Welcome to 02561: Computer Graphics

Jeppe Revall Frisvad

August 2022

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

- Three weeks for covering the basics.

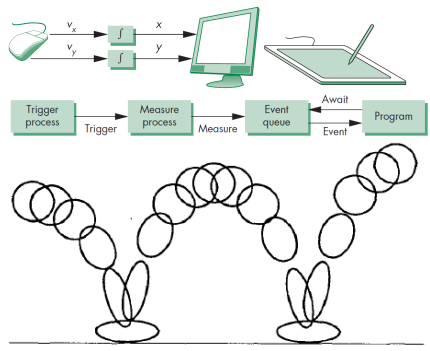


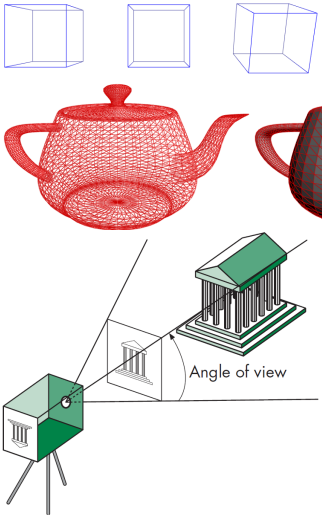
FIGURE 2. Squash & stretch in bouncing ball.

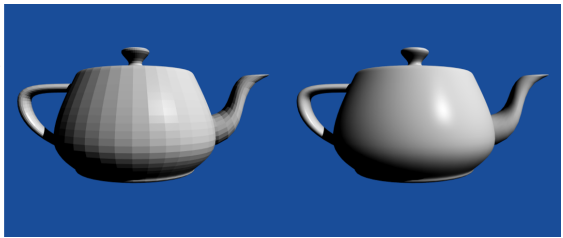
Figure references

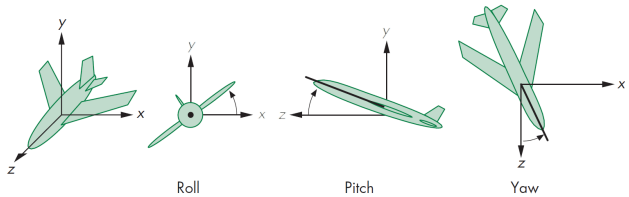
- Worksheet 2 and Wikimedia Commons.
- Angel, E., and Shreiner, D. *Interactive Computer Graphics: A Top-Down Approach with WebGL*, seventh edition. Pearson, 2015.
- Lasseter, J. Principles of traditional animation applied to 3D computer animation. *Computer Graphics (SIGGRAPH '87) 21*(4):35-44, 1987.

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

- Three weeks for adding depth.

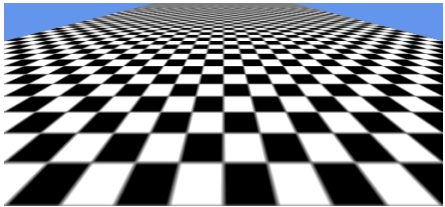


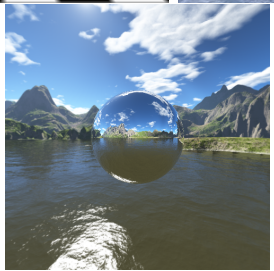
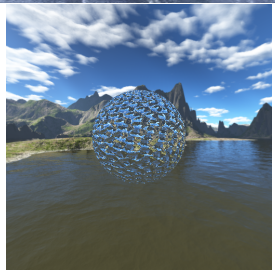




Mapping, blending, off-screen buffers, multiple shaders (weeks 7–10)

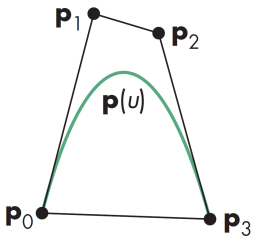
- Four weeks for shading pixels.

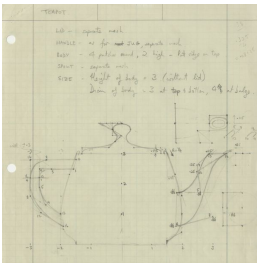


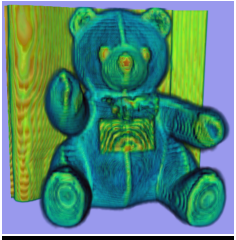




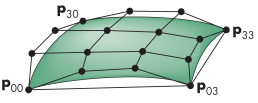
Advanced techniques (weeks 11–13)

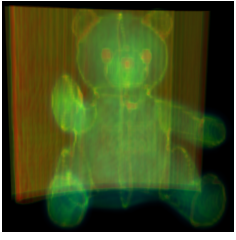
- Three weeks for curves, surfaces, volumes, and visual effects.





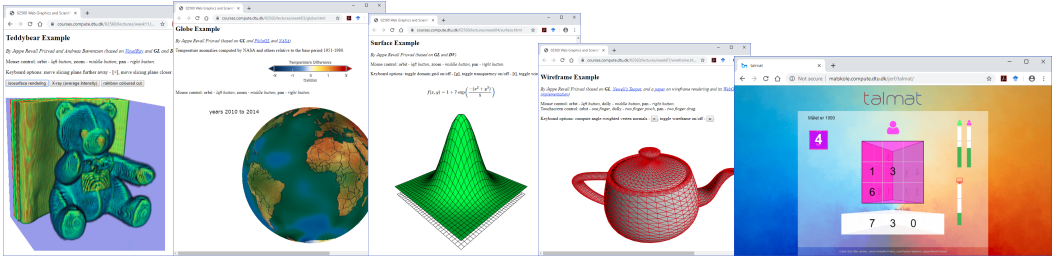






Why web graphics?

- 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

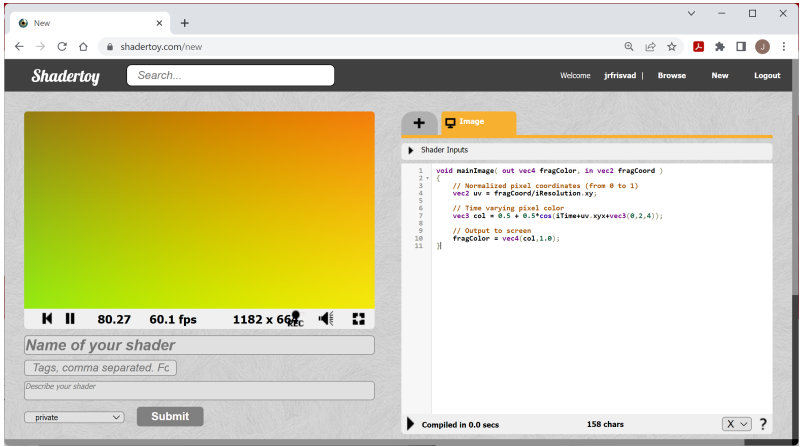
- Course responsible: Jeppe Revall Frisvad
- TA (online): Henrik Philippi, heph@dtu.dk
- TA (onsite): Minh Tran

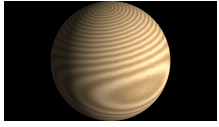
- Lectures and exercises interspersed (8:00-10:00)
- Exercises (10:00-12:00)

- 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 and/or PDF (include all code in a ZIP file)
- Deadline: **18 December 2022 at 23:59**

ShaderToy intro: go to shadertoy.com





- Let's make a sphere carved out of wood.
- We own all the pixels and write one function to be executed for each pixel.
- **Input** (`fragCoord`): pixel index. **Output** (`fragColor`): RGBA color vector in $[0,1]^4$.

02561 Computer Graphics

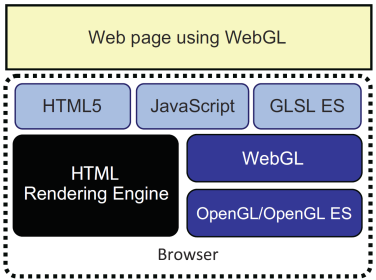
WebGL and Graphics Pipeline

Jeppe Revall Frisvad

August 2022

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**)

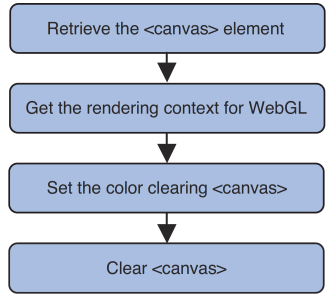


- Load utility libraries from existing JS files (webgl-utils.js, initShaders.js, MV.js) [**A**: 2.8]
- Open HTML file in browser and debug using "**Inspect** [Element]" <F12>
- Re-run the program after an edit by **reload**ing the webpage <F5>
- Save your graphic as an image by right-clicking the canvas (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>
```

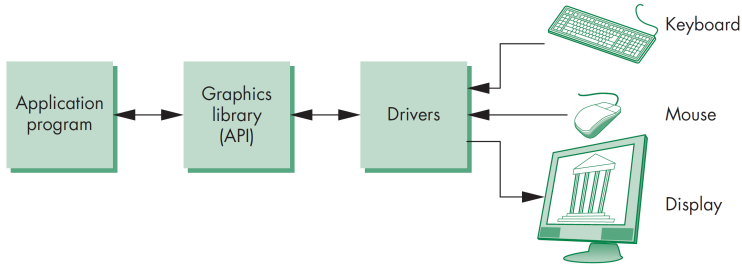


- Get the library files from angelCommon.zip on DTU Learn.
- Use **A**: 2.8 to set canvas size (this is the resolution of the rendered image) and an init function (in filename.js) and solve the first part of the first worksheet.

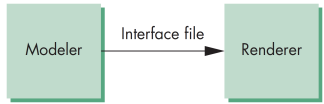
```
window.onload = function init()
{
  // My JavaScript code which runs when the webpage is loaded by the browser
}
```

Interactive computer graphics

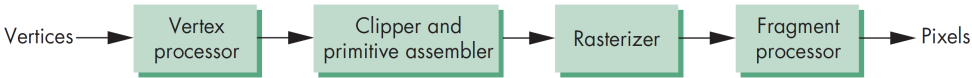
- Graphics system:



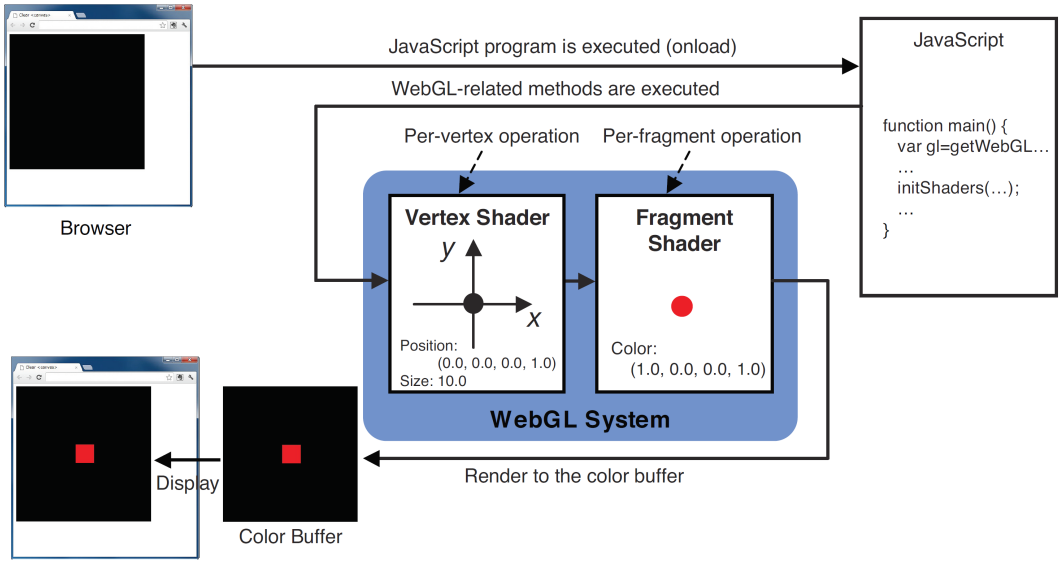
- Modeling-rendering paradigm:



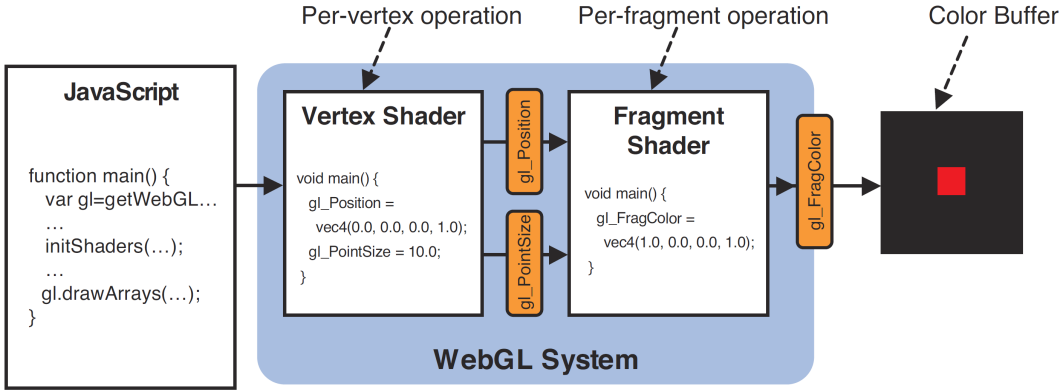
- Rasterization pipeline:



Shaders and processing flow



WebGL shaders in practice



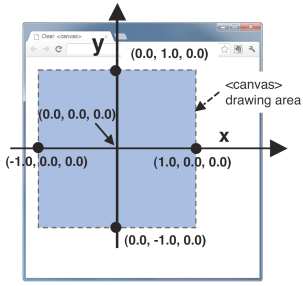
- **A**: 2.8

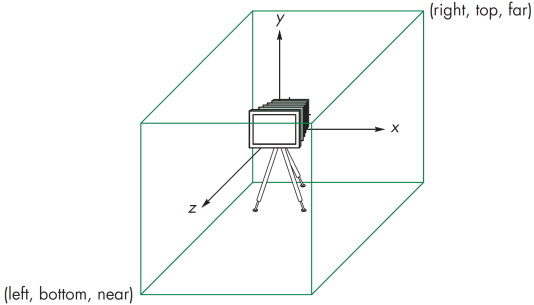
```
<script type="text/javascript" src="../common/initShaders.js"></script>
```

```
<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>
```

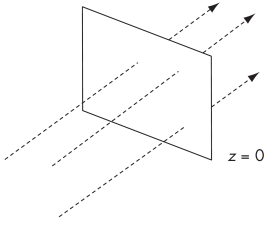
```
<script id="fragment-shader" type="x-shader/x-fragment">
    precision mediump float;
    void main() {
      gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
    }
</script>
```

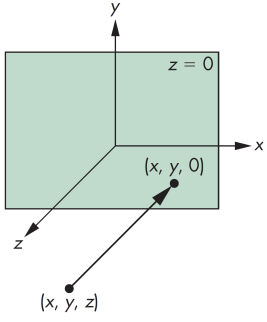
Drawing in 2D





- 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:

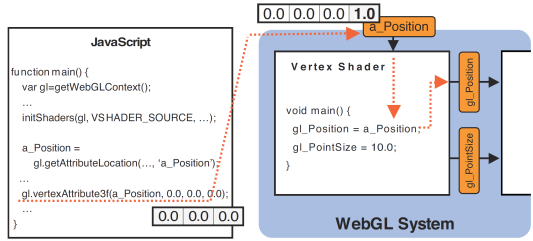
```
<script id="vertex-shader" type="x-shader/x-vertex">
    attribute vec4 a_Position;
    void main() {
      gl_Position = a_Position;
      gl_PointSize = 10.0;
    }
</script>
<script type="text/javascript" src="../common/MV.js"></script>
```

Storage Qualifier Type Variable Name

```
attribute vec4 a_Position;
```

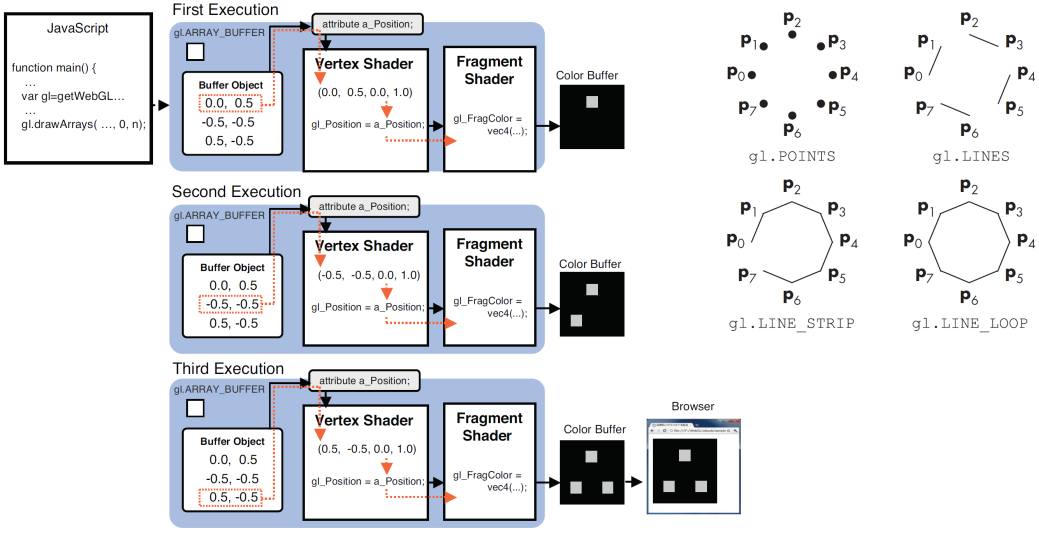
- In JavaScript init/main function:

```
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);
```



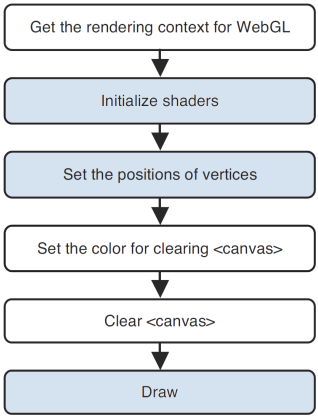
Start drawing

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



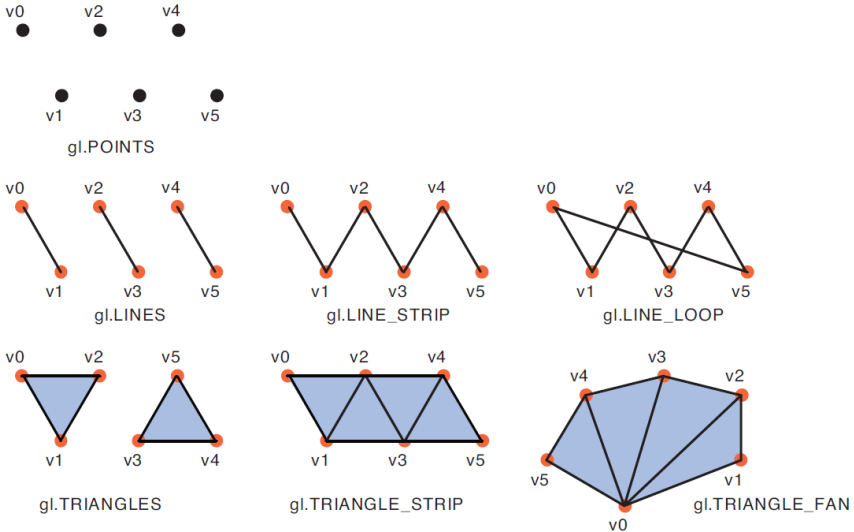
Exercise: hello points (W01P2)

- 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).



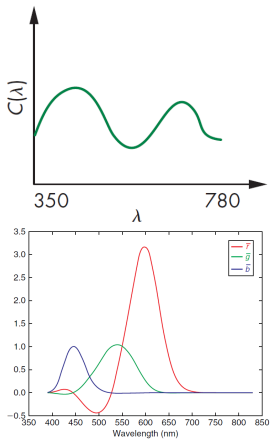
Basic shapes

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

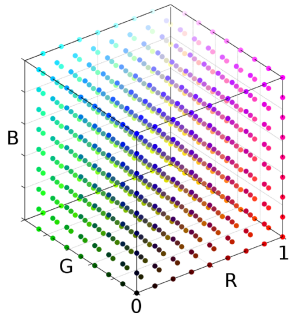


Colors

spectrum



RGB color space

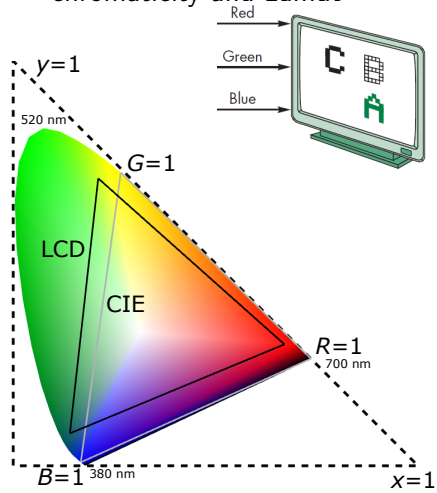


$$R = \int_{\mathcal{V}} C(\lambda)\bar{r}(\lambda)\,\mathrm{d}\lambda$$

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

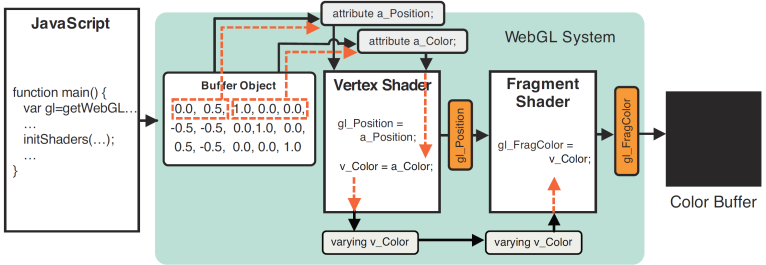
$$B = \int_{\mathcal{V}} C(\lambda)\bar{b}(\lambda)\,\mathrm{d}\lambda$$

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.

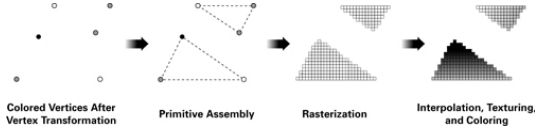


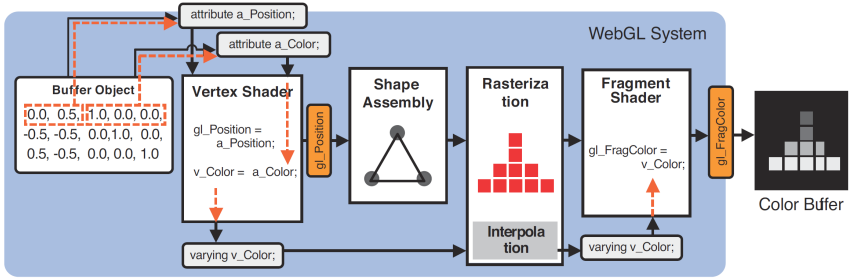
- **A**: 2.10

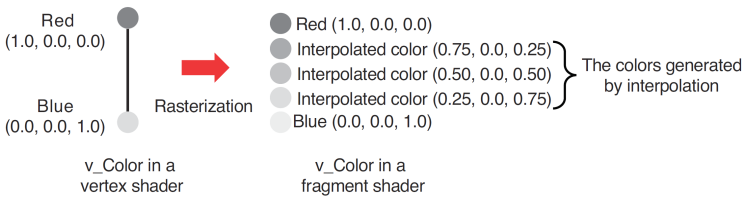
```
<script id="vertex-shader" type="x-shader/x-vertex">
    attribute vec4 a_Position;
    attribute vec4 a_Color;
    varying vec4 v_Color;
    void main() {
      v_Color = a_Color;
      gl_Position = a_Position;
    }
</script>
```

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

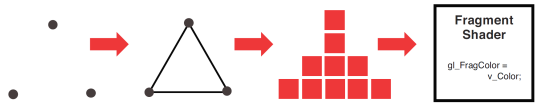
Rasterization and interpolation







Exercise: hello triangle (W01P3)



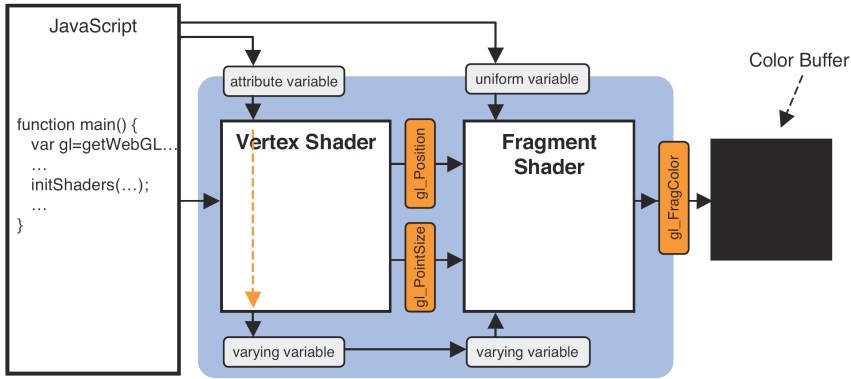
- Copy and extend your solution for Part 2.
- Update the vertex shader to include a color attribute that is passed to the fragment shader as a varying variable.
- Define colors (array of vectors).
- Connect color attribute variable to buffer:
  - Create a buffer.
  - Bind the buffer object to a target.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