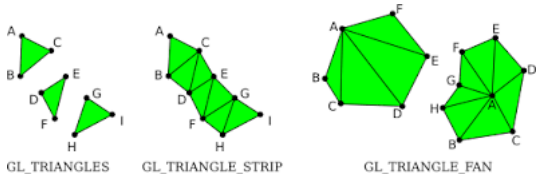
Introduction to Computer Graphics with WebGL

- Ed Angel
- Professor Emeritus of Computer Science
- Founding Director, Arts, Research, Technology and Science Laboratory
- University of New Mexico

Primitives



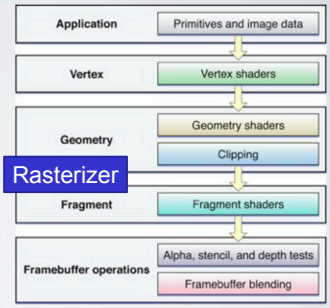
GL_Points

Alon:

The term '*location*' refers to location in Memory
There term '*position*' refers to geometric position.

HOW SHADERS WORK

- Vertex shader: Transforms vertices
- Geometry shader: Adds or filters extra vertices
- Fragment shader: Computes the final color of the pixel



developer.apple.com

```
<html>
  <head></head>
▼ <body>
  ▼ <doctype html>
      <!-- Copyright 2020, Cem Yuksel, University of Utah -->
      <title>CS 4600 - WebGL Example: Square</title>
    ▶ <script id="vertexShader" type="x-shader/x-vertex">…</script>
    ▶ <script id="fragmentShader" type="x-shader/x-fragment">…</scri
    ▶ <script type="text/javascript">…</script>
    ▶ <style>…</style>
      <canvas id="mycanvas" width="834" height="416">
    </doctype>
  </body>
</html> == $0
```



```
const fs_source = document.getElementById('fragmentShader').text;

const fs = gl.createShader(gl.FRAGMENT_SHADER);
gl.shaderSource(fs, fs_source);
gl.compileShader(fs);
```

```
prog = gl.createProgram();
gl.attachShader(prog, vs);
gl.attachShader(prog, fs);
gl.linkProgram(prog);
```

```
<html>
  <head></head>
▼ <body>
  ▼ <doctype html>
      <!-- Copyright 2020, Cem Yuksel, University of Utah -->
      <title>CS 4600 - WebGL Example: Square</title>
    ▶ <script id="vertexShader" type="x-shader/x-vertex">…</script>
    ▶ <script id="fragmentShader" type="x-shader/x-fragment">…</scri
    ▶ <script type="text/javascript">…</script>
    ▶ <style>…</style>
      <canvas id="mycanvas" width="834" height="416">
    </doctype>
  </body>
</html> == $0
```



```
var positions = [
    -0.8,  0.4, 0,
     0.8,  0.4, 0,
     0.8, -0.4, 0,
    -0.8,  0.4, 0,
     0.8, -0.4, 0,
    -0.8, -0.4, 0
    ];

var colors = [
    1, 0, 0, 1,
    0, 1, 0, 1,
    0, 0, 1, 1,
    1, 0, 0, 1,
    0, 0, 1, 1,
    1, 0, 1, 1
    ];
```

```
var position_buffer = gl.createBuffer();

gl.bindBuffer(
    gl.ARRAY_BUFFER,
    position_buffer );

gl.bufferData(
    gl.ARRAY_BUFFER,
    new Float32Array(positions),
    gl.STATIC_DRAW );
```

```
▼ <script id="vertexShader" type="x-shader/x-vertex">
    attribute vec3 pos;
    attribute vec4 clr;

    uniform mat4 trans;

    varying vec4 vcolor;

    void main()
    {
        gl_Position = trans * vec4(pos,1);
        vcolor = clr;
    } == $0
  </script>
```


VERTEX SHADER

- **Input** comes from the client program, through "uniform variables" and "attributes"
  - uniform: Constant for all vertices
  - attribute: Some part of a vertex (normal, position, tangent, color, etc.)
- **Output** goes to the rasterizer, through "varying variables"
  - varying: Automatically interpolated values
  - gl_Position: special output, must be written to tell OpenGL the vertex position

USEFUL BUILT-IN OPERATIONS

- normalize(vec)
- length(vec)
- reflect(vec, vec)
- pow, max, sin, cos, etc.
- dot(vec, vec)
- Transforms: mat * vec
- Overloaded operators: +, -, *
- Swizzling: vec.xyz = vec.zyx
- tranpose(mat)

Data Types

- C types: int, float, bool
- Vectors:
  float vec2, vec3, vec4
  Also int (ivec) and boolean (bvec)
- Matrices: mat2, mat3, mat4
  Stored by columns
  Standard referencing m[row][column]
- C++ style constructors
  vec3 a =vec3(1.0, 2.0, 3.0)
  vec2 b = vec2(a)

No Pointers

- There are no pointers in GLSL
- We can use C structs which can be copied back from functions
- Because matrices and vectors are basic types they can be passed into and output from GLSL functions, e.g.

  mat3 func(mat3 a)
- variables passed by copying

CREATING AND COMPILING A SHADER

- glCreateShader
- glShaderSource
- glCompileShader
- glCreateProgram
- glAttachShader
- glLinkProgram

http://www.lighthouse3d.com/opengl/glsl/index.php?ogloverview

Qualifiers

- GLSL has many of the same qualifiers such as `const` as C/C++
- Need others due to the nature of the execution model
- Variables can change
  - Once per primitive
  - Once per vertex
  - Once per fragment
  - At any time in the application
- Vertex attributes are interpolated by the rasterizer into fragment attributes

Attribute Qualifier

- Attribute-qualified variables can change at most once per vertex
- Input to vertex attribute - at most 16 attributes (vec4)
- There are a few built in variables such as gl_Position but most have been deprecated
- User defined (in application program)

```
attribute float temperature
attribute vec3 velocity
```

recent versions of GLSL use `in` and `out` qualifiers to get to and from shaders

Uniform Qualified

- Variables that are constant for an entire primitive
- Can be changed in application and sent to shaders.
- Cannot be changed in shader
- Used to pass information to shader such as the time or a bounding box of a primitive or transformation matrices

Varying Qualified

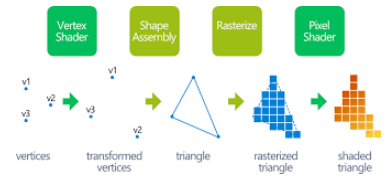
- Variables that are passed from vertex shader to fragment shader
- Automatically interpolated by the rasterizer
- With WebGL, GLSL uses the varying qualifier in both shaders

```
varying vec4 color;
```

- More recent versions of WebGL use **out** in vertex shader and **in** in the fragment shader

```
out vec4 color; //vertex shader
in vec4 color;  // fragment shader
```

Tessellation Shaders, Geometry Shaders, - only in OpenGL but not WebGL



Application (JS) - uses graphics API (on CPU) is in charge of controlling the shades ,
But shaders run on GPU
Important - Apps have different memory than GPU

Shaders always begin with a version declaration, followed by a list of input and output variables, uniforms and its `main` function.

```
#version version_number
in type in_variable_name;
in type in_variable_name;

out type out_variable_name;

uniform type uniform_name;

void main()
{
  // process input(s) and do some weird graphics
stuff
  ...
  // output processed stuff to output variable
  out variable name = weird stuff we processed;
}
```

Vertex Input=Vertex Attribute

Buffers

Allocating GPU memory -via buffers

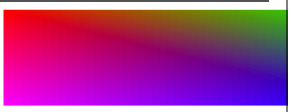
```
var positions = [
  -0.8,  0.4, 0,
   0.8,  0.4, 0,
   0.8, -0.4, 0,
  -0.8,  0.4, 0,
   0.8, -0.4, 0,
  -0.8, -0.4, 0
 ];
```

```
var position_buffer = gl.createBuffer();

gl.bindBuffer(
  gl.ARRAY_BUFFER,
  position_buffer );

gl.bufferData(
  gl.ARRAY_BUFFER,
  new Float32Array(positions),
  gl.STATIC_DRAW );
```



```
<script id="vertexShader" type="x-
shader/x-vertex">
attribute vec3 pos;
attribute vec4 clr;

uniform mat4 trans;

varying vec4 vcolor;

void main()
{
    gl_Position = trans *
vec4(pos,1);
    vcolor = clr;
}
</script>
```

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

varying vec4 vcolor;

void main()
{
    gl_FragColor = vcolor;
}
</script>
```



Vertices must be in canonical space [-1,1] - note the use of trans


```
const vs_source = document.getElementById('vertexShader').text;

const vs = gl.createShader(gl.VERTEX_SHADER);
gl.shaderSource(vs, vs_source);
gl.compileShader(vs);
```



```
var m = gl.getUniformLocation(prog,'trans');

var matrix = [
 1,0,0,0,
 0,1,0,0,
 0,0,1,0,
 0,0,0,1 ];

gl.useProgram(prog);
gl.uniformMatrix4fv( m, false, matrix );
```

```
var p = gl.getAttribLocation(prog, 'pos');
 gl.bindBuffer(gl.ARRAY_BUFFER, position_buffer);
 gl.vertexAttribPointer(p, 3, gl.FLOAT, false, 0, 0);
 gl.enableVertexAttribArray(p);

 var c = gl.getAttribLocation(prog, 'clr');
 gl.bindBuffer(gl.ARRAY_BUFFER, color_buffer);
 gl.vertexAttribPointer(c, 4, gl.FLOAT, false, 0, 0);
 gl.enableVertexAttribArray(c);


gl.clear( gl.COLOR_BUFFER_BIT );
 gl.useProgram( prog );
 gl.drawArrays( gl.TRIANGLES, 0, 6 );
```


Attributes for texture

Vertex shader

```
attribute vec3 vert_pos;
attribute vec3 vert_tang;
attribute vec3 vert_bitang;
attribute vec2 vert_uv;

uniform mat4 model_mtx;
uniform mat4 norm_mtx;
uniform mat4 proj_mtx;

varying vec2 frag_uv;
varying vec3 ts_light_pos; // Tangent space values
varying vec3 ts_view_pos;  //
varying vec3 ts_frag_pos;  //
```

https://apoorvaj.io/exploring-bump-mapping-with-webgl/

Texture with GLSL

Vertex shader

```
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;
}
```

```
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);
}
```

https://webglfundamentals.org/webgl/lessons/webgl-3d-textures.html

Our Naming Convention

- attributes passed to vertex shader have names beginning with v (v Position, vColor) in both the application and the shader
  - Note that these are different entities with the same name
- Variable variables begin with f (fColor) in both shaders
  - must have same name
- Uniform variables are unadorned and can have the same name in application and shaders

Corresponding Fragment Shader

```
precision mediump float;

varying vec3 fColor;
void main()
{
  gl_FragColor = fColor;
}
```


Sending Colors from Application

```
var cBuffer = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, cBuffer );
gl.bufferData( gl.ARRAY_BUFFER, flatten(colors),
                gl.STATIC_DRAW );

var vColor = gl.getAttribLocation( program, "vColor" );
gl.vertexAttribPointer( vColor, 3, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( vColor );
```

Sending a Uniform Variable

```
// in application

vec4 color = vec4(1.0, 0.0, 0.0, 1.0);
colorLoc = gl.getUniformLocation( program, "color" );
gl.uniform4f( colorLoc, color);

// in fragment shader (similar in vertex shader)

uniform vec4 color;

void main()
{
   gl_FragColor = color;
}
```


Operators and Functions

- Standard C functions
  - Trigonometric
  - Arithmetic
  - Normalize, reflect, length
- Overloading of vector and matrix types

```
mat4 a;
vec4 b, c, d;
c = b*a; // a column vector stored as a 1d array
d = a*b; // a row vector stored as a 1d array
```


Swizzling and Selection

- Can refer to array elements by element using [] or selection (.) operator with
  - x, y, z, w
  - r, g, b, a
  - s, t, p, q
  - `a[2], a.b, a.z, a.p` are the same
- **Swizzling** **(In computer graphics, swizzles are a class of operations that transform vectors by rearranging components)** operator lets us manipulate components

```
vec4 a, b;
a.yz = vec2(1.0, 2.0, 3.0, 4.0);
b = a.yxzw;
```