WebGL

CS425: Computer Graphics I

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COMPUTER SCIENCE

Overview

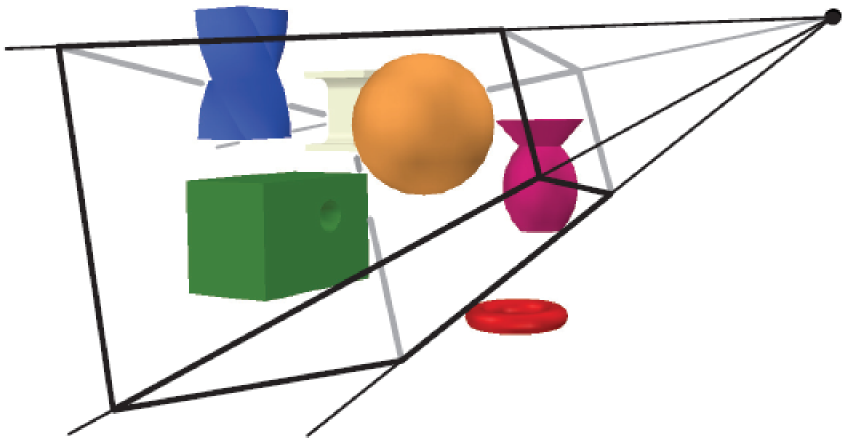
- Introduction to the graphics rendering pipeline
- WebGL
- Shaders

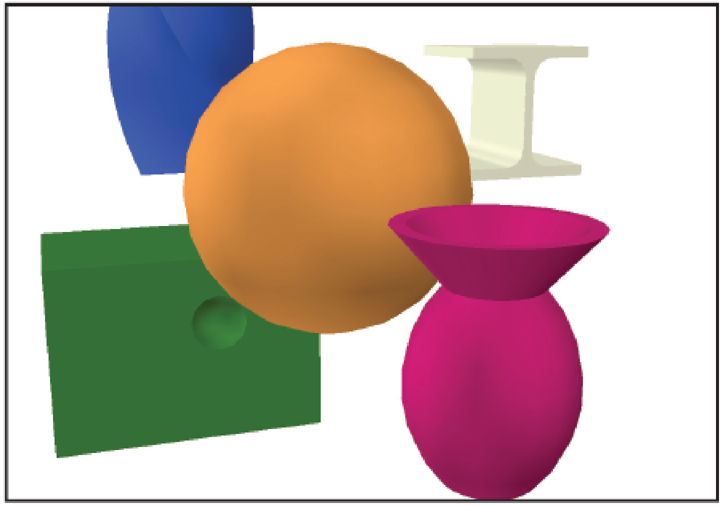
WebGL

- 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

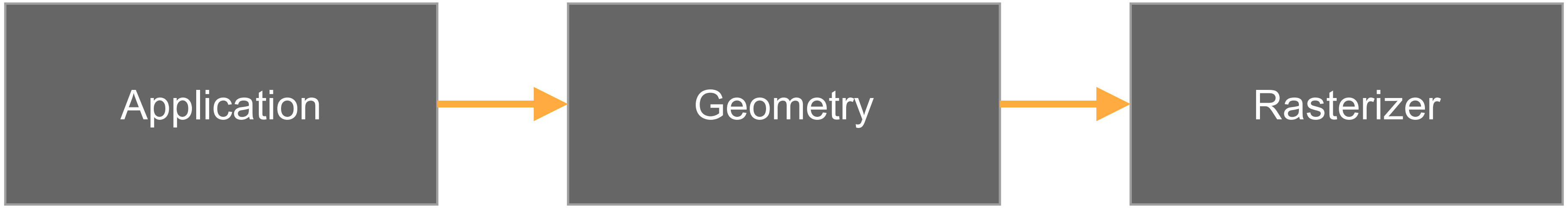
- Graphics system steps to render a scene to a 2D screen.





From: Real-Time Rendering 4th Ed

Rendering pipeline



- Control interaction
- Load data
- Initialize context
- Compile shaders
- Create matrices
- Load vertices

- Transformations
- Projections
- What is to be drawn, how it should be drawn, where it should be drawn

- Per-pixel operations
- Draws (renders) final image

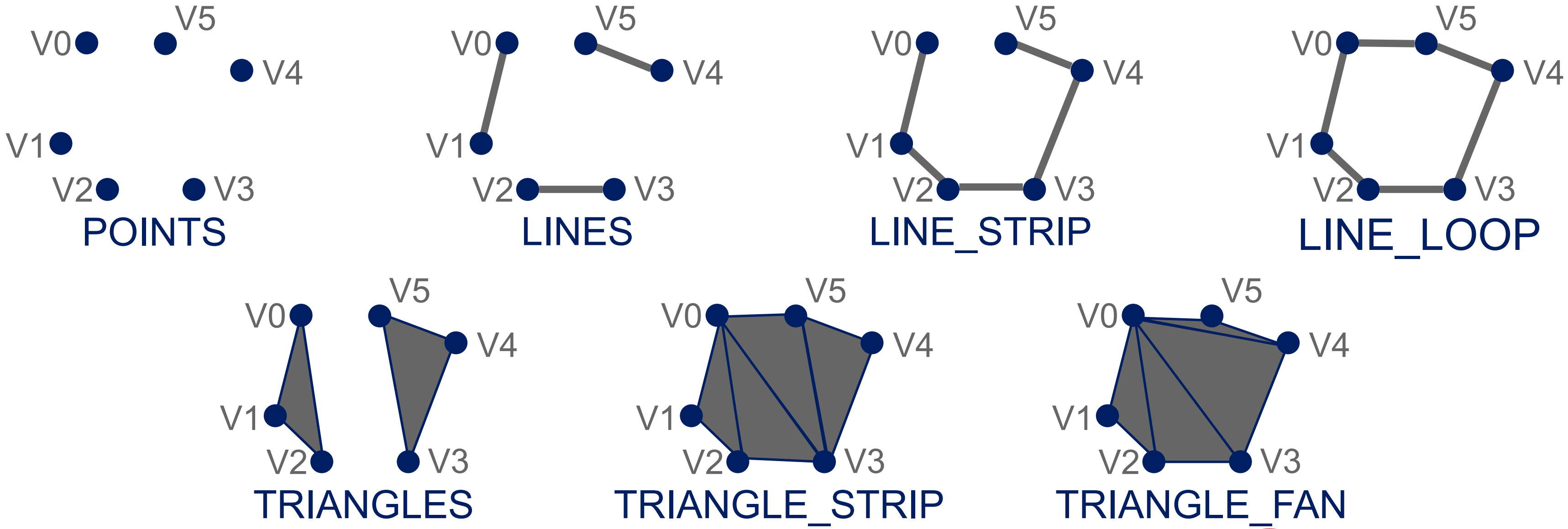
CPU

GPU

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.



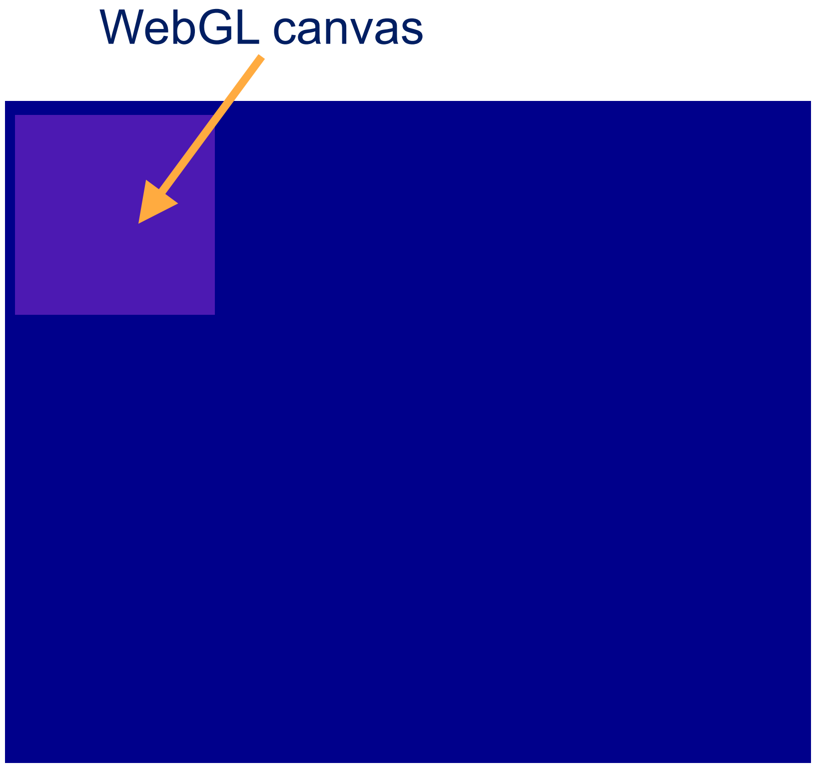
Application stage and WebGL

- 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
<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>
```

```javascript
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);
}
```

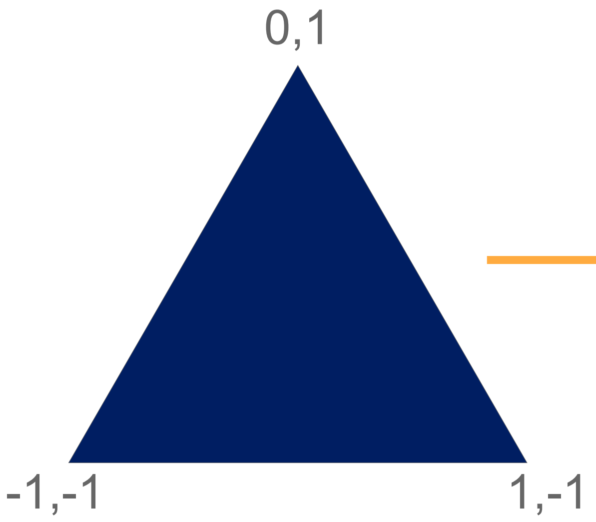
Sending data to the GPU

- 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);
```

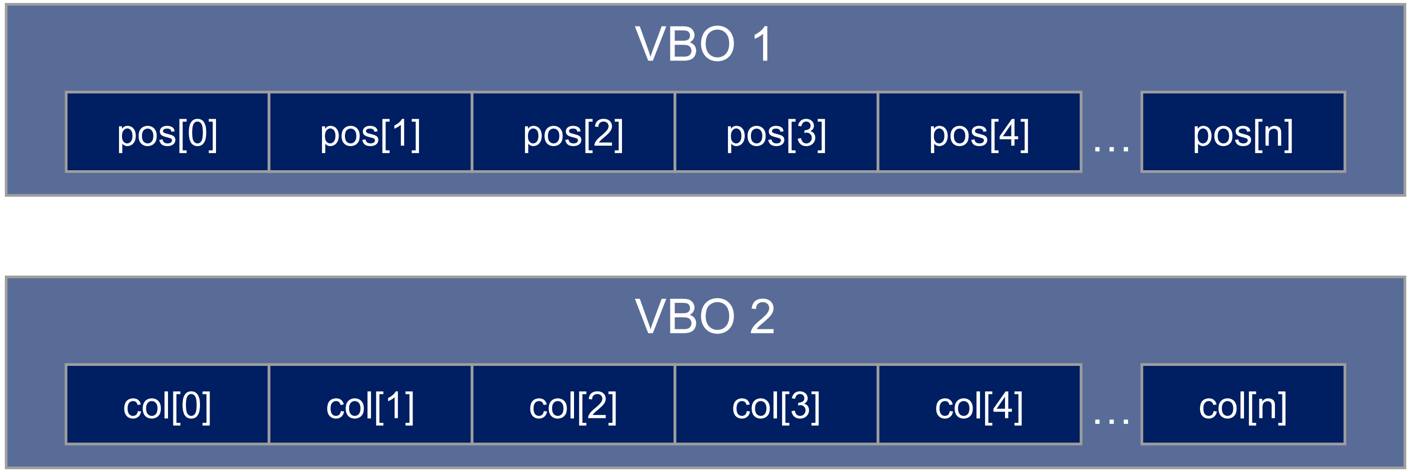
Vertex array object

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

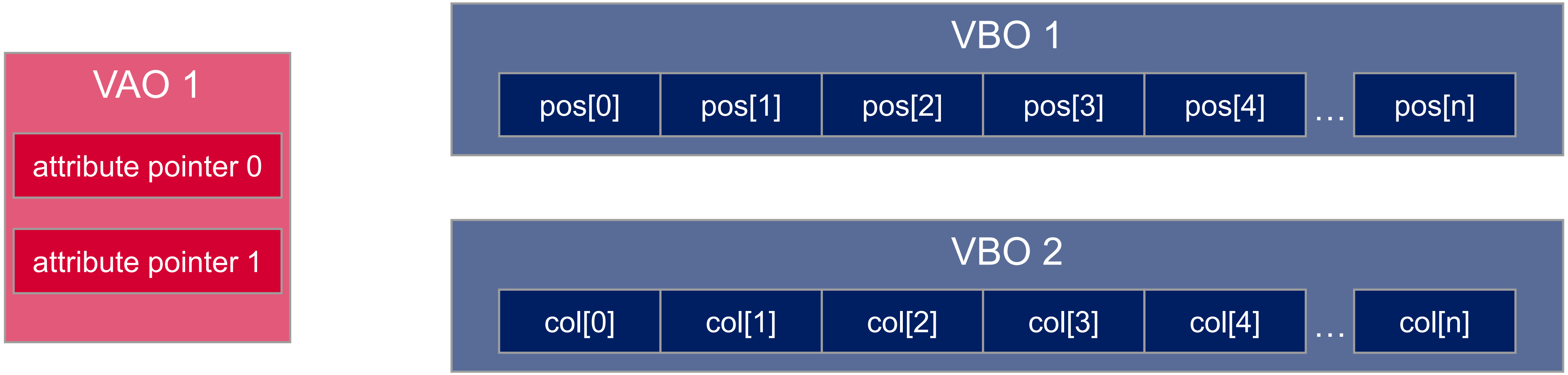
Vertex array object

pos[0]	x, y, z
col[0]	r, g, b

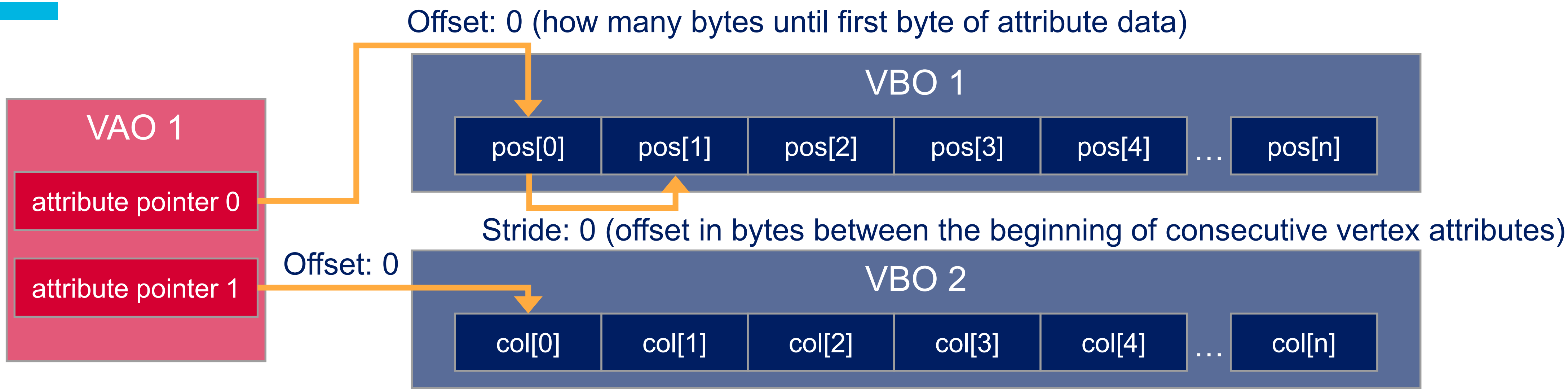
Vertex array object



Vertex array object



Vertex array object



Vertex array object

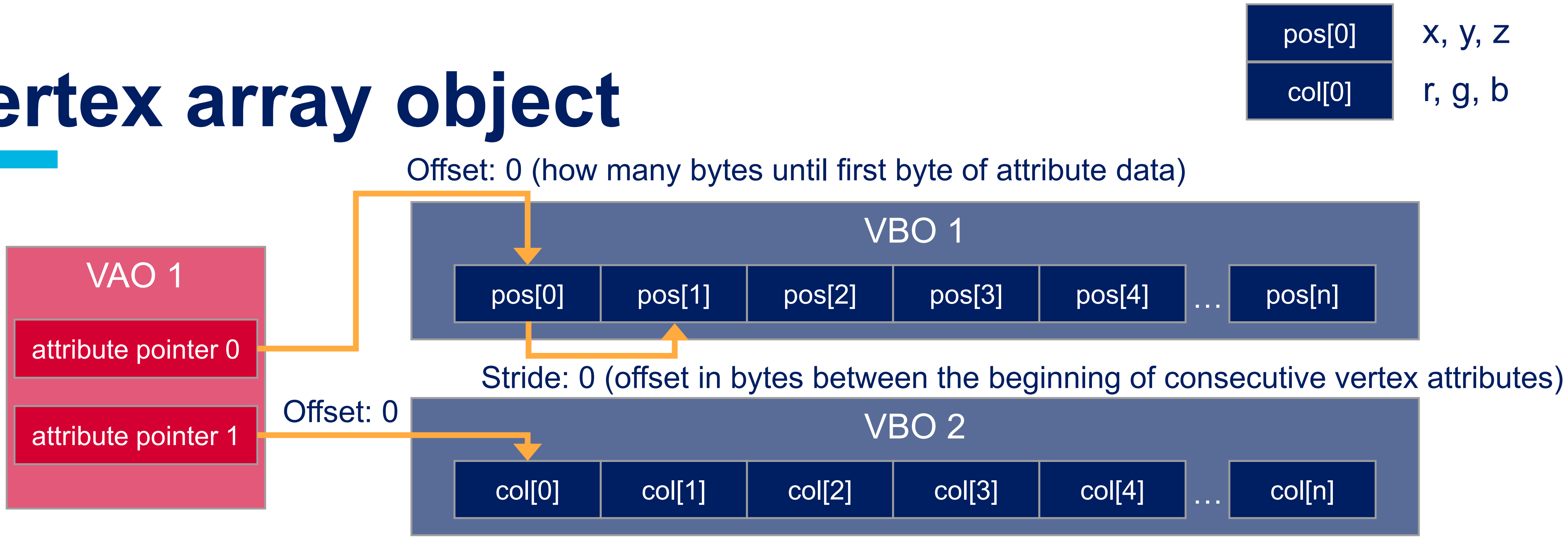
- VAO specifies layout of how data will be accessed by vertex shader.
- Location of the attribute in the program we created:

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

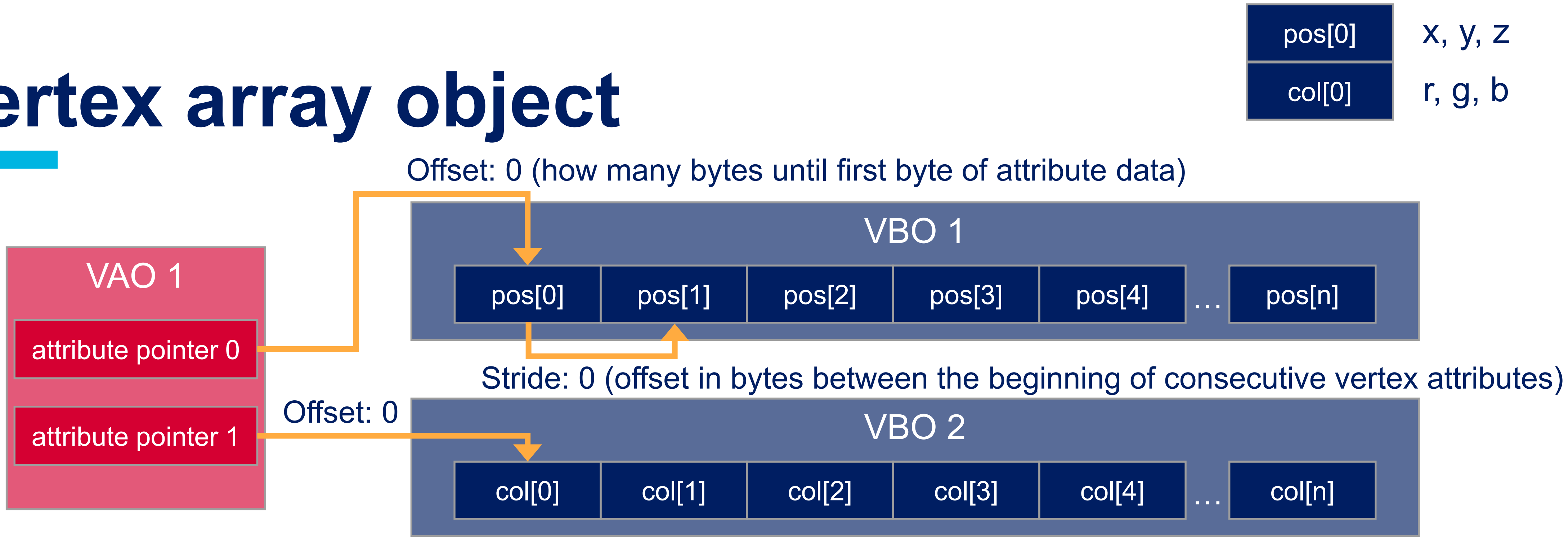
- Creating a vertex array object so shader can access buffer:

```
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);
```

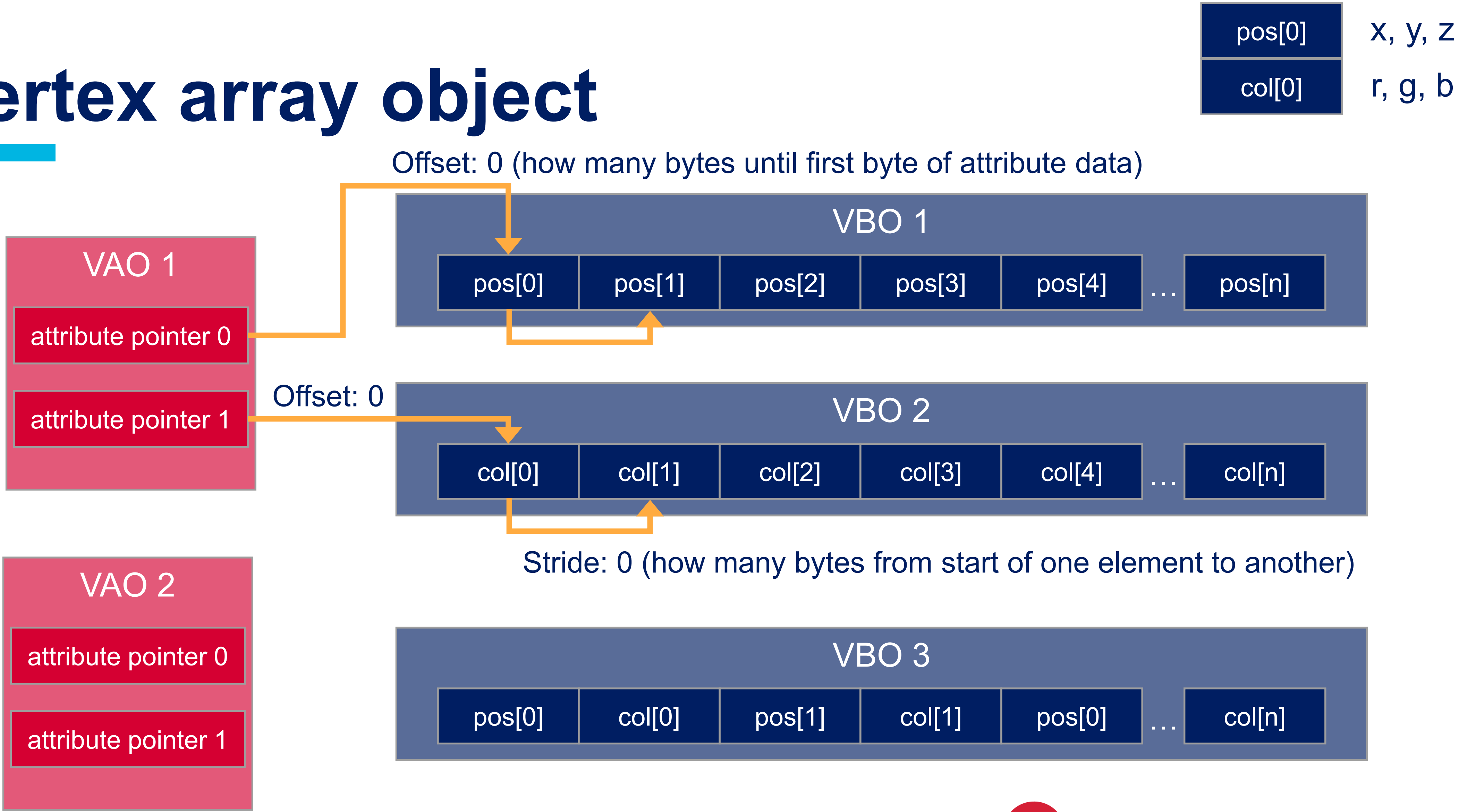
Vertex array object



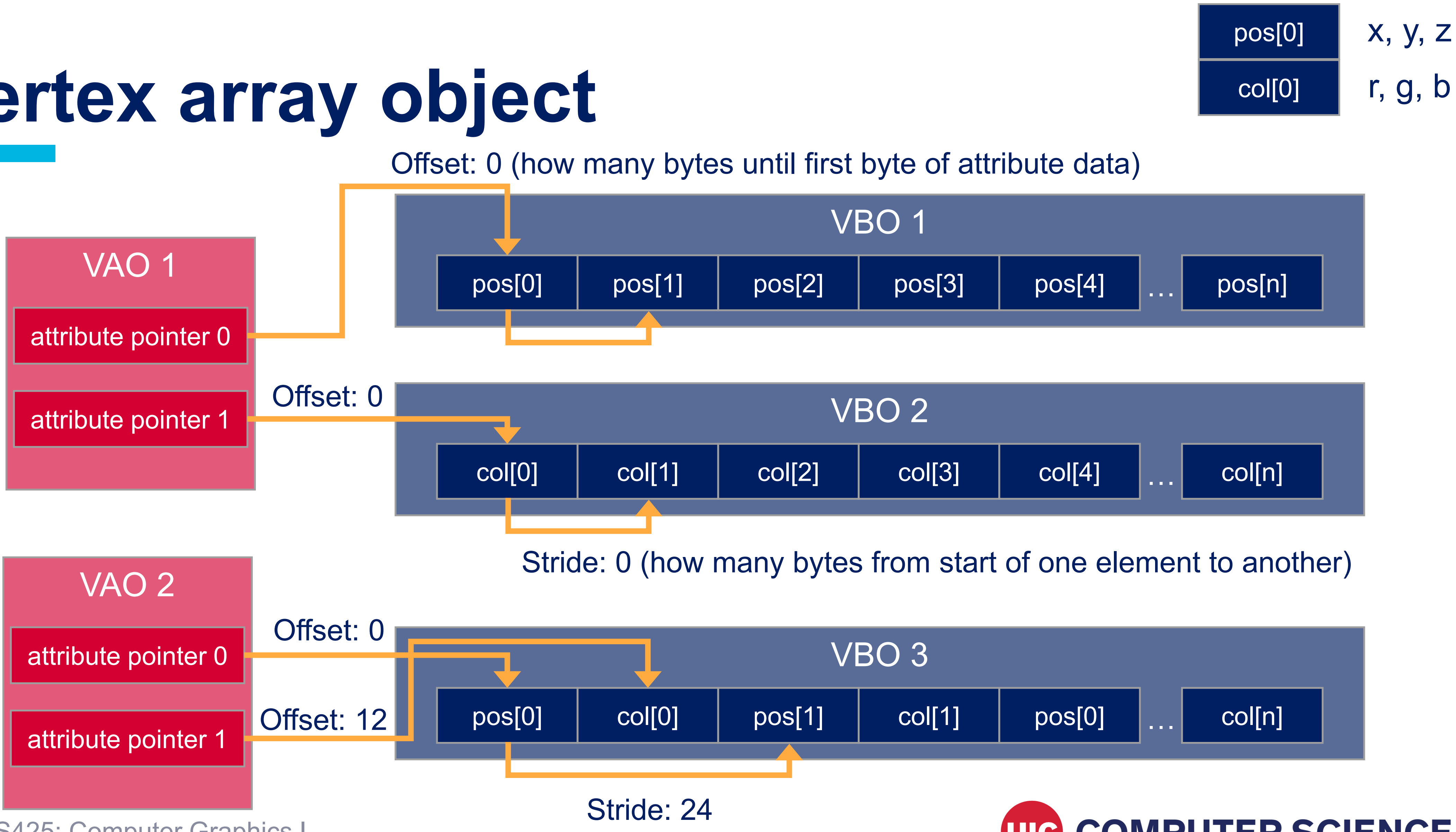
Vertex array object



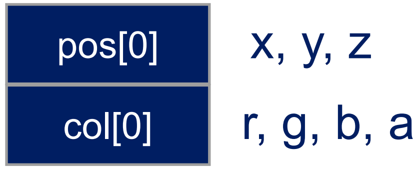
Vertex array object

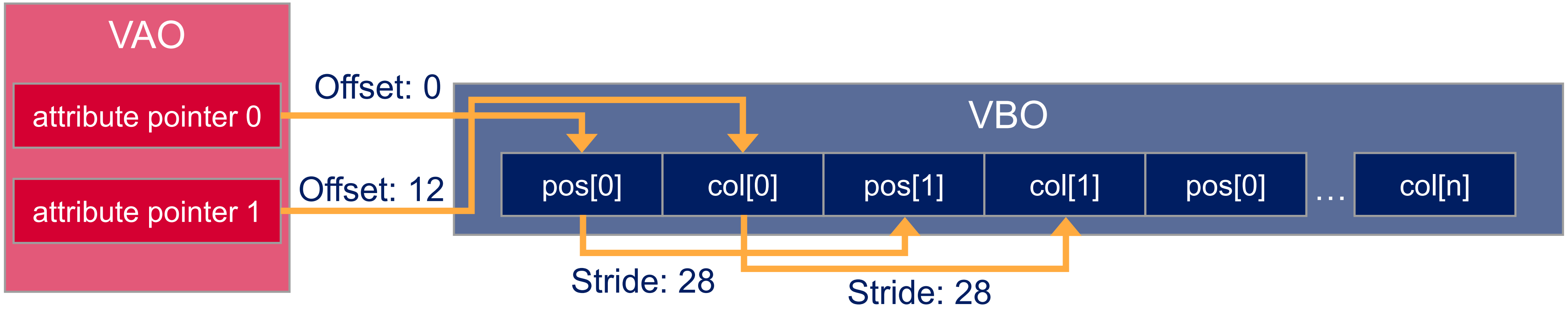


Vertex array object



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

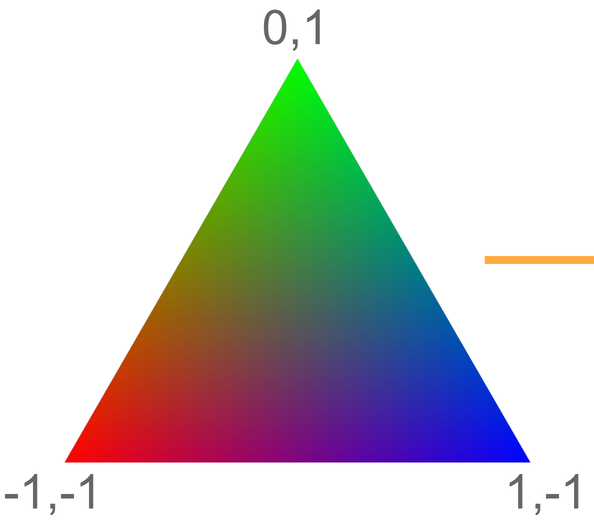
gl.getAttribLocation | gl.enableVertexAttribArray | gl.bindBuffer | gl.vertexAttribPointer — Vertex layout

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;
}
`;
```

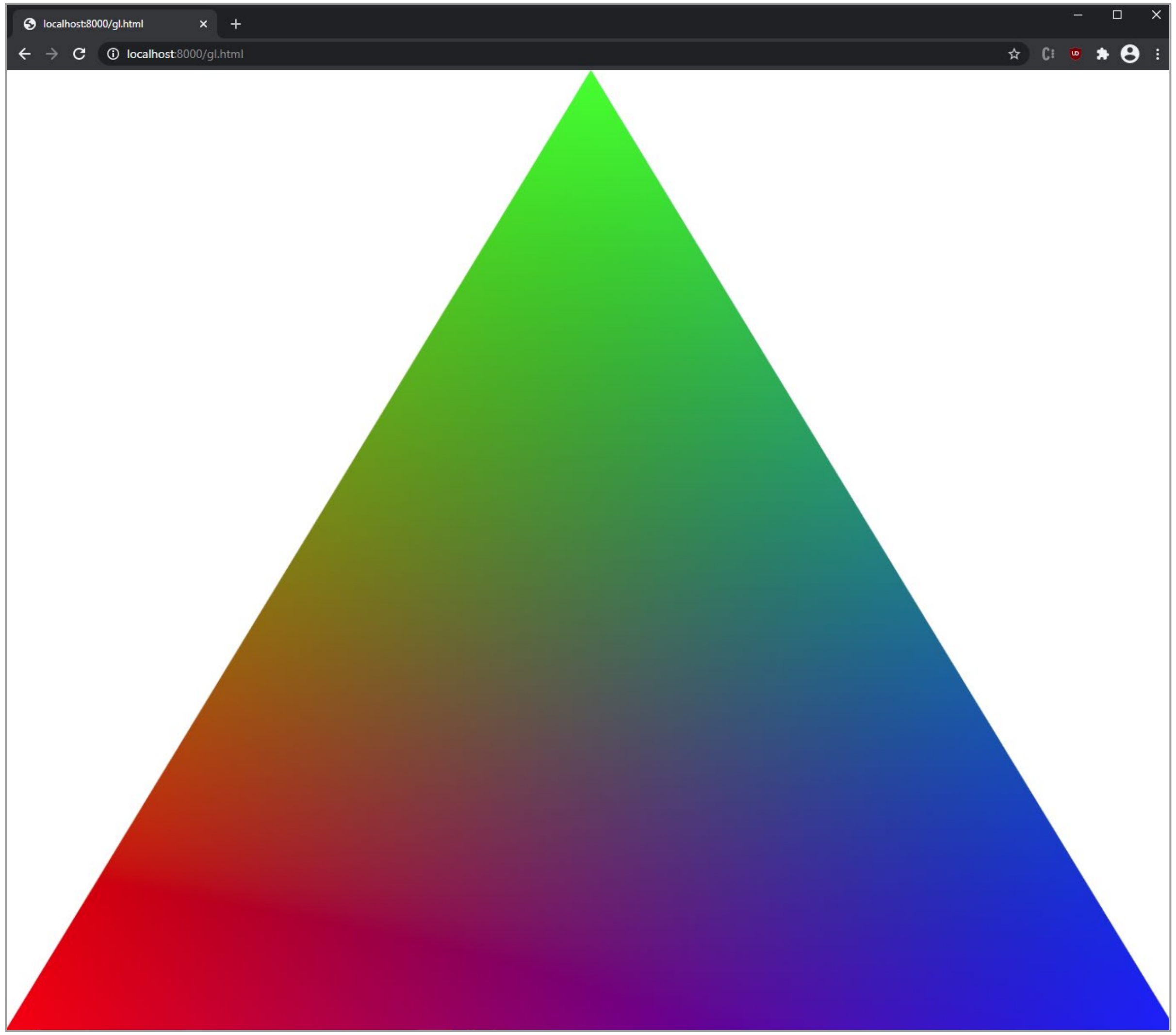
Simple example: Initialization

```
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

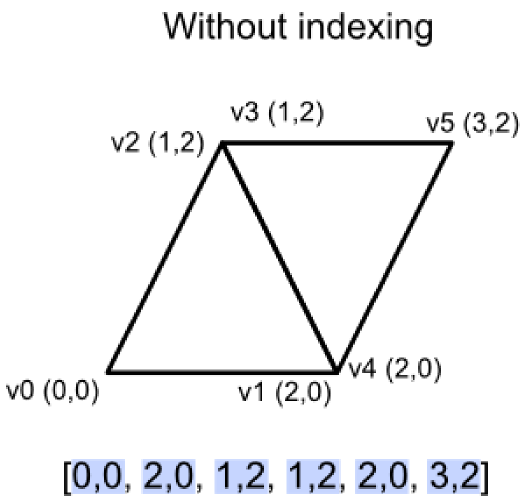
```
function draw() {
    gl.viewport(0, 0, gl.canvas.width, gl.canvas.height);

    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

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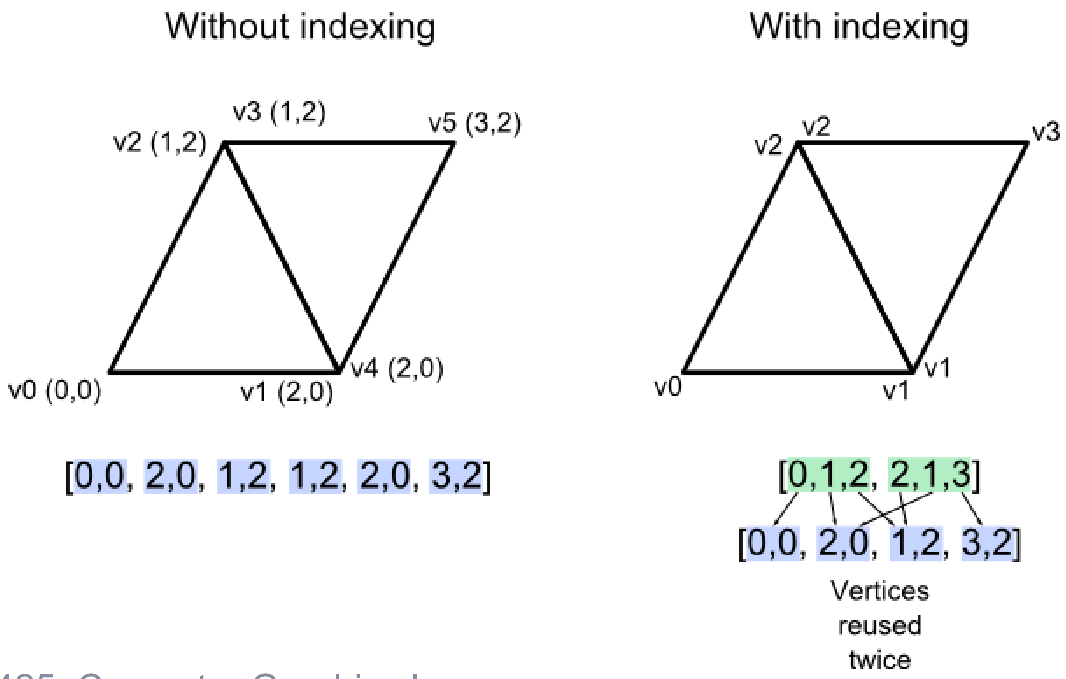
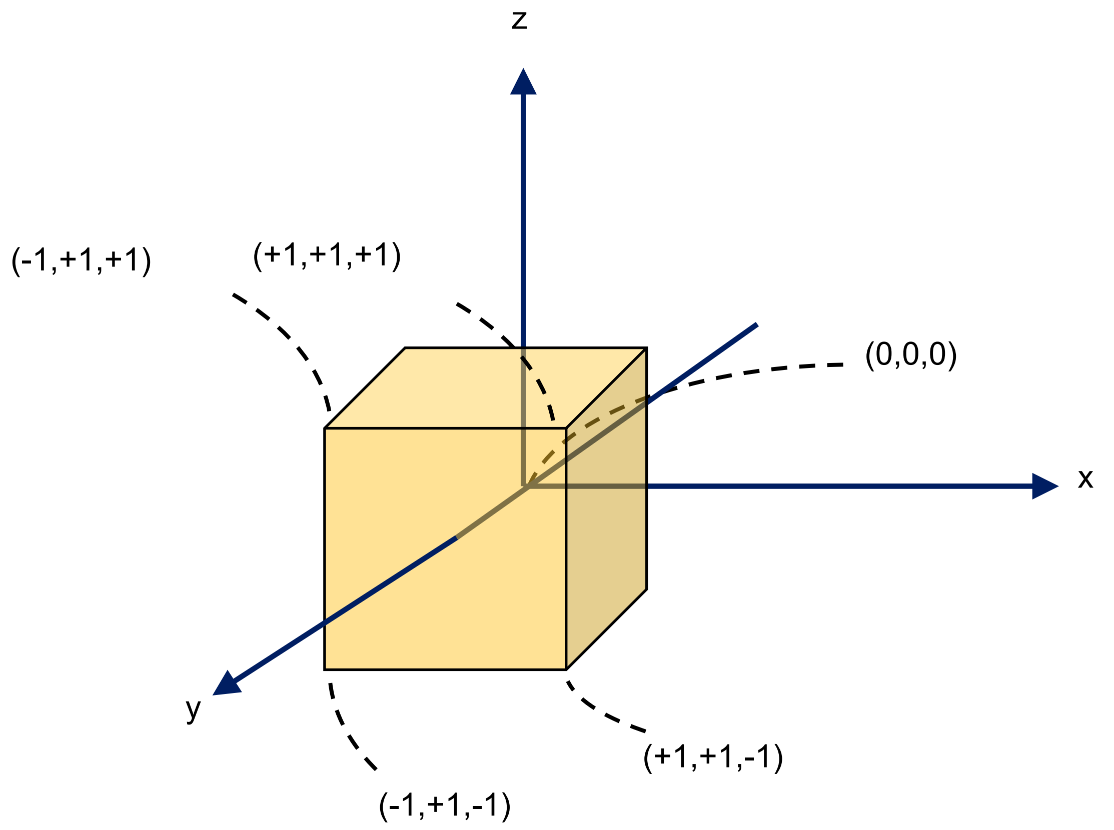



```
gl.bindVertexArray(vao);
gl.drawArrays(gl.TRIANGLES, 0, count);
```

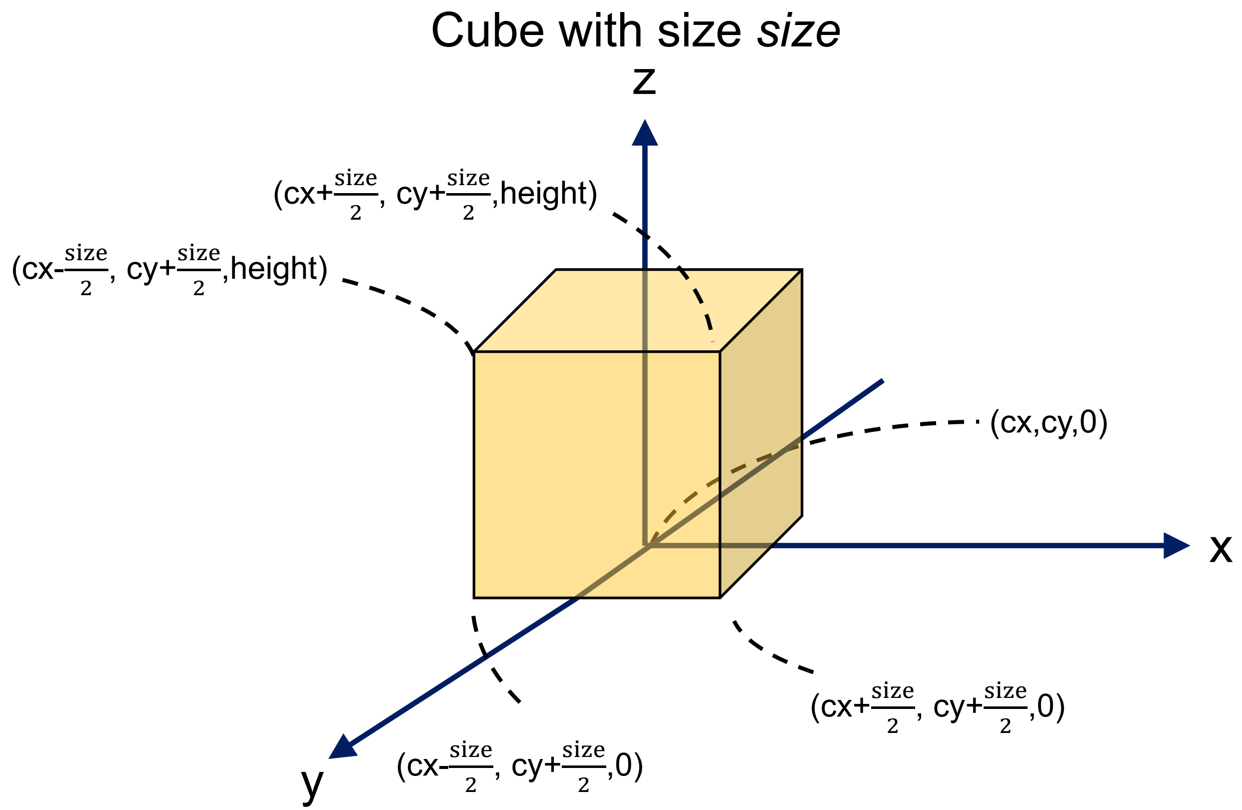
```
gl.bindVertexArray(vao);
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER,
buffers.elements);
gl.drawElements(gl.TRIANGLES, count,
gl.UNSIGNED_SHORT, 0);
```

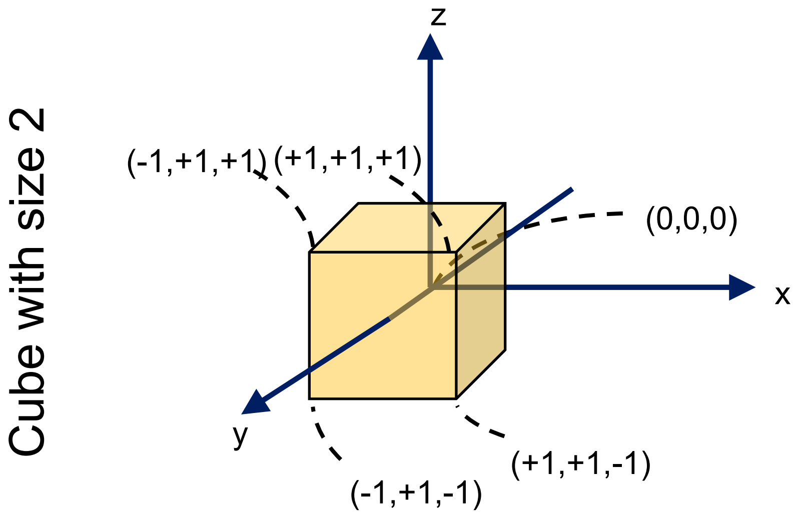
Cube example

Cube with size 2

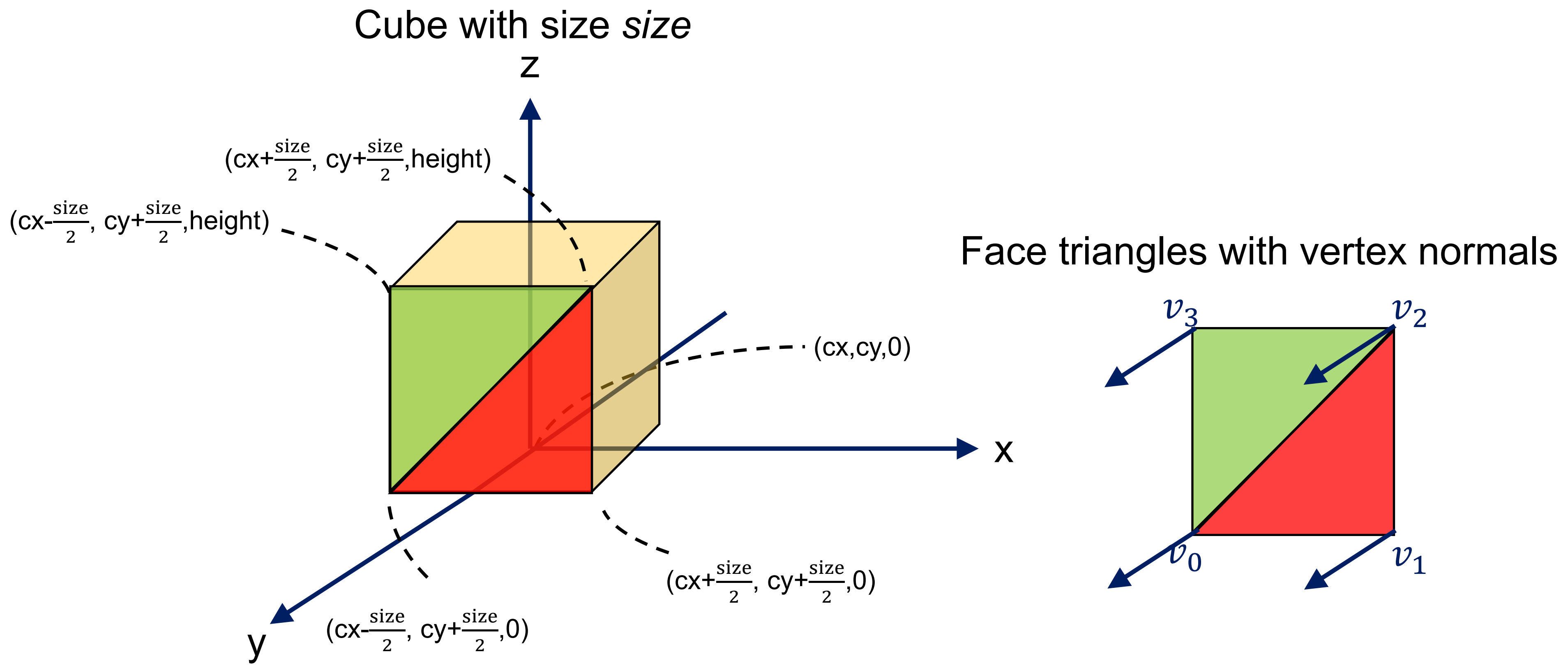


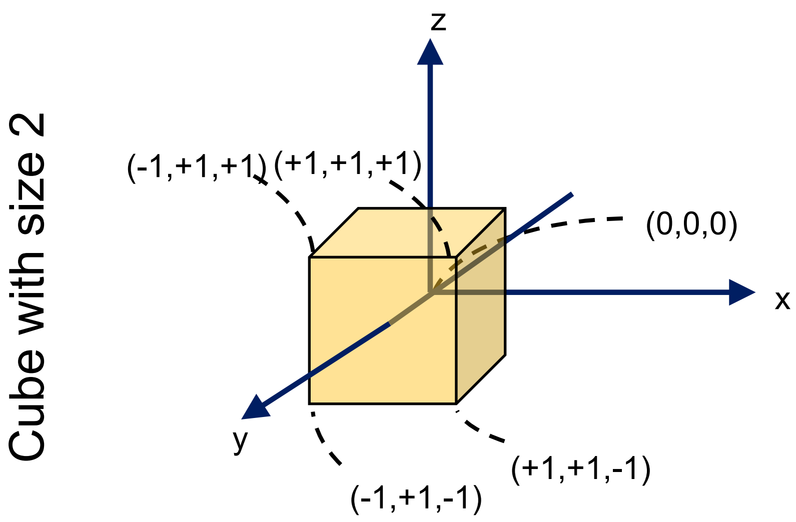
Cube example





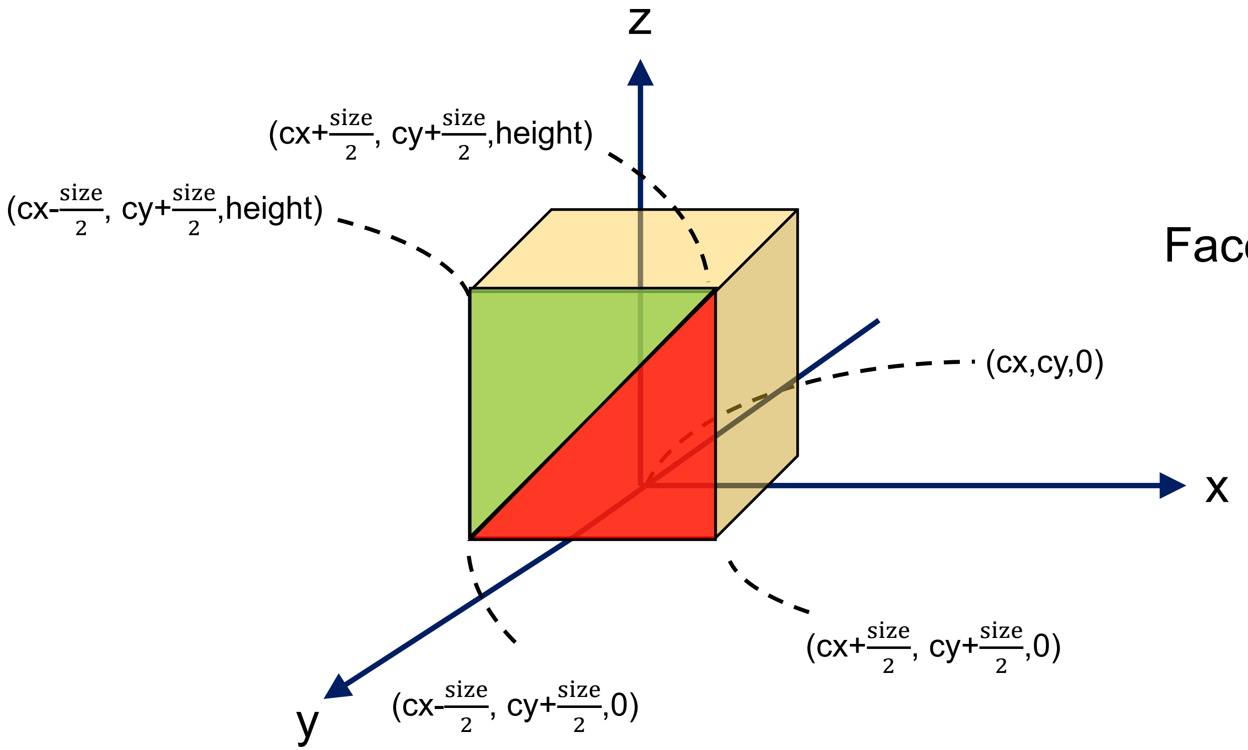
Cube example



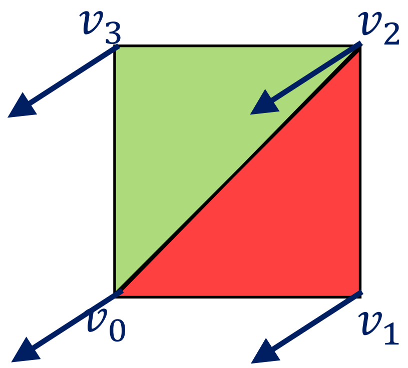


Cube example

Cube with size *size*

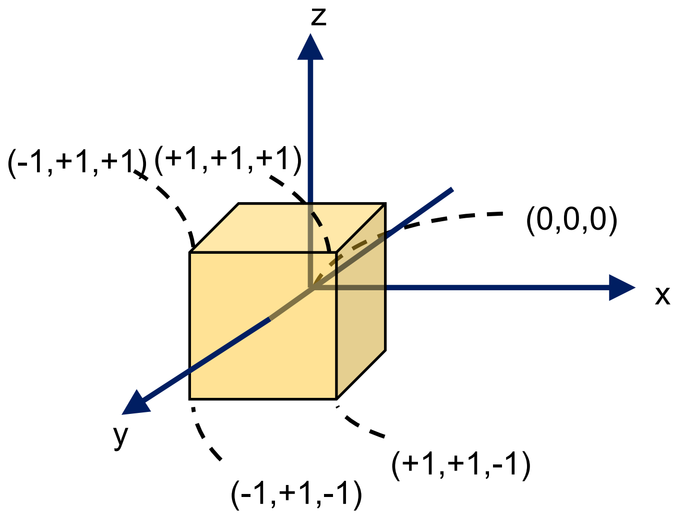


Face triangles with vertex normals



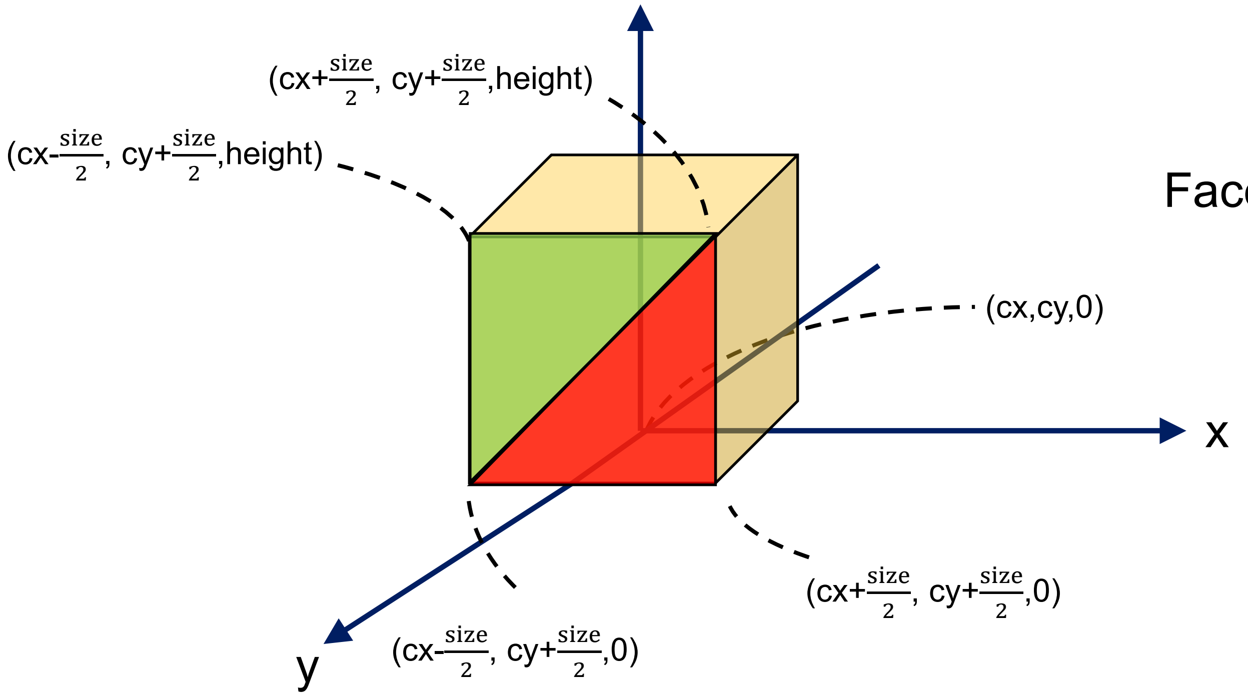
Vertex coordinates: $[v_0, v_1, v_2, v_3]$
Normals: $[0,1,0, 0,1,0, 0,1,0, 0, 1, 0]$

Cube with size 2

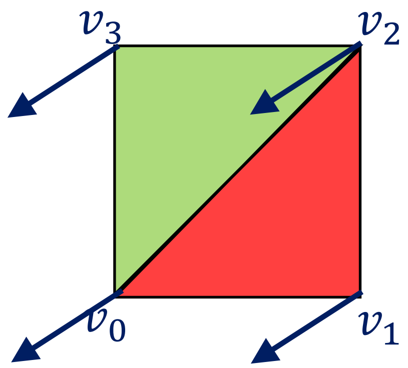


Cube example

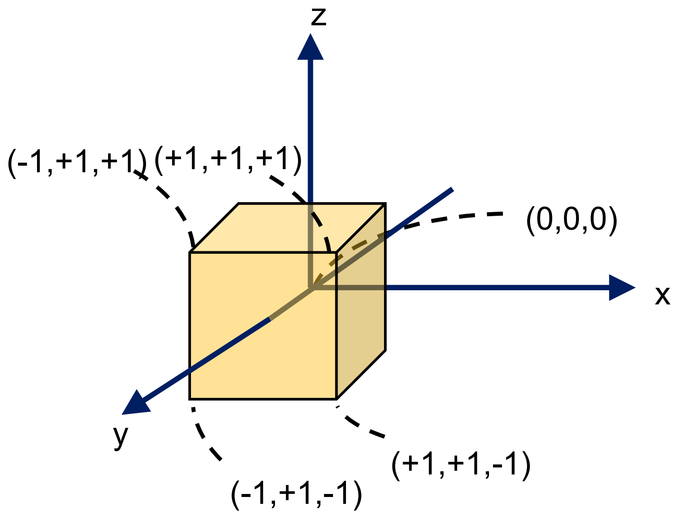
Cube with size *size*



Face triangles with vertex normals



Cube with size 2



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

Rendering pipeline

Application → Geometry → Rasterizer

Application
- Control interaction
- Load data
- Initialize context
- Compile shaders
- Create matrices
- Load vertices

Geometry
- Transformations
- Projections
- What is to be drawn, how it should be drawn, where it should be drawn

Rasterizer
- Per-pixel operations
- Draws (renders) final image

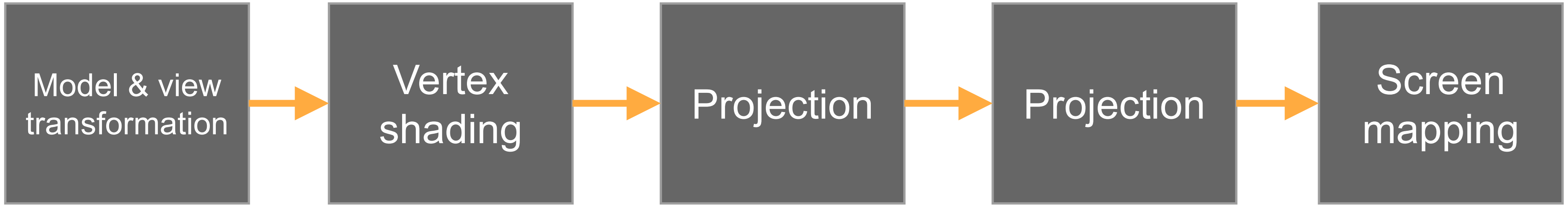
CPU: Application

GPU: Geometry, Rasterizer

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.

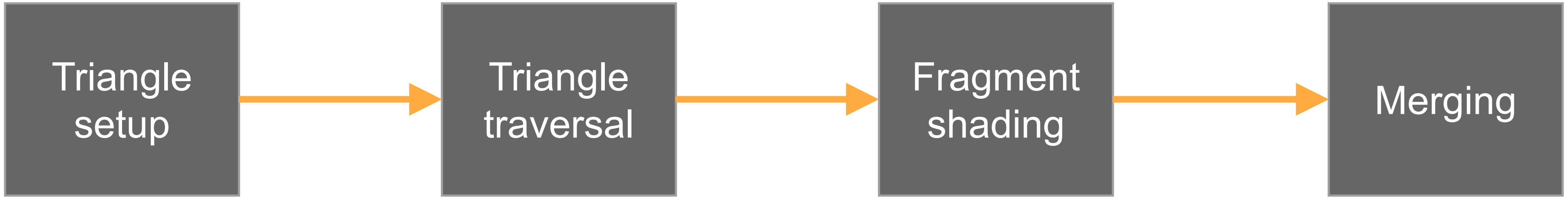
Geometry stage

- 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