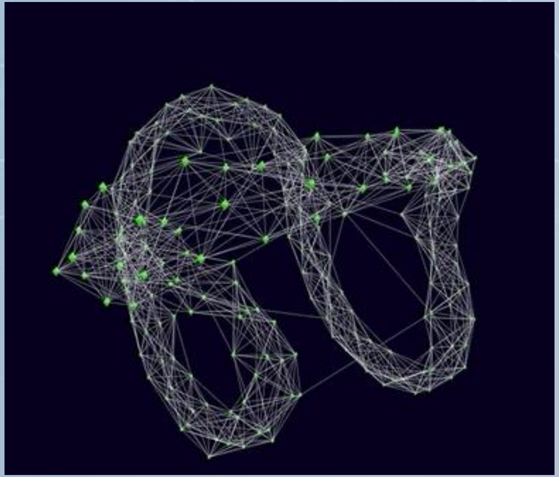
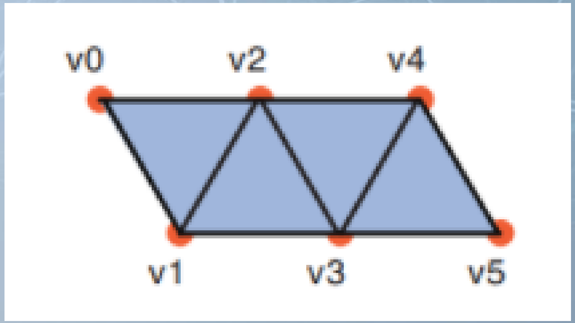
Vertex Buffer Object (VBO)

CSU0021: Computer Graphics

What if …

- You want to draw a complicated scene with thousands vertices
  - Pass them to shader and run one by one using a javascript for loop?
    - This implementation does not utilize the resource of graphics card well
    - Shaders does not know the connection between vertices to render a surface

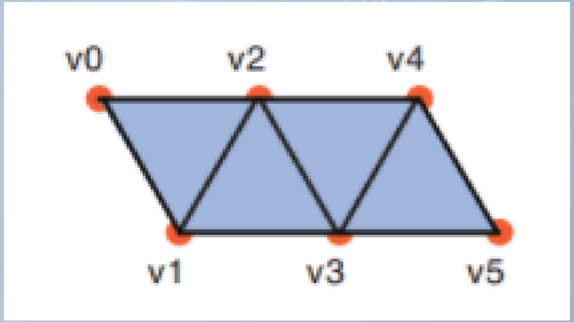




What We Want ...

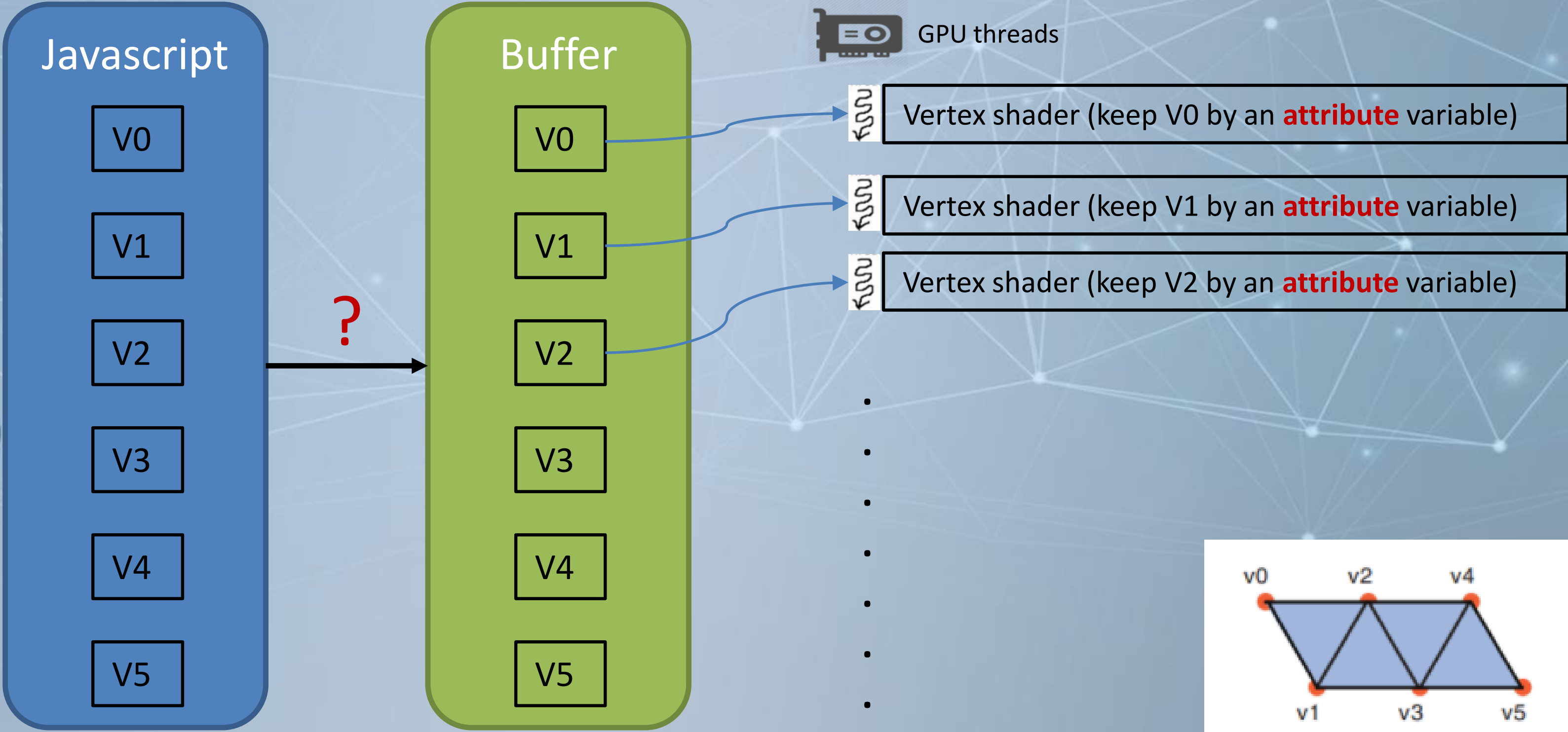
- Prepare all vertices (v0 … v5) in javascript and pass to graphics card (shader)
- Run shaders just once (call ”gl.drawArrays()”) to render all triangles for us

- “Vertex Buffer Object” (VBO) can help

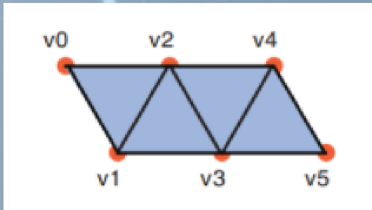


Vertex Buffer Object (VBO)

- VBO is a buffer for you to keep the vertices information for drawing



Javascript
V0
V1
V2
V3
V4
V5
?
Buffer
V0
V1
V2
V3
V4
V5
GPU threads
Vertex shader (keep V0 by an **attribute** variable)
Vertex shader (keep V1 by an **attribute** variable)
Vertex shader (keep V2 by an **attribute** variable)



Vertex Buffer Object (VBO)

- VBO is a buffer for you to keep the vertices information for drawing
- To use VBO, there are multiple steps
  - Create a buffer: **gl.createBuffer()**
  - Bind the buffer: **gl.bindBuffer()**
  - Write vertices information to the buffer: **gl.bufferData()**
  - Assign the buffer to an "attribute" variable in vertex shader: **gl.vertexAttribPointer()**
  - Enable the attribute variable: **gl.enableVertexAttributeArray()**

- "attribute" is a keyword for variable in vertex shader
  - Similar to "uniform"
  - Let's see what the difference between "uniform" and "attribute"

“uniform” and “attribute” in Shaders

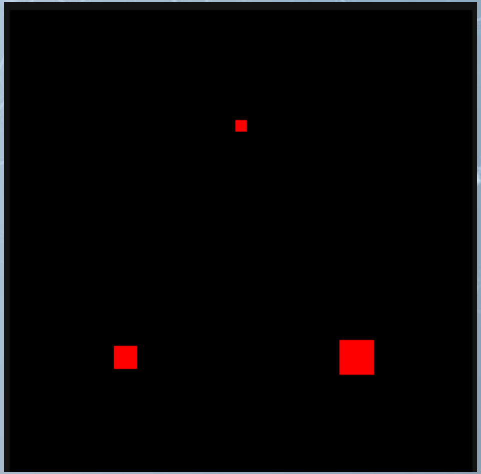
- “uniform”
  - can be used in both **vertex and fragment shader**
  - The same uniform variable of all threads has the **same** value
    - ex: **uniform float var**, and we pass “1.5” to var using gl.uniform1f()
    - All “var” in different threads has the same value, 1.5

- “attribute”
  - Only for **vertex shader**
  - The same attribute variable of all threads suppose to have **different** values
    - ex: **attribute vec3 var**
  - So, what the values of ”var” in each threads are?

Example (Ex02-1)

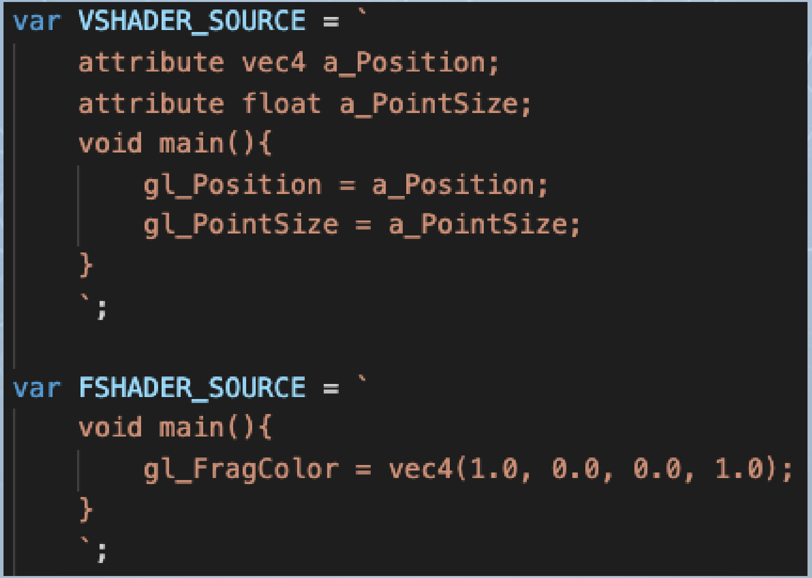
- Draw three points with different sizes
- Call gl.drawArrays() just once
- Vertex shader should receive positions and sizes of these points

- Files:
  - Index.html
  - WebGL.js



Example (Ex02-1)

- WegGL.js: vertex and fragment shaders
- We have three points (three positions and sizes)
  - E.g. a_Position stores the position of one point
  - What happens in the vertex shader?



```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute float a_PointSize;
    void main(){
        gl_Position = a_Position;
        gl_PointSize = a_PointSize;
    }
    `;

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

Example (Ex02-1)

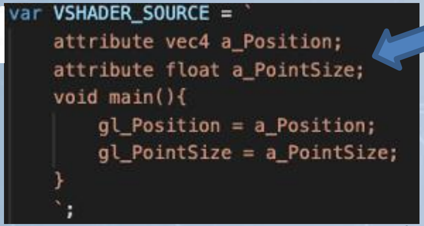
- Shaders runs in **data parallelism** mechanism
  - More details: https://en.wikipedia.org/wiki/Data_parallelism

- In short, each thread runs the same code but different input data
  - In our vertex shader example, each thread runs the same vertex shader code, but the data in their "a_Position" and "a_PointSize" are different

Example (Ex02-1)

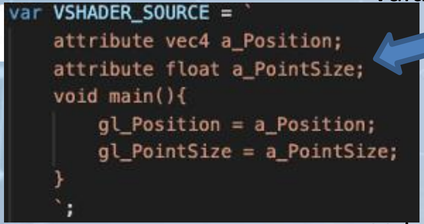
GPU threads

Values in a_Position and a_PointSize of this thread are position and size of point 1



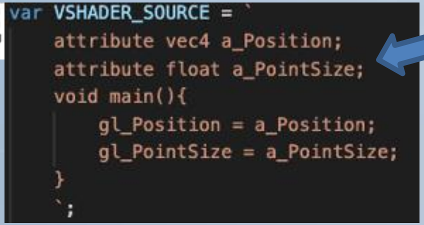
```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute float a_PointSize;
    void main(){
        gl_Position = a_Position;
        gl_PointSize = a_PointSize;
    }
    `;
```

Values in a_Position and a_PointSize of this thread are position and size of point 2



```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute float a_PointSize;
    void main(){
        gl_Position = a_Position;
        gl_PointSize = a_PointSize;
    }
    `;
```

Values in a_Position and a_PointSize of this thread are position and size of point 3

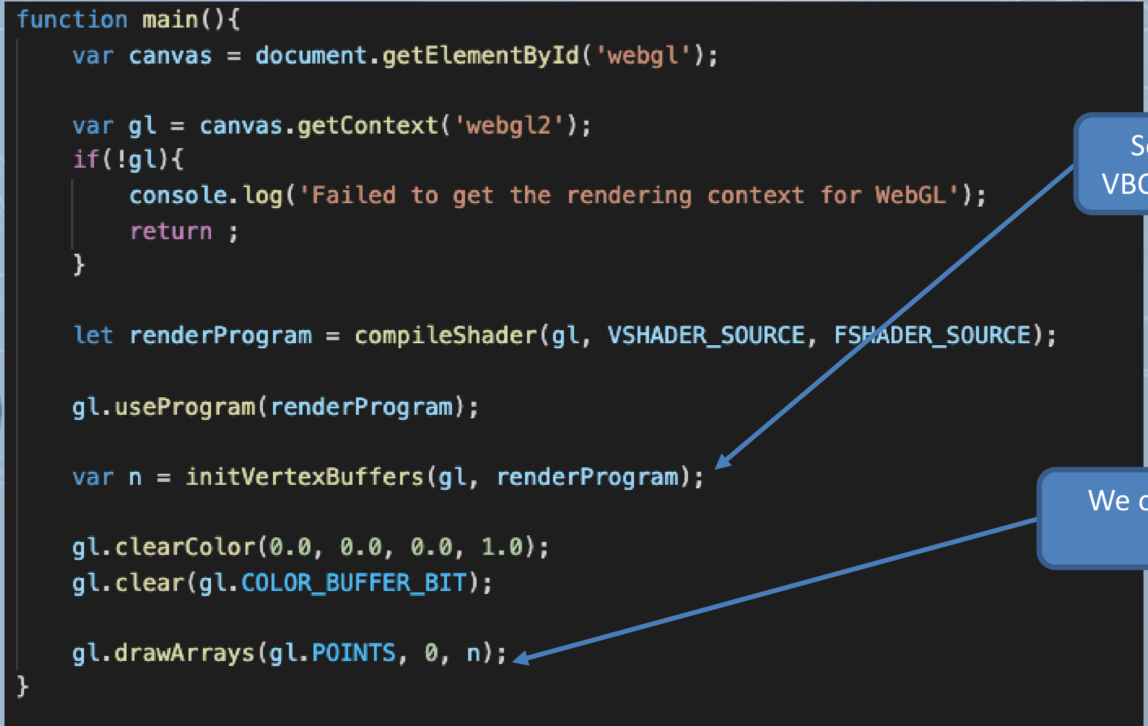


```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute float a_PointSize;
    void main(){
        gl_Position = a_Position;
        gl_PointSize = a_PointSize;
    }
    `;
```

How to make this happen in WebGL???

Example (Ex02-1)

- WebGL.js: main()



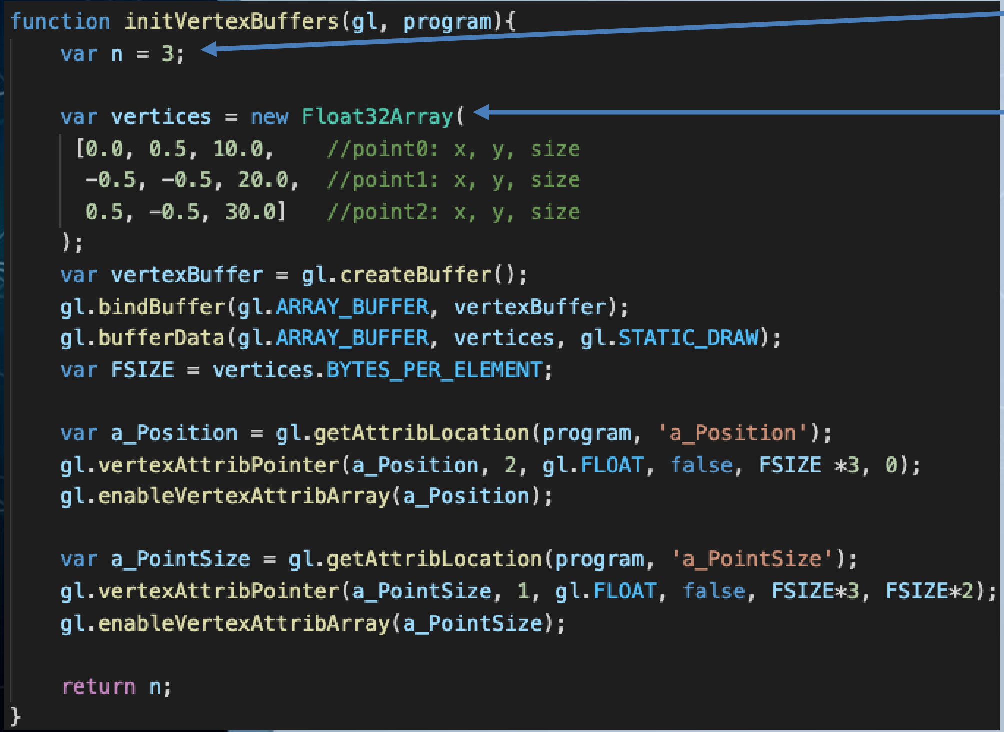
```
function main(){
    var canvas = document.getElementById('webgl');

    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);

    var n = initVertexBuffers(gl, renderProgram);

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

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

Self-defined function using VBO to pass vertex information

We only call gl.drawArrays() once here

Example (Ex02-1)

- WebGL.js: initVertexBuffers()



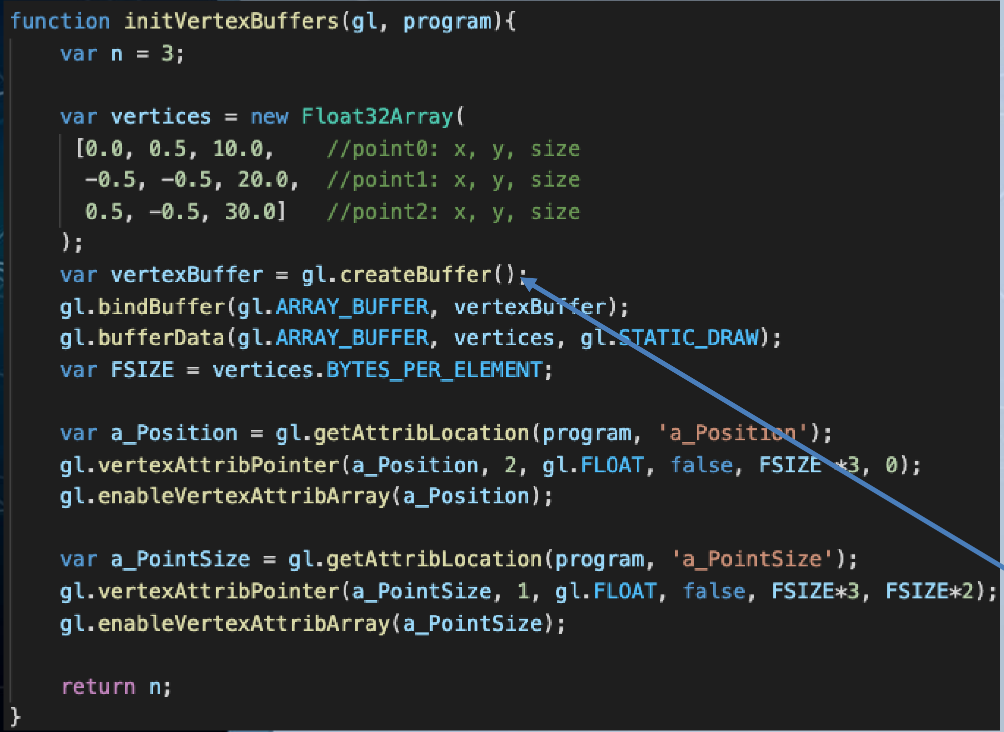
```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 10.0,     //point0: x, y, size
      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```

Number of vertices we will draw

Vertex information in javascript array

Example (Ex02-1)

- WebGL.js: initVertexBuffers()



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    var n = 3;

    var vertices = new Float32Array(
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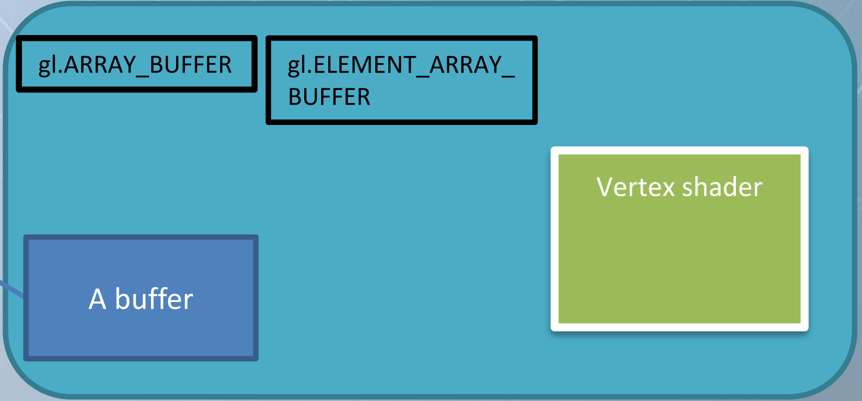
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

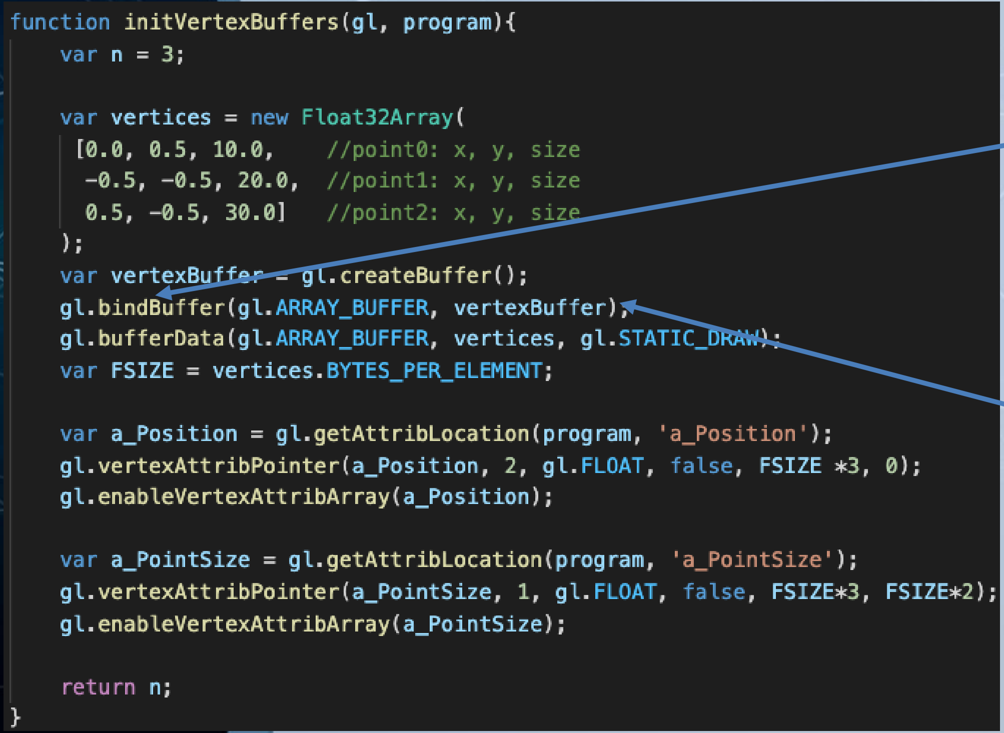
    return n;
}
```

- Check document for gl.createBuffre():
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/createBuffer



Example (Ex02-1)

- WebGL.js: initVertexBuffers()



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      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```
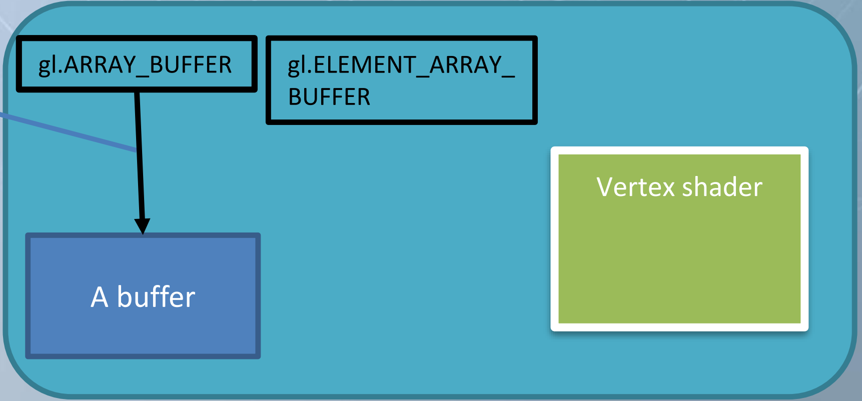

gl.bindBuffer(target, buffer)

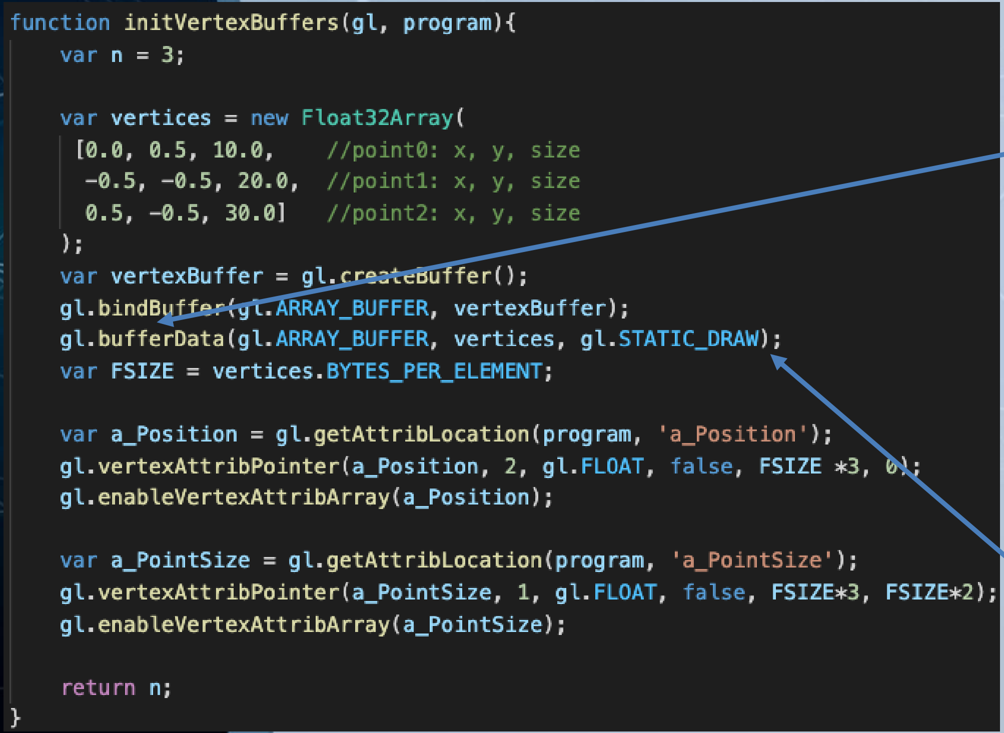
target: gl.ARRAY_BUFFER or gl.ELEMENT_ARRAY_BUFFER

https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/bindBuffer



Example (Ex02-1)

- WebGL.js: initVertexBuffers()



```
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    var vertices = new Float32Array(
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      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```
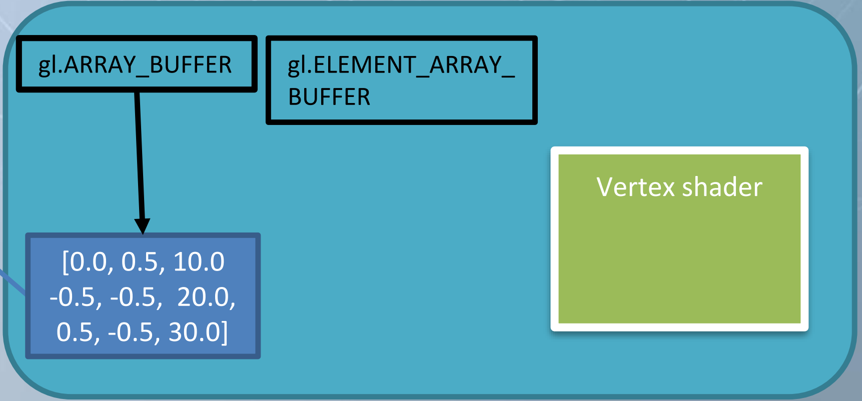

gl.bufferData(target, data, usage)

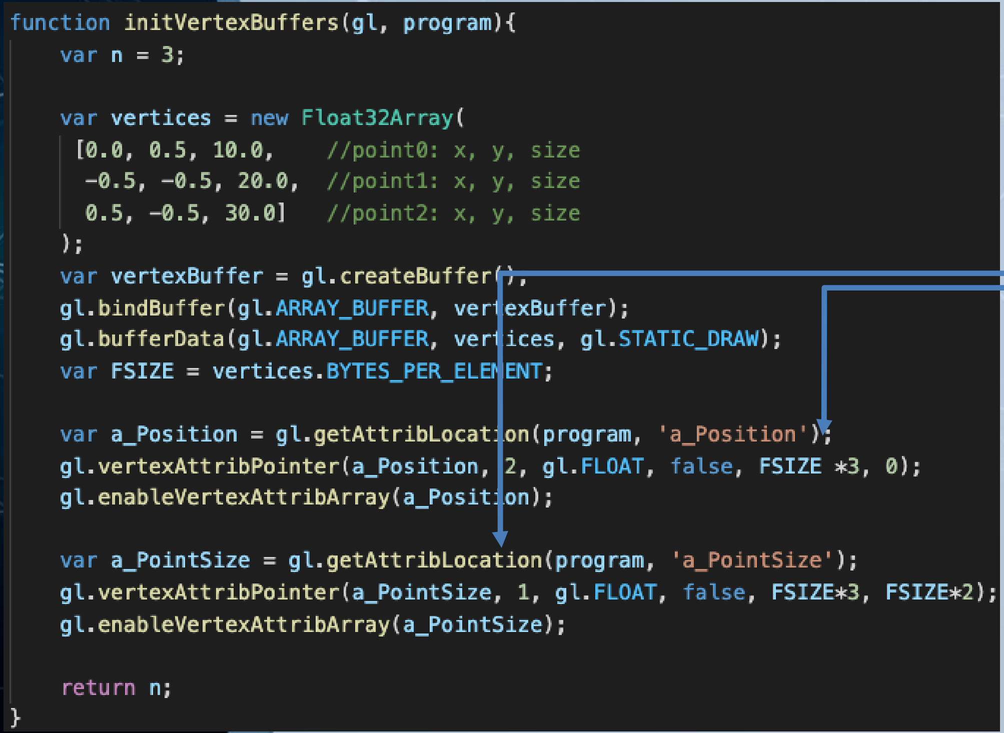
target: gl.ARRAY_BUFFER or gl.ELEMENT_ARRAY_BUFFER
usage: gl.STATIC_DRAW, gl.STREAM_DRAW or gl.DYNAMIC_DRAW (tell webgl how will you use the buffer. This only affects on performance)

https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/bufferData



Example (Ex02-1)

- WebGL.js: initVertexBuffers()

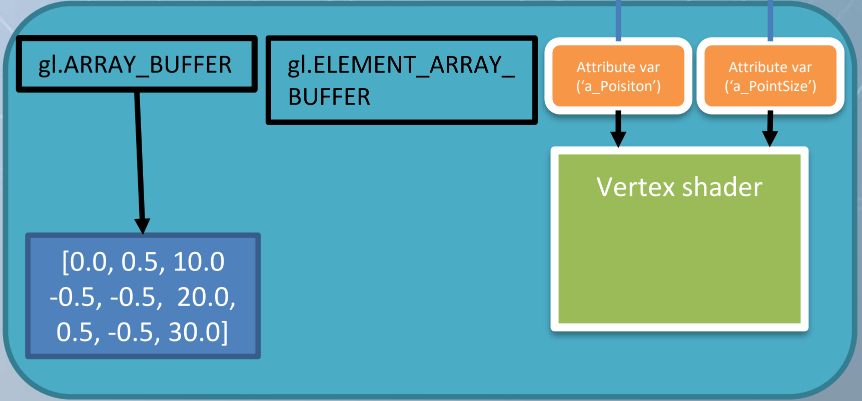


```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 10.0,     //point0: x, y, size
      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```

gl.getAttribLocation(program, varName):

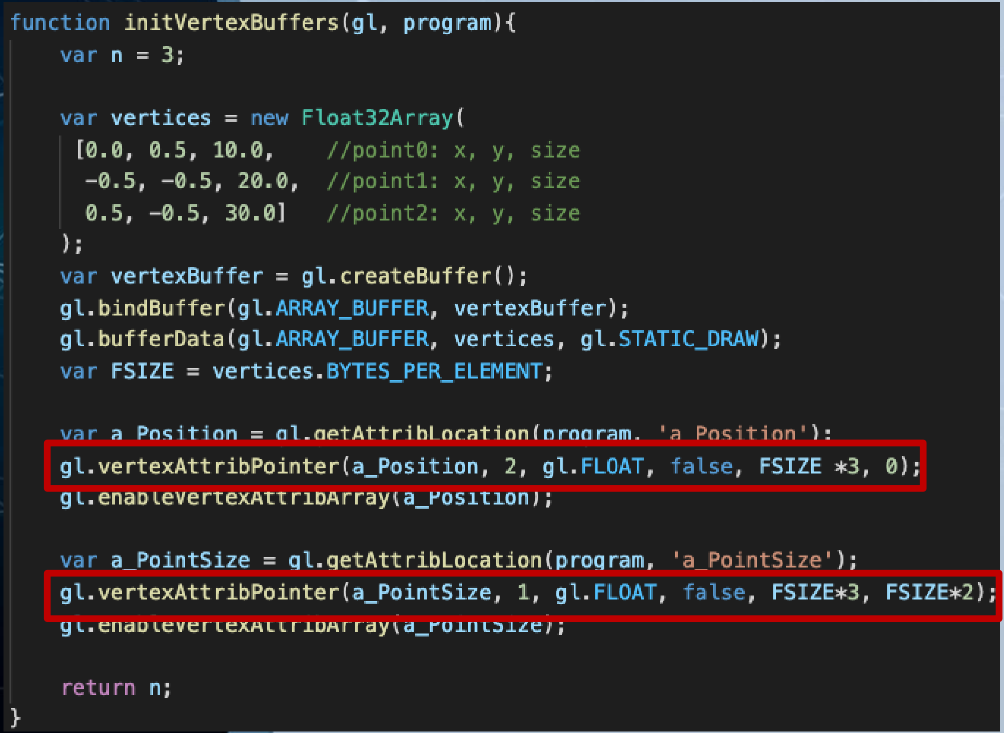
return reference of the attribute variable in vertex shader

https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/getAttribLocation



Example (Ex02-1)

- WebGL.js: initVerte

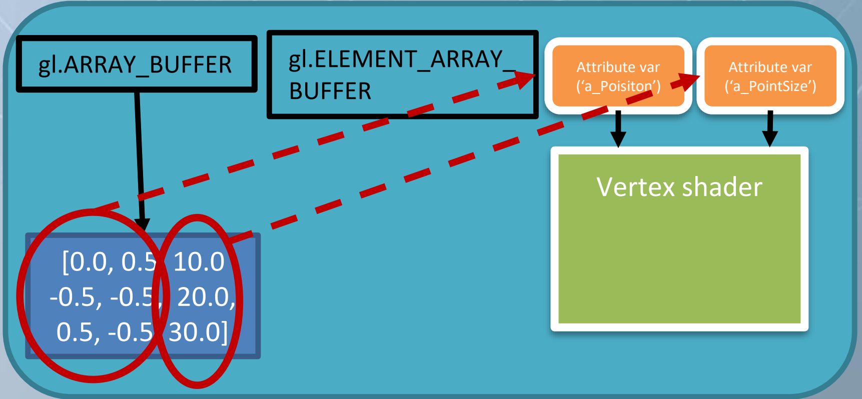


```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 10.0,     //point0: x, y, size
      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```

gl.vertexAttribPointer(location, size, type, normalized, stride, offset)

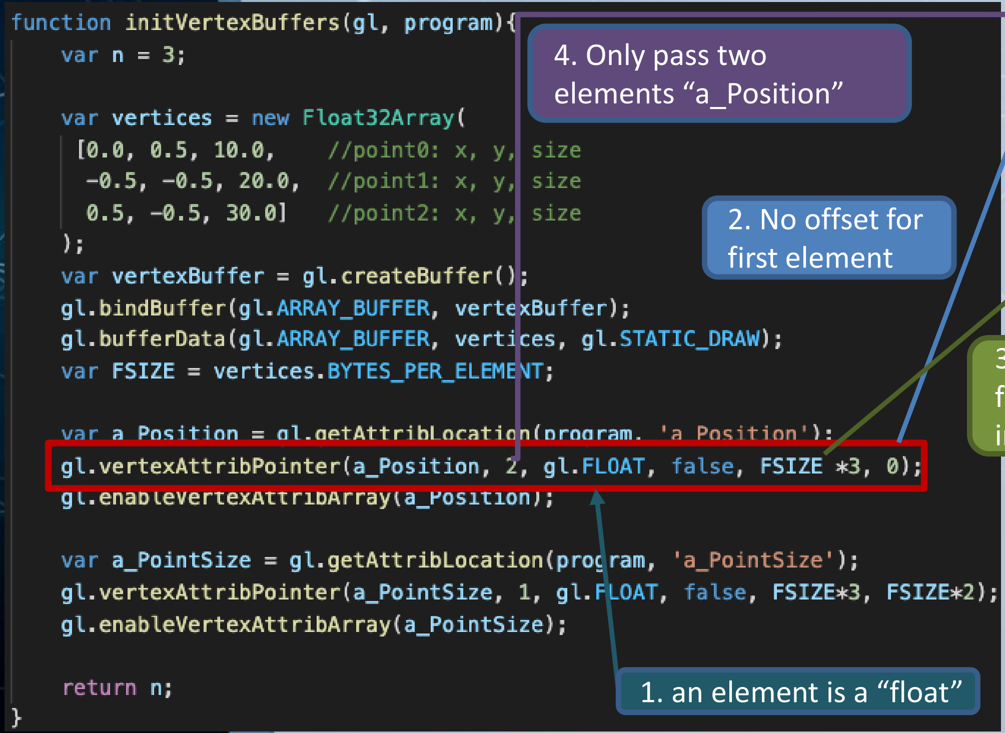
location: where (attribute variable) to pass data
size: number of components per vertex shader attribute
normalize: normalize data to a value range or not
stride: offset in bytes between the beginning of consecutive vertex attributes
offset: offset in bytes of the first component in the vertex attribute array

Document: https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/vertexAttribPointer



Example (Ex02-1)

- WebGL.js: initVertexBuffers()



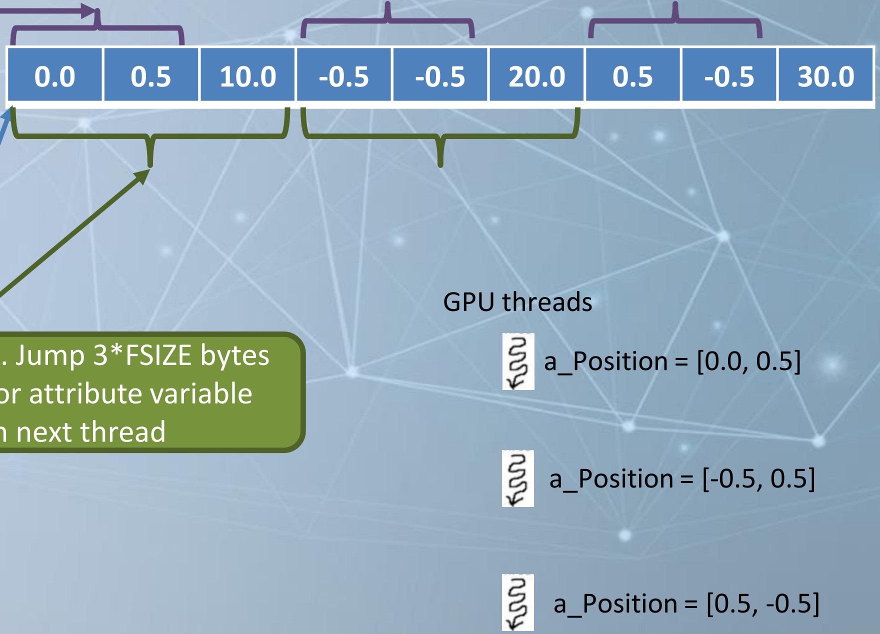
```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 10.0,     //point0: x, y, size
      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```

4. Only pass two elements "a_Position"

2. No offset for first element

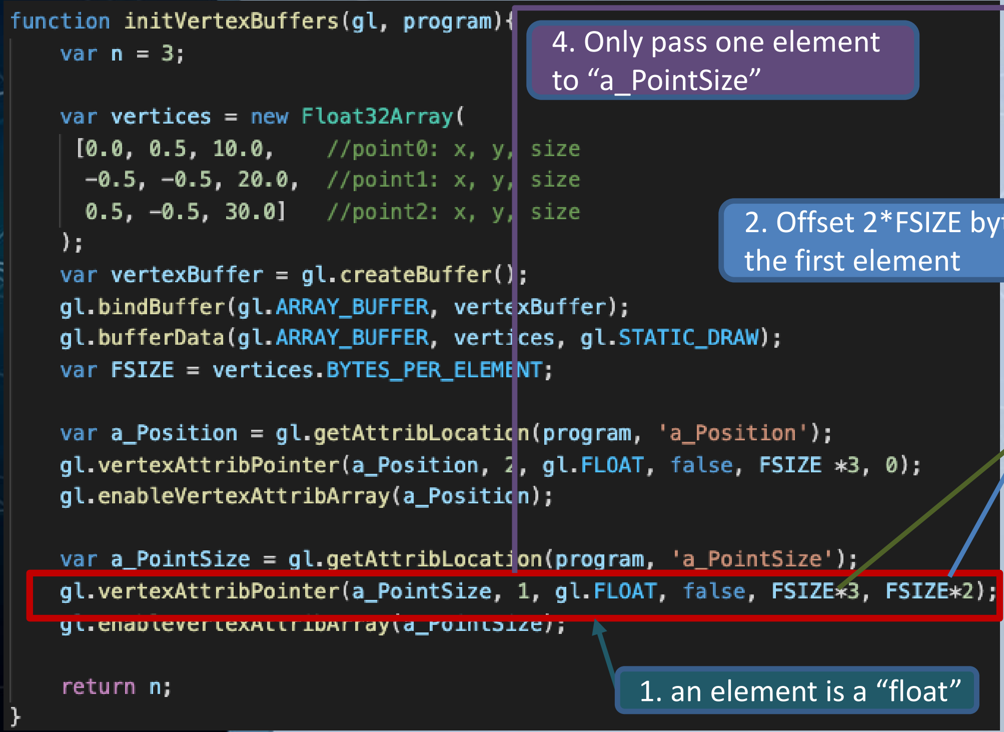
3. Jump 3*FSIZE bytes for attribute variable in next thread

1. an element is a "float"



Example (Ex02-1)

- WebGL.js: initVertexBuffers()



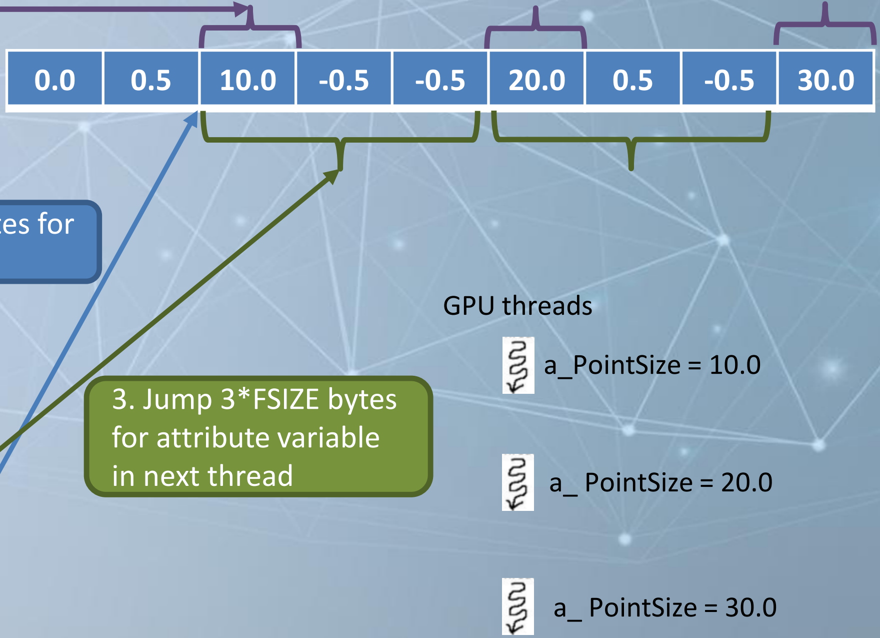
```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 10.0,     //point0: x, y, size
      -0.5, -0.5, 20.0,   //point1: x, y, size
      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```

4. Only pass one element to “a_PointSize”

2. Offset 2*FSIZE bytes for the first element

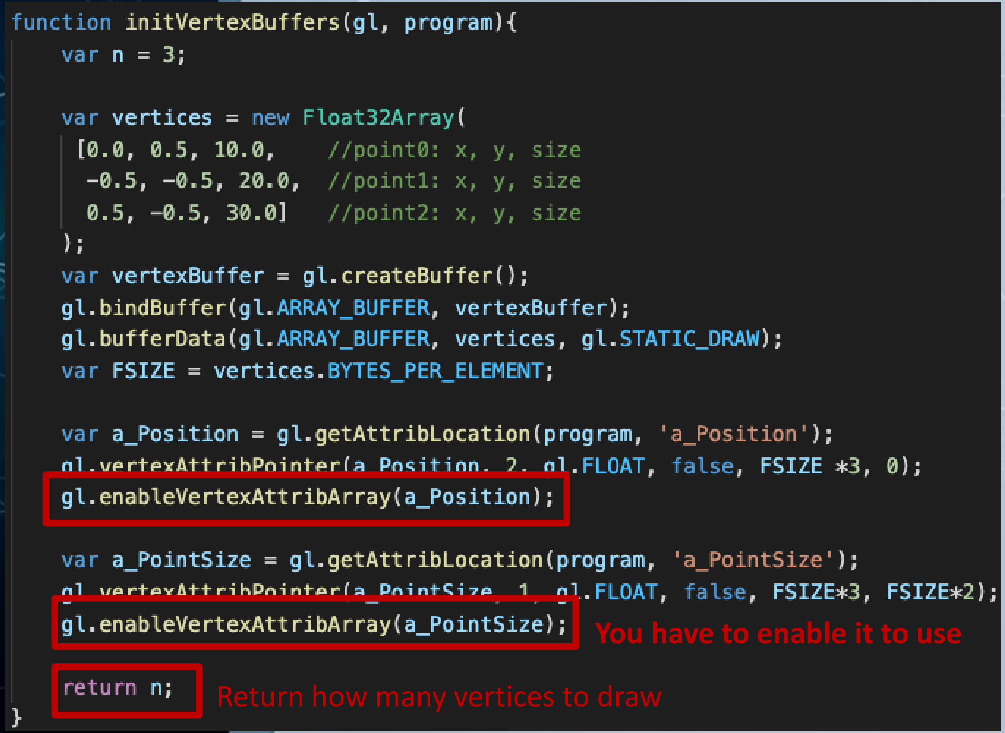
3. Jump 3*FSIZE bytes for attribute variable in next thread

1. an element is a “float”



Example (Ex02-1)

- WebGL.js: initVertexBuffers()



```
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      0.5, -0.5, 30.0]    //point2: x, y, size
    );
    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE *3, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_PointSize = gl.getAttribLocation(program, 'a_PointSize');
    gl.vertexAttribPointer(a_PointSize, 1, gl.FLOAT, false, FSIZE*3, FSIZE*2);
    gl.enableVertexAttribArray(a_PointSize);

    return n;
}
```
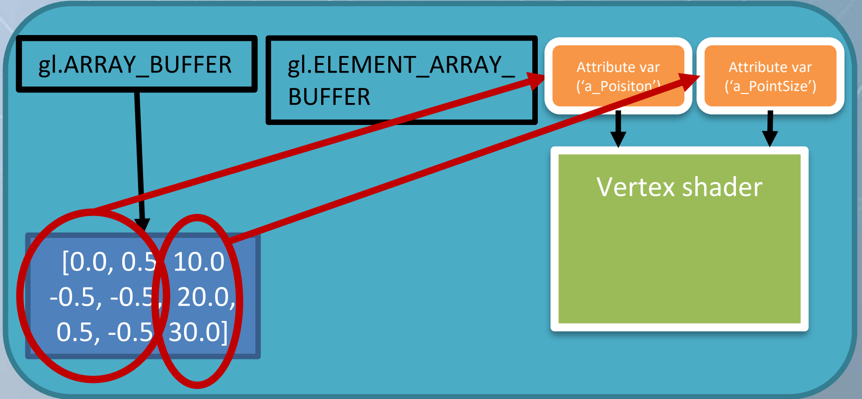

You have to enable it to use

Return how many vertices to draw

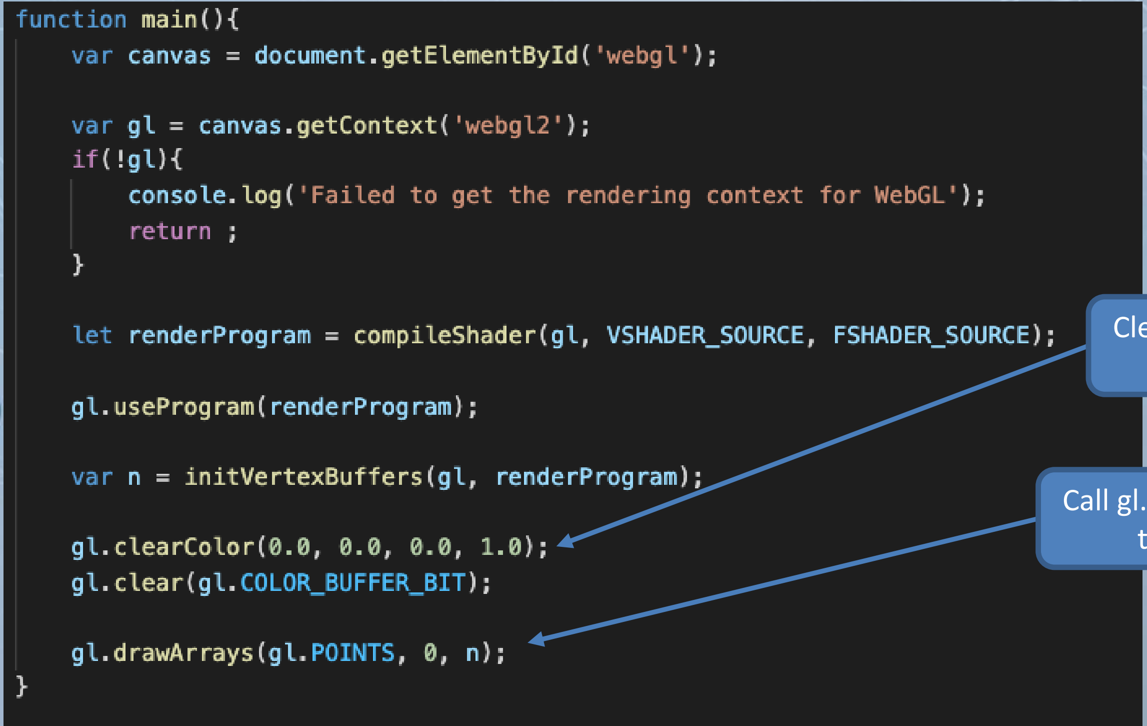
gl.enableVertexAttribArray(index)

Document: https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/enableVertexAttribArray



Example (Ex02-1)

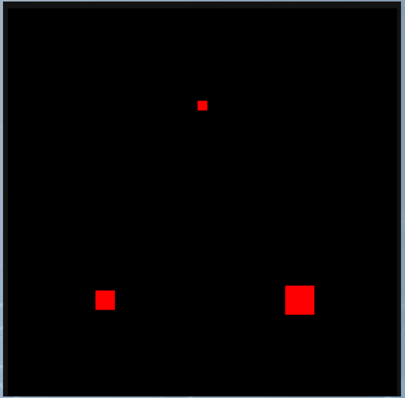
- WebGL.js: main()



```
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);

    var n = initVertexBuffers(gl, renderProgram);

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

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

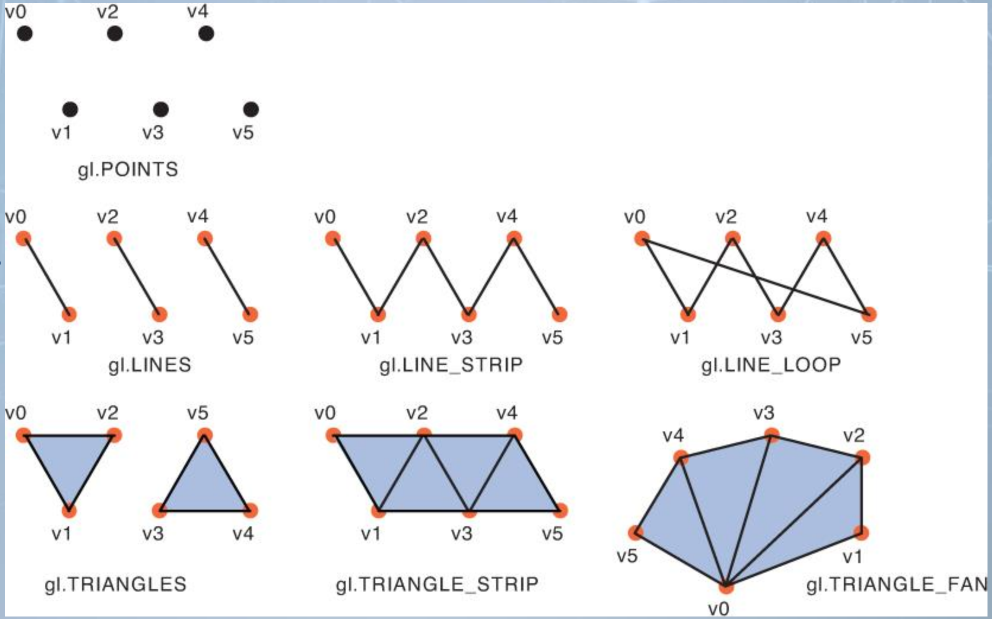
Clear screen by the background color

Call gl.drawArrays() once to run the shaders to draw



gl.drawArrays

- gl.drawArrays(mode, first, count);
  - mode: define the connections between points (make surface)
  - first: the starting index in the array of vector points
  - count: number of index (vertex) to be drawn
- https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/drawArrays



Let‘s Try

- Download Ex02-1 from Moodle
  - Try it on browser

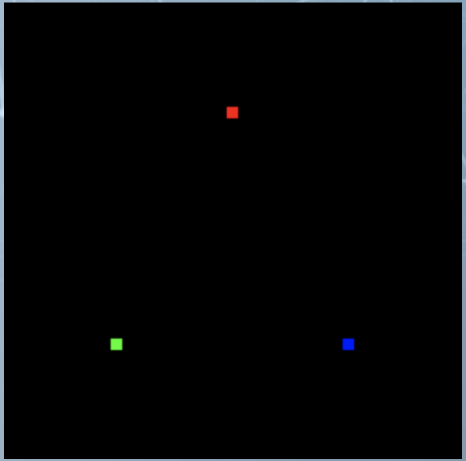
- What you can try
  - If you comment Line88 and Line 93 (gl.enableVertexAttribArray(a_Position); and gl.enableVertexAttribArray(a_PointSize);), can it run?
  - If you change ‘attribute’ to ‘uniform’ in vertex shader, can it run?
  - If you change ‘gl.POINTS’ at Line70 to
    - ‘gl.LINES’
    - ’gl.LINE_STRIP’
    - ‘gl.LINE_LOOP’
    - ‘gl.TRIANGLES’

“varying” in Shaders

- Keyboard for variables
  - “uniform”:
    - the variable in all threads have the same value.
    - Could be both in vertex or fragment shaders
  - ”attribute”
    - The variable in all thread have different values
    - Could be only in vertex shader
  - “varying”
    - Declare “varying” variable in vertex and fragment shaders with the same name
      - the value will be passed **“from vertex shader to fragment shader”**
      - **“interpolation”** will be applied if necessary
    - e.g. varying vec3 color;

Example (Ex:02-2)

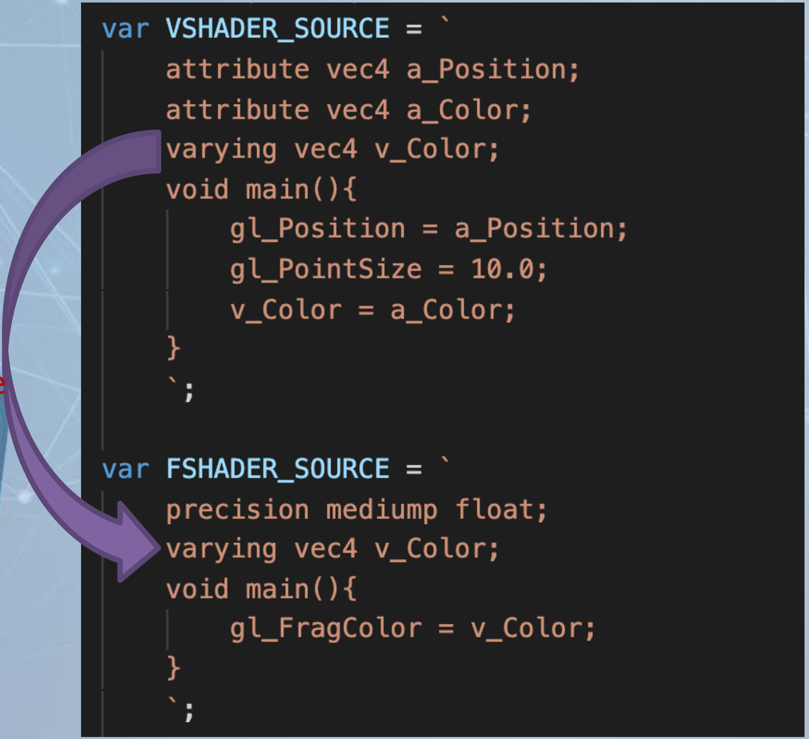
- Draw three points with different colors
  - Pass color information from JavaScript to vertex shader
  - Then, pass the color information from vertex shader to fragment shader using “varying” variable



- Files
  - Index.html
  - WebGL.js

Example (Ex:02-2)

- WebGL.js: shaders

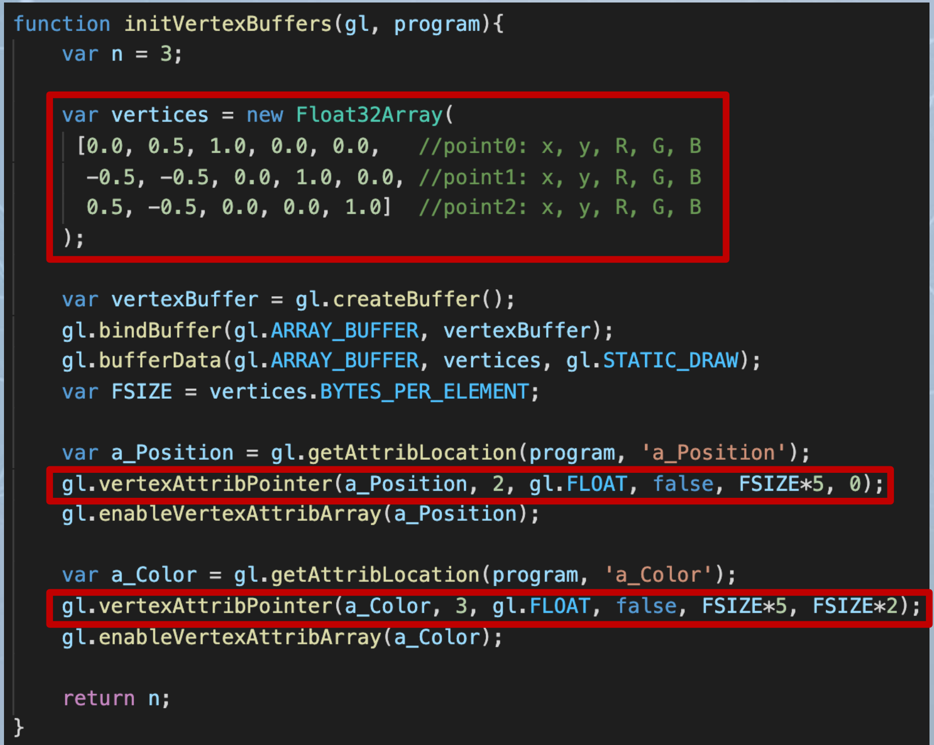


```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute vec4 a_Color;
    varying vec4 v_Color;
    void main(){
        gl_Position = a_Position;
        gl_PointSize = 10.0;
        v_Color = a_Color;
    }
    `;

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

varying variable
with the same name

Example (Ex:02-2)

- WebGL.js: initVertexBuffers()



```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 1.0, 0.0, 0.0,    //point0: x, y, R, G, B
      -0.5, -0.5, 0.0, 1.0, 0.0,  //point1: x, y, R, G, B
      0.5, -0.5, 0.0, 0.0, 1.0]   //point2: x, y, R, G, B
    );

    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE*5, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_Color = gl.getAttribLocation(program, 'a_Color');
    gl.vertexAttribPointer(a_Color, 3, gl.FLOAT, false, FSIZE*5, FSIZE*2);
    gl.enableVertexAttribArray(a_Color);

    return n;
}
```

Let‘s Try

- Download Ex02-2 from Moodle
  - Try it on browser
  - What happen if you change ‘gl.POINTS’ at Line74 to ‘gl.TRIANGLES’

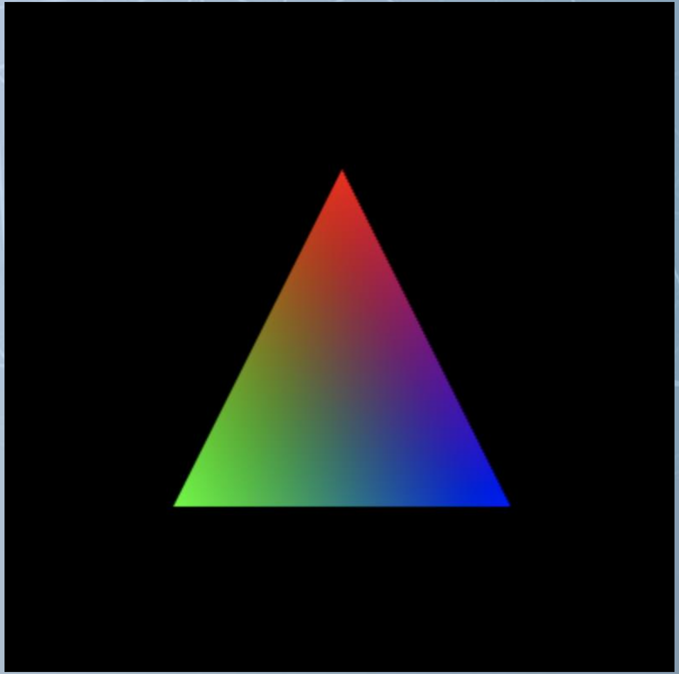
Interpolation

- When vertex shader pass “varying variable” to fragment shader, interpolation is applied within a surface

Example (Ex:02-3)

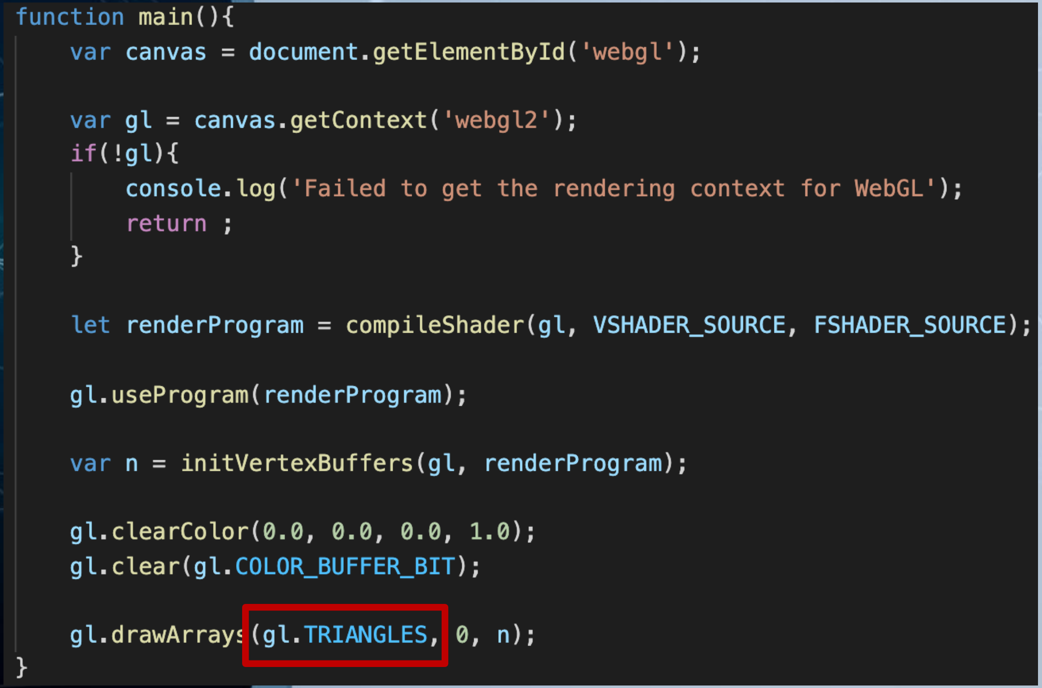
- Draw a triangle with varying color

- Files
  - Index.html
  - WebGL.js

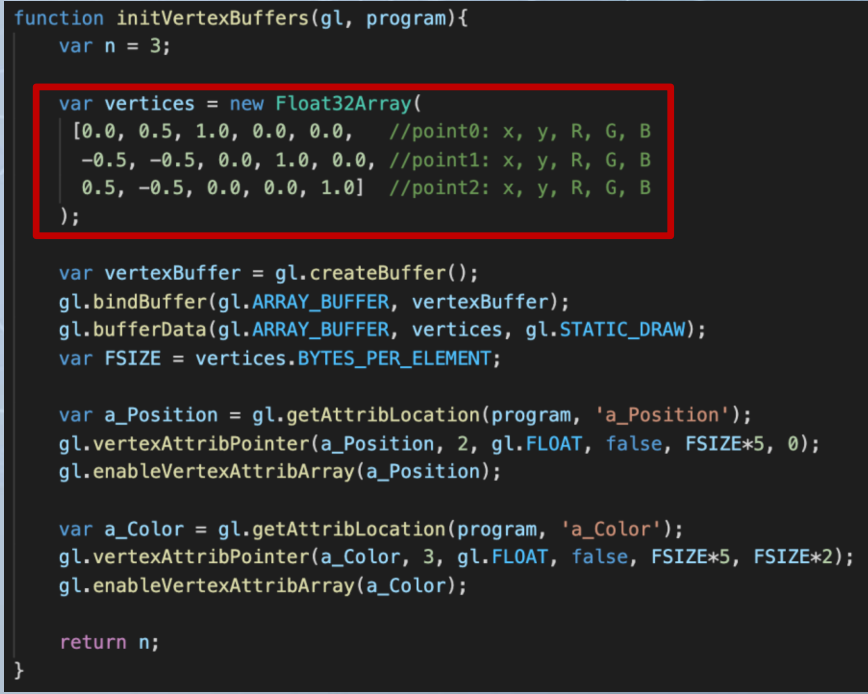


Example (Ex:02-3)

- WebGL.js: main(), initVertexBuffer()



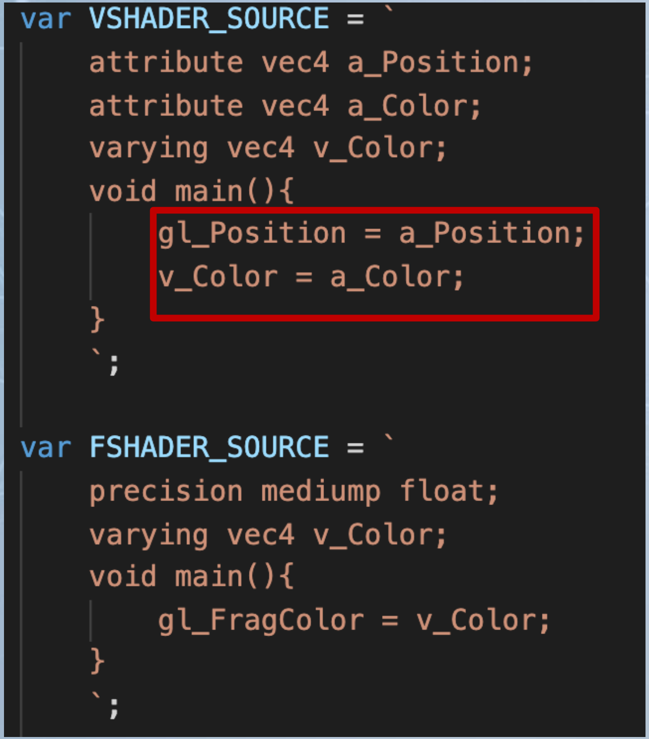
```
function main(){
    var canvas = document.getElementById('webgl');

    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);

    var n = initVertexBuffers(gl, renderProgram);

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

    gl.drawArrays(gl.TRIANGLES, 0, n);
}
```



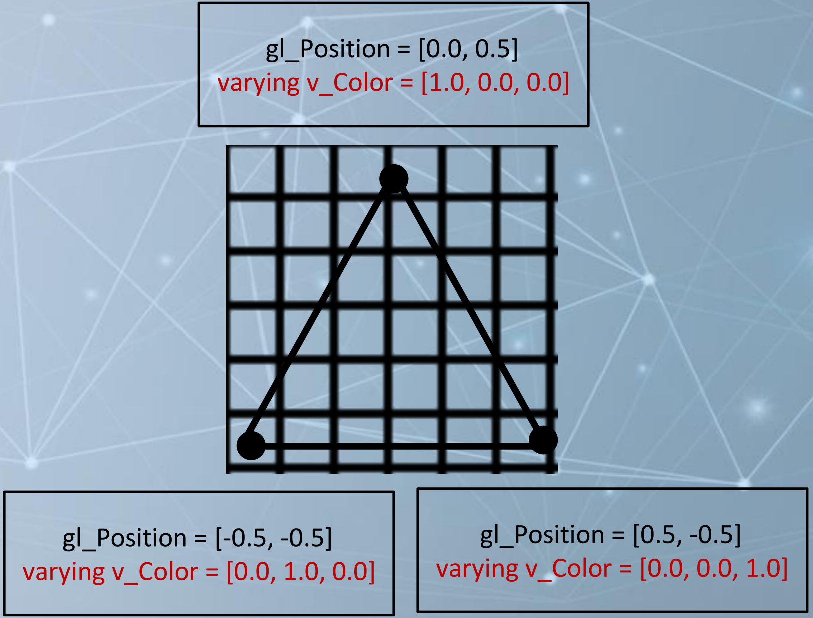
```
function initVertexBuffers(gl, program){
    var n = 3;

    var vertices = new Float32Array(
     [0.0, 0.5, 1.0, 0.0, 0.0,    //point0: x, y, R, G, B
      -0.5, -0.5, 0.0, 1.0, 0.0, //point1: x, y, R, G, B
      0.5, -0.5, 0.0, 0.0, 1.0]  //point2: x, y, R, G, B
    );

    var vertexBuffer = gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);
    gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
    var FSIZE = vertices.BYTES_PER_ELEMENT;

    var a_Position = gl.getAttribLocation(program, 'a_Position');
    gl.vertexAttribPointer(a_Position, 2, gl.FLOAT, false, FSIZE*5, 0);
    gl.enableVertexAttribArray(a_Position);

    var a_Color = gl.getAttribLocation(program, 'a_Color');
    gl.vertexAttribPointer(a_Color, 3, gl.FLOAT, false, FSIZE*5, FSIZE*2);
    gl.enableVertexAttribArray(a_Color);

    return n;
}
```

Example (Ex:02-3)

- WebGL.js: shaders



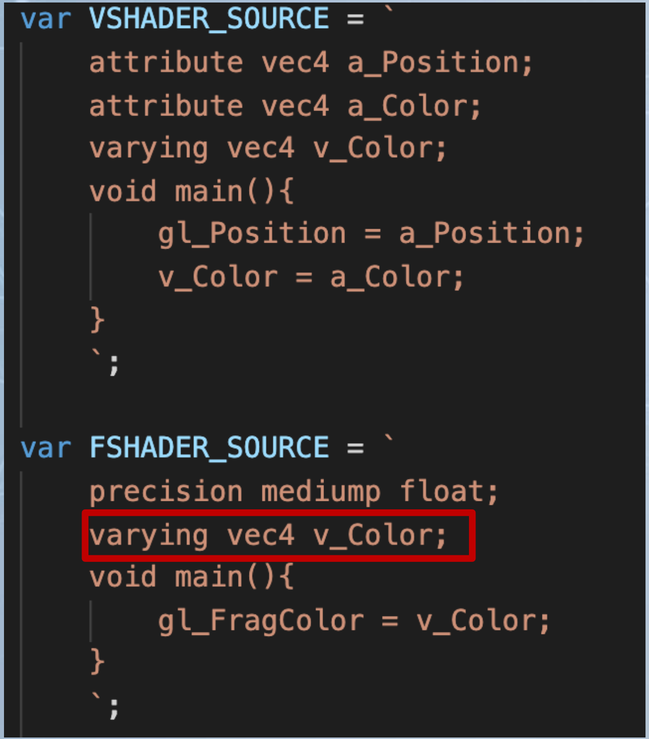
```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute vec4 a_Color;
    varying vec4 v_Color;
    void main(){
        gl_Position = a_Position;
        v_Color = a_Color;
    }
    `;

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


gl_Position = [0.0, 0.5]
varying v_Color = [1.0, 0.0, 0.0]
gl_Position = [-0.5, -0.5]
varying v_Color = [0.0, 1.0, 0.0]
gl_Position = [0.5, -0.5]
varying v_Color = [0.0, 0.0, 1.0]

Example (Ex:02-3)

This interpolation is done by WebGL automatically between vertex and fragment shader

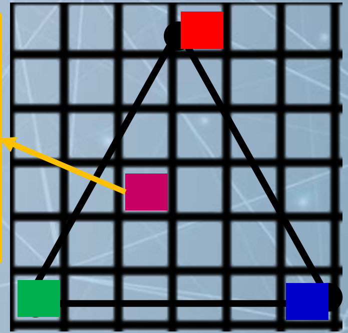
- WebGL.js: shaders



```
var VSHADER_SOURCE = `
    attribute vec4 a_Position;
    attribute vec4 a_Color;
    varying vec4 v_Color;
    void main(){
        gl_Position = a_Position;
        v_Color = a_Color;
    }
    `;

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

gl_Position = [0.0, 0.5]
varying v_Color = [1.0, 0.0, 0.0]

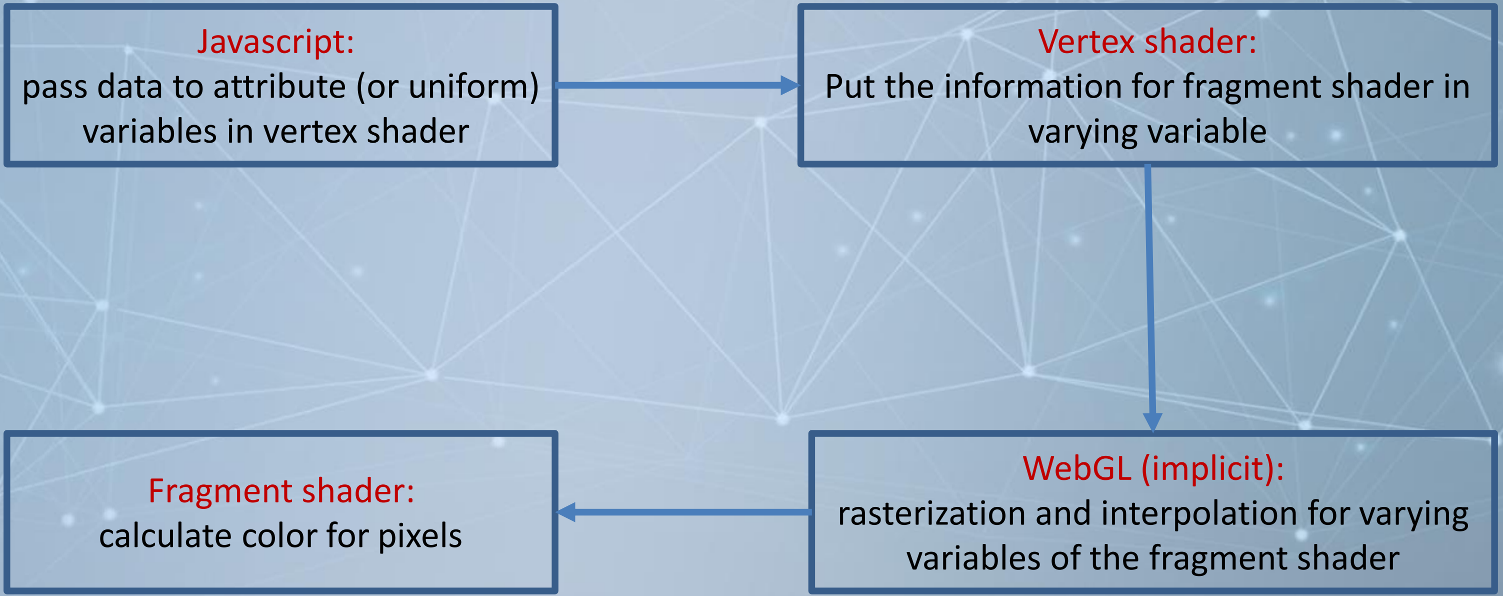
value of v_Color in the thread of the fragment shader of this pixel is automatically calculated by the interpolation from the three vertices's v_Color



gl_Position = [-0.5, -0.5]
varying v_Color = [0.0, 1.0, 0.0]

gl_Position = [0.5, -0.5]
varying v_Color = [0.0, 0.0, 1.0]

Summary of Vertex and Fragment Shader Pipeline



Javascript:
pass data to attribute (or uniform) variables in vertex shader

Vertex shader:
Put the information for fragment shader in varying variable

WebGL (implicit):
rasterization and interpolation for varying variables of the fragment shader

Fragment shader:
calculate color for pixels