3D Web App Creation

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Contents

Why use Web technologies for 3D?

- **mobile** experiences
- **open** technology stack
  - **cross-platform**, no installation, no app store
  - open source
  - **non-proprietary** (unlike Unity or Unreal Engine)
  - **free**
- leverage many other existing web APIs

cover art : "Chill the lion" by Karim Maaloul https://codepen.io/Yakudoo/details/YXxmYR/

Steps

- Run
- Debug
- Build
- Modify
- Create

Run: check your drivers

- Update your graphics card drivers if possible
- **Linux**: if your GPU is not properly detected, [uninstall NVIDIA drivers]() and use the default ones provided by Ubuntu

```
sudo apt-get remove --purge '^nvidia-.*'
sudo apt-get install ubuntu-desktop
sudo rm /etc/X11/xorg.conf
echo 'nouveau' | sudo tee -a /etc/modules
reboot
```

Run: testing on your mobile

- Check that your smartphone can read QR codes
- iOS : default Camera app
- Android
  - use Google Chrome + scan button
  - or install a **trustworthy** QR code scanning app like **Trend Micro**
- Other 100% web based alternatives
  - webqr.com
  - qrcodescan.in

Debug

- There will be bugs :) 🐛
- F12
- `debugger` statement
- Tips:
  - https://webglfundamentals.org/webgl/lessons/webgl-setup-and-installation.html
  - https://threejs.org/manual/en/debugging-javascript.html
  - https://www.khronos.org/webgl/wiki/Debugging

Build: tools

- Web development
  - browser (Firefox, Chrome, Safari Mobile)
  - Git (optional yet extremely useful)
  - editor (VSCode), or Glitch (slow, but no installation needed!)
- Technologies: HTML, JS, CSS, WebGL, THREE.js
- Optional:
  - OpenStreetMap, OpenLayers, CesiumJS, Géoservices IGN

Browser installation

- Firefox installed by default
  - should be enough!
- Chrome
  - to test compatibility as well as some special features
  - install latest version (97+) on mobile
  - you may install Chromium on your desktop
    - open-source without proprietary services

```
sudo apt-get install chromium-browser
```

Git installation

```
sudo apt-get install git

git config --global user.name "myusername"
git config --global user.email myname@mymailprovider.com
```

VSCode installation

```
sudo apt update
sudo apt install software-properties-common apt-transport-https wget

wget -q https://packages.microsoft.com/keys/microsoft.asc -O- | sudo apt-key add -

sudo add-apt-repository "deb [arch=amd64] https://packages.microsoft.com/repos/vscode stable main"

sudo apt install code
```

Remove GPG warnings

```
sudo gpgconf --kill dirmngr
sudo chown -R $USER:$USER ~/.gnupg
```

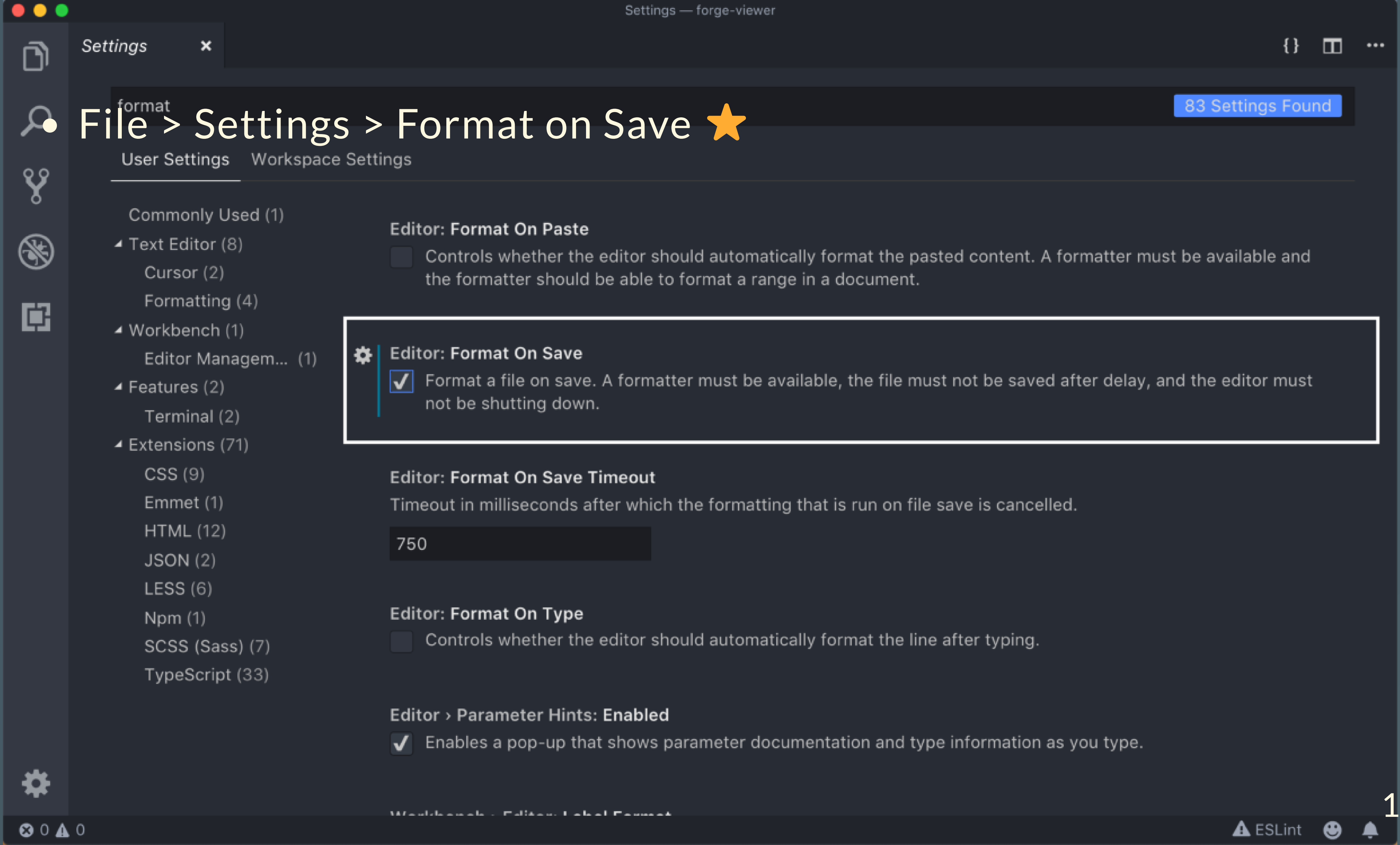
Customize VS Code

- Avoid UI blinking by changing the settings:

```
set window.titleBarStyle to custom
```

- Recommended extensions
  - Live Server
  - Git Graph and/or Git Lens
  - glTF Model Viewer, glTF Tools
  - WebGL GLSL Editor, glsl-canvas
  - Todo Tree, Color Highlight

File > Settings > Format on Save ★



Development environment setup

- Files cannot be loaded from disk without a user action
- **CORS**: Cross Origin Resource Sharing
    - one of the many web browser security measures

➡️ need to run a server like Live Server, or:

```
$ cd /home/somedir
$ python -m SimpleHTTPServer
```

And then point your browser at `http://localhost:8000`

Glitch: online interactive editor

- https://glitch.com/
- THREE.js example

But also VSCode.dev, Codepen.io, Repl.it etc.

WebGL Exercices

inspired by

- [webglacademy]
- [webglfundamentals] ⭐
- [webgl2fundamentals]

Check that WebGL is supported

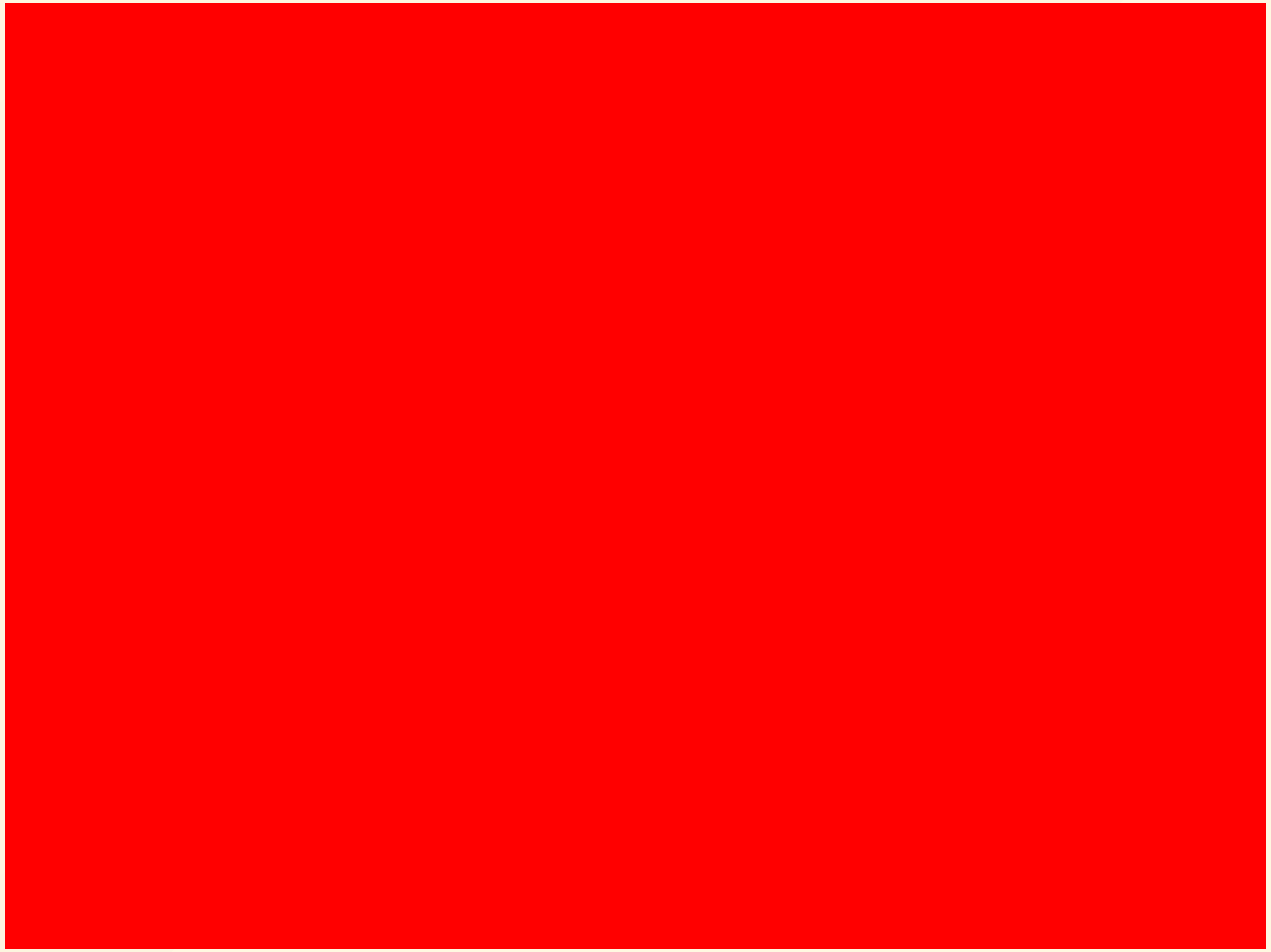
- https://caniuse.com/webgl
- https://webglreport.com/

Reminder: Minimalistic web page

```html
<!DOCTYPE html>
<html>

<head>
    <meta charset='utf-8'>
</head>

<body>
</body>

</html>
```

Reminder: Minimalistic drawing program using the Canvas API

```html
<!DOCTYPE html>
<html>

<head>
    <meta charset='utf-8'>
</head>
<body>
    <canvas width='640' height='480'></canvas>
    <script>
        const canvas = document.querySelector('canvas');
        const ctx = canvas.getContext('2d'); // get 2D rendering context, on which we'll draw
        ctx.fillStyle = 'rgba(255, 0, 0, 1)'; // a.k.a. 'red': opaque red
        ctx.fillRect(0, 0, canvas.width, canvas.height); // uses current color
    </script>
</body>

</html>
```



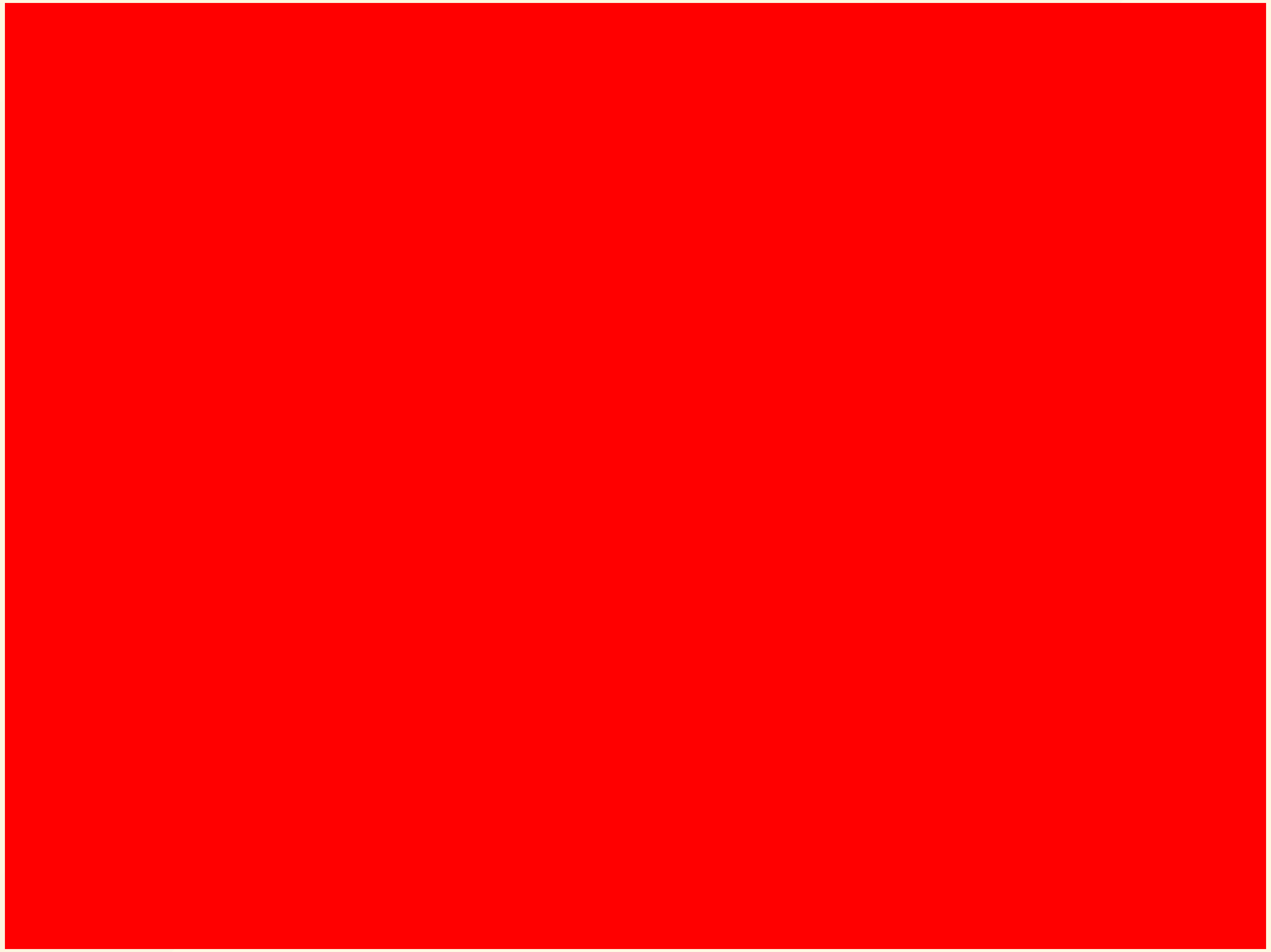
"There Is Also Canvas"

Bruno Imbrizi

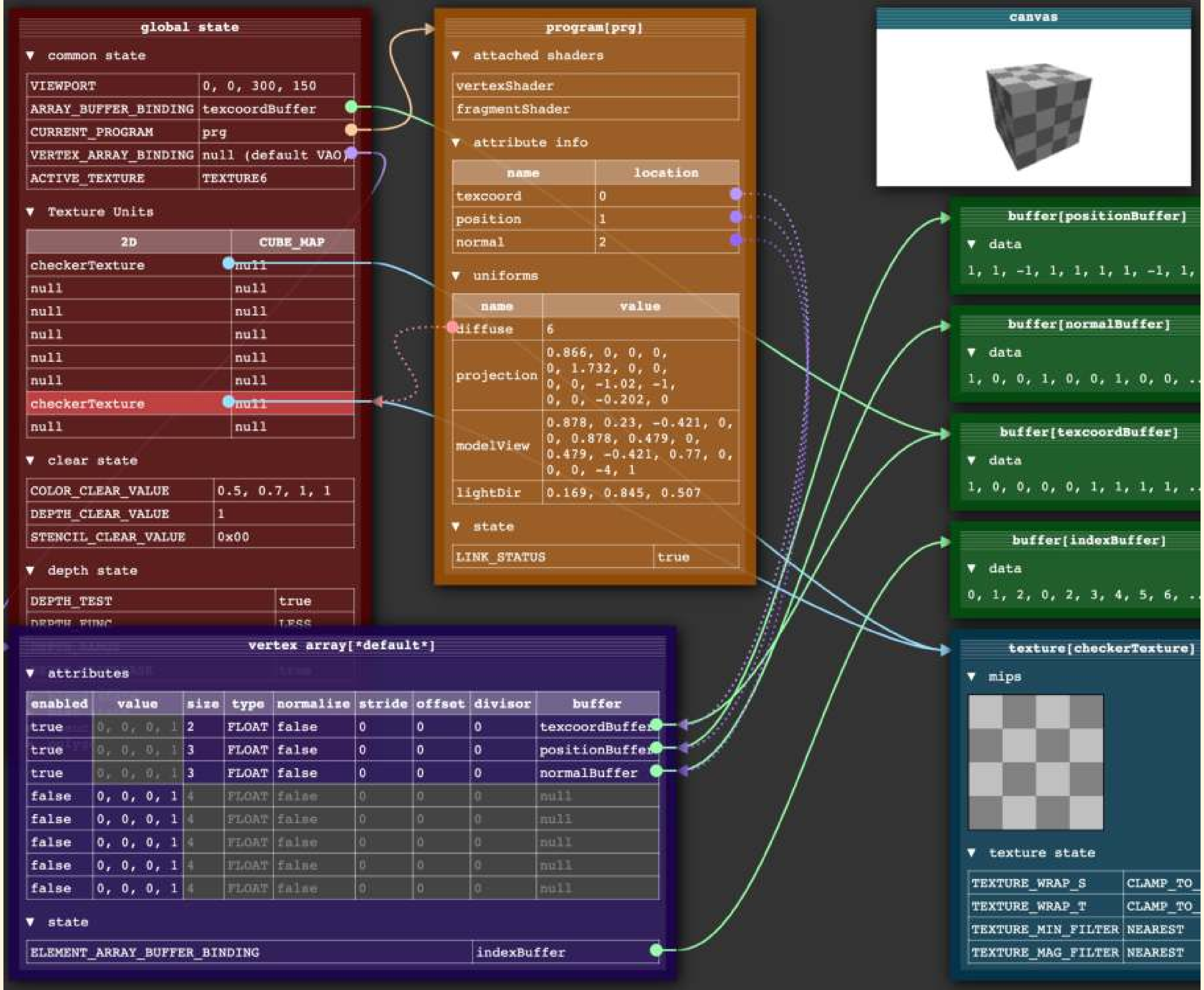
Minimalistic WebGL program: to ensure that everything works fine

⚠️ **no error checks**, for clarity reasons (*don't do this at home!* 😉)

```
<!DOCTYPE html>
<html>
<head>
    <meta charset='utf-8'>
</head>
<body>
    <canvas width='640' height='480'></canvas>
    <script>
        const canvas = document.querySelector('canvas');
        /** @type {WebGLRenderingContext} */
        const gl = canvas.getContext('webgl'); // instead of '2d'
        gl.clearColor(1., 0., 0., 1.); // RGBA: opaque red
        gl.clear(gl.COLOR_BUFFER_BIT); // uses current color (state machine)
    </script>
</body>
</html>
```



States


global state
common state
VIEWPORT
0, 0, 300, 150
ARRAY_BUFFER_BINDING
texcoordBuffer
CURRENT_PROGRAM
prg
VERTEX_ARRAY_BINDING
null (default VAO)
ACTIVE_TEXTURE
TEXTURE6
Texture Units
2D
CUBE_MAP
checkerTexture
null
checkerTexture
clear state
COLOR_CLEAR_VALUE
0.5, 0.7, 1, 1
DEPTH_CLEAR_VALUE
1
STENCIL_CLEAR_VALUE
0x00
depth state
DEPTH_TEST
true
program[prg]
attached shaders
vertexShader
fragmentShader
attribute info
name
location
texcoord
0
position
1
normal
2
uniforms
name
value
diffuse
6
projection
0.866, 0, 0, 0,
0, 1.732, 0, 0,
0, 0, -1.02, -1,
0, 0, -0.202, 0
modelView
0.878, 0.23, -0.421, 0,
0, 0.878, 0.479, 0,
0.479, -0.421, 0.77, 0,
0, 0, -4, 1
lightDir
0.169, 0.845, 0.507
state
LINK_STATUS
true
canvas
buffer[positionBuffer]
data
1, 1, -1, 1, 1, 1, 1, -1, 1,
buffer[normalBuffer]
data
1, 0, 0, 1, 0, 0, 1, 0, 0, ..
buffer[texcoordBuffer]
data
1, 0, 0, 0, 0, 1, 1, 1, 1, ..
buffer[indexBuffer]
data
0, 1, 2, 0, 2, 3, 4, 5, 6, ..
texture[checkerTexture]
mips
texture state
TEXTURE_WRAP_S
CLAMP_TO_
TEXTURE_WRAP_T
CLAMP_TO_
TEXTURE_MIN_FILTER
NEAREST
TEXTURE_MAG_FILTER
NEAREST
vertex array[*default*]
attributes
enabled
value
size
type
normalize
stride
offset
divisor
buffer
true
2
FLOAT
false
0
0
0
texcoordBuffer
true
3
FLOAT
false
0
0
0
positionBuffer
true
3
FLOAT
false
0
0
0
normalBuffer
false
0, 0, 0, 1
null
state
ELEMENT_ARRAY_BUFFER_BINDING
indexBuffer

Minimalistic "useful" program: **shaders**, but no vertex buffer yet

Add this code after `gl.clear`:

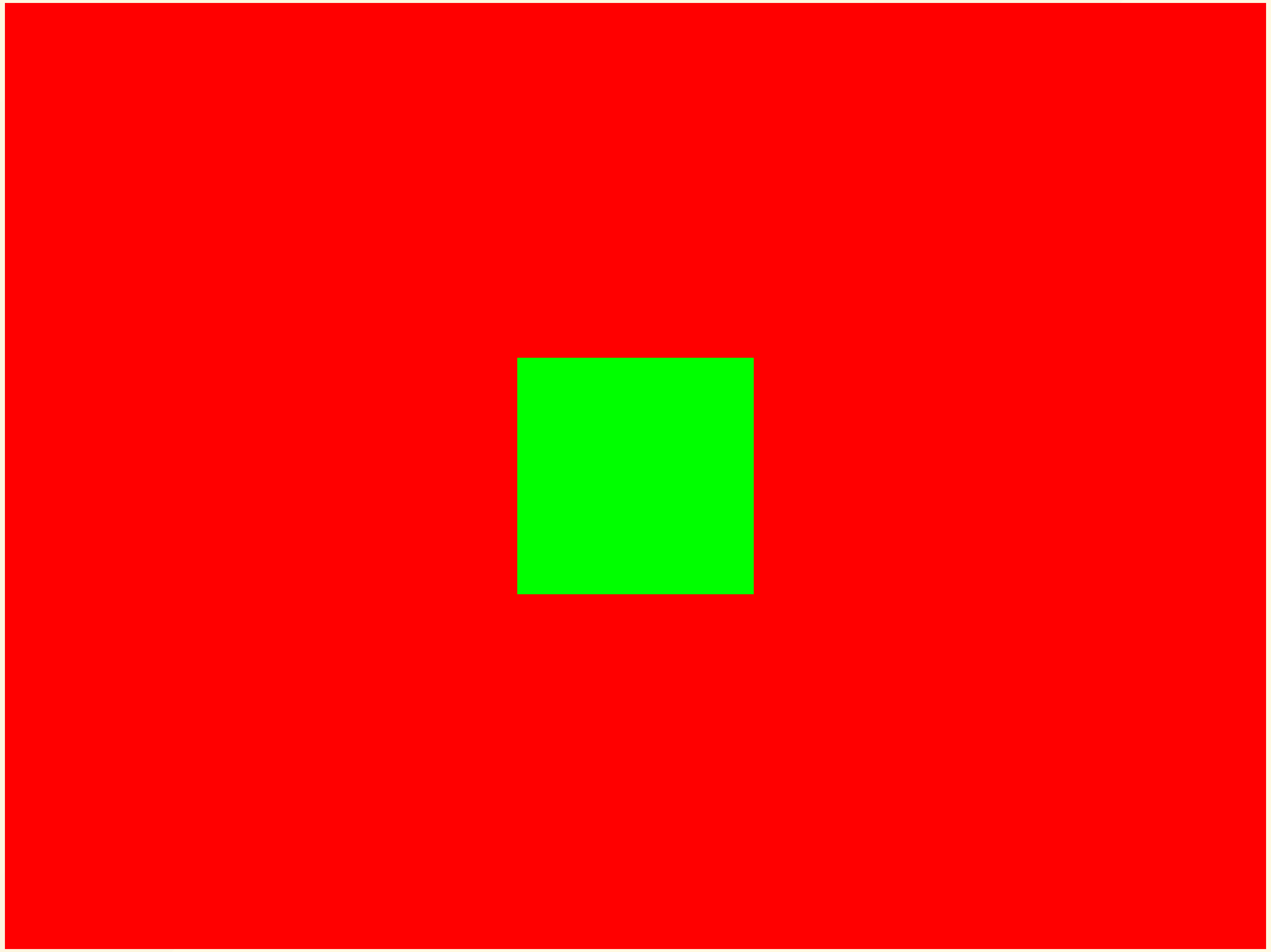
```
// vertex shader
const vs_source = `
void main() {
    gl_Position = vec4(0., 0., 0., 1.);  // center
    gl_PointSize = 120.0;
}`;

// fragment shader
const fs_source = `
precision mediump float;

void main() {
    gl_FragColor = vec4(0., 1., 0., 1.);  // green
}`;
```

Additional code: useful functions (still no error checks!)

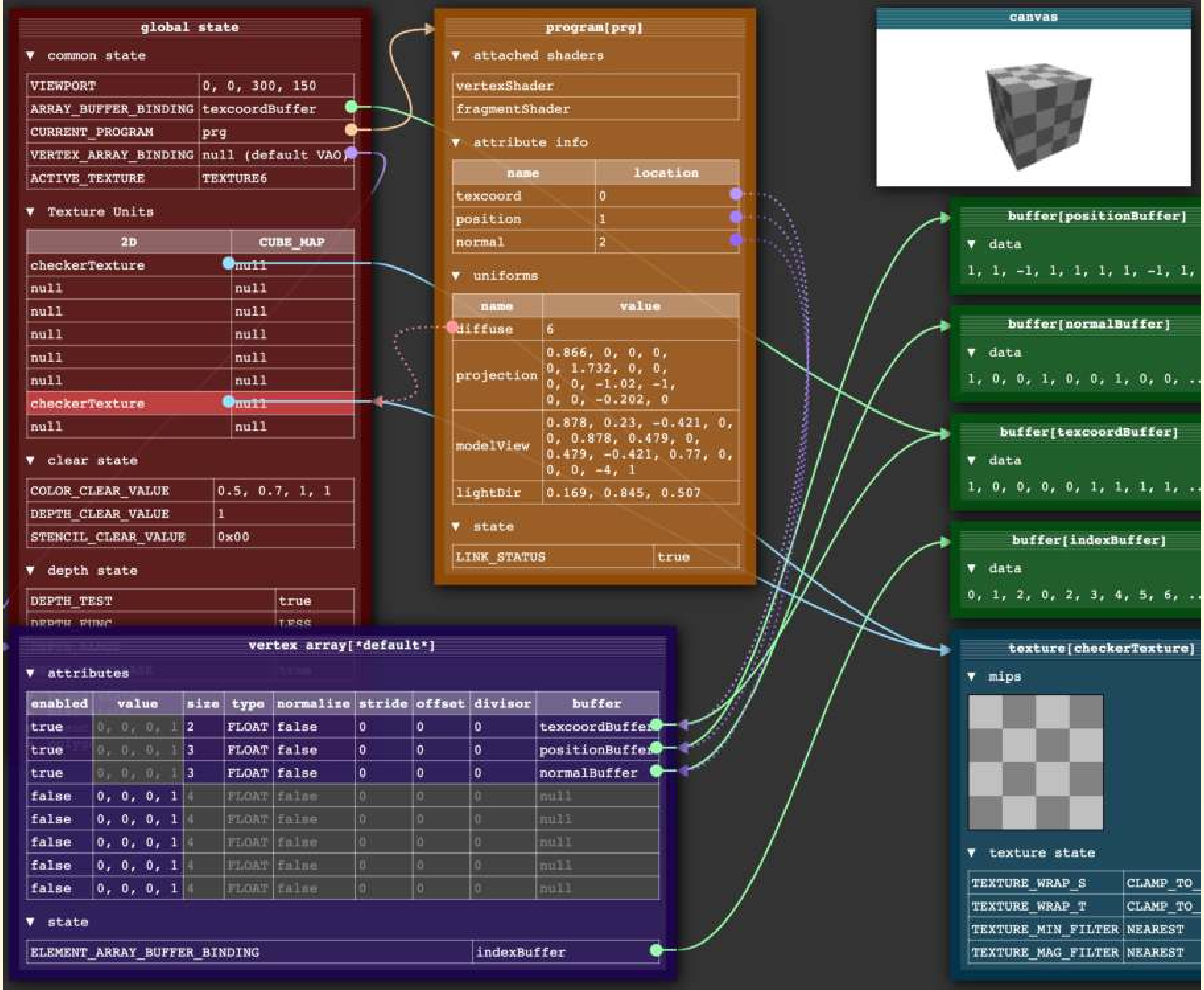
```
function buildShader(gl, shaderSource, shaderType) {
    const shader = gl.createShader(shaderType); // Create the shader object
    gl.shaderSource(shader, shaderSource); // Load the shader source
    gl.compileShader(shader); // Compile the shader
    return shader;
}

function createProgram(gl, shaders) {
    const program = gl.createProgram();
    shaders.forEach(function(shader) {
        gl.attachShader(program, shader);
    });
    gl.linkProgram(program);
    return program;
}
```

Finally : load shaders, program and render

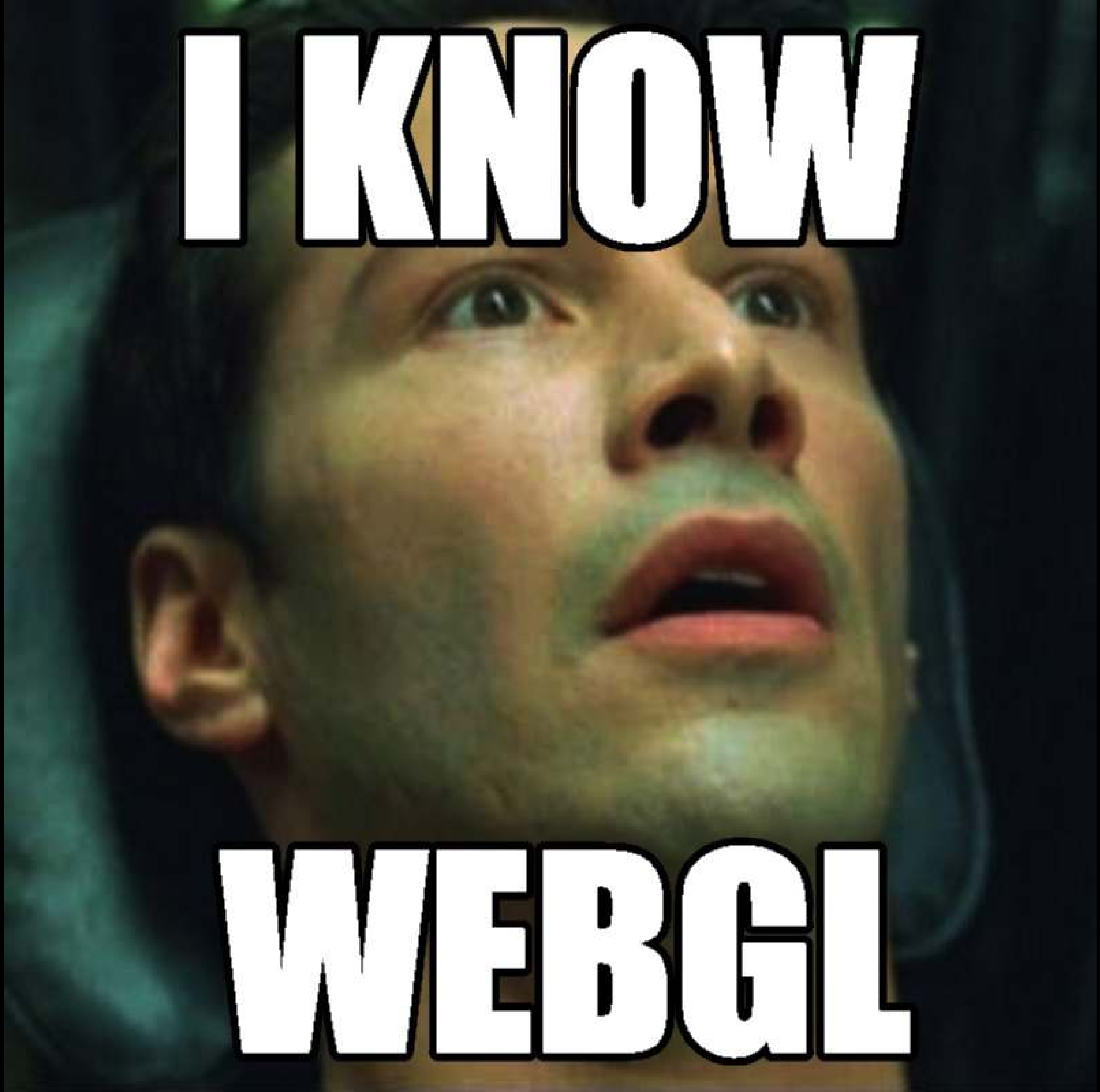
```
// load and compile the shaders
const vs = buildShader(gl, vs_source, gl.VERTEX_SHADER);
const fs = buildShader(gl, fs_source, gl.FRAGMENT_SHADER);

// Create program on the GPU!
const program = createProgram(gl, [vs, fs]);

// Set current program (WebGL is a state machine!)
gl.useProgram(program);

// Draw 1 big point, see shaders
const offset = 0;
const count = 1;
gl.drawArrays(gl.POINTS, offset, count);
```



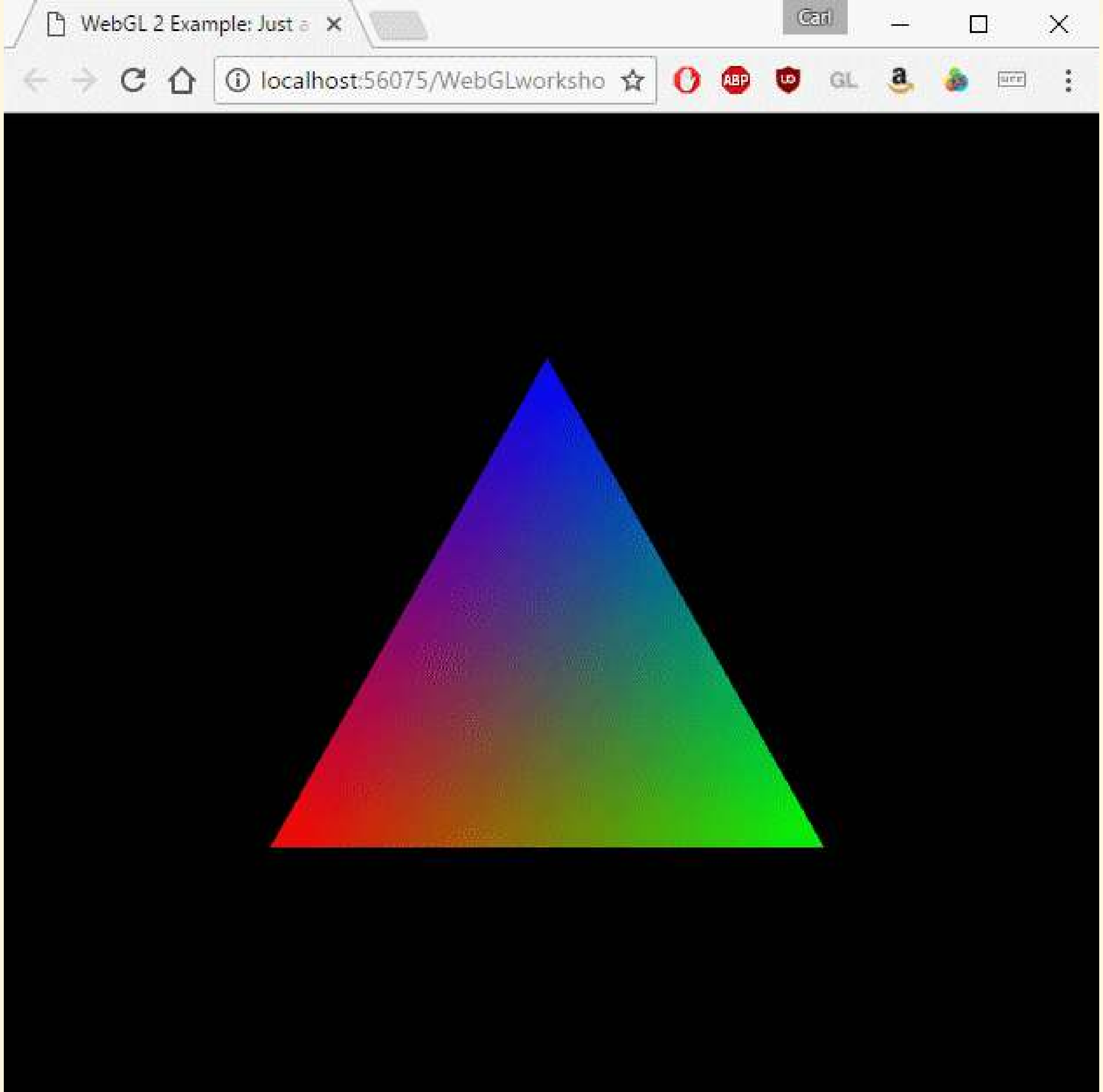
States



global state
common state
VIEWPORT | 0, 0, 300, 150
ARRAY_BUFFER_BINDING | texcoordBuffer
CURRENT_PROGRAM | prg
VERTEX_ARRAY_BINDING | null (default VAO)
ACTIVE_TEXTURE | TEXTURE6
Texture Units
2D | CUBE_MAP
checkerTexture | null
null | null
null | null
null | null
null | null
null | null
checkerTexture | null
null | null
clear state
COLOR_CLEAR_VALUE | 0.5, 0.7, 1, 1
DEPTH_CLEAR_VALUE | 1
STENCIL_CLEAR_VALUE | 0x00
depth state
DEPTH_TEST | true
program[prg]
attached shaders
vertexShader
fragmentShader
attribute info
name | location
texcoord | 0
position | 1
normal | 2
uniforms
name | value
diffuse | 6
projection | 0.866, 0, 0, 0, 0, 1.732, 0, 0, 0, 0, -1.02, -1, 0, 0, -0.202, 0
modelView | 0.878, 0.23, -0.421, 0, 0, 0.878, 0.479, 0, 0.479, -0.421, 0.77, 0, 0, 0, -4, 1
lightDir | 0.169, 0.845, 0.507
state
LINK_STATUS | true
canvas
buffer[positionBuffer]
data
1, 1, -1, 1, 1, 1, 1, -1, 1,
buffer[normalBuffer]
data
1, 0, 0, 1, 0, 0, 1, 0, 0, ...
buffer[texcoordBuffer]
data
1, 0, 0, 0, 0, 1, 1, 1, 1, ...
buffer[indexBuffer]
data
0, 1, 2, 0, 2, 3, 4, 5, 6, ...
texture[checkerTexture]
mips
texture state
TEXTURE_WRAP_S | CLAMP_TO_
TEXTURE_WRAP_T | CLAMP_TO_
TEXTURE_MIN_FILTER | NEAREST
TEXTURE_MAG_FILTER | NEAREST
vertex array[*default*]
attributes
enabled | value | size | type | normalize | stride | offset | divisor | buffer
true | 0, 0, 0, 1 | 2 | FLOAT | false | 0 | 0 | 0 | texcoordBuffer
true | 0, 0, 0, 1 | 3 | FLOAT | false | 0 | 0 | 0 | positionBuffer
true | 0, 0, 0, 1 | 3 | FLOAT | false | 0 | 0 | 0 | normalBuffer
false | 0, 0, 0, 1 | 4 | FLOAT | false | 0 | 0 | 0 | null
false | 0, 0, 0, 1 | 4 | FLOAT | false | 0 | 0 | 0 | null
false | 0, 0, 0, 1 | 4 | FLOAT | false | 0 | 0 | 0 | null
false | 0, 0, 0, 1 | 4 | FLOAT | false | 0 | 0 | 0 | null
false | 0, 0, 0, 1 | 4 | FLOAT | false | 0 | 0 | 0 | null
state
ELEMENT_ARRAY_BUFFER_BINDING | indexBuffer


I KNOW
WEBGL


SHOW ME


WebGL 2 Example: Just a
localhost:56075/WebGLworksho

My first triangle

see webglfundamentals

Initialization

1 . Data

- Describe triangle geometry with [Float32Array]() in [clip space]()

```
const vertices = new Float32Array([
     0.5,  0.5,
    -0.5,  0.5,
    -0.5, -0.5]); // 2D points: 3 * (x, y) coordinates
```

- Create Vertex Buffer Object (VBO) + **UPLOAD** to the GPU

```
const vbo = gl.createBuffer(); // create Vertex Buffer Object (VBO) id
// Set current VBO: bind 'vbo' to the ARRAY_BUFFER bind point,
//  a global variable internal to WebGL (state machine!)
gl.bindBuffer(gl.ARRAY_BUFFER, vbo);
// UPLOAD current VBO to GPU, where it will be processed by the shaders
// NOTE: STATIC_DRAW: optimization hint for WebGL: our data won't change
gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);
```

2 . Shaders

which will use buffer data

- Vertex Shader: gl_Position will be used by the fragment shader

```
attribute vec2 a_position; // IN, from buffer: 2D point
void main() {
    gl_Position = vec4(a_position, 0.0, 1.0); // a_position.x, a_position.y, 0, 1, used by the fragment shader
}
```

- Fragment Shader: gl_FragColor is the final fragment color

```
precision mediump float; // float accuracy: lowp, mediump, highp
uniform vec4 u_color; // UNIFORM == CONSTANT for entire shader program

void main() {
    gl_FragColor = u_color; // final framebuffer color: RGBA
}
```

https://webglfundamentals.org/webgl/lessons/webgl-precision-issues.html)

Detecting shader compilation errors

Call this before `gl.useProgram` (optional, slow, but often useful 😉)

```
function checkShaders(gl, vs, fs, program) {
    if (!gl.getShaderParameter(vs, gl.COMPILE_STATUS))
        console.error(gl.getShaderInfoLog(vs));

    if (!gl.getShaderParameter(fs, gl.COMPILE_STATUS))
        console.error(gl.getShaderInfoLog(fs));

    if (!gl.getProgramParameter(program, gl.LINK_STATUS))
        console.error(gl.getProgramInfoLog(program));
}
```

3 . Connecting Buffer and Shaders

- Retrieve the variables declared in the shaders
  - costly call (like most `gl.getXXX` calls)
  - only do this during initialization
  - will be used during rendering
- ⚠️ use the exact same name that has been defined in the shader
  - arbitrary name, chosen by the developer! (`u_` for `uniform`, `a_` for `attribute`, `v_` for `varying` are common conventions)

```
// Retrieve 'u_color' shader UNIFORM variable as an id
const u_colorLoc = gl.getUniformLocation(program, 'u_color');

// Retrieve 'a_position' shader ATTRIBUTE variable as an id
const a_positionLoc = gl.getAttribLocation(program, 'a_position');
```

4 . Rendering!

Buffers and Shaders are ready, we still need to:

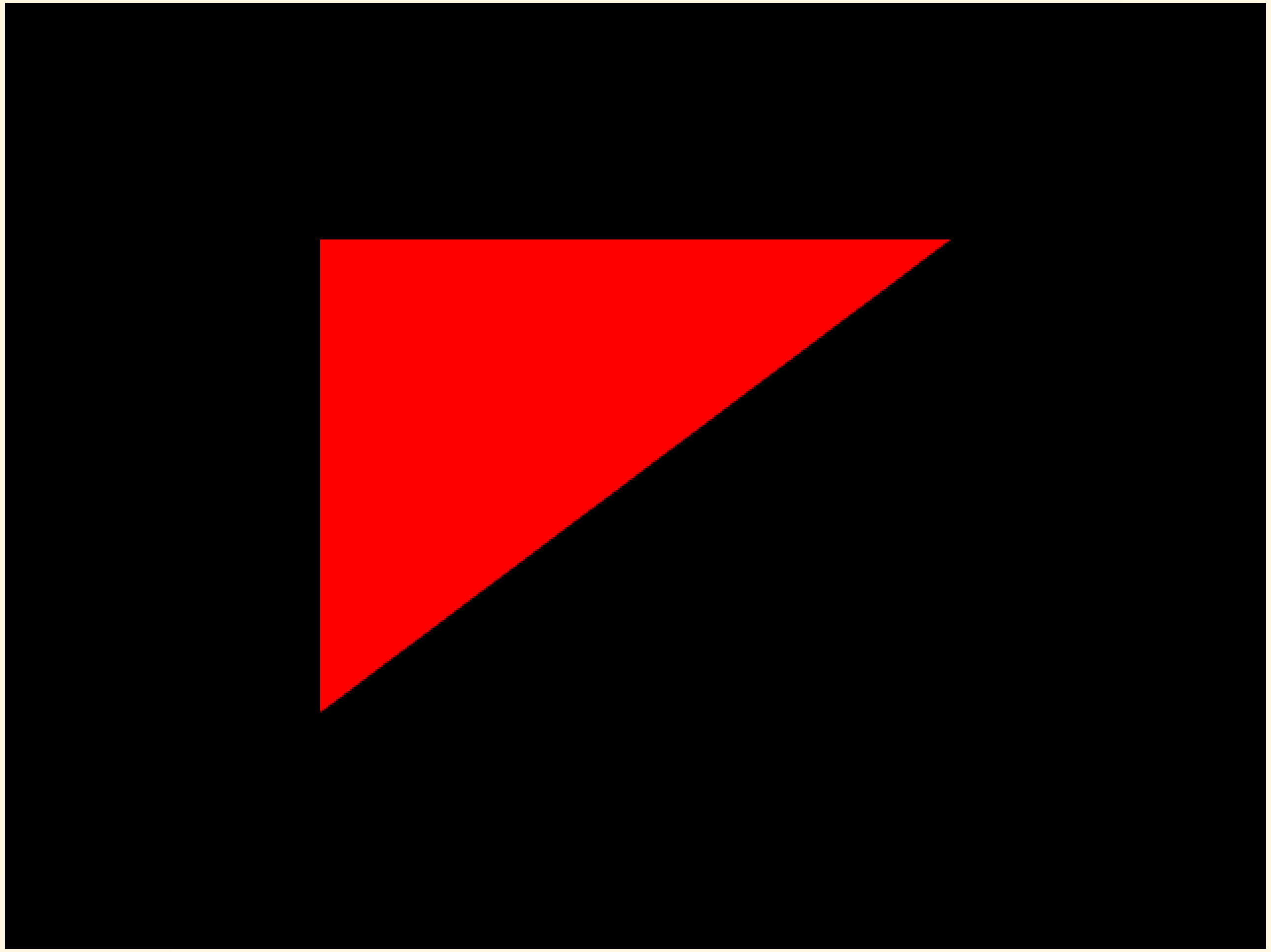
- define states
- describe buffer layout (often complex since it is very flexible!)
- draw the scene

```
gl.clearColor(0., 0., 0., 1.); // Set current clear color (black)
gl.clear(gl.COLOR_BUFFER_BIT); // Clear the canvas to current color

gl.useProgram(program); // Set current program (pair of shaders)

// Set the color (constant triangle color, see shader)
gl.uniform4fv(u_colorLoc, [1.0, 0.0, 0.0, 1.0]);
// Tell WebGL how to take data from the VBO
// and supply it to the attribute in the shader.
gl.enableVertexAttribArray(a_positionLoc); // Turn the attribute on
gl.bindBuffer(gl.ARRAY_BUFFER, vbo); // set current vbo
// Tell the attribute how to get data out of positionBuffer
// (ARRAY_BUFFER)
const size = 2; // 2 components per iteration
const type = gl.FLOAT; // the data is 32bit floats
const normalize = false; // don't normalize the data
// stride: 0 = move forward size * sizeof(type) each iteration
// to get the next position
const stride = 0;
const offset = 0; // start at the beginning of the buffer
gl.vertexAttribPointer(a_positionLoc, size, type, normalize, stride, offset);
```

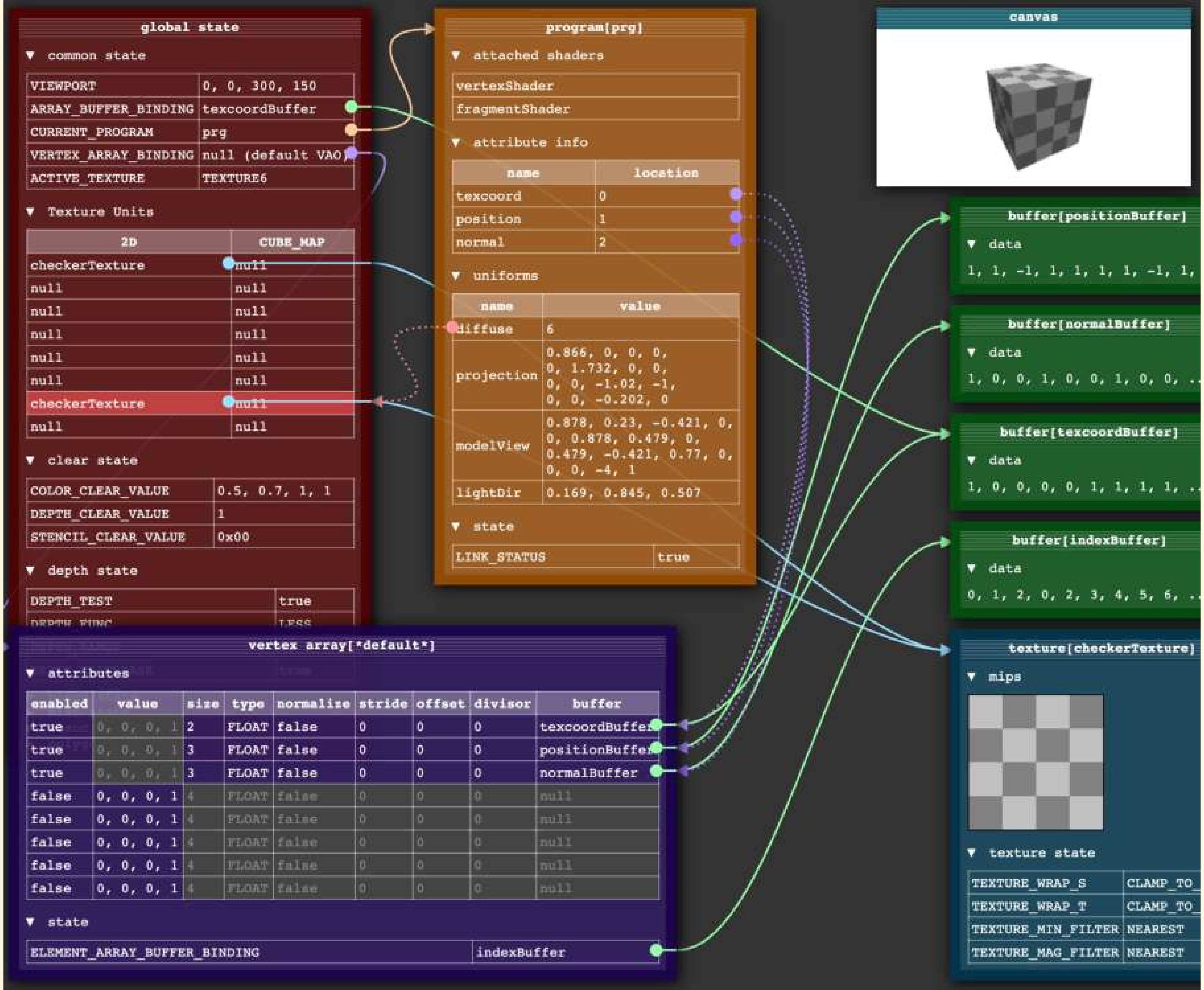
https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/vertexAttribPointer

- Draw: here we'll be using `gl.drawArrays`

```
// primitiveType == gl.TRIANGLES:
// each time our vertex shader is run 3 times,
// WebGL will draw a triangle
// based on the 3 values we set gl_Position to (see shader)
const primitiveType = gl.TRIANGLES;

// Start index of the first vertex
// Must be a valid multiple of the size of the given type.
const startIndex = 0;

// Execute our vertex shader 3 times,
// using 2 elements from the array (see size 2 above)
// setting a_position.x and a_position.y
const count = 3;
gl.drawArrays(primitiveType, startIndex, count);
```



States



global state
common state
VIEWPORT 0, 0, 300, 150
ARRAY_BUFFER_BINDING texcoordBuffer
CURRENT_PROGRAM prg
VERTEX_ARRAY_BINDING null (default VAO)
ACTIVE_TEXTURE TEXTURE6
Texture Units
2D CUBE_MAP
checkerTexture null
null null
null null
null null
null null
null null
checkerTexture null
null null
clear state
COLOR_CLEAR_VALUE 0.5, 0.7, 1, 1
DEPTH_CLEAR_VALUE 1
STENCIL_CLEAR_VALUE 0x00
depth state
DEPTH_TEST true
program[prg]
attached shaders
vertexShader
fragmentShader
attribute info
name location
texcoord 0
position 1
normal 2
uniforms
name value
diffuse 6
projection 0.866, 0, 0, 0, 0, 1.732, 0, 0, 0, 0, -1.02, -1, 0, 0, -0.202, 0
modelView 0.878, 0.23, -0.421, 0, 0, 0.878, 0.479, 0, 0.479, -0.421, 0.77, 0, 0, 0, -4, 1
lightDir 0.169, 0.845, 0.507
state
LINK_STATUS true
canvas
buffer[positionBuffer]
data
1, 1, -1, 1, 1, 1, 1, -1, 1,
buffer[normalBuffer]
data
1, 0, 0, 1, 0, 0, 1, 0, 0, ...
buffer[texcoordBuffer]
data
1, 0, 0, 0, 0, 1, 1, 1, 1, ...
buffer[indexBuffer]
data
0, 1, 2, 0, 2, 3, 4, 5, 6, ...
vertex array[*default*]
attributes
enabled value size type normalize stride offset divisor buffer
true 0, 0, 0, 1 2 FLOAT false 0 0 0 texcoordBuffer
true 0, 0, 0, 1 3 FLOAT false 0 0 0 positionBuffer
true 0, 0, 0, 1 3 FLOAT false 0 0 0 normalBuffer
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
state
ELEMENT_ARRAY_BUFFER_BINDING indexBuffer
texture[checkerTexture]
mips
texture state
TEXTURE_WRAP_S CLAMP_TO_
TEXTURE_WRAP_T CLAMP_TO_
TEXTURE_MIN_FILTER NEAREST
TEXTURE_MAG_FILTER NEAREST

Almost there!

We still need to define one color per vertex instead of the constant `uniform` color

cf. webglfundamentals

1. Data

adding a color attribute per vertex, with a new array and a new buffer!

```
 // 2D points: 3 * (x, y) coordinates
// (sqrt(3) / 2 - 0.5) * 640 / 480 == 0.4880338..
const vertices = new Float32Array([-0.75,  -0.5,
                                    0.75,  -0.5,
                                    0., 0.49]);
// create Vertex Buffer Object (VBO) id
const vertexBuffer = gl.createBuffer();

 // set current VBO (WebGL is a state machine!)
gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer);

// UPLOAD vertexBuffer VBO to GPU,
gl.bufferData(gl.ARRAY_BUFFER, vertices, gl.STATIC_DRAW);

 // ** NEW **

 // RGB colors: 3 * (r, g, b, a) values
const colors = new Float32Array([   1., 0., 0., 1.,
                                    0., 1., 0., 1.,
                                    0., 0., 1., 1.]);
// create Vertex Buffer Object (VBO) id
const colorBuffer = gl.createBuffer();

 // set current VBO (WebGL is a state machine!)
gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);

// UPLOAD colorBuffer VBO to GPU,
gl.bufferData(gl.ARRAY_BUFFER, colors, gl.STATIC_DRAW);
```

2 . Shaders

we use the new color attribute that we choose to name `a_color`
(we could name it `mylittlevertexcolor` but it looks less professional)

- Vertex Shader: new `varying` variable, will be **interpolated**

```
attribute vec2 a_position; // IN, from buffer: 2D point
attribute vec4 a_color; // IN, from buffer: RGB color

varying vec4 v_color; // OUT, to fragment shader

void main() {
    v_color = a_color; // color passthrough, sent to fragment shader (interpolated)

    gl_Position = vec4(a_position, 0.0, 1.0); // used by the fragment shader
}
```

- Fragment Shader

```
precision mediump float; // float accuracy: lowp, mediump, highp

varying vec4 v_color; // IN, INTERPOLATED color from vertex shader

void main() {
    gl_FragColor = vec4(v_color); // final framebuffer color: RGBA
}
```

3 . Connecting Buffer and Shaders

- Retrieve the variables declared in the shaders
  - costly call (like most `gl.getXXX` calls)
  - only do this during initialization
  - will be used during rendering
- ⚠️ use the exact same name that has been defined in the shader

```
// Retrieve 'a_color' shader ATTRIBUTE variable as an id
const a_colorLoc = gl.getAttribLocation(program, 'a_color');

// Retrieve 'a_position' shader ATTRIBUTE variable as an id
const a_positionLoc = gl.getAttribLocation(program, 'a_position');
```

4 . Rendering!

Buffers and Shaders are ready, we still need to:

- define states
- describe buffer layout (often complex since it is very flexible!)
- draw the scene

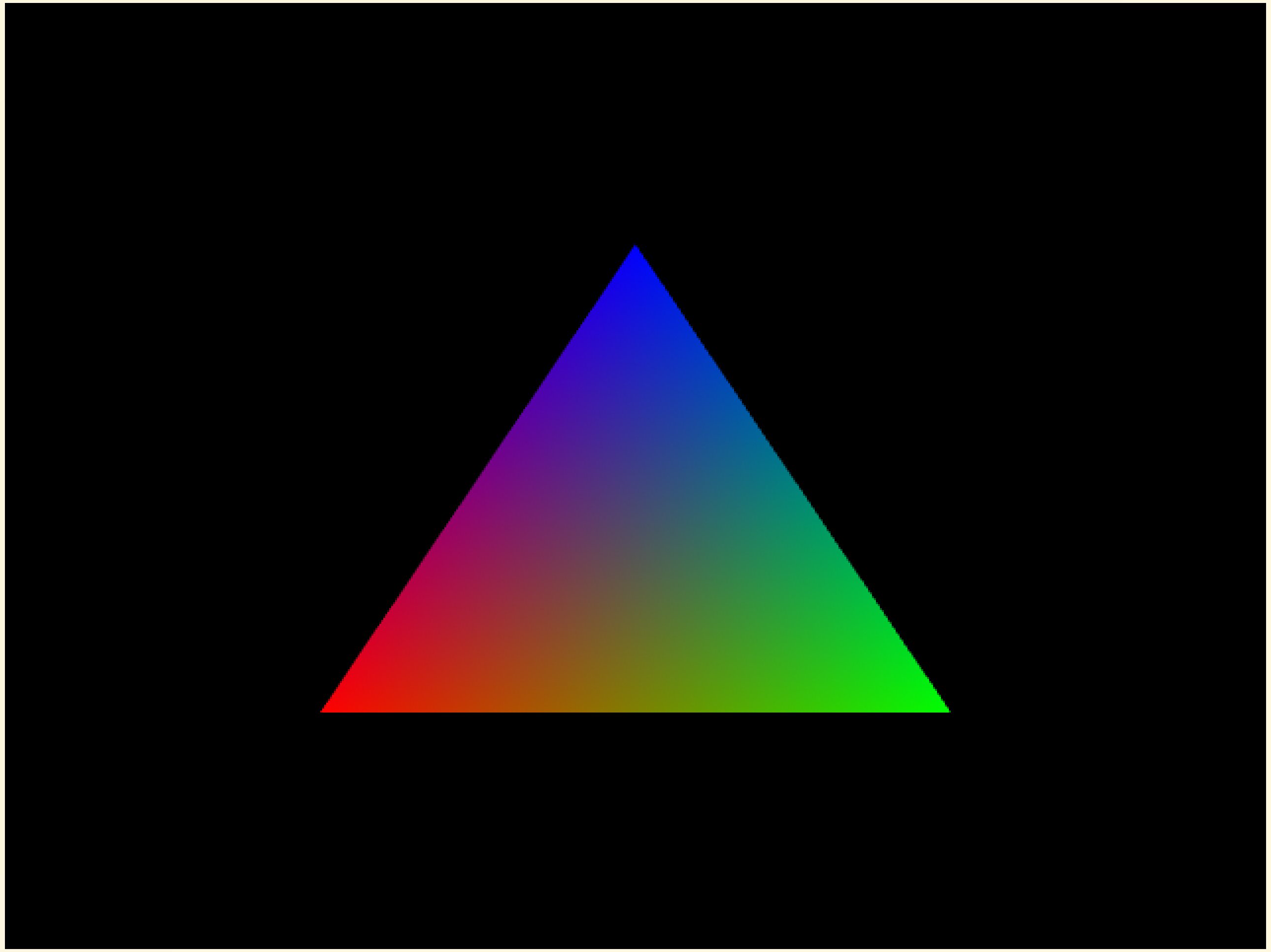
```
    gl.clearColor(0., 0., 0., 1.);
    gl.clear(gl.COLOR_BUFFER_BIT);

    gl.useProgram(program); // Set current program

{
    // Turn the attribute on
    gl.enableVertexAttribArray(a_positionLoc);
    gl.bindBuffer(gl.ARRAY_BUFFER, vertexBuffer); // set current vbo
    // Tell the attribute how to get data out of positionBuffer
    // (ARRAY_BUFFER)
    const size = 2; // 2 components per iteration
    const type = gl.FLOAT; // the data is 32bit floats
    const normalize = false; // don't normalize the data
    // stride: 0 = move forward size * sizeof(type) each iteration
    // to get the next position
    const stride = 0;
    const offset = 0; // start at the beginning of the buffer
    gl.vertexAttribPointer(a_positionLoc, size, type, normalize, stride, offset);
}
```

- Same steps for `colorBuffer`
  NOTE: Refactoring! In real life we try and avoid repetition: [DRY](#)

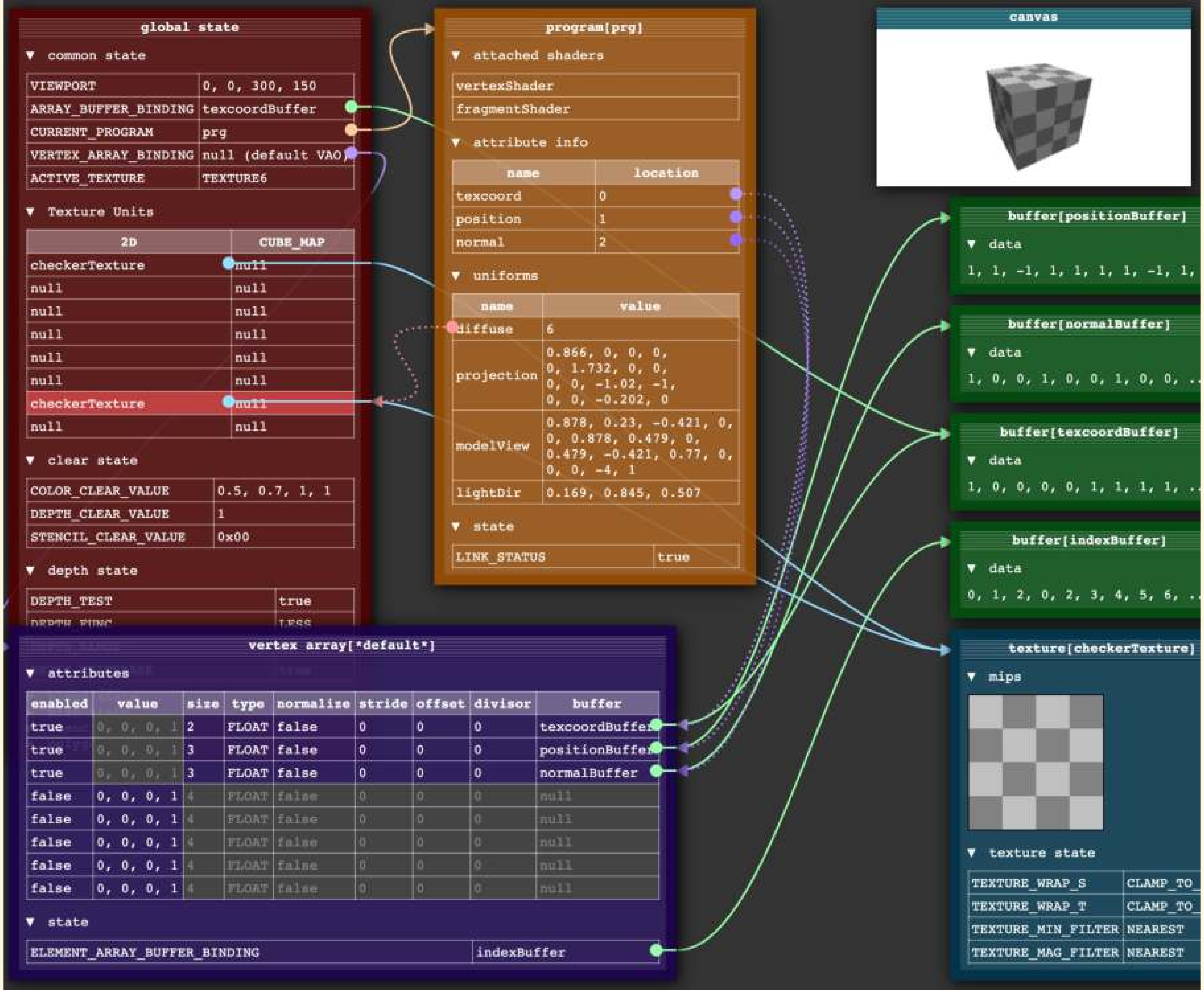
```
{
    // Tell WebGL how to take data from the VBO
    // and supply it to the attribute in the shader.
    gl.enableVertexAttribArray(a_colorLoc); // Turn the attribute on
    gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);
    // Tell the color attribute how to get data out of colorBuffer (ARRAY_BUFFER)
    const size = 4; // NOTE: 4 components per iteration
    const type = gl.FLOAT; // the data is 32bit floats
    const normalize = false; // don't normalize the data
    // stride: 0 = move forward size * sizeof(type) each iteration
    // to get the next position
    const stride = 0;
    const offset = 0; // start at the beginning of the buffer
    gl.vertexAttribPointer( a_colorLoc, size, type, normalize, stride, offset);
}
```

- Draw: same code as before!

```javascript
// primitiveType == gl.TRIANGLES:
// each time our vertex shader is run 3 times,
// WebGL will draw a triangle
// based on the 3 values we set gl_Position to (see shader)
const primitiveType = gl.TRIANGLES;

// Start index of the first vertex
// Must be a valid multiple of the size of the given type.
const startIndex = 0;

// Execute our vertex shader 3 times,
// using 2 elements from the array (see size 2 above)
// setting a_position.x and a_position.y
const count = 3;
gl.drawArrays(primitiveType, startIndex, count);
```



States

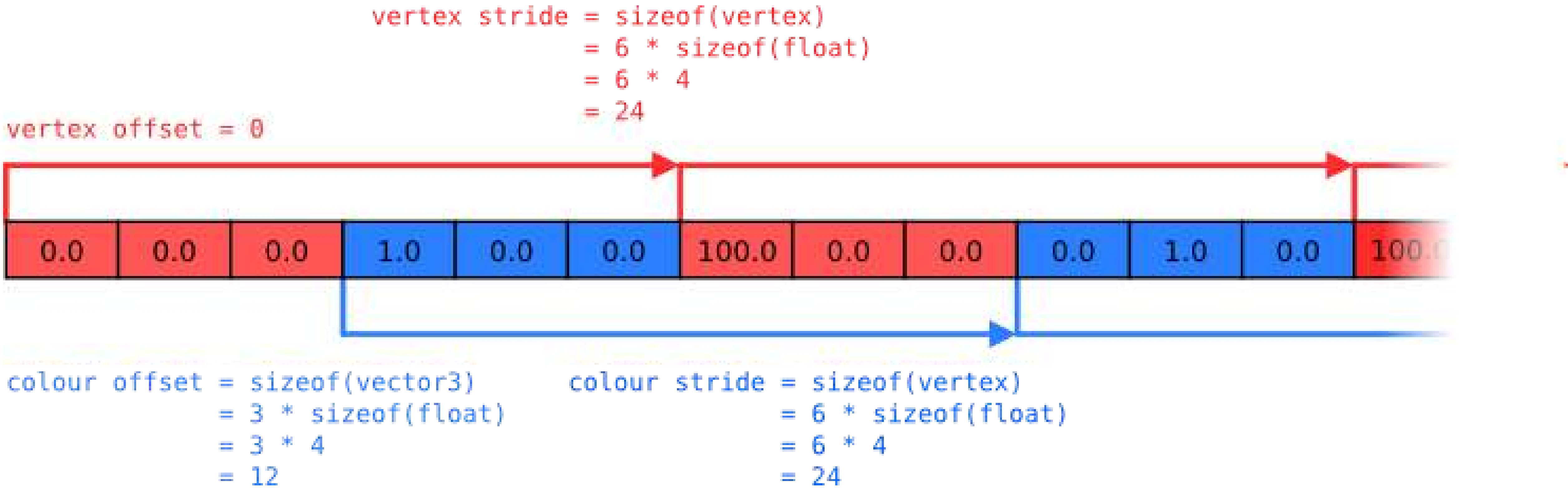

global state
common state
VIEWPORT 0, 0, 300, 150
ARRAY_BUFFER_BINDING texcoordBuffer
CURRENT_PROGRAM prg
VERTEX_ARRAY_BINDING null (default VAO)
ACTIVE_TEXTURE TEXTURE6
Texture Units
2D CUBE_MAP
checkerTexture null
clear state
COLOR_CLEAR_VALUE 0.5, 0.7, 1, 1
DEPTH_CLEAR_VALUE 1
STENCIL_CLEAR_VALUE 0x00
depth state
DEPTH_TEST true
program[prg]
attached shaders
vertexShader
fragmentShader
attribute info
name location
texcoord 0
position 1
normal 2
uniforms
name value
diffuse 6
projection 0.866, 0, 0, 0, 0, 1.732, 0, 0, 0, 0, -1.02, -1, 0, 0, -0.202, 0
modelView 0.878, 0.23, -0.421, 0, 0, 0.878, 0.479, 0, 0.479, -0.421, 0.77, 0, 0, 0, -4, 1
lightDir 0.169, 0.845, 0.507
state
LINK_STATUS true
canvas
buffer[positionBuffer]
data
1, 1, -1, 1, 1, 1, 1, -1, 1,
buffer[normalBuffer]
1, 0, 0, 1, 0, 0, 1, 0, 0, ..
buffer[texcoordBuffer]
1, 0, 0, 0, 0, 1, 1, 1, 1, ..
buffer[indexBuffer]
0, 1, 2, 0, 2, 3, 4, 5, 6, ..
texture[checkerTexture]
mips
texture state
TEXTURE_WRAP_S CLAMP_TO_
TEXTURE_WRAP_T CLAMP_TO_
TEXTURE_MIN_FILTER NEAREST
TEXTURE_MAG_FILTER NEAREST
vertex array[*default*]
attributes
enabled value size type normalize stride offset divisor buffer
true 0, 0, 0, 1 2 FLOAT false 0 0 0 texcoordBuffer
true 0, 0, 0, 1 3 FLOAT false 0 0 0 positionBuffer
true 0, 0, 0, 1 3 FLOAT false 0 0 0 normalBuffer
false 0, 0, 0, 1 4 FLOAT false 0 0 0 null
ELEMENT_ARRAY_BUFFER_BINDING indexBuffer

💪 😎 🎉

Variations

- A single buffer, **interlaced** and **indexed** + `gl.DrawElements`
  - indexing: share a vertex between triangles (no need to repeat)
  - is it really an optimization? (platform specific profiling needed)
  - brief history of vertex specifications buffer types and layout, vocabulary, structures, illustrations
- WebGL 2 version

Interlaced buffer



```
// POINTS : position + color
const vertexBuffer = new Float32Array([
-0.5, -0.5, // vertex 1 : left
1., 0., 0., // color 1 : red
0.5, -0.5, // vertex 2 : right
0., 1. , 0., // color 2 : green
0., 0.48, // vertex 3 : top
0., 0., 1. // color 3 : blue
]);

const vbo = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, vbo);
gl.bufferData(gl.ARRAY_BUFFER, vertexBuffer, gl.STATIC_DRAW); // send to GPU

// FACES : indices
const indices = new Uint16Array([0, 1, 2]);
var indexBuffer = gl.createBuffer();
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, indexBuffer);
gl.bufferData(gl.ELEMENT_ARRAY_BUFFER, indices, gl.STATIC_DRAW); // send to GPU
```

- Rendering : `gl.DrawElements` + `window.requestAnimationFrame`

```
gl.enableVertexAttribArray(a_colorLoc);
gl.enableVertexAttribArray(a_positionLoc);
gl.useProgram(program);
gl.clearColor(0.0, 0.0, 0.0, 1.0);
const animate = () => {
    gl.viewport(0.0, 0.0, canvas.width, canvas.height);
    gl.clear(gl.COLOR_BUFFER_BIT);

    gl.bindBuffer(gl.ARRAY_BUFFER, vbo);

    gl.vertexAttribPointer(a_positionLoc, 2, gl.FLOAT, false,4*(2+3),0) ;
    gl.vertexAttribPointer(a_colorLoc, 3, gl.FLOAT, false,4*(2+3),2*4) ;

    gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, indexBuffer);
    gl.drawElements(gl.TRIANGLES, 3, gl.UNSIGNED_SHORT, 0);
    gl.flush();
    window.requestAnimationFrame(animate);
};
animate();
```

More examples

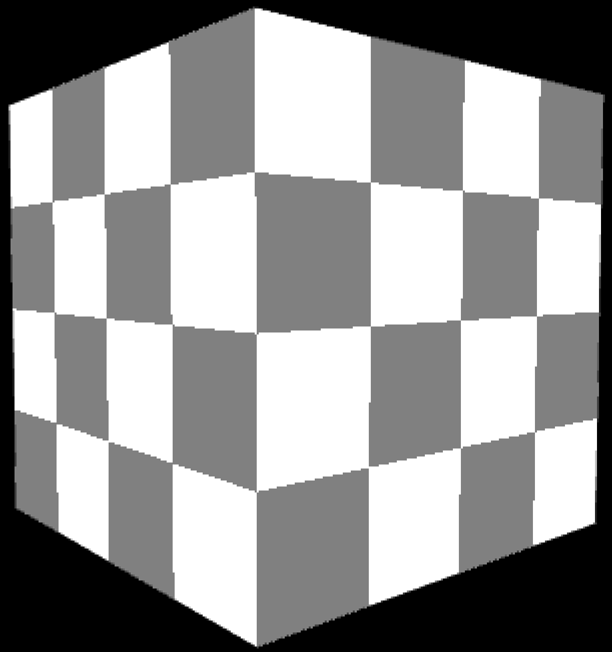
- spinning triangle
  - ➡️ using **matrices**
- spinning cube
  - ➡️ advanced buffer layout
- textures

WebGL Textured Cube (HTML)

```
<canvas id="canvas"></canvas>
<!-- vertex shader -->
<script  id="vertex-shader-3d" type="x-shader/x-vertex">
attribute vec4 a_position;
attribute vec2 a_texcoord;

uniform mat4 u_matrix;

varying vec2 v_texcoord;

void main() {
  // Multiply the position by the matrix.
  gl_Position = u_matrix * a_position;

  // Pass the texcoord to the fragment shader.
  v_texcoord = a_texcoord;
}
</script>
<!-- fragment shader -->
<script  id="fragment-shader-3d" type="x-shader/x-fragment">
precision mediump float;

// Passed in from the vertex shader.
varying vec2 v_texcoord;

// The texture.
uniform sampler2D u_texture;

void main() {
   gl_FragColor = texture2D(u_texture, v_texcoord);
}
</script><!--
for most samples webgl-utils only provides shader compiling/linking and
canvas resizing because why clutter the examples with code that's the same in every sample.
See https://webglfundamentals.org/webgl/lessons/webgl-boilerplate.html
and https://webglfundamentals.org/webgl/lessons/webgl-resizing-the-canvas.html
for webgl-utils, m3, m4, and webgl-lessons-ui.
-->
<script src="https://webglfundamentals.org/webgl/resources/webgl-utils.js"></script>
<script src="https://webglfundamentals.org/webgl/resources/m4.js"></script>
```

WebGL Textured Cube (JS, >250 lines)

```
"use strict";

function main() {
  // Get A WebGL context
  /** @type {HTMLCanvasElement} */
  var canvas = document.querySelector("#canvas");
  var gl = canvas.getContext("webgl");
  if (!gl) {
    return;
  }

  // setup GLSL program
  var program = webglUtils.createProgramFromScripts(gl, ["vertex-shader-3d", "fragment-shader-3d"]);

  // look up where the vertex data needs to go.
  var positionLocation = gl.getAttribLocation(program, "a_position");
  var texcoordLocation = gl.getAttribLocation(program, "a_texcoord");

  // lookup uniforms
  var matrixLocation = gl.getUniformLocation(program, "u_matrix");
  var textureLocation = gl.getUniformLocation(program, "u_texture");

  // Create a buffer for positions
  var positionBuffer = gl.createBuffer();
  // Bind it to ARRAY_BUFFER (think of it as ARRAY_BUFFER = positionBuffer)
  gl.bindBuffer(gl.ARRAY_BUFFER, positionBuffer);
  // Put the positions in the buffer
  setGeometry(gl);

  // provide texture coordinates for the rectangle.
  var texcoordBuffer = gl.createBuffer();
  gl.bindBuffer(gl.ARRAY_BUFFER, texcoordBuffer);
  // Set Texcoords.
  setTexcoords(gl);

  // Create a texture.
  var texture = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, texture);
  // Fill the texture with a 4x4 LUMINANCE pixel.
  const level = 0;
  const format = gl.LUMINANCE;
  const type = gl.UNSIGNED_BYTE;
  const border = 0;
  const width = 4;
  const height = 4;
  const pixels = new Uint8Array([
    255, 128, 255, 128,
    128, 255, 128, 255,
    255, 128, 255, 128,
    128, 255, 128, 255,
  ]);
  gl.texImage2D(gl.TEXTURE_2D, level, format, width, height, border,
                format, type, pixels);
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.NEAREST);
  gl.generateMipmap(gl.TEXTURE_2D);

  function radToDeg(r) {
    return r * 180 / Math.PI;
  }

  function degToRad(d) {
    return d * Math.PI / 180;
  }

  var fieldOfViewRadians = degToRad(60);
  var modelXRotationRadians = degToRad(0);
  var modelYRotationRadians = degToRad(0);

  // Get the starting time.
  var then = 0;

  requestAnimationFrame(drawScene);

  // Draw the scene.
  function drawScene(time) {
    // convert to seconds
    time *= 0.001;
    // Subtract the previous time from the current time
    var deltaTime = time - then;
    // Remember the current time for the next frame.
    then = time;

    webglUtils.resizeCanvasToDisplaySize(gl.canvas);

    // Tell WebGL how to convert from clip space to pixels
    gl.viewport(0, 0, gl.canvas.width, gl.canvas.height);

    gl.enable(gl.CULL_FACE);
    gl.enable(gl.DEPTH_TEST);

    // Animate the rotation
    modelYRotationRadians += -0.7 * deltaTime;
    modelXRotationRadians += -0.4 * deltaTime;

    // Clear the canvas AND the depth buffer.
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    // Tell it to use our program (pair of shaders)
    gl.useProgram(program);

    // Turn on the position attribute
    gl.enableVertexAttribArray(positionLocation);

    // Bind the position buffer.
    gl.bindBuffer(gl.ARRAY_BUFFER, positionBuffer);

    // Tell the position attribute how to get data out of positionBuffer (ARRAY_BUFFER)
    var size = 3;          // 3 components per iteration
    var type = gl.FLOAT;   // the data is 32bit floats
    var normalize = false; // don't normalize the data
    var stride = 0;        // 0 = move forward size * sizeof(type) each iteration to get the next position
    var offset = 0;        // start at the beginning of the buffer
    gl.vertexAttribPointer(
        positionLocation, size, type, normalize, stride, offset);

    // Turn on the texcoord attribute
    gl.enableVertexAttribArray(texcoordLocation);

    // bind the texcoord buffer.
    gl.bindBuffer(gl.ARRAY_BUFFER, texcoordBuffer);

    // Tell the texcoord attribute how to get data out of texcoordBuffer (ARRAY_BUFFER)
    var size = 2;          // 2 components per iteration
    var type = gl.FLOAT;   // the data is 32bit floats
    var normalize = false; // don't normalize the data
    var stride = 0;        // 0 = move forward size * sizeof(type) each iteration to get the next position
    var offset = 0;        // start at the beginning of the buffer
    gl.vertexAttribPointer(
        texcoordLocation, size, type, normalize, stride, offset);

    // Compute the projection matrix
    var aspect = gl.canvas.clientWidth / gl.canvas.clientHeight;
    var projectionMatrix =
        m4.perspective(fieldOfViewRadians, aspect, 1, 2000);

    var cameraPosition = [0, 0, 2];
    var up = [0, 1, 0];
    var target = [0, 0, 0];

    // Compute the camera's matrix using look at.
    var cameraMatrix = m4.lookAt(cameraPosition, target, up);

    // Make a view matrix from the camera matrix.
    var viewMatrix = m4.inverse(cameraMatrix);

    var viewProjectionMatrix = m4.multiply(projectionMatrix, viewMatrix);

    var matrix = m4.xRotate(viewProjectionMatrix, modelXRotationRadians);
    matrix = m4.yRotate(matrix, modelYRotationRadians);

    // Set the matrix.
    gl.uniformMatrix4fv(matrixLocation, false, matrix);

    // Tell the shader to use texture unit 0 for u_texture
    gl.uniform1i(textureLocation, 0);

    // Draw the geometry.
    gl.drawArrays(gl.TRIANGLES, 0, 6 * 6);

    requestAnimationFrame(drawScene);
  }
}

// Fill the buffer with the values that define a cube.
function setGeometry(gl) {
  var positions = new Float32Array(
    [
    -0.5, -0.5,  -0.5,
    -0.5,  0.5,  -0.5,
     0.5, -0.5,  -0.5,
    -0.5,  0.5,  -0.5,
     0.5,  0.5,  -0.5,
     0.5, -0.5,  -0.5,

    -0.5, -0.5,   0.5,
     0.5, -0.5,   0.5,
    -0.5,  0.5,   0.5,
    -0.5,  0.5,   0.5,
     0.5, -0.5,   0.5,
     0.5,  0.5,   0.5,

    -0.5,   0.5, -0.5,
    -0.5,   0.5,  0.5,
     0.5,   0.5, -0.5,
    -0.5,   0.5,  0.5,
     0.5,   0.5,  0.5,
     0.5,   0.5, -0.5,

    -0.5,  -0.5, -0.5,
     0.5,  -0.5, -0.5,
    -0.5,  -0.5,  0.5,
    -0.5,  -0.5,  0.5,
     0.5,  -0.5, -0.5,
     0.5,  -0.5,  0.5,

    -0.5,  -0.5, -0.5,
    -0.5,  -0.5,  0.5,
    -0.5,   0.5, -0.5,
    -0.5,  -0.5,  0.5,
    -0.5,   0.5,  0.5,
    -0.5,   0.5, -0.5,

     0.5,  -0.5, -0.5,
     0.5,   0.5, -0.5,
     0.5,  -0.5,  0.5,
     0.5,  -0.5,  0.5,
     0.5,   0.5, -0.5,
     0.5,   0.5,  0.5,

    ]);
  gl.bufferData(gl.ARRAY_BUFFER, positions, gl.STATIC_DRAW);
}

// Fill the buffer with texture coordinates the cube.
function setTexcoords(gl) {
  gl.bufferData(
      gl.ARRAY_BUFFER,
      new Float32Array(
        [
          0, 0,
          0, 1,
          1, 0,
          0, 1,
          1, 1,
          1, 0,

          0, 0,
          0, 1,
          1, 0,
          1, 0,
          0, 1,
          1, 1,

          0, 0,
          0, 1,
          1, 0,
          0, 1,
          1, 1,
          1, 0,

          0, 0,
          0, 1,
          1, 0,
          1, 0,
          0, 1,
          1, 1,

          0, 0,
          0, 1,
          1, 0,
          0, 1,
          1, 1,
          1, 0,

          0, 0,
          0, 1,
          1, 0,
          1, 0,
          0, 1,
          1, 1,

      ]),
      gl.STATIC_DRAW);
}

main();
```



Optimization

Vertex Array Object ⭐ (bad name for a modern and very cool feature)

- optimizes rendering speed and **encapsulates WebGL state** ➡️ **always use it!**
- makes WebGL look like a **modern** API
- see below

- WebGL 1 (extension always available today)

```
const ext = gl.getExtension("OES_vertex_array_object");
if (!ext) { // should never happen, extension is omnipresent!
  // tell user they don't have the required extension or work around it
} else {
  let myVAO = ext.createVertexArrayOES();
}
```

- WebGL 2

```
const myVAO = gl.createVertexArray();
```

```
// at init time
for each model / geometry / ...
    const vao = gl.createVertexArray();
    gl.bindVertexArray(vao);
    for each attribute
    gl.enableVertexAttribArray(...);
    gl.bindBuffer(gl.ARRAY_BUFFER, bufferForAttribute);
    gl.vertexAttribPointer(...);
    if indexed geometry
    gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, indexBuffer);
    gl.bindVertexArray(null);
```

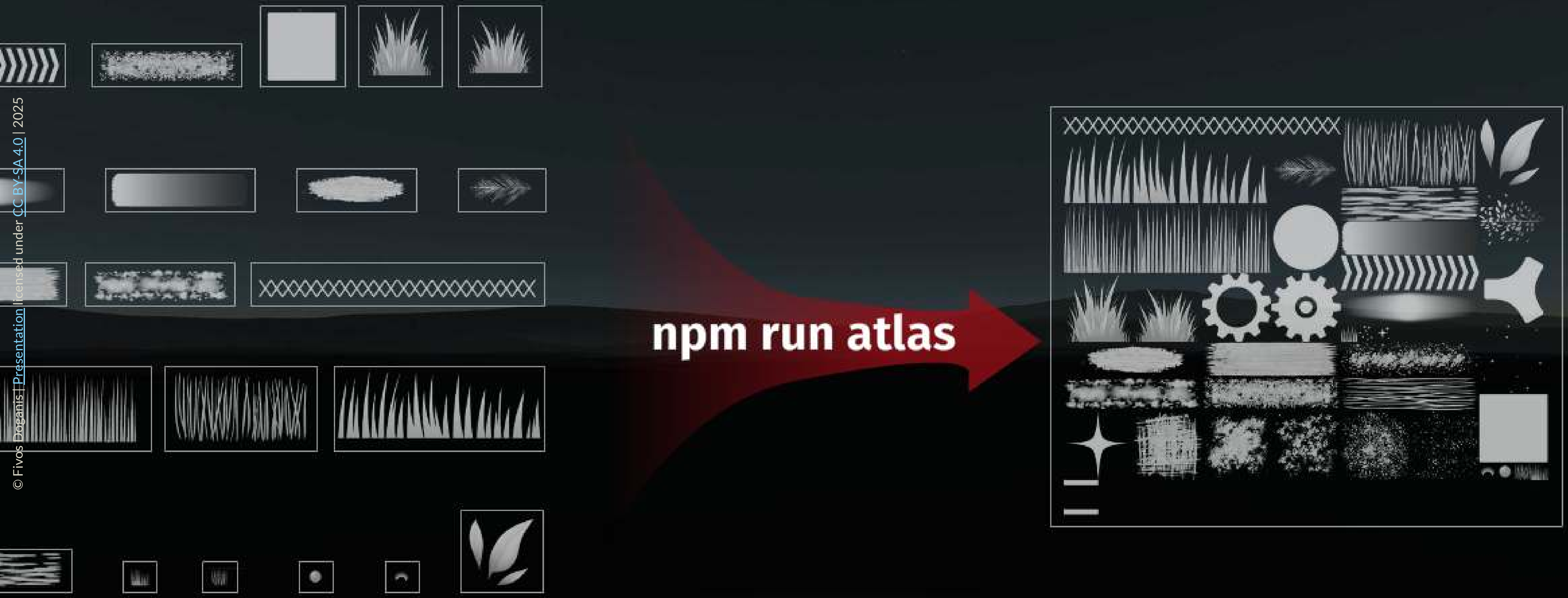
```
// draw
gl.bindVertexArray(vao); // only 1 DrawCall !
```

```
// clean
gl.bindVertexArray(null); //Always unbind the VAO when you're done
```

More optimizations ⭐

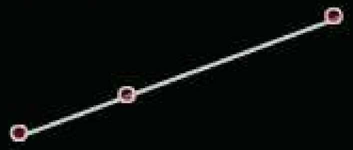
Valid for any API!

- **Profiling**
- **"Batching"**:
  - Texture Atlas
  - Degenerate Triangle Strips

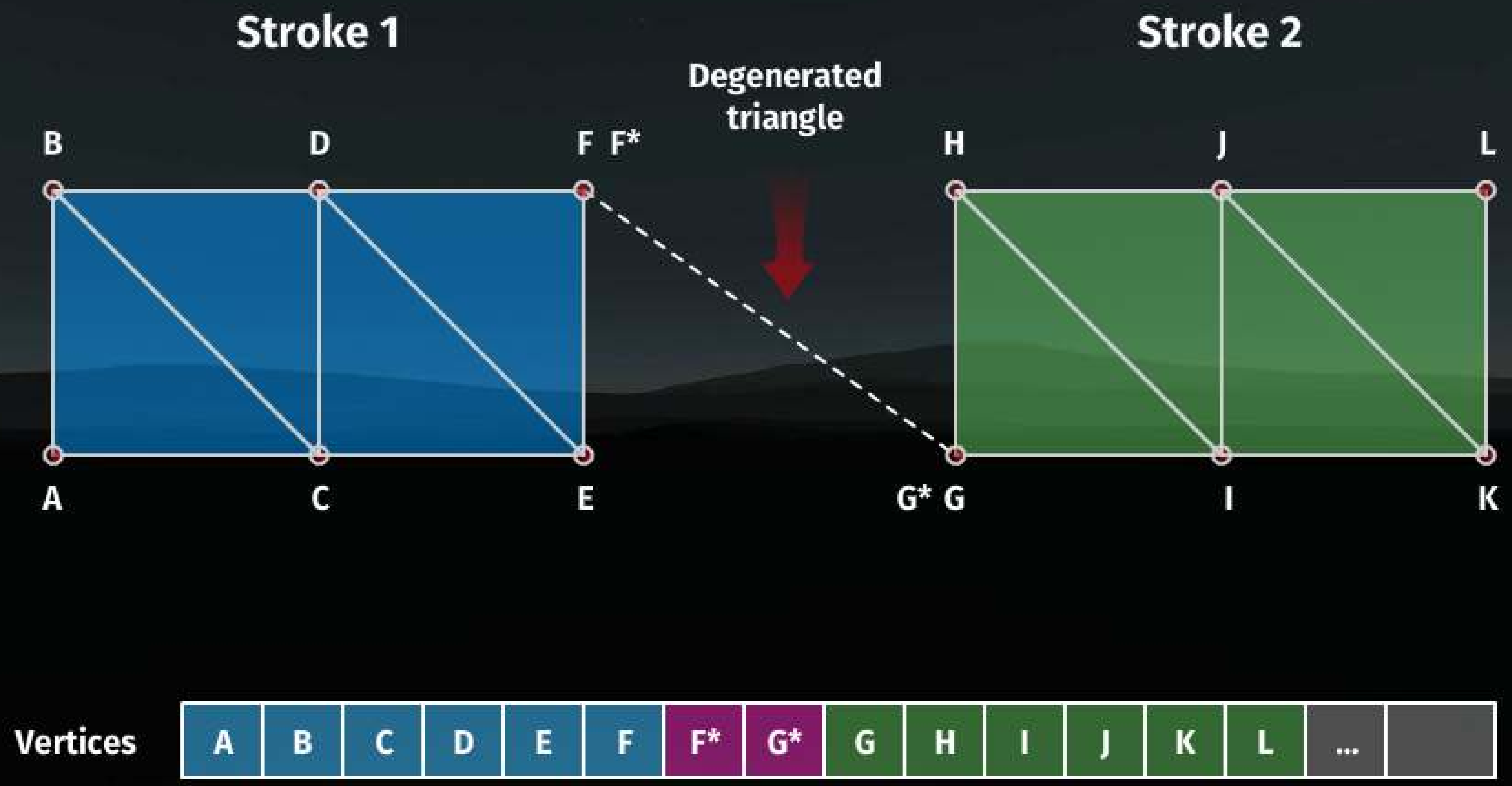

npm run atlas

DEGENERATED TRIANGLE

Normal triangle
(Rendered)

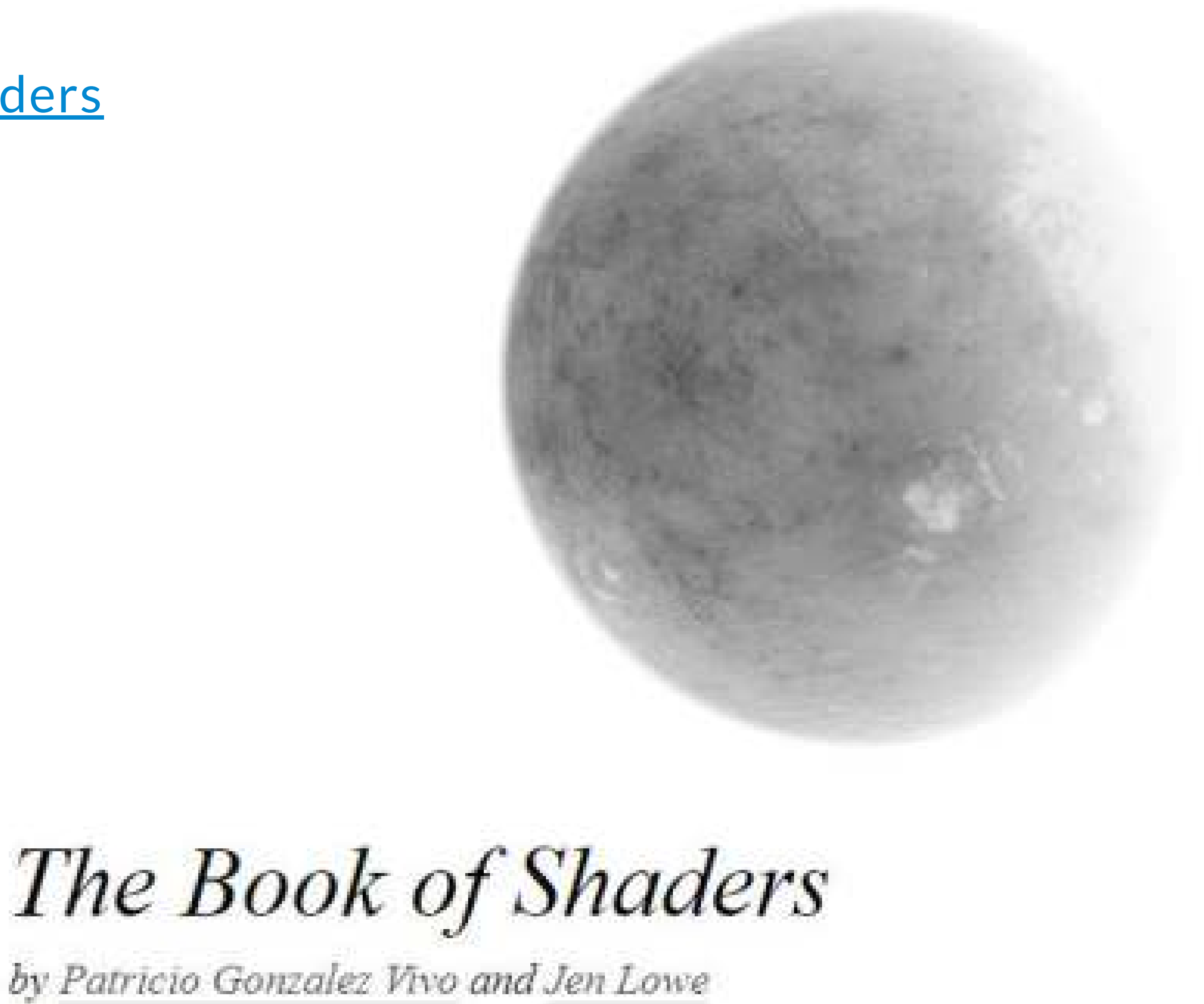


Degenerated triangle
(Discarded by GPU)

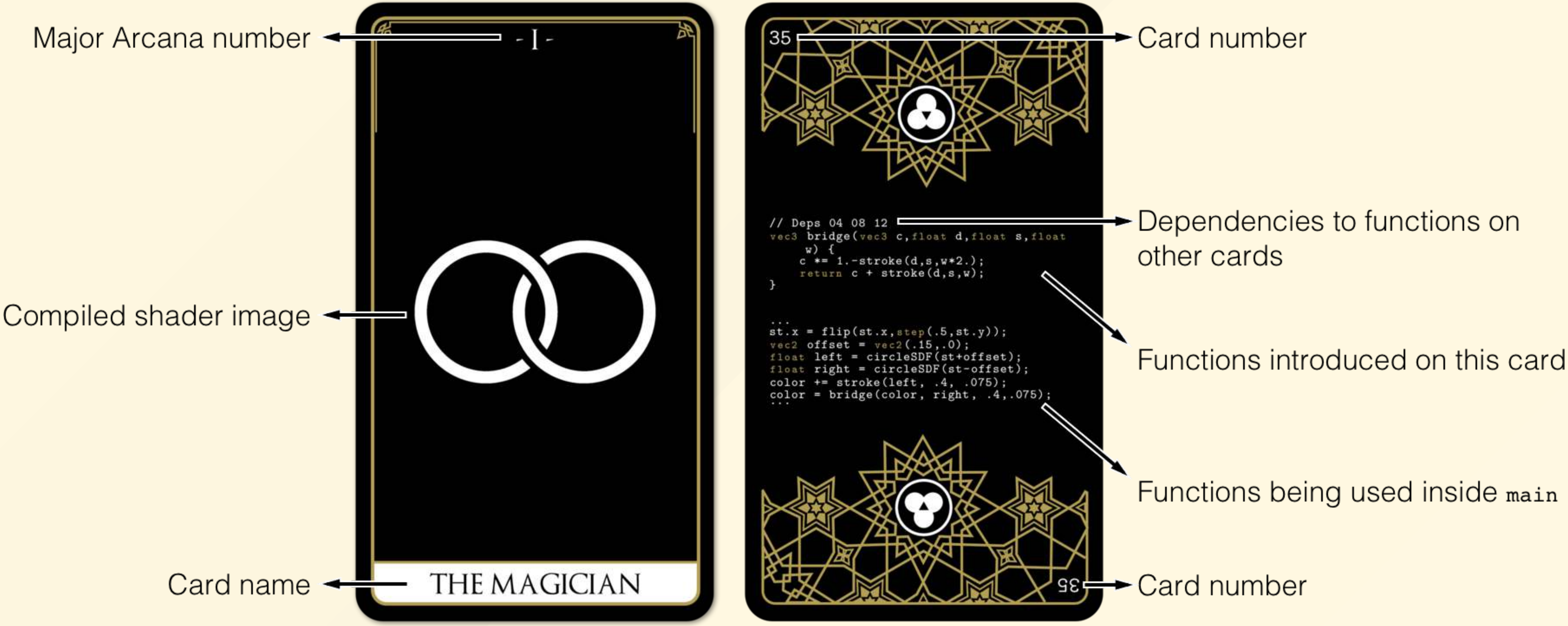


More shaders!

The Book of Shaders



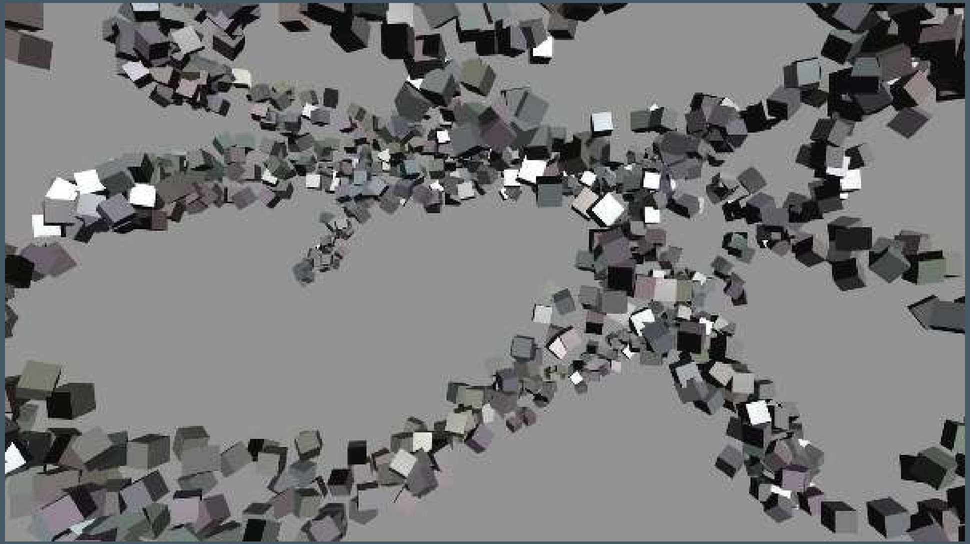
PixelSpiritDeck

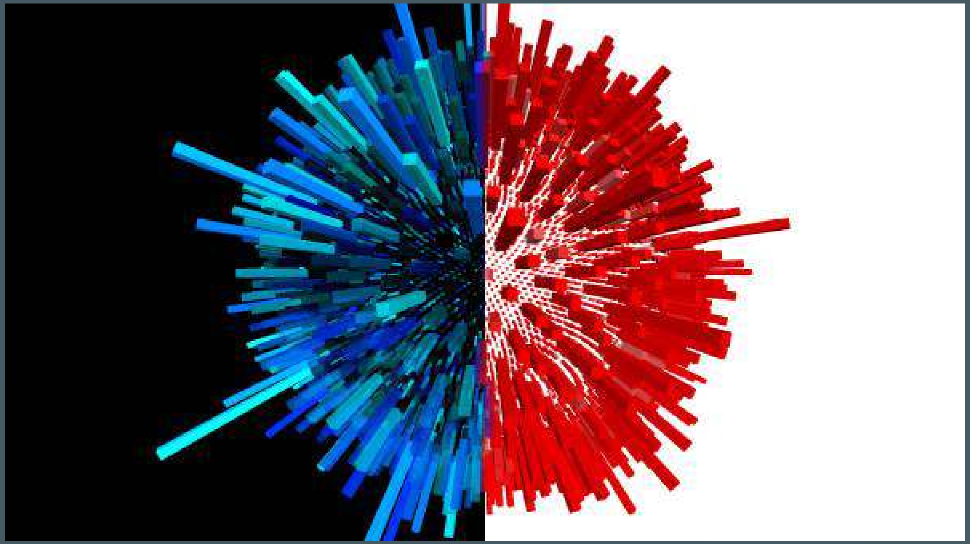


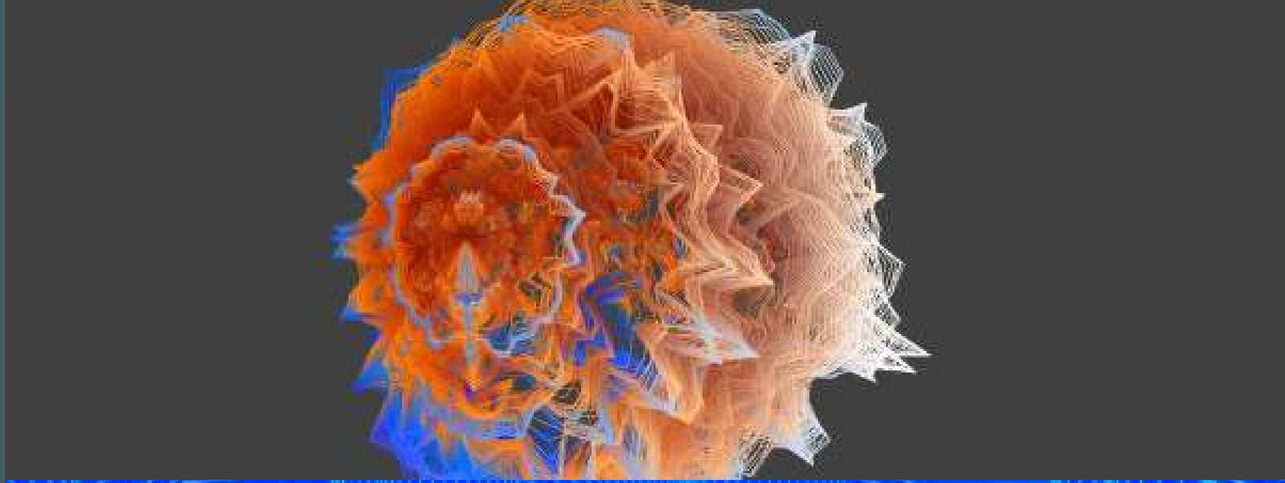
[ShaderToy](https://www.shadertoy.com/user/Shakemayster)

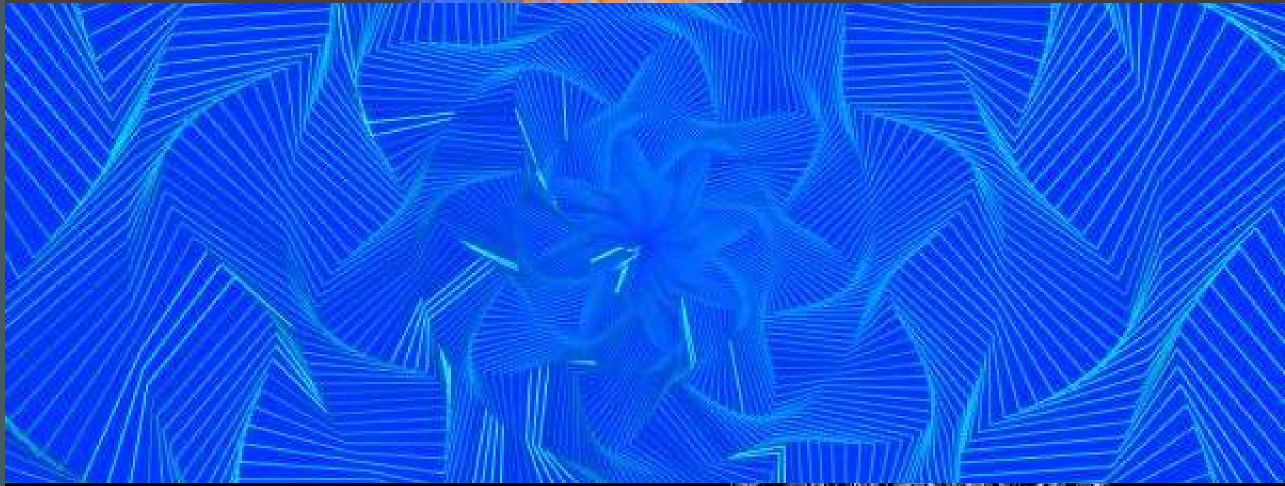
https://www.shadertoy.com/user/Shakemayster

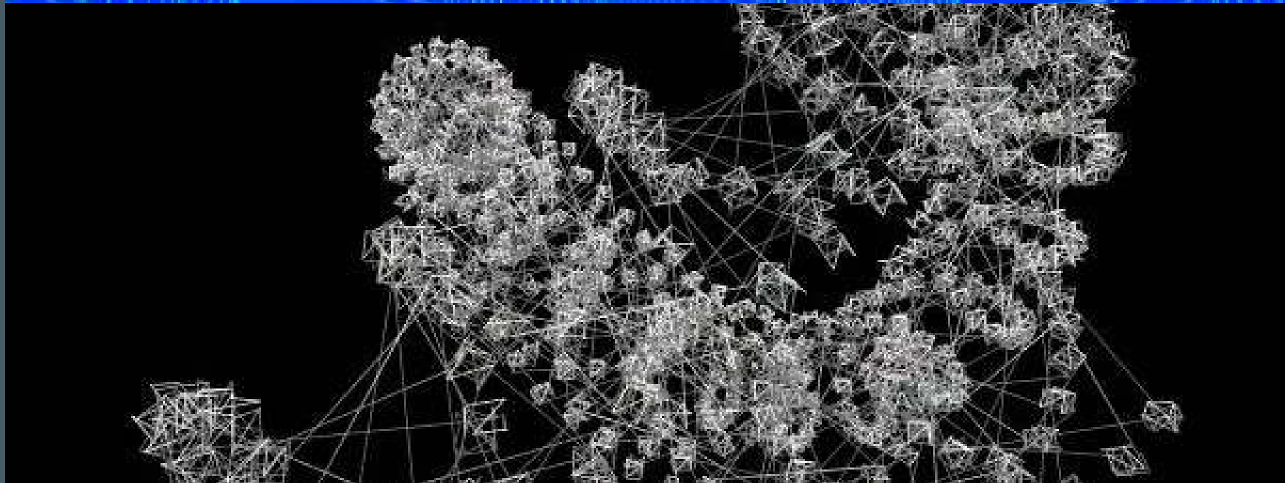
Vertex Shader Art











Online shader editors

- http://shdr.bkcore.com/
- https://shaderfrog.com/
- http://glslb.in/
- http://glslsandbox.com/

More advanced APIs

- WebGL 2.0
  - new shaders: `in`, `out`, flexibility, draw_buffers, UBO and more
- WebGPU (from WebGL to WebGPU)
  - generalizes **VAO** concepts to all attributes and states
- THREE.js ⭐ ⭐ ⭐ ⭐ ⭐
  - high-level API: abstracts WebGL! 🎉
    - **SceneGraph** (like OpenInventor, Unity or Blender)
      granularity: ~~buffers~~ ~~triangles~~ 3D objects!
  - seamless transition to WebGL2, WebGPU etc.

WebAssembly (Wasm)

- Compile your native code for theweb

{ C++, OpenGL } ➡️ emscripten ➡️ { HTML, JS (Wasm), WebGL }

- Minimalistic example summarized below

- C++

```cpp
#include <functional>

#include <emscripten.h>
#include <SDL.h>

#define GL_GLEXT_PROTOTYPES 1
#include <SDL_opengles2.h>

//...

// an example of something we will control from the javascript side
bool background_is_black = true;

// the function called by the javascript code
extern "C" void EMSCRIPTEN_KEEPALIVE toggle_background_color() { background_is_black = !background_is_black; }

std::function<void()> loop;
void main_loop() { loop(); }

int main()
{
    SDL_Window *window;
    SDL_CreateWindowAndRenderer(640, 480, 0, &window, nullptr);
```

```cpp
//...

    loop = [&]
    {
        // move a vertex
        const uint32_t milliseconds_since_start = SDL_GetTicks();
        const uint32_t milliseconds_per_loop = 3000;
        vertices[0] = ( milliseconds_since_start % milliseconds_per_loop ) / float(milliseconds_per_loop) - 0.5f;
        glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);

        // Clear the screen
        if( background_is_black )
            glClearColor(0.0f, 0.0f, 0.0f, 1.0f);
        else
            glClearColor(0.9f, 0.9f, 0.9f, 1.0f);
        glClear(GL_COLOR_BUFFER_BIT);

        // Draw a triangle from the 3 vertices
        glDrawArrays(GL_TRIANGLES, 0, 3);

        SDL_GL_SwapWindow(window);
    };

    emscripten_set_main_loop(main_loop, 0, true);

    return EXIT_SUCCESS;
}
```

- HTML / JavaScript

```html
<body>

    <!-- Create the canvas that the C++ code will draw into -->
    <canvas id="canvas" oncontextmenu="event.preventDefault()"></canvas>

    <!-- Allow the C++ to access the canvas element -->
    <script type='text/javascript'>
        var canv = document.getElementById('canvas');
        var Module = {
            canvas: canv
        };
    </script>

    <!-- Call the javascript glue code (index.js) as generated by Emscripten -->
    <script src="index.js"></script>

    <!-- Allow the javascript to call C++ functions -->
    <script type='text/javascript'>
        canv.addEventListener('click',    _toggle_background_color, false);
        canv.addEventListener('touchend', _toggle_background_color, false);
    </script>

    <!-- Describe what the user is seeing -->
    <p>Click the canvas to change the background color.</p>
    <hr>
    <p>Minimal example of animating the HTML5 canvas from C++ using OpenGL through WebAssembly.</p>
    <p>Source code: <a href="https://github.com/timhutton/opengl-canvas-wasm">https://github.com/timhutton/opengl-canvas-wasm</a></p>

</body>
```

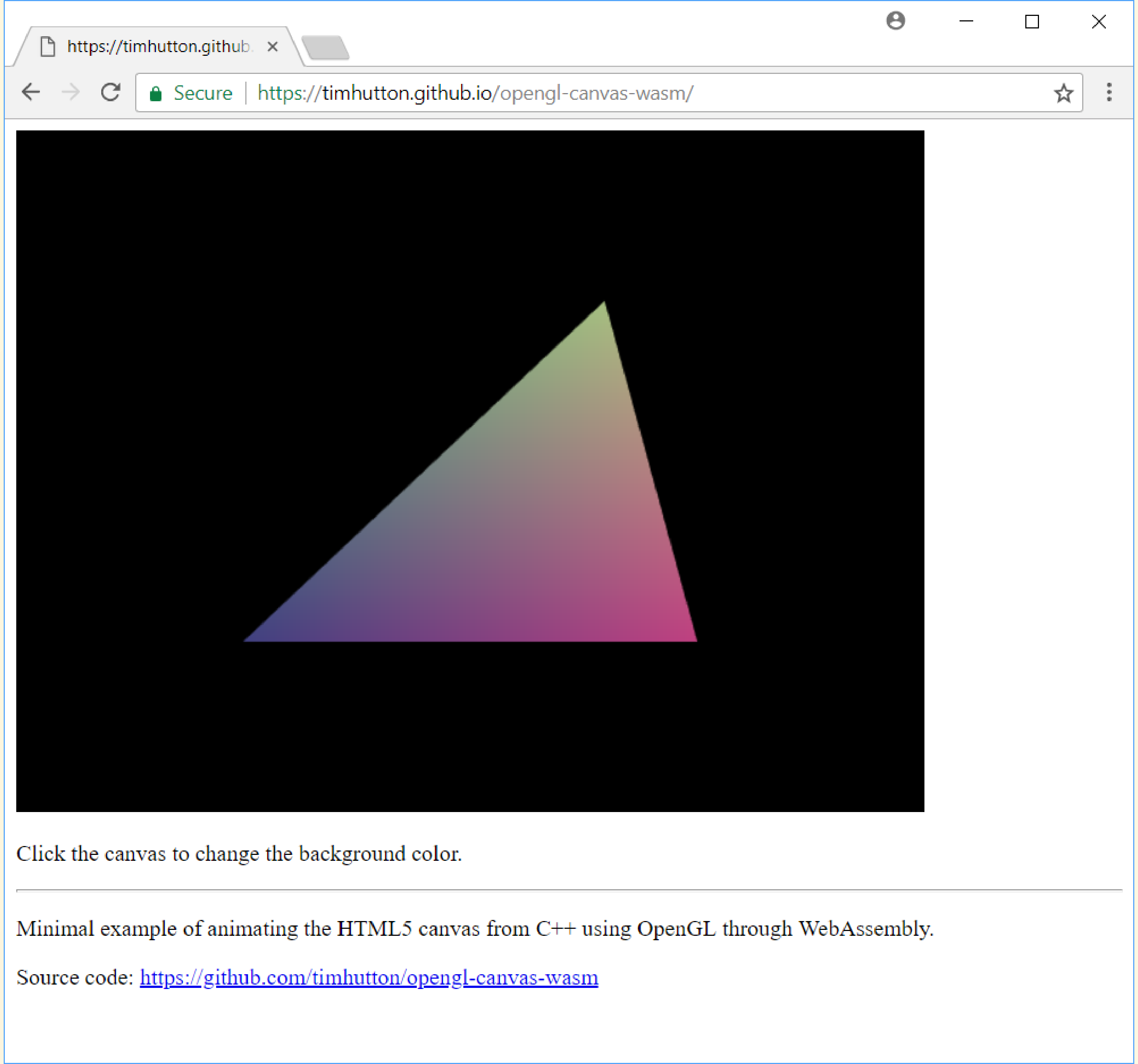
Compilation

- Install Emscripten
- Generate `index.js` and `index.wasm`:

```
emcc main.cpp -std=c++11 -s WASM=1 -s USE_SDL=2 -O3 -o index.js
```

- Open index.html (using server)

Result


https://timhutton.github.
Secure
https://timhutton.github.io/opengl-canvas-wasm/
Click the canvas to change the background color.
Minimal example of animating the HTML5 canvas from C++ using OpenGL through WebAssembly.
Source code: https://github.com/timhutton/opengl-canvas-wasm

“ I implemented WebGL in Chrome and my name is on the spec so I have some clue how it works ”

“ TL;DR
If you want to get stuff done use three.js. ”

Gregg Tavares (@greggman)

THREE.js

Interactive overview
by
David Lyons
https://davidlyons.dev/threejs-intro

Intro to WebGL with Three.js

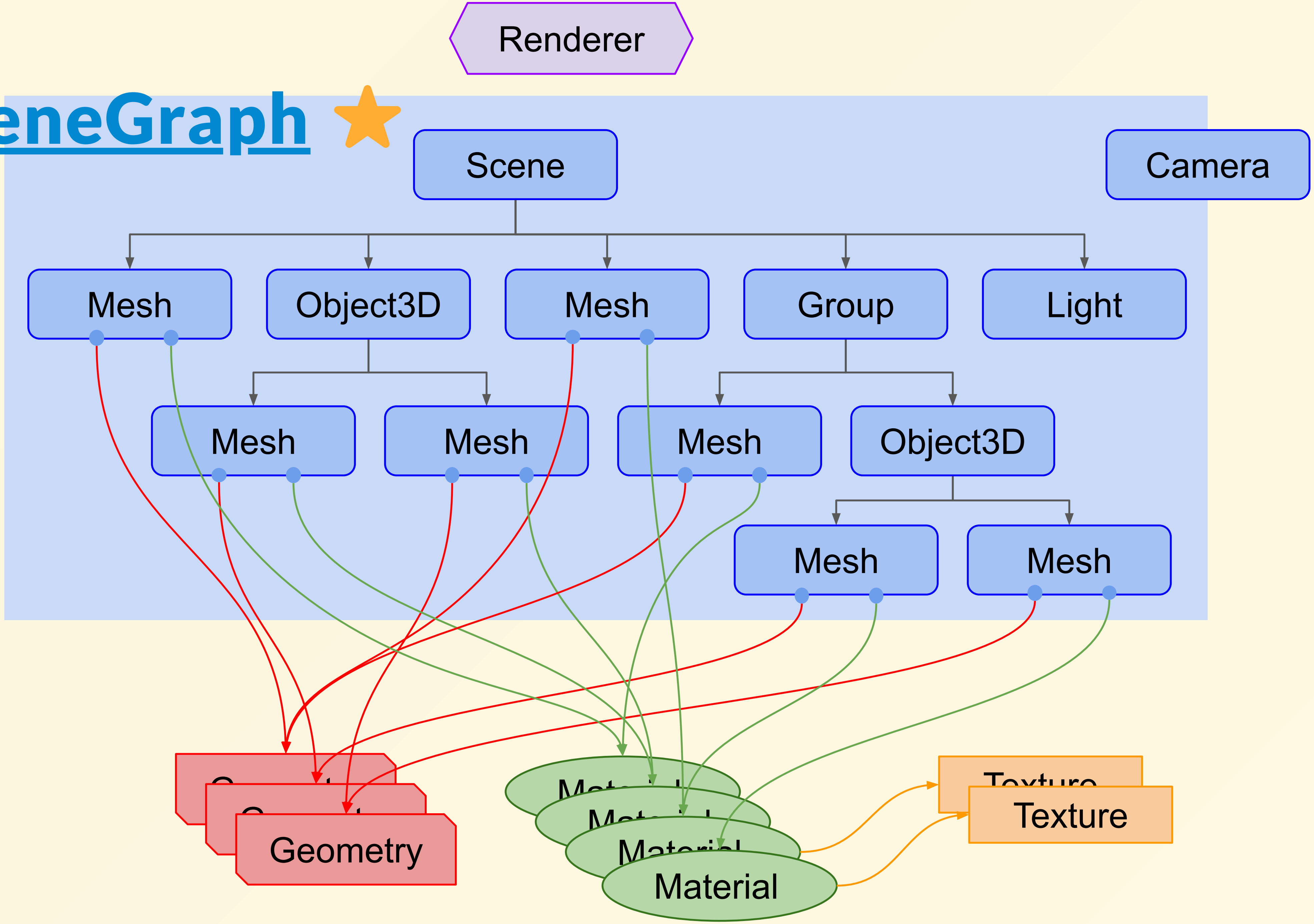
THREE.js Manual

⭐ BEST Guide ⭐

https://threejs.org/manual/#en/fundamentals

Complete and simple guide

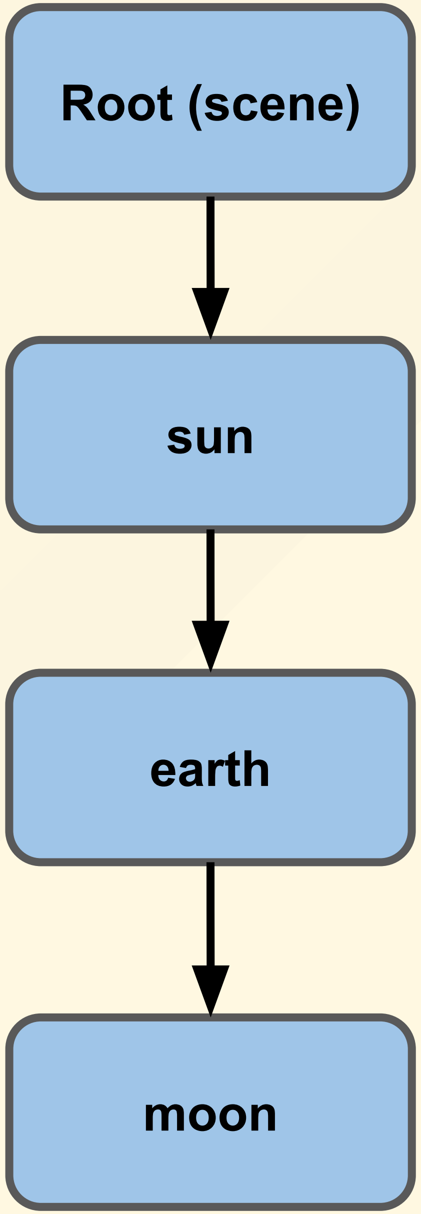
SceneGraph ★



Renderer
Scene
Camera
Mesh
Object3D
Mesh
Group
Light
Mesh
Mesh
Mesh
Object3D
Mesh
Mesh
Geometry
Material
Texture
Texture

- we handle **3D objects** instead of buffers
    - higher level, easier, more intuitive
- each scene is organized as a **hierarchy** of objets
    - hence the term **"scene graph"**
- allows to combine **local transforms** into global transforms
    - ex: solar system (see below), wheels of a car
- **rendering API abstraction**
    - ex: seamless transition from WebGL to WebGPU
- scene graph **optimizations**
    - batching
    - smart update of 3D objects

Solar system example



THREE.js Manual (excerpts)

- load and handle **glTF / glb** models
- how to create a **game**
  - presentation (**progress bar**)
  - code **architecture** notions
  - **keyboard** input
  - glTF **animations**

Setup

in order to "Build"

How to run the examples locally

Setup

- THREE.js is a **library**, **NOT** a standard API like WebGL
- THREE.js abstracts WebGL 1, WebGL 2 and WebGPU
- We need to **import** its modules before coding:
  - 1️⃣ either using **CDN** (Content Delivery Network)
    - **zero setup**: allows **quick tests, without installation**
  - 2️⃣ or through a full **installation** (via Node.js)
    - allows complete access to all resources, but introduces a complex toolchain (npm, webpack, rollup etc.)
  - ⚠️ zip download **NOT** recommended (complex dependencies)

1 Zero Setup: using a CDN

```
<!DOCTYPE html>
<html lang="en">

   <head>
       <title>three.js</title>
       <meta charset="utf-8">
       <meta name="viewport" content="width=device-width, user-scalable=no, minimum-scale=1.0, maximum-scale=1.0">
   </head>

   <style>
     html, body { margin: 0; padding: 0;  overflow: hidden; }
   </style>

   <body>

       <script type="importmap">
         {
           "imports": {
             "three": "https://cdn.jsdelivr.net/npm/three@0.173.0/build/three.module.js",
             "three/addons/": "https://cdn.jsdelivr.net/npm/three@0.173.0/examples/jsm/"
           }
         }
       </script>

       <script type="module">

           // Example of hard link to official repo for data, if needed
           const MODEL_PATH = 'https://raw.githubusercontent.com/mrdoob/three.js/r173/examples/models/gltf/LeePerrySmith/LeePerrySmith.glb';

           import * as THREE from 'three'

           import { OrbitControls } from 'three/addons/controls/OrbitControls.js';
           import { GLTFLoader } from 'three/addons/loaders/GLTFLoader.js';

           // INSERT CODE HERE

       </script>
   </body>
</html>
```

- **[Hello Cube](#)** ([modern ES6+](#) version, using `const`, `let` and `=>`)

```
const scene = new THREE.Scene();
const aspect = window.innerWidth / window.innerHeight;
const camera = new THREE.PerspectiveCamera( 75, aspect, 0.1, 1000 );
const renderer = new THREE.WebGLRenderer();
renderer.setSize( window.innerWidth, window.innerHeight );
document.body.appendChild( renderer.domElement );

const geometry = new THREE.BoxGeometry( 1, 1, 1 );
const material = new THREE.MeshNormalMaterial();
const cube = new THREE.Mesh( geometry, material );
scene.add( cube );
camera.position.z = 5;

const render = () => {
  requestAnimationFrame( render );
  cube.rotation.x += 0.1;
  cube.rotation.y += 0.1;
  renderer.render( scene, camera );
};

render();
```

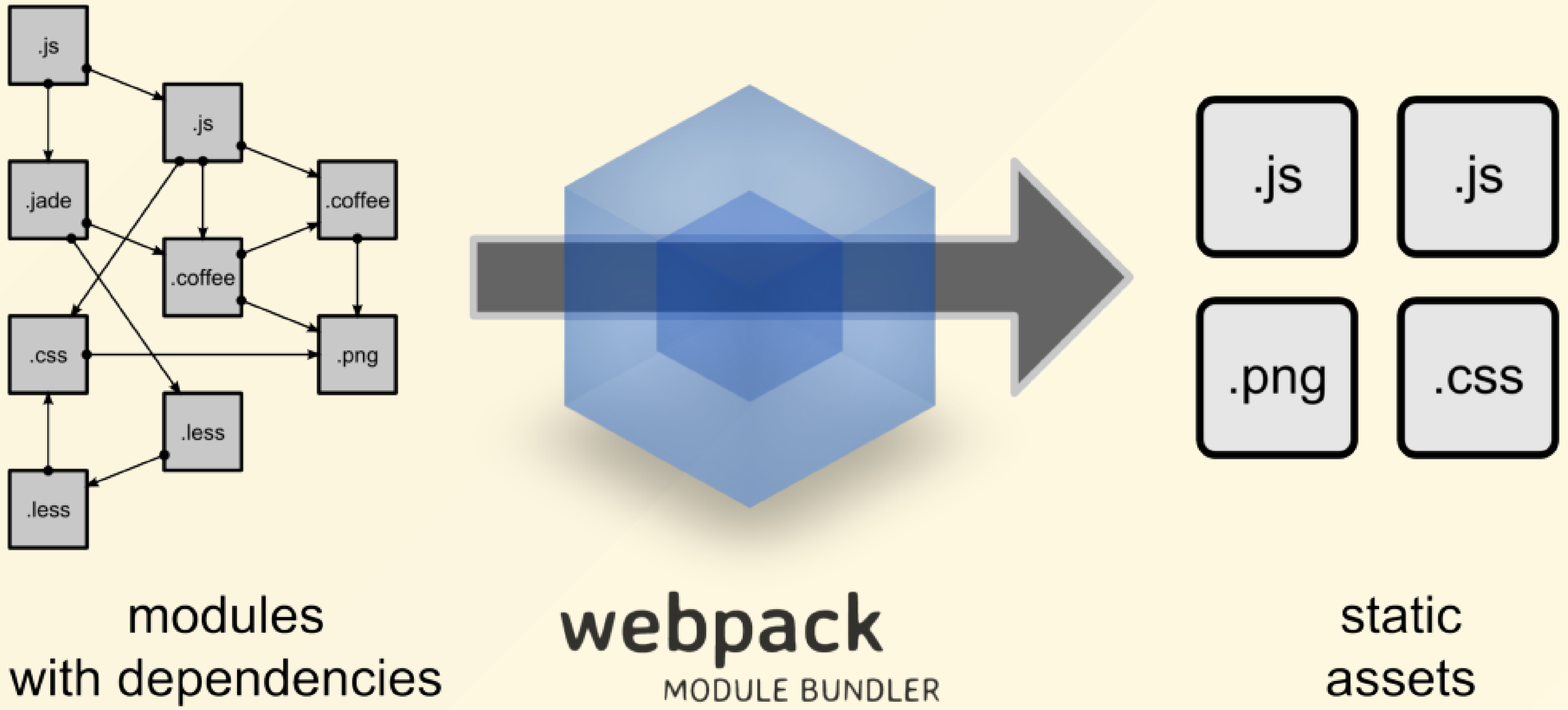
2️⃣ Full setup using NPM

- install Node.js + install npm

```
sudo apt install nodejs
curl -L https://npmjs.org/install.sh | sudo sh
```

See below

Bundlers



.js
.js
.jade
.coffee
.coffee
.css
.png
.less
.less
modules
with dependencies
webpack
MODULE BUNDLER
.js
.js
.png
.css
static
assets

Manual installation 😠

- ⚠️ **avoid manual installation!**
  - shown here for educational purposes
  - ➡️ **use three_vite template instead: automatic installation**
- install vite

```
npm install --save-dev vite
```

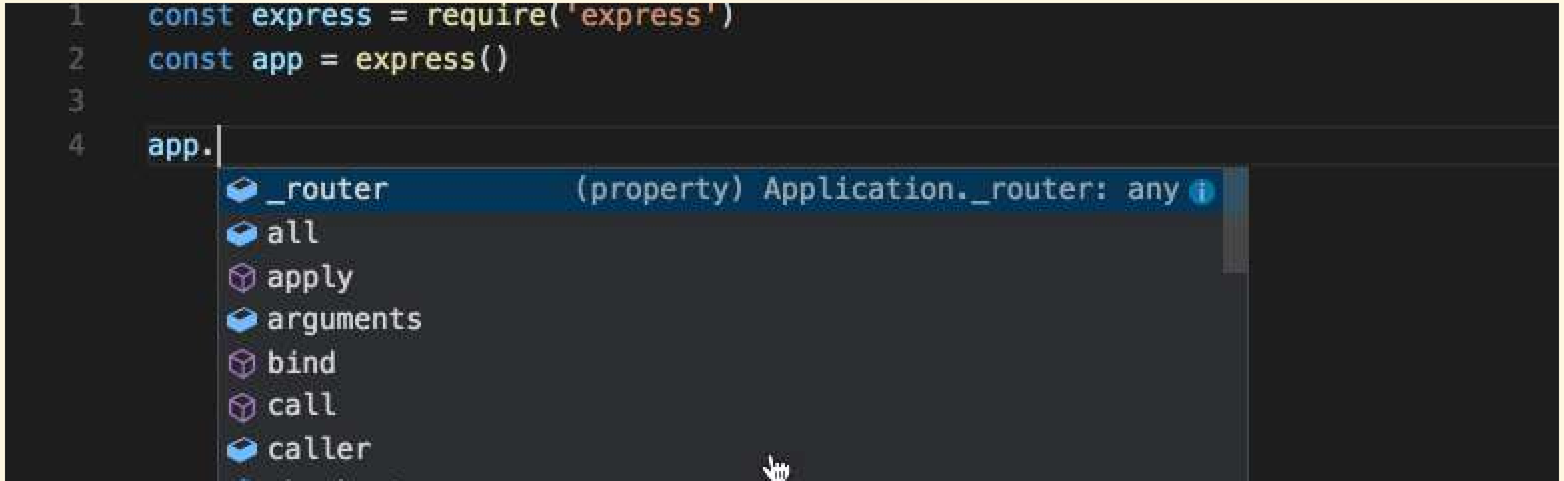
- install **three**

```
npm install three
```

THREE.js IntelliSense

- easy access to the **documentation** of THREE.js classes
- **autocompletion**
- **type checking**, even in JavaScript

```
npm install @types/three --save-dev
```



Automatic installation

THREE.js with "batteries included" 🎉

THREE Vite boilerplate ⚡ + = ❤️

Preconfigured environment (allows to test all official examples)

https://github.com/fdoganis/three_vite ⭐

```
git clone https://github.com/fdoganis/three_vite.git

cd three_vite

npm install
```

Run with `npm run dev` or use `F5` in VS Code

Open `http://localhost:5173` in your browser

Boilerplate alternatives

- Vite (uses Rollup and esbuild for speed) ⭐
  - https://github.com/j13ag0/vite-GLTFloader-test
- Rollup (the bundler by THREE developer team)
  - https://github.com/Mugen87/three-jsm
- Parcel (tutorial) (boilerplate)
  - https://github.com/fdoganis/three_parcel
  - https://github.com/franky-adl/threejs-starter-template (article)
- webpack
  - https://github.com/edwinwebb/three-seed/

Bundler wars 💥

- Rollup vs webpack vs Parcel (Comparison)
- Vite vs Parcel vs esbuild (Comparison)
- ➡️ If you don't have a favorite bundler, use:
  - **Vite** (simple, very fast and recent, might be used by THREE) ⭐
  - **Rollup** (quite simple and fast, used by THREE)
  - ~~**Parcel**~~ (too simple for THREE modules)
  - **webpack** (flexible but complex and slow)
  - **esbuild** (the fastest!)

Basic THREE.js concepts

Let's build a solar system

- full tutorial here ⬅️
- create a webpage with a `canvas`
- create a `scene` with `light`s and `mesh`es
  - understand object hierarchy
    - `add` vs `attach`
- render the scene using a `camera` and `renderer`
- animate the scene using `requestAnimationFrame`
  - or `setAnimationLoop`
- see below 👇

THREE.js Editor

- https://threejs.org/editor/ ⭐
    - basic 3D model edition
    - basic material edition
    - simple 3D format conversion
- ➡️ use THREE.js editor to create a hierarchy
    - sun ☀️
    - earth 🌍
    - moon 🌘

Advanced THREE.js

Advanced THREE.js features

- THREE.js API still allows low-level (WebGL) access, using : **BufferGeometry** + **RawShaderMaterial**
  - example: convert a terrain texture into 3D
    - see webglacademy
- Custom Geometry, indexed, dynamic

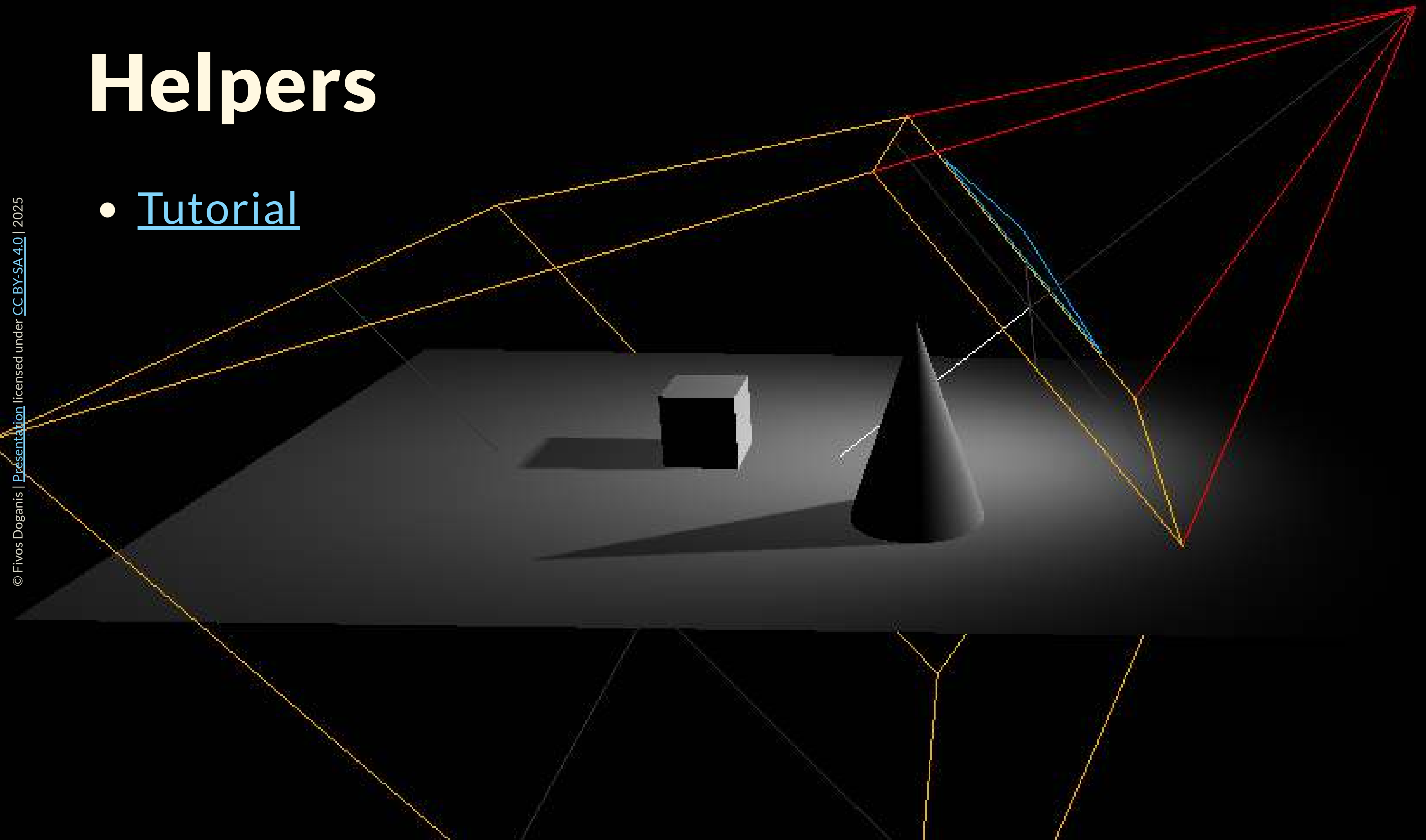
➡️ **you can still create your own WebGL shaders and custom geometry in THREE.js!** ⭐ 🎉
But most of the time the existing classes should be enough!

Good coding practices

- Modernize JavaScript code!
- WebGL best practices
- WebGL2 best practices
- Reduce Draw Calls
- use OffscreenCanvas and JavaScript workers
  - Web Workers in the Real World
  - Moving a Three.js-based WebXR app off-main-thread
    - OffscreenCanvas still not available on iOS 😢

Helpers

- [Tutorial]



Debugging tips 🐛

- **https://threejs.org/manual/en/debugging-javascript.html** ⭐
- https://discoverthreejs.com/tips-and-tricks/
- Rendering on demand (onTouch) + **lil-gui** (dat.gui) https://threejs.org/manual/en/rendering-on-demand.html
- lil-gui: Nice UI example to modify fog parameters interactively
- **Debugger**: https://github.com/spite/ThreeJSEditorExtension
- https://github.com/threejs/three-devtools for Firefox , Three-tools by BACE (Chrome et Firefox), and Spector.js

Extra features

- Troika (Doc)
- Advanced camera
- 3D Tiles (NY Times)
- Optimized post-processing
- BVH (Bounding Volume Hierarchy)
- GPU PathTracer (BVH)
- Official THREE.js links

Physics (official examples)

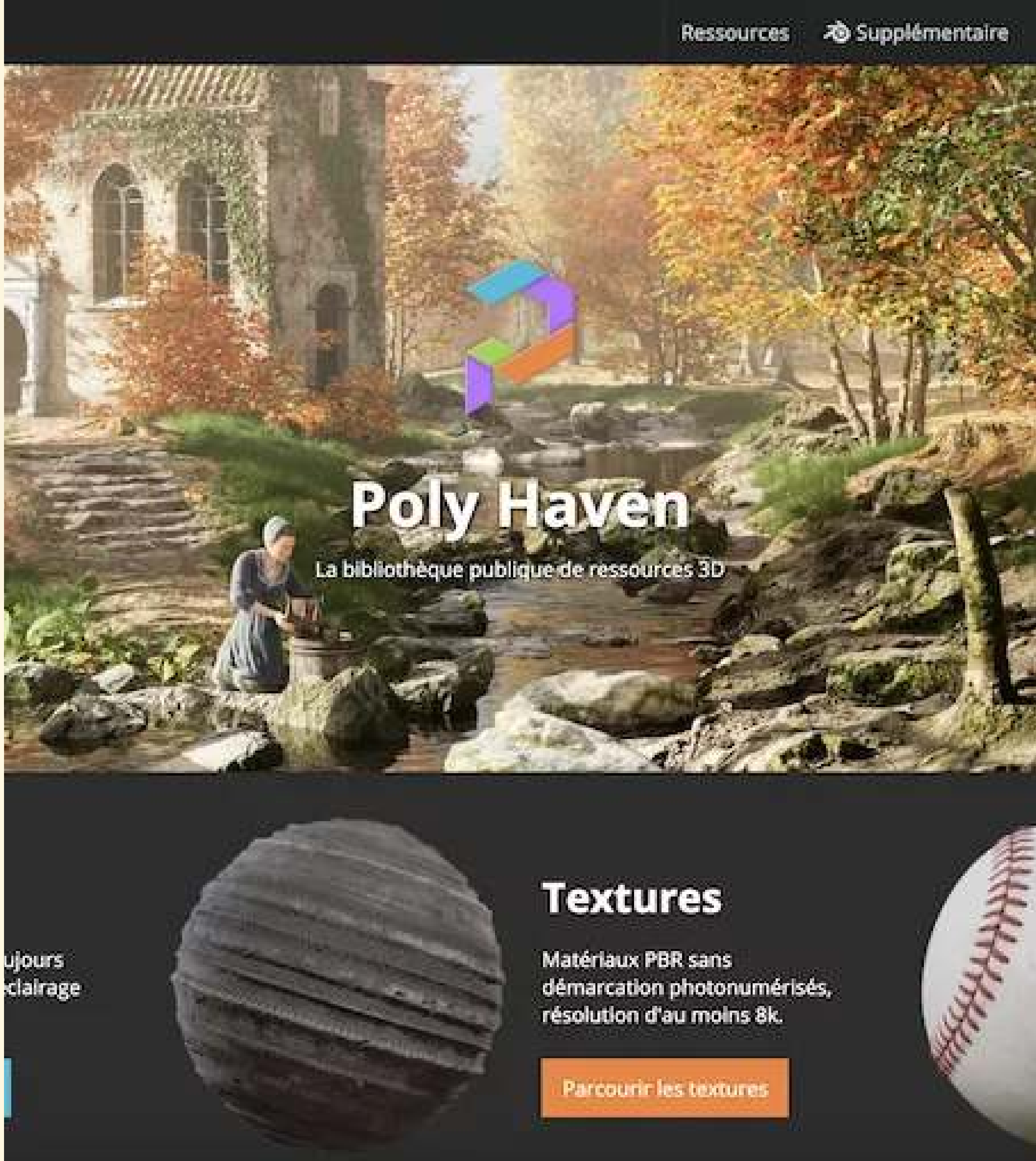
- ~~Cannon.js~~ 💀 / Cannon-es⭐ : JS port of Bullet Engine (Tutorial)
    - **Demo**! 🚗 🚁 ✈️
- Ammo.js : conversion of Bullet (C++) to JS (Wasm) (Tutorial)
    - very fast but can be difficult to debug
- Rapier : Rust physics engine converted to JS (Wasm) (Tutorial)
- Oimo : Haxe physics engine coverted to JS (Wasm) (Tutorial)
- Box2D : sometimes 2D is enough! (planar movements) (Tutorial)
- Phy : a wrapper to rule them all, including PhysX, Havok and Jolt!

3D Models

- **prefer glTF / glb format ➡️ Official THREE.js Tutorial** ⭐
  - optimize your models using glTF-Transform
- **SketchFab**
- **Low poly marketplace**
- **Poly pizza**, backup of Google Poly 💀 : **here**
- TurboSquid
- Sketchup 3D Warehouse
- Polyhaven
- Legal? (ripped)

Textures

- PolyHaven
  - HDRIs
  - Textures
- Unsplash
- Pexels



THREE.js exercises

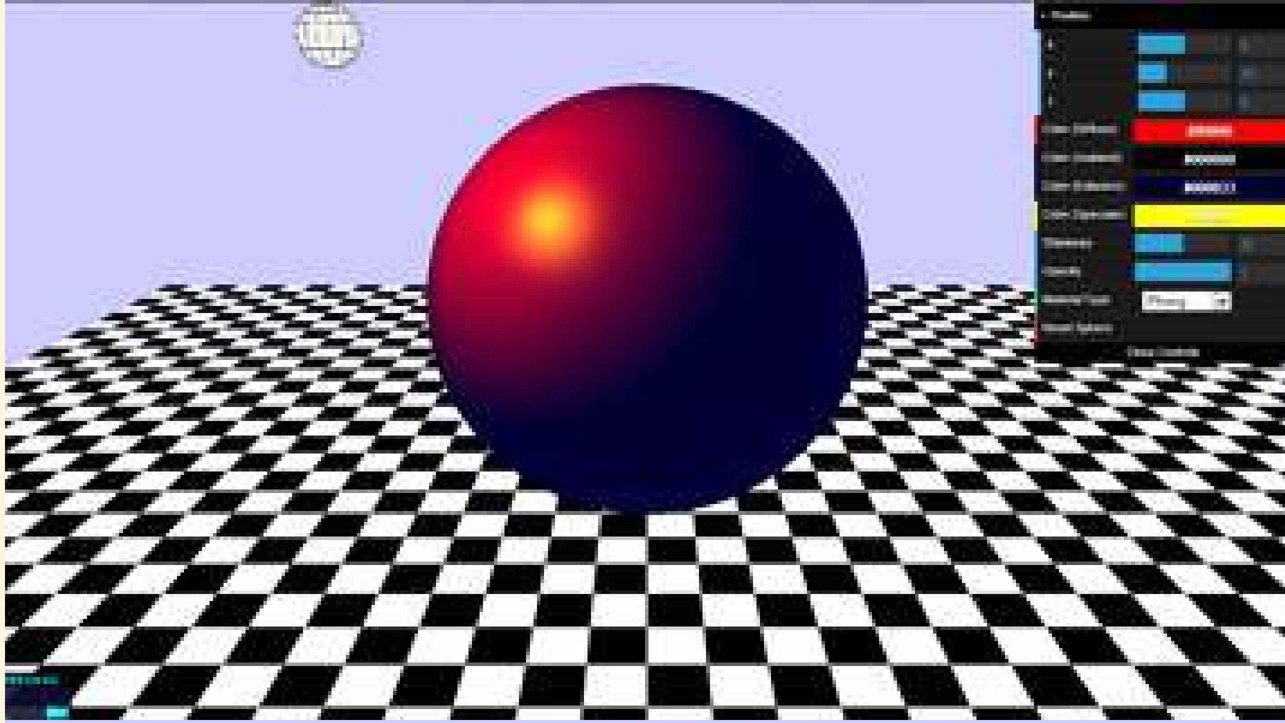
THREE.js exercises

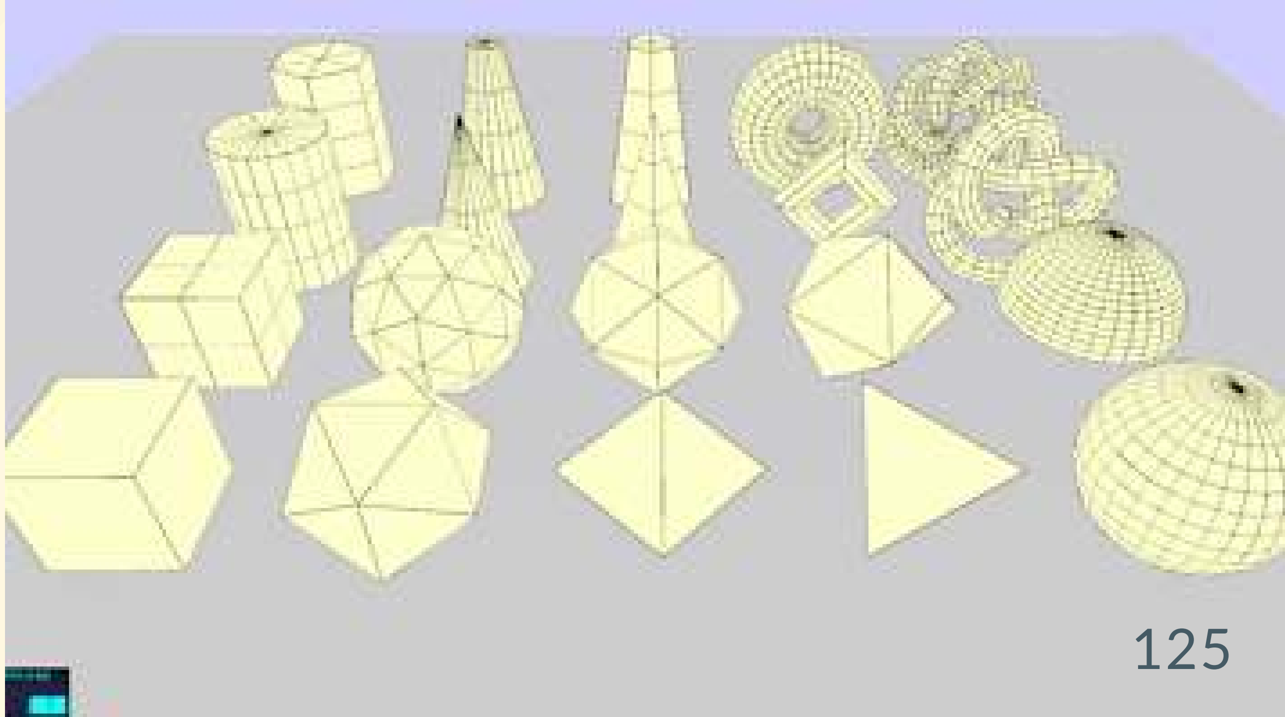
- Reminder: **[THREE.js Manual]** ⭐
- [Karim Maaloul]
  - practice:
    - [animals]
    - [aviator] ⭐
    - [aviator 2] (update) 👀
    - [red bull]

THREE.js Projects

Examples

- Official examples
  - always up to date!
  - recommended!
    - ⚠️ THREE.js API changes **very** often!
    - JavaScript API too...
- Lee Stemkoski
  - old examples
    - code needs updating





Project ideas

Fun

- Adapt existing code or games to use THREE
  - board games
  - "Flash" games
  - classic (video) games (mini-games, party games, sports)
  - add sound, and physics
    - Christmas Cannon ⭐

More project ideas

- implement a complex effect
  - raytracing, SSAO, OIT, NPR
- image processing, OpenCV
- physics
  - pool, bowling, domino, jenga, stacks
- particles: text / image to cloud of cubes
- 3D WebRTC pong (other WebRTC examples here, here and here)
- animal crossing
- personal website, interactive CV: HTML layout, THREE.js Journey

Technologies

- Gaussian splatting
- Animations
  - UI
  - IK skeleton
- Annotations
- UX
  - Haptic feedback
  - Text
  - Positional Audio

GIS Links

http://www.itowns-project.org/itowns/examples/index.html#3dtiles_25d

http://www.itowns-project.org/itowns/examples/#source_stream_wfs_3d

https://geoservices.ign.fr/documentation/services/utilisation-web/affichage-wmts/cesiumjs-et-wmts https://codepen.io/photonlines/pen/JzaLYJ

https://douglasduhaime.com/posts/visualizing-tsne-maps-with-three-js.html

https://openlayers.org/en/latest/examples/wmts.html

https://www.3ds.com/insights/customer-stories/rennes-metropole

https://www.usinenouvelle.com/article/simulation-de-singapour-a-rennes-comment-la-ville-tire-profit-de-son-double-virtuel.N1018329 https://docs.mapbox.com/mapbox-gl-js/example/3d-buildings/

https://osmbuildings.org

https://github.com/Microsoft/USBuildingFootprints

https://wiki.openstreetmap.org/wiki/Simple_3D_buildings

https://threejs.org/examples/#misc_controls_map

Extrude using geo json:
https://threejs.org/examples/webgl_geometry_extrude_shapes2.html

From height field to 3D grid mesh
https://blog.mastermaps.com/2013/10/terrain-building-with-

Infinitown
https://demos.littleworkshop.fr/infinitown

OSMBuildings 3D
https://github.com/OSMBuildings/OSMBuildings

OpenLayers
https://openlayers.org

Leaflet
https://leafletjs.com

More:
https://www.sitepoint.com/3d-maps-with-eegeo-and-leaflet/

Other tech:
https://www.igismap.com/everything-about-web-3d-map-examples-tools-library-and-uses/

Terrain
https://felixpalmer.github.io/procedural-gl-js/docs/

3D Tiles (RealityCapture) ⭐

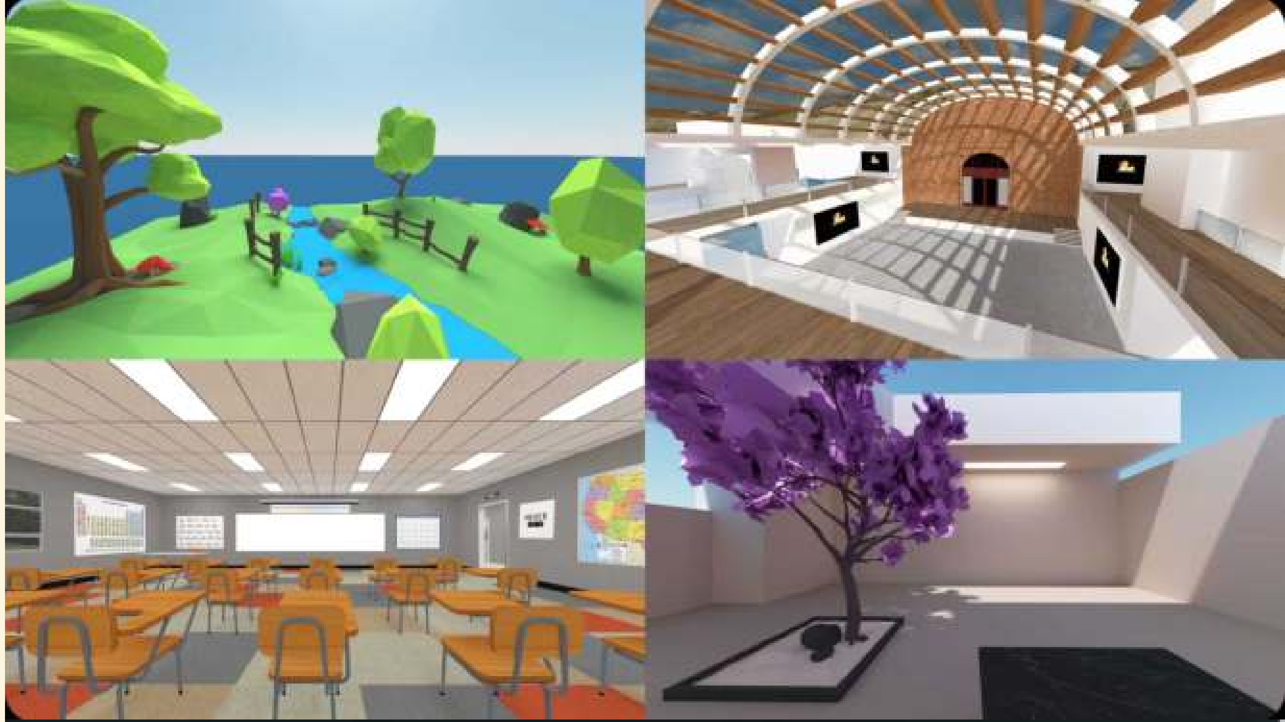
Wrappers

React Three Fiber (R3F)

- Great for "pro" web sites
- Tutorial
- Demos
  - EDF electric days
  - Racing game
- React Native

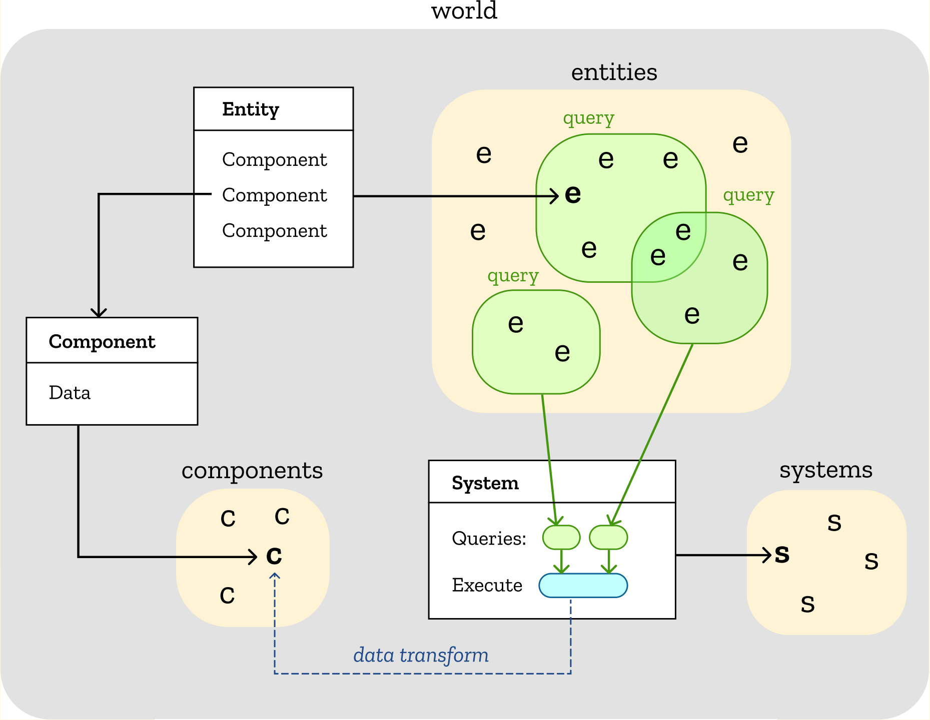
A-Frame

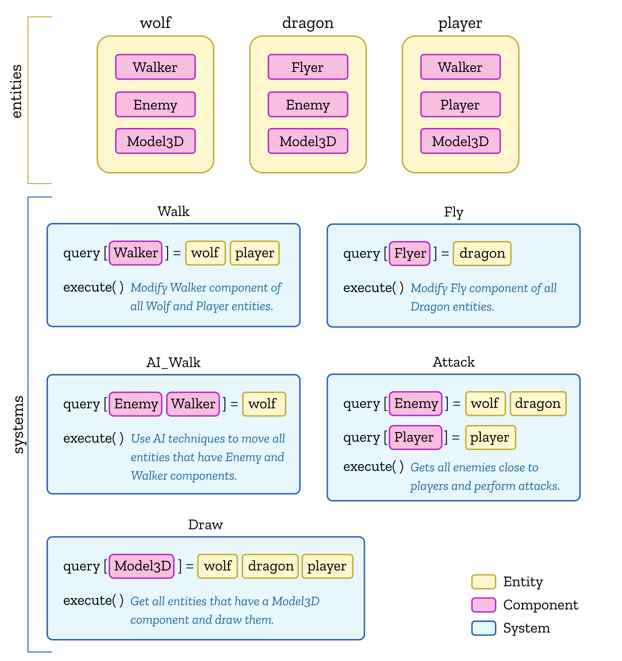
- Declarative wrapper (tags)
- Extremely simple to use (very high-level)
- Modular and extensible (**ECS**: Entity Component System)
- Ideal for AR and VR
  - Mozilla Hubs
  - A-Painter



ECS

- ECSY 💀
  - articles: Mozilla, Medium
  - ECS in 99 lines of code
- bitECS ⭐
- WolfECS
- Ape-ECS
- nopun-ecs
- ECS @ Apple (Video 25') ⭐
- used in Overwatch!





Tests

```
const THREE = require('three');
const assert = require('assert');

describe('The THREE object', function() {
  it('should have a defined BasicShadowMap constant', function() {
    assert.notEqual('undefined', THREE.BasicShadowMap);
  }),

  it('should be able to construct a Vector3 with default of x=0', function() {
    const vec3 = new THREE.Vector3();
    assert.equal(0, vec3.x);
  })
})
```

The End!