WebGL

Mike Bailey
mjb@cs.oregonstate.edu
Oregon State University

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License
What is “WebGL”? 

From WikiPedia:

**WebGL** (*Web Graphics Library*) is a JavaScript API for rendering interactive 3D graphics and 2D graphics within any compatible web browser without the use of plug-ins. WebGL is integrated completely into all the web standards of the browser allowing GPU accelerated usage of physics and image processing and effects as part of the web page canvas. WebGL elements can be mixed with other HTML elements and composited with other parts of the page or page background. WebGL programs consist of control code written in JavaScript and shader code that is executed on a computer's Graphics Processing Unit (GPU). WebGL is designed and maintained by the non-profit Khronos Group.

[of which OSU is a member]
What are the Important Things to Know about WebGL?

1. WebGL programs are written in JavaScript. This means that the code is downloaded and run by the browser.

2. WebGL programs are written in JavaScript. This means that the code is interpreted, not compiled. This makes the code slower than the equivalent C/C++.

3. The JavaScript API for WebGL talks to the C-OpenGL library which in turn talks to the graphics hardware on the web browser client’s system. This gives you access to all of the speed and capability that the hardware provides. Use it! Especially use the vertex buffer object capability to store your displayable geometry on the graphics card. Anything that you can put on the GPU side minimizes the amount of code necessary to get it drawn.

4. WebGL uses the OpenGL-ES 2.0 as its graphics API. “ES” stands for “Embedded Systems”. This is the same flavor of OpenGL that mobile devices use.
What are the Important Things to Know about OpenGL-ES 2.0?

1. WebGL uses OpenGL-ES 2.0 as its graphics API.

2. There is no fixed-function pipeline -- you must use vertex and fragment shaders.

3. You can’t use `glBegin…glEnd` to draw things. You must use VBOs.

4. You can’t use built-in transformation functions (e.g., `glRotatef`, `glScalef`, `glTranslatef`, `gluLookAt`, `glOrtho`, `gluPerspective`). You must use your own matrices passed in as vertex shader attribute variables.

5. Attribute variables for the vertex shader are declared as “attribute”, not “in”.

6. Output variables from the vertex shader which are then rasterized to become input variables for the fragment shader are declared as “varying”, not “out” and “in”.

7. Fragment shaders must set the precision to be used, for example:
   ```
   precision highp float;
   ```
Cube Example
Cube Vertices =
{ -1., -1., -1. },
{ 1., -1., -1. },
{ -1., 1., -1. },
{ 1., 1., -1. },
{ -1., -1., 1. },
{ 1., -1., 1. },
{ -1., 1., 1. },
{ 1., 1., 1. }

Cube Colors =
{ 0., 0., 0. },
{ 1., 0., 0. },
{ 0., 1., 0. },
{ 1., 1., 0. },
{ 0., 0., 1. },
{ 1., 0., 1. },
{ 0., 1., 1. },
{ 1., 1., 1. }

Cube Indices =
{ 1, 0, 2, 3 },
{ 4, 5, 7, 6 },
{ 5, 1, 3, 7 },
{ 0, 4, 6, 2 },
{ 6, 7, 3, 2 },
{ 0, 1, 5, 4 }
Some things to note:

1. This code displays a cube with 5 colored sides and one textured side. The cube is rotated in 3D by holding down the left mouse button and moving the mouse. It is scaled by using a jQuery-generated slider. The display is toggled between perspective and orthographic with HTML buttons.

2. This code is written to be clear-to-understand. It is not necessarily written in the most efficient style using the very best practices.

3. In computer graphics, vertex properties come in two flavors: (1) those that are the same for that vertex no matter what face that vertex is on, and (2) those that are different for that vertex depending on what face the vertex is on. This program demonstrates both. The colors are the first flavor. The texture coordinates are the second.
The Vertex Shader Source Code in the HTML File

```html
<script id="vertex-shader" type="x-shader/x-vertex">
uniform mat4 uModelViewMatrix;
uniform mat4 uProjectionMatrix;

attribute vec3 aVertex;
attribute vec3 aColor;
attribute vec2 aTexCoord0;

varying vec3 vColor;
varying vec2 vST;
varying float vZ;

void main() {
  vColor = aColor;
  vST = aTexCoord0;
  vZ = aVertex.z;
  gl_Position = uProjectionMatrix * uModelViewMatrix * vec4(aVertex,1.);
}
</script>
```

- **Announces that this is a vertex shader**
- **The name of the vertex shader**
- **Uniform variables**
- **Per-vertex attribute variables**
- **Vertex shader-created output variables to be interpolated through the rasterizer**
- **Set varying variables and transform the vertex**
### The Fragment Shader Source Code in the HTML File

```html
<script id="fragment-shader" type="x-shader/x-fragment">
precision highp float;

uniform sampler2D uTexture;

varying vec3 vColor;
varying vec2 vST;
varying float vZ;

void main( ) {
  if( vZ <= 0.99 ) {
    gl_FragColor = vec4( vColor, 1. );
  } else {
    vec4 rgba = texture2D( uTexture, vST );
    gl_FragColor = vec4( rgba.rgb, 1. );
  }
}
</script>
```

- **sample.html**
- **precision highp float**: Announces that this is a fragment shader
- **uTexture**: The name of the fragment shader
- **Must set the precision in OpenGL-ES
- **Uniform sampler2D**: Uniform variable
- **varying vec3 vColor; varying vec2 vST; varying float vZ;**: Fragment shader input variables that were interpolated through the rasterizer
- **void main( )**: Used to identify which face to texture
- **if( vZ <= 0.99 )**: Decide to use the color or the texture, based on the Z model coordinate
The General Format of the HTML File

```html
<link rel="stylesheet" href="http://code.jquery.com/ui/1.9.2/themes/base/jquery-ui.css">
<style>
#slider { margin: 10px; }
</style>
<script src="http://code.jquery.com/jquery-1.8.3.js"></script>
<script src="http://code.jquery.com/ui/1.9.2/jquery-ui.js"></script>
```

Get the CSS style sheet and get the jQuery user interface JavaScript code
The General Format of the HTML File

```
<button id = "PerspButton">Perspective</button>
<button id = "OrthoButton">Orthographic</button>
<p></p>

<div id="slider">
<script>
$( "#slider" ).slider( );
$( "#slider" ).slider( "option", "min",  0.1  );
$( "#slider" ).slider( "option", "max",  2.0  );
$( "#slider" ).slider( "option", "value", 1.0  );
$( "#slider" ).slider( "option", "step",  0.01  );
$( "#slider" ).slider( "option", "orientation", "horizontal" );
$( "#slider" ).slider( "enable" );
</script>
</div>

<canvas id="gl-canvas" width="512" height="512">
Oops ... your browser doesn't support the HTML5 canvas element
</canvas>

<script type="text/javascript" src="http://cs.oregonstate.edu/~mjb/WebGL/Webgl-Utils.js"></script>
<script type="text/javascript" src="http://cs.oregonstate.edu/~mjb/WebGL/InitShaders.js"></script>
<script type="text/javascript" src="http://cs.oregonstate.edu/~mjb/WebGL/GlMatrix.js"></script>
<script type="text/javascript" src="sampledata.js"></script>
<script type="text/javascript" src="sample.js"></script>
```
What is in Webgl-Utils.js?

Webgl-Utils.js is a Google-supplied set of Javascript to setup the WebGL window, canvas, and context.
What is in InitShaders.js?

InitShaders.js contains the calls to `gl.createShader`, `gl.shaderSource`, `gl.compileShader`, `gl.createProgram`, `gl.attachShader`, and `gl.linkProgram` to create the shader program from the vertex and fragment shader source.

The logic is exactly the same as it is in C, but written in Javascript.
GlMatrix.js came from Brandon Jones and Ed Angel. It contains vec2, vec3, vec4, mat2, mat3, and mat4 data types along with methods to create transformation matrices to pass into vertex shaders as attribute variables.

Basically, it acts as a Javascript GLM.

Take a look through it sometime. It is very readable.
The General Format of the JavaScript File

```javascript
var canvas;
var gl;

var Program;
var Vertices;
var Color;

var NumPoints;
var VertexArray;
var ColorArray;
var TexArray;

var MouseDown = false;
var LastMouseX;
var LastMouseY;
var Left, Middle, Right;
var Perspective;
var SaveScale = 1.;

var MvMatrix = mat4.create( );
var PMatrix = mat4.create( );
var MvLoc;
var PLoc;
var TLoc;
var SampleTexture;
var ModelMatrix = mat4.create( );

var ST00, ST01, ST10, ST11;

window.onload = InitGraphics; // function to call first
```

sample.js

- Compiled and linked shader program
- OpenGL arrays for vertices, colors, and texture coordinates
- Mouse and transformation information
- Matrix and texture information
- Texture coordinates
- Function to call first
The General Format of the JavaScript File

```
function DrawTriangle( i, a, b, c, sta, stb, stc )
{
    VertexArray[i+0] = Vertices[a];
    ColorArray[i+0]  = Colors[a];
    TexArray[i+0]    = sta;

    VertexArray[i+1] = Vertices[b];
    ColorArray[i+1]  = Colors[b];
    TexArray[i+1]    = stb;

    VertexArray[i+2] = Vertices[c];
    ColorArray[i+2]  = Colors[c];
    TexArray[i+2]    = stc;

    return i+3;
}

function DrawQuad( i, a, b, c, d )
{
    i = DrawTriangle( i, a, b, c,  ST00, ST10, ST11 );
    i = DrawTriangle( i, a, c, d,  ST00, ST11, ST01 );
    return i ;
}
```

**sample.js**

Call this to draw a quadrilateral

DrawQuad( ) calls this twice to draw two triangles per quad
function InitGraphics( )
{
    canvas = document.getElementById( "gl-canvas" );

    gl = WebGLUtils.setupWebGL( canvas );
    if( ! gl )
    {
        alert( "WebGL isn't available" );
    }

    canvas.onmousedown = HandleMouseDown;
document.onmouseup = HandleMouseUp;
document.onmousemove = HandleMouseMove;

    // set some handy constants for later:
    ST00 = vec2.create( [ 0., 0. ] );
    ST01 = vec2.create( [ 0., 1. ] );
    ST10 = vec2.create( [ 1., 0. ] );
    ST11 = vec2.create( [ 1., 1. ] );

    // set globals:
    Perspective = true;
    mat4.identity( ModelMatrix );

    InitGraphics( ) sets everything up

    Quadrilateral texture coordinates
The General Format of the JavaScript File

```javascript
// load shaders:
Program = InitShaders( gl, "vertex-shader", "fragment-shader" );
gl.useProgram( Program );
MvLoc = gl.getUniformLocation( Program, "uModelViewMatrix" );
CheckError( "MvLoc " );
PLoc = gl.getUniformLocation( Program, "uProjectionMatrix" );
CheckError( "PLoc " );
TLoc = gl.getUniformLocation( Program, "uTexture" );
CheckError( "TLoc " );

// setup the texture:
SampleTexture = gl.createTexture( );
SampleTexture.image = new Image( );
SampleTexture.image.onload = function( )
{
    HandleLoadedTexture( SampleTexture );
}
SampleTexture.image.src = "http://cs.oregonstate.edu/~mjb/webgl/beaver.bmp";
CheckError( "Texture src " );

// setup ui:
var b1 = document.getElementById( "PerspButton" );
b1.addEventListener( "click", function( ) { Perspective = true; Display( ); }, false );

b2 = document.getElementById( "OrthoButton" )
b2.addEventListener( "click", function( ) { Perspective = false; Display( ); }, false );
```

Load, compile, and link the shaders
Obtain the symbol table location of the uniform variables
Setup the texture
Here’s where the texture can be found - setting this causes the texture to be loaded
What to do when a button is pressed
The General Format of the JavaScript File

```javascript
// initialize the data:
InitData();

// put the data in opengl buffers:
var vertexBufferId = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, vertexBufferId);
gl.bufferData(gl.ARRAY_BUFFER, flatten(VertexArray), gl.STATIC_DRAW);
var vLoc = gl.getAttribLocation(Program, "aVertex");
gl.vertexAttribPointer(vLoc, 3, gl.FLOAT, false, 0, 0);
gl.enableVertexAttribArray(vLoc);

var colorBufferId = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, colorBufferId);
gl.bufferData(gl.ARRAY_BUFFER, flatten(ColorArray), gl.STATIC_DRAW);
var cLoc = gl.getAttribLocation(Program, "aColor");
gl.vertexAttribPointer(cLoc, 3, gl.FLOAT, false, 0, 0);
gl.enableVertexAttribArray(cLoc);

var texBufferId = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, texBufferId);
gl.bufferData(gl.ARRAY_BUFFER, flatten(TexArray), gl.STATIC_DRAW);
var tcLoc = gl.getAttribLocation(Program, "aTexCoord0");
gl.vertexAttribPointer(tcLoc, 2, gl.FLOAT, false, 0, 0);
gl.enableVertexAttribArray(tcLoc);

// get everything running:
Animate();
}
```

Sample.js

Fill the arrays with data
- Setup the vertex buffer to map to the vertex shader attribute variable “aVertex”
- Setup the color buffer to map to the vertex shader attribute variable “aColor”
- Setup the texture coordinate buffer to map to the vertex shader attribute variable “aTexCoord0”

Start the display
The General Format of the JavaScript File

```javascript
function Animate() {
  requestAnimFrame(Animate);
  Display();
}

function Display() {
  gl clearColor(0.0, 0.0, 0.0, 1.0);
  gl clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);
  gl viewport(0, 0, canvas.width, canvas.height);
  gl enable(gl.DEPTH_TEST);

  // projection matrix:
  if (Perspective) {
    PMatrix = mat4.perspective(60., 1., 0.1, 100.0);
  } else {
    PMatrix = mat4.ortho(-2., 2., -2., 2., 0.1, 100.);
  }
}
```

- Ask for the next display and then render the scene
- Typical OpenGL start-up
- Use the correct projection matrix
The General Format of the JavaScript File

```javascript
// read the scaling slider:

var s = $( "#slider" ).slider( "value" );
if( s != SaveScale )
{
    var newScaleMatrix = mat4.create( );
    mat4.identity( newScaleMatrix );
    var s2 = s / SaveScale;
    mat4.scale( newScaleMatrix, [ s2, s2, s2 ] );
    mat4.multiply( newScaleMatrix, ModelMatrix, ModelMatrix );
    SaveScale = s;
}

// modelview and projection matrices:

gl.useProgram( Program );
mat4.identity( MvMatrix );
mat4.translate( MvMatrix, [0, 0, -4] ); // viewing
mat4.multiply( MvMatrix, ModelMatrix ); // modeling
gl.uniformMatrix4fv( MvLoc, false, MvMatrix );
gl.uniformMatrix4fv( PLoc, false, PMatrix );

// texture sampler:

gl.activeTexture( gl.TEXTURE6 );
gl.bindTexture( gl.TEXTURE_2D, SampleTexture );
gl.uniform1i( TLoc, 6 );

// do the drawing:

gl.drawArrays( gl.TRIANGLES, 0, NumPoints );
}
```
The General Format of the JavaScript File

```javascript
function HandleLoadedTexture( texture ) {
    gl.bindTexture( gl.TEXTURE_2D, texture );
    gl.pixelStorei( gl.UNPACK_FLIP_Y_WEBGL, true );
    gl.texImage2D( gl.TEXTURE_2D, 0, gl.RGB, gl.RGB, gl.UNSIGNED_BYTE, texture.image );
    gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR );
    gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR_MIPMAP_LINEAR );
    gl.generateMipmap( gl.TEXTURE_2D );
    gl.bindTexture( gl.TEXTURE_2D, null );
    CheckError( "Loading texture " );
}

function HandleMouseDown( event ) {
    MouseDown = true;
    LastMouseX = event.clientX;
    LastMouseY = event.clientY;
    WhichButton( event );
}

function HandleMouseUp( event ) {
    MouseDown = false;
}
```

What to do with the texture after it's been loaded (usual OpenGL procedure)

Handle mouse events
function HandleMouseMove( event )
{
    if( ! MouseDown )
    {
        return;
    }
    var newX = event.clientX;
    var newY = event.clientY;

    var deltaX = newX - LastMouseX;
    var deltaY = newY - LastMouseY;

    if( Left )
    {
        var newModelMatrix = mat4.create( );
        mat4.identity( newModelMatrix );
        mat4.rotate( newModelMatrix, degToRad(deltaX / 2.), [0, 1, 0] );
        mat4.rotate( newModelMatrix, degToRad(deltaY / 2.), [1, 0, 0] );

        mat4.multiply( newModelMatrix, ModelMatrix, ModelMatrix );
    }
    
    LastMouseX = newX;
    LastMouseY = newY;
}
The General Format of the JavaScript File

sample.js

```javascript
function WhichButton( event )
{
    var b = event.button;

    Left   = ( b == 0 );
    Middle = ( b == 1 );
    Right  = ( b == 2 );
}
```

Determine which mouse button was hit.
function InitData() {
    // define the data:

    Vertices = new Array(8);
    Colors = new Array(8);

    Vertices[0] = point3.create([ -1., -1., -1. ]); 
    Vertices[1] = point3.create([  1., -1., -1. ]); 
    Vertices[2] = point3.create([ -1.,  1., -1. ]); 
    Vertices[3] = point3.create([  1.,  1., -1. ]); 
    Vertices[4] = point3.create([ -1.,  1.,  1. ]); 
    Vertices[5] = point3.create([  1.,  1.,  1. ]); 
    Vertices[6] = point3.create([ -1., -1.,  1. ]); 
    Vertices[7] = point3.create([  1., -1.,  1. ]); 

    Colors[0] = color3.create([ 0., 0., 0. ]); 
    Colors[1] = color3.create([ 1., 0., 0. ]); 
    Colors[2] = color3.create([ 0., 1., 0. ]); 
    Colors[3] = color3.create([ 1., 1., 0. ]); 
    Colors[4] = color3.create([ 0., 0., 1. ]); 
    Colors[5] = color3.create([ 1., 0., 1. ]); 
    Colors[6] = color3.create([ 0., 1., 1. ]); 
    Colors[7] = color3.create([ 1., 1., 1. ]); 
}

Generating the data arrays.
(I like to put this in its own file so that I can generate this with a
C/C++ program if I want)

Cube Vertices =
{ -1., -1., -1. },
  {  1., -1., -1. },
  { -1.,  1., -1. },
  {  1.,  1., -1. },
  { -1., -1.,  1. },
  {  1., -1.,  1. },
  { -1.,  1.,  1. },
  {  1.,  1.,  1. }

Cube Colors =
{ 0., 0., 0. },
  { 1., 0., 0. },
  { 0., 1., 0. },
  { 1., 1., 0. },
  { 0., 0., 1. },
  { 1., 0., 1. },
  { 0., 1., 1. },
  { 1., 1., 1. }
NumPoints = 6 * 2 * 3; // sides * triangles/side * vertices/triangle
VertexArray = new Array( NumPoints );
ColorArray  = new Array( NumPoints );
TexArray    = new Array( NumPoints );

var index = 0;
index = DrawQuad( index, 1, 0, 2, 3 );
index = DrawQuad( index, 4, 5, 7, 6 );
index = DrawQuad( index, 5, 1, 3, 7 );
index = DrawQuad( index, 0, 4, 6, 2 );
index = DrawQuad( index, 6, 7, 3, 2 );
index = DrawQuad( index, 0, 1, 5, 4 );

Cube Indices =

{ 1, 0, 2, 3 },
{ 4, 5, 7, 6 },
{ 5, 1, 3, 7 },
{ 0, 4, 6, 2 },
{ 6, 7, 3, 2 },
{ 0, 1, 5, 4 }
The Results

The face that gets textured because its at \( Z = +1.0 \)
The Khronos Group's WebGL Page:  
http://khronos.org/webgl

Khronos Group’s WebGL Quick Reference Card:  

O'Reilly WebGL book:  

OSU WebGL site:  
http://cs.oregonstate.edu/~mjb/webgl

A set of WebGL tutorials:  
http://learningwebgl.com

The jQuery user interface site:  
http://api.jqueryui.com/

Ed Angel’s WebGL site for his book examples:  