Introduction to GLSL (WebGL/OpenGL)

CSU0021: Computer Graphics

What is OpenGL

- A low-level graphics rendering API (application programming interface)
- Generate high-quality images from geometric and image primitives
- Portability
  - Display/window/OS independent

History of OpenGL

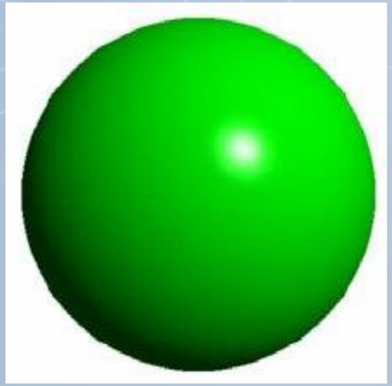
- Iris GL is developed by Silicon Graphics Inc.
- OpenGL 1.0 API is finalized in 1992 and first release in 1993
- OpenGL 1.0 (1993) ~ 1.5(2003)
  - Texture objects, 3D textures, cubemap textures, mipmap generation, shadow map, vertex buffer object …

History of OpenGL

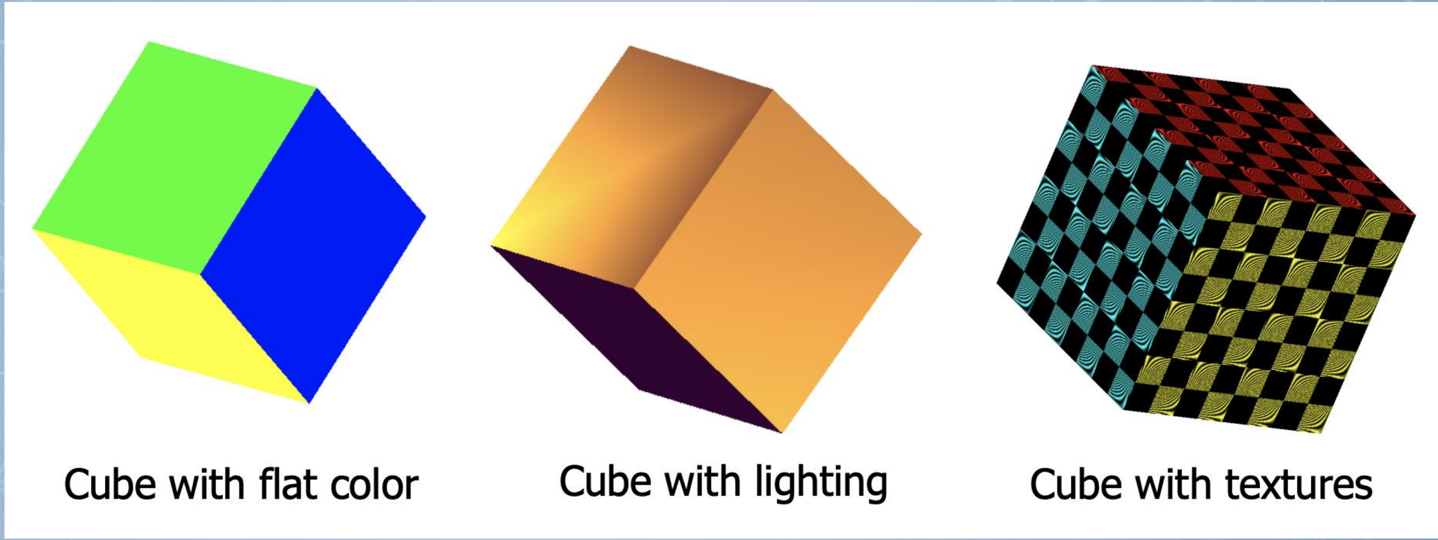
- OpenGL 2.0 (2004) ~ 2.1 (2006)
  - Vertex and fragment shading (GLSL), pixel buffer objects …
- OpenGL 3.0 (2008) ~ 3.3 (2010)
  - Framebuffer object, texture buffer objects …
- OpenGL 4.0 (2010) ~ 4.6 (2017)
  - More modern modules
- https://en.wikipedia.org/wiki/OpenGL#Version_history

Brief Introduction of OpenGL

- Main function of OpenGL – Rendering
- What is rendering?
  - Converting **geometric object description** into **frame buffer values** (convert model to image)
    - A 3D model: a green surface sphere, radius is 3, center at (0, 0, 0), and a light source at (1,1,1)
    - “Render” the above model



OpenGL Example



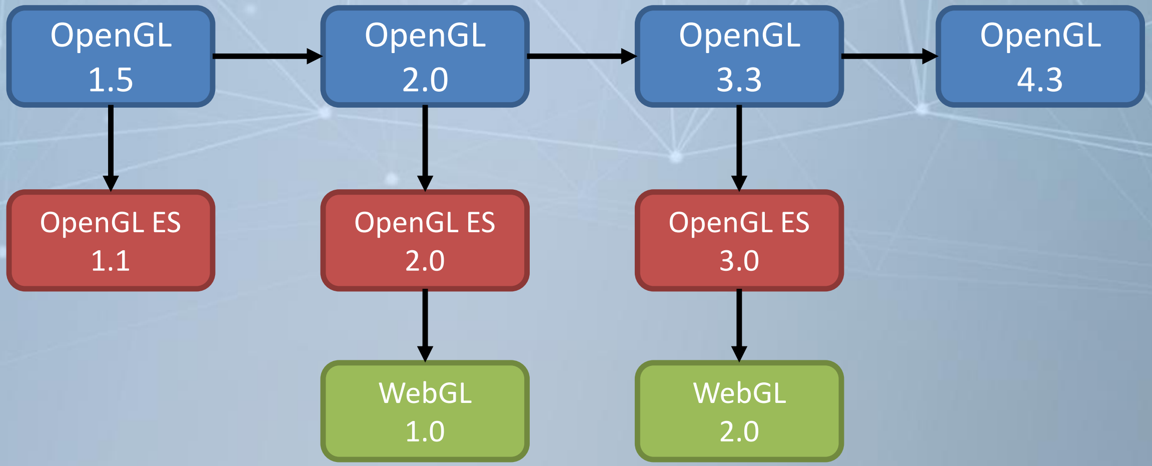
WebGL

- Javascript implementation of OpenGL
  - Run on web environment

- What you have to know/learn
  - OpenGL basics
    - pipeline architecture, OpenGL Shading Language …
  - Web basics
  - Javascript

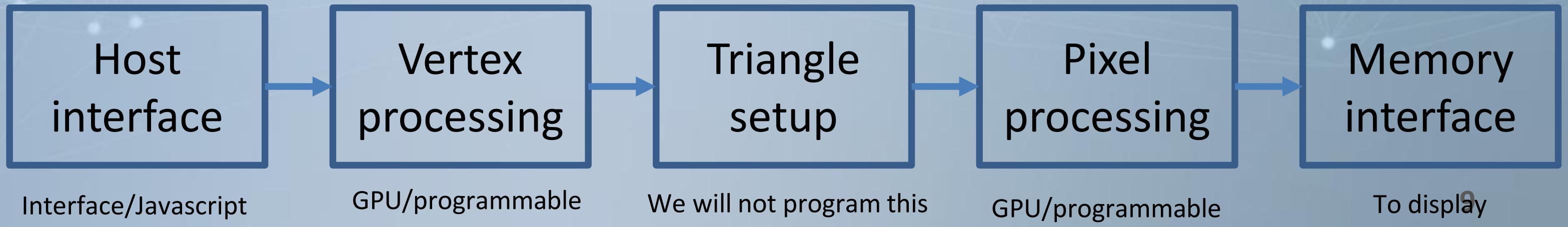
Brief History of WebGL

- OpenGL ES
  - Lightweight OpenGL for embedded system/mobile phone
  - A subset of OpenGL 3.1 API
- WebGL
  - Javascript implementation of ES 2.0
  - Run on browsers
  - https://en.wikipedia.org/wiki/WebGL



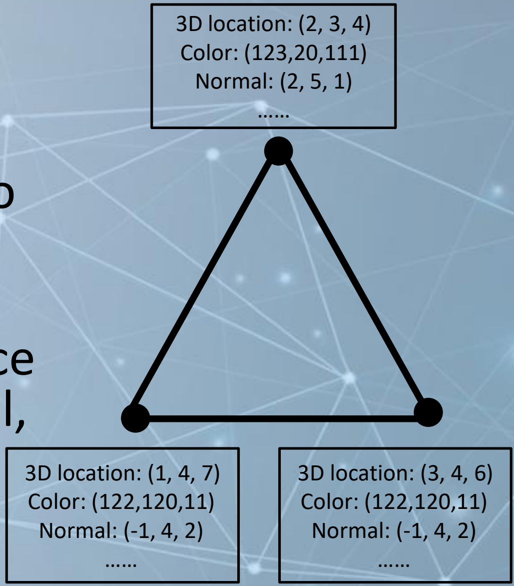
WebGL Rendering Pipeline

- Host interface: move data from CPU to GPU
- Vertex processing: transform vertex from object to screen space
- Triangle setup: rasterization
- Pixel processing: color pixels
- Memory interface: produce final image



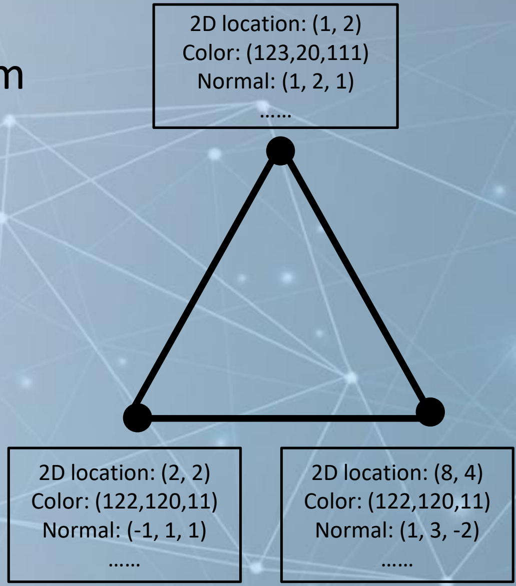
Host Interface

- The host interface is the communication bridge between the CPU and the GPU
- It receives commands from the CPU and also pulls geometry information from system memory
- It outputs a stream of vertices in object space with all their associated information (normal, texture coordinates, per vertex color etc.)



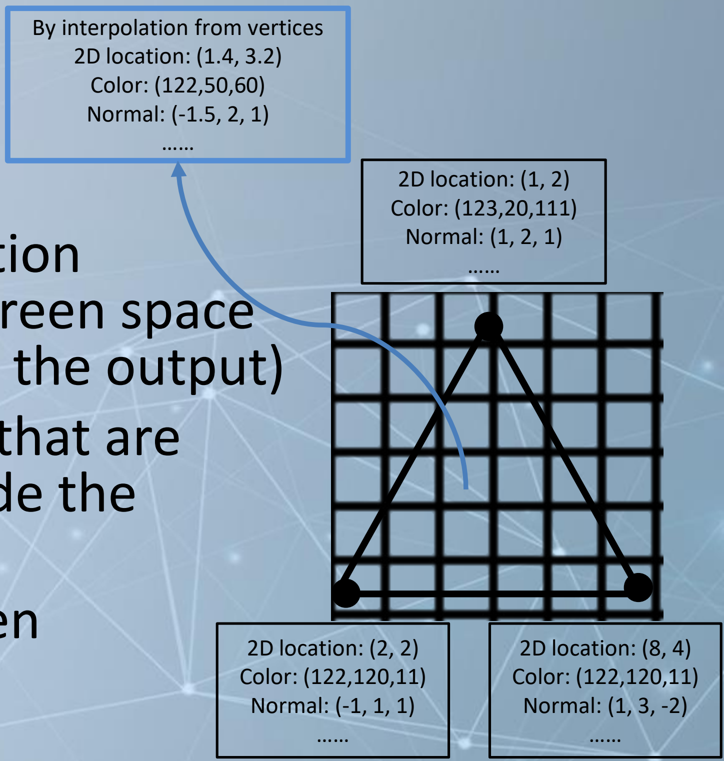
Vertex Processing

- The vertex processing stage receives vertices from the host interface in object space and outputs them in **screen space**
- This may be a simple linear transformation, or a complex operation
- **Normals, texture coordinates etc. are also transformed**
- No new vertices are created in this stage, and no vertices are discarded (input/output has 1: 1 mapping)



Triangle setup

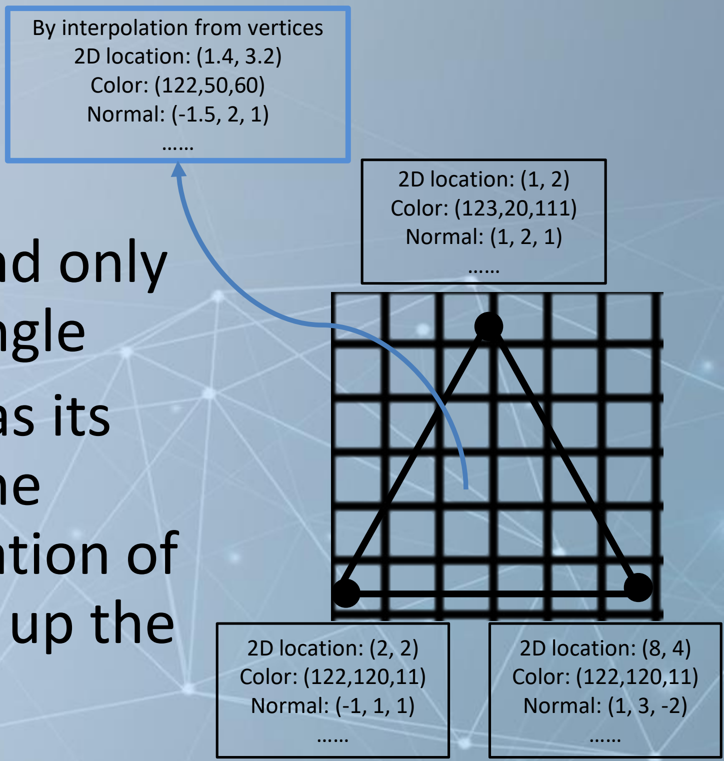
- In this stage geometry information becomes raster information (screen space geometry is the input, pixel are the output)
- Prior to rasterization, triangles that are backfacing or are located outside the viewing frustrum are rejected
- Some GPUs also do some hidden surface removal at this stage



Host interface → Vertex processing → **Triangle setup** → Pixel processing → Memory interface

Triangle setup

- A fragment is generated if and only if its center is inside the triangle
- Every fragment generated has its attributes computed to be the perspective correct interpolation of the three vertices that make up the triangle

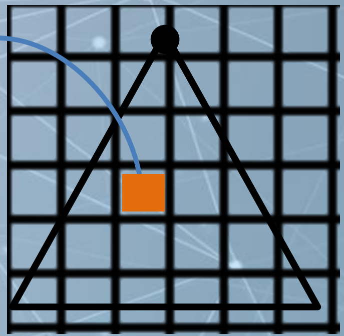


Host interface → Vertex processing → **Triangle setup** → Pixel processing → Memory interface

Fragment Processing

By interpolation from vertices
2D location: (1.4, 3.2)
Color: (122,50,60)
Normal: (-1.5, 2, 1)
……

- Each fragment provided by triangle setup is fed into fragment processing as a set of attributes (position, normal, texture coordinates etc.), which are used to compute the final color for this pixel
- The computations taking place here include texture mapping and math operations
- Typically, the bottleneck in modern applications



Color every pixel
by the information of the pixel

Host interface → Vertex processing → Triangle setup → Pixel processing → Memory interface

Memory Interface

- Fragment colors provided by the previous stage are written to the framebuffer
- Used to be the biggest bottleneck before fragment processing took over
- Before the final write occurs, some fragments are rejected by the z-buffer, stencil and alpha tests
- On modern GPUs, z and color are compressed to reduce framebuffer bandwidth (but not size)

Programmability in the GPU

- Vertex and fragment processing, and now triangle set-up, are programmable
- The programmer can write programs that are executed for every vertex as well as for every fragment
- This allows fully customizable geometry and shading effects that go well beyond the generic look and feel of older 3D applications

WebGL Programming

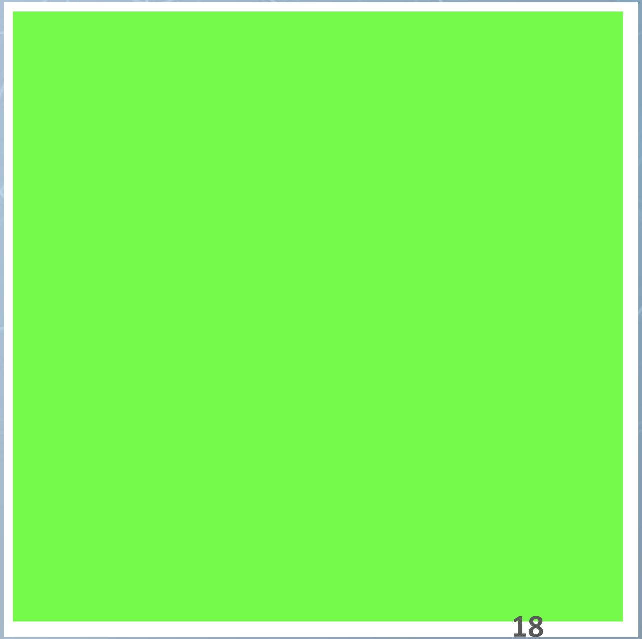
- HTML + Javascript + GLSL

- HTML:
  - WebGL renders image on HTML5 “canvas” element
- Javascript:
  - prepare GLSL, data for rendering, and user interface
- GLSL:
  - rendering

WebGL Programming (Ex1-1)

- Just clear the background by a specific color

- Two files in this example
  - Index.html
  - WebGL.js



WebGL Programming (Ex1-1)

index.html

```html
<!DOCTYPE html>
<html>
<head>
<meta charset="utf-8" />
<title>WebPage Title </title>
</head>

<body onload="main()">
<canvas id="webgl" width = "400" height = "400">
Please use a browser that support "canvas"
</canvas>
<script src="WebGL.js"></script>
</body>
</html>
```

3. Call “main()” in our javascript after <body> is loaded

1. The canvas tag (where WebGL draws)

2. Javascript for data and GLSL preparation

WebGL Programming (Ex1-1)

WebGL.js

```
function main(){
    ///// get the canvas
    var canvas = document.getElementById('webgl');

    ///// get the context for draw
    var gl = canvas.getContext('webgl2');
    if(!gl){
        console.log('Failed to get the rendering context for
        WebGL');
        return ;
    }

    ///// clear the screen by designated background color
    gl.clearColor(0.0, 1.0, 0.0, 1.0); //background color
    gl.clear(gl.COLOR_BUFFER_BIT); // clear
}
```

1. Get the canvas

2. Get the context (gl). We will use "gl" to setup everything about WebGL

3. Just set the background color (no clear action here) (R, G, B, A)

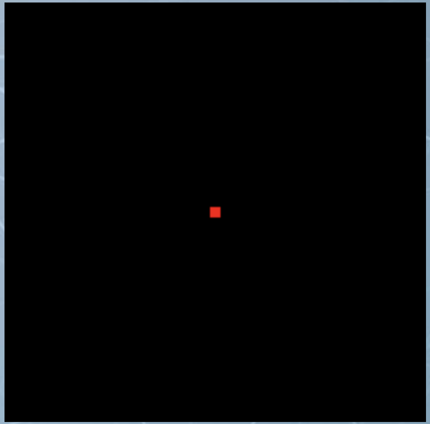
4. Clear screen by the background color

Let’s Try (5 mins)

- Download Ex1-1 from Moodle
  - Run it on browser first
- What you can try
  - Change to other background color
  - What if you remove “onload=main()” in index.html
  - What happen if you comment the line “gl.clear()”

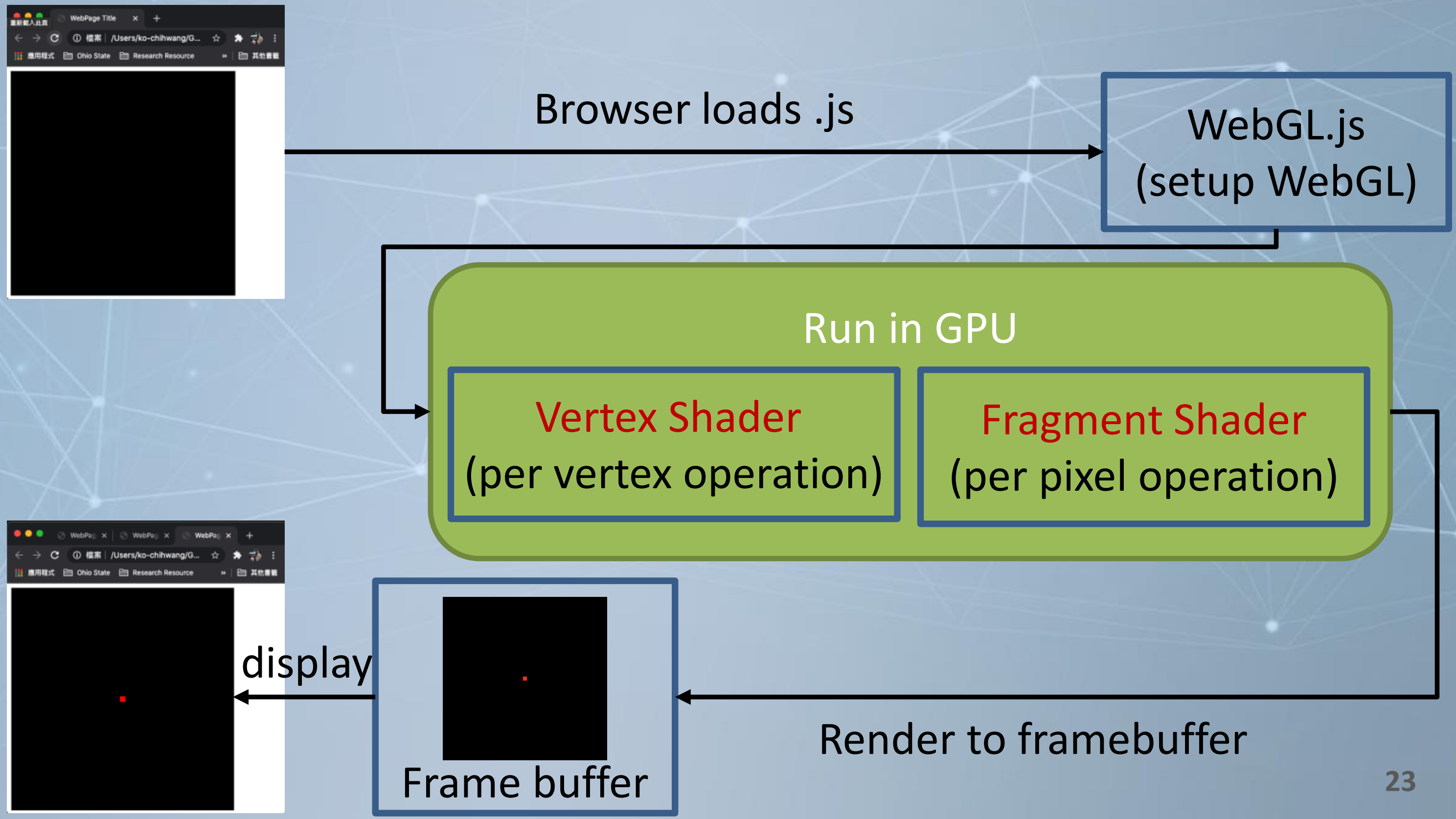
WebGL Programming (Ex1-2)

- Draw a point



- Two files in this example
  - Index.html (same as Ex1-1)
  - WebGL.js (javascript and GLSL)

WebGL Programming (Ex1-2)



WebGL Programming (Ex1-2)

WebGL.js: main()

```
function main(){
    var canvas = document.getElementById('webgl');

    var gl = canvas.getContext('webgl2');
    if(!gl){
        console.log('Failed to get the rendering context for WebGL');
        return ;
    }

    let renderProgram = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);
    gl.useProgram(renderProgram);

    gl.clearColor(0.0, 0.0, 0.0, 1.0);
    gl.clear(gl.COLOR_BUFFER_BIT);

    gl.drawArrays(gl.POINTS, 0, 1);
}
```

1. Compile vertex and fragment shader

2. Say “I want to use renderProgram” to draw

3. Draw a point

WebGL Programming (Ex1-2)

- gl.drawArrays()
  - drawArrays() is usually called after you setup everything
  - Call drawArrays() to really render a frame
  - We will introduce the details later

- gl.drawArrays(mode, first, count)
  - mode: how to draw
    - Gl.POINTS, gl.LINES, gl.LINE_STRIP, gl.LINE_LOOP, gl.TRIANGLES, gl.TRIANGLE_STRIP, gl.TRIANGLE_FAN
  - first (int): the first vertex for drawing in vertex array
  - count (int): how many vertices to draw

WebGL Programming (Ex1-2)

To draw…we need vertex and fragment shaders and compile it

```
function main(){
      var canvas = document.getElementById('webgl');

      var gl = canvas.getContext('webgl2');
      if(!gl){
            console.log('Failed to get the rendering context for WebGL');
            return ;
      }

      let renderProgram = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);
      gl.useProgram(renderProgram);

      gl.clearColor(0.0, 0.0, 0.0, 1.0);
      gl.clear(gl.COLOR_BUFFER_BIT);

      gl.drawArrays(gl.POINTS, 0, 1);
}
```

WebGL Programming (Ex1-2)

- WebGL.js: shaders
  - The code of shaders can be string variables in .js
  - Use ` for shader code

````
var VSHADER_SOURCE = `
void main(){
    gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
    gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
    gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
````

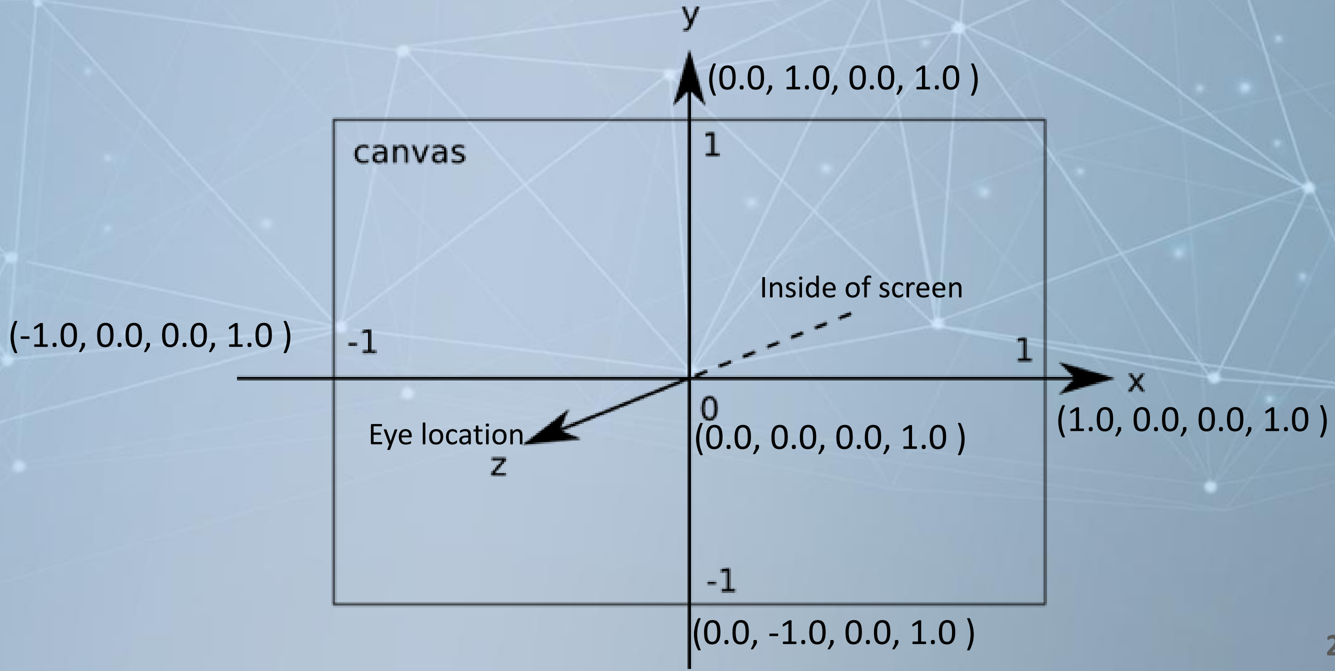
WebGL Programming (Ex1-2)

- GLSL build-in variable for vertex shader
  - vec4 gl_Position (vertex location)
    - vec4 is a type in GLSL, a vector with 4 floats
  - float gl_PointSize (vertex size)
    - This is not necessary to assign a value (default: 1.0)
    - float is also a type in GLSL
    - GLSL does not do auto-type conversion.
      - You will get error if you write gl_PointSize = 10

```
var VSHADER_SOURCE = `
void main(){
    gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
    gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
    gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```

WebGL Programming (Ex1-2)

- Coordinate system
  - Homogenous system (this is why we use 4 numbers to define a 3D point)
    - (x, y, z, w) = (x/w, y/w, z/w)
    - We will introduce homogenous system in detail later



WebGL Programming (Ex1-2)

- GLSL build-in variable for fragment shader
  - vec4 gl_FragColor (pixel color)
- In this example, we assign red color to pixels

```
var VSHADER_SOURCE = `
void main(){
     gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
     gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
     gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```

WebGL Programming (Ex1-2)

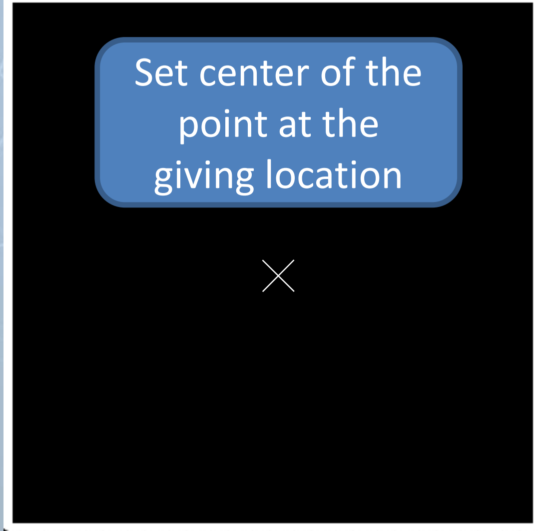
- WebGL.js: function to compile shaders (VSHADER_SOURCE, FSHADER_SOURCE)
  - We ignore details of this utility function here

```
function compileShader(gl, vShaderText, fShaderText){
        //////Build vertex and fragment shader objects
        var vertexShader = gl.createShader(gl.VERTEX_SHADER)
        var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
        //The way to set up shader text source
        gl.shaderSource(vertexShader, vShaderText)
        gl.shaderSource(fragmentShader, fShaderText)
        //compile vertex shader
        gl.compileShader(vertexShader)
        if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
                console.log('vertex shader ereror');
                var message = gl.getShaderInfoLog(vertexShader);
                console.log(message);//print shader compiling error message
        }
        //compile fragment shader
        gl.compileShader(fragmentShader)
        if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
                console.log('fragment shader ereror');
                var message = gl.getShaderInfoLog(fragmentShader);
                console.log(message);//print shader compiling error message
        }

        /////link shader to program (by a self-define function)
        var program = gl.createProgram();
        gl.attachShader(program, vertexShader);
        gl.attachShader(program, fragmentShader);
        gl.linkProgram(program);
        //if not success, log the program info, and delete it.
        if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
                alert(gl.getProgramInfoLog(program) + "");
                gl.deleteProgram(program);
        }

        return program;
}
```

WebGL Programming (Ex1-2)

- Let's illustrate what the shader is doing in this example
- When gl.drawArrays(gl.POINTS, 0, 1) is called, the the shader starts to run
  - In this example, we just say "hey shader, help me drawing one point", and do not pass any vertex information to shader because we hardcode the information in the shader
- Note: WebGL runs "vertex shader" first, then pass information produced by vertex shader to "fragment shader" to run
  - The vertex shader process all vertices parallelly (but, we only have one vertex here. Let's keep the concept of penalization for later)

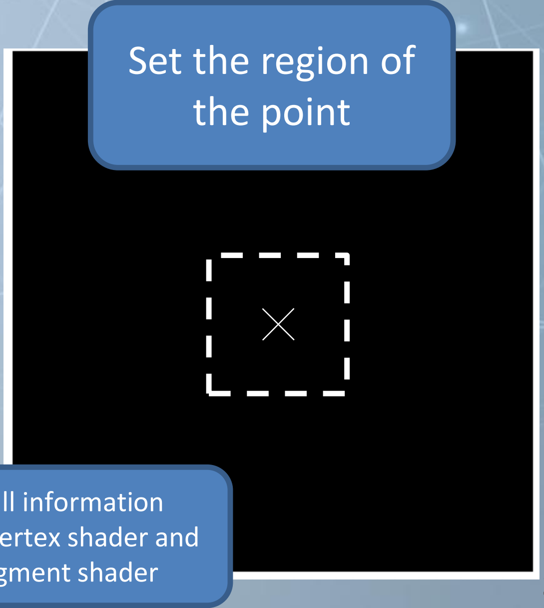
```
var VSHADER_SOURCE = `
void main(){
      gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
      gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```



WebGL Programming (Ex1-2)

- Let’s illustrate what the shader is doing in this example
- When gl.drawArrays(gl.POINTS, 0, 1) is called, the the shader starts to run
  - In this example, we just say “hey shader, help me drawing one point”, and do not pass any vertex information to shader because we hardcode the information in the shader
- Note: WebGL runs “vertex shader” first, then pass information produced by vertex shader to “fragment shader” to run

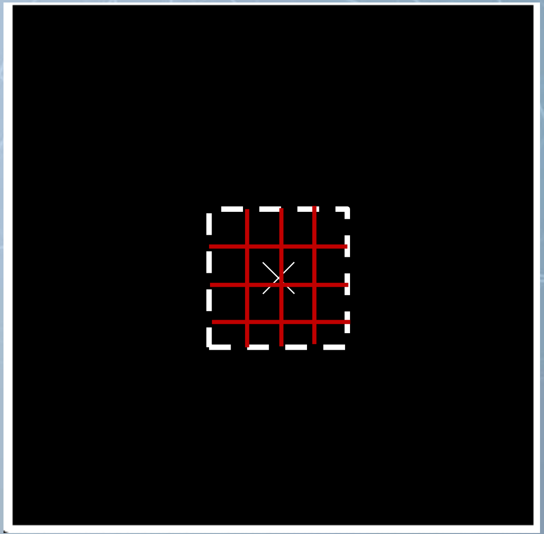
```
var VSHADER_SOURCE = `
void main(){
      gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
      gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```



WebGL Programming (Ex1-2)

- Between vertex and fragment shader, WebGL automatically do many things for you
  - One of them is “rasterization”
  - Subdivide the regions which should be colored into pixels

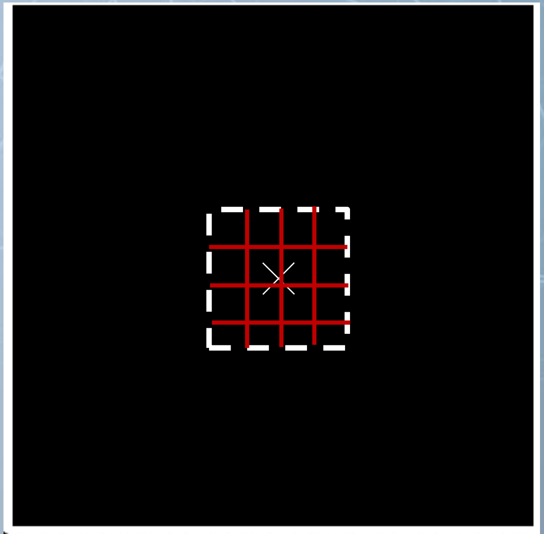
```
var VSHADER_SOURCE = `
void main(){
      gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
      gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```



WebGL Programming (Ex1-2)

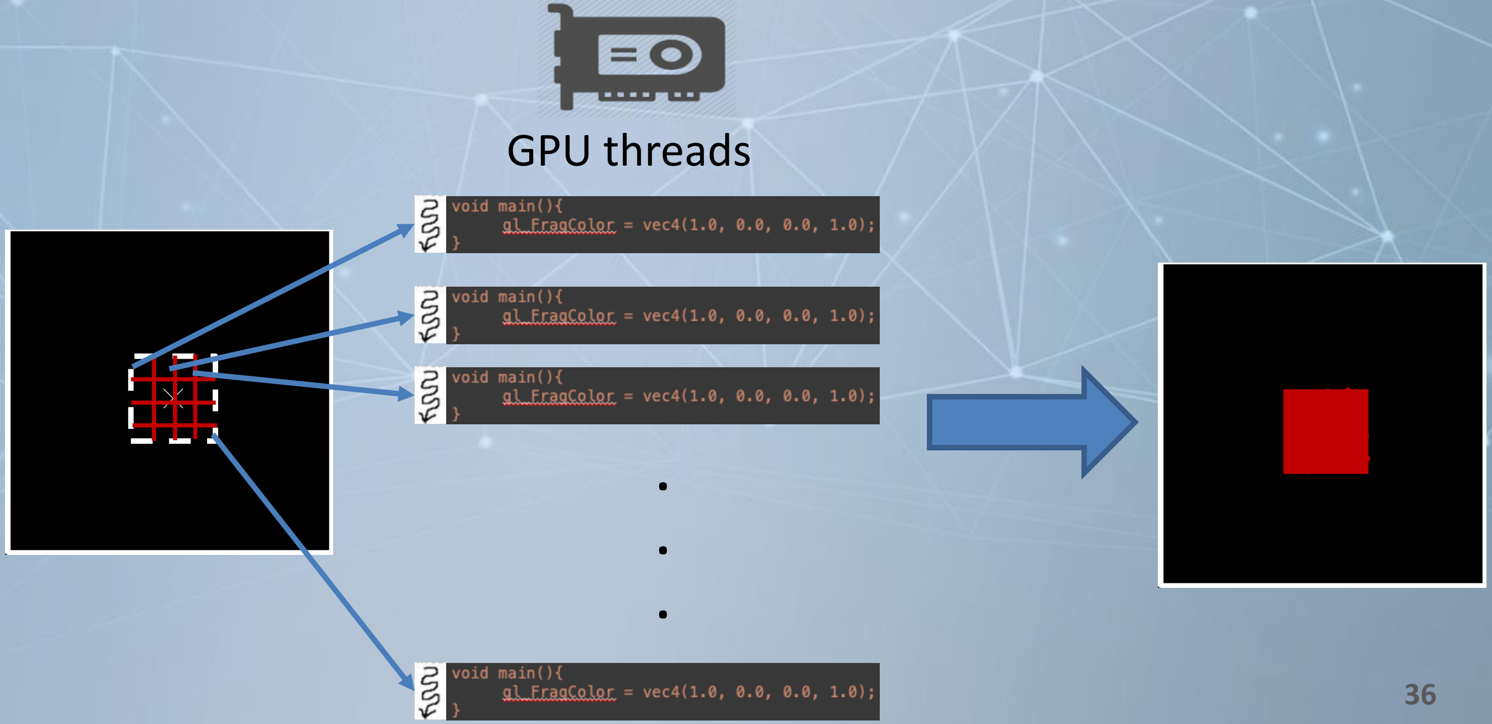
- Fragment shader
  - The fragment shader process all “pixels” parallelly
  - In this example, we have 4*4=16 pixels after rasterization
    - So, the fragment shader will have 16 copies on 16 threads and each one colors one pixel

```
var VSHADER_SOURCE = `
void main(){
      gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
      gl_PointSize = 10.0;
}
`;

var FSHADER_SOURCE = `
void main(){
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
`;
```



WebGL Programming (Ex1-2)

- Illustration of parallelization on graphics card



Some Variable Types in GLSL

- float, int, bool
  - No double, no long int, no short int…..
    - GLSL uses additional keyboard to control the variable precision. We will see it soon
- Type conversion: newType(oldType)
  - int a = 10;
  - float b = float(a)

- Other data types
  - float vector: vec2, vec3, vec4
  - Integer vector: ivec2, ivec3, ivec4
  - Boolean vector: bvec2, bvec3, bvec4
  - Matrix: mat2, mat3, mat4
    - mat2: 2x2matrix, mat3: 3x3 matrix, mat4: 4x4 matrix

Let’s Try (5 mins)

- Download Ex1-2 from Moodle
  - Try it on browser
- What you can try
  - Draw the point at different location
  - Draw the point with different color
  - What if you change the last element of gl_Position to 0.0
  - What if you change the last element of gl_FragColor to 0.0
  - What if you change “gl_PointSize = 10.0” to “gl_PointSize = 10”
  - What if you change “gl_PointSize = 10.0” to “gl_PointSize = float(10)”

“attribute”, “uniform” and “varying”

- “attribute”, “uniform” and “varying” are keywords for GLSL variables
  - ex:

    keyword — type — variable name

    - attribute vec4 a_Position;
    - uniform float u_Factor;
    - varying vec3 v_Color;

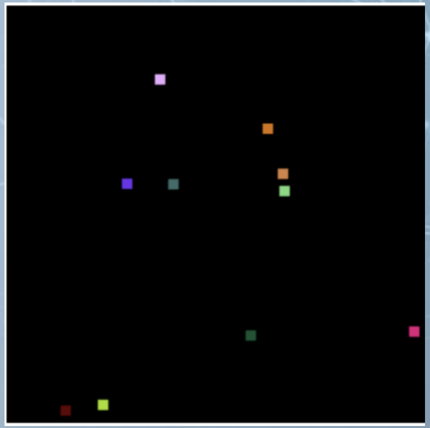
- attribute, uniform variables: pass data from outside of graphics card (javascript) to inside (GLSL)
- varying variables: pass data from vertex and fragment shaders

- Let’s introduce “uniform” here, but keep attribute and varying for later

WebGL Programming (Ex1-3)

- Draw multiple points with random color at random locations

- Files
  - index.html
  - WebGL.js



WebGL Programming (Ex1-3)

- WebGL.js: shaders

```
var VSHADER_SOURCE = `
    uniform vec4 u_Position;
    void main(){
        gl_Position = u_Position;
        gl_PointSize = 10.0;
    }
    `;

var FSHADER_SOURCE = `
    precision mediump float;
    uniform vec4 u_FragColor;
    void main(){
        gl_FragColor = u_FragColor;
    }
    `;
```

Receive a position vector from outside (javascript)

Assign it to gl_Position (where to draw a point)

Receive a color from outside (javascript)

Use it to draw a point

WebGL Programming (Ex1-3)

- WebGL.js: shaders

```
var VSHADER_SOURCE = `
    uniform vec4 u_Position;
    void main(){
        gl_Position = u_Position;
        gl_PointSize = 10.0;
    }
    `;

var FSHADER_SOURCE = `
    precision mediump float;
    uniform vec4 u_FragColor;
    void main(){
        gl_FragColor = u_FragColor;
    }
    `;
```

- Determine how much precision the GPU uses when calculating “floats” (this statement is necessary in fragment shader. Otherwise, the shader will not compile)
    - “highp”: high precision
    - “mediump”: medium precision
    - “lowp”: low precision
- Check here for definition of each precision: http://learnwebgl.brown37.net/12_shader_language/glsl_data_types.html
- Tradeoff: you will see a performance hit if you always use “highp”

WebGL Programming (Ex1-3)

- WebGL.js: shaders

```
var VSHADER_SOURCE = `
    uniform vec4 u_Position;
    void main(){
        gl_Position = u_Position;
        gl_PointSize = 10.0;
    }
    `;

var FSHADER_SOURCE = `
    precision mediump float;
    uniform vec4 u_FragColor;
    void main(){
        gl_FragColor = u_FragColor;
    }
    `;
```

- Suggestion:
  - “highp” for vertex position
  - “mediump” for texture coordinate
  - “lowp” for colors
- This statements says that ”use MEDIUM PRECISION to calculate ALL floats in this fragment shader“
- Can we assign different variables to different precision?
  - Yes
  - Ex: uniform highp vec4 u_FragColor;

WebGL Programming (Ex1-3)

- How to pass data to the uniform variable in shaders?
  - 1. get reference of the uniform variable
    - gl.getUniformLocation()
  - 2. pass data
    - gl.uniform4f(location, v0, v1, v2, v3): to a uniform vec4
    - gl.uniform3f(location, v0, v1, v2): to a uniform vec3
    - gl.uniform2f(location, v0, v1): to a uniform vec2
    - gl.uniform1f(location, v0): to a uniform float

WebGL Programming (Ex1-3)

- WebGL.js: main()

```
function main(){
        var canvas = document.getElementById('webgl');
        var gl = canvas.getContext('webgl2');
        if(!gl){
                console.log('Failed to get the rendering context for WebGL');
                return ;
        }

        let renderProgram = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);
        gl.useProgram(renderProgram);

        renderProgram.u_Position = gl.getUniformLocation(renderProgram, 'u_Position');
        renderProgram.u_FragColor = gl.getUniformLocation(renderProgram, 'u_FragColor');

        gl.clearColor(0.0, 0.0, 0.0, 1.0);
        gl.clear(gl.COLOR_BUFFER_BIT);

        for(let i = 0; i < 10; i++){
                gl.uniform4f(renderProgram.u_Position, Math.random() * 2.0 - 1.0, Math.random() * 2.0 - 1.0, 0.0, 1.0);
                gl.uniform4f(renderProgram.u_FragColor, Math.random(), Math.random(), Math.random(), 1.0);
                gl.drawArrays(gl.POINTS, 0, 1);
        }
}
```

1. Compile shaders and use the compiled program

2. Get reference of "u_Position" from the program, "renderProgram"

3. Keep the reference for use later (you can just use any javascript variable to keep it)

WebGL Programming (Ex1-3)

- WebGL.js: main()

```
function main(){
        var canvas = document.getElementById('webgl');
        var gl = canvas.getContext('webgl2');
        if(!gl){
                console.log('Failed to get the rendering context for WebGL');
                return ;
        }

        let renderProgram = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);
        gl.useProgram(renderProgram);

        renderProgram.u_Position = gl.getUniformLocation(renderProgram, 'u_Position');
        renderProgram.u_FragColor = gl.getUniformLocation(renderProgram, 'u_FragColor');

        gl.clearColor(0.0, 0.0, 0.0, 1.0);
        gl.clear(gl.COLOR_BUFFER_BIT);

        for(let i = 0; i < 10; i++){
                gl.uniform4f(renderProgram.u_Position, Math.random() * 2.0 - 1.0, Math.random() * 2.0 - 1.0, 0.0, 1.0);
                gl.uniform4f(renderProgram.u_FragColor, Math.random(), Math.random(), Math.random(), 1.0);
                gl.drawArrays(gl.POINTS, 0, 1);
        }
}
```

Use ”gl.uniform4f” to pass data to a uniform vec4 variable in shader

Four floats because we use gl.uniform4f

Let‘s Try

- Download Ex1-3 from Moodle
  - Try it on browser

- What you can try
  - What if you comment “gl.useProgram()”
  - Change ‘renderProgram.u_Position’ at Line 66 to any variable name, such as “abc”. Also, change ‘renderProgram.u_Position’ to “abc” at Line 73. Then, run it.
  - What if you change all “u_Position” in vertex shader to “position”. Do you get error message? If so, change ‘u_Position’ at Line 66 to ‘position’. Is that fixed?

Compile the Shaders

- The compilation functions in the example code
  - compileShader()

```
function compileShader(gl, vShaderText, fShaderText){
    //////Build vertex and fragment shader objects
    var vertexShader = gl.createShader(gl.VERTEX_SHADER)
    var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
    //The way to set up shader text source
    gl.shaderSource(vertexShader, vShaderText)
    gl.shaderSource(fragmentShader, fShaderText)
    //compile vertex shader
    gl.compileShader(vertexShader)
    if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
        //print shader compiling error message
    }
    //compile fragment shader
    gl.compileShader(fragmentShader)
    if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
        //print shader compiling error message
    }

    /////link shader to program (by a self-define function)
    var program = gl.createProgram();
    gl.attachShader(program, vertexShader);
    gl.attachShader(program, fragmentShader);
    gl.linkProgram(program);
    //if not success, log the program info, and delete it.
    if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
        alert(gl.getProgramInfoLog(program) + "");
        gl.deleteProgram(program);
    }

    return program;
}
```

Take the context, vertex shader source and fragment shader source

Create shader object and tell what type (vertex or fragment) shader you want

Assign shader source code to shader objects

```
function compileShader(gl, vShaderText, fShaderText){
      //////Build vertex and fragment shader objects
      var vertexShader = gl.createShader(gl.VERTEX_SHADER)
      var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
      //The way to set up shader text source
      gl.shaderSource(vertexShader, vShaderText)
      gl.shaderSource(fragmentShader, fShaderText)
      //compile vertex shader
      gl.compileShader(vertexShader)
      if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }
      //compile fragment shader
      gl.compileShader(fragmentShader)
      if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }

      /////link shader to program (by a self-define function)
      var program = gl.createProgram();
      gl.attachShader(program, vertexShader);
      gl.attachShader(program, fragmentShader);
      gl.linkProgram(program);
      //if not success, log the program info, and delete it.
      if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
            alert(gl.getProgramInfoLog(program) + "");
            gl.deleteProgram(program);
      }

      return program;
}
```

Compile the Shaders

- The compilation functions in the example code
  - compileShader()

Compile shaders

Compile the Shaders

```
function compileShader(gl, vShaderText, fShaderText){
      //////Build vertex and fragment shader objects
      var vertexShader = gl.createShader(gl.VERTEX_SHADER)
      var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
      //The way to set up shader text source
      gl.shaderSource(vertexShader, vShaderText)
      gl.shaderSource(fragmentShader, fShaderText)
      //compile vertex shader
      gl.compileShader(vertexShader)
      if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }
      //compile fragment shader
      gl.compileShader(fragmentShader)
      if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }

      /////link shader to program (by a self-define function)
      var program = gl.createProgram();
      gl.attachShader(program, vertexShader);
      gl.attachShader(program, fragmentShader);
      gl.linkProgram(program);
      //if not success, log the program info, and delete it.
      if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
            alert(gl.getProgramInfoLog(program) + "");
            gl.deleteProgram(program);
      }

      return program;
}
```

- The compilation functions in the example code
  - compileShader()

Handle the error if the compilation fails

Compile the Shaders

- The compilation functions in the example code
  - compileShader()

```
function compileShader(gl, vShaderText, fShaderText){
	//////Build vertex and fragment shader objects
	var vertexShader = gl.createShader(gl.VERTEX_SHADER)
	var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
	//The way to set up shader text source
	gl.shaderSource(vertexShader, vShaderText)
	gl.shaderSource(fragmentShader, fShaderText)
	//compile vertex shader
	gl.compileShader(vertexShader)
	if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
		//print shader compiling error message
	}
	//compile fragment shader
	gl.compileShader(fragmentShader)
	if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
		//print shader compiling error message
	}

	/////link shader to program (by a self-define function)
	var program = gl.createProgram();
	gl.attachShader(program, vertexShader);
	gl.attachShader(program, fragmentShader);
	gl.linkProgram(program);
	//if not success, log the program info, and delete it.
	if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
		alert(gl.getProgramInfoLog(program) + "");
		gl.deleteProgram(program);
	}

	return program;
}
```

Create a GPU program and link compiled shader objects to it

Compile the Shaders

- The compilation functions in the example code
  - compileShader()

```
function compileShader(gl, vShaderText, fShaderText){
      //////Build vertex and fragment shader objects
      var vertexShader = gl.createShader(gl.VERTEX_SHADER)
      var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER)
      //The way to set up shader text source
      gl.shaderSource(vertexShader, vShaderText)
      gl.shaderSource(fragmentShader, fShaderText)
      //compile vertex shader
      gl.compileShader(vertexShader)
      if(!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }
      //compile fragment shader
      gl.compileShader(fragmentShader)
      if(!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)){
            //print shader compiling error message
      }

      /////link shader to program (by a self-define function)
      var program = gl.createProgram();
      gl.attachShader(program, vertexShader);
      gl.attachShader(program, fragmentShader);
      gl.linkProgram(program);
      //if not success, log the program info, and delete it.
      if(!gl.getProgramParameter(program, gl.LINK_STATUS)){
            alert(gl.getProgramInfoLog(program) + "");
            gl.deleteProgram(program);
      }

      return program;
}
```

Check and handle linking error