3D Web App Creation

Fivos Doganis
fivos.doganis@gmail.com

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
```

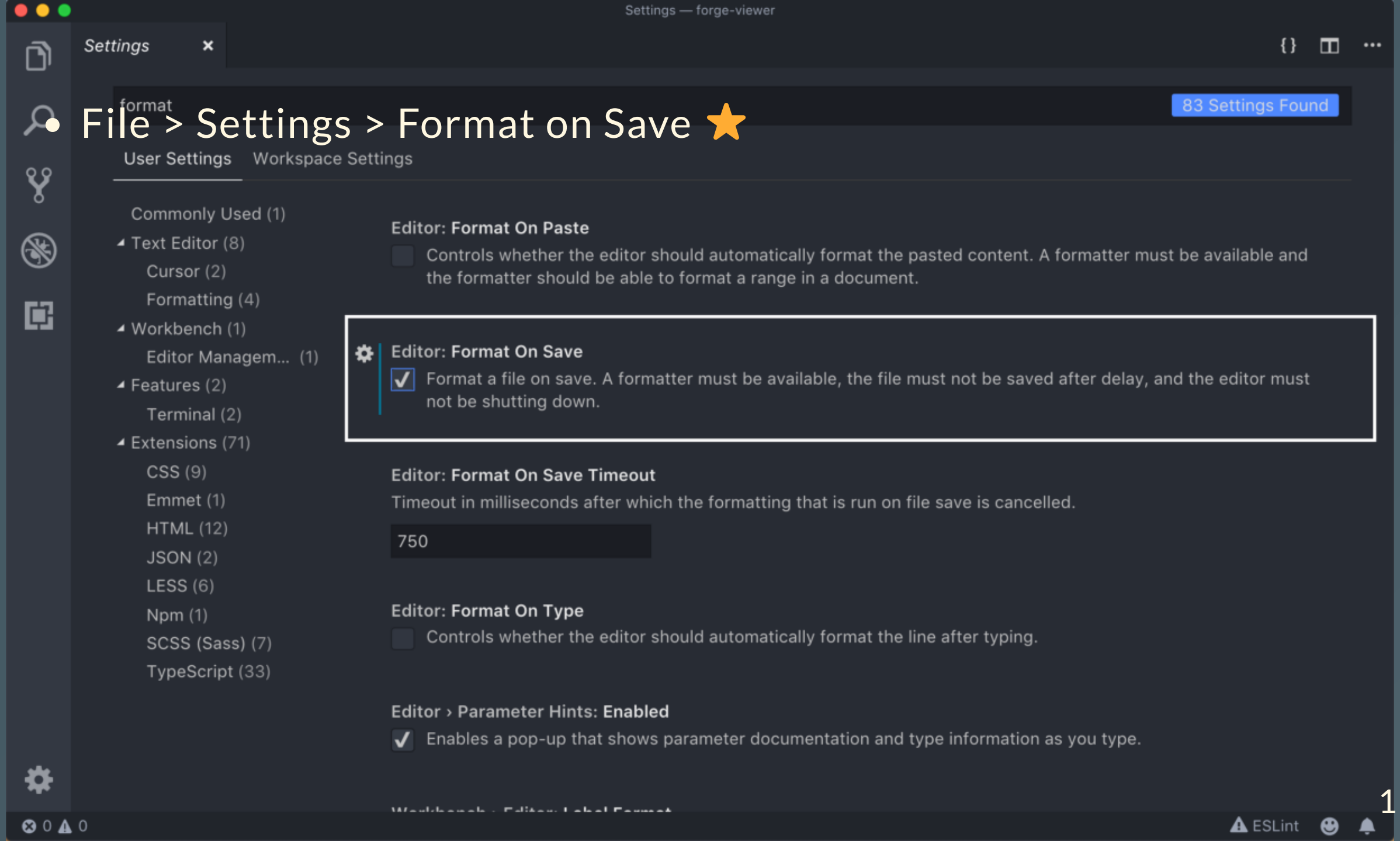
Customize VS Code

- 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

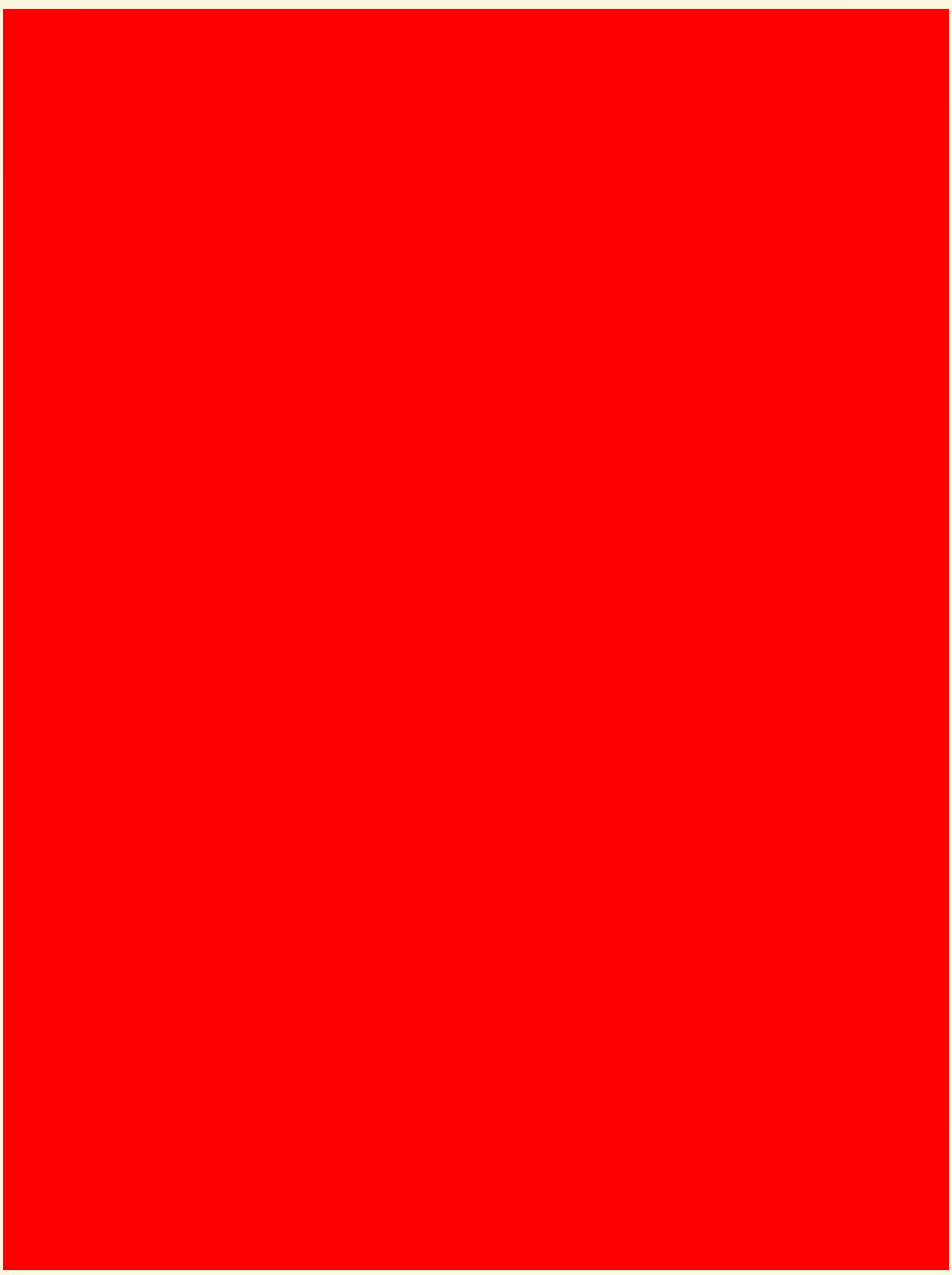
- https://caniuse.com/webgl
- https://webglreport.com/

Reminder: Minimalistic web page

```
<!DOCTYPE html>
<html>

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

<body>
</body>

</html>
```

Reminder: Minimalistic drawing program using the **Canvas** API

```
<!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>
```



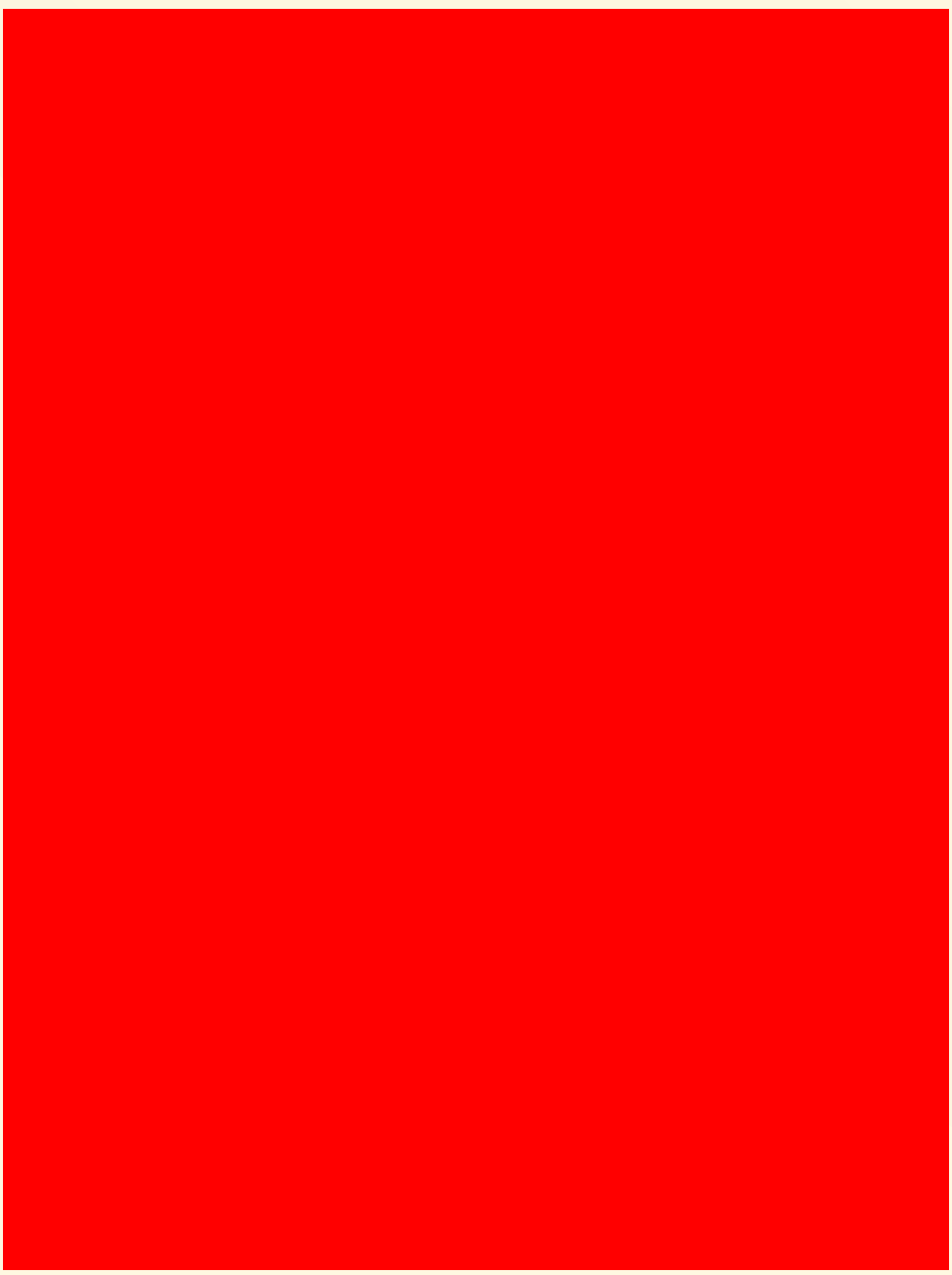
"There Is Also Canvas"

Bruno Imbrizi

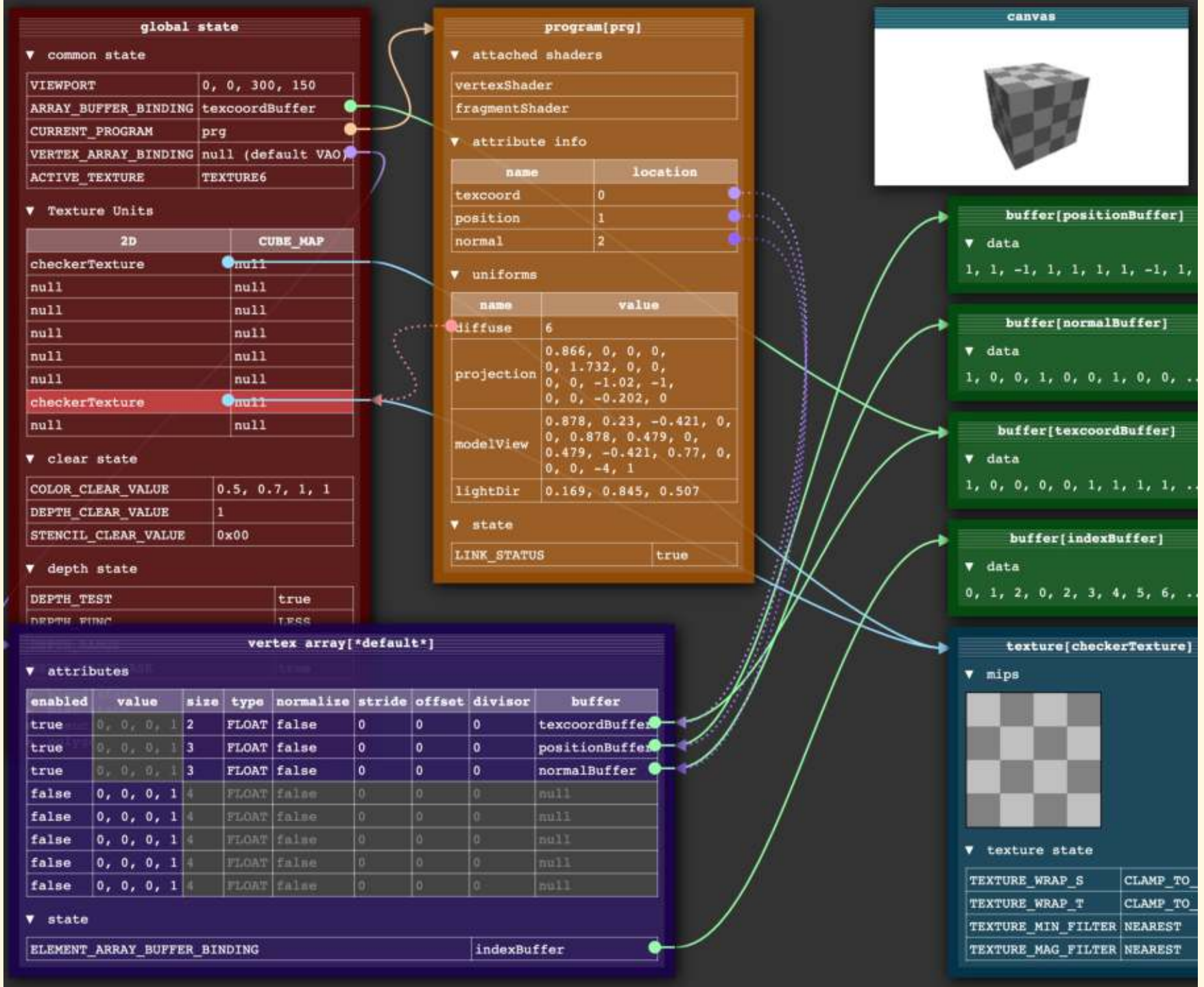
Minimalistic WebGL program: to ensure that everything works fine

⚠️ **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



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

Add this code after `gl.clear`:

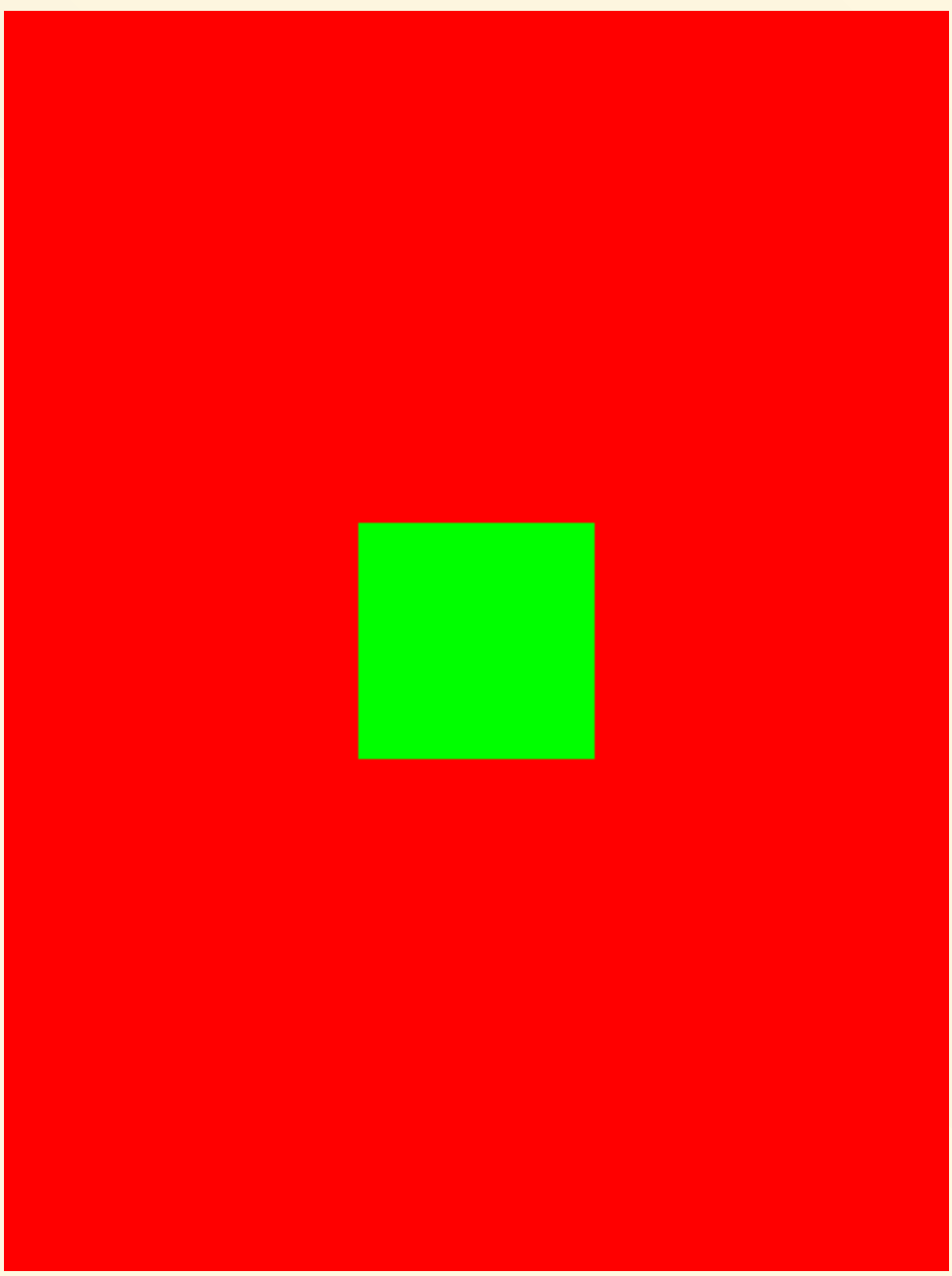
```
// vertex shader
const vs_source = `
void main() {
    gl_Position = vec4(0., 0., 0., 1.);  // center
    gl_PointSize = 120.0;
}`;

// 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!)

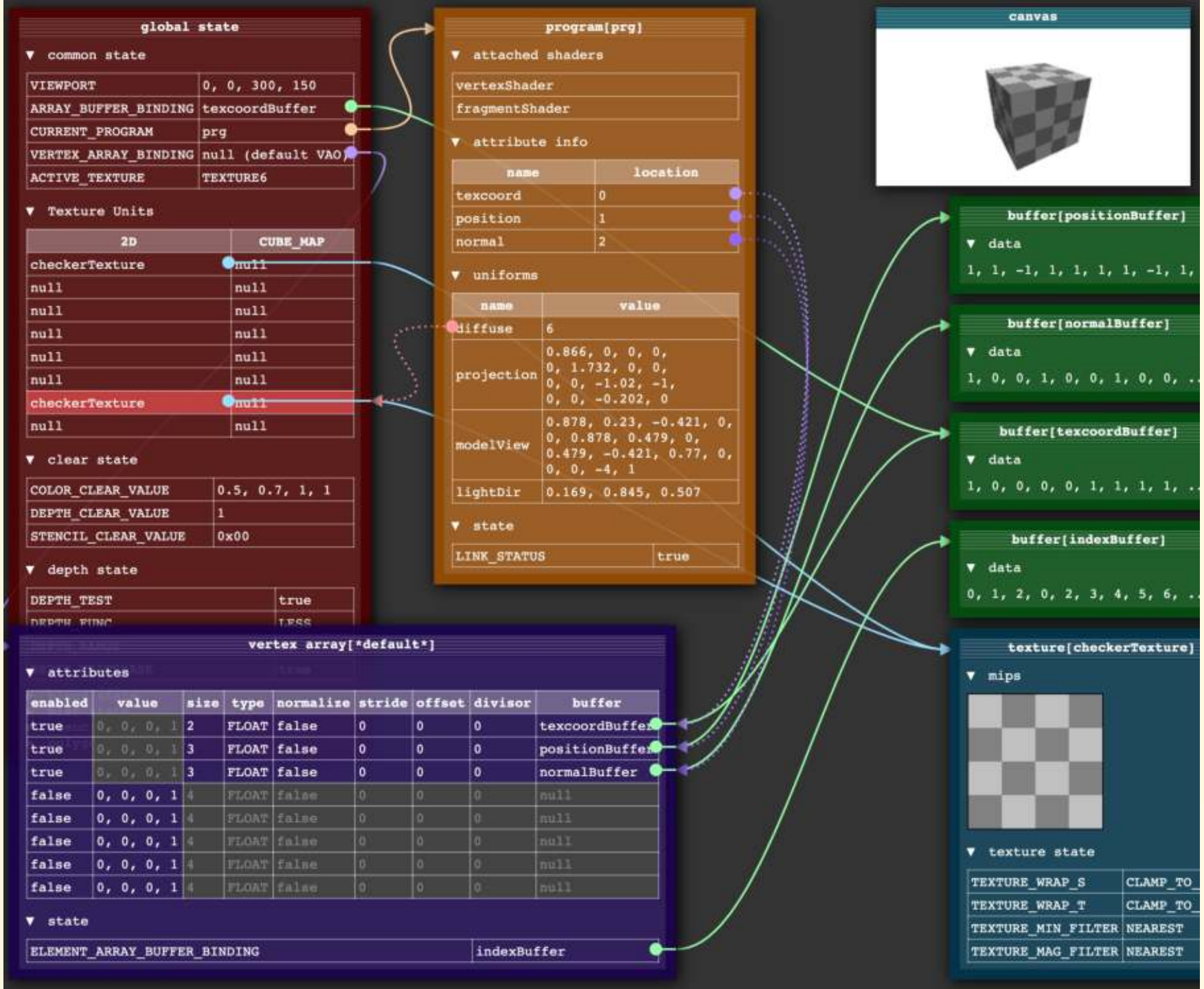
```
function buildShader(gl, shaderSource, shaderType) {
    const shader = gl.createShader(shaderType); // Create the shader object
    gl.shaderSource(shader, shaderSource); // Load the shader source
    gl.compileShader(shader); // Compile the shader
    return shader;
}

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

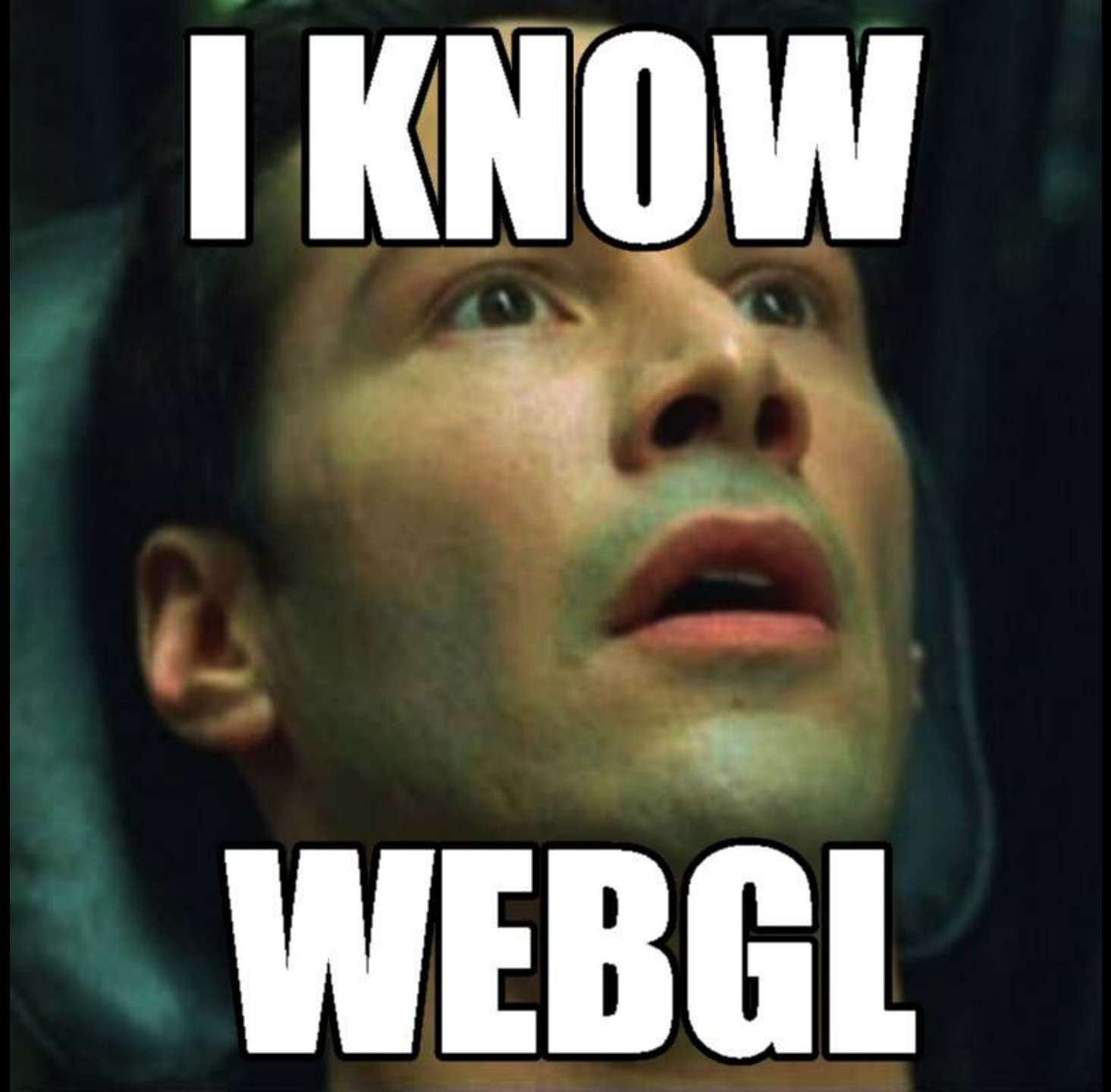
Finally : load shaders, program and render

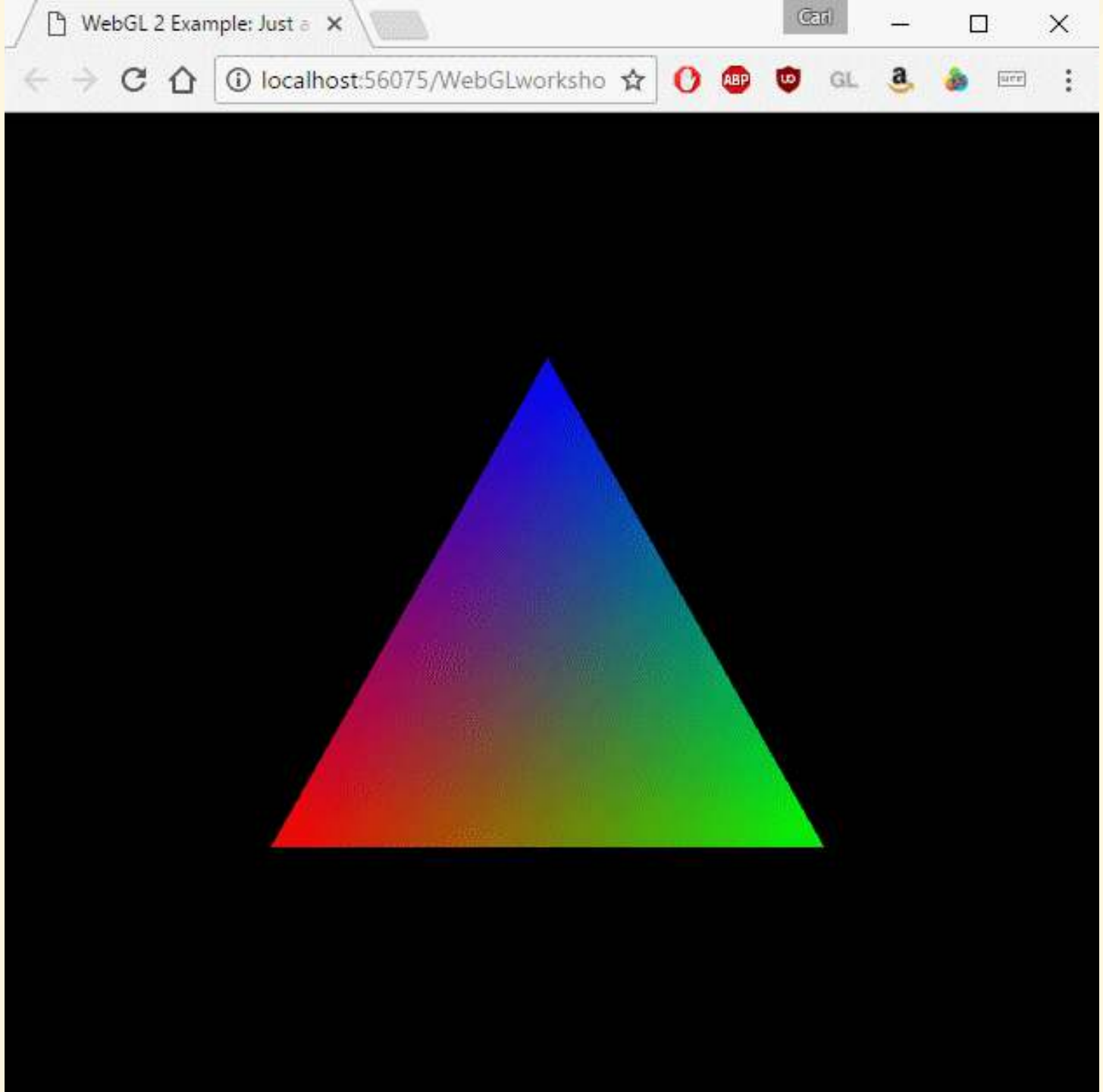
```
// load and compile the shaders
const vs = buildShader(gl, vs_source, gl.VERTEX_SHADER);
const fs = buildShader(gl, fs_source, gl.FRAGMENT_SHADER);

// 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







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:

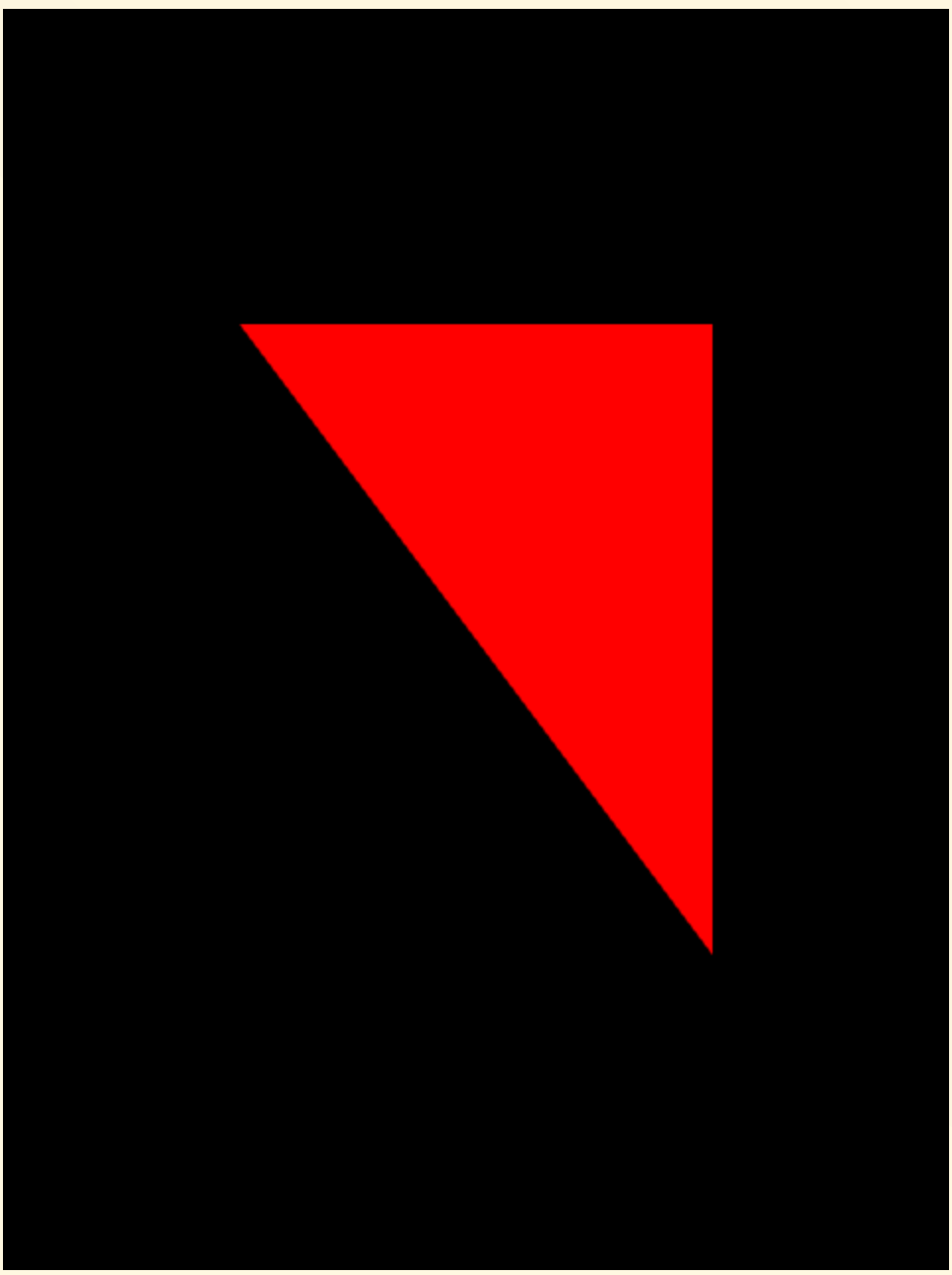
- define states
- describe buffer layout (often complex since it is very flexible!)
- draw the scene

```
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);
```

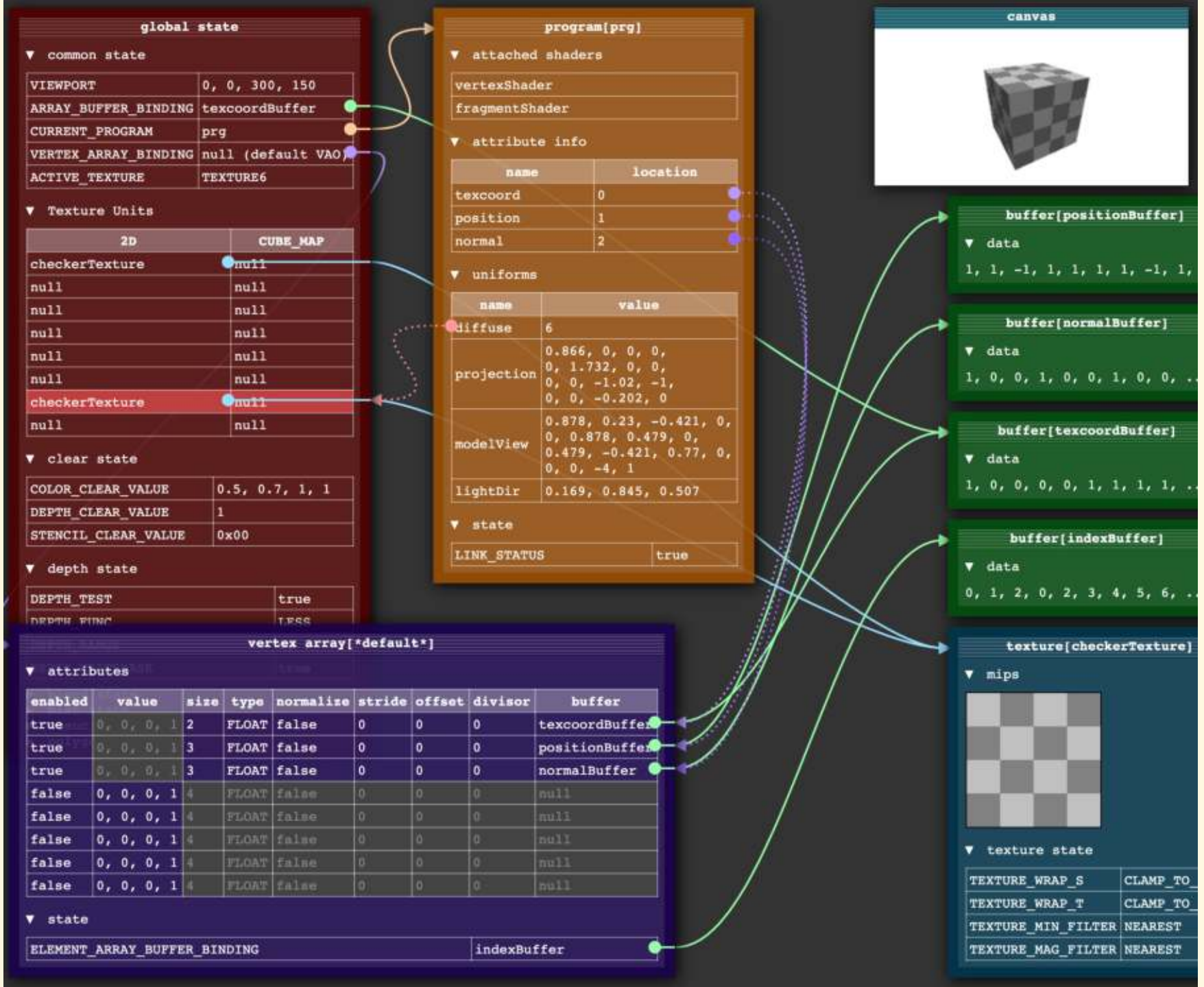

https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/vertexAttribPointer

- 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



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

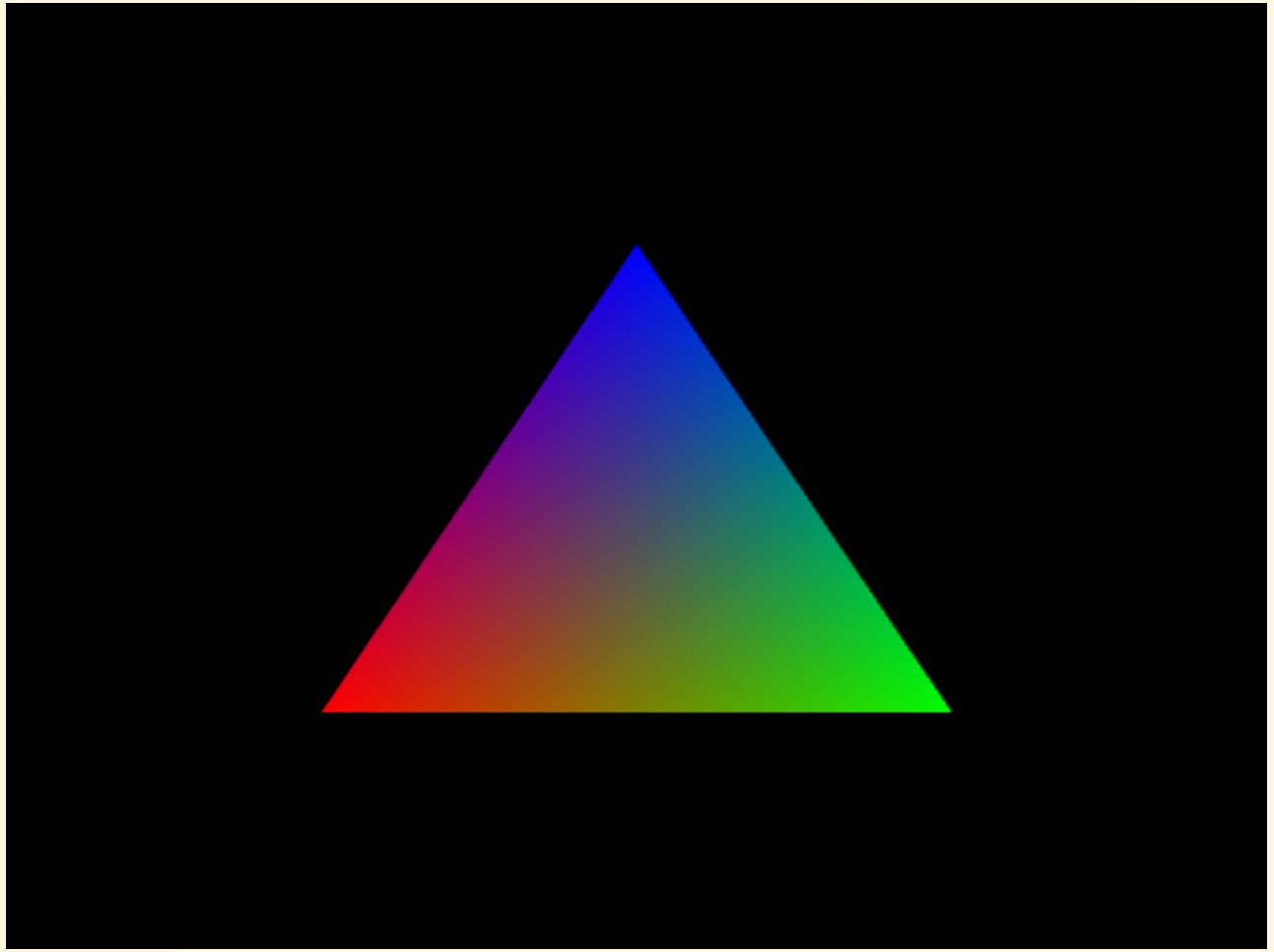
```
    gl.clearColor(0., 0., 0., 1.);
    gl.clear(gl.COLOR_BUFFER_BIT);

    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

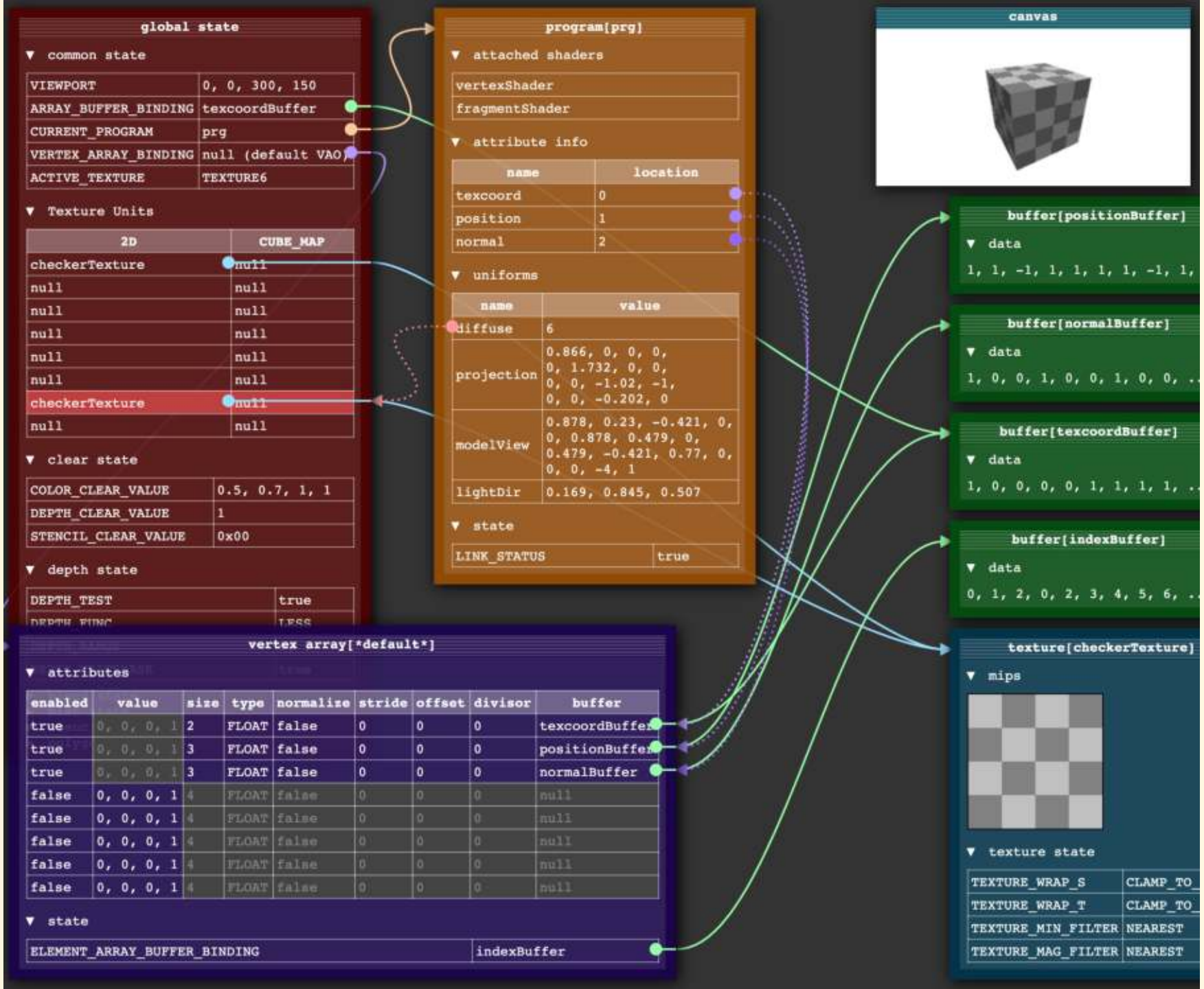
```
{
    // Tell WebGL how to take data from the VBO
    // and supply it to the attribute in the shader.
    gl.enableVertexAttribArray(a_colorLoc); // Turn the attribute on
    gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);
    // Tell the color attribute how to get data out of colorBuffer (ARRAY_BUFFER)
    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!

```
// 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



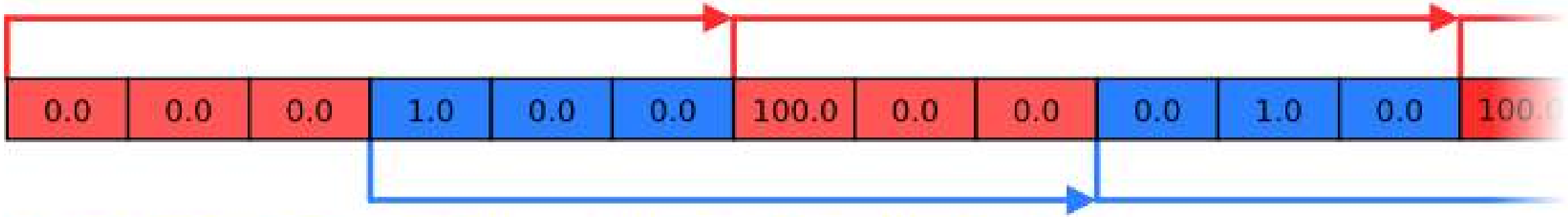
Variations

- 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

```
vertex stride = sizeof(vertex)
              = 6 * sizeof(float)
              = 6 * 4
              = 24
```

```
vertex offset = 0
```




```
colour offset = sizeof(vector3)
              = 3 * sizeof(float)
              = 3 * 4
              = 12
```

```
colour stride = sizeof(vertex)
              = 6 * sizeof(float)
              = 6 * 4
              = 24
```

```
// 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();
```

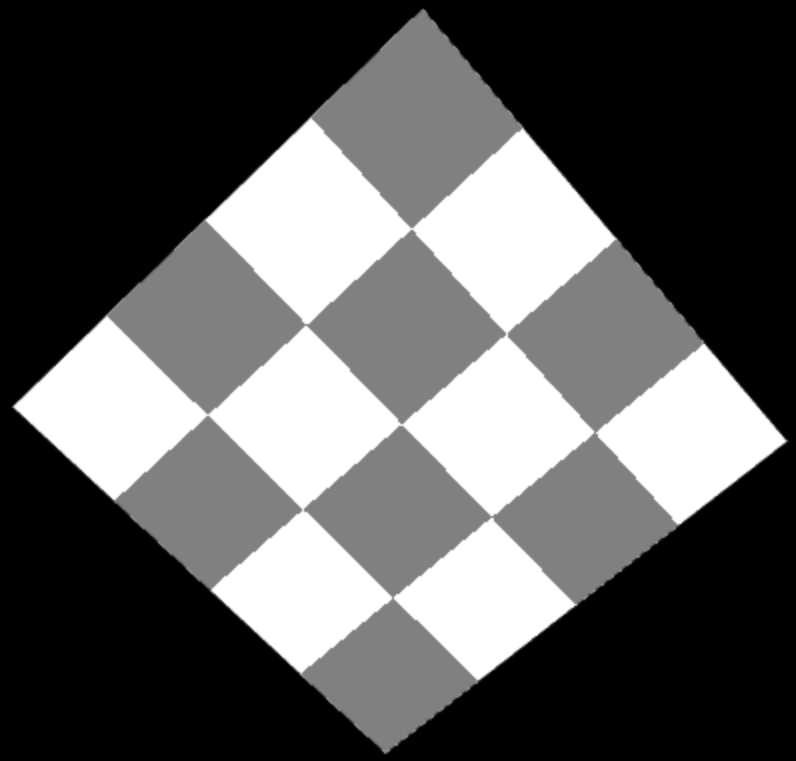
More examples

- 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)



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 !
```

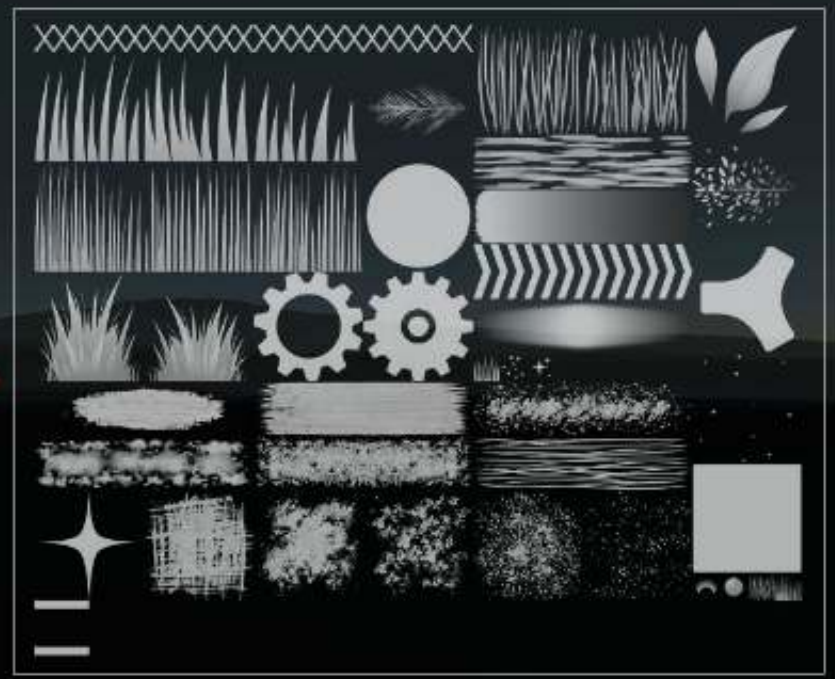
```
// clean
gl.bindVertexArray(null); //Always unbind the VAO when you're done
```

More optimizations ★

Valid for any API!

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

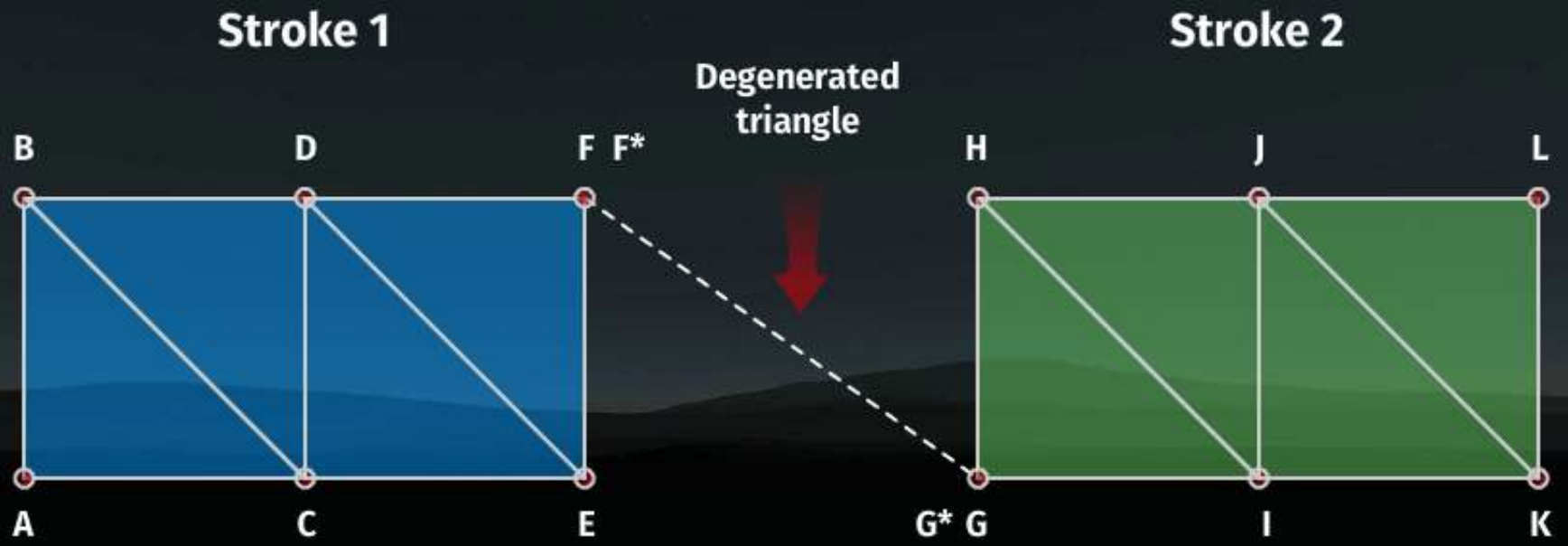
npm run atlas



DEGENERATED TRIANGLE

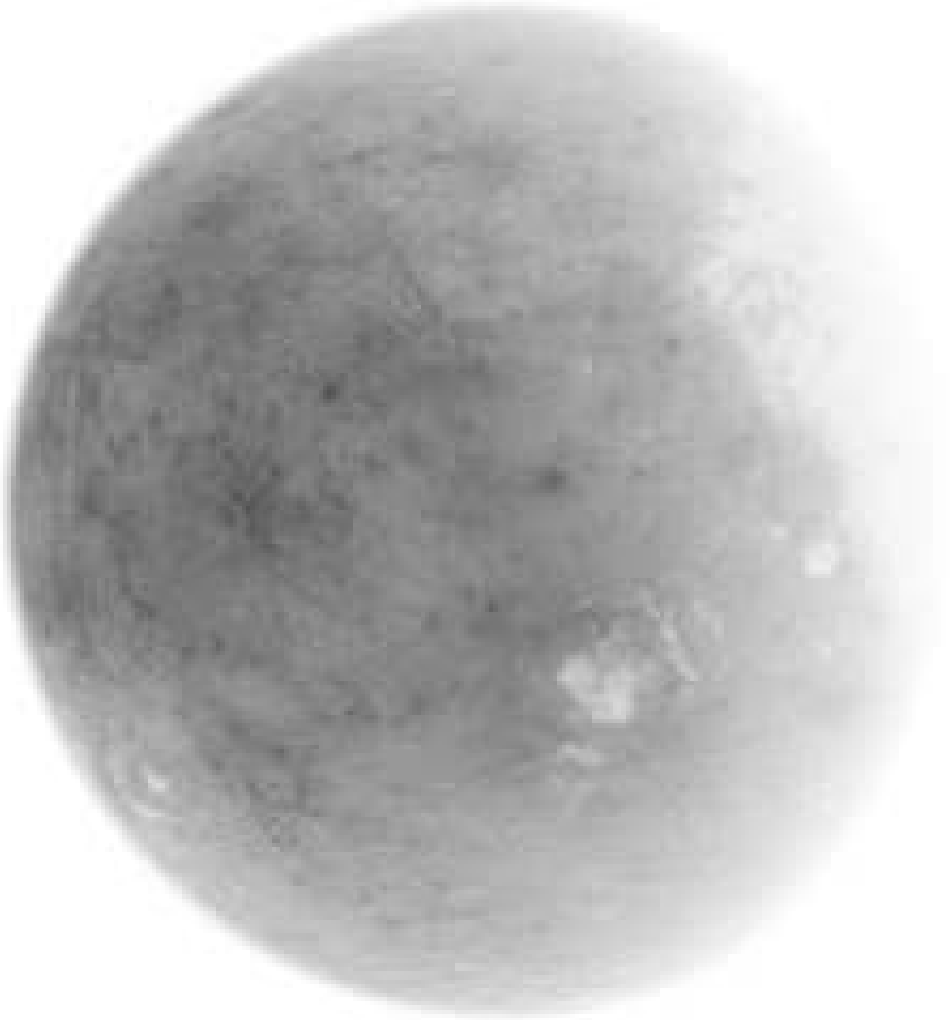
Normal triangle
(Rendered)

Degenerated triangle
(Discarded by GPU)



More shaders!

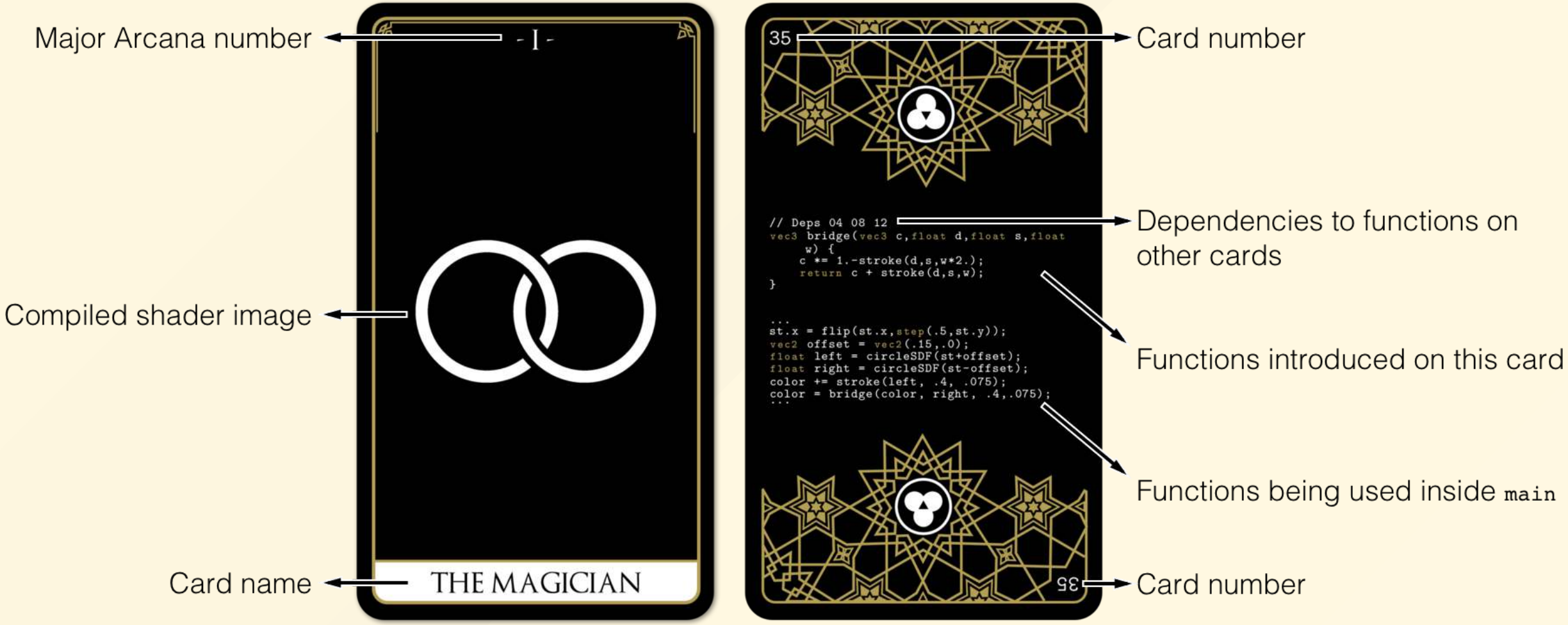
The Book of Shaders



The Book of Shaders

by Patricio Gonzalez Vivo and Jen Lowe

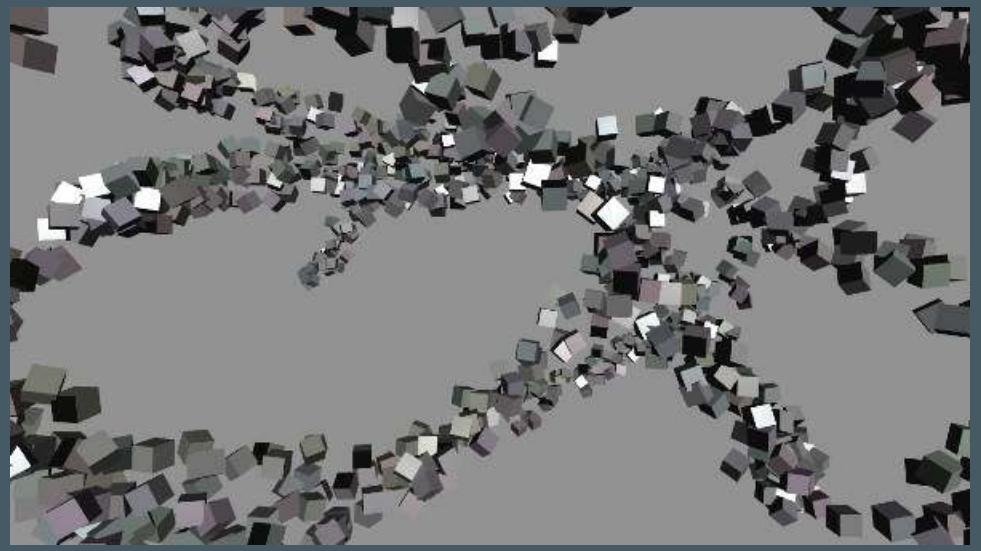
PixelSpiritDeck

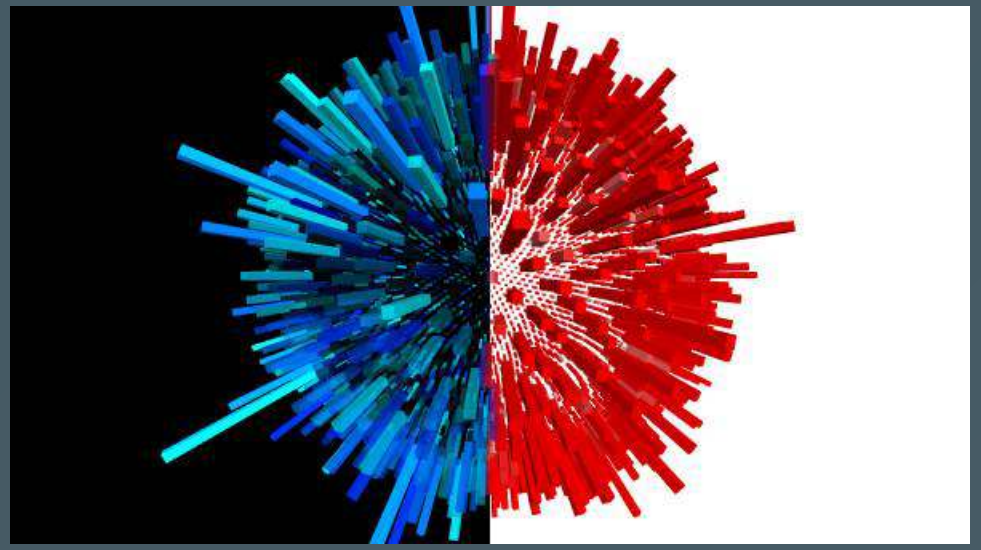


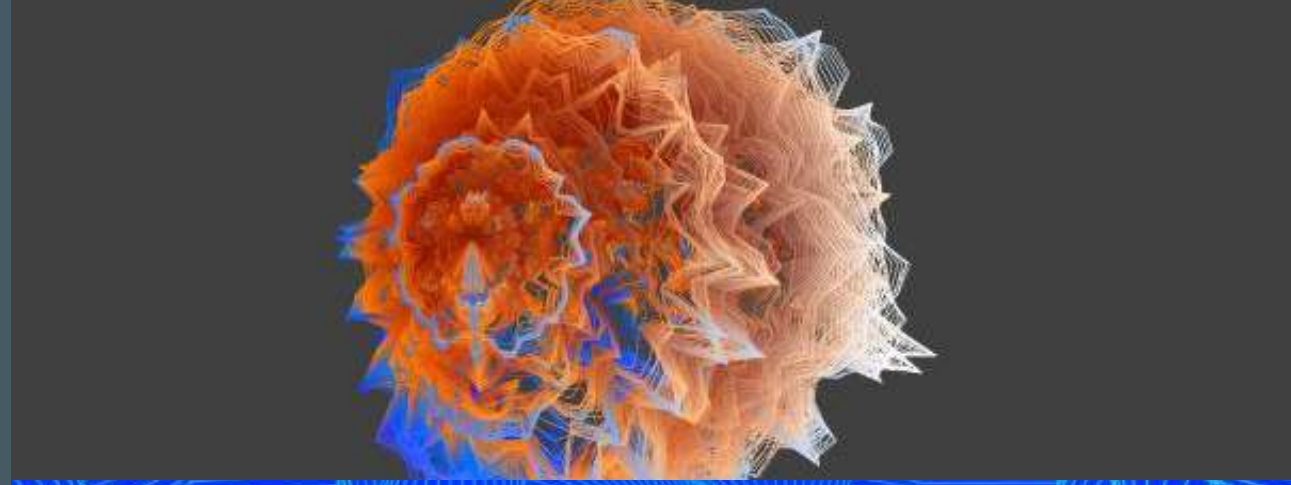
ShaderToy

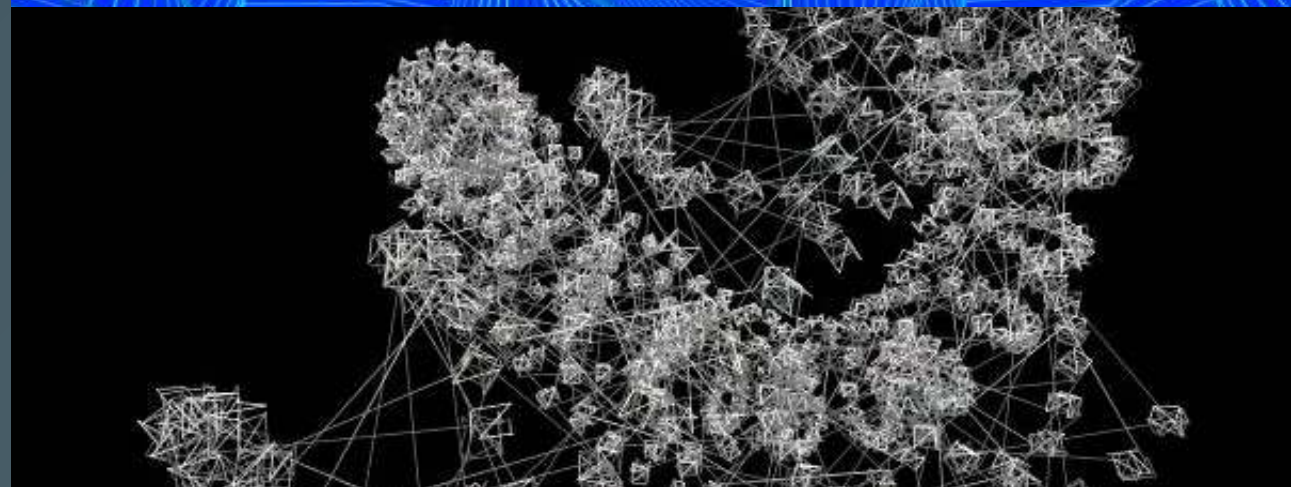
https://www.shadertoy.com/user/Shakemayster

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);
```

```
//...

    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

```
<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>
```

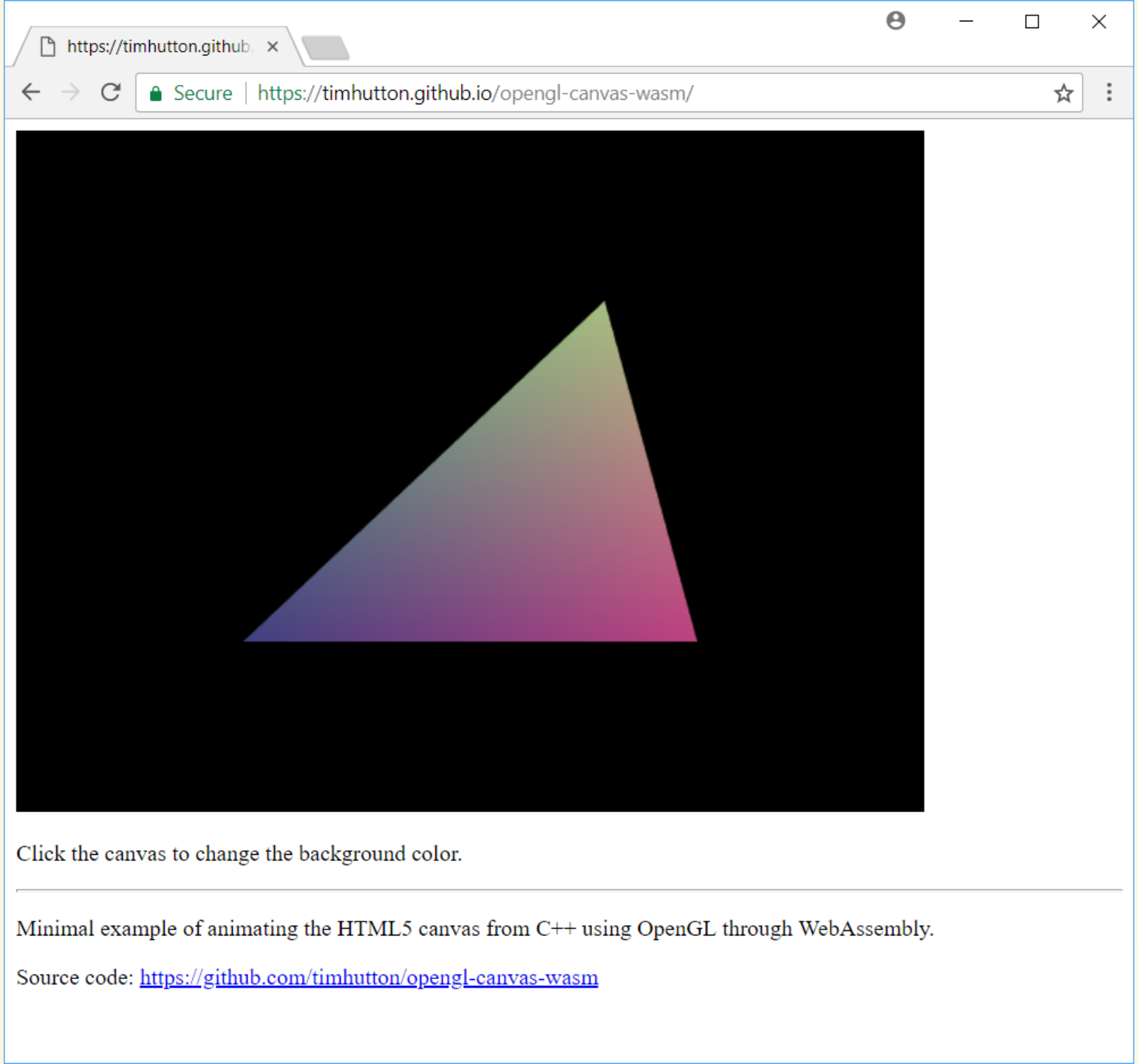
Compilation

- 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)

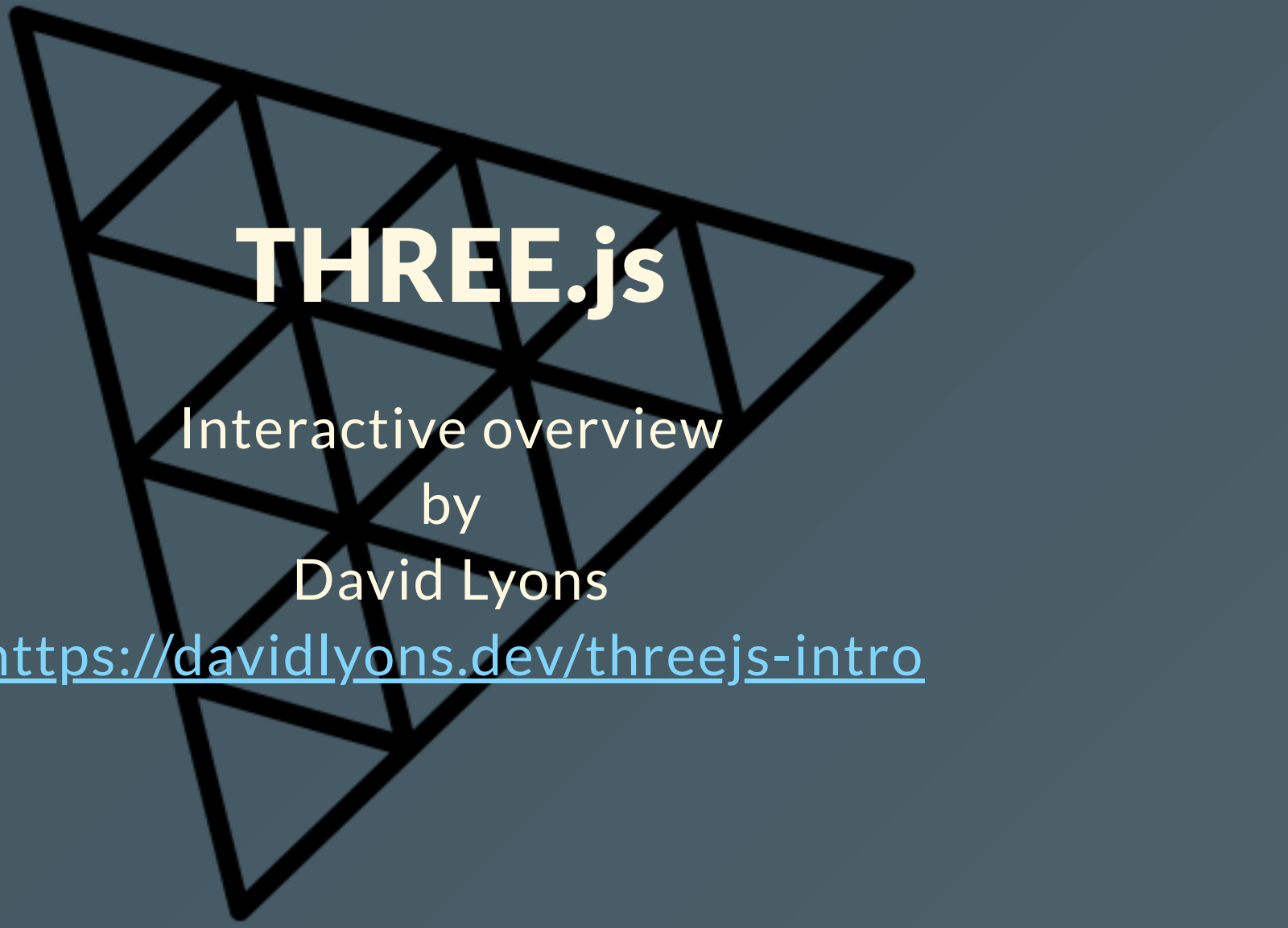
Result



> 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 WebGLwith Three.js

Go to slide: Go

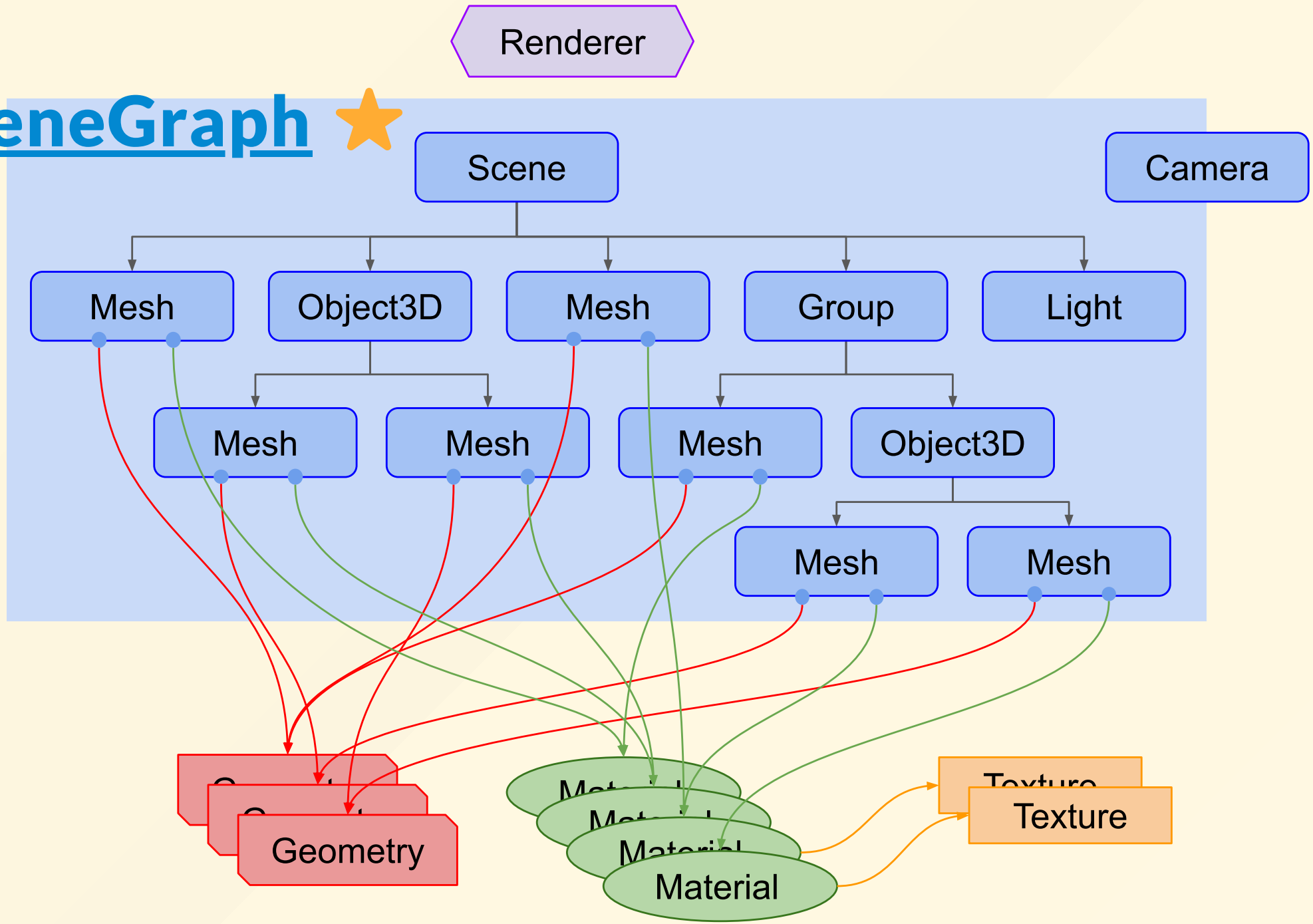
THREE.js Manual

★ BEST Guide ★

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

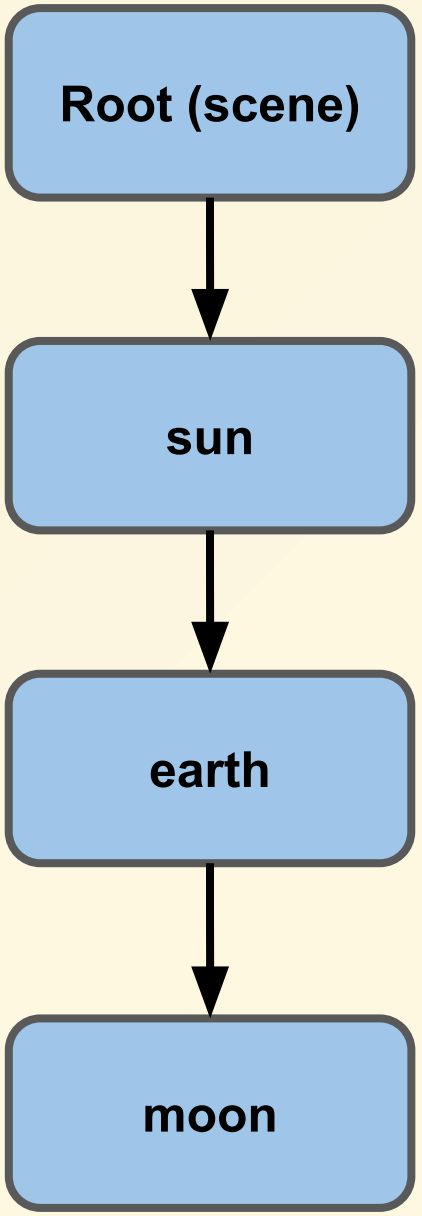
Complete and simple guide

SceneGraph



- 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

```html
<!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@.169.0/build/three.module.js",
              "three/addons/": "https://cdn.jsdelivr.net/npm/three@0.169.0/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/r169/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();
```

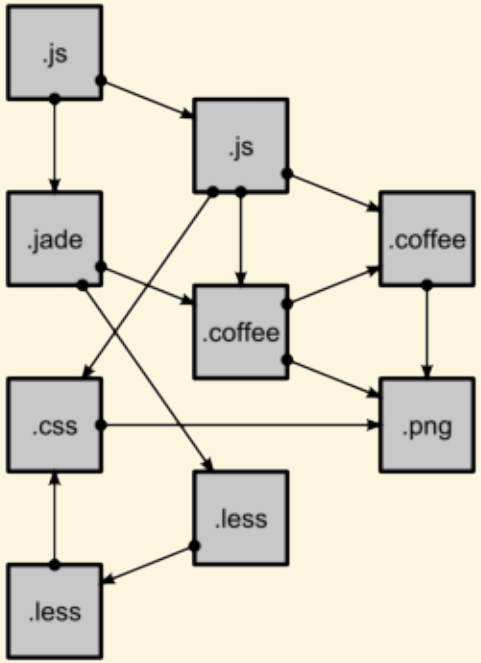
2 Full setup using NPM

- install Node.js + install npm

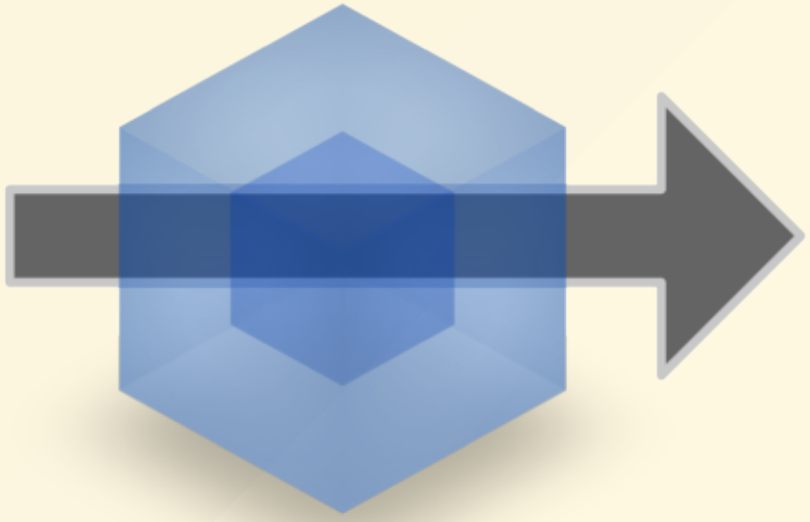
```
sudo apt install nodejs
curl -L https://npmjs.org/install.sh | sudo sh
```

See below

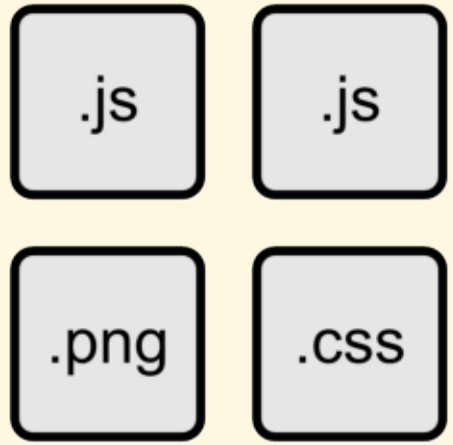
Bundlers



modules
with dependencies



webpack
MODULE BUNDLER



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
```

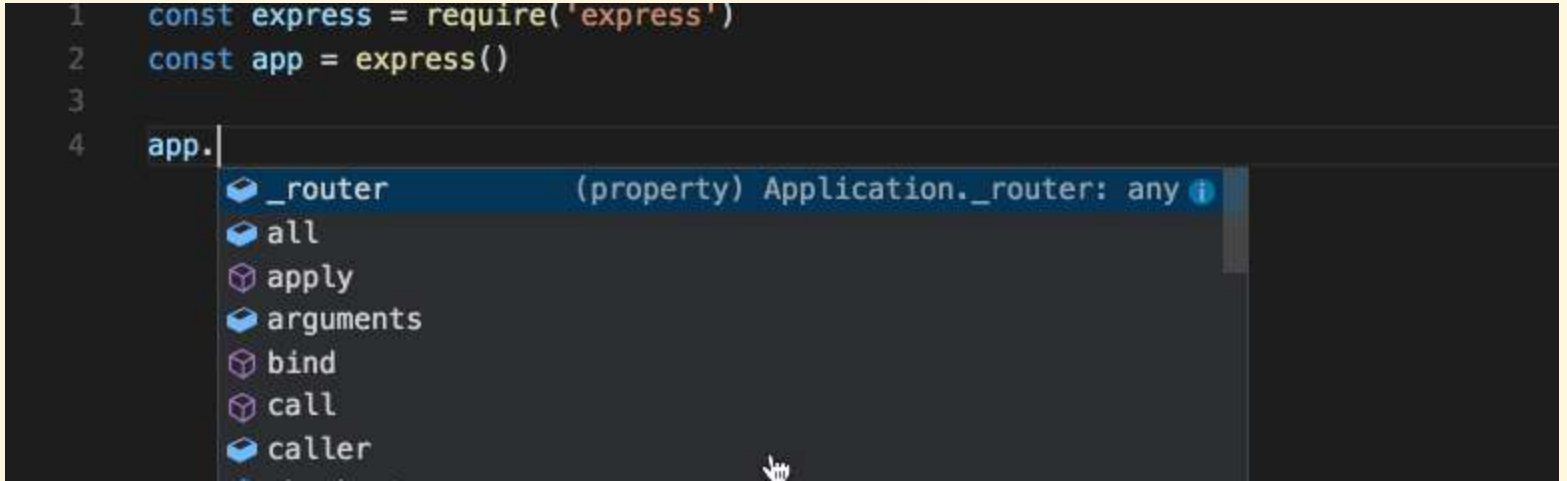
- install **three**

```
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

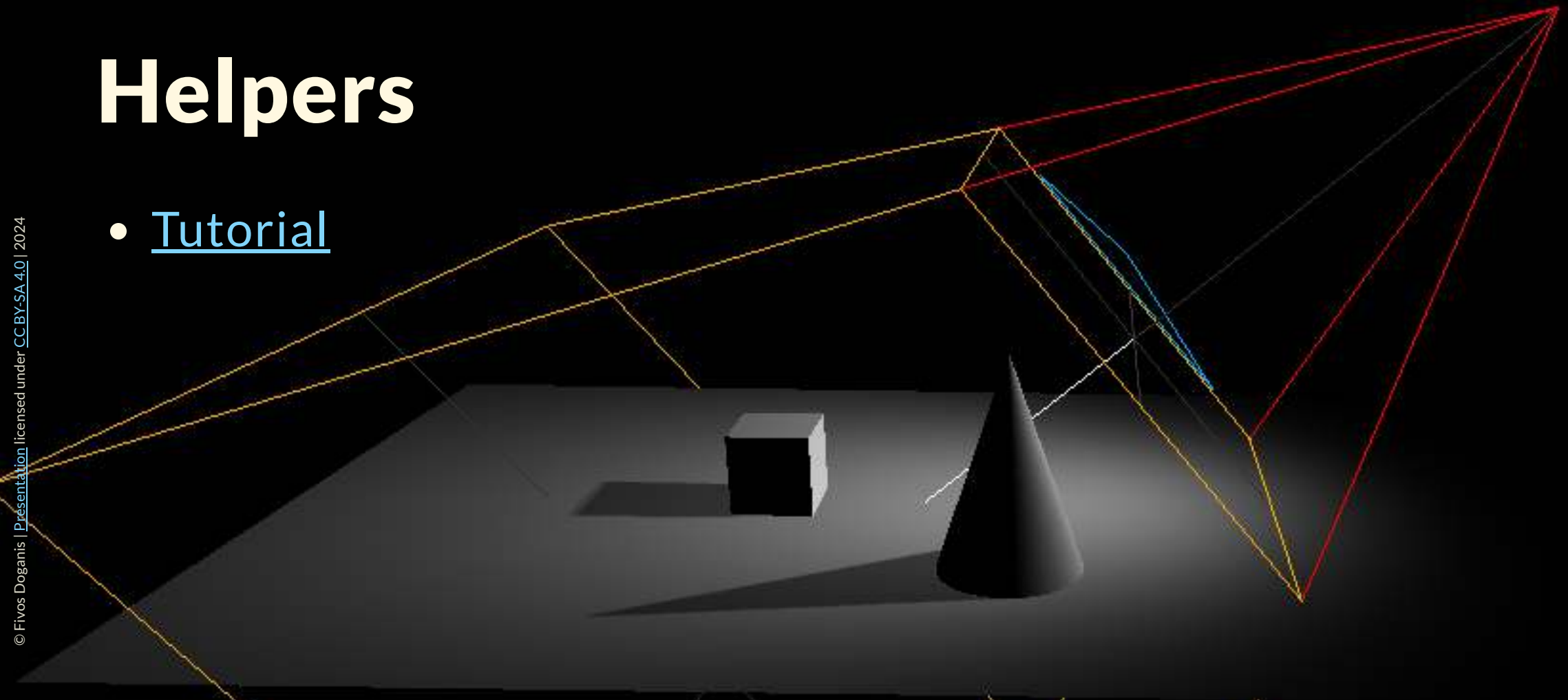
➡️ **you can still create your own WebGL shaders and custom geometry in THREE.js!** ⭐ 🎉
But most of the time the existing classes should be enough!

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)

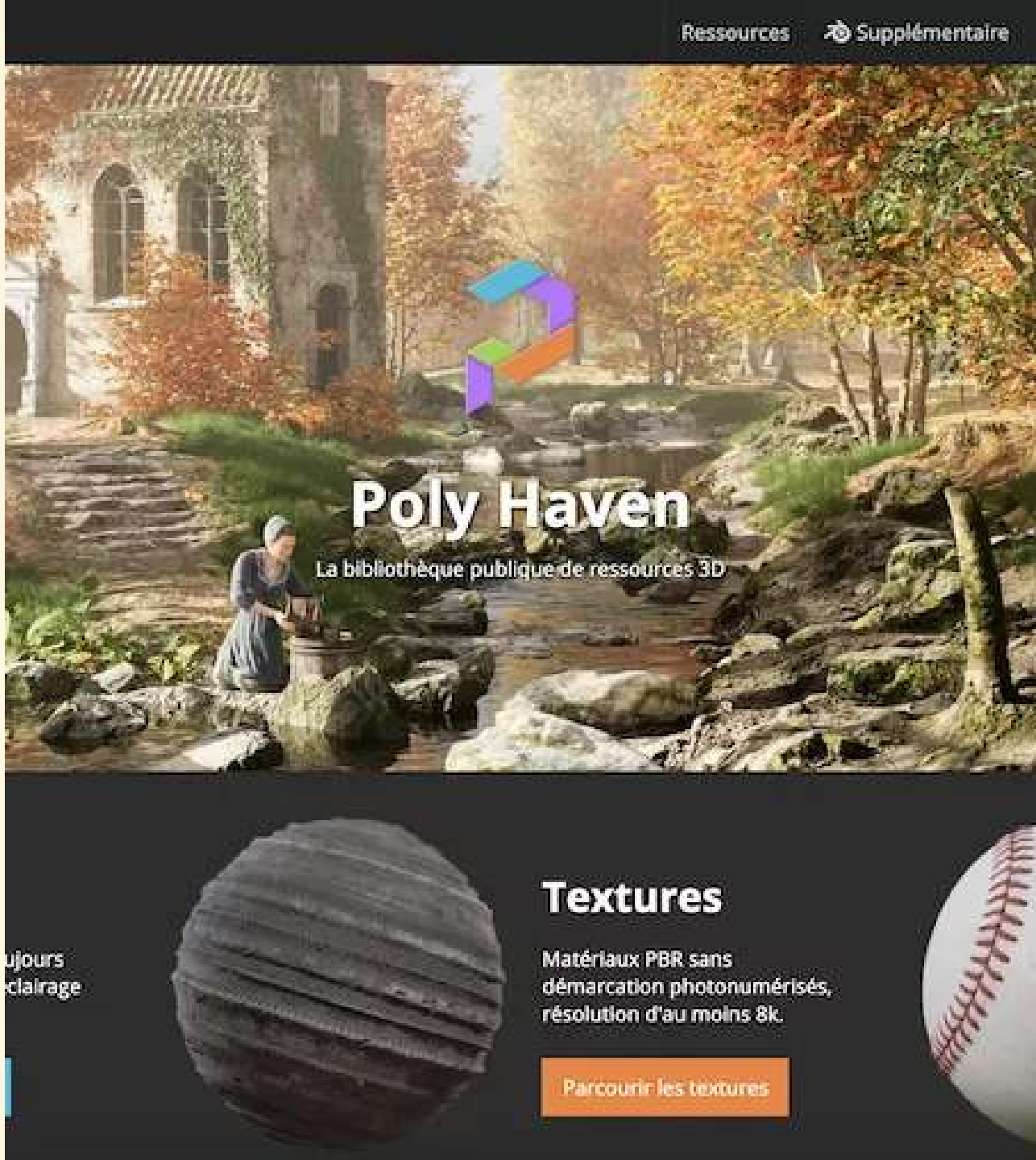
- ~~Cannon.js~~ 💀 / Cannon-es ⭐ : JS port of Bullet Engine (Tutorial)
  - **Demo**! 🚗 🚁 ✈️
- Ammo.js : conversion of Bullet (C++) to JS (Wasm) (Tutorial)
  - very fast but can be difficult to debug
- Rapier : Rust physics engine converted to JS (Wasm) (Tutorial)
- Oimo : Haxe physics engine coverted 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

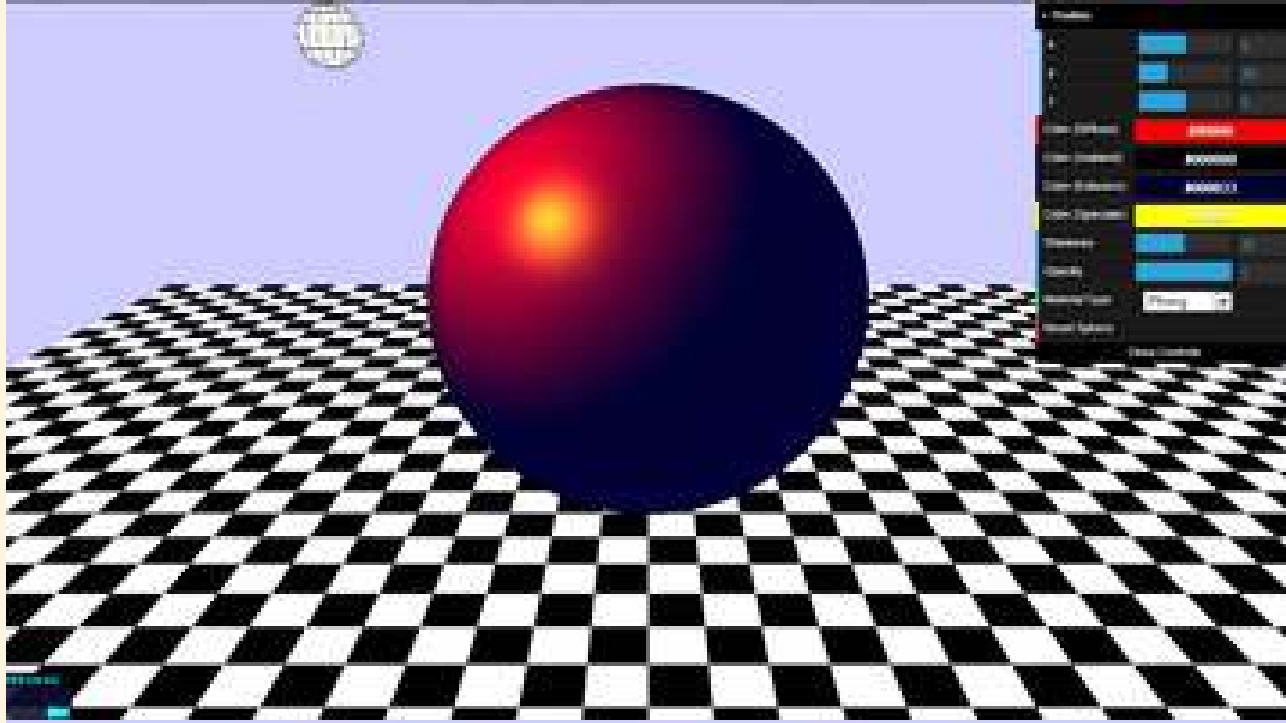
THREE.js exercises

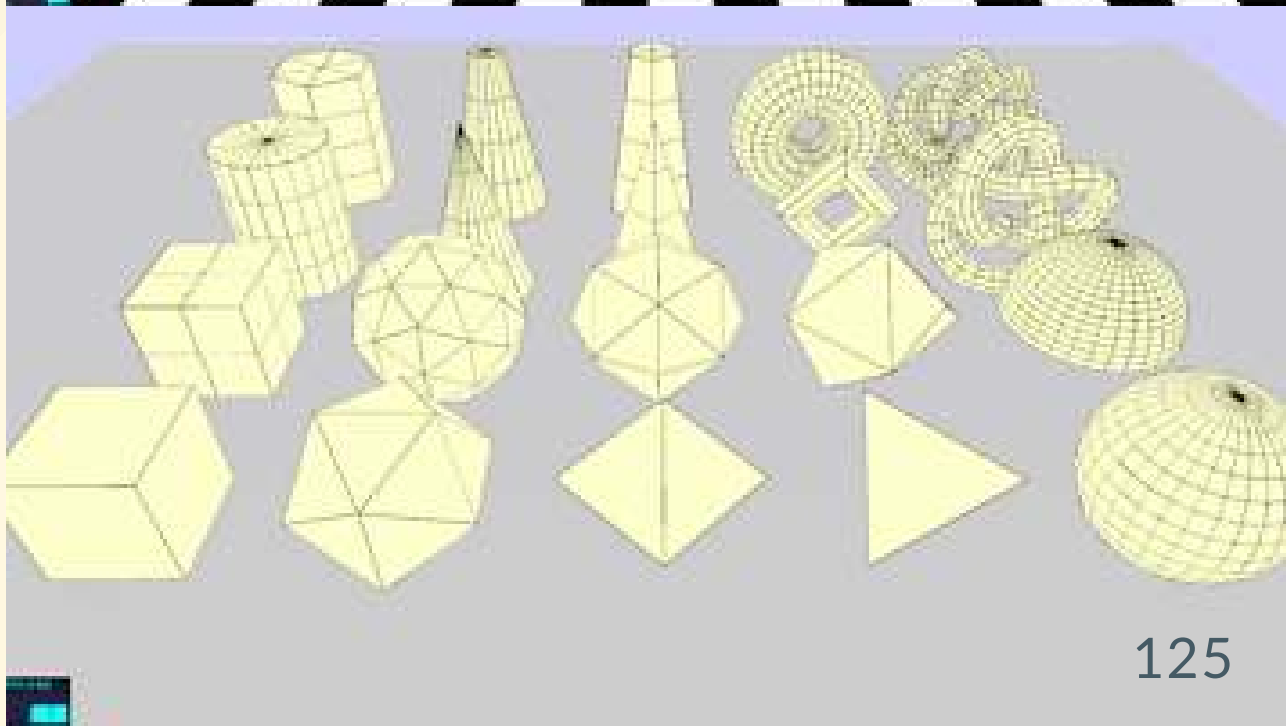
- Reminder: **THREE.js Manual** ★
- Karim Maaloul
  - practice:
    - animals
    - aviator ★
    - aviator 2 (update) 👀
    - red bull

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

Healthcare Projects

- Volume rendering
- Cinematic rendering
- Gaussian splatting
- Transparency
  - OIT
  - Depth Peeling
- Organ hide / show / clip / manipulate
- DICOM / CT Scan

Healthcare Projects 2

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

Healthcare Projects 3

- Communicate / Educate / Train / Guide
  - Load models
  - Z anatomy / Zygote body viewer
    - Performance
      - Show difference in fps
    - BVH / Octree / Tiles / LOD / Load / unload
  - Medical Quizz

Healthcare Projects 4

- Staying Alive
  - In AR?
  - Use face or image
- Step by step surgical operation
- Magic mirror see through
  - Skeleton
  - Back face rendering
  - Plastic surgery

Healthcare Projects 5

- Simulation
  - Stenosis
  - Beating heart
  - Mesh Deformation
  - Soft tissues
  - Cut organ
    - "Organ Ninja"

Healthcare Projects 6

- Operation Game (Dr Maboul)
  - Surgeon Simulator
  - Blood
  - Splat
- Air flow virus spread
- Virtual Twin / 3D reconstruction / scan / Scaniverse : patient / surgeon / room
  - Mesh / Gaussian Splats
  - Avatars

Healthcare Projects 7

- Instrument manipulation
  - UI
  - GraspUI
  - Pillbox AR
- Collab
- 360 video
- Hospital twin
  - Indoor GPS

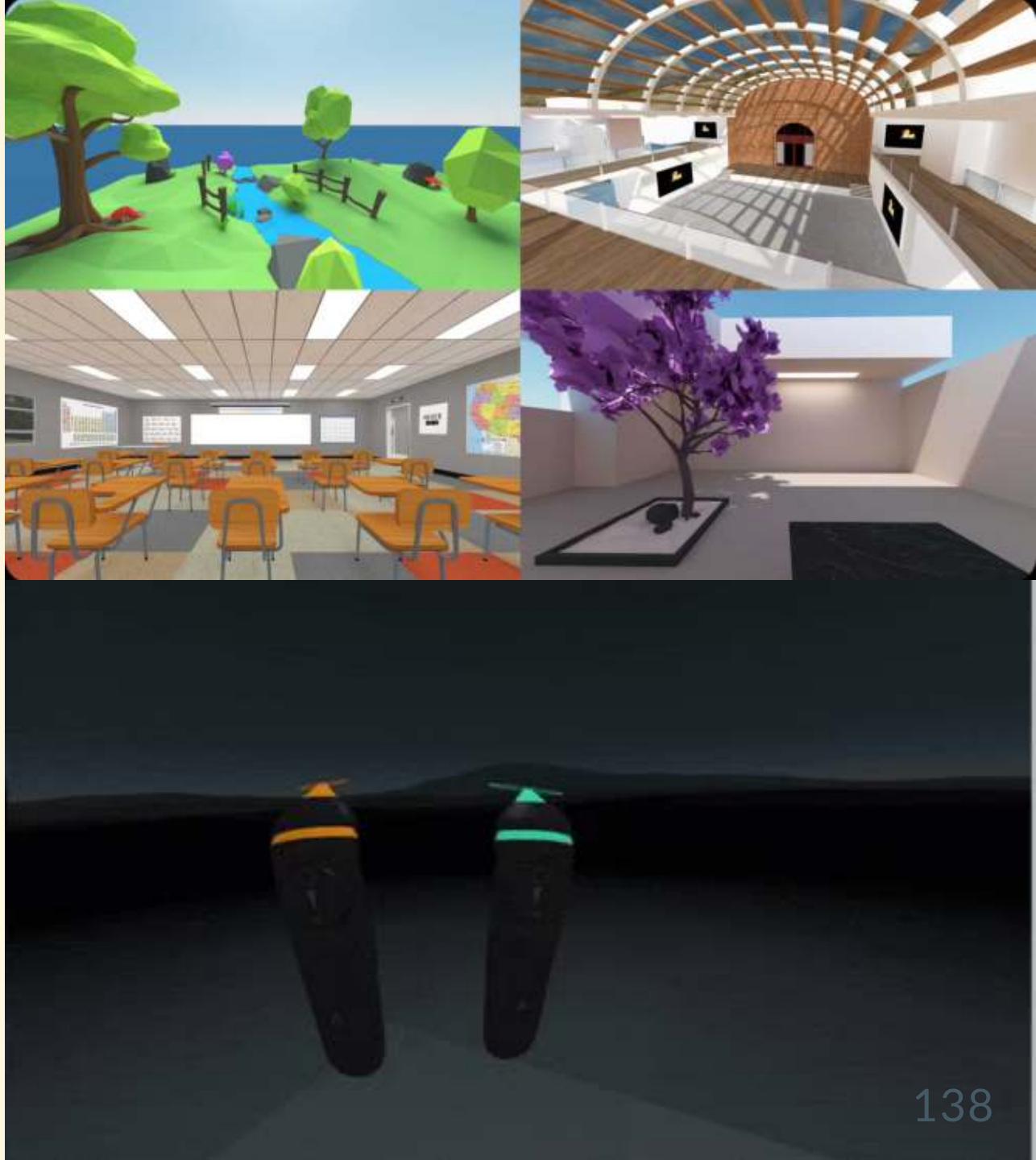
Wrappers

React Three Fiber (R3F)

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

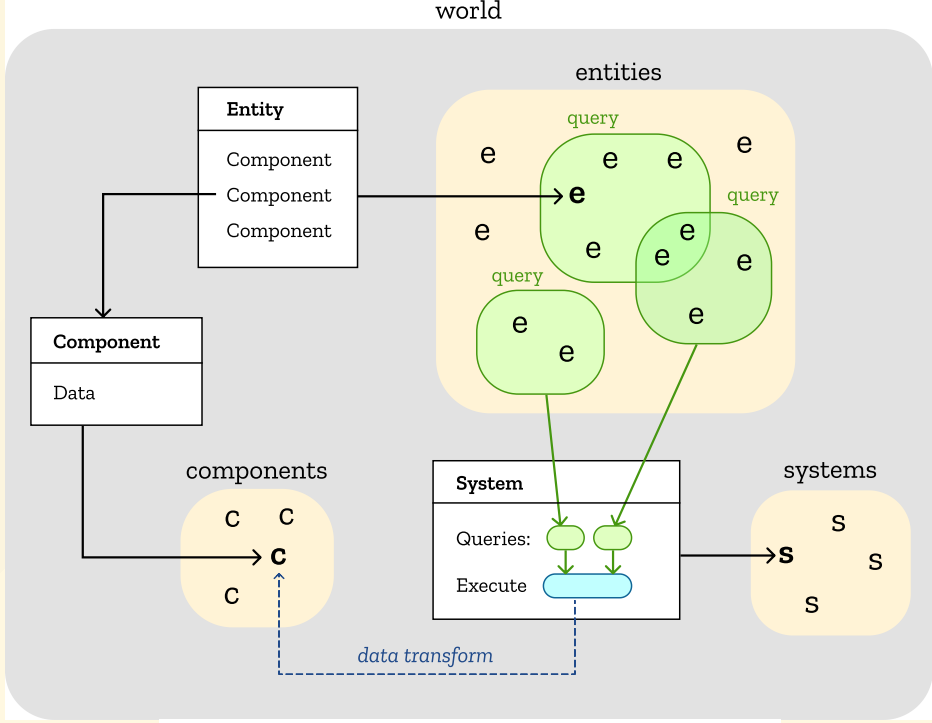
A-Frame

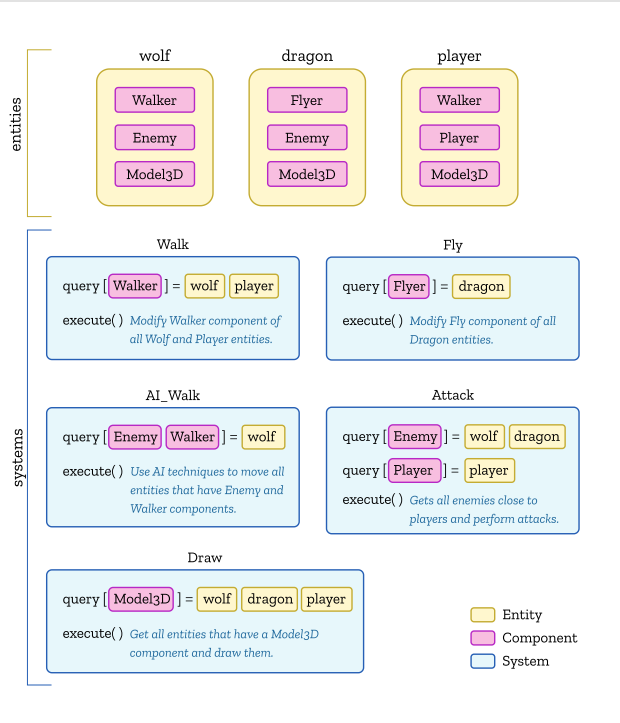
- Declarative wrapper (tags)
- Extremely simple to use (very high-level)
- Modular and extensible (**ECS**: Entity Component System)
- Ideal for AR and VR
  - Mozilla Hubs
  - A-Painter



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!