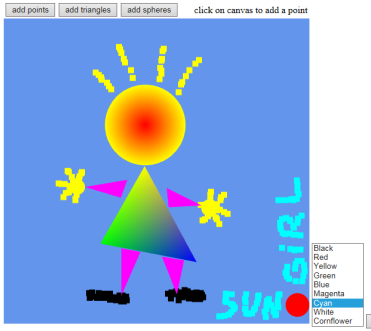
Welcome to 02561: Computer Graphics

Jeppe Revall Frisvad

August 2024

Web graphics, drawing in 2D, animation, interaction (weeks 1–3)

- Three weeks for covering the basics.



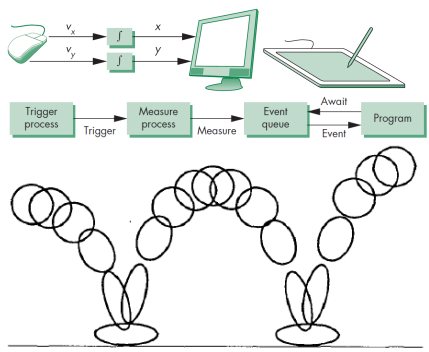


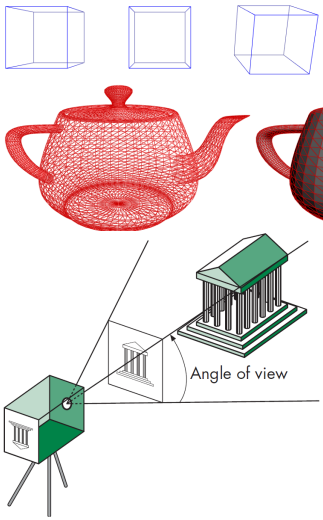
FIGURE 2. Squash & stretch in bouncing ball.

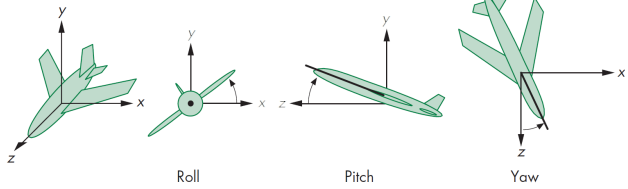
Figure references

- Worksheet 2 and Wikimedia Commons.
- Angel, E., and Shreiner, D. *Interactive Computer Graphics: A Top-Down Approach with WebGL*, seventh edition. Pearson, 2015.
- Lasseter, J. Principles of traditional animation applied to 3D computer animation. *Computer Graphics (SIGGRAPH '87) 21*(4):35-44, 1987.

Drawing in 3D, triangle meshes, viewing, lighting (weeks 4–6)

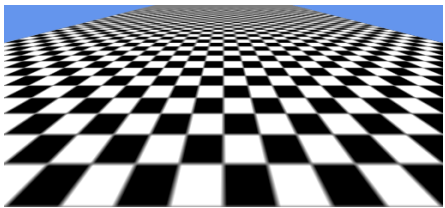
- Three weeks for adding depth.

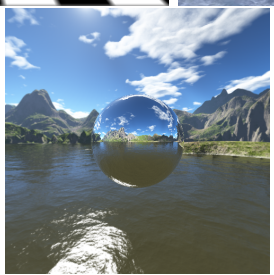
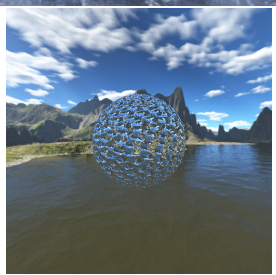




Mapping, blending, off-screen buffers, multiple shaders (weeks 7–10)

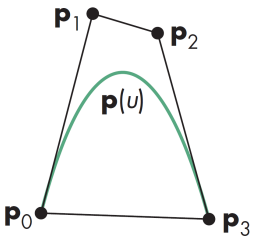
- Four weeks for shading pixels.

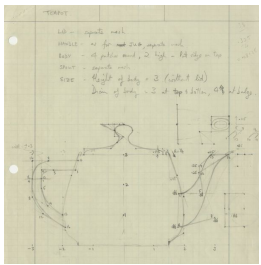


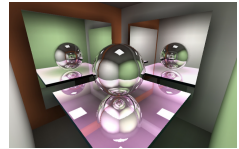




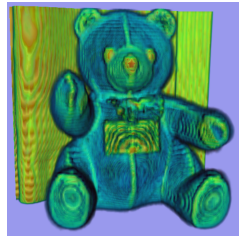
Advanced techniques (weeks 11–13)

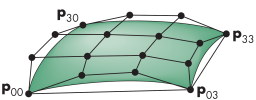
- Three weeks for curves, surfaces, volumes, and visual effects.

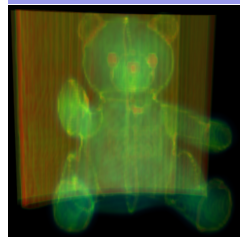






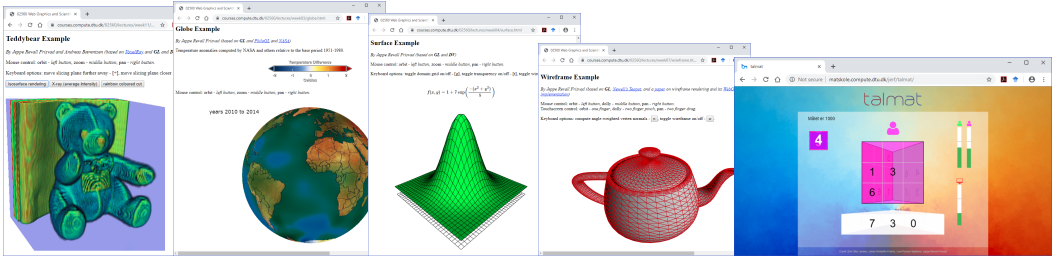






Why web graphics?

- Develop 3D graphics applications using only a text editor and a browser.
- Easy sharing of 3D graphics on all platforms (mobile included).
- Combine scientific reporting with interactive visualization in a webpage.
- Effortless integration of graphics with browser UI and image file I/O.



Instructors and teaching style

- Course responsible: Jeppe Revall Frisvad
- TA: Albert Garde
- TA: Frithjof Sletten
- Online TA: Julian Sempruch-Szachowicz, s230211@student.dtu.dk

- Lecture (8:00-9:30)
- Exercises (9:30-12:00)

- Lab journal: Save a set of solution files for each part of each worksheet.
- Project: Select, study and implement, describe in a report.

- Hand-in: HTML, JavaScript, and PDF (include all code in a ZIP file)
- Deadline: **18 December 2024 at 23:59**

02561 Computer Graphics

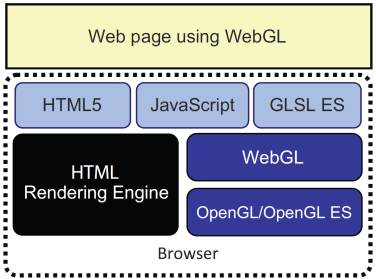
WebGL and Graphics Pipeline

Jeppe Revall Frisvad

August 2024

How to work with WebGL

- Select a browser and check its compatibility: `https://webglreport.com/`
- Select an editor. Some provide more code completion help than others.
- Create a webpage (HTML file) with
  - **HTML5** canvas element
  - **JavaScript** (in a separate JS file)
  - vertex shader script (**GLSL ES**)
  - fragment shader script (**GLSL ES**)

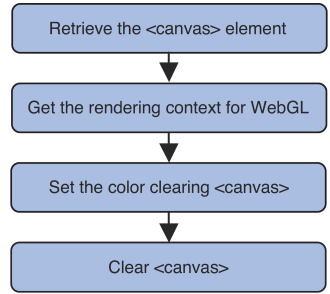


- Load utility libraries from existing JS files (webgl-utils.js, initShaders.js, MV.js) [**A**: 2.8]
- Open HTML file in browser and debug using "**Inspect** [Element]" <F12>
- Re-run the program after an edit by **reload**ing the webpage <F5>
- Save your graphic as an image by right-clicking the canvas (not all browsers)

Exercise: getting started (W01P1)

- Minimal program (quick reference card)

```
<!DOCTYPE html>
<html><body>
<canvas id="c" />
<script type="text/javascript">
    var canvas = document.getElementById("c");
    var gl = canvas.getContext("webgl");
    gl.clearColor(1.0, 0.0, 0.0, 1.0);
    gl.clear(gl.COLOR_BUFFER_BIT);
</script>
</body></html>
```

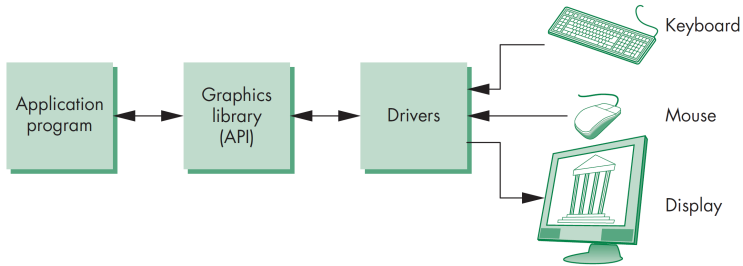


- Get the library files from angelCommon.zip on DTU Learn.
- Use **A**: 2.8 to set canvas size (this is the resolution of the rendered image) and an init function (in filename.js) and solve the first part of the first worksheet.

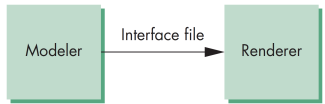
```
window.onload = function init()
{
  // My JavaScript code which runs when the webpage is loaded by the browser
}
```

Interactive computer graphics

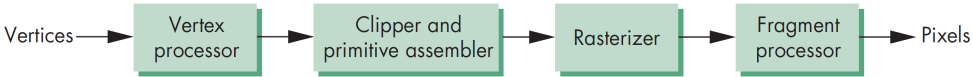
- Graphics system:



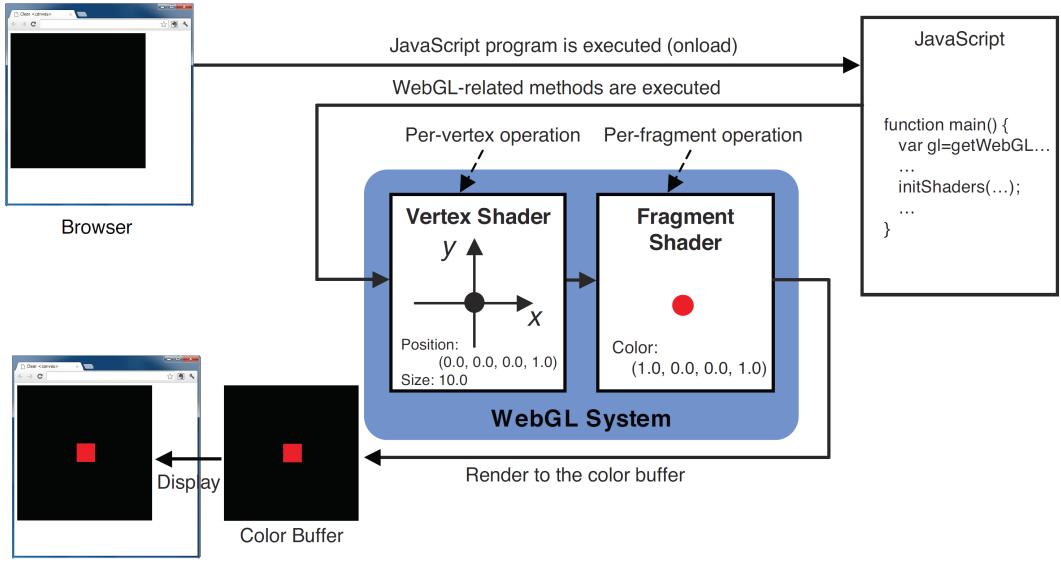
- Modeling-rendering paradigm:



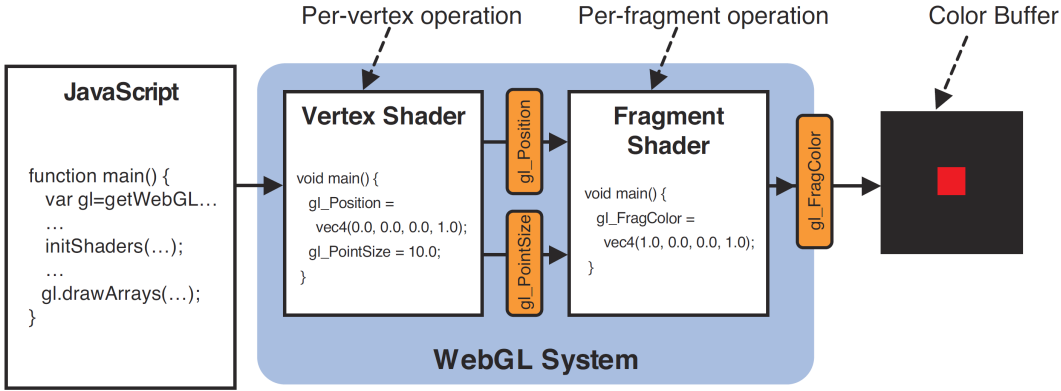
- Rasterization pipeline:



Shaders and processing flow



WebGL shaders in practice



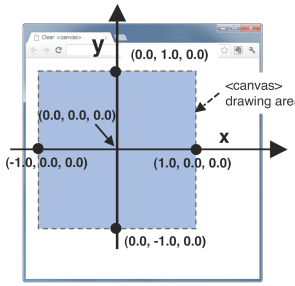
- **A**: 2.8

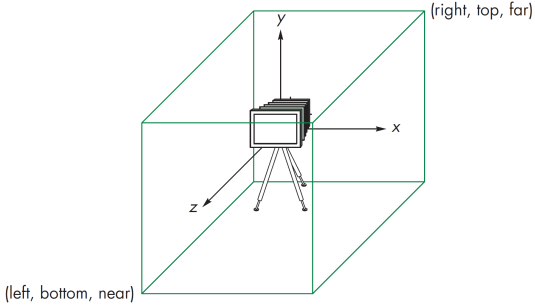
```
<script type="text/javascript" src="../common/initShaders.js"></script>
```

```
<script id="vertex-shader" type="x-shader/x-vertex">
    void main() {
      gl_Position = vec4(0.0, 0.0, 0.0, 1.0);
      gl_PointSize = 10.0;
    }
</script>
```

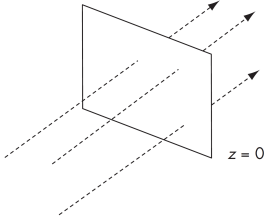
```
<script id="fragment-shader" type="x-shader/x-fragment">
    precision mediump float;
    void main() {
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
    }
</script>
```

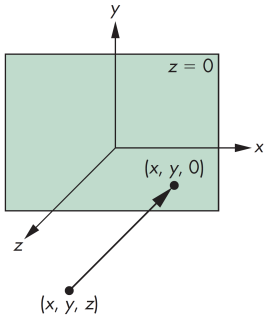
Drawing in 2D





- The default camera: $x, y, z \in [-1, 1]$.
- View volume and orthographic projection.





Attribute variables and data flow

- Stream data from the CPU to draw a number of points using the same shader:

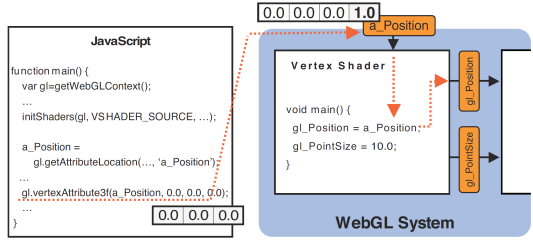
```
<script id="vertex-shader" type="x-shader/x-vertex">
    attribute vec4 a_Position;
    void main() {
      gl_Position = a_Position;
      gl_PointSize = 10.0;
    }
</script>
<script type="text/javascript" src="../common/MV.js"></script>
```

Storage Qualifier Type Variable Name

```
attribute vec4 a_Position;
```

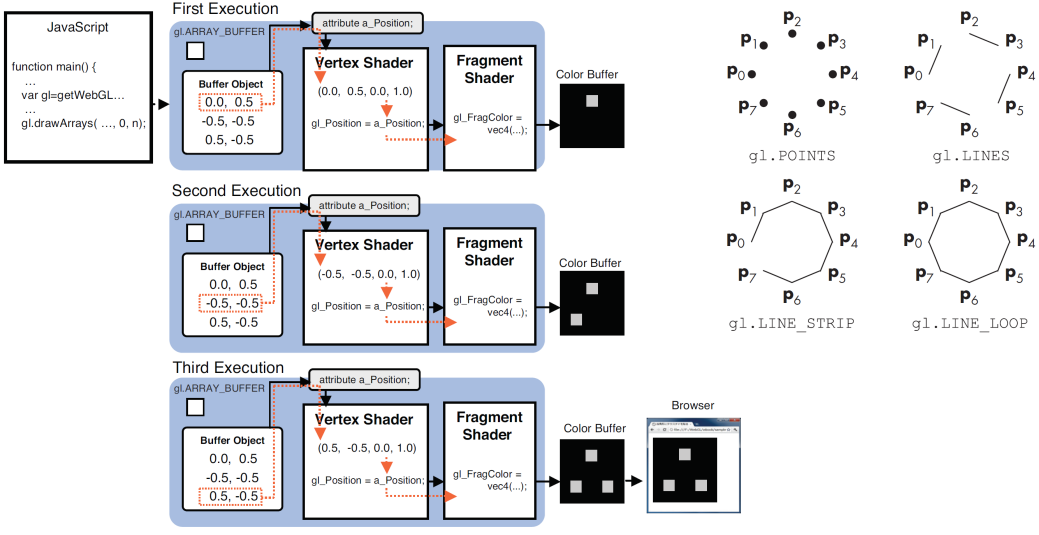
- In JavaScript init/main function:

```
var program = initShaders(gl, "vertex-shader", "fragment-shader");
gl.useProgram(program);

var vertices = [ vec2(0.0, 0.5), vec2(-0.5, -0.5), vec2(0.5, -0.5) ];
var vBuffer = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, vBuffer);
gl.bufferData(gl.ARRAY_BUFFER, flatten(vertices), gl.STATIC_DRAW);

var vPosition = gl.getAttribLocation(program, "a_Position");
gl.vertexAttribPointer(vPosition, 2, gl.FLOAT, false, 0, 0);
gl.enableVertexAttribArray(vPosition);
```



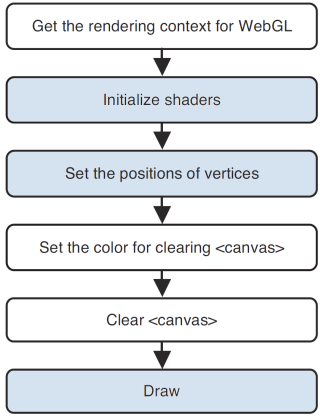
Start drawing

- Execution starts at the draw call. Example: `gl.drawArrays(gl.POINTS, 0, numPoints);`



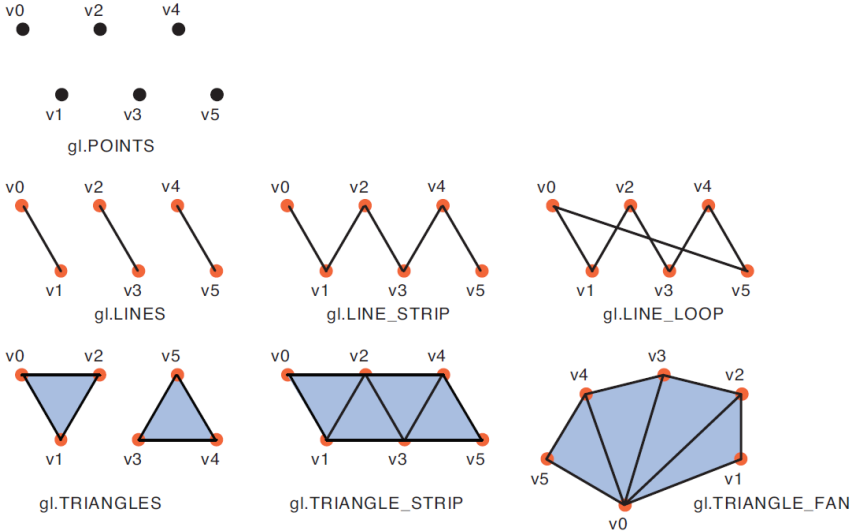
Exercise: hello points (W01P2)

- Copy and extend your solution for Part 1.
- Write, load, and use a shader program (**A**: 2.8.3-2.8.7).
- Set point size in the vertex shader (**A**: 2.5.3).
- Define point coordinates (array of vectors).
- Connect attribute variable to buffer (**A**: 2.8):
  - Create a buffer.
  - Bind the buffer object to a target.
  - Submit data to the buffer.
  - Assign the buffer object to an attribute variable.
  - Enable assignment.
- Draw the points after clearing (**A**: 2.4, 2.8.2).



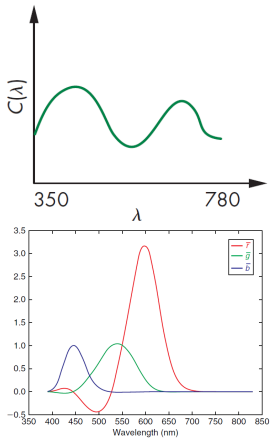
Basic shapes

- Another draw call example: `gl.drawArrays(gl.TRIANGLES, 0, numVertices);`

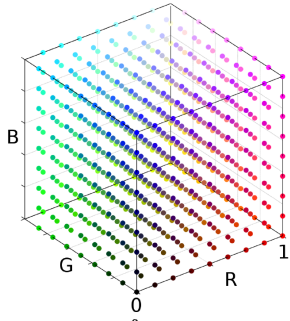


Colors

spectrum



RGB color space

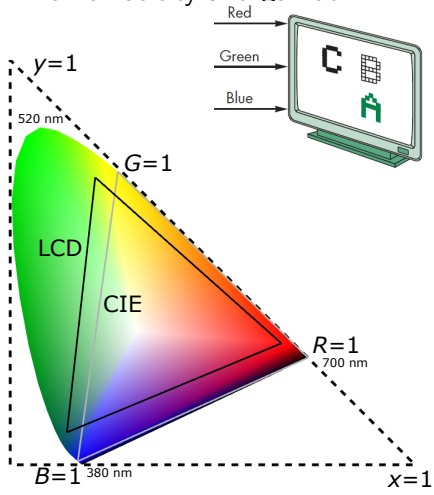


$$R = \int_{\mathcal{V}} C(\lambda)\bar{r}(\lambda)\,\mathrm{d}\lambda$$

$$G = \int_{\mathcal{V}} C(\lambda)\bar{g}(\lambda)\,\mathrm{d}\lambda$$

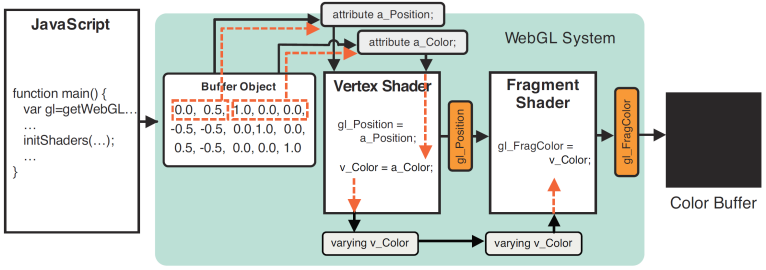
$$B = \int_{\mathcal{V}} C(\lambda)\bar{b}(\lambda)\,\mathrm{d}\lambda$$

chromaticity and gamut



From vertex to fragment

- We can attach color as a vertex attribute just like position (see above).
- Pass data from vertex to fragment shader using a varying variable.

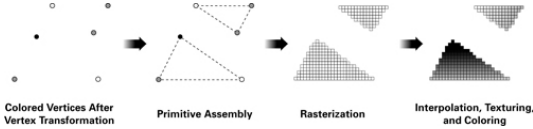


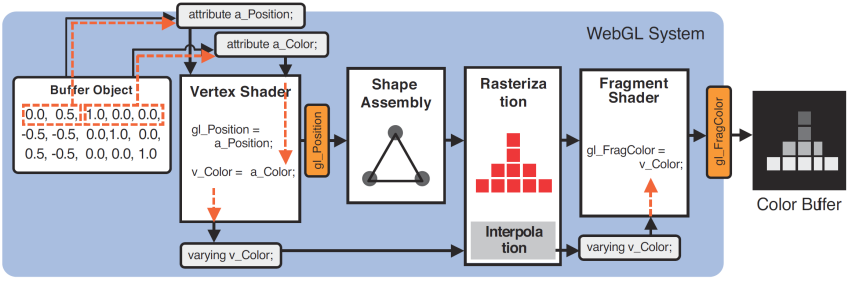
- **A**: 2.10

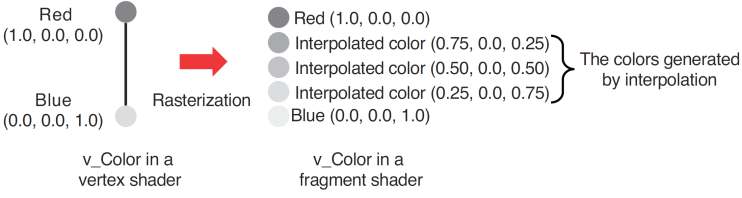
```
<script id="vertex-shader" type="x-shader/x-vertex">
    attribute vec4 a_Position;
    attribute vec4 a_Color;
    varying vec4 v_Color;
    void main() {
      v_Color = a_Color;
      gl_Position = a_Position;
    }
</script>
```

```
<script id="fragment-shader" type="x-shader/x-fragment">
    precision mediump float;
    varying vec4 v_Color;
    void main() {
      gl_FragColor = v_Color;
    }
</script>
```

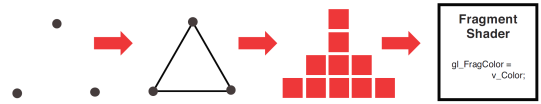
Rasterization and interpolation







Exercise: hello triangle (W01P3)



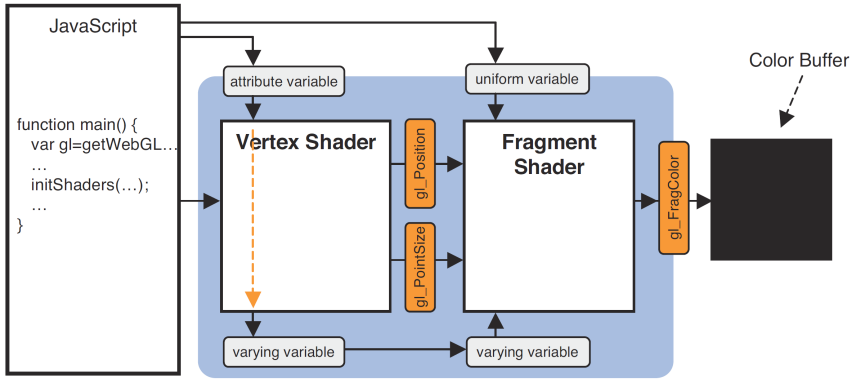
- Copy and extend your solution for Part 2.
- Update the vertex shader to include a color attribute that is passed to the fragment shader as a varying variable.
- Define colors (array of vectors).
- Connect color attribute variable to buffer:
  - Create a buffer.
  - Bind the buffer object to a target.
  - Submit data to the buffer.
  - Assign the buffer object to an attribute variable.
  - Enable assignment.
- Draw a triangle after clearing.

Uniform variables

Storage Qualifier Type Variable Name

```
uniform vec4 u_FragColor;
```

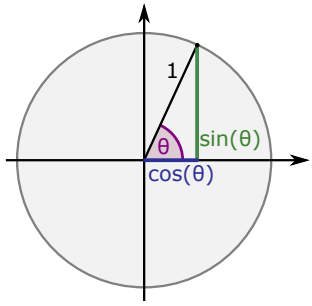
- Use uniform variables to pass parameters that do not change per vertex.
- Uniforms can be used in both vertex and fragment shader.

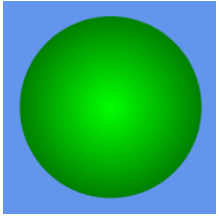



```
var u_FragColorLoc = gl.getUniformLocation(program, "u_FragColor");
gl.uniform4f(u_FragColorLoc, rgba[0], rgba[1], rgba[2], rgba[3]);
```

Drawing a circle

- Create a position array and a color array containing the center vertex only.
- Select radius r and number of points n to represent the circle.
- Loop from $i = 0$ to $i = n$:
  - Calculate angle $\theta = 2\pi i/n$ (π is available as `Math.PI`).
  - Use radius, sine (`Math.sin`), and cosine (`Math.cos`) to calculate a position $(r\cos\theta, r\sin\theta)$ on the circle.
  - Push position and color to corresponding arrays.
- Submit data to position and color attribute buffers.
- Draw as a triangle fan with $n + 2$ vertices.





The WebGPU version (new API expected to supersede WebGL)

- The application consists of an HTML file and a JS file (just like WebGL)

make a canvas

```
<!DOCTYPE html>
<html>
<head>
    <title>W1P1</title>
    <script type="text/javascript" src="w1p1.js"></script>
</head>
<body>
    <canvas id="webgpu-canvas" width="512" height="512">
        Please use a browser that supports HTML5 canvas.
    </canvas>
</body>
</html>
```

- The background JavaScript needs an asynchronous main function:

make a rendering context

```
"use strict";
window.onload = function () { main(); }
async function main()
{
  const gpu = navigator.gpu;
  const adapter = await gpu.requestAdapter();
  const device = await adapter.requestDevice();
  const canvas = document.getElementById("webgpu-canvas");
  const context = canvas.getContext("gpupresent") || canvas.getContext("webgpu");
  const canvasFormat = navigator.gpu.getPreferredCanvasFormat();
  context.configure({
    device: device,
    format: canvasFormat,
  });

  // Create a render pass in a command buffer and submit it
  ⋮
}
```

Clearing the canvas (W01P1)

- The render pass command buffer:

```
// Create a render pass in a command buffer and submit it
const encoder = device.createCommandEncoder();
const pass = encoder.beginRenderPass({
  colorAttachments: [{
     view: context.getCurrentTexture().createView(),
     loadOp: "clear",
     clearValue: { r: 1.0, g: 0.0, b: 0.0, a: 1.0 },
     storeOp: "store",
  }]
});
// Insert render pass commands here
pass.end();
device.queue.submit([encoder.finish()]);
```

- Writing WGSL shaders in the HTML file:

```
<script id="wgsl" type="x-shader">
@vertex
fn main_vs(@location(0) pos: vec2f) -> @builtin(position) vec4f
{
    return vec4f(pos, 0, 1);
}

@fragment
fn main_fs() -> @location(0) vec4f
{
    return vec4f(0.0, 0.0, 0.0, 1.0);
}
</script>
```

Setting up a render pipeline

- Load the WGSL shaders from the HTML file and use them for the render pipeline:

```
const wgsl = device.createShaderModule({
  code: document.getElementById("wgsl").text
});

const pipeline = device.createRenderPipeline({
  layout: "auto",
  vertex: {
    module: wgsl,
    entryPoint: "main_vs",
    buffers: [vertexBufferLayout]
  },
  fragment: {
    module: wgsl,
    entryPoint: "main_fs",
    targets: [{ format: canvasFormat }]
  },
  primitive: {
    topology: "triangle-list",
    // GPUPrimitiveTopology { "point-list", "line-list", "line-strip", "triangle-list", "triangle-strip" };
  },
});
```

- Add the pipeline and a draw call to the render pass:

```
pass.setPipeline(pipeline);
pass.setVertexBuffer(0, vertexBuffer);
pass.draw(vertices.length);
```

Setting up a vertex buffer and drawing points (W01P2)

- Creating a buffer and connecting it to location 0 of the vertex shader:

```
const point_size = 10*(2/canvas.height);
var vertices = [];
add_point(vertices, vec2( 0.0,  0.5), point_size);
add_point(vertices, vec2(-0.5, -0.5), point_size);
add_point(vertices, vec2( 0.5, -0.5), point_size);

const vertexBuffer = device.createBuffer({
  size: flatten(vertices).byteLength,
  usage: GPUBufferUsage.VERTEX | GPUBufferUsage.COPY_DST,
});
device.queue.writeBuffer(vertexBuffer, /*bufferOffset=*/0, flatten(vertices));

const vertexBufferLayout = {
  arrayStride: sizeof["vec2"],
  attributes: [{
    format: "float32x2",
    offset: 0,
    shaderLocation: 0, // Position, see vertex shader
  }],
};
```

- Point size is one and immutable in WebGPU. Use triangles to draw points:

```
function add_point(array, point, size)
{
  const offset = size/2;
  var point_coords = [ vec2(point[0] - offset, point[1] - offset), vec2(point[0] + offset, point[1] - offset),
                       vec2(point[0] - offset, point[1] + offset), vec2(point[0] - offset, point[1] + offset),
                       vec2(point[0] + offset, point[1] - offset), vec2(point[0] + offset, point[1] + offset) ];
  array.push.apply(array, point_coords);
}
```

Passing information from the vertex to the fragment shader (W01P3)

- Setting up a varying variable in WebGPU:

```
<script id="wgsl" type="x-shader">
struct VSOut {
  @builtin(position) position: vec4f,
  @location(0)       color   : vec3f,
};

@vertex
fn main_vs(@location(0) inPos: vec2f,
           @location(1) inColor: vec3f) -> VSOut
{
  var vsOut: VSOut;
  vsOut.position = vec4f(inPos, 0.0, 1.0);
  vsOut.color    = inColor;
  return vsOut;
}

@fragment
fn main_fs(@location(0) inColor: vec3f) -> @location(0) vec4f
{
  return vec4f(inColor, 1.0);
}
</script>
```

- A vertex color buffer is set up in the same way as a vertex position buffer.
- The color buffer layout needs to be added to the `buffers` array of the pipeline.
- The vertex color buffer needs to be added to the render pass at location 1.

Setting up uniform variables

- Data that are the same for all vertices are called Uniforms.
- We can define them at the top of our WGSL code:

```
struct Uniforms {
  theta: f32,
};
@group(0) @binding(0) var<uniform> uniforms : Uniforms;
```

- and use them like other structs:

```
let sin_theta = sin(uniforms.theta);
```

- But they require some infrastructure on the JavaScript side:

```
var theta = new Float32Array([0.0]);
const uniformBuffer = device.createBuffer({
  size: theta.byteLength,
  usage: GPUBufferUsage.UNIFORM | GPUBufferUsage.COPY_DST,
});
const bindGroup = device.createBindGroup({
  layout: pipeline.getBindGroupLayout(0),
  entries: [{
    binding: 0,
    resource: { buffer: uniformBuffer }
  }],
});
device.queue.writeBuffer(uniformBuffer, 0, theta);
```

- and a command needs to be added to the render pass before the draw call:

```
pass.setBindGroup(0, bindGroup);
```