WebGL

CS425: Computer Graphics I

Fabio Miranda

https://fmiranda.me

Overview

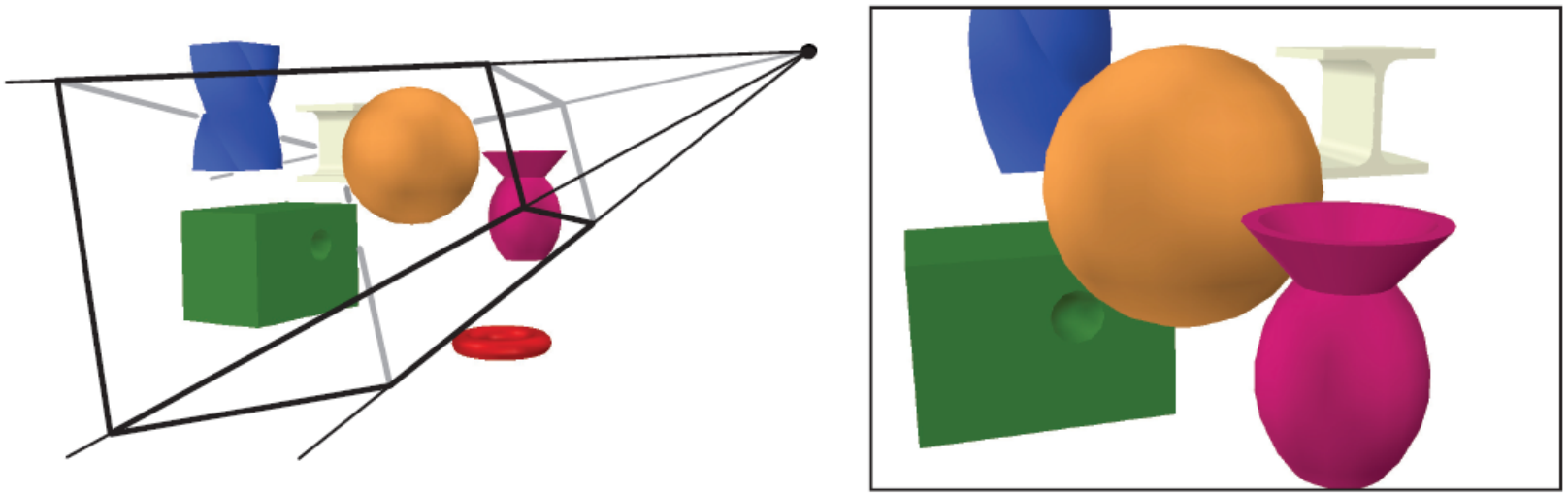
- Introduction to the graphics rendering pipeline
- WebGL
- Shaders

WebGL

- API for rendering graphics within a web browser without plug-ins.
- Hardware accelerated.
- Shader based (no fixed-function API).
  - Fixed function pipeline: set of calls for matrix transformation, lighting.
  - Programmable pipeline: shaders for vertex and fragment processing.
- WebGL 2.0 based on OpenGL ES 3.0.

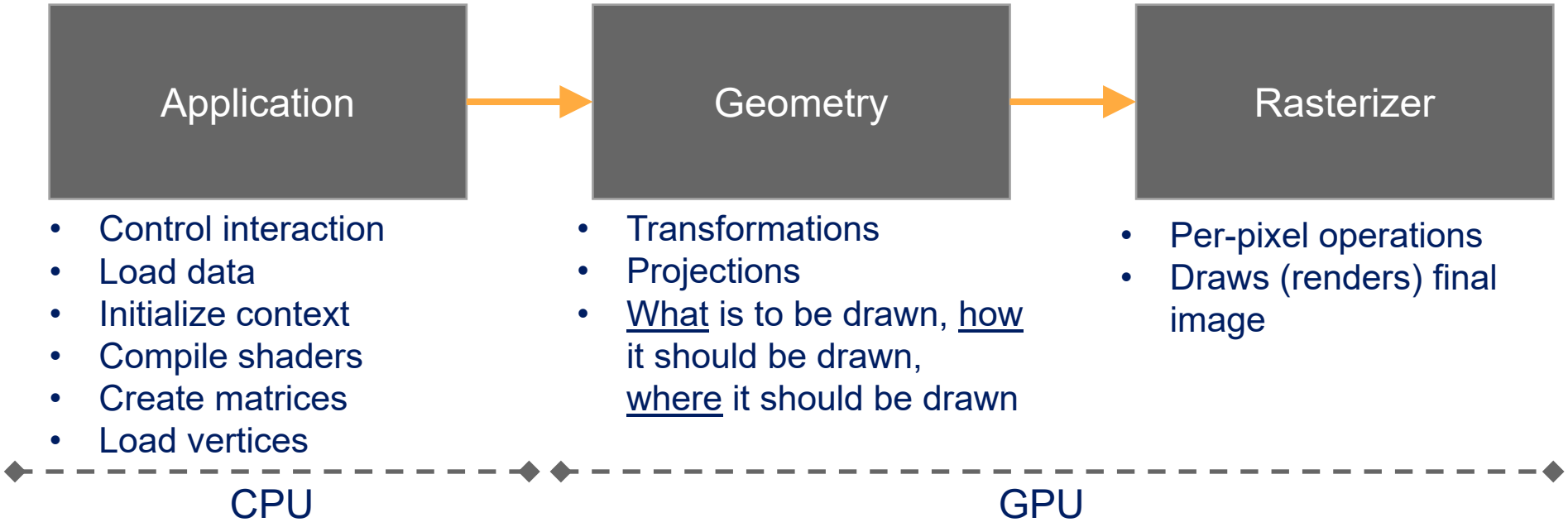
Rendering pipeline

- Graphics system steps to render a scene to a 2D screen.



From: Real-Time Rendering 4th Ed

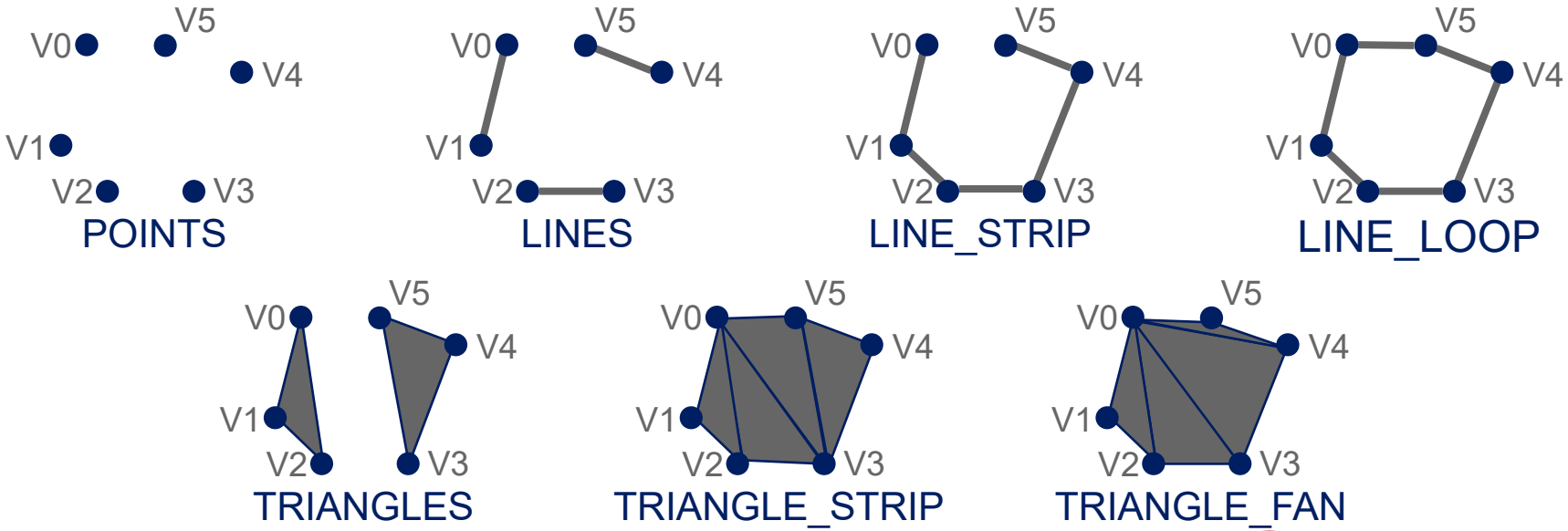
Rendering pipeline



Slowest pipeline stage will determine *rendering speed* (in frames per second).
Simple example: bottleneck stage takes 20 ms to execute. Rendering speed: 1/0.020 = 50 fps.

Application stage

- Executed on the CPU.
- Sends the geometry to be rendered to the geometry stage.
  - Primitives: points, lines, triangles.



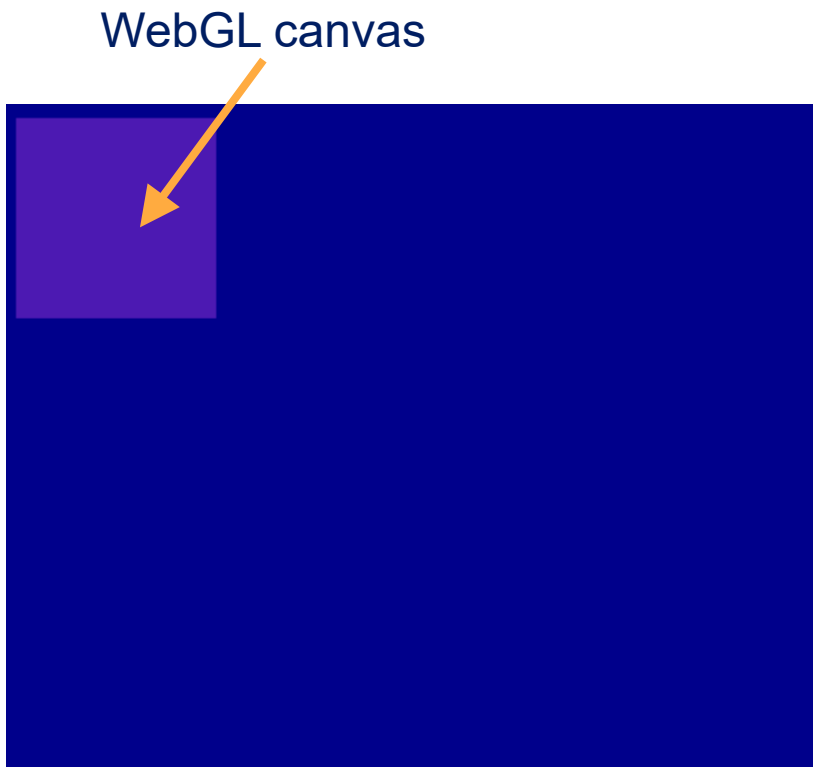
Application stage and WebGL

- Important: WebGL is a **state machine**, functions set or retrieve some state in WebGL. Information necessary for rendering is stored in the WebGL context.
- Creates canvas element.
- Loads and initializes shaders (WebGLShader) and programs (WebGLProgram).
- Loads geometries (attributes and buffers).
- Handles rendering loop.

WebGL canvas

```
<html lang="en">
<style>
    body { background-color: darkblue;}
    #glcanvas { width: 100px; height: 100px;}
</style>
<script src="main.js" type="module"></script>
<body>
    <canvas id="glcanvas"></canvas>
</body>
</html>
```

```
function main() {
    var canvas = document.querySelector("#glcanvas");
    gl = canvas.getContext("webgl2");
    gl.clearColor(0.3, 0.1, 0.7, 1.0);
    gl.clear(gl.COLOR_BUFFER_BIT);
}
window.onload = main;
```



Loading shaders

- Add GLSL shaders to external files and import them:

```
import vertexShaderSrc from './vertex.glsl.js';
import fragmentShaderSrc from './fragment.glsl.js'
```

- Simple vertex shader and fragment shaders:

```
export default `#version 300 es

in vec4 position;

void main() {
  gl_Position = position;
}
`;
```

```
export default `#version 300 es
precision highp float;
out vec4 outColor;

void main() {
    outColor = vec4(1, 0, 0, 1);
}
`;
```

Loading shaders

- Vertex shader creation:

```
var vertexShader = gl.createShader(gl.VERTEX_SHADER);

gl.shaderSource(vertexShader, vertexShaderSrc);
gl.compileShader(vertexShader);

if (!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS) ) {
    var info = gl.getShaderInfoLog(vertexShader);
    console.log('Could not compile WebGL program:' + info);
}
```

Loading shaders

- Create a program - combination of two compile WebGL shaders (vertex and fragment):

```
var program = gl.createProgram();

gl.attachShader(program, vertexShader);
gl.attachShader(program, fragmentShader);

gl.linkProgram(program);

if (!gl.getProgramParameter(program, gl.LINK_STATUS) ) {
    var info = gl.getProgramInfoLog(program);
    console.log('Could not compile WebGL program:' + info);
}
```

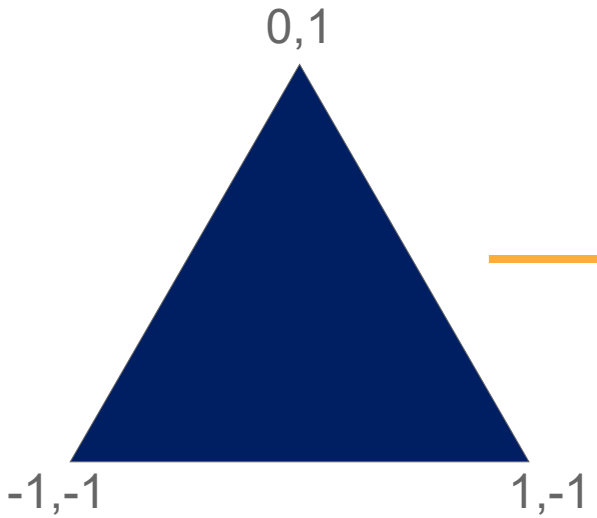
Sending data to the GPU

- OpenGL objects are the structures responsible for *transmitting* data to and from the GPU.
- Several types of objects:
  - Buffers: arrays with data to send to the GPU.
    - Vertex positions, normals, indices, texture coordinates, colors.
  - Vertex array object: describes how vertex attributes are stored in the buffers.
  - Many others: uniforms, textures, varyings.

Sending data to the GPU

- Initialization:
  1. Create vertex buffer objects to store vertex data.
  2. Create a vertex array object to specify how this data can be accessed by the vertex shader.
- Every rendering frame:
  1. Use shader programs.
  2. Bind buffers.
  3. Draw arrays.

Buffer




```
var vertices2D = [
    0.0,  1.0, 0.0,
   -1.0, -1.0, 0.0,
    1.0, -1.0  0.0,

];
```

1. Create buffer object
2. Bind resource to binding point
3. Send strongly typed data to binded buffer

Creating a buffer to store the triangle:

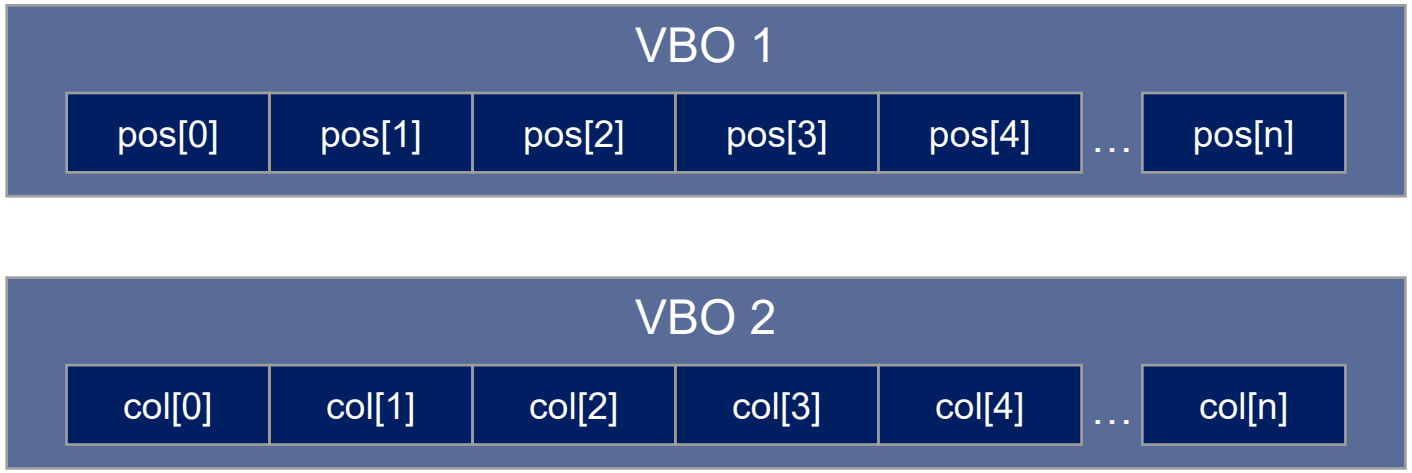
```
var positionBuffer = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, positionBuffer);
gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertices2D), gl.STATIC_DRAW);
```

Vertex array object

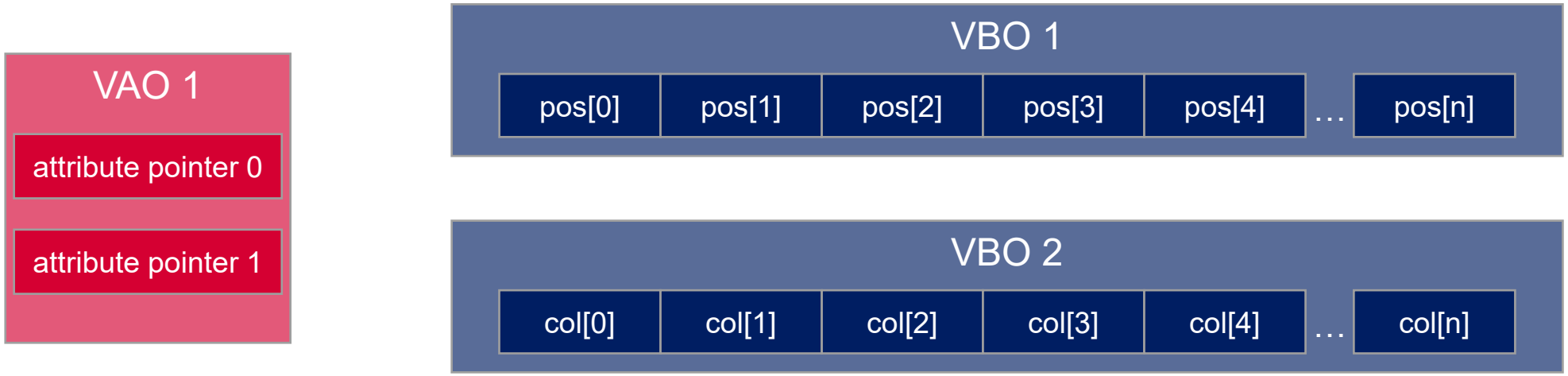
- VAO specifies layout of how data will be accessed by vertex shader.

Vertex array object

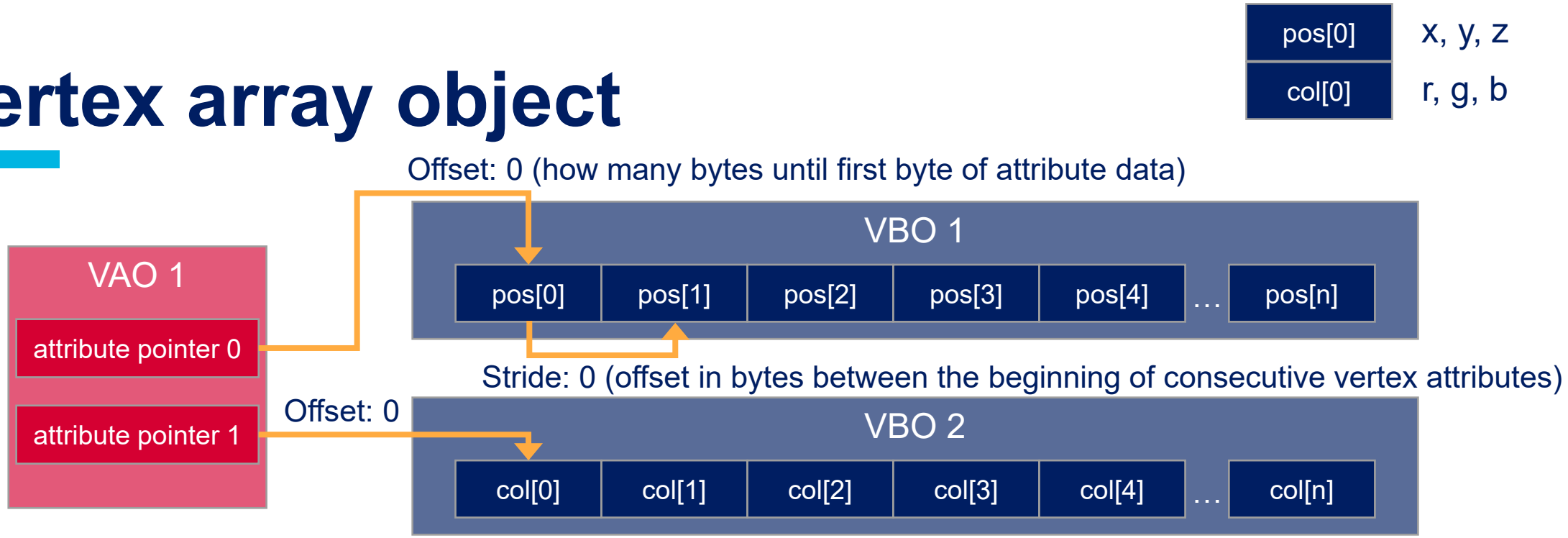
Vertex array object



Vertex array object



Vertex array object



Vertex array object

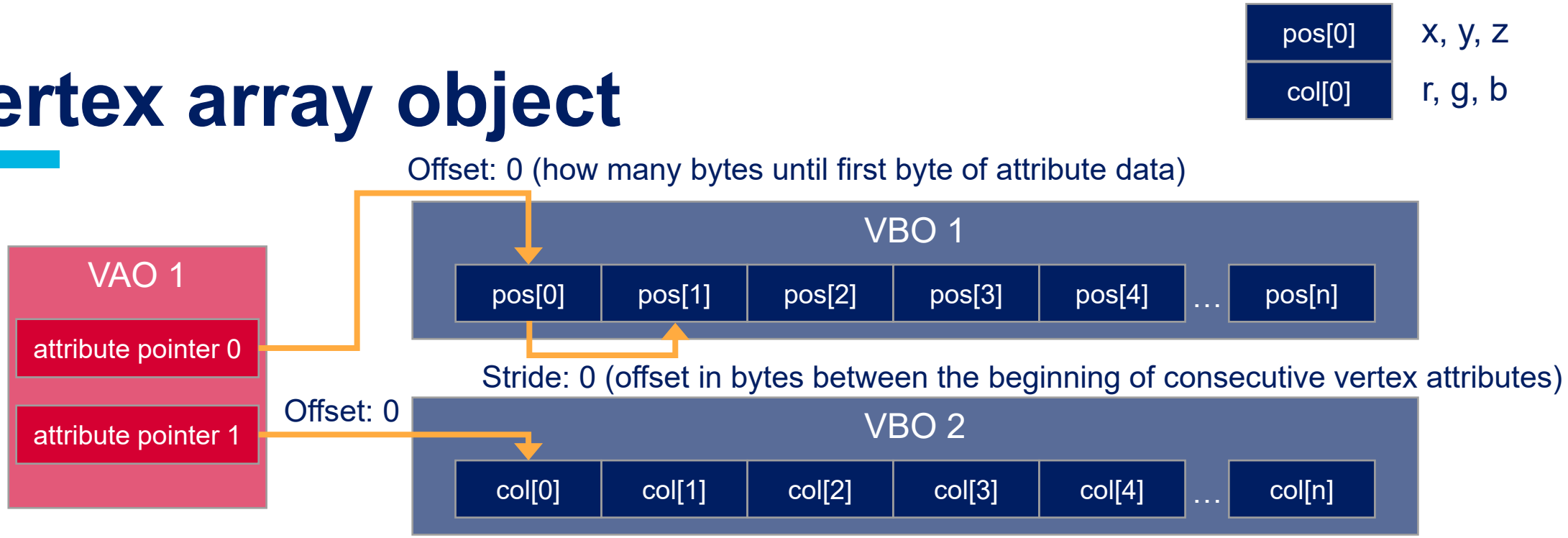
- VAO specifies layout of how data will be accessed by vertex shader.
- Location of the attribute in the program we created:

```
var  posAttribLoc = gl.getAttribLocation(program, "position");
```

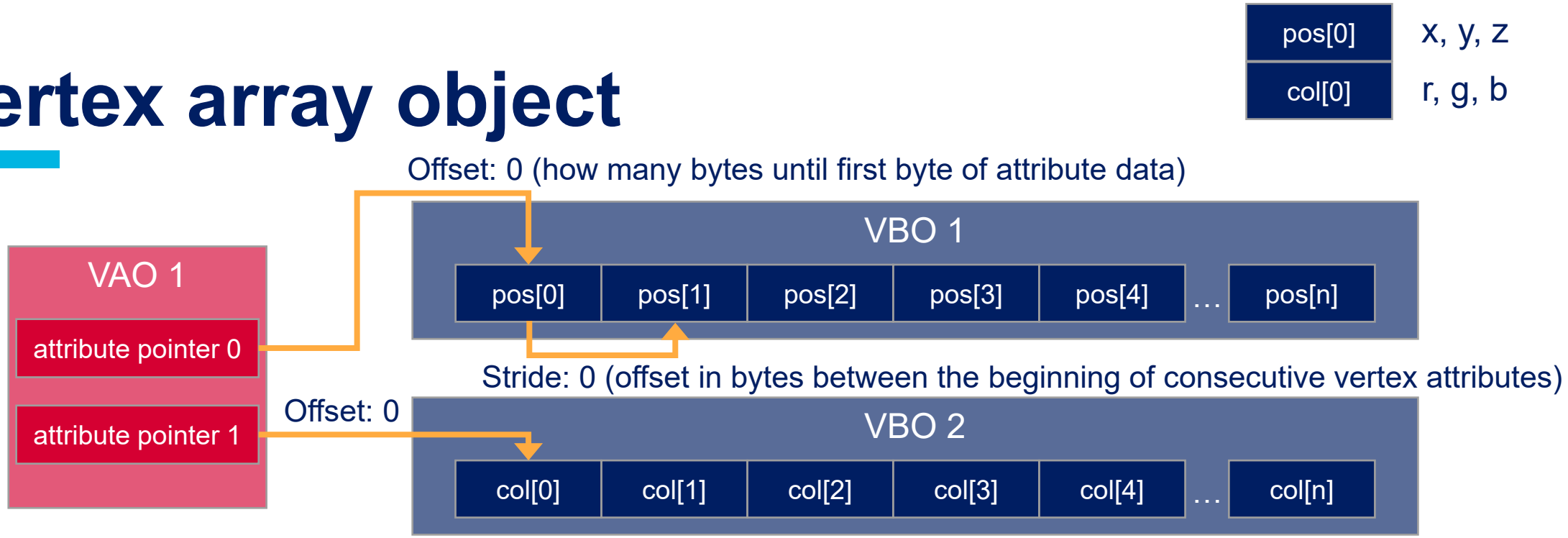
- Creating a vertex array object so shader can access buffer:

```
var vao = gl.createVertexArray();
gl.bindVertexArray(vao);
gl.enableVertexAttribArray(posAttribLoc);
var size = 3;          // 3 components
var type = gl.FLOAT; // 32bit floats
var normalization = false;
var stride = 0; var offset = 0;
gl.bindBuffer(gl.ARRAY_BUFFER, buffer);
gl.vertexAttribPointer(posAttribLoc, size, type, normalized, stride, offset);
```

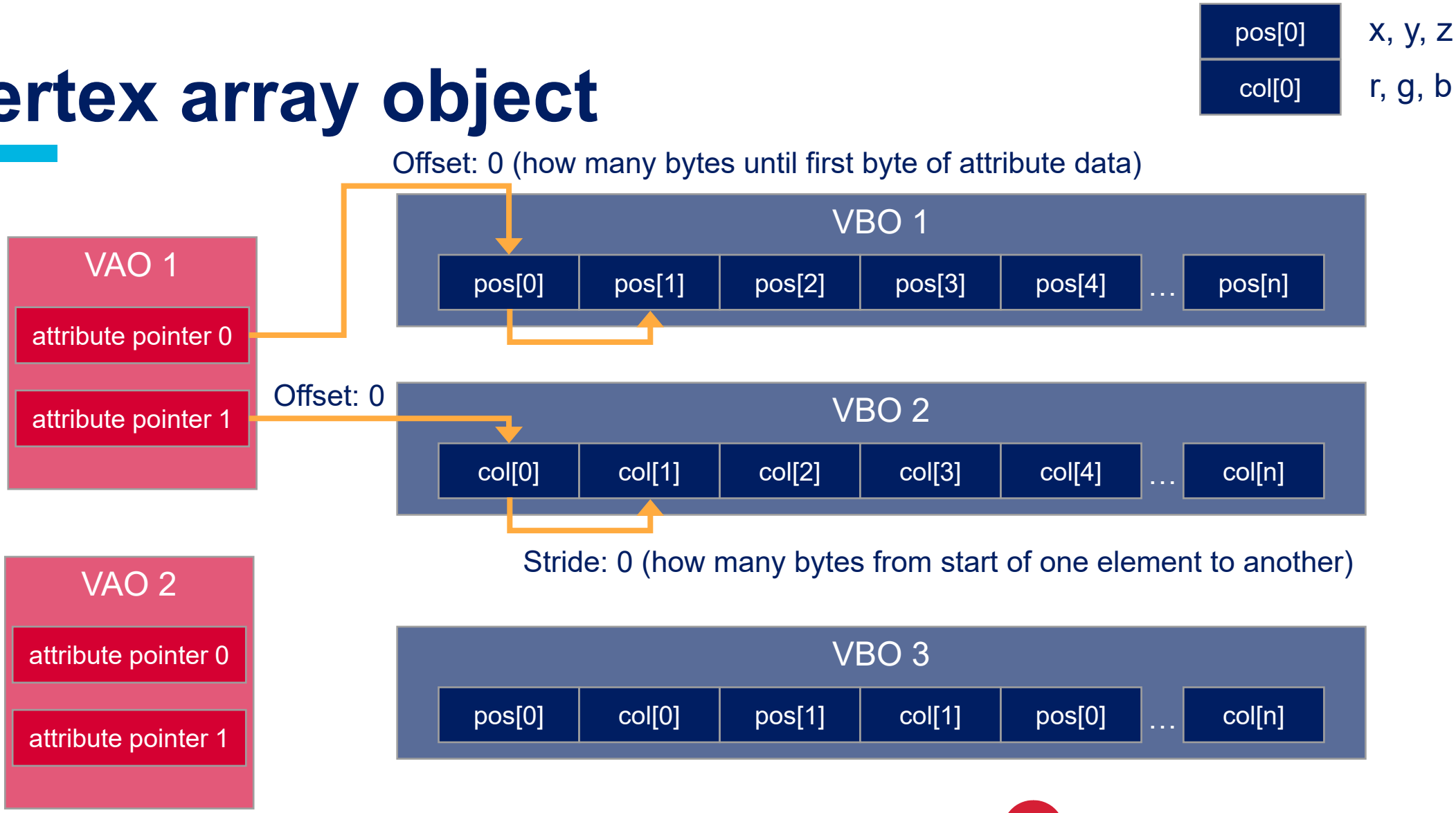
Vertex array object



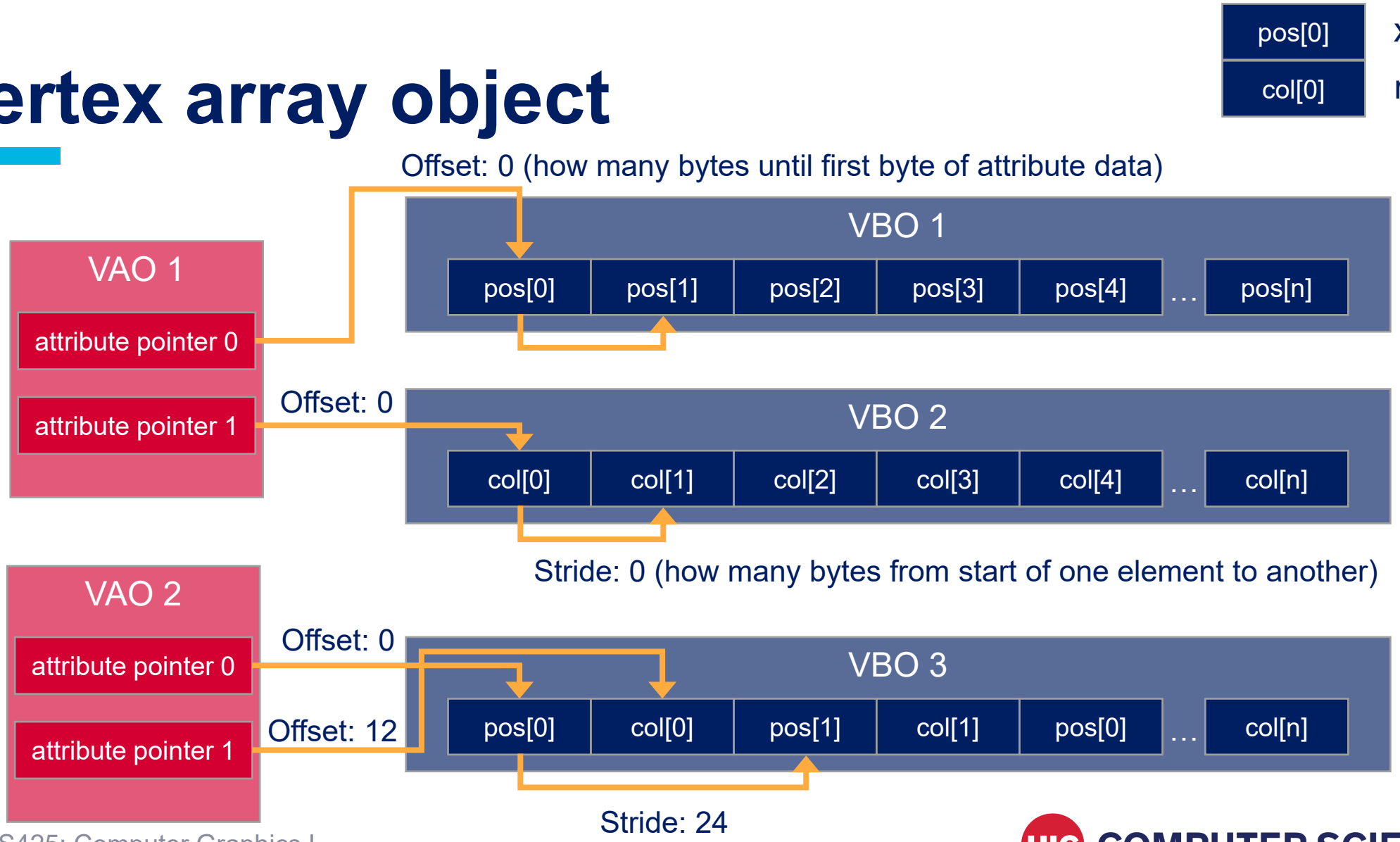
Vertex array object



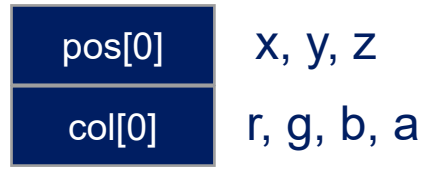
Vertex array object

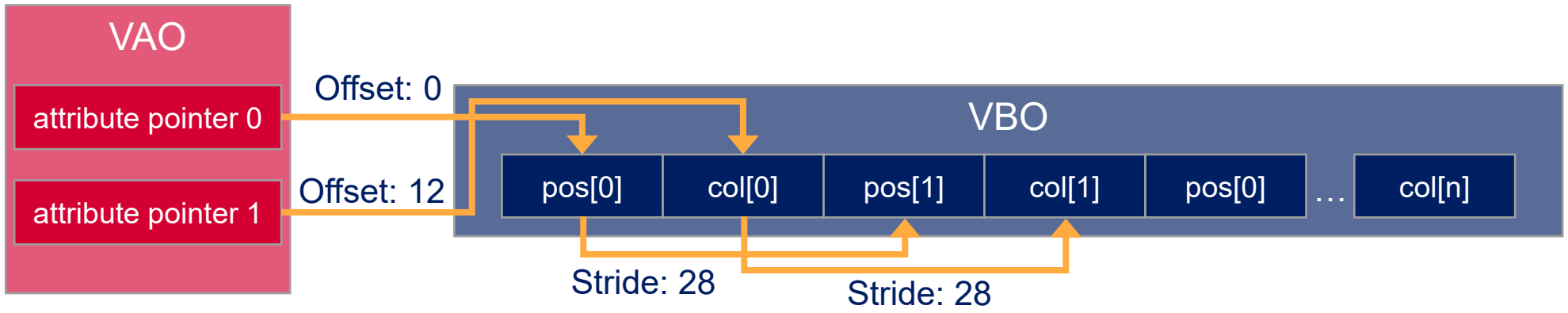


Vertex array object



Vertex array object





Uniform variables

- Uniforms are variables that can be sent to the shaders from the application.
- Shader:

```
uniform vec4 uColor;
```

- Creating uniform:

```
var uniformLoc = gl.getUniformLocation(program, 'uColor');
```

- Send data to shader (per render call):

```
gl.uniform4v(uniformLoc, new Float32Array([0.0,0.0,1.0,1.0]));
```

Rendering frame

- This will be executed every time we want to render.
- Set viewport (maps clip space to screen space):

```
gl.viewport(0, 0, gl.canvas.width, gl.canvas.height);
```

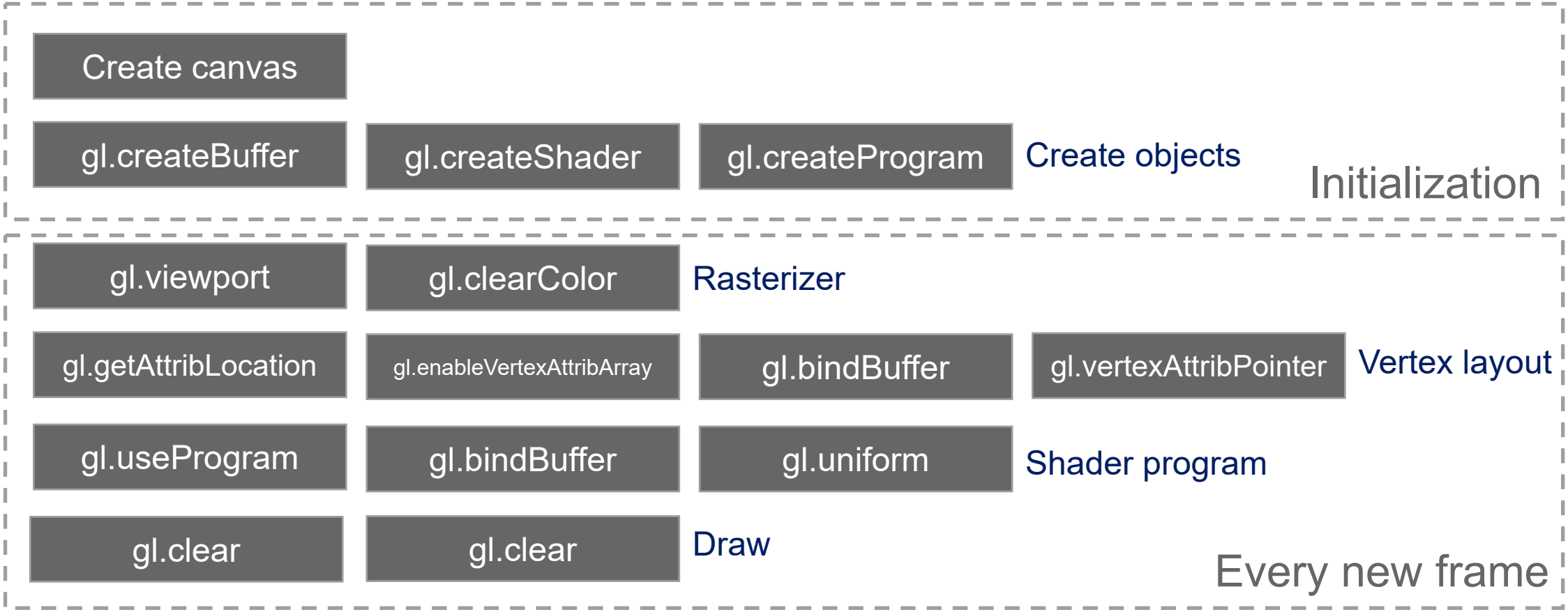
- Clear the canvas:

```
gl.clearColor(0, 0, 0, 0);
gl.clear(gl.COLOR_BUFFER_BIT);
```

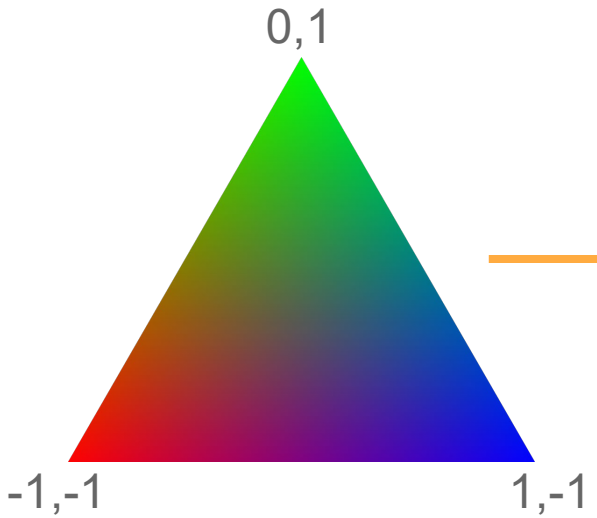
- Use program, bind VAO and draw arrays:

```
gl.useProgram(program);
gl.bindVertexArray(vao);
var primitiveType = gl.TRIANGLES;
var count = 3;
gl.drawArrays(primitiveType, 0, count);
```

Overview


Create canvas
gl.createBuffer
gl.createShader
gl.createProgram
Create objects
Initialization
gl.viewport
gl.clearColor
Rasterizer
gl.getAttribLocation
gl.enableVertexAttribArray
gl.bindBuffer
gl.vertexAttribPointer
Vertex layout
gl.useProgram
gl.bindBuffer
gl.uniform
Shader program
gl.clear
gl.clear
Draw
Every new frame

Simple example




```
var vertices = [
     0.0,  1.0, 0.0,
    -1.0, -1.0, 0.0,
     1.0, -1.0, 0.0
];
```

```
var colors = [
    0.0, 1.0, 0.0, 1.0,
    1.0, 0.0, 0.0, 1.0,
    0.0, 0.0, 1.0, 1.0,
];
```

- Initialization:
  1. Create shaders and program.
  2. Create buffers.
  3. Create VAO.
- Rendering:
  1. Use program.
  2. Bind VAO.
  3. Draw arrays.

Simple example: Create shader

```
function createShader(type, source) {
    var shader = gl.createShader(type);

    gl.shaderSource(shader, source);
    gl.compileShader(shader);

    if (!gl.getShaderParameter(shader, gl.COMPILE_STATUS) ) {
        var info = gl.getShaderInfoLog(shader);
        console.log('Could not compile WebGL program:' + info);
    }

    return shader;
}
```

Simple example: Create program

```
function createProgram(vertexShader, fragmentShader) {
    var program = gl.createProgram();

    gl.attachShader(program, vertexShader);
    gl.attachShader(program, fragmentShader);
    gl.linkProgram(program);
    if (!gl.getProgramParameter(program, gl.LINK_STATUS) ) {
        var info = gl.getProgramInfoLog(program);
        console.log('Could not compile WebGL program:' + info);
    }

    return program;
}
```

Simple example: Create buffer and VAO

```
function createBuffer(vertices) {
    var buffer= gl.createBuffer();
    gl.bindBuffer(gl.ARRAY_BUFFER,buffer);
    gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertices), gl.STATIC_DRAW);

    return buffer;
}
```

Simple example: Create buffer and VAO

```
function createVAO(posAttribLoc, colorAttribLoc) {
    var vao = gl.createVertexArray();

    gl.bindVertexArray(vao);
    gl.enableVertexAttribArray(posAttribLoc);
    var size = 3;
    var type = gl.FLOAT;
    gl.bindBuffer(gl.ARRAY_BUFFER, posBuffer);
    gl.vertexAttribPointer(posAttribLoc, size, type, false, 0, 0);

    gl.enableVertexAttribArray(colorAttribLoc);
    var size = 4;
    var type = gl.FLOAT;
    gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);
    gl.vertexAttribPointer(colorAttribLoc, size, type, false, 0, 0);

    return vao;
}
```

Simple example: shaders

```
export default `#version 300 es

in vec4 position;
in vec4 color;

out vec4 vColor;

void main() {
  vColor = color;
  gl_Position = position;
}
`;
```

```
export default `#version 300 es

precision highp float;


in vec4 vColor;
out vec4 outColor;

void main() {
    outColor = vColor;
}
`;
```

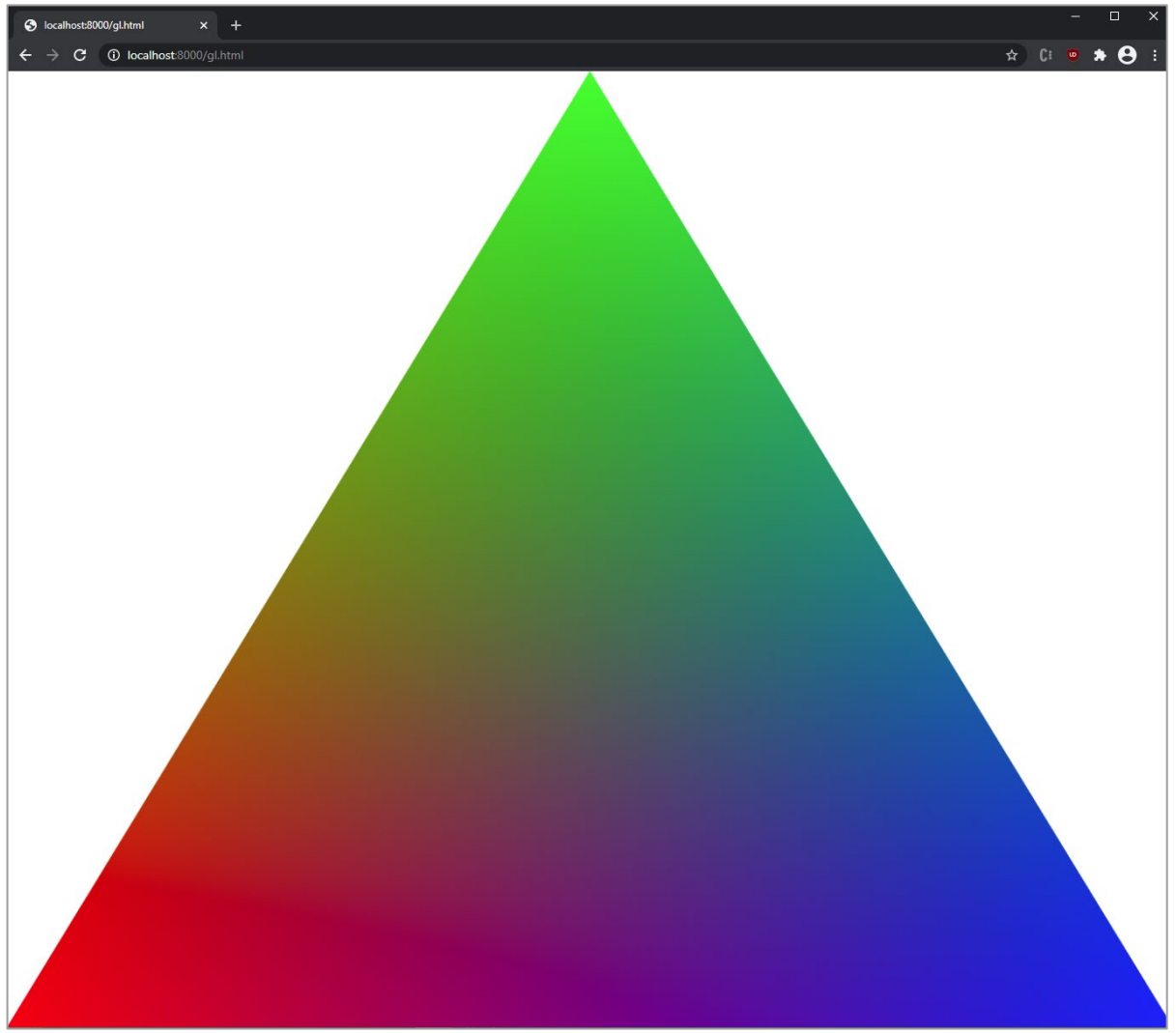
Simple example: Initialization

```
function main() {
    var canvas = document.querySelector("#glcanvas");
    canvas.width = canvas.clientWidth;
    canvas.height = canvas.clientHeight;
    gl = canvas.getContext("webgl2");

    var vertexShader = createShader(gl.VERTEX_SHADER, vertexShaderSrc);
    var fragmentShader = createShader(gl.FRAGMENT_SHADER, fragmentShaderSrc);
    program = createProgram(vertexShader, fragmentShader);
    posBuffer = createBuffer(vertices);
    colorBuffer = createBuffer(colors);
    var posAttribLoc = gl.getAttribLocation(program, "position");
    var colorAttribLoc = gl.getAttribLocation(program, "color");
    vao = createVAO(posAttribLoc, colorAttribLoc);
}

window.onload = main;
window.requestAnimationFrame(draw);
```

Simple example: Render loop

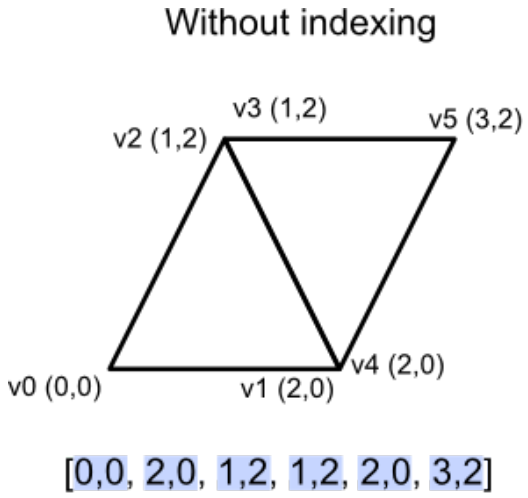
```
function draw() {
    gl.viewport(0, 0, gl.canvas.width, gl.canvas.height);

    gl.clearColor(1, 1, 1, 1);
    gl.clear(gl.COLOR_BUFFER_BIT);

    gl.useProgram(program);
    gl.bindVertexArray(vao);
    var primitiveType = gl.TRIANGLES;
    var count = 3;
    gl.drawArrays(primitiveType, 0, count);

}
```

Simple example



VBO indexing

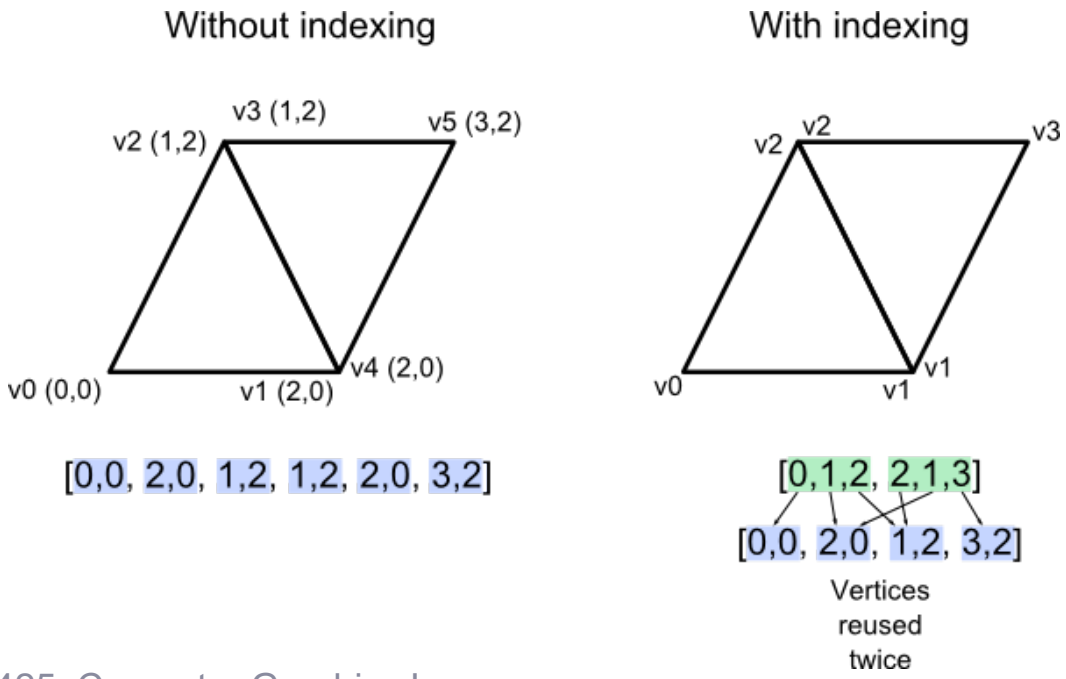
- In order to avoid duplicating our vertices whenever two triangles share an edge, we can use indexing.




```
gl.bindVertexArray(vao);
gl.drawArrays(gl.TRIANGLES, 0, count);
```

VBO indexing

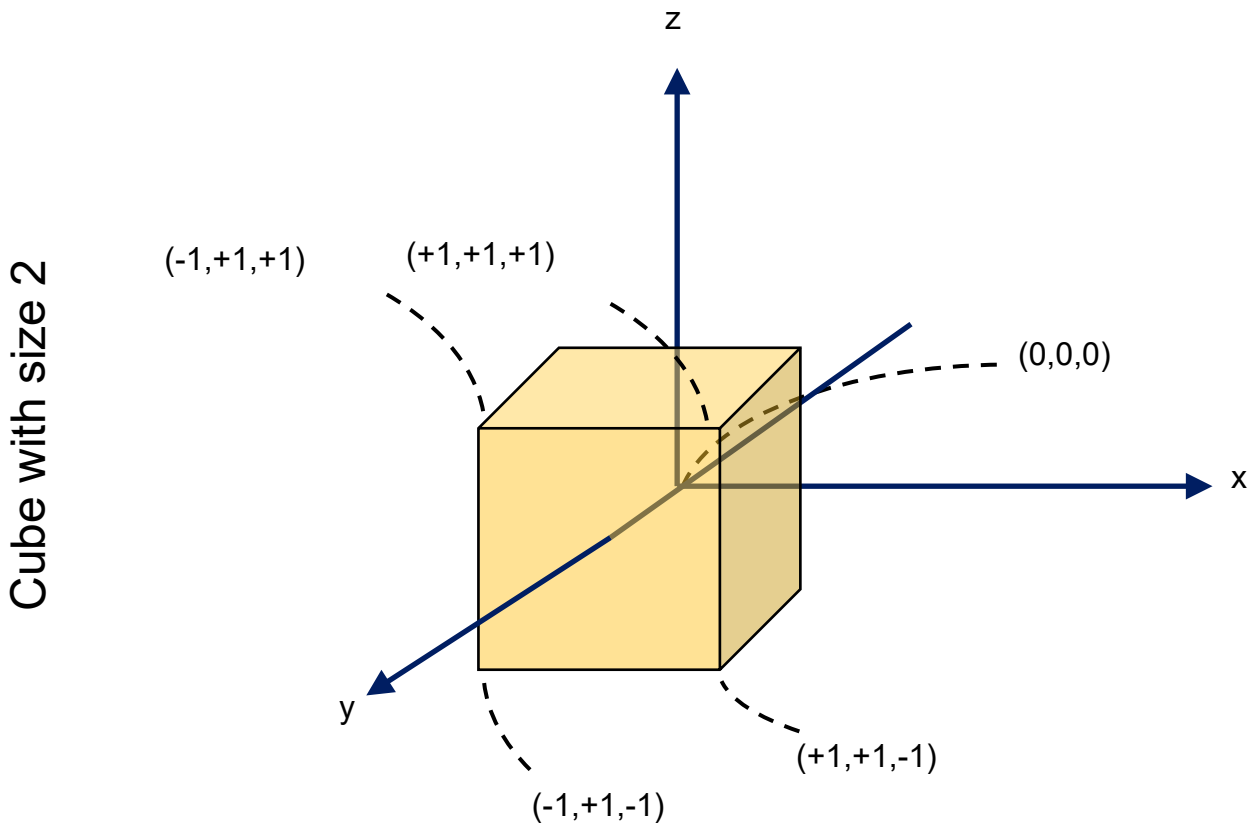
- In order to avoid duplicating our vertices whenever two triangles share an edge, we can use indexing.



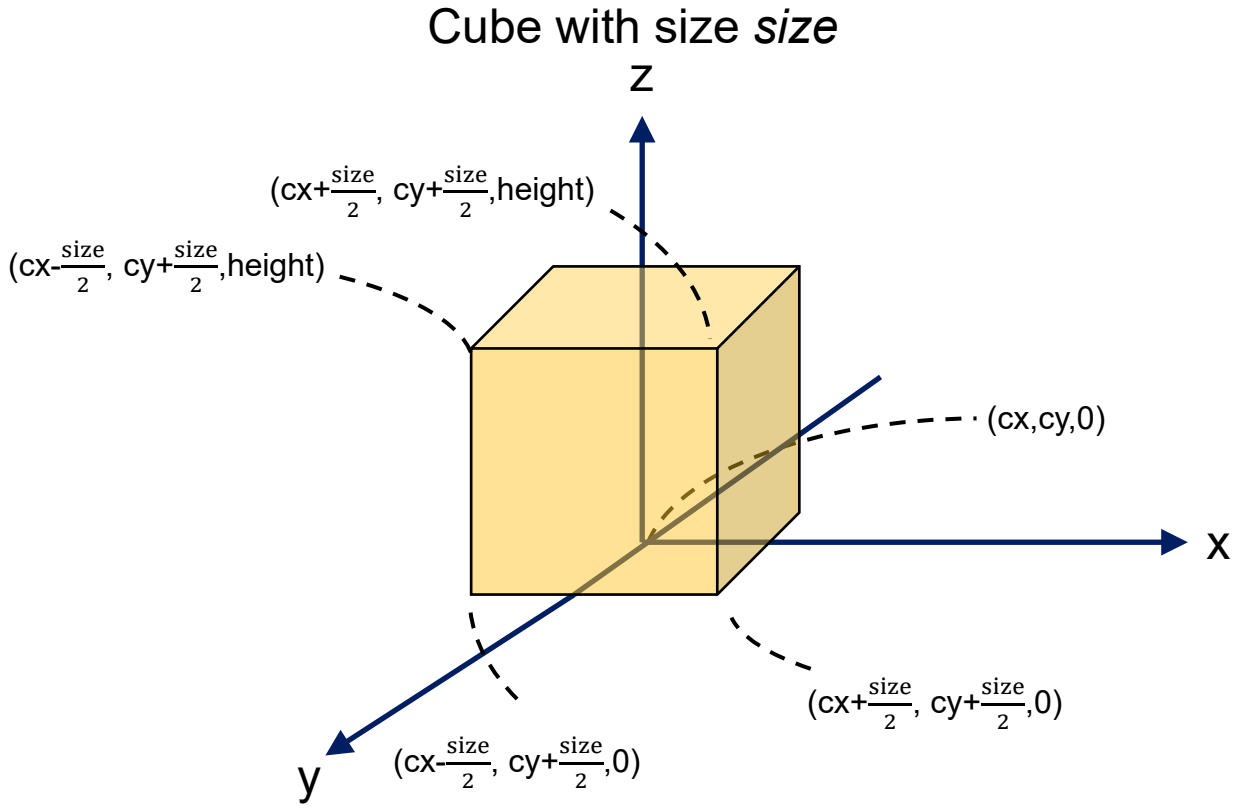

```
gl.bindVertexArray(vao);
gl.drawArrays(gl.TRIANGLES, 0, count);
```

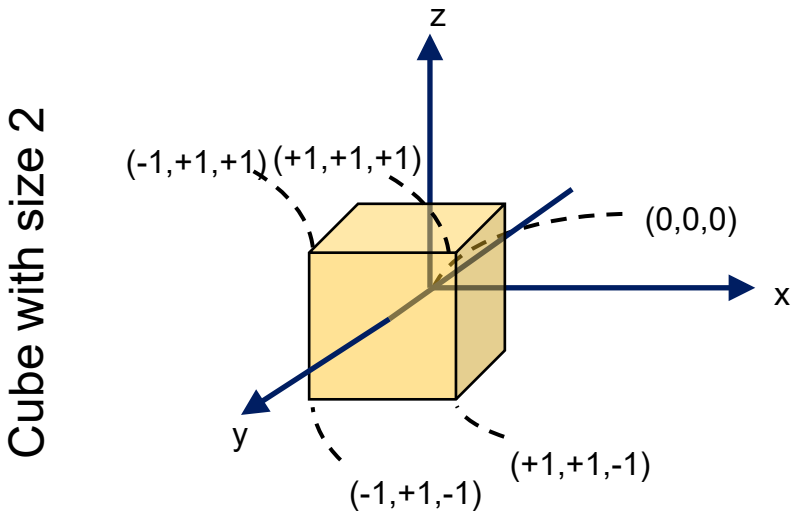
```
gl.bindVertexArray(vao);
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER,
buffers.elements);
gl.drawElements(gl.TRIANGLES, count,
gl.UNSIGNED_SHORT, 0);
```

Cube example

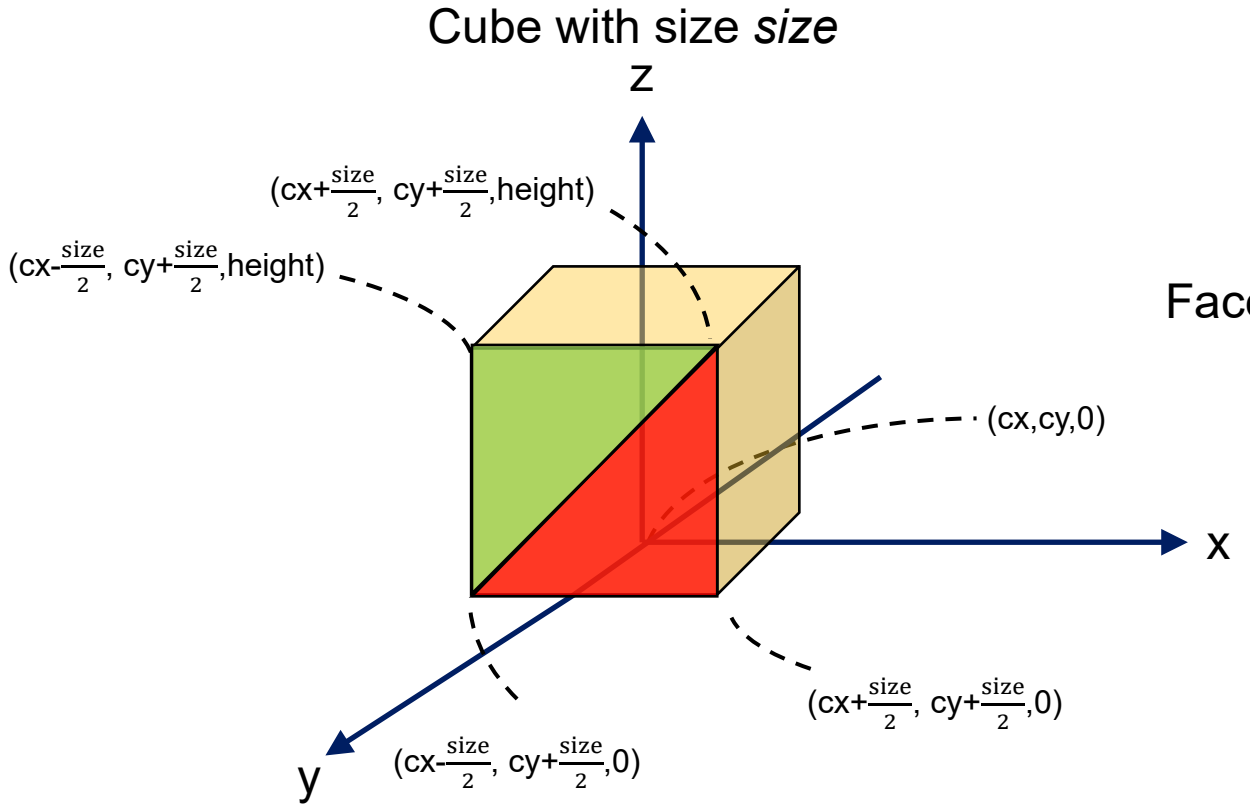


Cube example

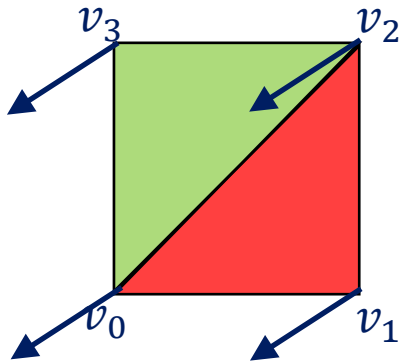


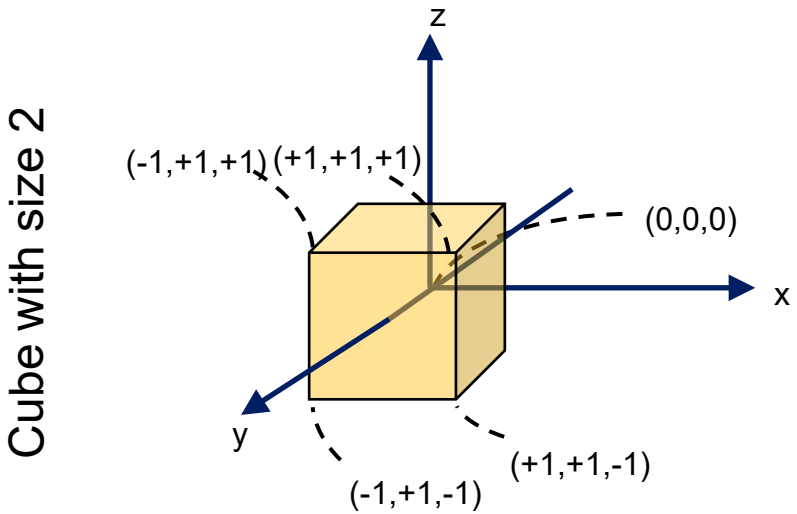


Cube example

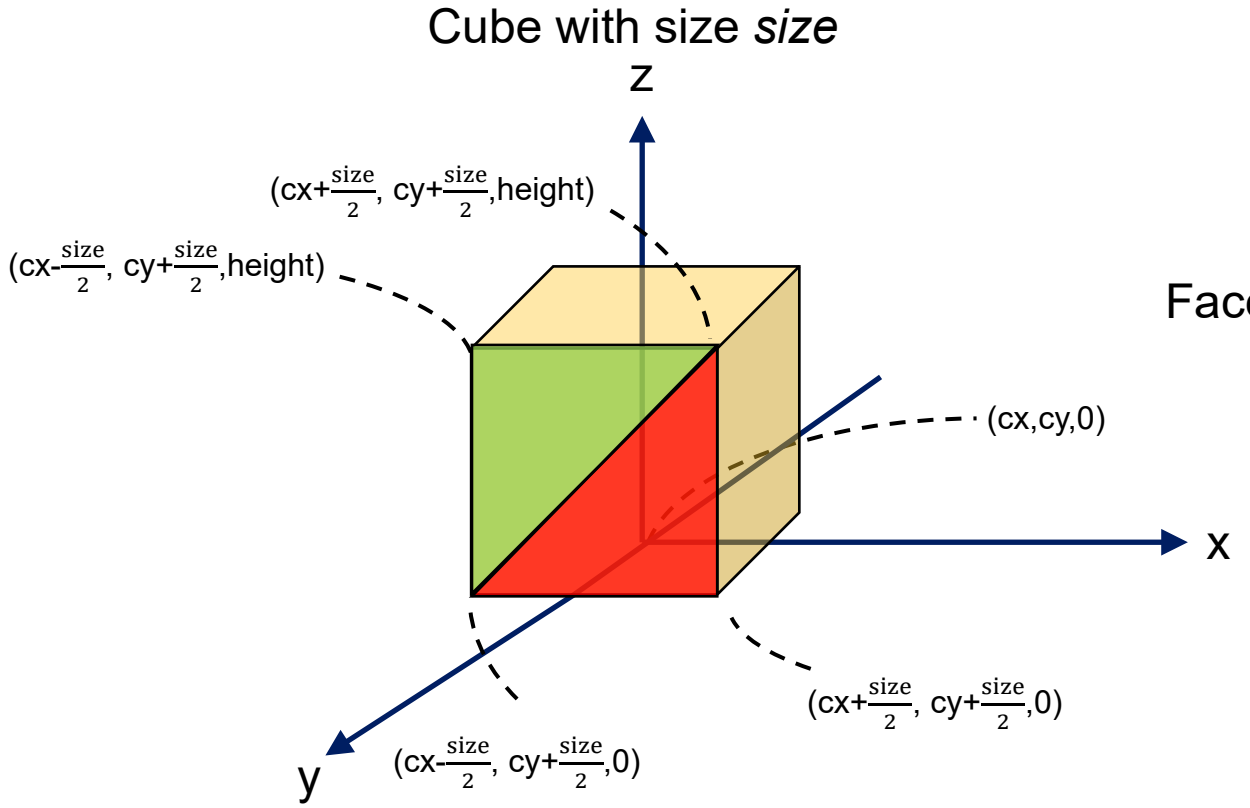


Face triangles with vertex normals

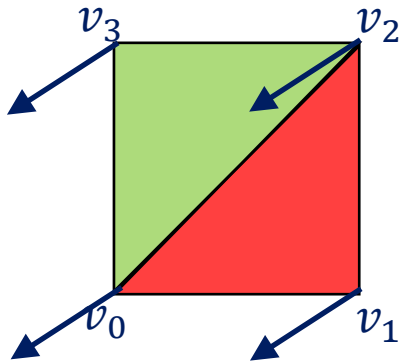


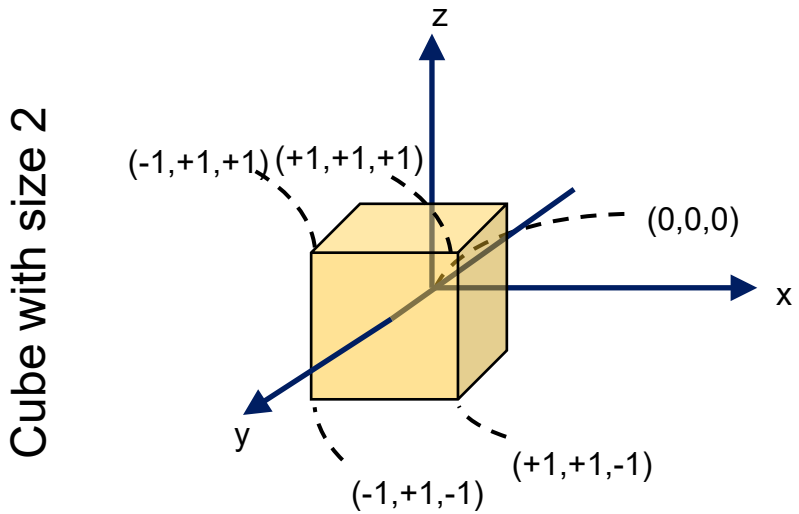


Cube example



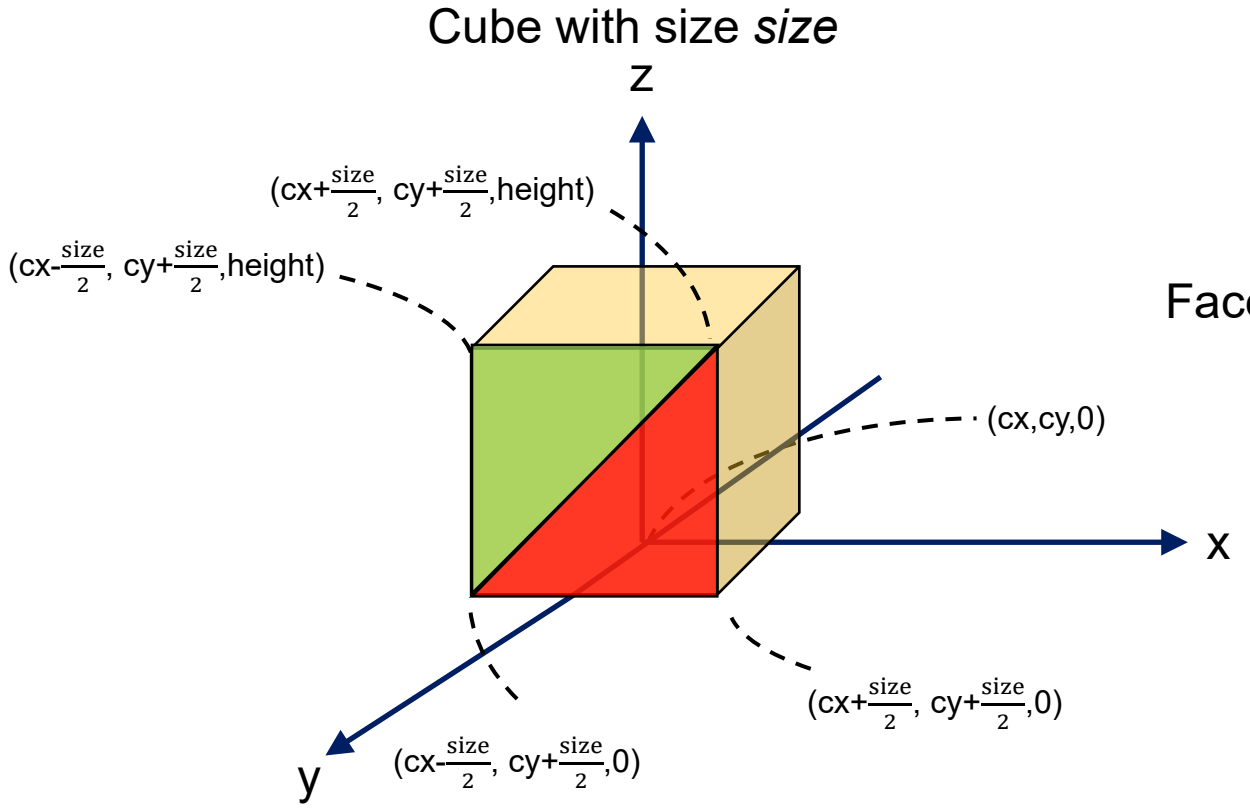
Face triangles with vertex normals



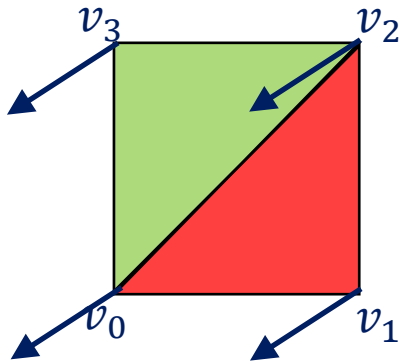


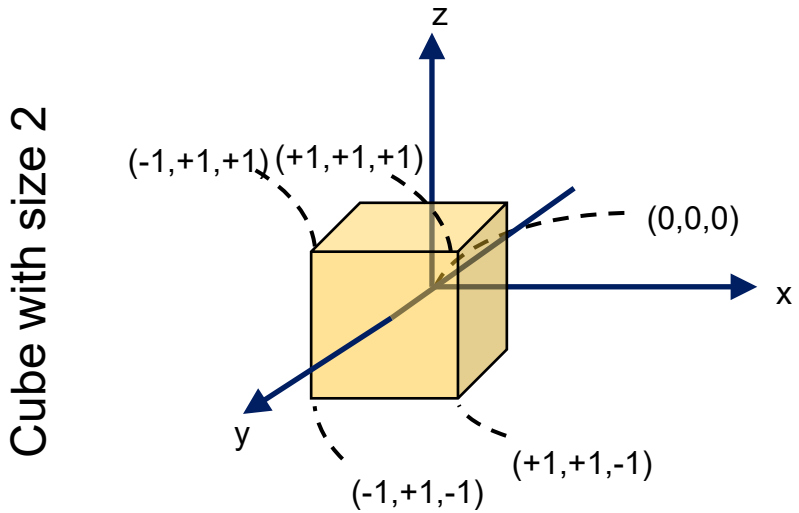
Vertex coordinates: $[v_0, v_1, v_2, v_3]$
Normals: $[0,1,0, 0,1,0, 0,1,0, 0, 1, 0]$

Cube example



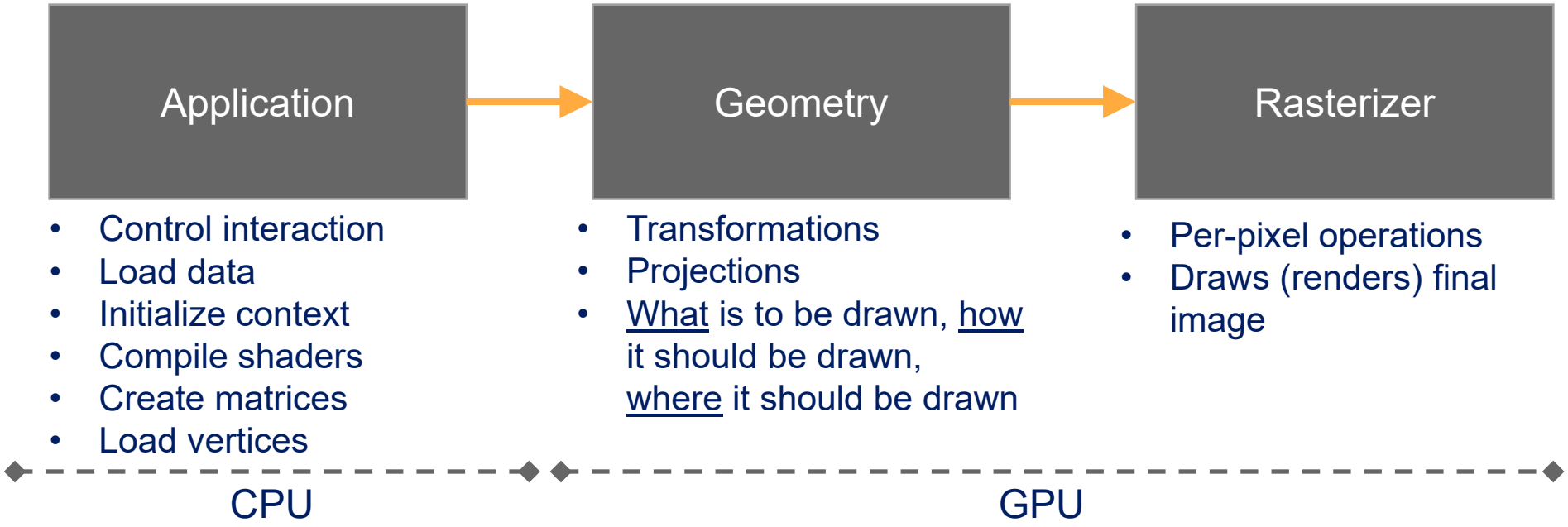
Face triangles with vertex normals





Vertex coordinates: $[v_0, v_1, v_2, v_3]$
Normals: $[0,1,0, 0,1,0, 0,1,0, 0,1,0]$
Indices: [0,1,2,0,2,3]

Rendering pipeline



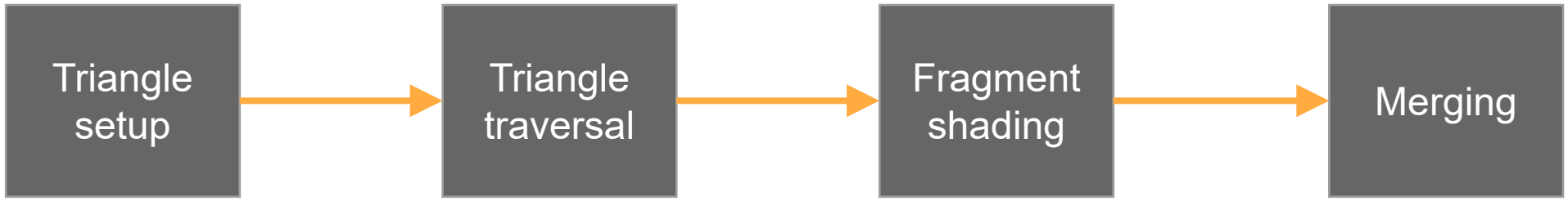
Slowest pipeline stage will determine *rendering speed* (in frames per second).
Simple example: bottleneck stage takes 20 ms to execute. Rendering speed: 1/0.020 = 50 fps.

Geometry stage

- Responsible for most of the per-polygon and per-vertex operations.

Rasterizer stage

- Responsible for the computation of fragment and pixel colors.



Lab

- Create a web application to render triangles. This application should be composed of two main elements: a configuration panel, and a WebGL canvas.
- The configuration panel should be composed of:
  1. Three sliders to set the current RGB color of triangles.
  2. One slider with the number of triangles to be rendered in the WebGL canvas (minimum of 1 triangle, maximum of 100 triangles). Position and size of triangles should be randomly selected, making sure that *all* triangles are rendered inside canvas.
  3. Start and stop buttons. Once start is pressed, current RGB color should randomly change, *smoothly* updating the RGB sliders and color of rendered triangles. **CAREFUL NOT TO CHANGE COLORS TOO FAST!**
- WebGL canvas should render triangles according to configuration panel.

Useful links

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

https://www.khronos.org/registry/webgl/specs/latest/2.0/

https://www.khronos.org/files/webgl20-reference-guide.pdf