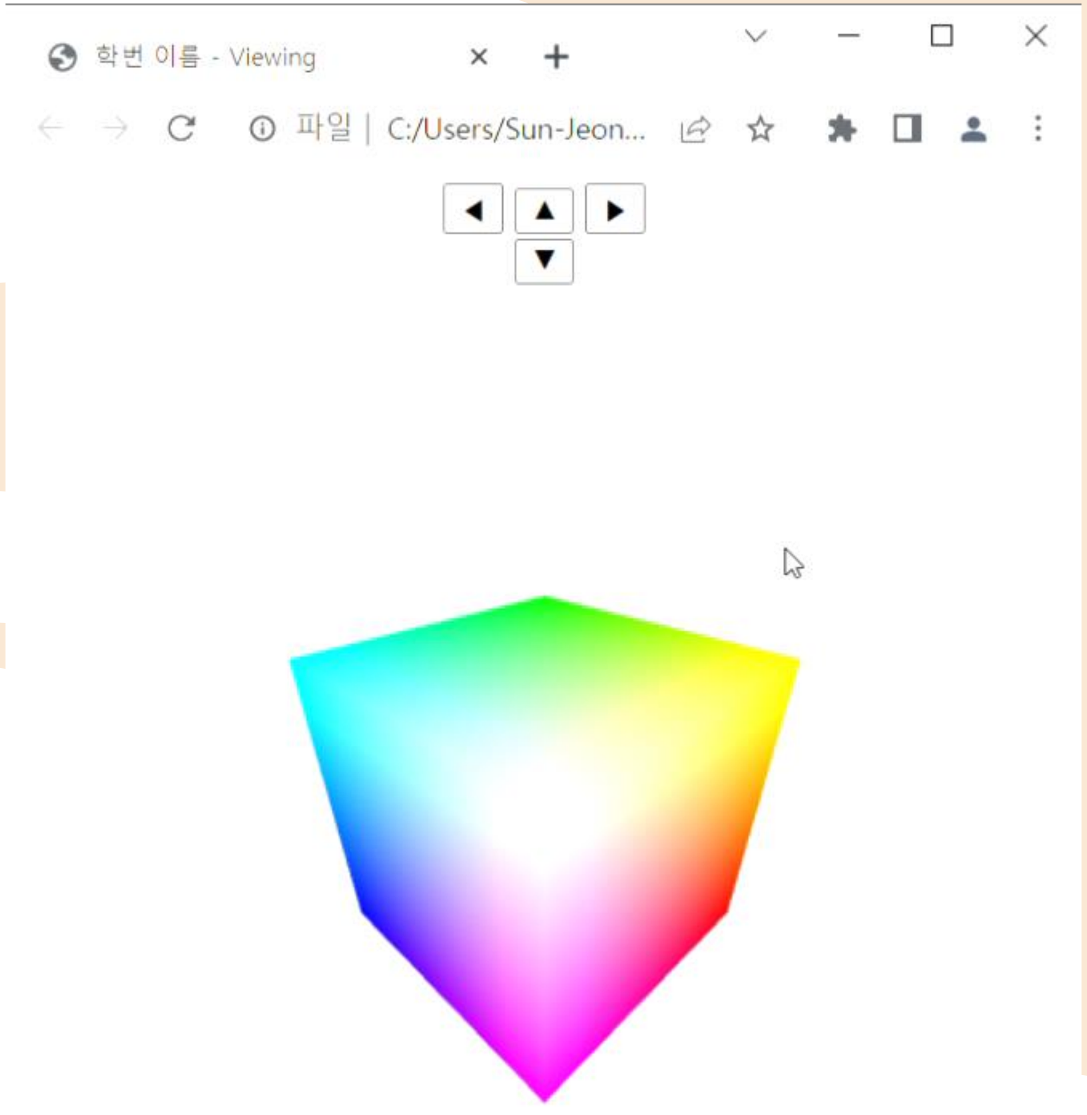
Locating the Camera


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > eye

```
var gl;
var points = [];
var colors = [];

var modelViewMatrix, projectionMatrix;
var modelViewMatrixLoc, projectionMatrixLoc;
var eye = vec3(1.0, 1.0, 1.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);

var trballMatrix = mat4(1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1);

window.onload = function init()
{
    var canvas = document.getElementById("gl-canvas");

    gl = WebGLUtils.setupWebGL(canvas);
    if( !gl ) {
        alert("WebGL isn't available!");
    }

    generateColorCube();

    // virtual trackball
    var trball = trackball(canvas.width, canvas.height);
    var mouseDown = false;
```


학번 이름 - Viewing
파일 | C:/Users/Sun-Jeon...
◀
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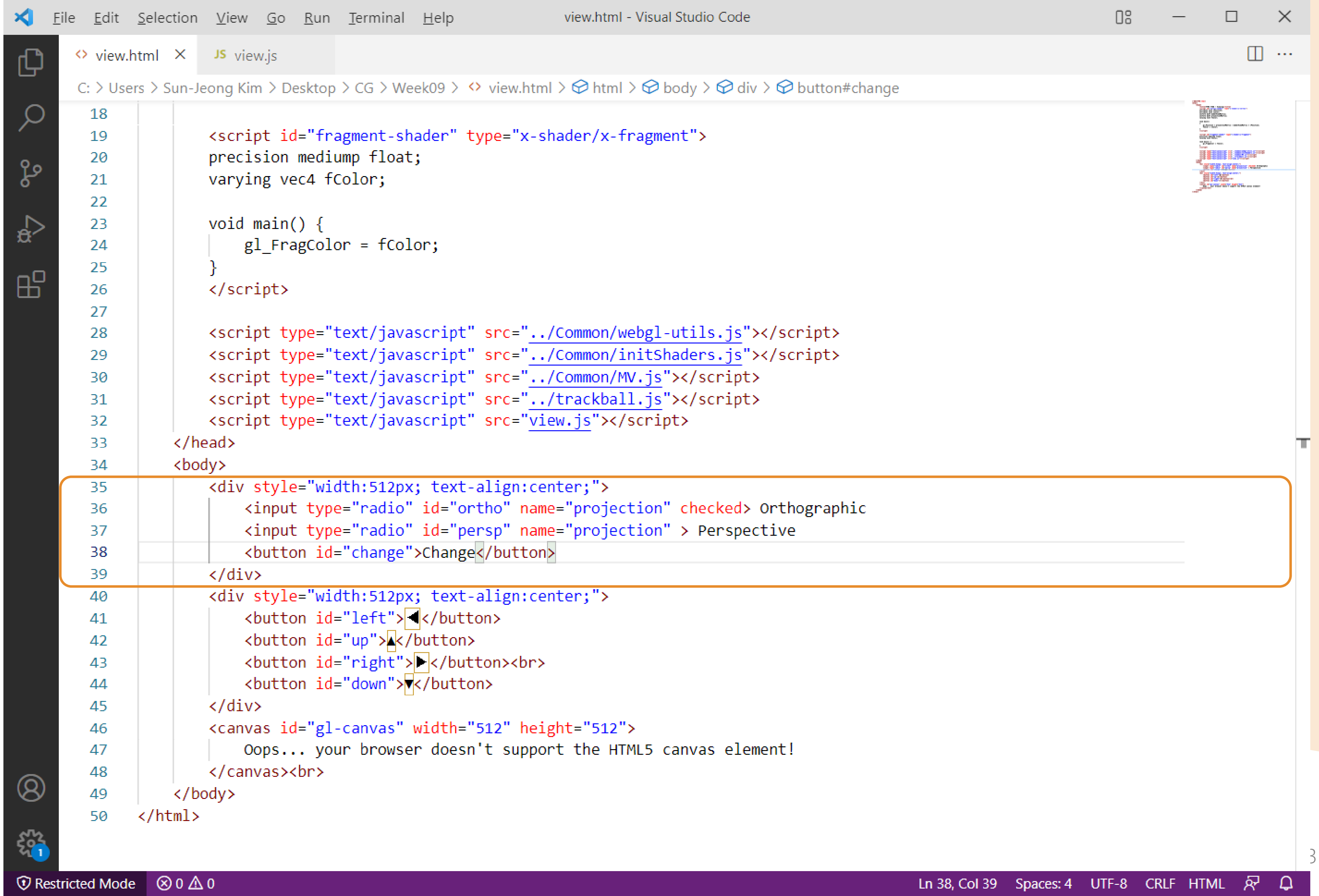
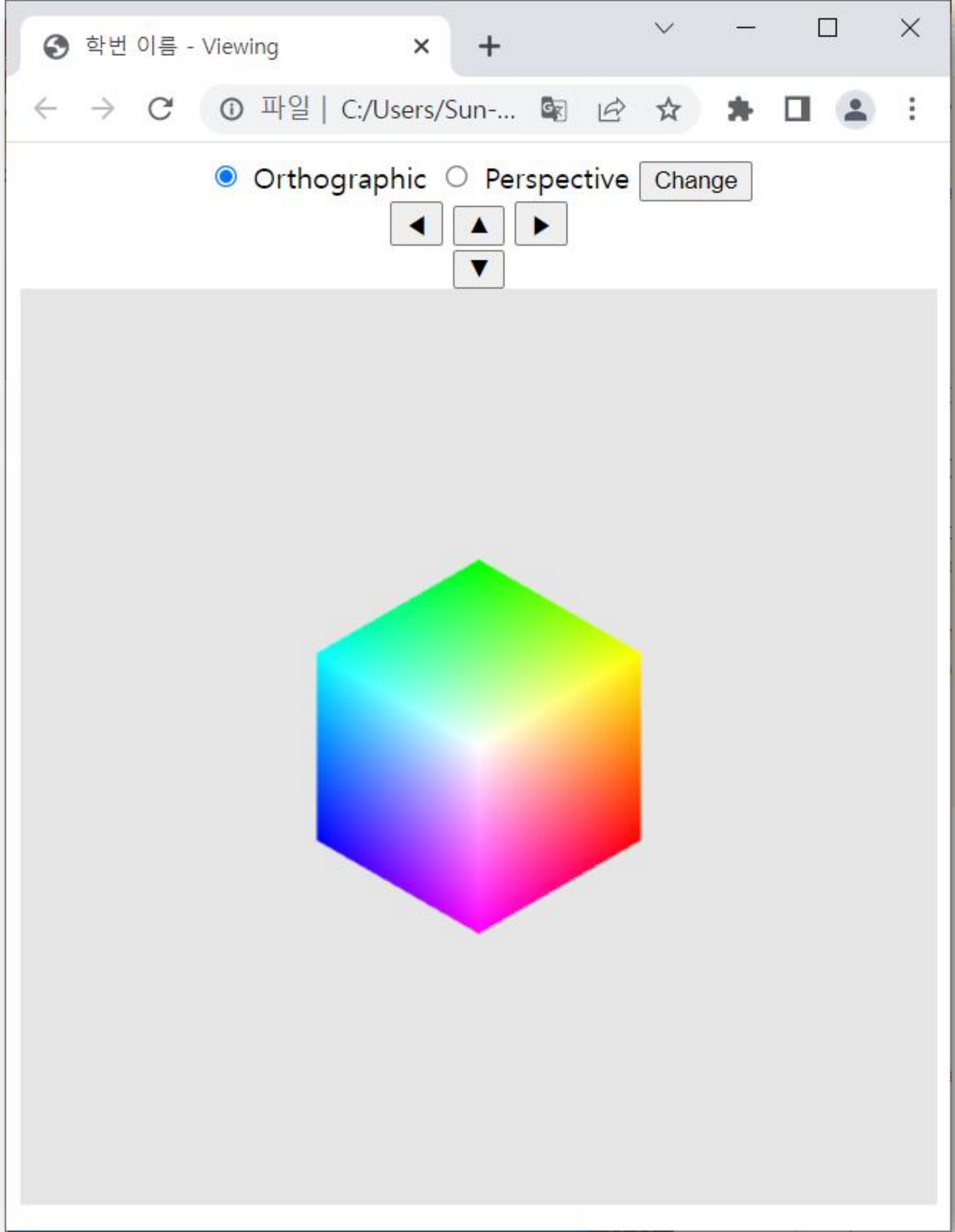
연습 문제 (2)

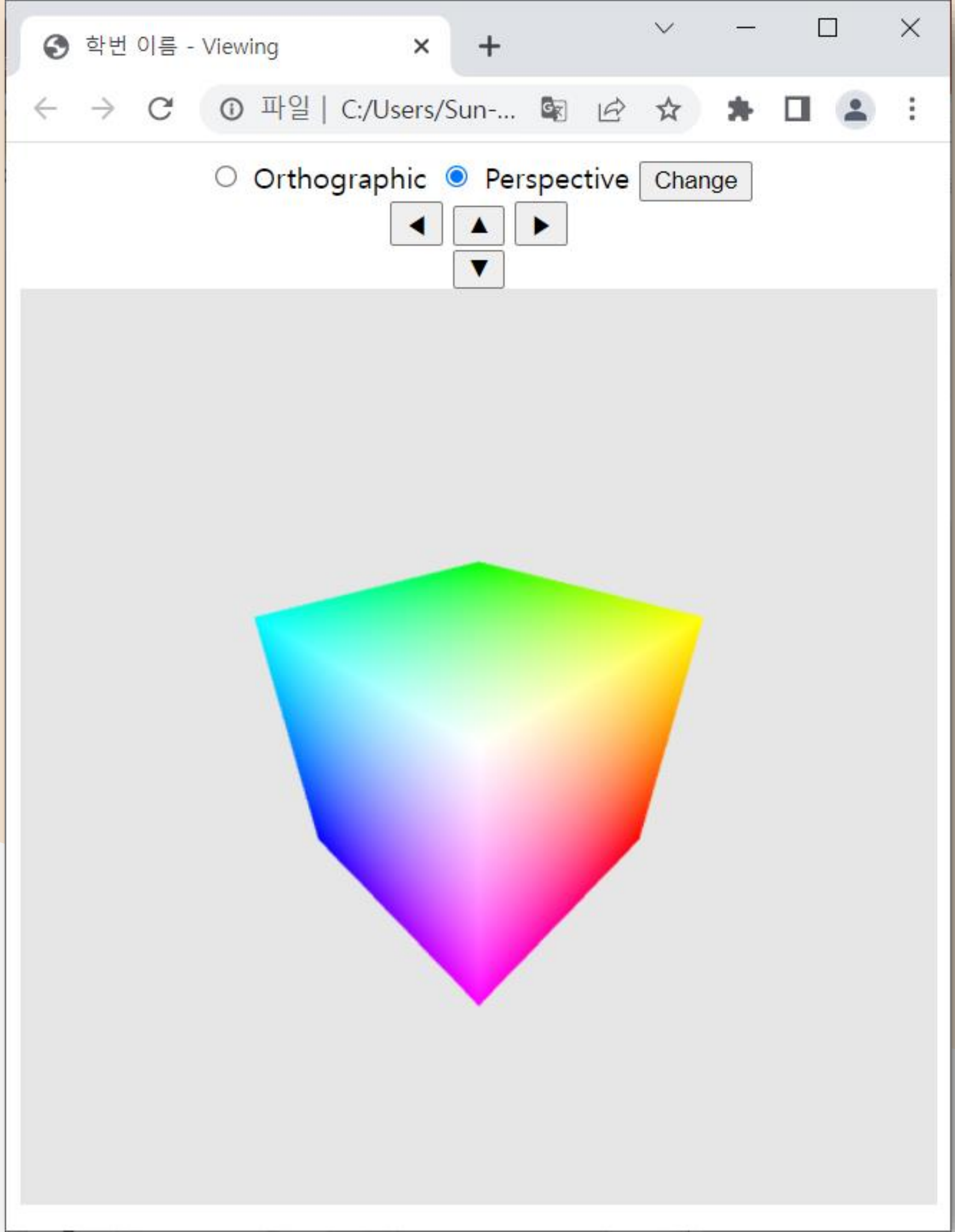
- perspective( ) 함수에서 fovy 파라미터 값을 변경해보고, 그 의미를 파악하시오.
  - 예) 90도 대신 60도 또는 120도

- perspective( )함수에서 near, far 파라미터 값을 변경해보고, 그 의미를 파악하시오.
  - 0.1 대신 0.01 또는 1.0
  - 1000 대신 100 또는 10000


File Edit Selection View Go Run Terminal Help
view.html - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.html > html > body > div > button#change
Restricted Mode
0 0
Ln 38, Col 39 Spaces: 4 UTF-8 CRLF HTML

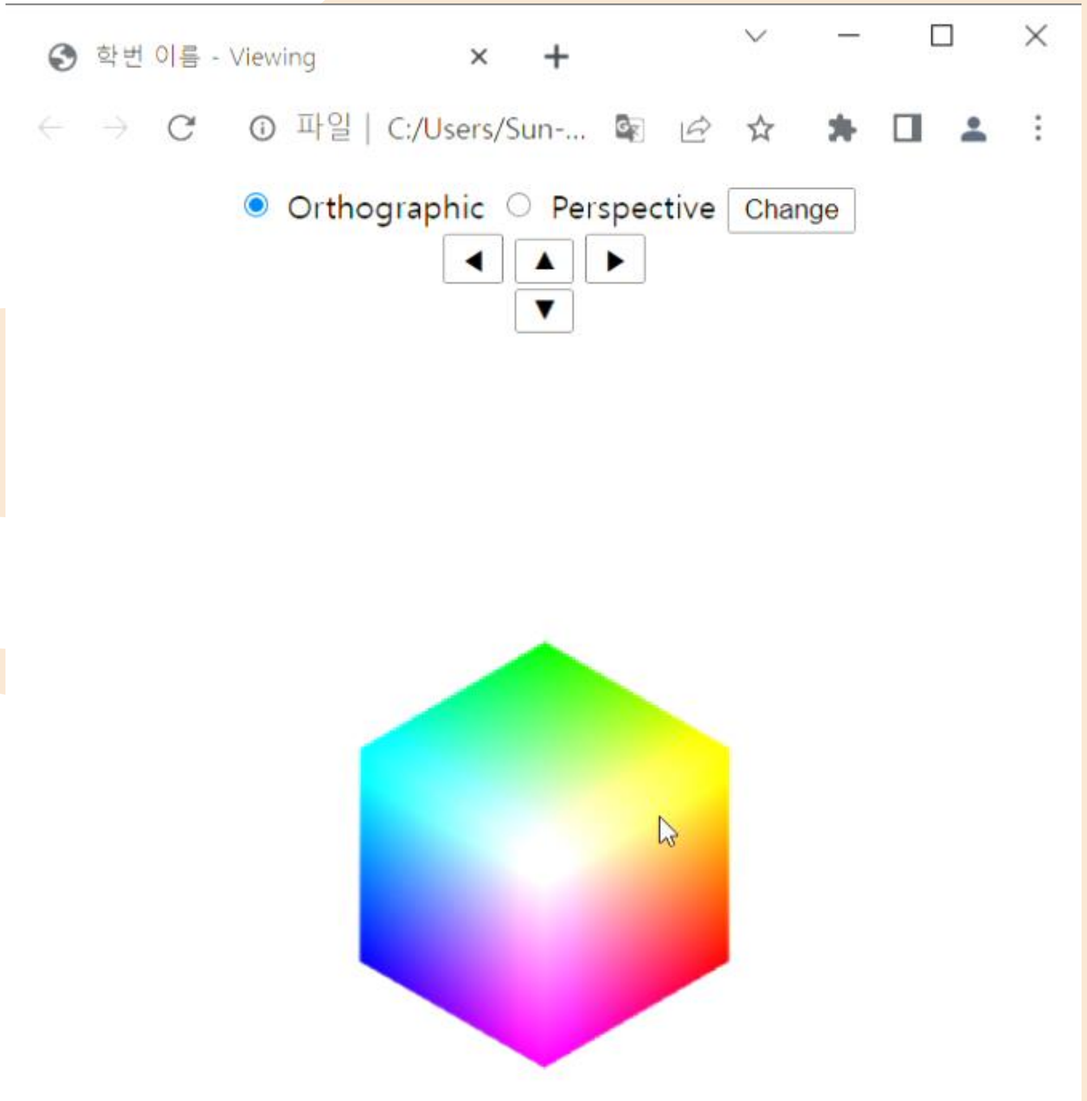
```html

        <script id="fragment-shader" type="x-shader/x-fragment">
        precision mediump float;
        varying vec4 fColor;

        void main() {
            gl_FragColor = fColor;
        }
        </script>

        <script type="text/javascript" src="../Common/webgl-utils.js"></script>
        <script type="text/javascript" src="../Common/initShaders.js"></script>
        <script type="text/javascript" src="../Common/MV.js"></script>
        <script type="text/javascript" src="../trackball.js"></script>
        <script type="text/javascript" src="view.js"></script>
    </head>
    <body>
        <div style="width:512px; text-align:center;">
            <input type="radio" id="ortho" name="projection" checked> Orthographic
            <input type="radio" id="persp" name="projection" > Perspective
            <button id="change">Change</button>
        </div>
        <div style="width:512px; text-align:center;">
            <button id="left">◀</button>
            <button id="up">▲</button>
            <button id="right">▶</button><br>
            <button id="down">▼</button>
        </div>
        <canvas id="gl-canvas" width="512" height="512">
            Oops... your browser doesn't support the HTML5 canvas element!
        </canvas><br>
    </body>
</html>
```


학번 이름 - Viewing
파일 | C:/Users/Sun-...
◉ Orthographic ○ Perspective
Change
◀ ▲ ▶
▼

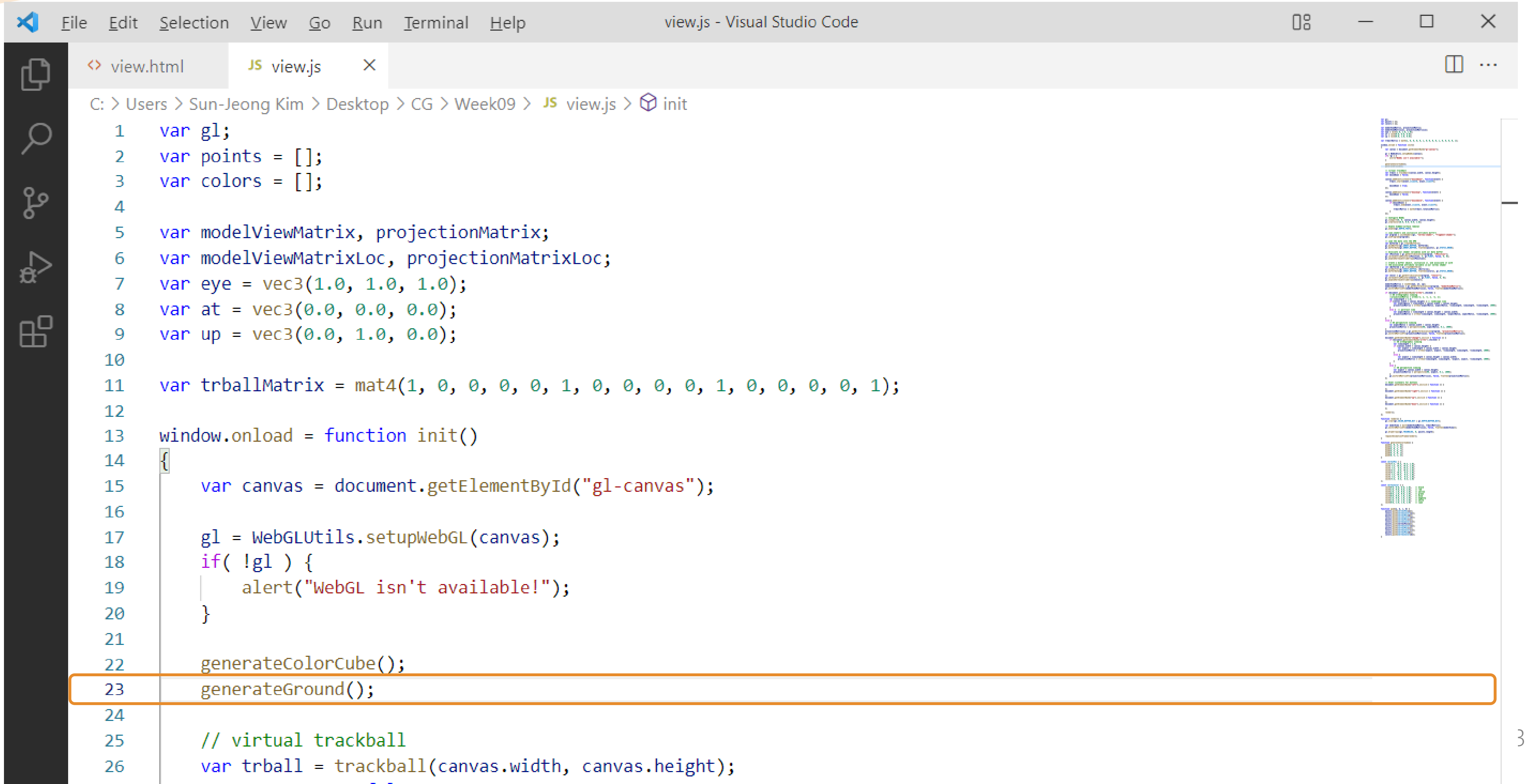

학번 이름 - Viewing
파일 | C:/Users/Sun-...
○ Orthographic ◉ Perspective
Change
◀ ▲ ▶
▼

연습 문제 (3)

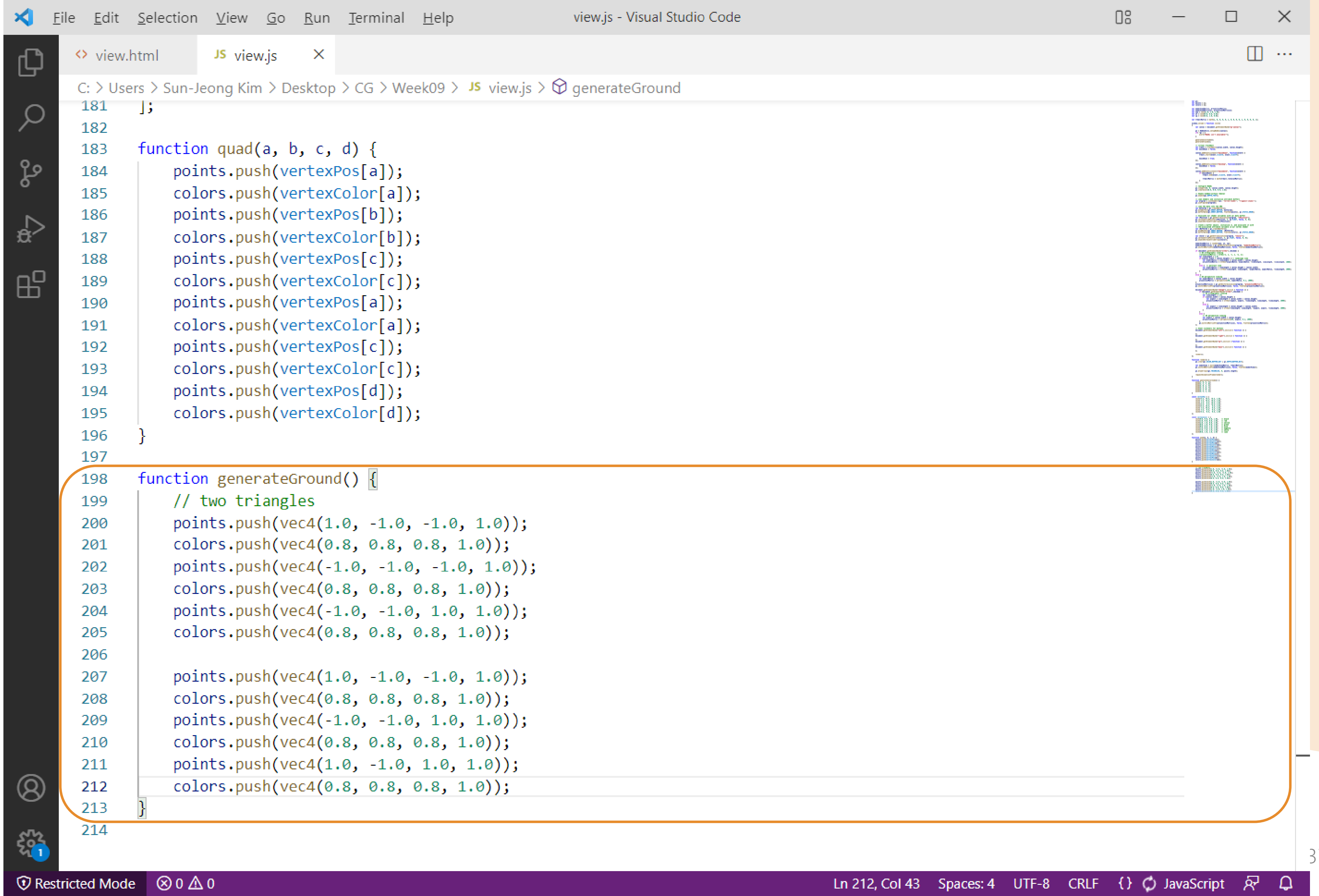
- 라디오 버튼을 만들어 Projection 방법을 선택할 수 있도록 구현하시오.
- Change 버튼을 누르면 선택된 Projection 방법으로 변경되도록 하시오.


학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic
Perspective
Change

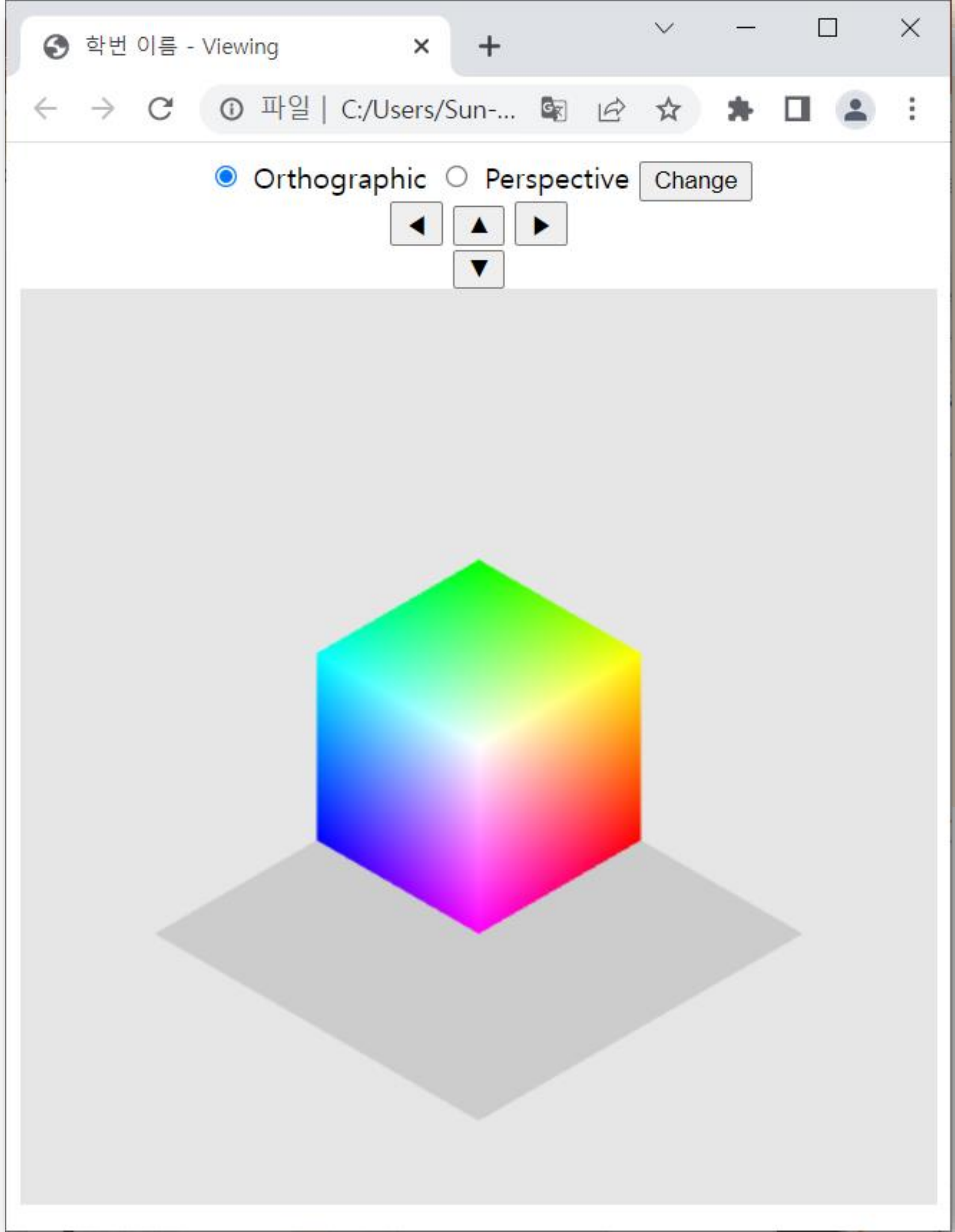
Drawing the Ground

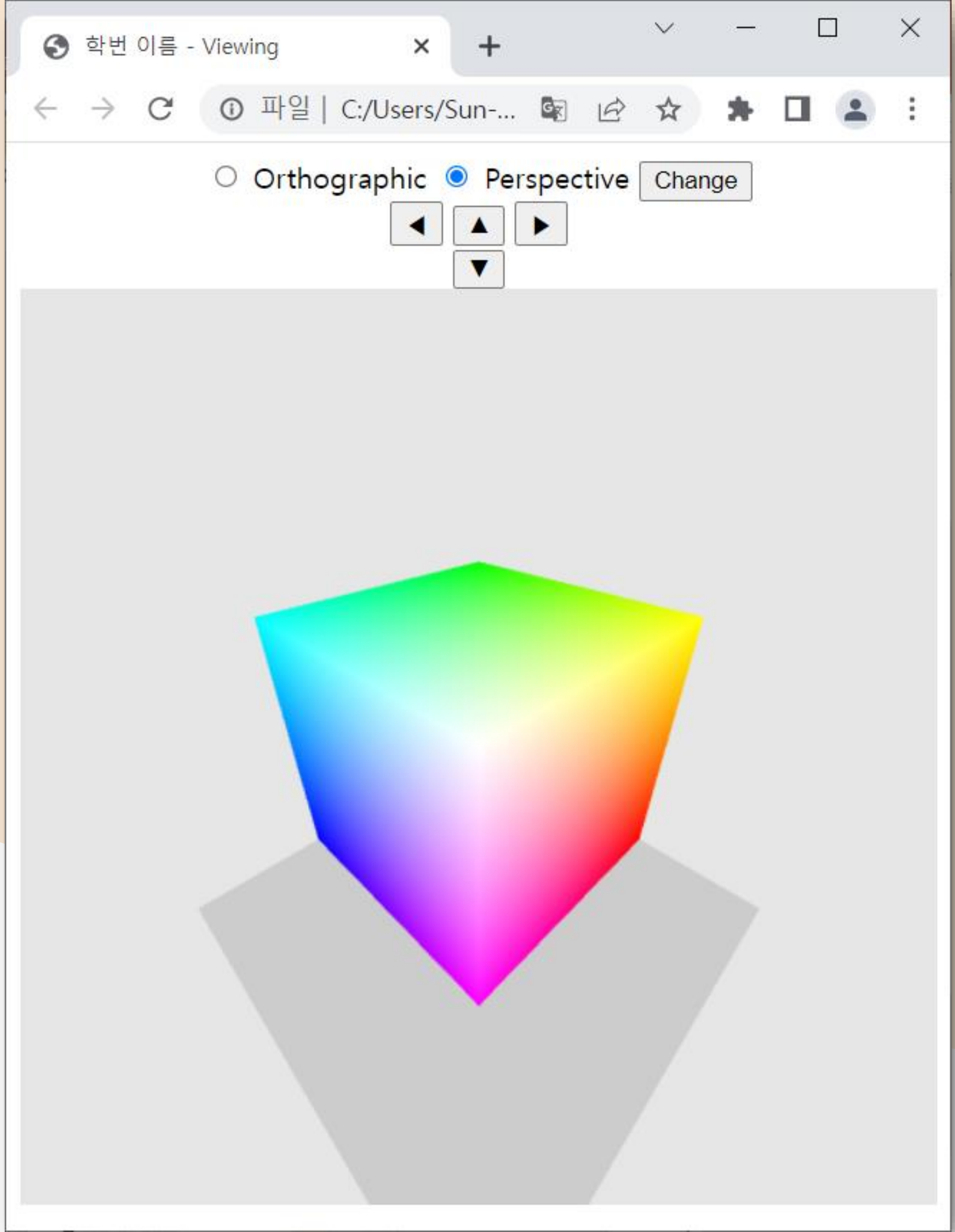

File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init

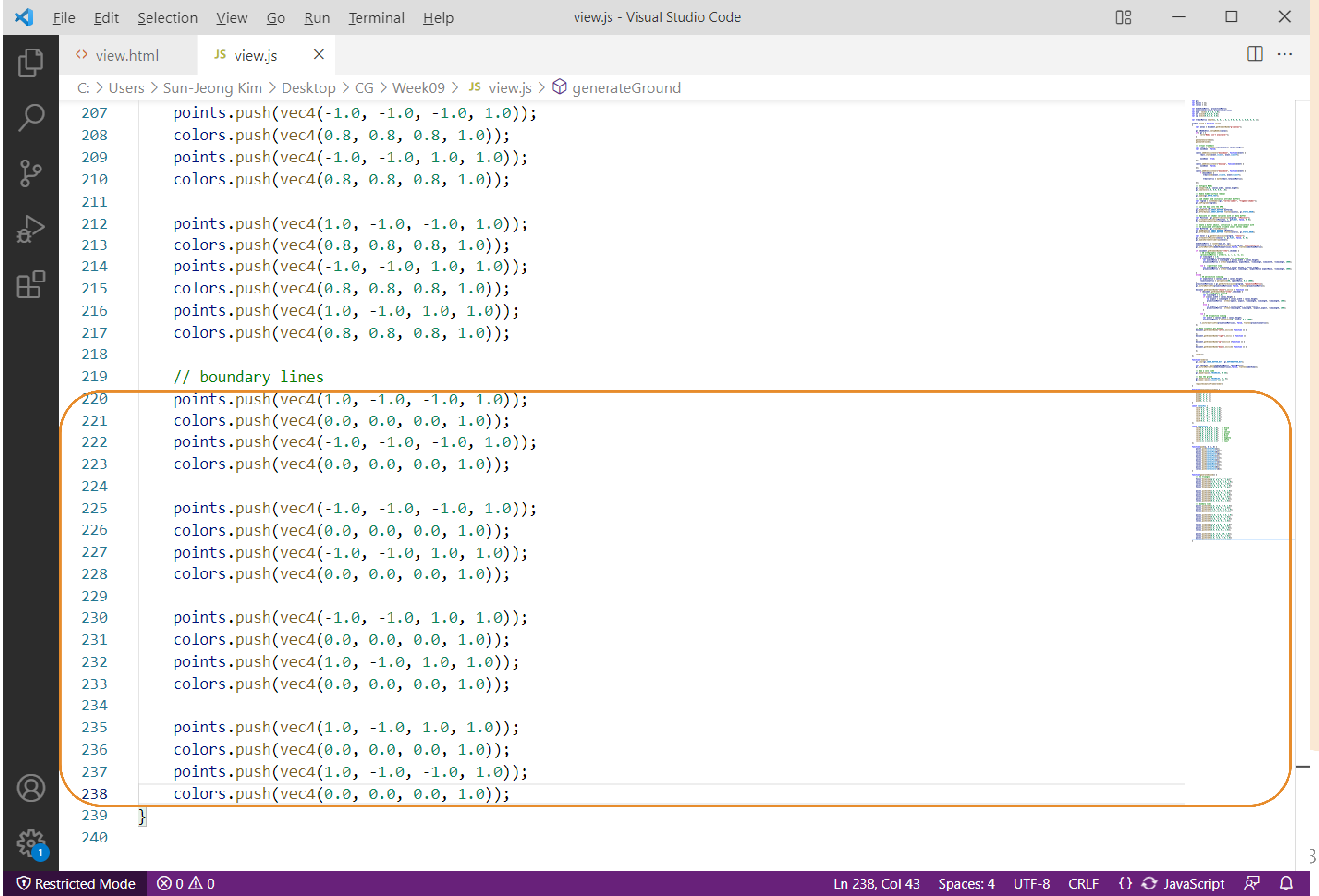
```
var gl;
var points = [];
var colors = [];

var modelViewMatrix, projectionMatrix;
var modelViewMatrixLoc, projectionMatrixLoc;
var eye = vec3(1.0, 1.0, 1.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);

var trballMatrix = mat4(1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1);

window.onload = function init()
{
    var canvas = document.getElementById("gl-canvas");

    gl = WebGLUtils.setupWebGL(canvas);
    if( !gl ) {
        alert("WebGL isn't available!");
    }

    generateColorCube();
    generateGround();

    // virtual trackball
    var trball = trackball(canvas.width, canvas.height);
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > generateGround
Restricted Mode
Ln 212, Col 43
Spaces: 4
UTF-8
CRLF
JavaScript

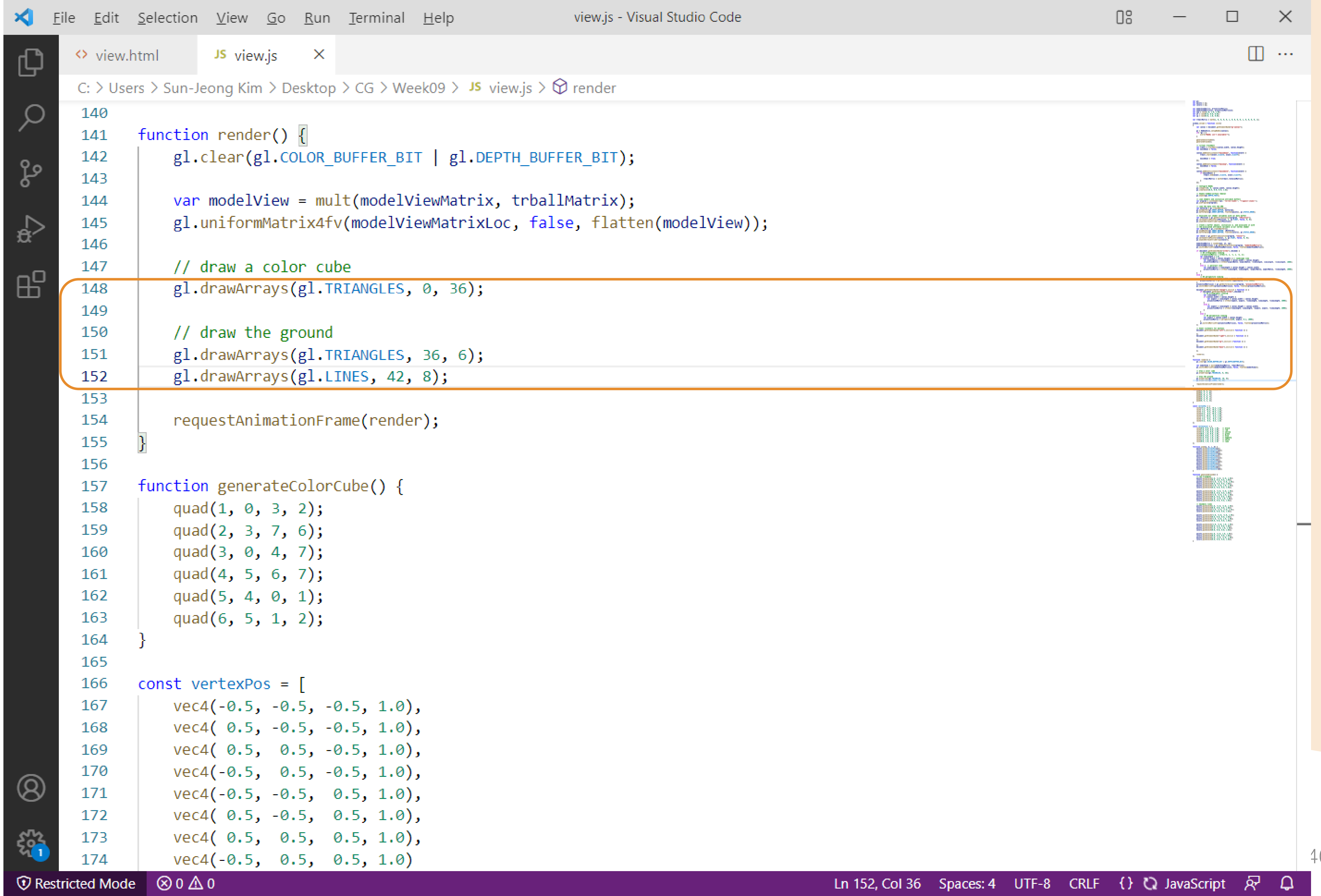
```javascript
];

function quad(a, b, c, d) {
    points.push(vertexPos[a]);
    colors.push(vertexColor[a]);
    points.push(vertexPos[b]);
    colors.push(vertexColor[b]);
    points.push(vertexPos[c]);
    colors.push(vertexColor[c]);
    points.push(vertexPos[a]);
    colors.push(vertexColor[a]);
    points.push(vertexPos[c]);
    colors.push(vertexColor[c]);
    points.push(vertexPos[d]);
    colors.push(vertexColor[d]);
}

function generateGround() {
    // two triangles
    points.push(vec4(1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));

    points.push(vec4(1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
}
```


학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic [✓]
Perspective
Change

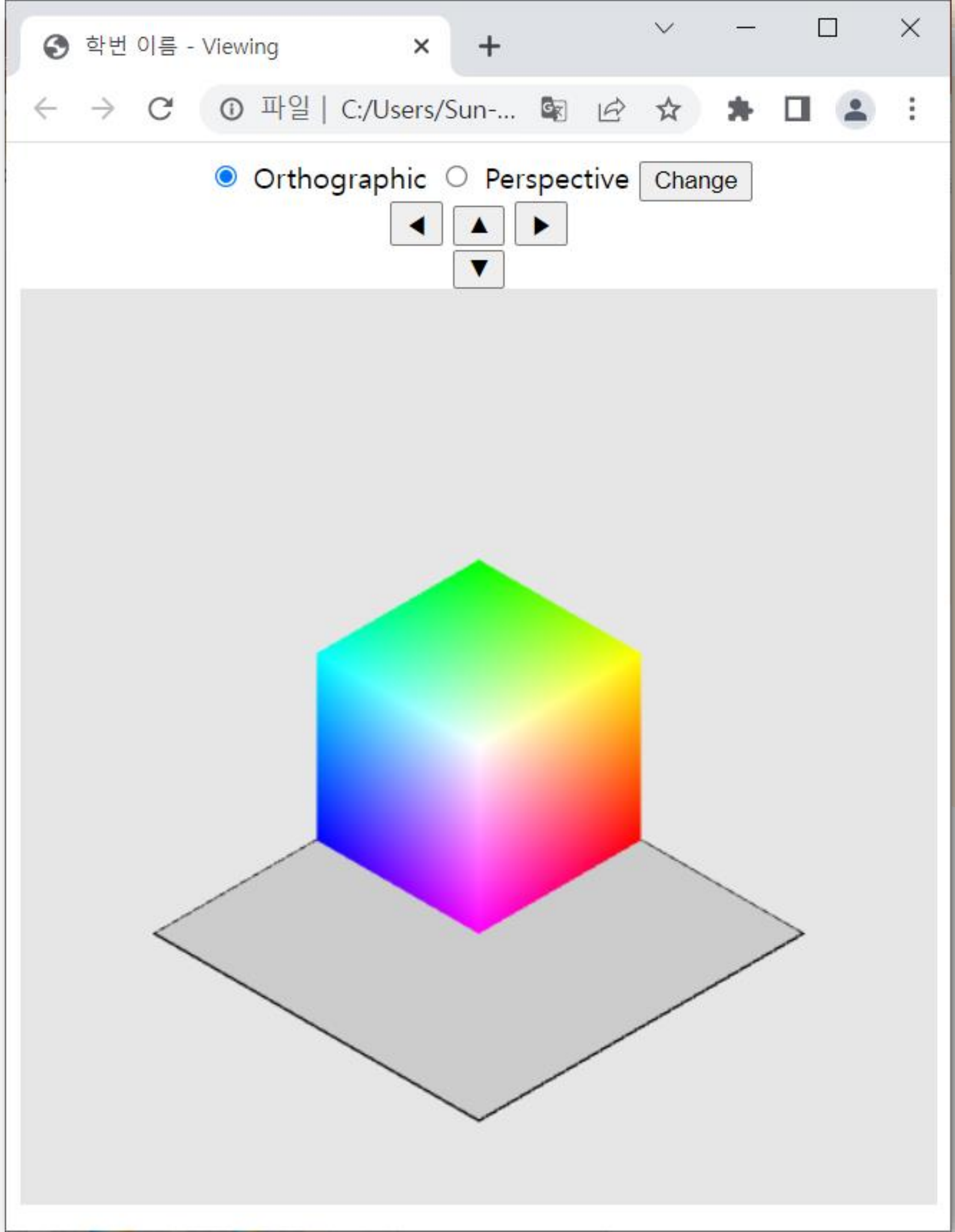

학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic
Perspective [✓]
Change


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > generateGround
Restricted Mode ⊗ 0 ⚠ 0
Ln 238, Col 43 Spaces: 4 UTF-8 CRLF {} JavaScript

```
    points.push(vec4(-1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));

    points.push(vec4(1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));

    // boundary lines
    points.push(vec4(1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    points.push(vec4(-1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));

    points.push(vec4(-1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));

    points.push(vec4(-1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    points.push(vec4(1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));

    points.push(vec4(1.0, -1.0, 1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    points.push(vec4(1.0, -1.0, -1.0, 1.0));
    colors.push(vec4(0.0, 0.0, 0.0, 1.0));
}
```

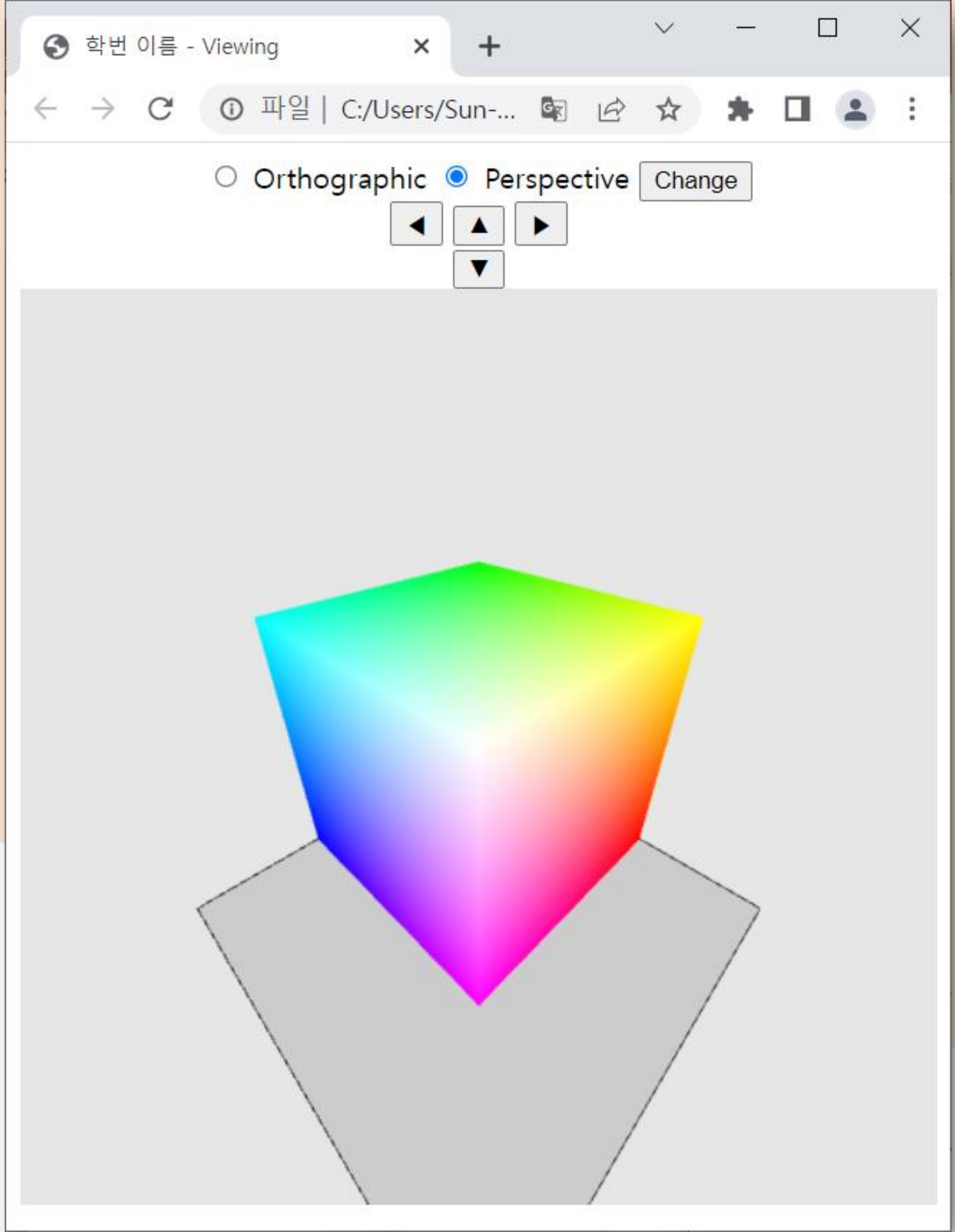

File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > render
Restricted Mode
Ln 152, Col 36 Spaces: 4 UTF-8 CRLF JavaScript

```

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    // draw a color cube
    gl.drawArrays(gl.TRIANGLES, 0, 36);

    // draw the ground
    gl.drawArrays(gl.TRIANGLES, 36, 6);
    gl.drawArrays(gl.LINES, 42, 8);

    requestAnimationFrame(render);
}

function generateColorCube() {
    quad(1, 0, 3, 2);
    quad(2, 3, 7, 6);
    quad(3, 0, 4, 7);
    quad(4, 5, 6, 7);
    quad(5, 4, 0, 1);
    quad(6, 5, 1, 2);
}

const vertexPos = [
    vec4(-0.5, -0.5, -0.5, 1.0),
    vec4( 0.5, -0.5, -0.5, 1.0),
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
    vec4(-0.5, -0.5,  0.5, 1.0),
    vec4( 0.5, -0.5,  0.5, 1.0),
    vec4( 0.5,  0.5,  0.5, 1.0),
    vec4(-0.5,  0.5,  0.5, 1.0)
```


학번 이름 - Viewing

파일 | C:/Users/Sun-...

[✓ Orthographic] Perspective

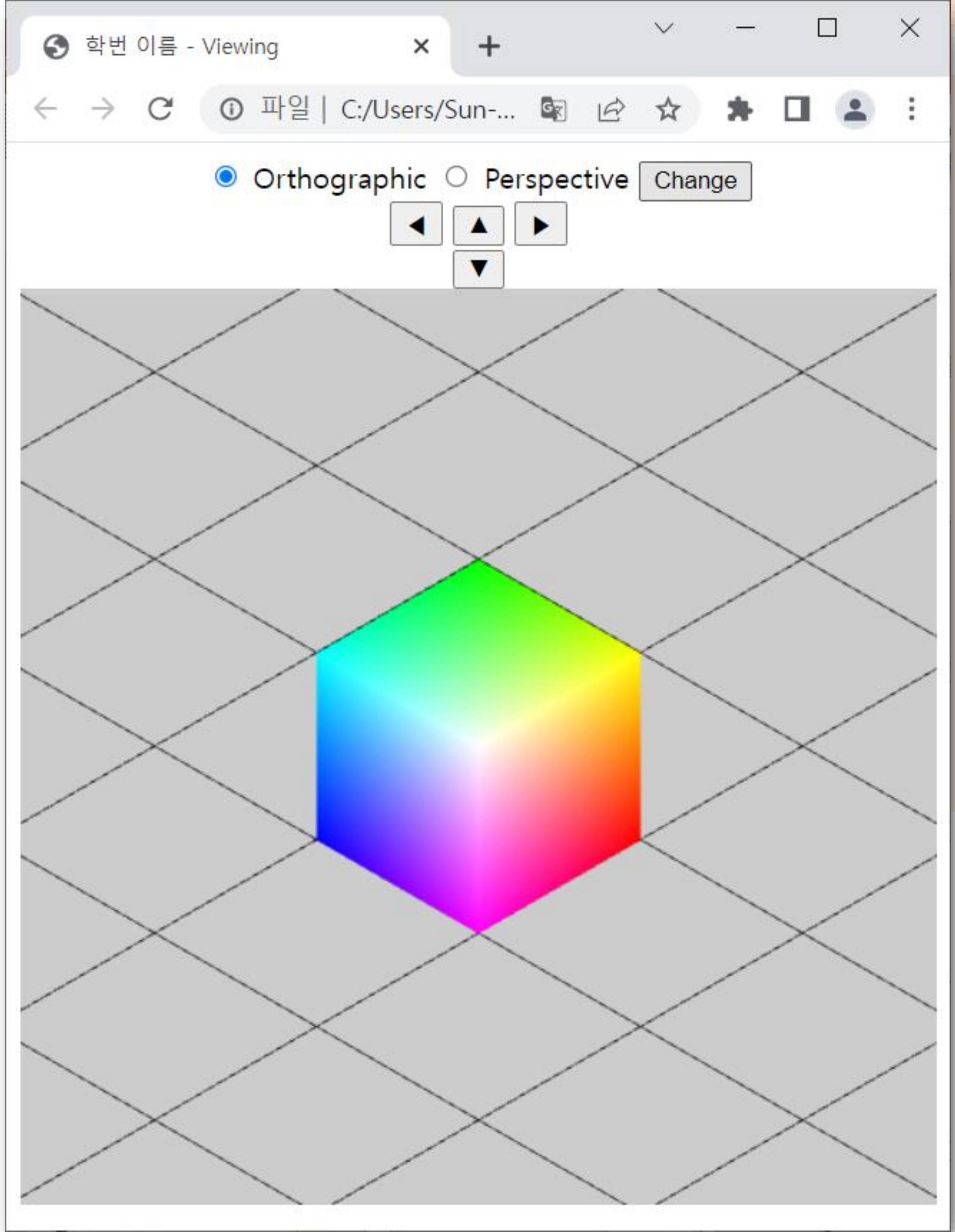

학번 이름 - Viewing

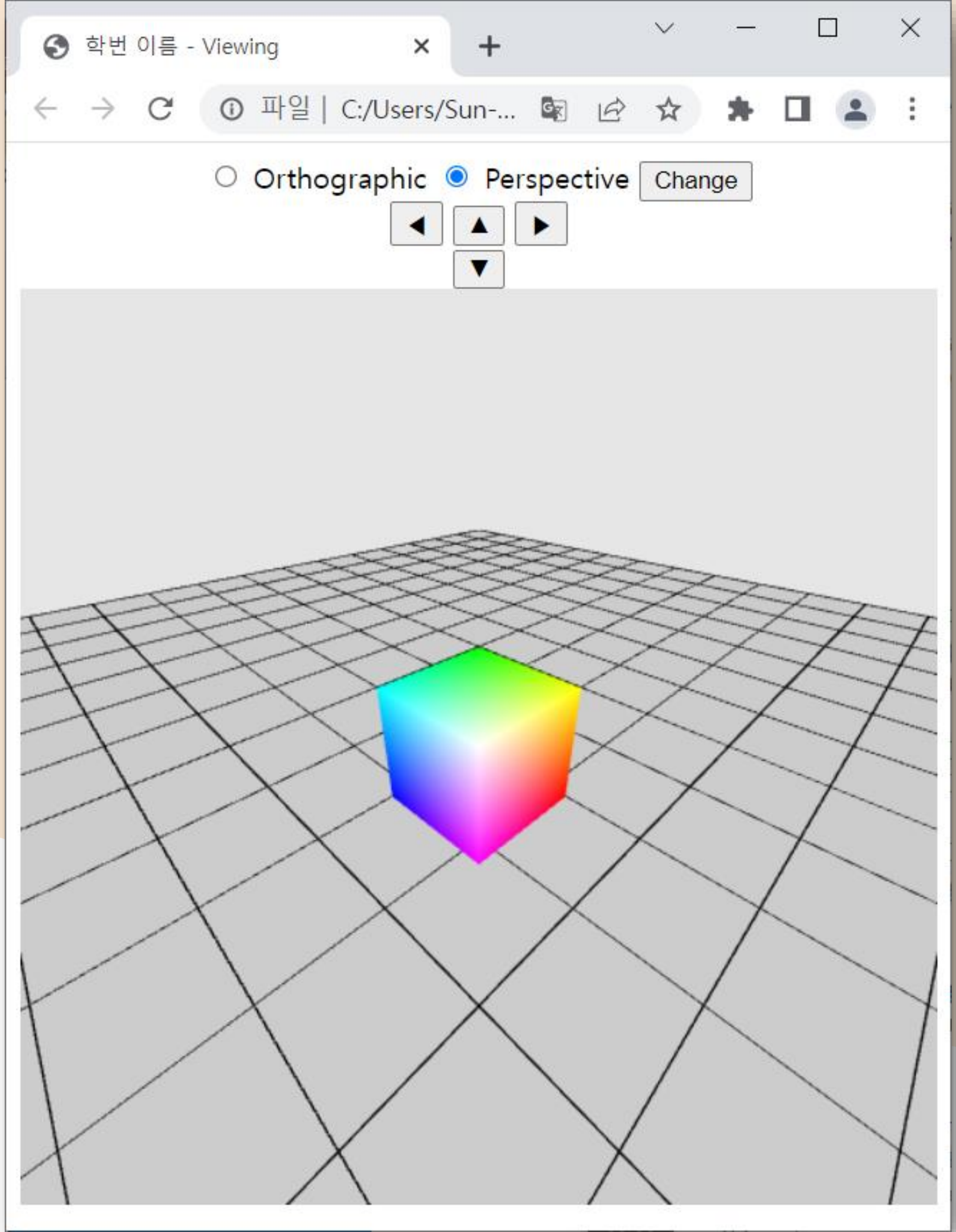
파일 | C:/Users/Sun-...

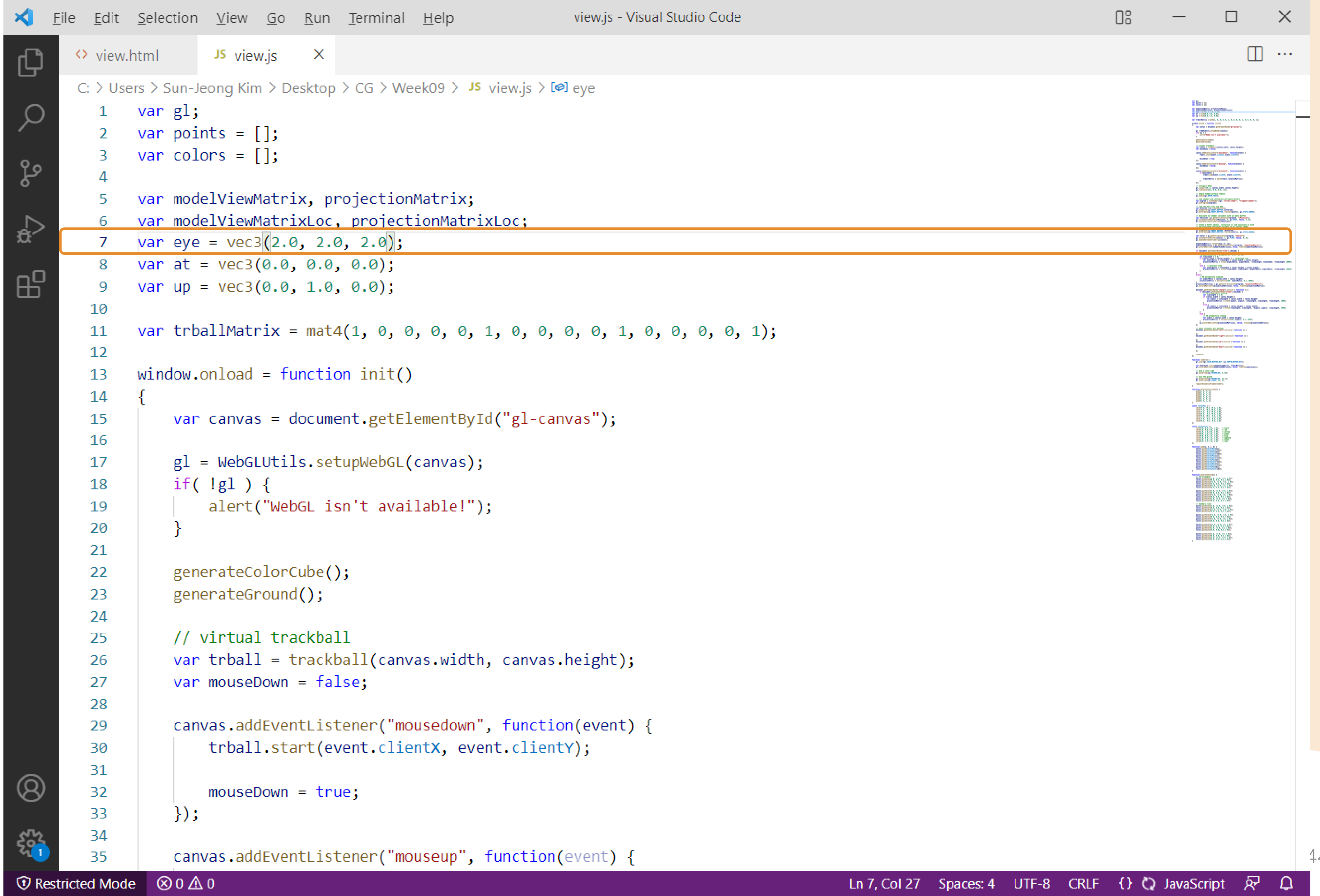
Orthographic [✓ Perspective]

연습 문제 (4)

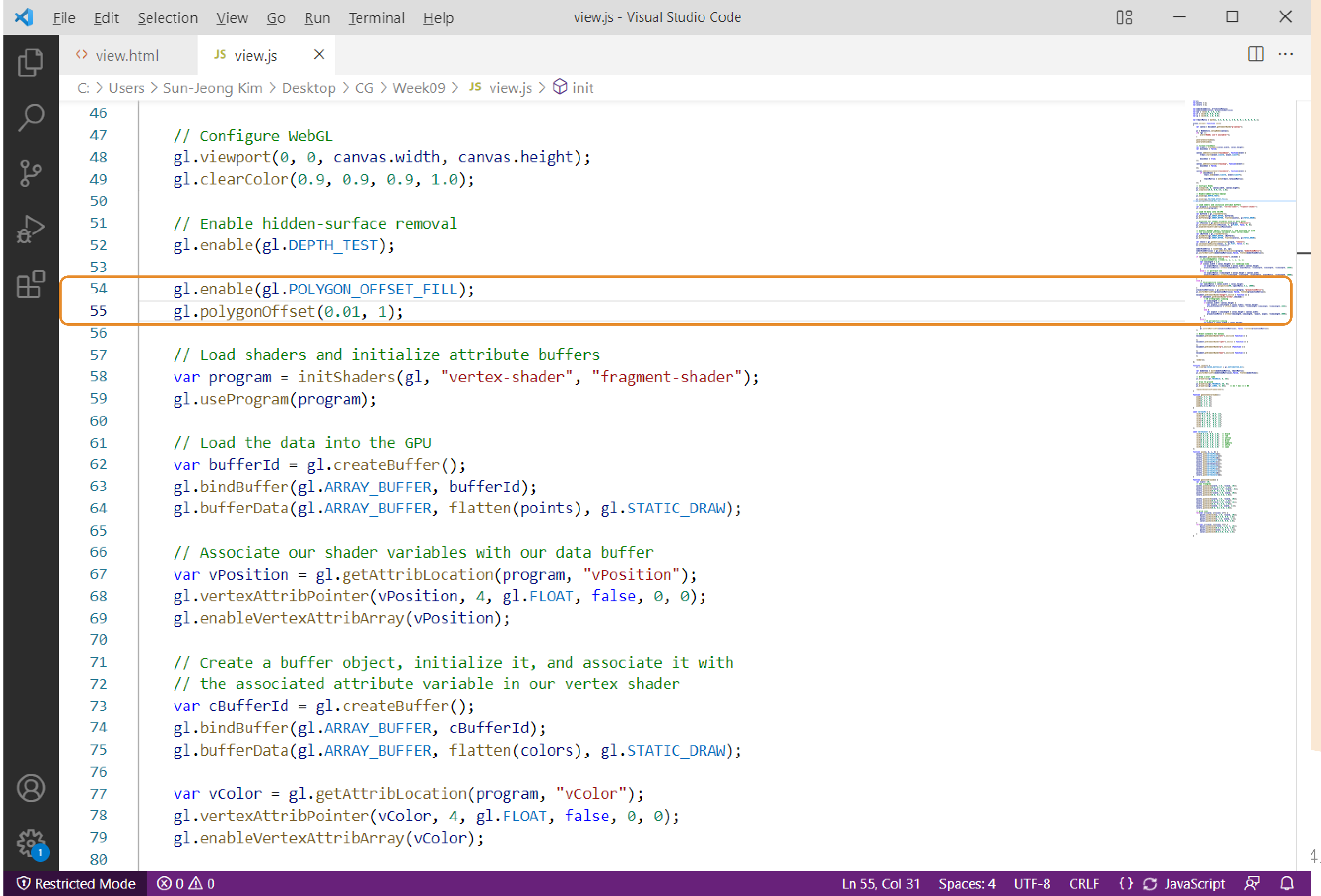
- Ground의 크기를 10배 늘리시오.
- Ground 간격 1마다 격자 선을 그리시오.
- 카메라의 위치를 (2, 2, 2)로 변경하시오.


학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic [✓]
Perspective
Change

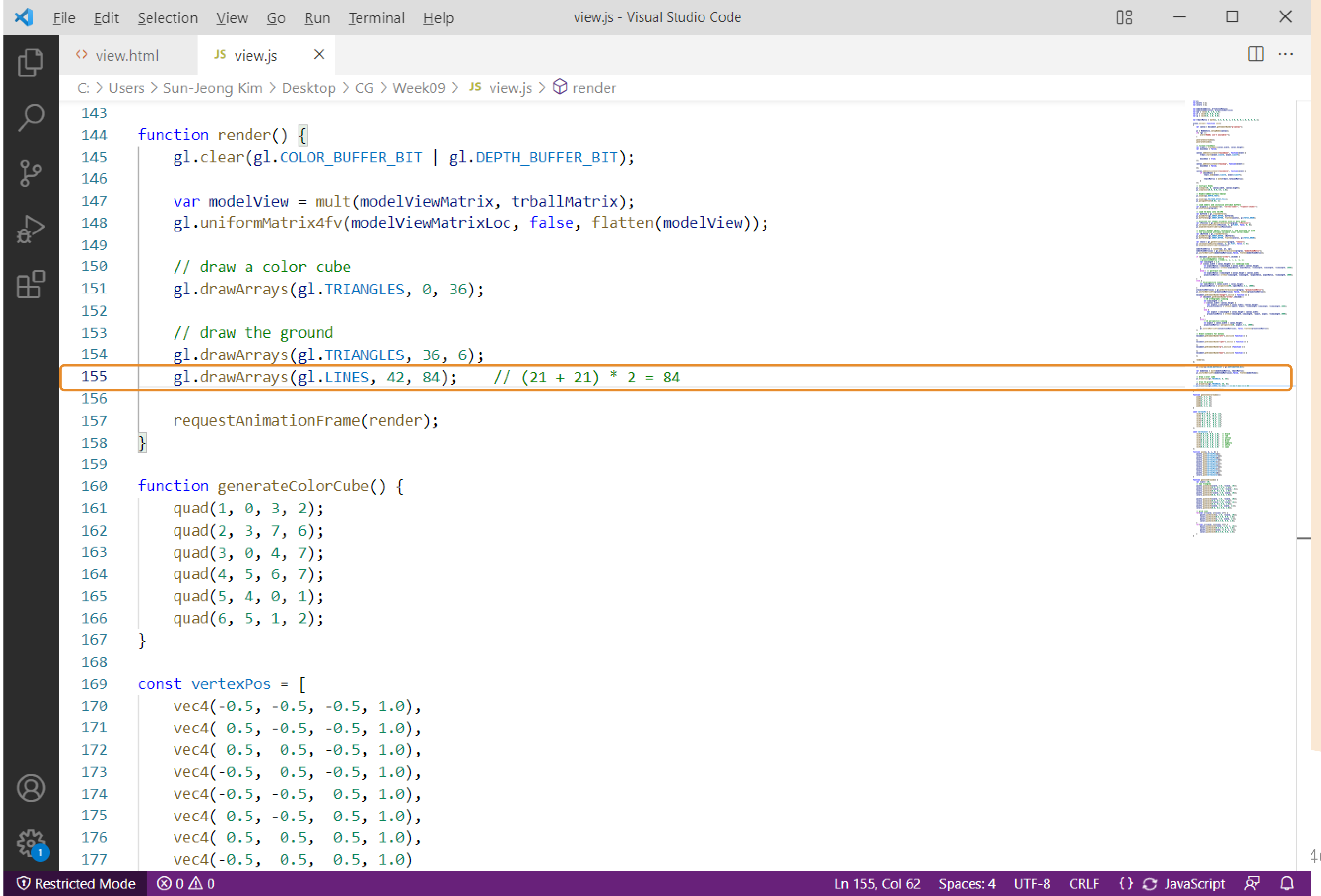

학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic
Perspective [✓]
Change


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > eye
Restricted Mode
Ln 7, Col 27
Spaces: 4
UTF-8
CRLF
JavaScript

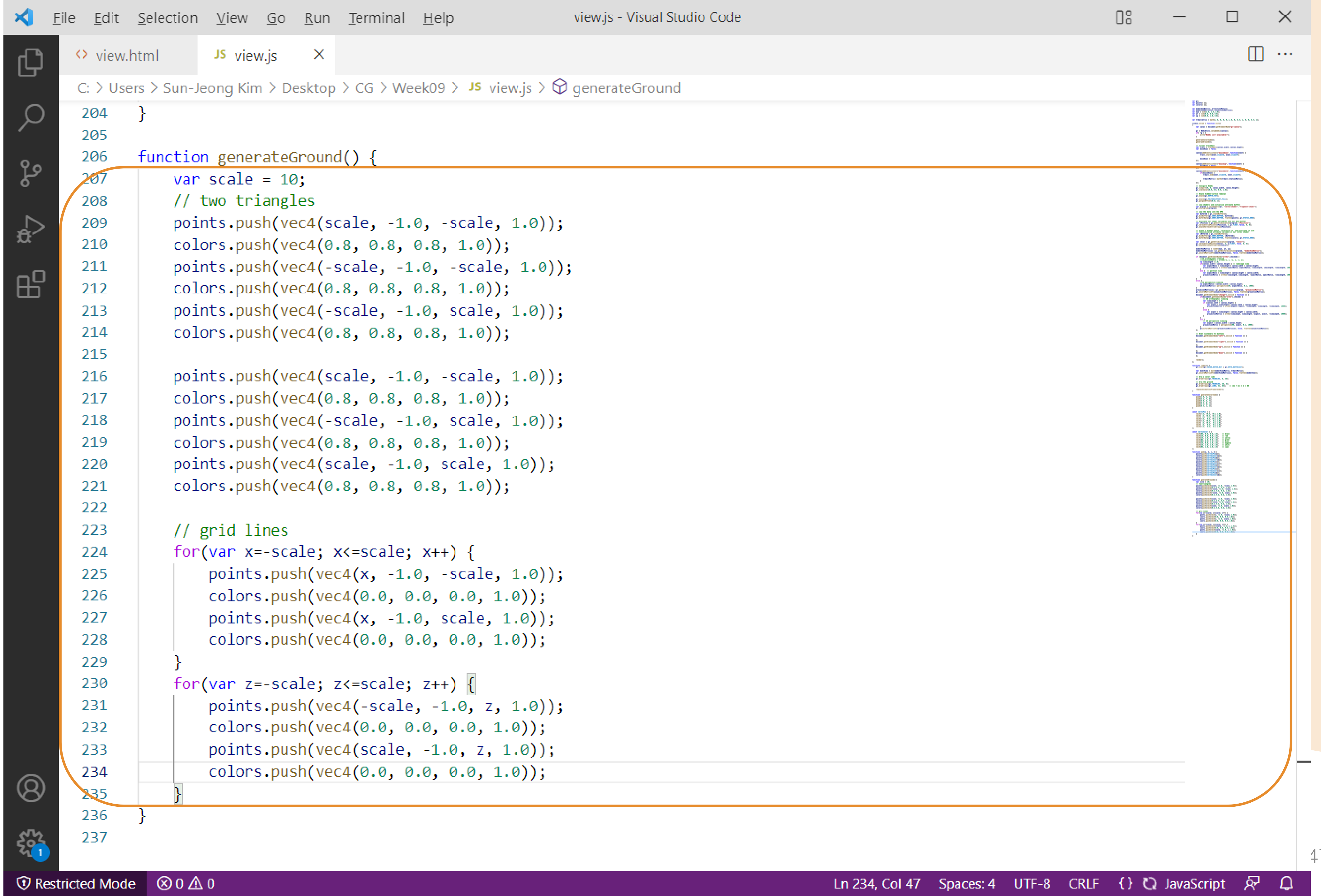
```javascript
var gl;
var points = [];
var colors = [];

var modelViewMatrix, projectionMatrix;
var modelViewMatrixLoc, projectionMatrixLoc;
var eye = vec3(2.0, 2.0, 2.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);

var trballMatrix = mat4(1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1);

window.onload = function init()
{
    var canvas = document.getElementById("gl-canvas");

    gl = WebGLUtils.setupWebGL(canvas);
    if( !gl ) {
        alert("WebGL isn't available!");
    }

    generateColorCube();
    generateGround();

    // virtual trackball
    var trball = trackball(canvas.width, canvas.height);
    var mouseDown = false;

    canvas.addEventListener("mousedown", function(event) {
        trball.start(event.clientX, event.clientY);

        mouseDown = true;
    });

    canvas.addEventListener("mouseup", function(event) {
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init
Restricted Mode
Ln 55, Col 31
Spaces: 4
UTF-8
CRLF
JavaScript

```

    // Configure WebGL
    gl.viewport(0, 0, canvas.width, canvas.height);
    gl.clearColor(0.9, 0.9, 0.9, 1.0);

    // Enable hidden-surface removal
    gl.enable(gl.DEPTH_TEST);

    gl.enable(gl.POLYGON_OFFSET_FILL);
    gl.polygonOffset(0.01, 1);

    // Load shaders and initialize attribute buffers
    var program = initShaders(gl, "vertex-shader", "fragment-shader");
    gl.useProgram(program);

    // Load the data into the GPU
    var bufferId = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, bufferId);
    gl.bufferData(gl.ARRAY_BUFFER, flatten(points), gl.STATIC_DRAW);

    // Associate our shader variables with our data buffer
    var vPosition = gl.getAttribLocation(program, "vPosition");
    gl.vertexAttribPointer(vPosition, 4, gl.FLOAT, false, 0, 0);
    gl.enableVertexAttribArray(vPosition);

    // Create a buffer object, initialize it, and associate it with
    // the associated attribute variable in our vertex shader
    var cBufferId = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, cBufferId);
    gl.bufferData(gl.ARRAY_BUFFER, flatten(colors), gl.STATIC_DRAW);

    var vColor = gl.getAttribLocation(program, "vColor");
    gl.vertexAttribPointer(vColor, 4, gl.FLOAT, false, 0, 0);
    gl.enableVertexAttribArray(vColor);

```

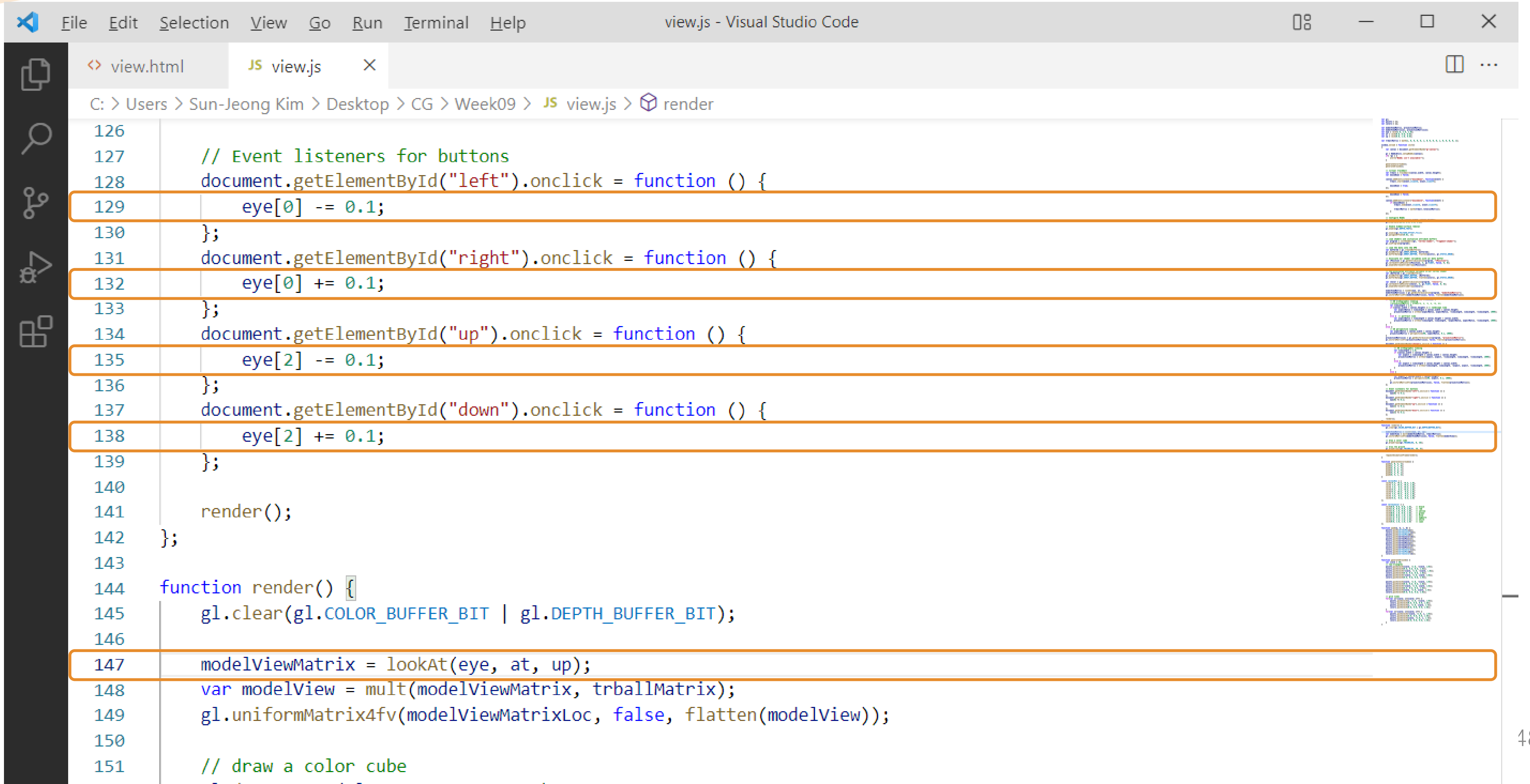

File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > render
Restricted Mode
Ln 155, Col 62
Spaces: 4
UTF-8
CRLF
JavaScript

```javascript

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    // draw a color cube
    gl.drawArrays(gl.TRIANGLES, 0, 36);

    // draw the ground
    gl.drawArrays(gl.TRIANGLES, 36, 6);
    gl.drawArrays(gl.LINES, 42, 84);    // (21 + 21) * 2 = 84

    requestAnimationFrame(render);
}

function generateColorCube() {
    quad(1, 0, 3, 2);
    quad(2, 3, 7, 6);
    quad(3, 0, 4, 7);
    quad(4, 5, 6, 7);
    quad(5, 4, 0, 1);
    quad(6, 5, 1, 2);
}

const vertexPos = [
    vec4(-0.5, -0.5, -0.5, 1.0),
    vec4( 0.5, -0.5, -0.5, 1.0),
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
    vec4(-0.5, -0.5,  0.5, 1.0),
    vec4( 0.5, -0.5,  0.5, 1.0),
    vec4( 0.5,  0.5,  0.5, 1.0),
    vec4(-0.5,  0.5,  0.5, 1.0)
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > generateGround
Restricted Mode
0 0
Ln 234, Col 47 Spaces: 4 UTF-8 CRLF JavaScript

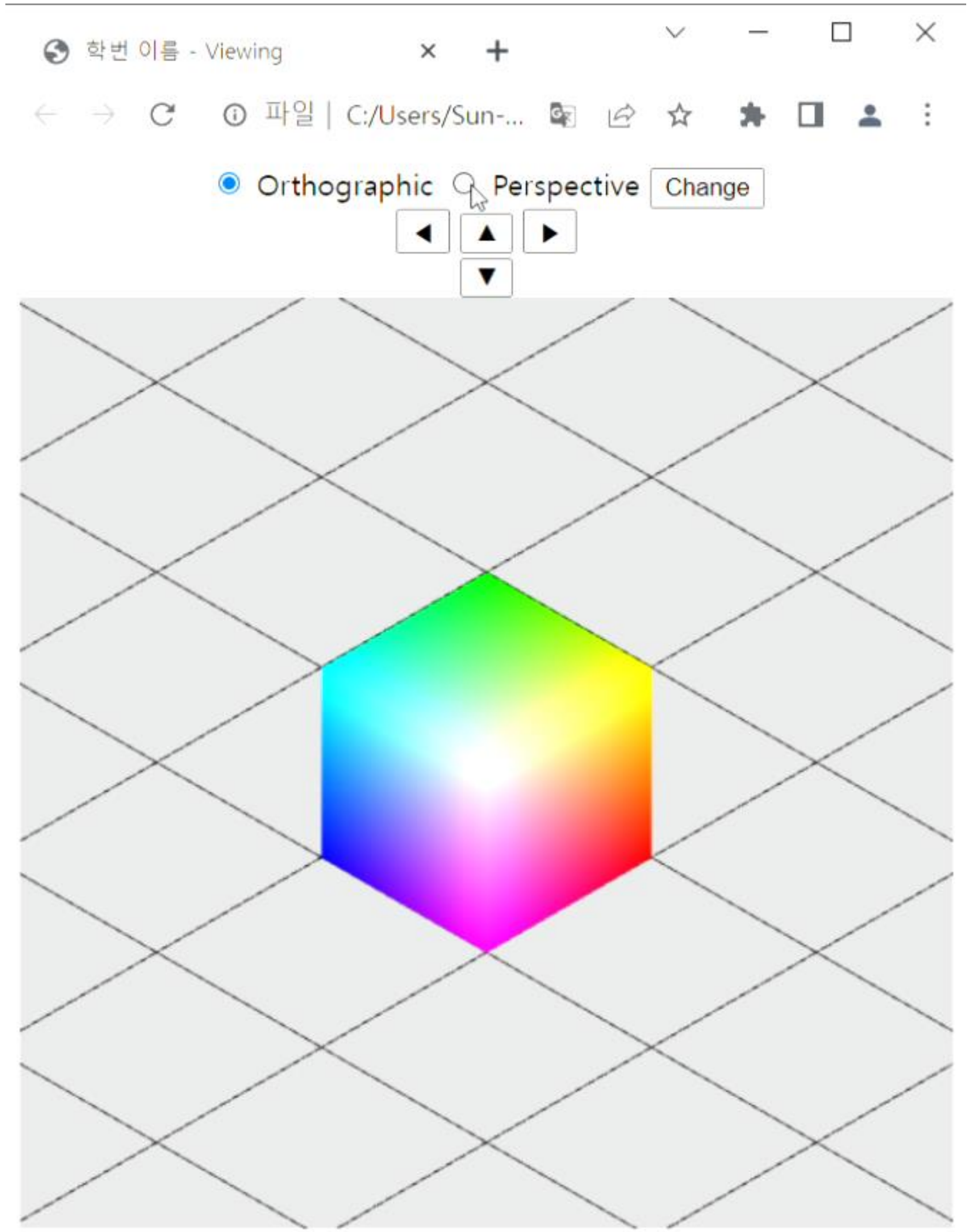
```
}

function generateGround() {
    var scale = 10;
    // two triangles
    points.push(vec4(scale, -1.0, -scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-scale, -1.0, -scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-scale, -1.0, scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));

    points.push(vec4(scale, -1.0, -scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(-scale, -1.0, scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));
    points.push(vec4(scale, -1.0, scale, 1.0));
    colors.push(vec4(0.8, 0.8, 0.8, 1.0));

    // grid lines
    for(var x=-scale; x<=scale; x++) {
        points.push(vec4(x, -1.0, -scale, 1.0));
        colors.push(vec4(0.0, 0.0, 0.0, 1.0));
        points.push(vec4(x, -1.0, scale, 1.0));
        colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    }
    for(var z=-scale; z<=scale; z++) {
        points.push(vec4(-scale, -1.0, z, 1.0));
        colors.push(vec4(0.0, 0.0, 0.0, 1.0));
        points.push(vec4(scale, -1.0, z, 1.0));
        colors.push(vec4(0.0, 0.0, 0.0, 1.0));
    }
}
```

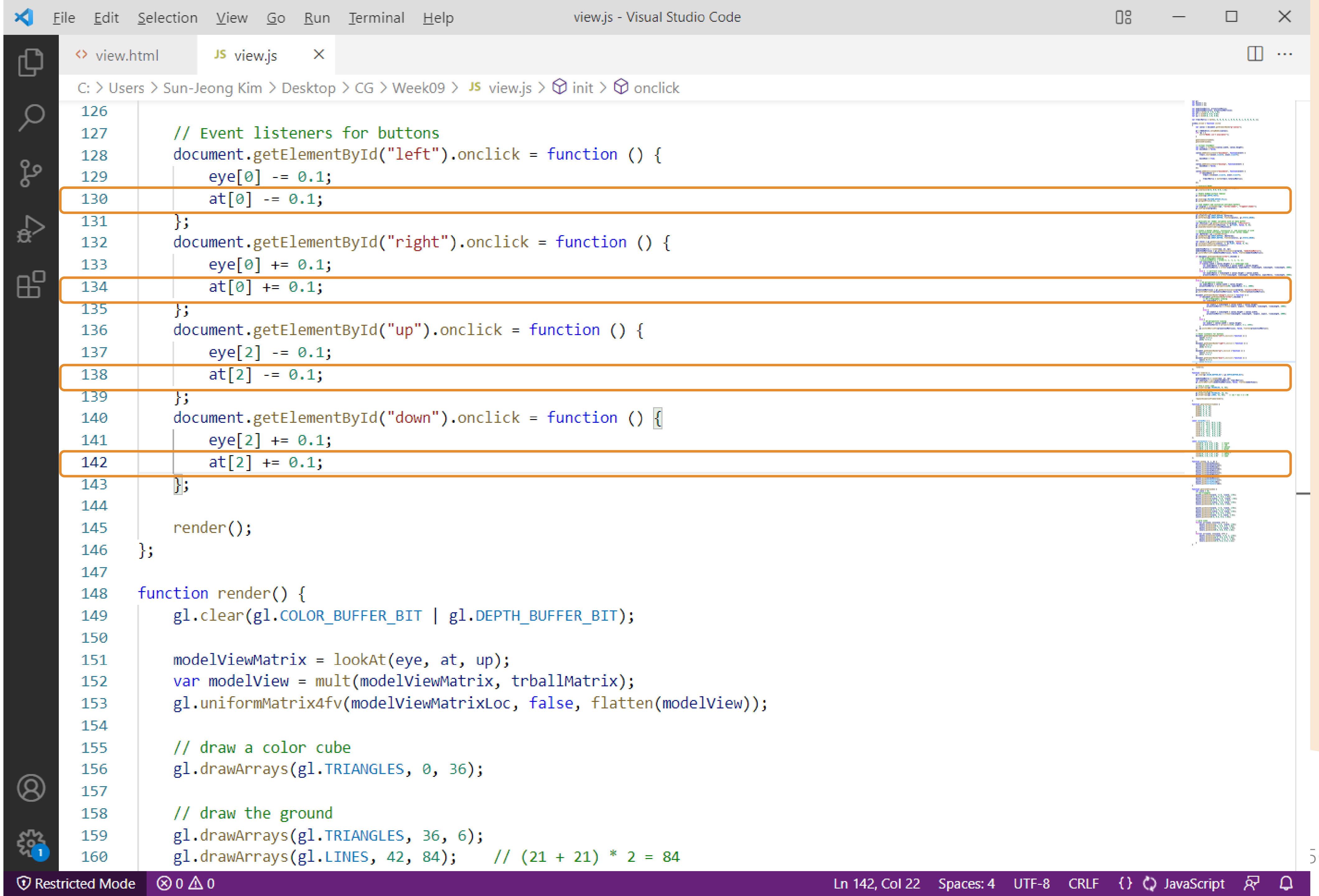
Walking Through


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > render

```

    // Event listeners for buttons
    document.getElementById("left").onclick = function () {
        eye[0] -= 0.1;
    };
    document.getElementById("right").onclick = function () {
        eye[0] += 0.1;
    };
    document.getElementById("up").onclick = function () {
        eye[2] -= 0.1;
    };
    document.getElementById("down").onclick = function () {
        eye[2] += 0.1;
    };

    render();
};

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    modelViewMatrix = lookAt(eye, at, up);
    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    // draw a color cube
```

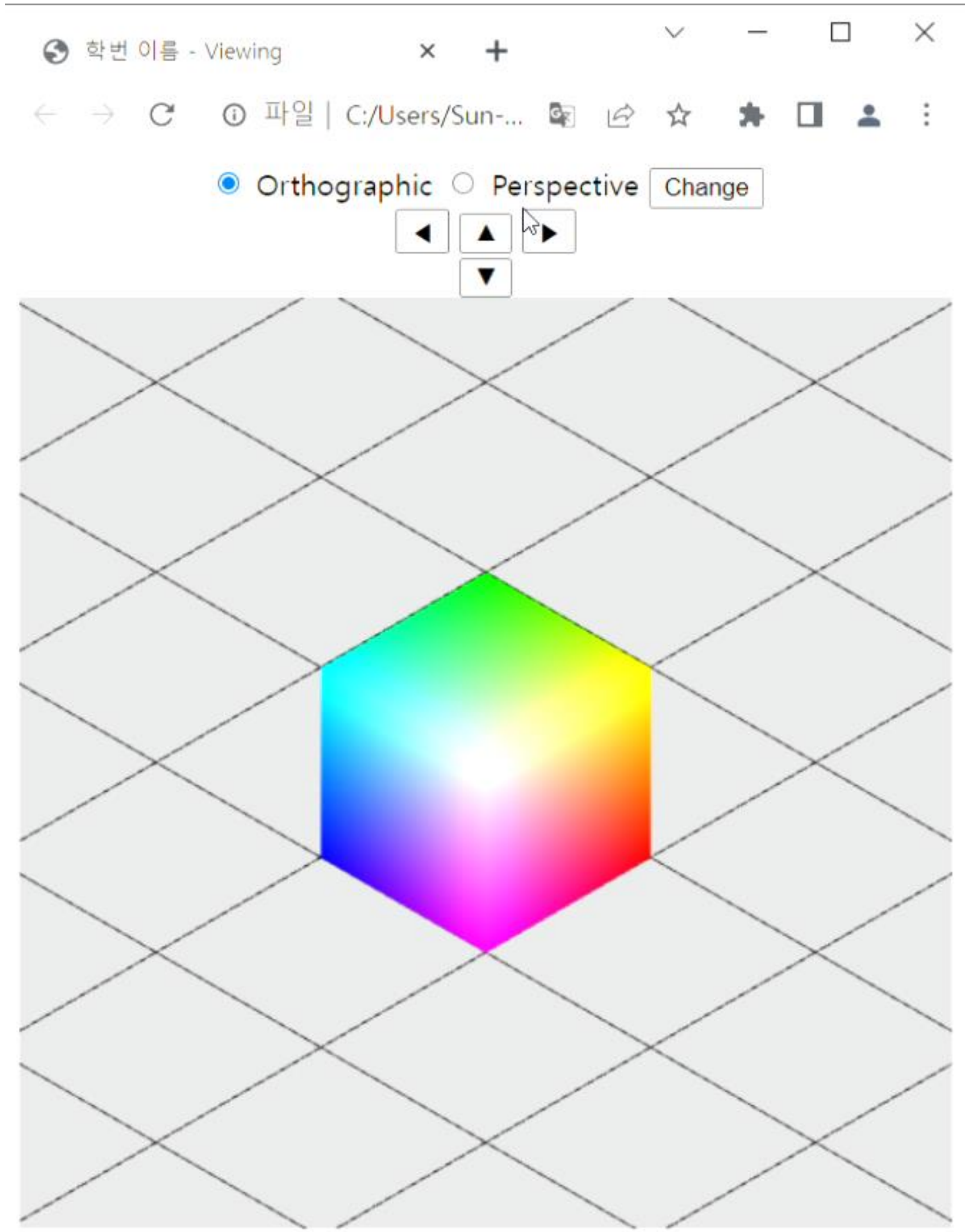
What's Wrong?


학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic
Perspective
Change


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init > onclick
Restricted Mode
0 0
Ln 142, Col 22 Spaces: 4 UTF-8 CRLF {} JavaScript

```javascript

    // Event listeners for buttons
    document.getElementById("left").onclick = function () {
        eye[0] -= 0.1;
        at[0] -= 0.1;
    };
    document.getElementById("right").onclick = function () {
        eye[0] += 0.1;
        at[0] += 0.1;
    };
    document.getElementById("up").onclick = function () {
        eye[2] -= 0.1;
        at[2] -= 0.1;
    };
    document.getElementById("down").onclick = function () {
        eye[2] += 0.1;
        at[2] += 0.1;
    };

    render();
};

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    modelViewMatrix = lookAt(eye, at, up);
    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    // draw a color cube
    gl.drawArrays(gl.TRIANGLES, 0, 36);

    // draw the ground
    gl.drawArrays(gl.TRIANGLES, 36, 6);
    gl.drawArrays(gl.LINES, 42, 84);    // (21 + 21) * 2 = 84
```

Is it Natural?



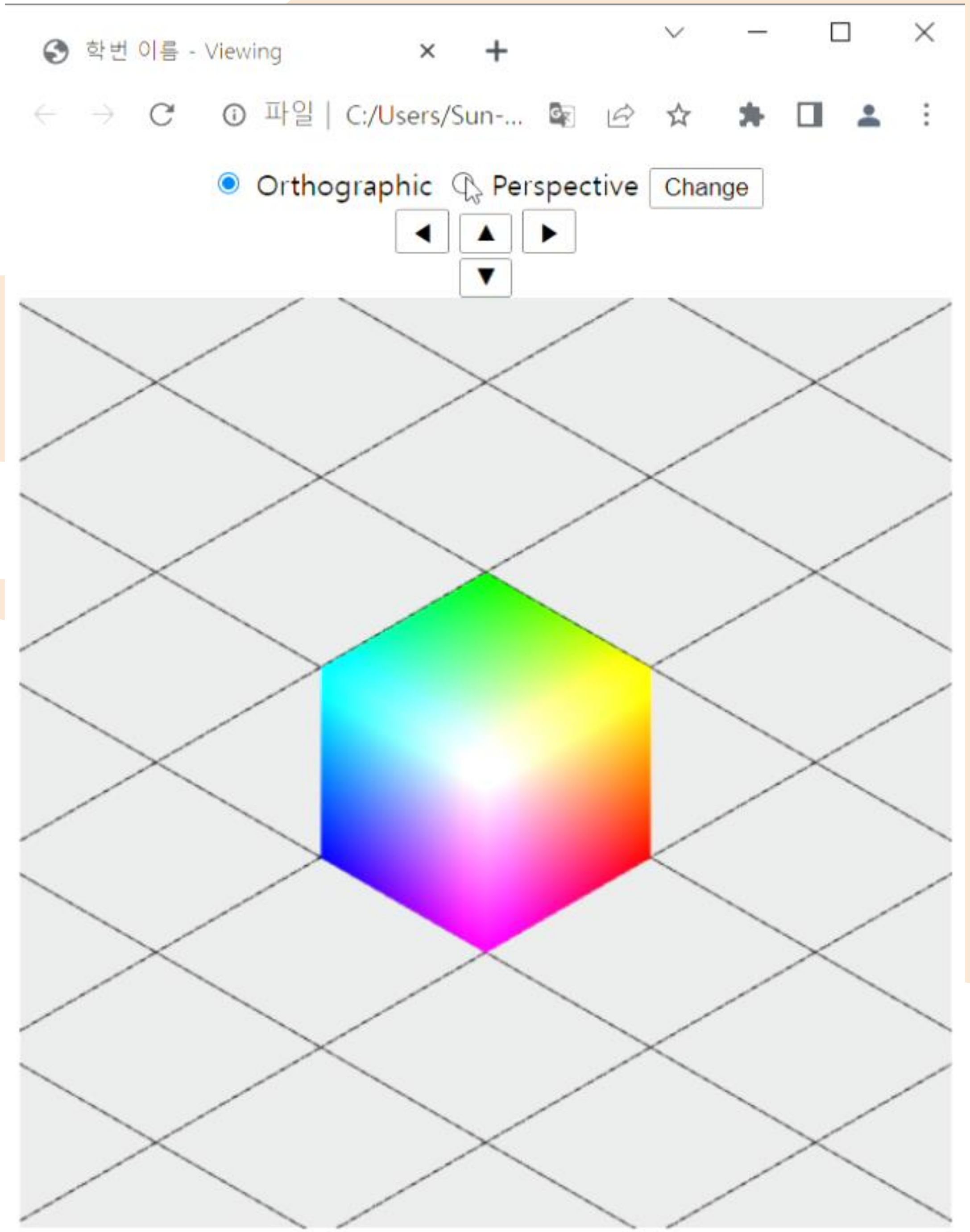
[✓ Orthographic] Perspective

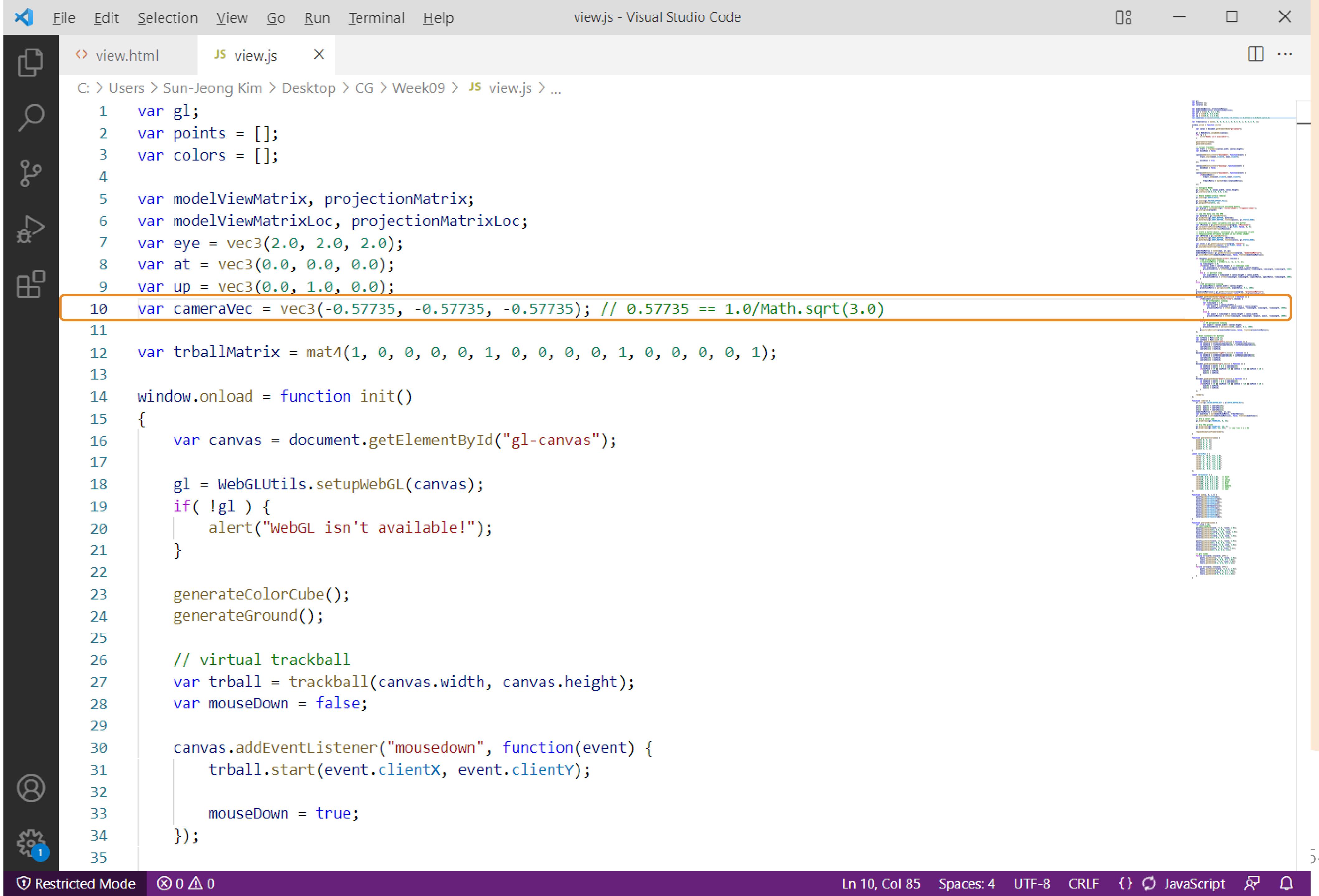
연습 문제 (5)

- ◀와 ▶ 버튼 입력에 대해,
  - 카메라의 로컬 y 축 회전하도록 구현하시오.
  - 즉, 제자리에서 바라보는 방향만 변경하시오.

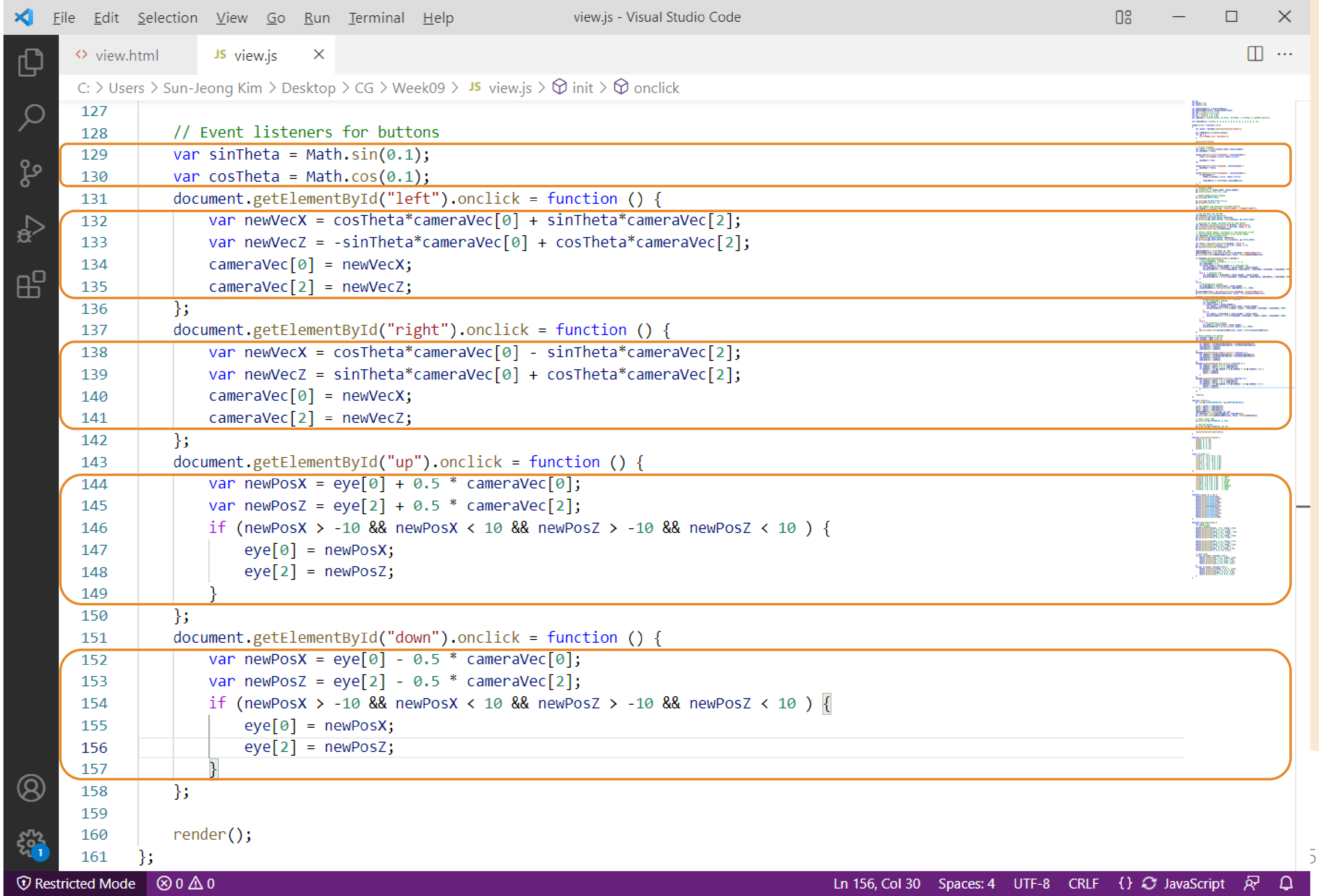
- ▲와 ▼ 버튼 입력에 대해,
  - 카메라가 바라보는 방향으로 전진 또는 후진하도록 구현하시오.

- 카메라의 위치가 Ground 밖으로 나가지 못하도록 구현하시오.

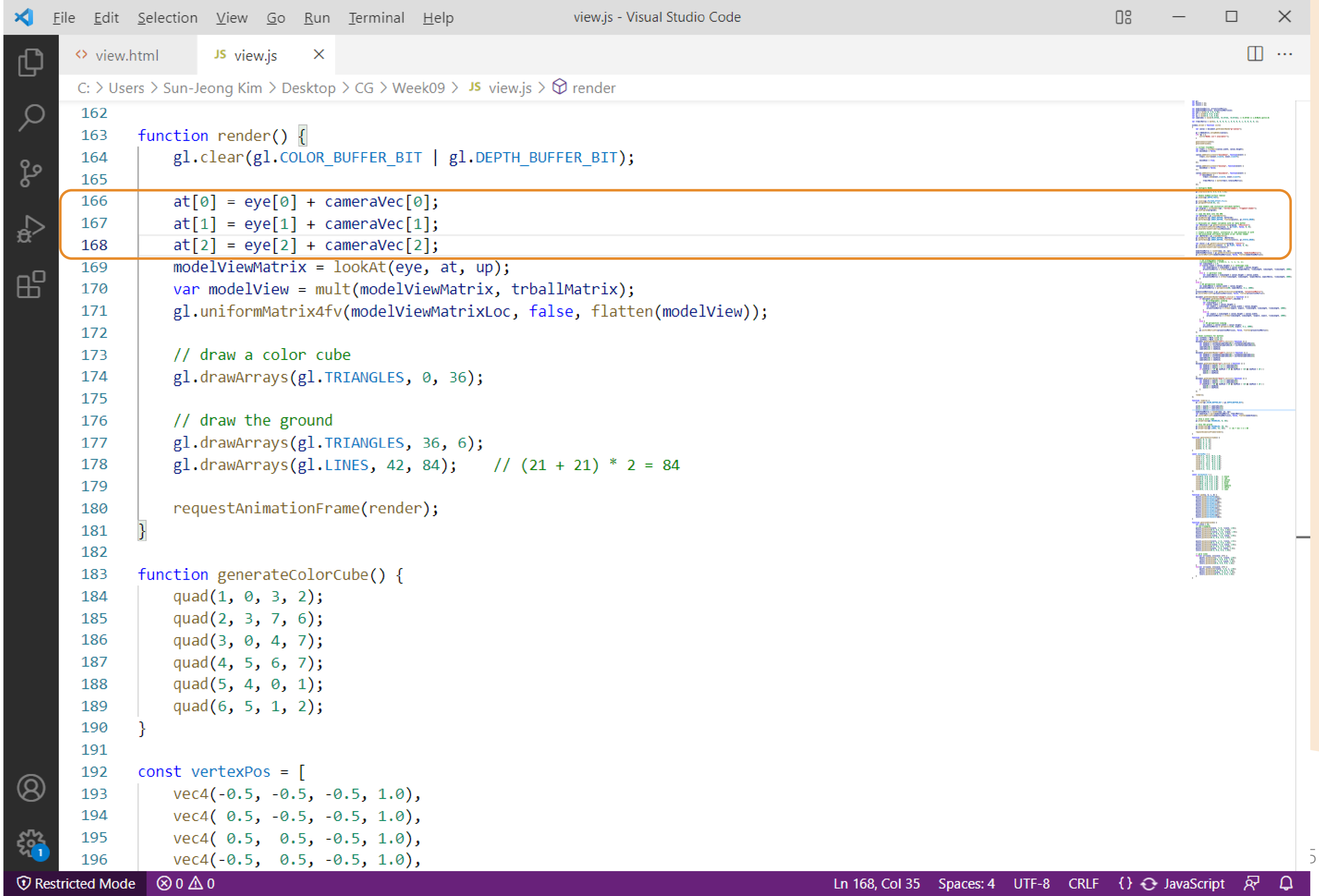

학번 이름 - Viewing
파일 | C:/Users/Sun-...
Orthographic
Perspective
Change


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > ...
Restricted Mode
0 0
Ln 10, Col 85 Spaces: 4 UTF-8 CRLF JavaScript

```
var gl;
var points = [];
var colors = [];

var modelViewMatrix, projectionMatrix;
var modelViewMatrixLoc, projectionMatrixLoc;
var eye = vec3(2.0, 2.0, 2.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);
var cameraVec = vec3(-0.57735, -0.57735, -0.57735); // 0.57735 == 1.0/Math.sqrt(3.0)

var trballMatrix = mat4(1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1);

window.onload = function init()
{
    var canvas = document.getElementById("gl-canvas");

    gl = WebGLUtils.setupWebGL(canvas);
    if( !gl ) {
        alert("WebGL isn't available!");
    }

    generateColorCube();
    generateGround();

    // virtual trackball
    var trball = trackball(canvas.width, canvas.height);
    var mouseDown = false;

    canvas.addEventListener("mousedown", function(event) {
        trball.start(event.clientX, event.clientY);

        mouseDown = true;
    });

```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > init > onclick
Restricted Mode
0 0
Ln 156, Col 30 Spaces: 4 UTF-8 CRLF JavaScript

```

    // Event listeners for buttons
    var sinTheta = Math.sin(0.1);
    var cosTheta = Math.cos(0.1);
    document.getElementById("left").onclick = function () {
        var newVecX = cosTheta*cameraVec[0] + sinTheta*cameraVec[2];
        var newVecZ = -sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
        cameraVec[0] = newVecX;
        cameraVec[2] = newVecZ;
    };
    document.getElementById("right").onclick = function () {
        var newVecX = cosTheta*cameraVec[0] - sinTheta*cameraVec[2];
        var newVecZ = sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
        cameraVec[0] = newVecX;
        cameraVec[2] = newVecZ;
    };
    document.getElementById("up").onclick = function () {
        var newPosX = eye[0] + 0.5 * cameraVec[0];
        var newPosZ = eye[2] + 0.5 * cameraVec[2];
        if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
            eye[0] = newPosX;
            eye[2] = newPosZ;
        }
    };
    document.getElementById("down").onclick = function () {
        var newPosX = eye[0] - 0.5 * cameraVec[0];
        var newPosZ = eye[2] - 0.5 * cameraVec[2];
        if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
            eye[0] = newPosX;
            eye[2] = newPosZ;
        }
    };

    render();
};
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
C: > Users > Sun-Jeong Kim > Desktop > CG > Week09 > view.js > render

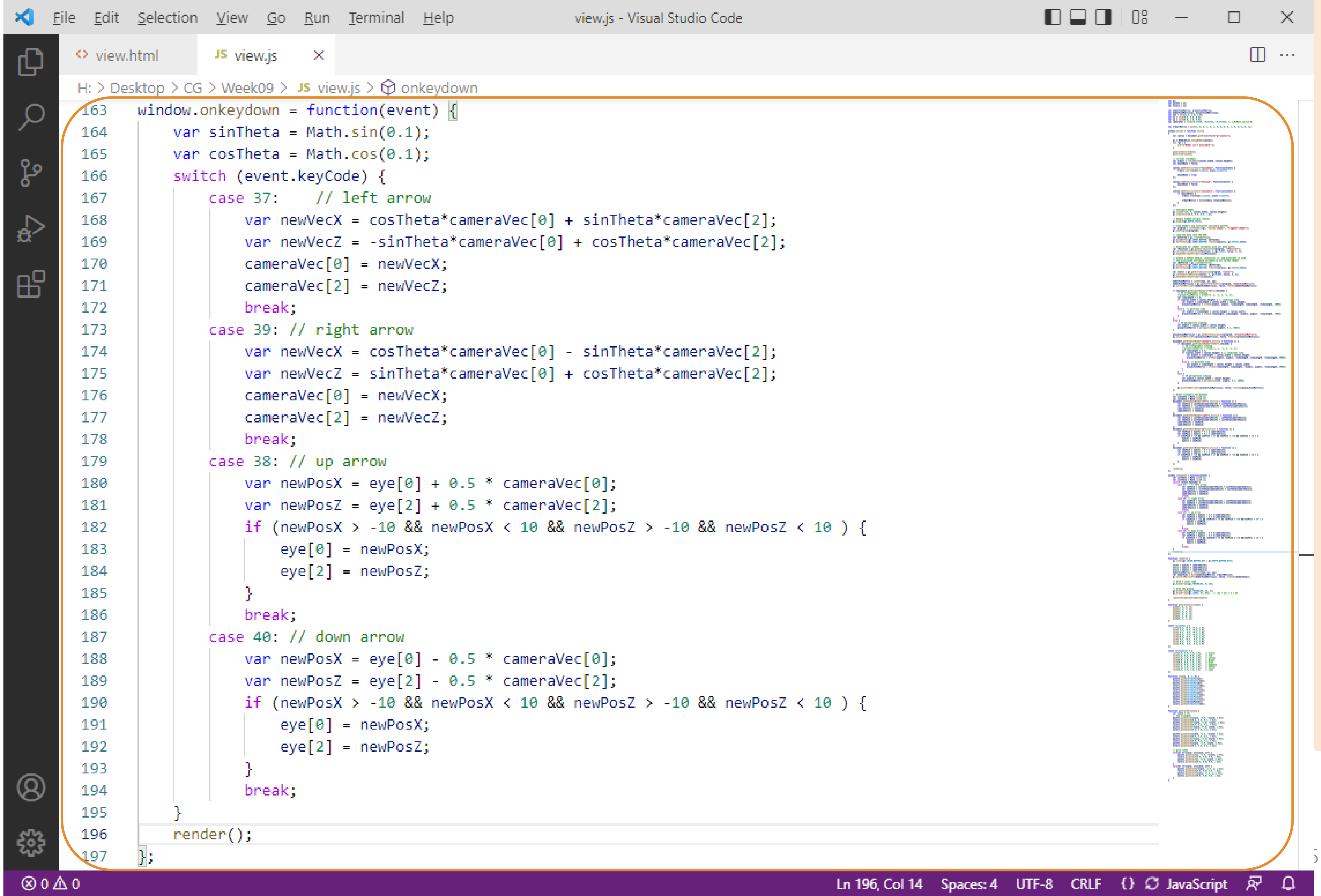
```javascript

function render() {
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    at[0] = eye[0] + cameraVec[0];
    at[1] = eye[1] + cameraVec[1];
    at[2] = eye[2] + cameraVec[2];
    modelViewMatrix = lookAt(eye, at, up);
    var modelView = mult(modelViewMatrix, trballMatrix);
    gl.uniformMatrix4fv(modelViewMatrixLoc, false, flatten(modelView));

    // draw a color cube
    gl.drawArrays(gl.TRIANGLES, 0, 36);

    // draw the ground
    gl.drawArrays(gl.TRIANGLES, 36, 6);
    gl.drawArrays(gl.LINES, 42, 84);    // (21 + 21) * 2 = 84

    requestAnimationFrame(render);
}

function generateColorCube() {
    quad(1, 0, 3, 2);
    quad(2, 3, 7, 6);
    quad(3, 0, 4, 7);
    quad(4, 5, 6, 7);
    quad(5, 4, 0, 1);
    quad(6, 5, 1, 2);
}

const vertexPos = [
    vec4(-0.5, -0.5, -0.5, 1.0),
    vec4( 0.5, -0.5, -0.5, 1.0),
    vec4( 0.5,  0.5, -0.5, 1.0),
    vec4(-0.5,  0.5, -0.5, 1.0),
```

연습 문제 (6)

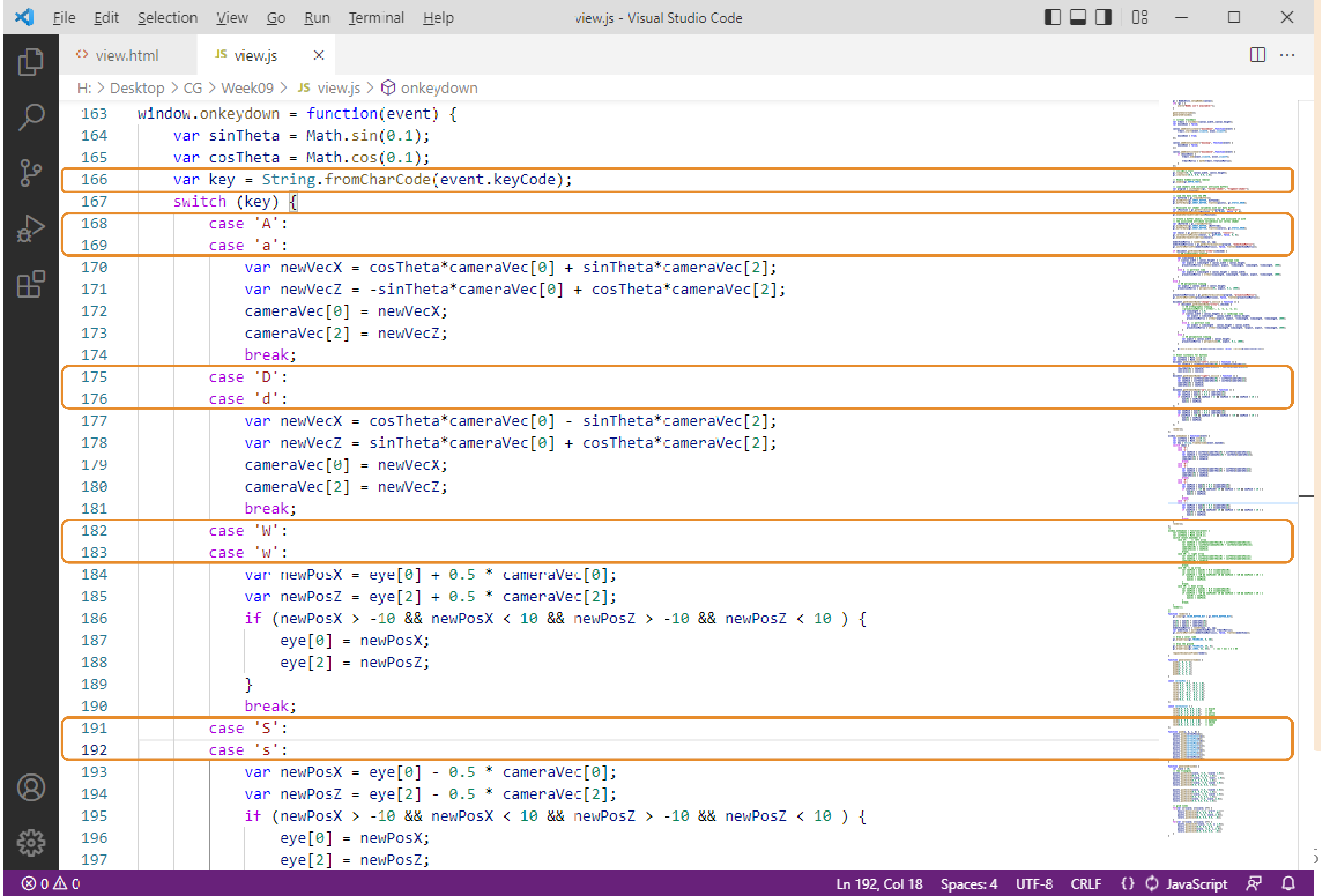
- 키보드 입력(화살표 키)을 받아 카메라를 이동시키시오.

```
window.addEventListener("keydown",
function() {
    switch (event.keyCode) {
        case 49: // '1' key
            direction = !direction;
            break;
        case 50: // '2' key
            delay /= 2.0;
            break;
        case 51: // '3' key
            delay *= 2.0;
            break;
    }
});
```

```
window.onkeydown = function(event) {
    var key = String.fromCharCode(event.keyCode);
    switch (key) {
      case '1':
        direction = !direction;
        break;
      case '2':
        delay /= 2.0;
        break;
      case '3':
        delay *= 2.0;
        break;
    }
};
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
H: > Desktop > CG > Week09 > view.js > onkeydown
Ln 196, Col 14 Spaces: 4 UTF-8 CRLF JavaScript

```javascript
window.onkeydown = function(event) {
    var sinTheta = Math.sin(0.1);
    var cosTheta = Math.cos(0.1);
    switch (event.keyCode) {
        case 37:    // left arrow
            var newVecX = cosTheta*cameraVec[0] + sinTheta*cameraVec[2];
            var newVecZ = -sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
            cameraVec[0] = newVecX;
            cameraVec[2] = newVecZ;
            break;
        case 39: // right arrow
            var newVecX = cosTheta*cameraVec[0] - sinTheta*cameraVec[2];
            var newVecZ = sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
            cameraVec[0] = newVecX;
            cameraVec[2] = newVecZ;
            break;
        case 38: // up arrow
            var newPosX = eye[0] + 0.5 * cameraVec[0];
            var newPosZ = eye[2] + 0.5 * cameraVec[2];
            if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
                eye[0] = newPosX;
                eye[2] = newPosZ;
            }
            break;
        case 40: // down arrow
            var newPosX = eye[0] - 0.5 * cameraVec[0];
            var newPosZ = eye[2] - 0.5 * cameraVec[2];
            if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
                eye[0] = newPosX;
                eye[2] = newPosZ;
            }
            break;
    }
    render();
};
```


File Edit Selection View Go Run Terminal Help
view.js - Visual Studio Code
view.html
view.js
H: > Desktop > CG > Week09 > view.js > onkeydown
Ln 192, Col 18 Spaces: 4 UTF-8 CRLF JavaScript

```
window.onkeydown = function(event) {
    var sinTheta = Math.sin(0.1);
    var cosTheta = Math.cos(0.1);
    var key = String.fromCharCode(event.keyCode);
    switch (key) {
        case 'A':
        case 'a':
            var newVecX = cosTheta*cameraVec[0] + sinTheta*cameraVec[2];
            var newVecZ = -sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
            cameraVec[0] = newVecX;
            cameraVec[2] = newVecZ;
            break;
        case 'D':
        case 'd':
            var newVecX = cosTheta*cameraVec[0] - sinTheta*cameraVec[2];
            var newVecZ = sinTheta*cameraVec[0] + cosTheta*cameraVec[2];
            cameraVec[0] = newVecX;
            cameraVec[2] = newVecZ;
            break;
        case 'W':
        case 'w':
            var newPosX = eye[0] + 0.5 * cameraVec[0];
            var newPosZ = eye[2] + 0.5 * cameraVec[2];
            if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
                eye[0] = newPosX;
                eye[2] = newPosZ;
            }
            break;
        case 'S':
        case 's':
            var newPosX = eye[0] - 0.5 * cameraVec[0];
            var newPosZ = eye[2] - 0.5 * cameraVec[2];
            if (newPosX > -10 && newPosX < 10 && newPosZ > -10 && newPosZ < 10 ) {
                eye[0] = newPosX;
                eye[2] = newPosZ;
```