WebGL and GLSL Basics

CS559 – Spring 2018

Lecture 17

March 13th 2018

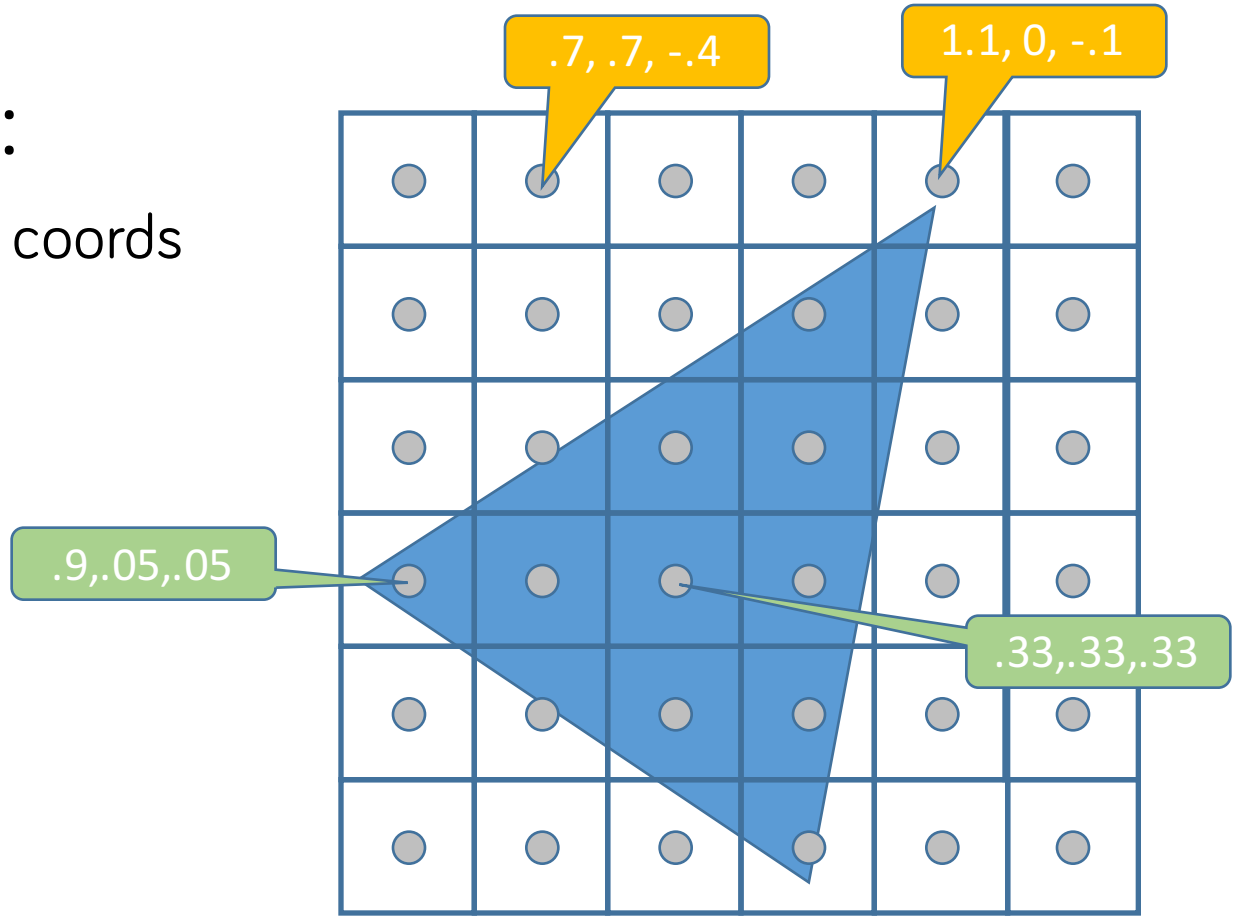
Review ...

Hardware Rasterization

For each point:

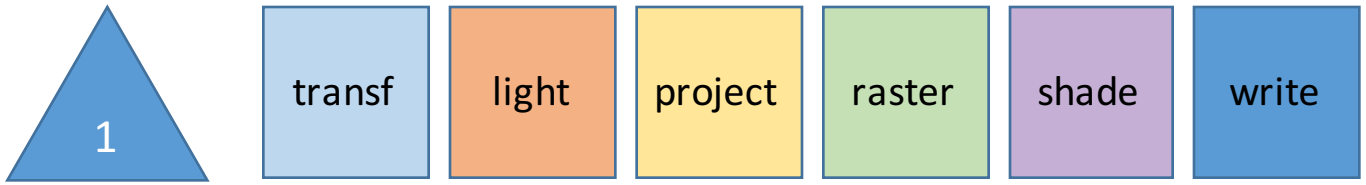
Compute barycentric coords

Decide if in or out

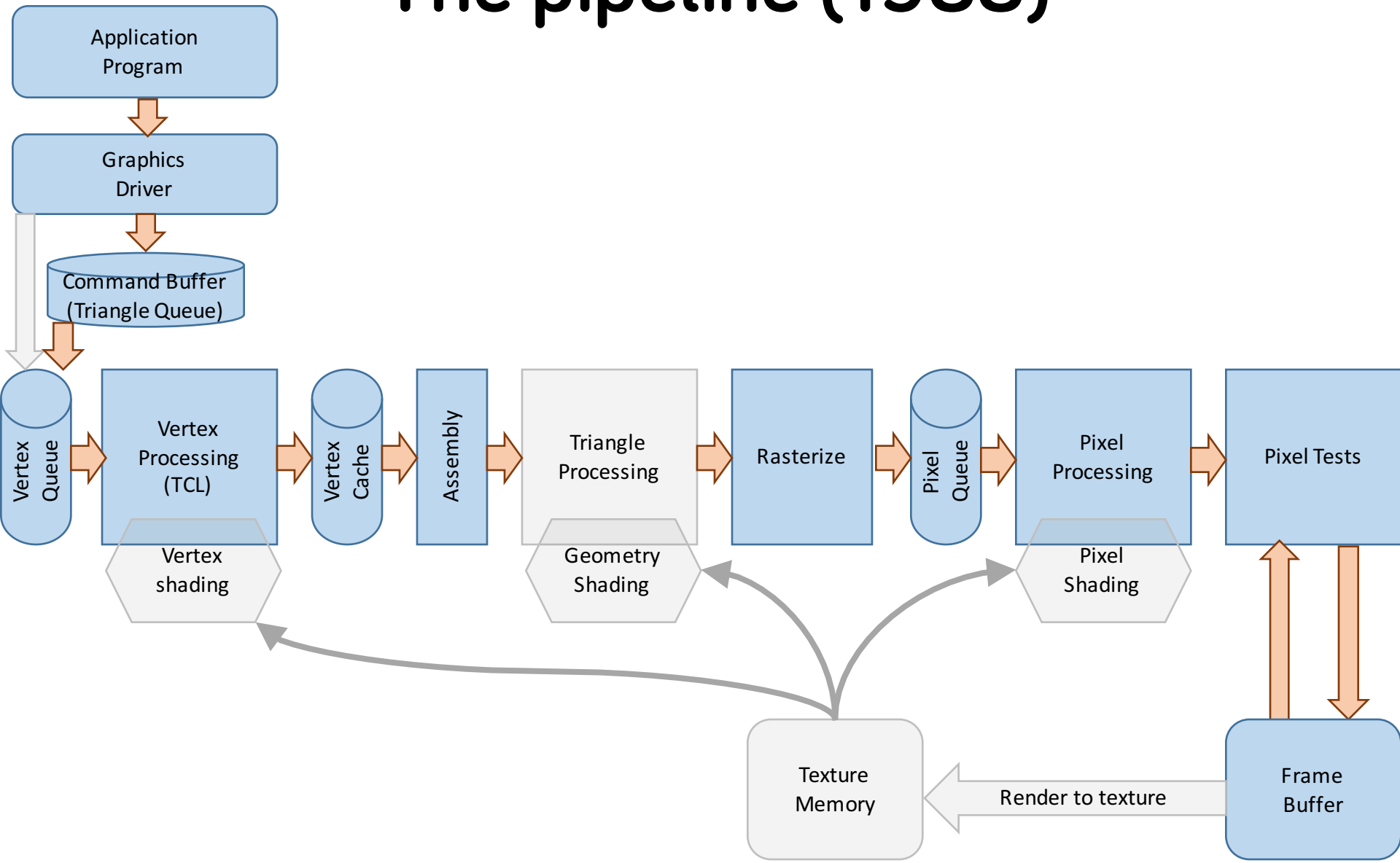


1988: The Personal Iris

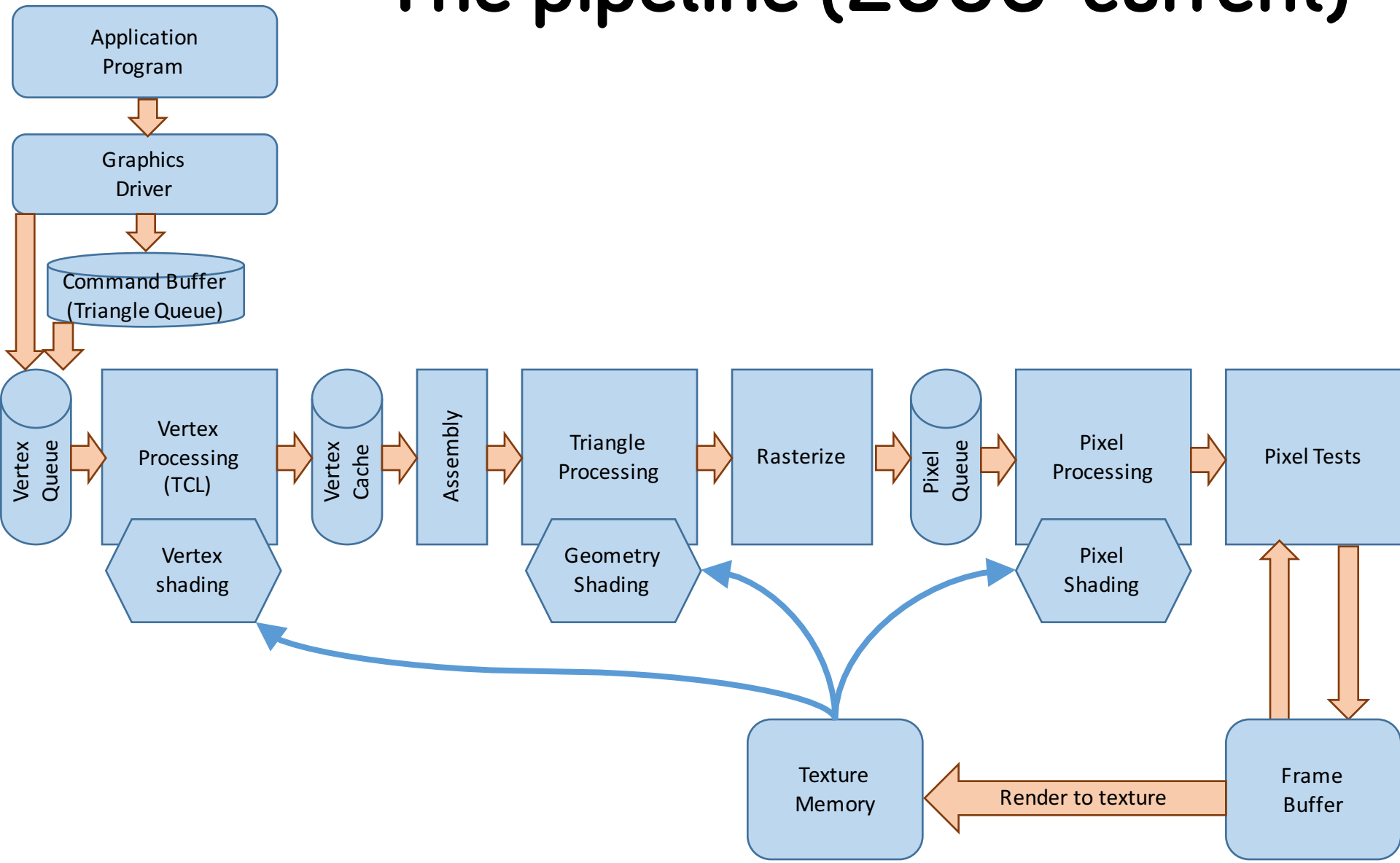
A Pipeline



The pipeline (1988)

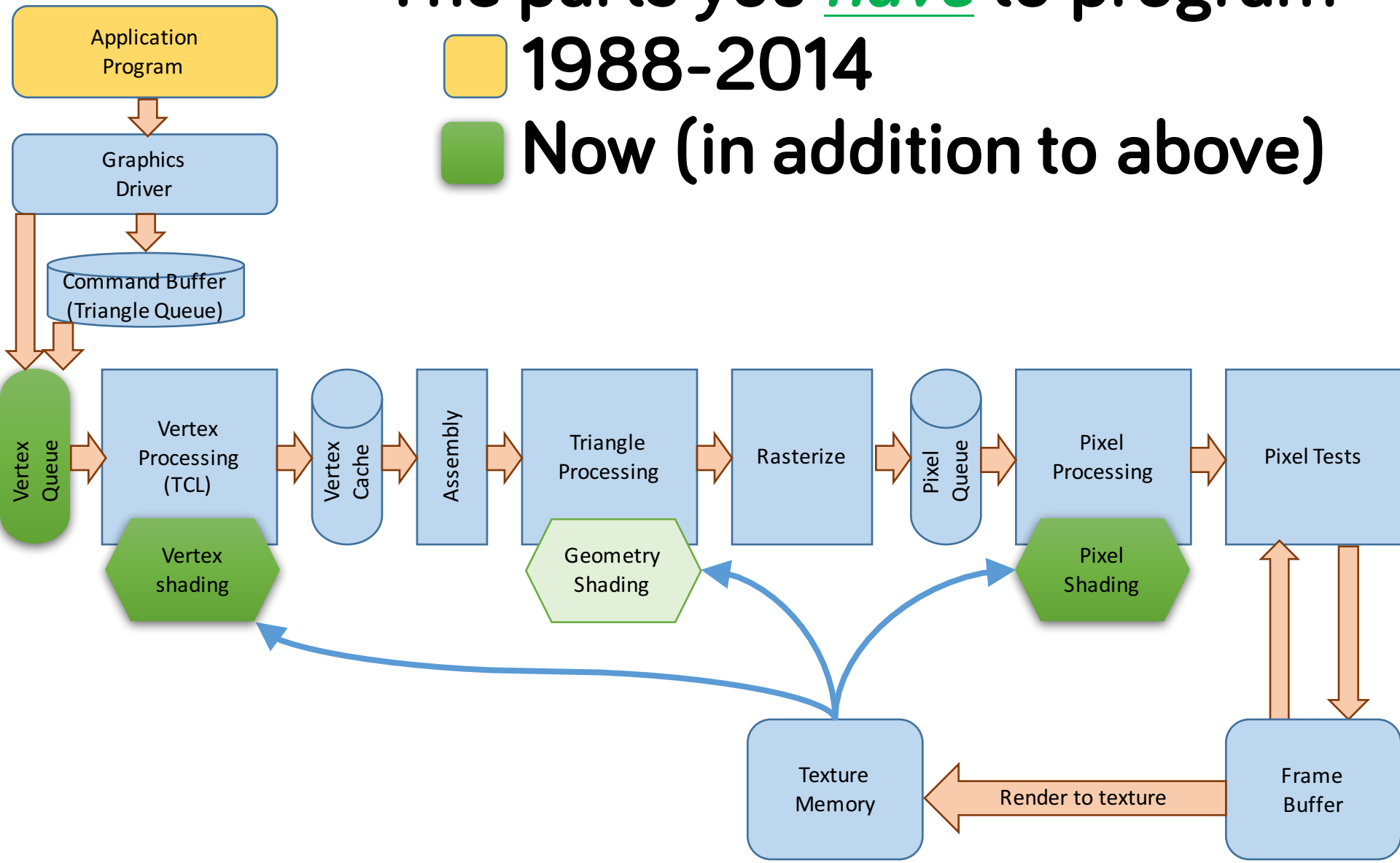


The pipeline (2006-current)



The parts you *have* to program

- 1988-2014
- Now (in addition to above)



A Triangle’s Journey

A Program to Draw a Triangle

The complete WebGL thing we need

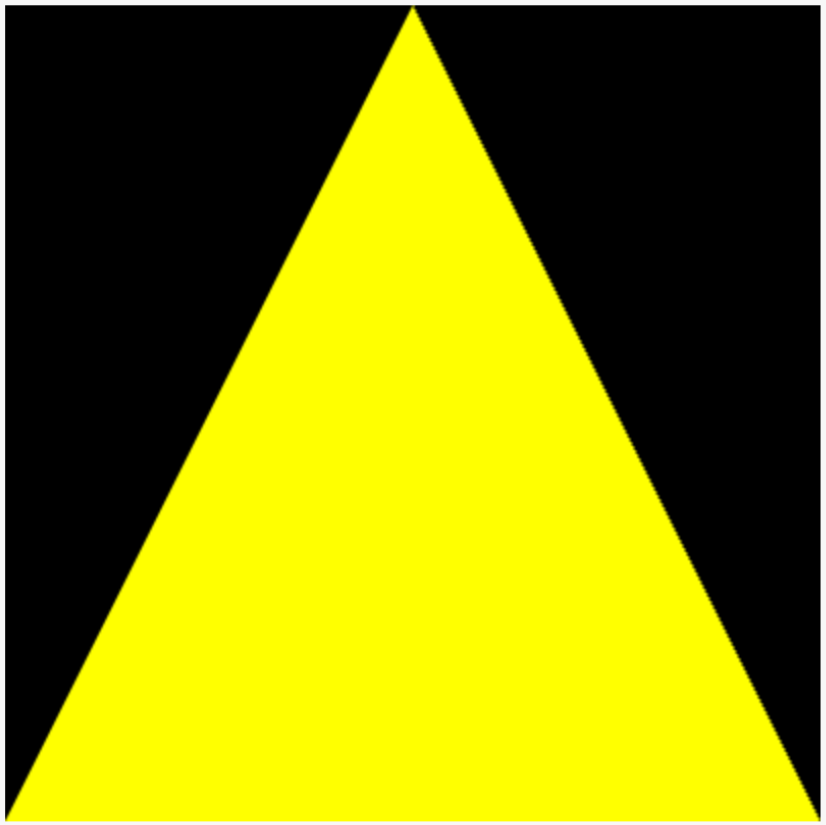
Doing each necessary steps

Just one triangle...

`http://jsbin.com/fowoku/edit`

Just a Triangle

Output



HTML like you are used to

HTML

```
1  <!DOCTYPE html>
2  <html>
3  <head>
4  <meta name="description" content="One Triangle">
5    <meta charset="utf-8">
6    <title>JS Bin</title>
7  </head>
8  <body onload="start()">
9  <canvas id="mycanvas" width="400" height="400"></canvas>
10 </body>
11 </html>
```

A Lot of Code

```javascript
// draw a triangle using WebGL
// write everything out, step at a time
//
// written by gleicher on October 3, 2015

function start() {
  "use strict";

  // first we need to get the canvas and make an OpenGL context
  // in practice, you need to do error checking
  var canvas = document.getElementById("mycanvas");
  var gl = canvas.getContext("experimental-webgl");


  // now we have to program the hardware
  // we need to have our GLSL code somewhere
  // putting it in strings is bad - but it's easy so I'll
  // do it for now
  var vertexSource = ""+
    "attribute vec3 pos;" +
    "void main(void) {" +
    "  gl_Position = vec4(pos, 1.0);" +
    "}";
  var fragmentSource = "" +
    "void main(void) {" +
    "  gl_FragColor = vec4(1.0, 1.0, 0.0, 1.0);" +
    "}";

  // now we need to make those programs into
  // "Shader Objects" - by running the compiler
  // watch the steps:
  //   create an object
  //   attach the source code
  //   run the compiler
  //   check for errors

  // first compile the vertex shader
  var vertexShader = gl.createShader(gl.VERTEX_SHADER);
  gl.shaderSource(vertexShader,vertexSource);
  gl.compileShader(vertexShader);

  if (!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)) {
          alert(gl.getShaderInfoLog(vertexShader));
          return null;
      }

  // now compile the fragment shader
  var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER);
  gl.shaderSource(fragmentShader,fragmentSource);
  gl.compileShader(fragmentShader);

  if (!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)) {
          alert(gl.getShaderInfoLog(fragmentShader));
          return null;
      }

  // OK, we have a pair of shaders, we need to put them together
  // into a "shader program" object
  var shaderProgram = gl.createProgram();
  gl.attachShader(shaderProgram, vertexShader);
  gl.attachShader(shaderProgram, fragmentShader);
  gl.linkProgram(shaderProgram);

  if (!gl.getProgramParameter(shaderProgram, gl.LINK_STATUS)) {
    alert("Could not initialise shaders");
  }

  // with the vertex shader, we need to pass it positions
  // as an attribute - so set up that communication
    shaderProgram.vertexPositionAttribute = gl.getAttribLocation(shaderProgram, "pos");
    gl.enableVertexAttribArray(shaderProgram.vertexPositionAttribute);


  // now that we have programs to run on the hardware, we can
  // make our triangle

  // let's define the vertex positions
  var vertexPos = [
        0.0,  1.0,  0.0,
       -1.0, -1.0,  0.0,
        1.0, -1.0,  0.0
   ];

  // we need to put the vertices into a buffer so we can
  // block transfer them to the graphics hardware
  var trianglePosBuffer = gl.createBuffer();
  gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
  gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertexPos), gl.STATIC_DRAW);
    trianglePosBuffer.itemSize = 3;
    trianglePosBuffer.numItems = 3;



  // this is the "draw scene" function, but since this
  // is execute once...

  // first, let's clear the screen
  gl.clearColor(0.0, 0.0, 0.0, 1.0);
  gl.enable(gl.DEPTH_TEST);
  gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

  // now we draw the triangle
  // we tell GL what program to use, and what memory block
  // to use for the data, and that the data goes to the pos
  // attribute
  gl.useProgram(shaderProgram);
  gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
  gl.vertexAttribPointer(shaderProgram.vertexPositionAttribute, trianglePosBuffer.itemSize, gl.FLOAT, false, 0, 0);
  gl.drawArrays(gl.TRIANGLES, 0, 3);
}
```

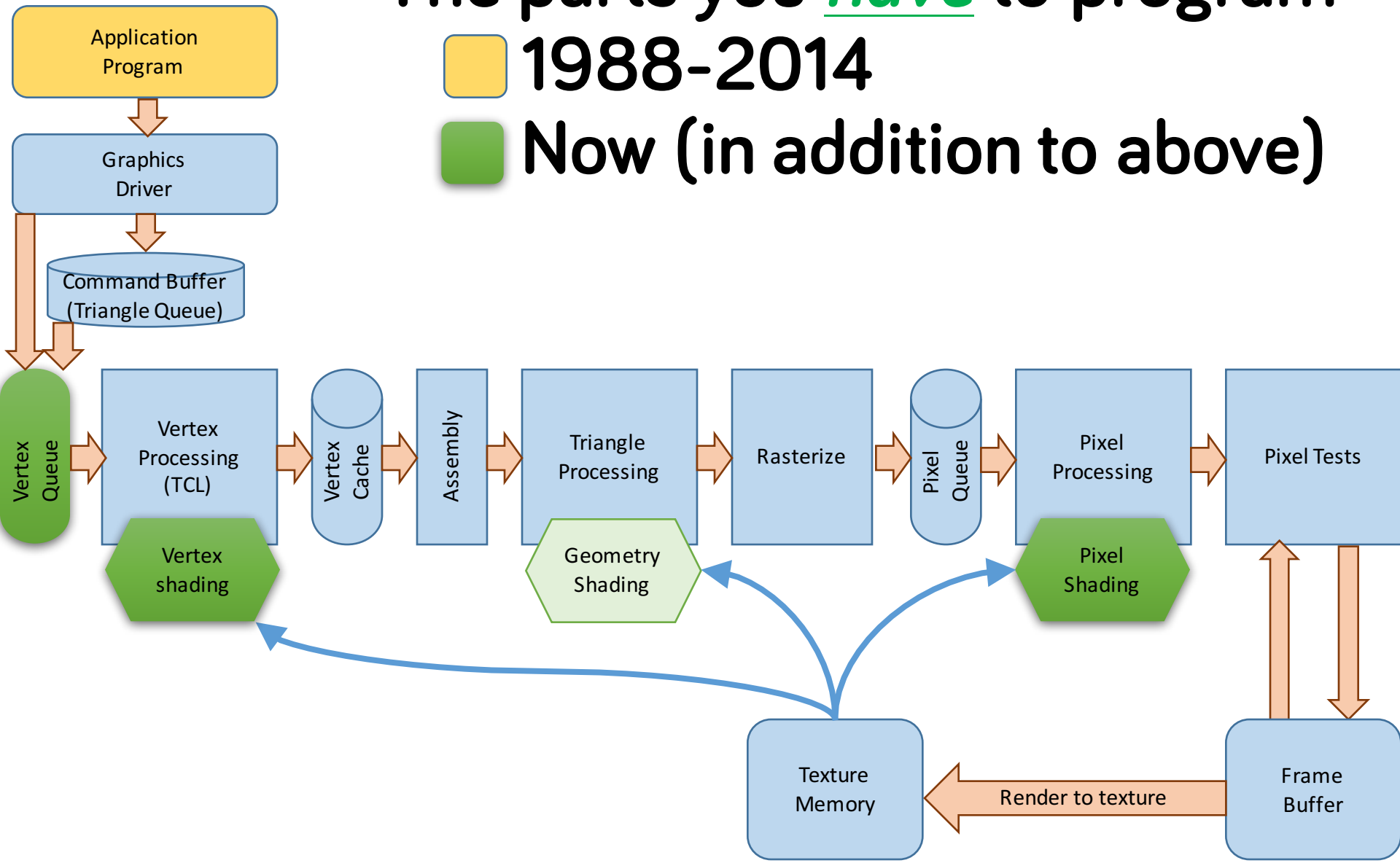
Look at the process inside-out

We'll start with the end of the pipeline

And work backwards…

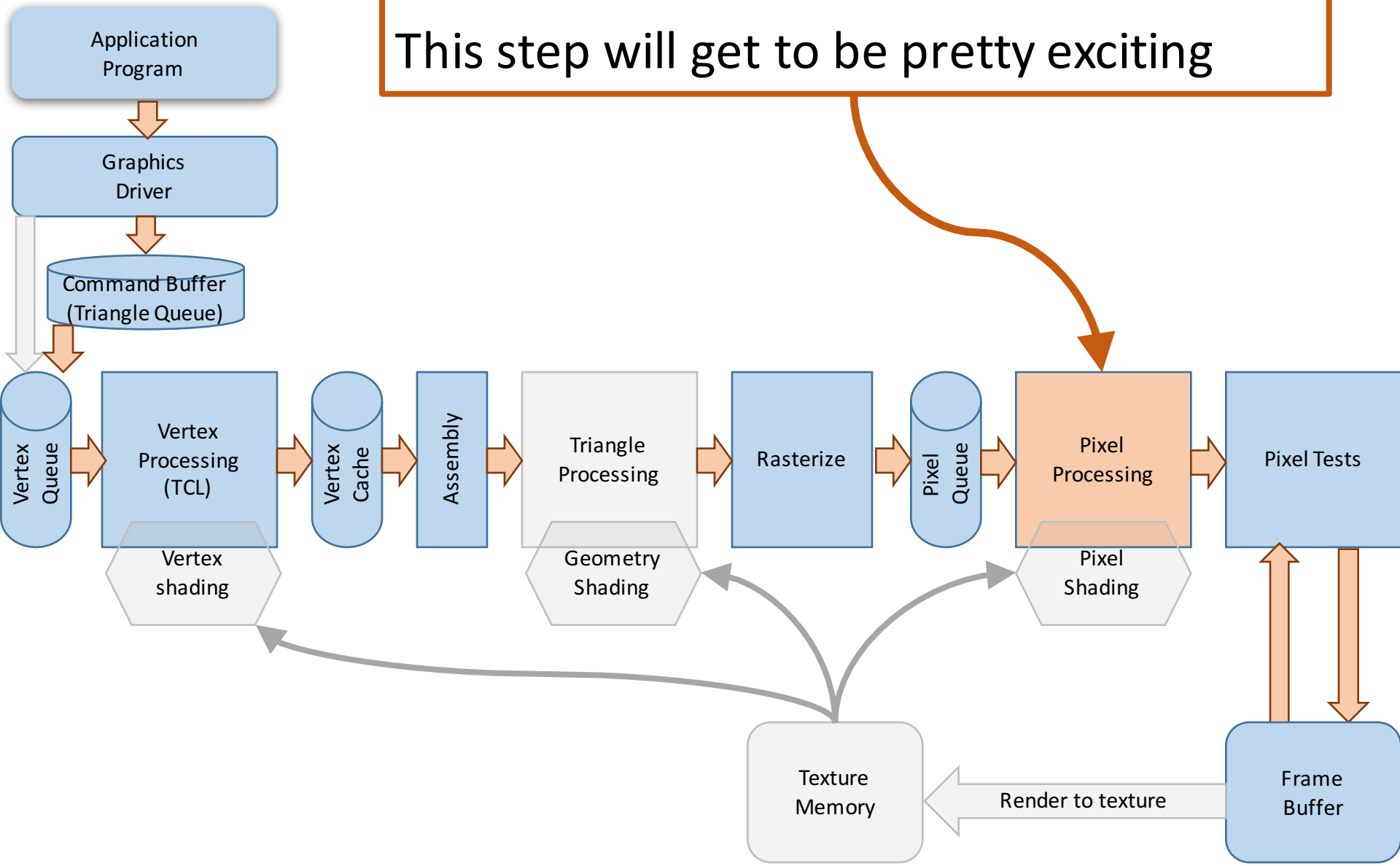
The parts you *have* to program

- 1988-2014
- Now (in addition to above)



I warned you:

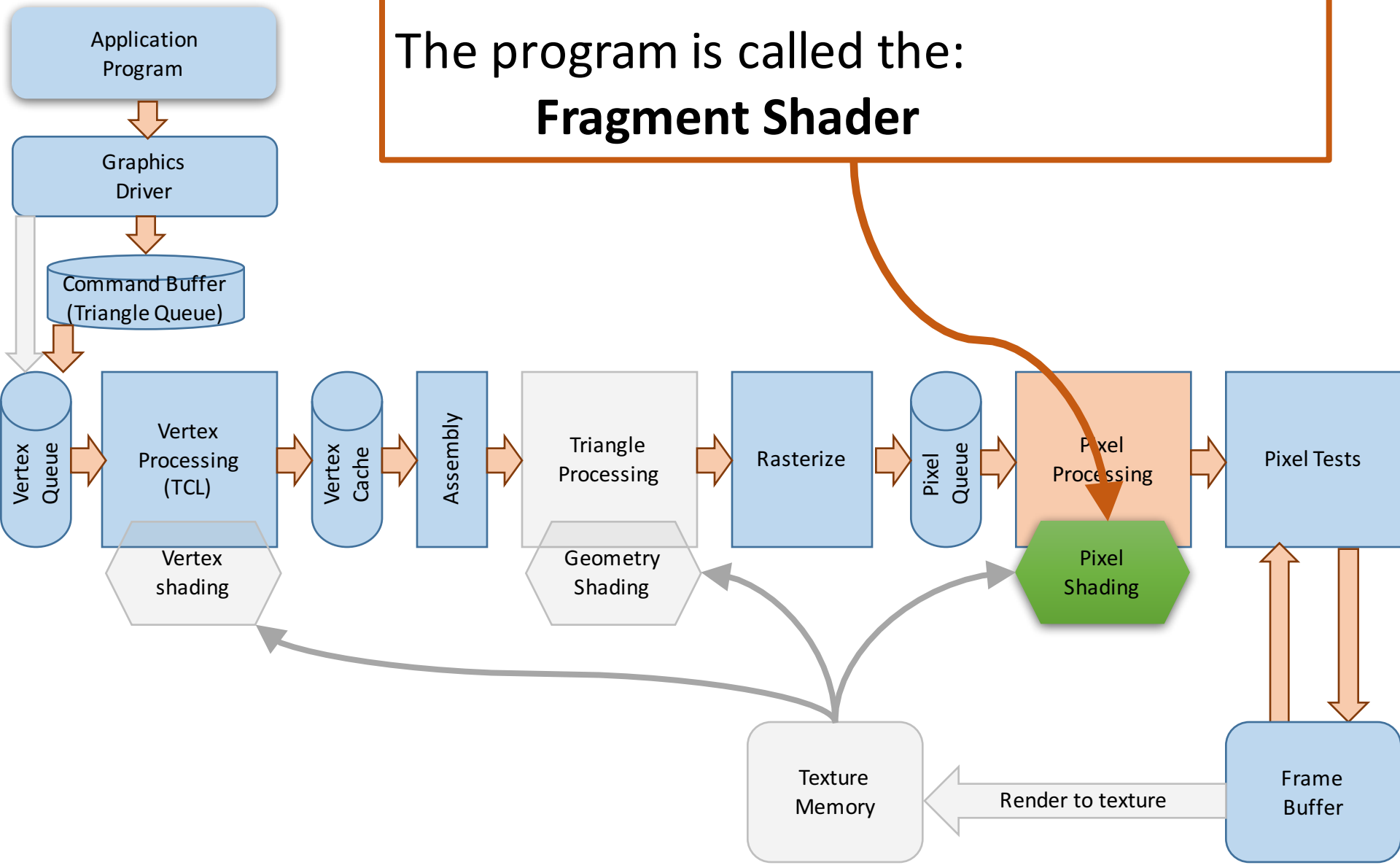
This step will get to be pretty exciting



We have to program this step!

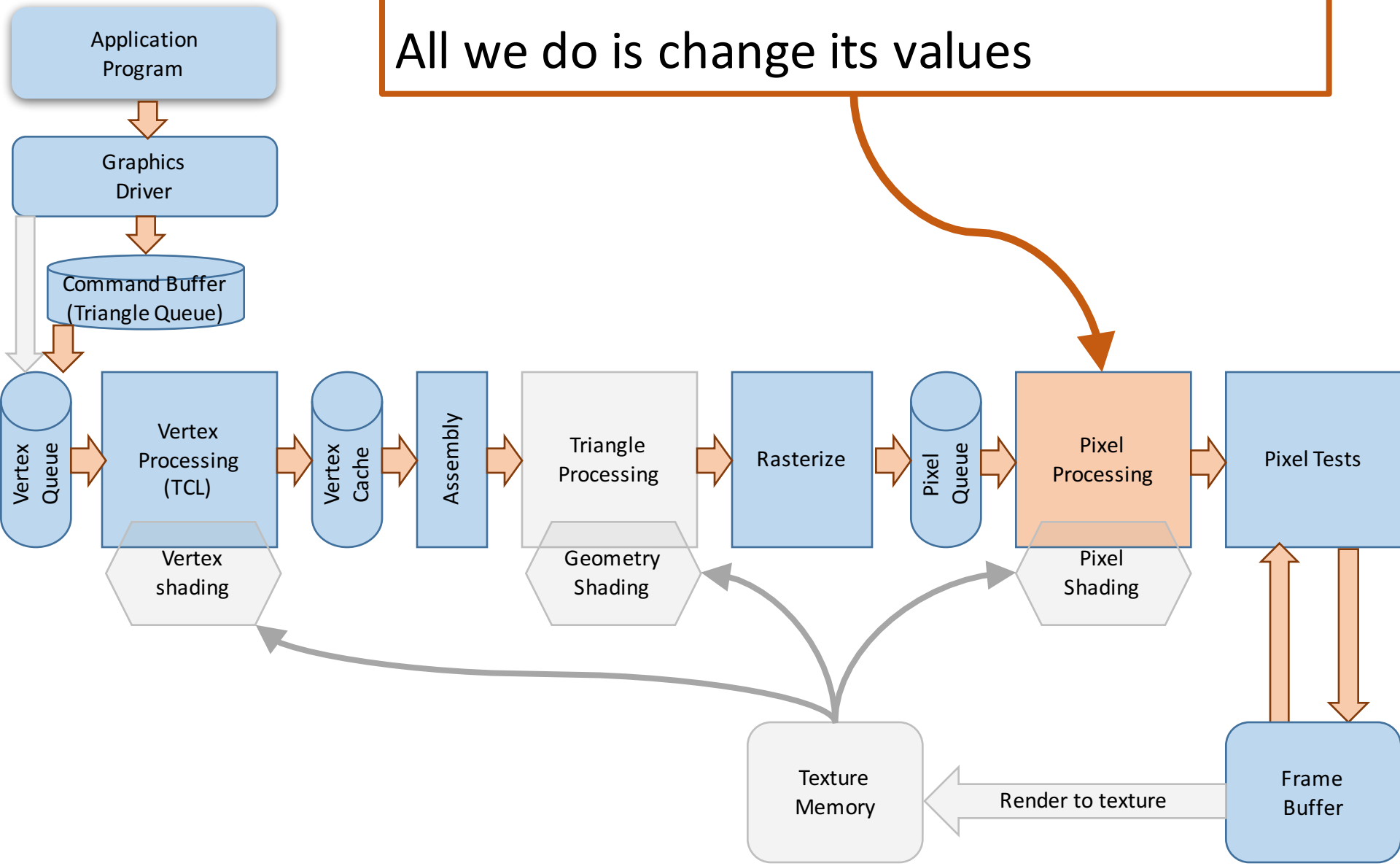
The program is called the:

Fragment Shader



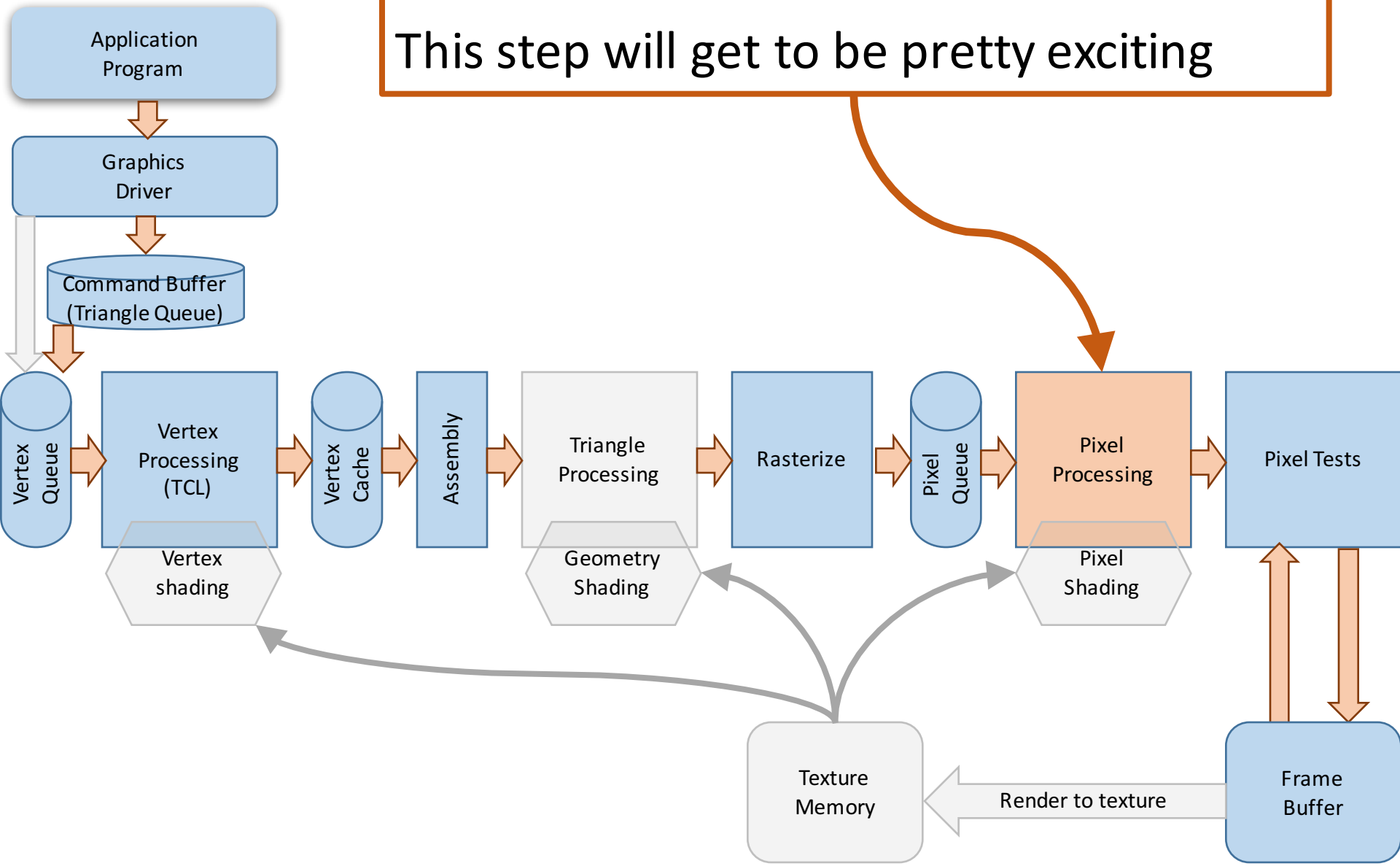
Pixel in → Pixel out, each independent

All we do is change its values



Coming attractions…

This step will get to be pretty exciting



The Pixel Shader

Given information about the pixel

Compute color

Optionally, compute other things

How to program it

Use a Shading Language

We'll use a language called GLSL

Compiler built into WebGL

Language specifics as we go…

A (boring) Fragment Shader

```
void main(void)
{
        gl_FragColor = vec4(0.0, 1.0, 1.0, 1.0);
}
```

A (boring) Fragment Shader

Shaders define a **main** function that take no arguments return no values

```
void main(void)
{
        gl_FragColor = vec4(0.0, 1.0, 1.0, 1.0);
}
```

A (boring) Fragment Shader

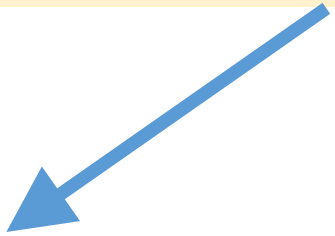
GLSL Shaders operate by side effects on special variables
(they look like globals)

```
void main(void)
{
        gl_FragColor = vec4(0.0, 1.0, 1.0, 1.0);
}
```

A (boring) Fragment Shader

GLSL has types useful in graphics
Like 4 vectors

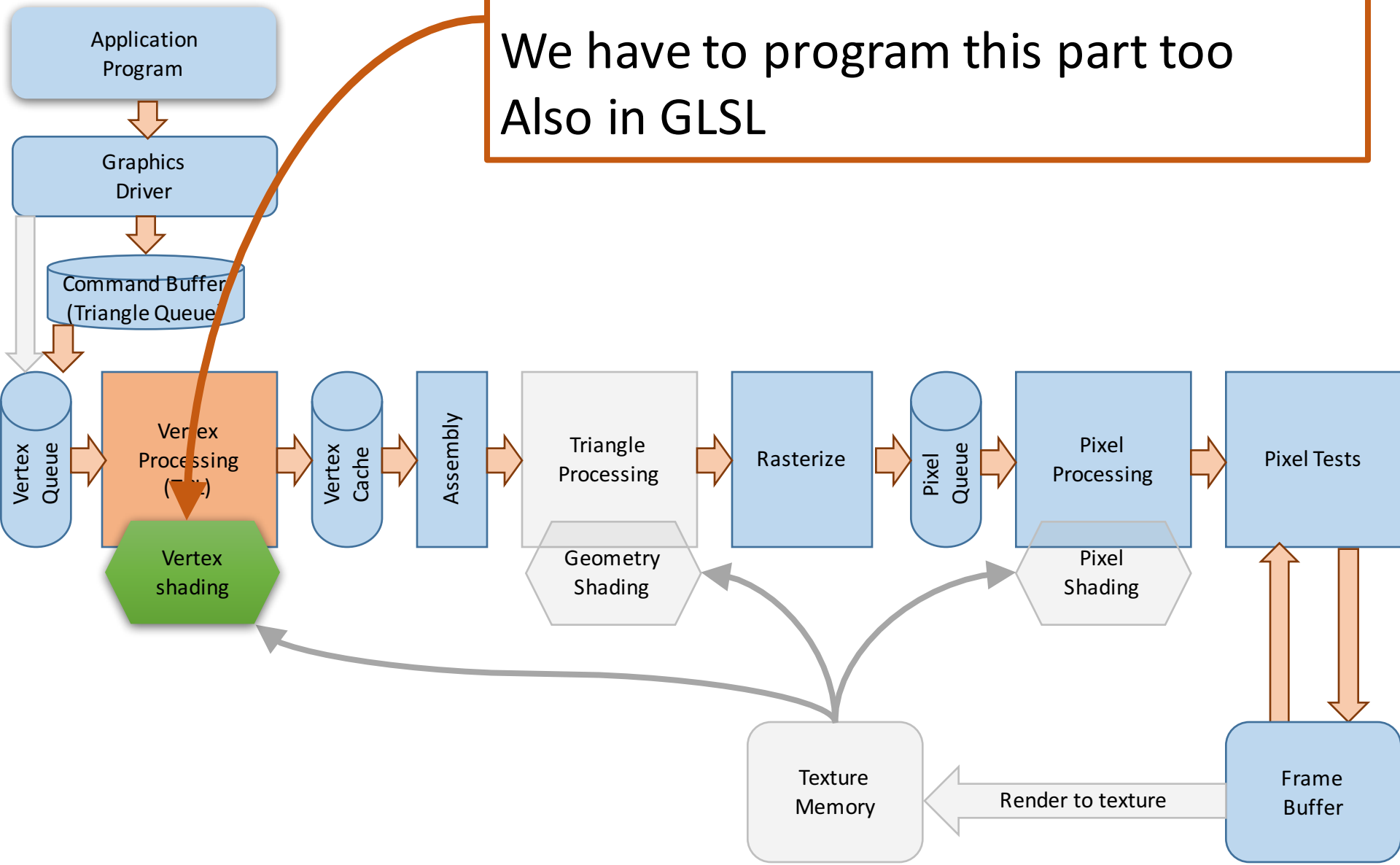
```
void main(void)
{
        gl_FragColor = vec4(0.0, 1.0, 1.0, 1.0);
}
```



This is opaque yellow
(even colors are 4-vectors)

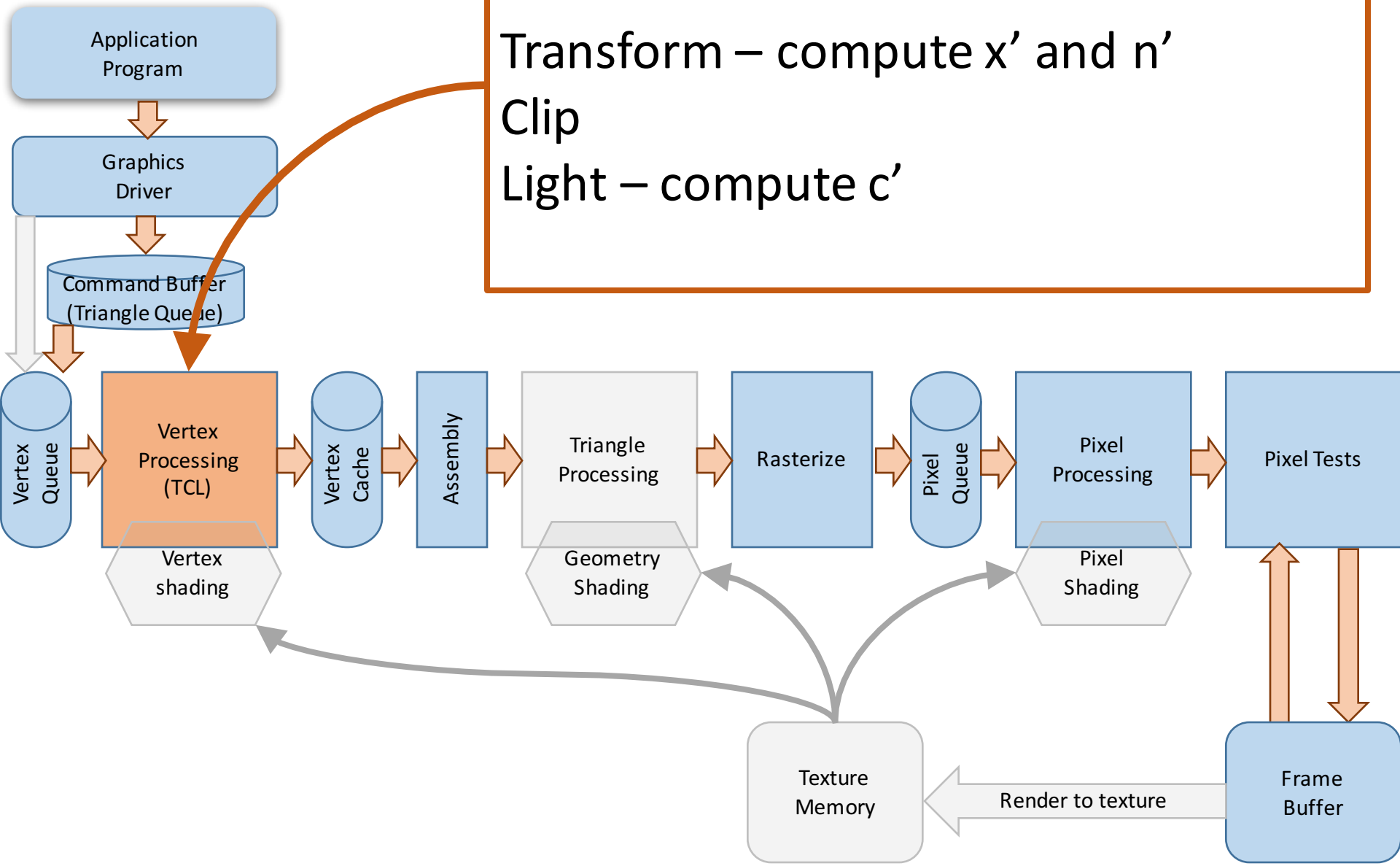
Vertex Processing

We have to program this part too
Also in GLSL



Process each vertex independently

Transform – compute x’ and n’
Clip
Light – compute c’



What data about vertices?

Inputs:

- Position
- Other Stuff

Vertex **Attributes** from application

Outputs:

- Position
- Other Stuff

varying properties to framgment Shaders (remember interpolation)

The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

The simplest vertex shader

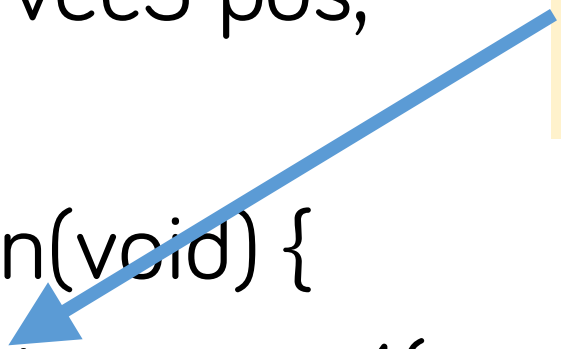
```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

Shaders define a **main** function that take no arguments return no values

The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

Shaders output by side effects: setting special variables



The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

Shaders get input by reading special variables

Special Variables

Built in (magic)

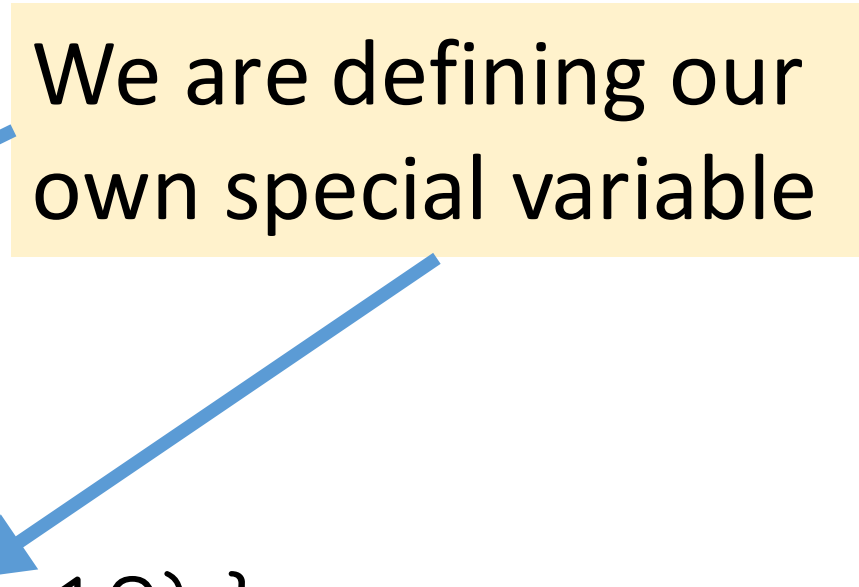
- gl_Position – output of vertex shader
- gl_FragColor – output of frag shader

User Defined

- attributes – inputs to vertex shader
- varying – output from vertex to fragment
- uniform – “constant” over triangle group

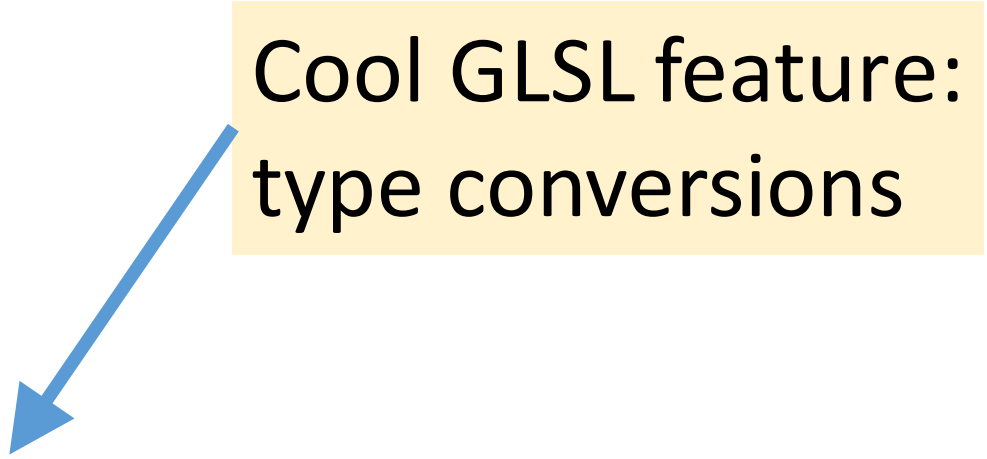
The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```



The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```



No Transformation?

I will assume the position is already in the right coordinate system.

The rasterizer (and everything else) works in **Normalized Device Coordinates** (NDC)

-1 to 1 in each dimension

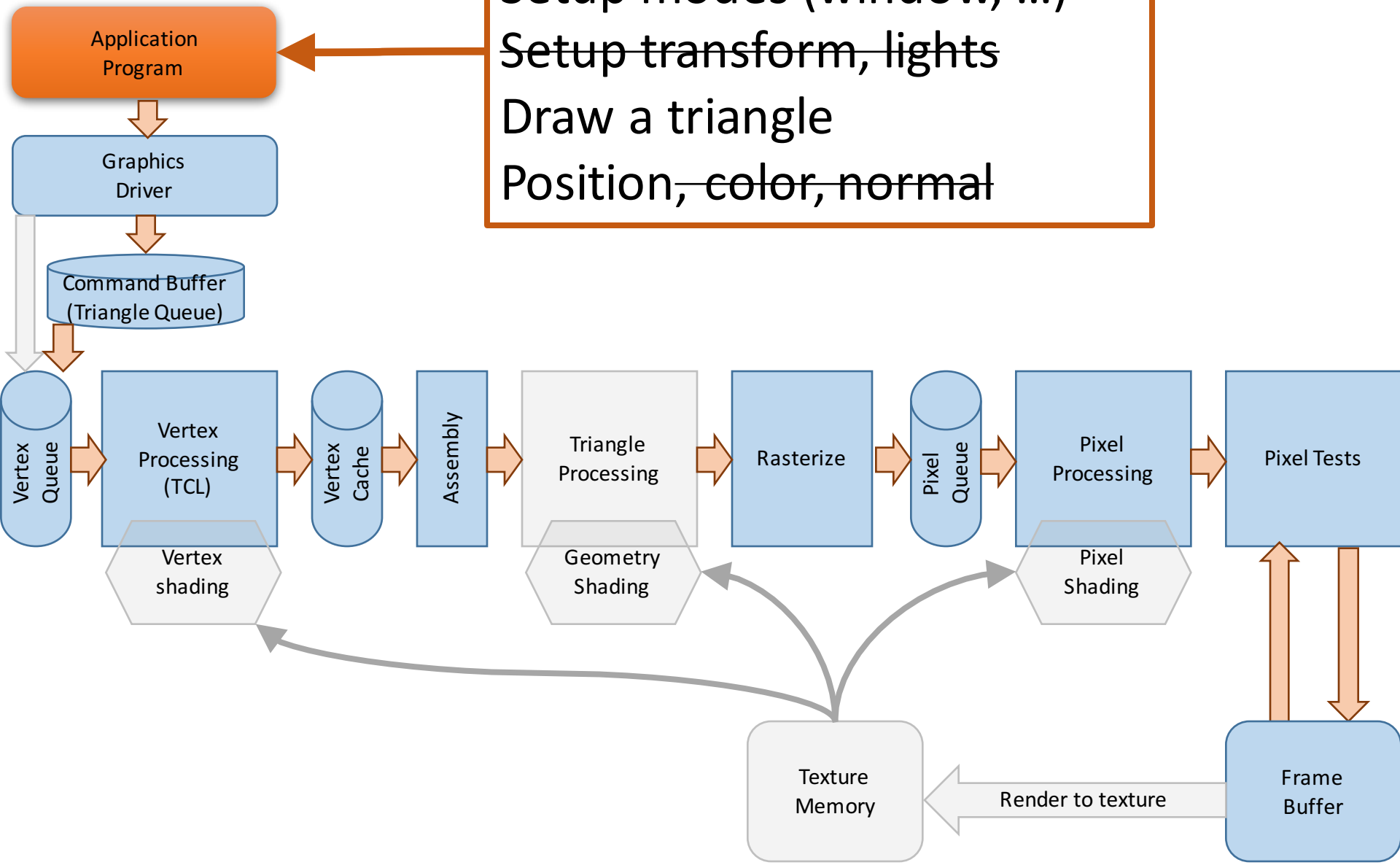
Start here

Setup modes (window, …)

~~Setup transform, lights~~

Draw a triangle

Position~~, color, normal~~



In JavaScript using WebGL...

The beginning

```
 6 function start() {
 7   "use strict";
 8
 9   // first we need to get the canvas and make an OpenGL context
10   // in practice, you need to do error checking
11   var canvas = document.getElementById("mycanvas");
12   var gl = canvas.getContext("webgl");
```

The beginning

```
 6 function start() {
 7   "use strict";
 8
 9   // first we need to get the canvas and make an OpenGL context
10   // in practice, you need to do error checking
11   var canvas = document.getElementById("mycanvas");
12   var gl = canvas.getContext("webgl");
```

This should look like HTML5 Canvas

You can have multiple contexts

(draw “canvas” over WebGL)

Now about those shaders...

```
14    // now we have to program the hardware
15    // we need to have our GLSL code somewhere
16    // putting it in strings is bad - but it's easy so I'll
17    // do it for now
18    var vertexSource = ""+
19      "attribute vec3 pos;" +
20      "void main(void) {" +
21      "  gl_Position = vec4(pos, 1.0);" +
22      "}";
23    var fragmentSource = "" +
24      "void main(void) {" +
25      "  gl_FragColor = vec4(1.0, 1.0, 0.0, 1.0);" +
26      "}";
```

Get them into strings

Use a library to read them from resources

Run the compiler!

```
28    // now we need to make those programs into
29    // "Shader Objects" - by running the compiler
30    // watch the steps:
31    //   create an object
32    //   attach the source code
33    //   run the compiler
34    //   check for errors
35
36    // first compile the vertex shader
37    var vertexShader = gl.createShader(gl.VERTEX_SHADER);
38    gl.shaderSource(vertexShader,vertexSource);
39    gl.compileShader(vertexShader);
40
41    if (!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)) {
42            alert(gl.getShaderInfoLog(vertexShader));
43            return null;
44        }
```

Error Checking

Here I checked for errors

(since I often have syntax errors)

You should check for errors everywhere

Run the compiler again!

```
46    // now compile the fragment shader
47    var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER);
48    gl.shaderSource(fragmentShader,fragmentSource);
49    gl.compileShader(fragmentShader);
50
51    if (!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)) {
52            alert(gl.getShaderInfoLog(fragmentShader));
53            return null;
54        }
```

Need to compile both shaders

Link the shaders together...

```
46  // now compile the fragment shader
47  var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER);
48  gl.shaderSource(fragmentShader,fragmentSource);
49  gl.compileShader(fragmentShader);
50
51  if (!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)) {
52          alert(gl.getShaderInfoLog(fragmentShader));
53          return null;
54      }
```

Shaders always work in pairs

Need to connect them

Setup the special variables

```
66
67    // with the vertex shader, we need to pass it positions
68    // as an attribute - so set up that communication
69      shaderProgram.vertexPositionAttribute = gl.getAttribLocation(shaderProgram,
    "pos");
70      gl.enableVertexAttribArray(shaderProgram.vertexPositionAttribute);
71
```

Important to communicate with shaders

The simplest vertex shader

```
attribute vec3 pos;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

Javascript needs to connect to the “pos” variable

Communicating an attribute

```
66
67    // with the vertex shader, we need to pass it positions
68    // as an attribute - so set up that communication
69      shaderProgram.vertexPositionAttribute = gl.getAttribLocation(shaderProgram,
    "pos");
70      gl.enableVertexAttribArray(shaderProgram.vertexPositionAttribute);
71
```

We give it an array of attributes

Assign it to a position

We have to ask which position

OK, Now for our triangle

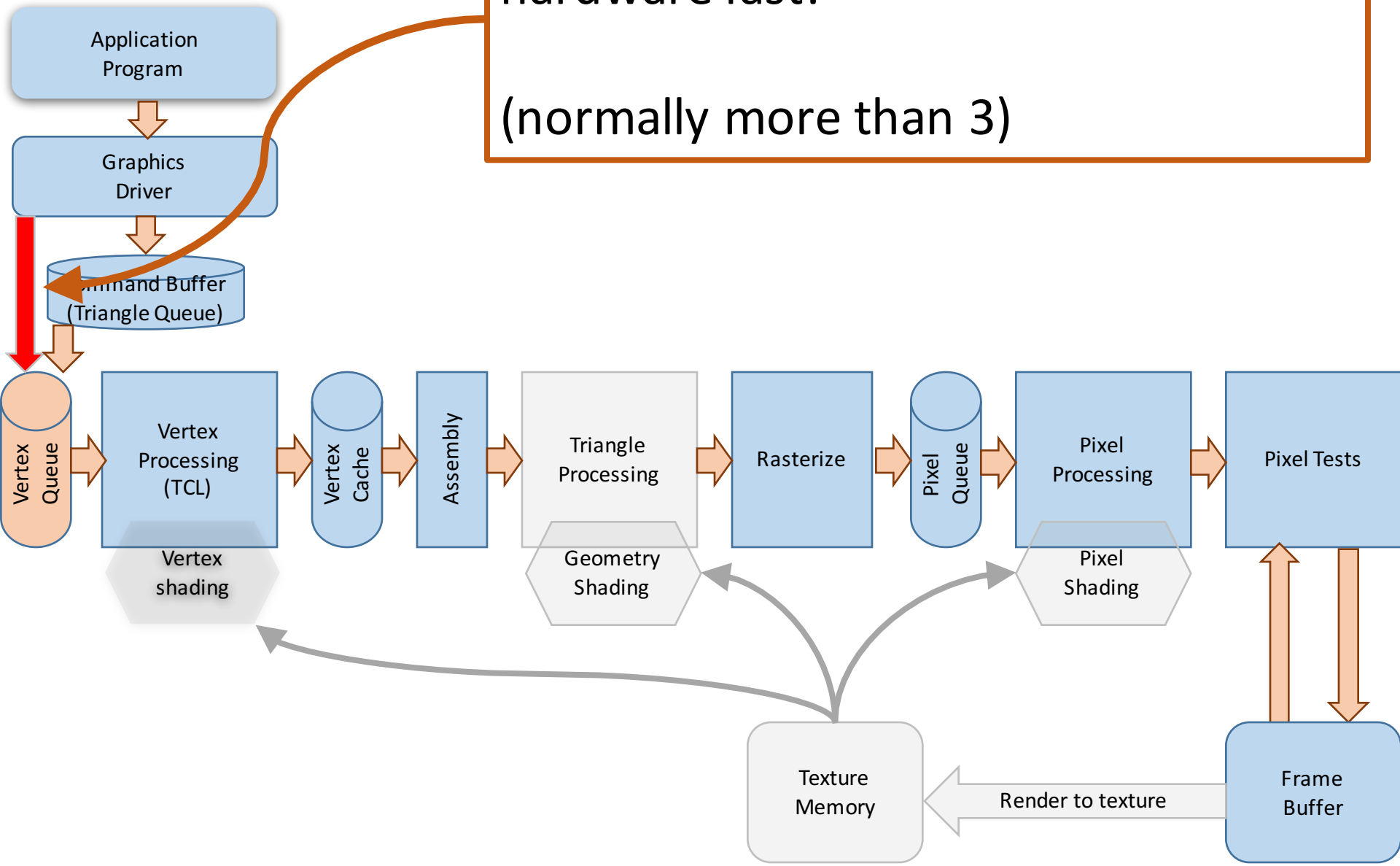
```
72
73   // now that we have programs to run on the hardware, we can
74   // make our triangle
75
76   // let's define the vertex positions
77   var vertexPos = [
78          0.0,  1.0,  0.0,
79         -1.0, -1.0,  0.0,
80          1.0, -1.0,  0.0
81    ];
82
```

How do we get this data to the hardware?

Need to do a block transfer

Need to get the vertices to the hardware fast!

(normally more than 3)



Key Idea: Buffer

```
83   // we need to put the vertices into a buffer so we can
84   // block transfer them to the graphics hardware
85   var trianglePosBuffer = gl.createBuffer();
86   gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
87   gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertexPos), gl.STATIC_DRAW);
88     trianglePosBuffer.itemSize = 3;
89     trianglePosBuffer.numItems = 3;
```

Create a **buffer**

buffer = a block of memory on the GPU

Copy the data into the buffer

Must be a special JavaScript object:

Float32Array (array of fixed types)

Now to draw

```
93    // this is the "draw scene" function, but since this
94    // is execute once...
95
96    // first, let's clear the screen
97    gl.clearColor(0.0, 0.0, 0.0, 1.0);
98    gl.enable(gl.DEPTH_TEST);
99    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);
```

First we have to clear the screen

Notice that color is a 4-vector

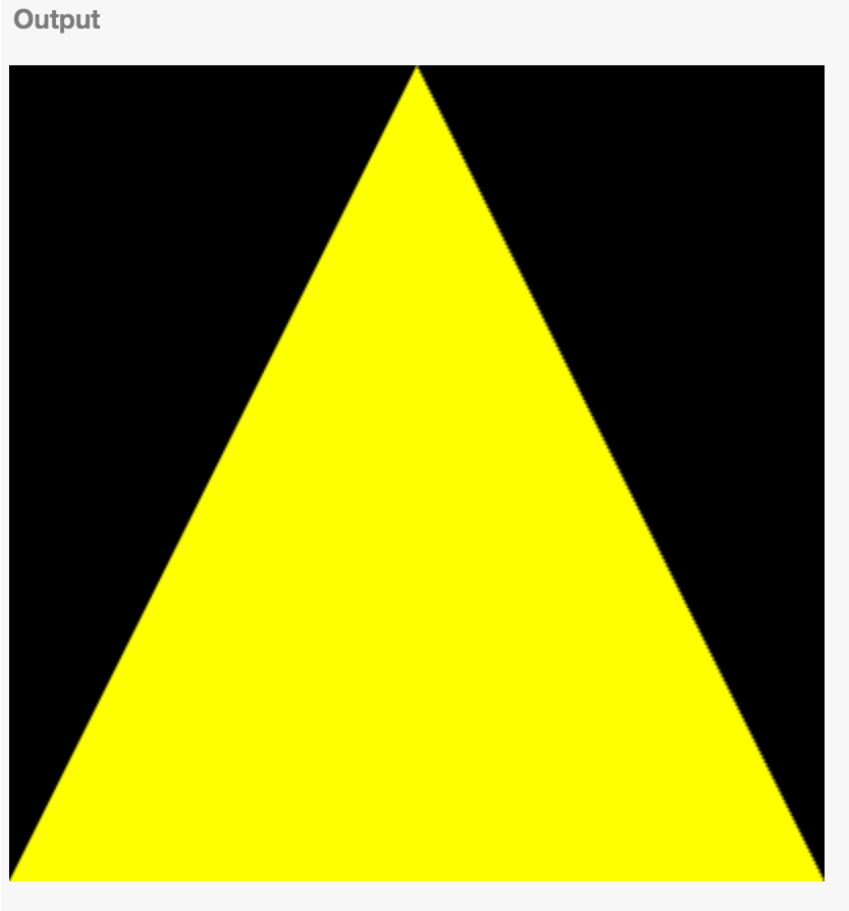
I don't really need the z-buffer

Now we actually draw the triangle

```
101    // now we draw the triangle
102    // we tell GL what program to use, and what memory block
103    // to use for the data, and that the data goes to the pos
104    // attribute
105    gl.useProgram(shaderProgram);
106    gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
107    gl.vertexAttribPointer(shaderProgram.vertexPositionAttribute,
     trianglePosBuffer.itemSize, gl.FLOAT, false, 0, 0);
108    gl.drawArrays(gl.TRIANGLES, 0, 3);
```

Notice that we use the shaders and the buffer

All that for a triangle!



Is it really 100 lines of code?

Not really – lots of comments

Build wrappers to be more concise

you do the same thing over and over

But there are lots of steps

and you should understand them

Two triangles...

```
77    var vertexPos = [
78            0.0,  1.0,  0.0,
79           -1.0,  0.0,  0.0,
80            0.5,  0.0,  0.0,
81            0.0, -1.0,  0.0,
82           -0.5,  0.0,  0.0,
83            1.0,  0.0,  0.0,
84     ];
```

Can you see where these triangles will go?

(remember they are in NDC)

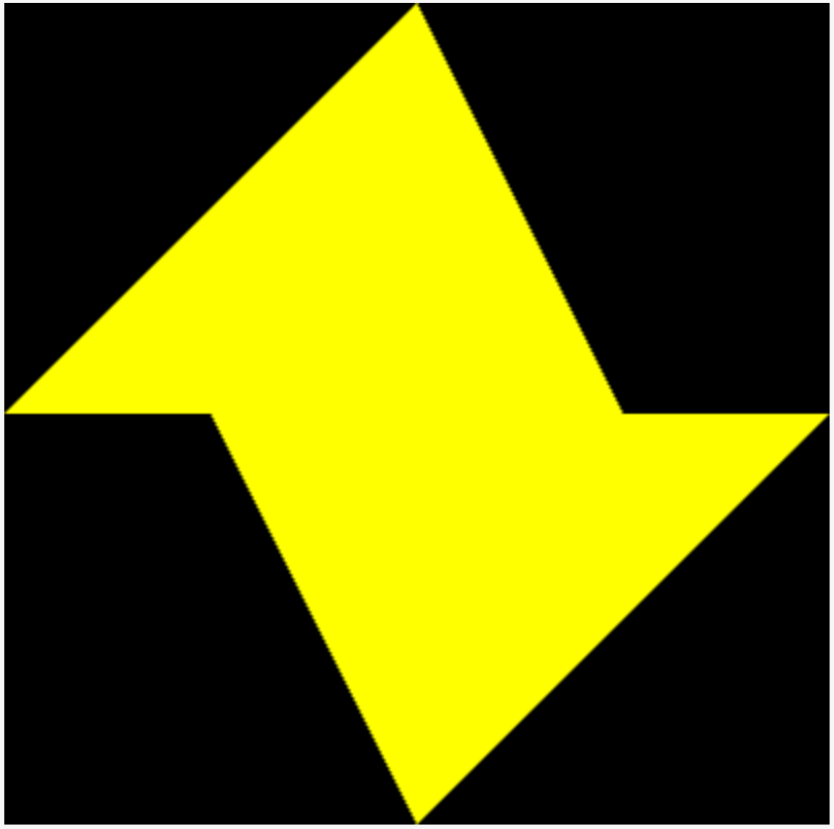
Change the array sizes

```
86    // we need to put the vertices into a buffer so we can
87    // block transfer them to the graphics hardware
88    var trianglePosBuffer = gl.createBuffer();
89    gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
90    gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertexPos), gl.STATIC_DRAW);
91      trianglePosBuffer.itemSize = 3;
92      trianglePosBuffer.numItems = 6;
```

```
104    // now we draw the triangle(s)
105    // we tell GL what program to use, and what memory block
106    // to use for the data, and that the data goes to the pos
107    // attribute
108    gl.useProgram(shaderProgram);
109    gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
110    gl.vertexAttribPointer(shaderProgram.vertexPositionAttribute,
    trianglePosBuffer.itemSize, gl.FLOAT, false, 0, 0);
111    gl.drawArrays(gl.TRIANGLES, 0, trianglePosBuffer.numItems);
```

Two triangles

Output



How do we color them differently?

Color per vertex

Add an **attribute** for each vertex

so we can pass a color for each

Have the vertex shader output the color

varying variable for fragment shader

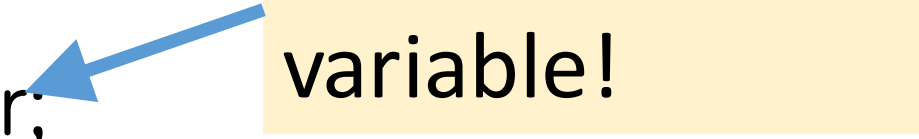
Have the fragment shader input the color

A (boring) Fragment Shader

```
void main(void)
{
        gl_FragColor = vec4(0.0, 1.0, 1.0, 1.0);
}
```

A (less boring) Fragment Shader

```
precision highp float;
varying vec3 outColor;

void main(void)
{
        gl_FragColor = vec4(outColor, 1.0);
}
```



A (less boring) Fragment Shader

```
precision highp float;
varying vec3 outColor;

void main(void)
{
        gl_FragColor = vec4(outColor, 1.0);
}
```

Required so the shaders can talk

Connecting Shaders

varying variables connect shaders

the output of a vertex shader becomes
the input to a fragment shader

The 3 vertices of a triangle are interpolated

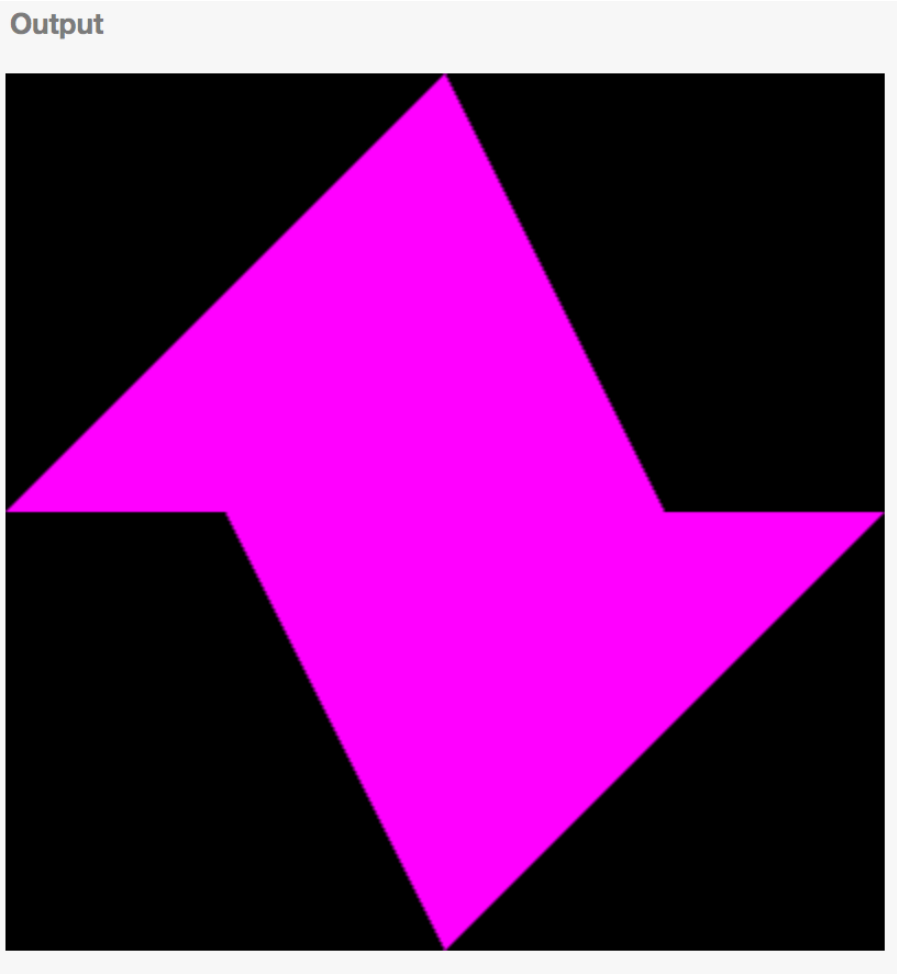
The simplest vertex shader

```
attribute vec3 pos;



void main(void) {
  gl_Position = vec4(pos, 1.0); }
}
```

The (almost) simplest vertex shader

```
attribute vec3 pos;

varying vec3 outColor;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
  outColor = vec3(1.0,0.0,1.0);
}
```

Two purple triangles



http://jsbin.com/wecaci/edit?js,output

Make color an input as well

```
attribute vec3 pos;
attribute vec3 inColor;
varying vec3 outColor;

void main(void) {
  gl_Position = vec4(pos, 1.0); }
  outColor = inColor;
}
```

Remember...

We can't pass values directly to a fragment

we don't even know what they will be!

We pass attributes of vertices

which can then pass them to fragments

Now to connect to JavaScript...

```
shaderProgram.inColor = gl.getAttribLocation(shaderProgram, "inColor");
gl.enableVertexAttribArray(shaderProgram.inColor);
```

Colors per vertex

```
 93    var vertexColors = [
 94      1.0, 1.0, 0.0,
 95      1.0, 1.0, 0.0,
 96      1.0, 1.0, 0.0,
 97      1.0, 0.0, 1.0,
 98      1.0, 0.0, 1.0,
 99      1.0, 0.0, 1.0
100      ];
```

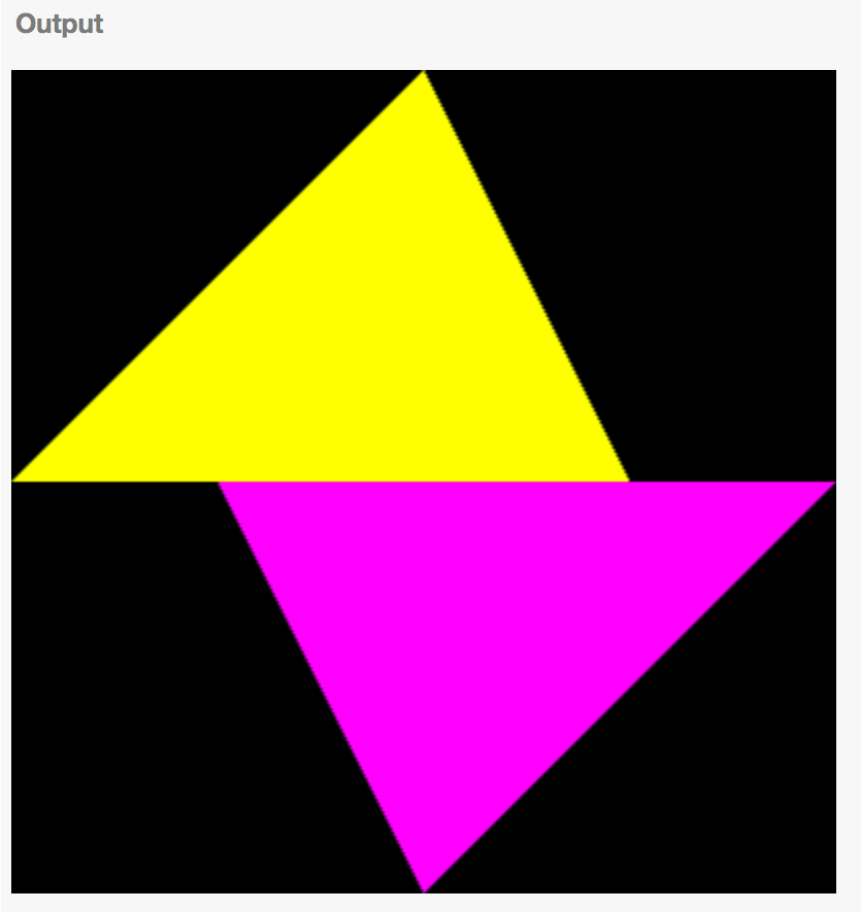
Put them in a buffer

```
110   // a buffer for colors
111   var colorBuffer = gl.createBuffer();
112   gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);
113   gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(vertexColors),
    gl.STATIC_DRAW);
114     colorBuffer.itemSize = 3;
115     colorBuffer.numItems = 6;
```

When we draw, use 2 buffers

```
132   gl.bindBuffer(gl.ARRAY_BUFFER, colorBuffer);
133   gl.vertexAttribPointer(shaderProgram.inColor, colorBuffer.itemSize,
    gl.FLOAT, false, 0, 0);
134   gl.bindBuffer(gl.ARRAY_BUFFER, trianglePosBuffer);
135   gl.vertexAttribPointer(shaderProgram.vertexPositionAttribute,
    trianglePosBuffer.itemSize, gl.FLOAT, false, 0, 0);
136   gl.drawArrays(gl.TRIANGLES, 0, trianglePosBuffer.numItems);
```

Two triangles...



http://jsbin.com/digupi/edit?js,output

Apply a transformation

One transformation for the triangle group

It is constant over the “drawArrays” call

This is a **uniform** variable

http://jsbin.com/tirapu/19/edit?js,output

Simplifying the Code

There is stuff you do over and over and …

Write it once and use it often
Or let someone else write it once…

This is where **twgl** comes in

Compile two vertex programs

For each…

- run the compiler
- check for errors

Link them together

Attach to the attributes

Set up to specify the uniforms

Do it by hand...

```
// first compile the vertex shader
var vertexShader = gl.createShader(gl.VERTEX_SHADER);
gl.shaderSource(vertexShader,vertexSource);
gl.compileShader(vertexShader);

if (!gl.getShaderParameter(vertexShader, gl.COMPILE_STATUS)) {
        alert(gl.getShaderInfoLog(vertexShader));
        return null;
    }

// now compile the fragment shader
var fragmentShader = gl.createShader(gl.FRAGMENT_SHADER);
gl.shaderSource(fragmentShader,fragmentSource);
gl.compileShader(fragmentShader);

if (!gl.getShaderParameter(fragmentShader, gl.COMPILE_STATUS)) {
        alert(gl.getShaderInfoLog(fragmentShader));
        return null;
    }

// OK, we have a pair of shaders, we need to put them together
// into a "shader program" object
var shaderProgram = gl.createProgram();
gl.attachShader(shaderProgram, vertexShader);
gl.attachShader(shaderProgram, fragmentShader);
gl.linkProgram(shaderProgram);

if (!gl.getProgramParameter(shaderProgram, gl.LINK_STATUS)) {
  alert("Could not initialise shaders");
}

// with the vertex shader, we need to pass it positions
// as an attribute - so set up that communication
  shaderProgram.vertexPositionAttribute = gl.getAttribLocation(shaderProgram, "pos");
  gl.enableVertexAttribArray(shaderProgram.vertexPositionAttribute);

  shaderProgram.inColor = gl.getAttribLocation(shaderProgram, "inColor");
  gl.enableVertexAttribArray(shaderProgram.inColor);

// this gives us access to the matrix uniform
shaderProgram.transf = gl.getUniformLocation(shaderProgram,"transf");
```

Do it with twgl

```
var shaders =
twgl.createProgramInfo(gl, ["vs", "fs"]);
```

Yes, one line...

And it grabs the string from script tags so they are separate from your JS program.

But the documentation is terrible.

How about those shaders...

They do very specific things

    you need to understand the pipeline

They have 3 kinds of weird variables

    you need to understand the model

They are written in a cool language

    you'll pick it up quickly

The language has a bunch of useful stuff

    look at the quick reference card

Learning Shader Programming

Connecting your program to shaders is hard

So, don't bother... (yet)

Use a Shader IDE that lets you focus on shaders

Gives you an object, a program, ...

Some things about GLSL

Very strongly typed

```
float x = 1;   // error! integer and float
```

Cool “sub-vector” access:

```
vec3 v;
```

v.xy (a 2-vector)

vec4(v,1) (a 4-vector)

vec4(v.xy, v.zx)

More cool stuff about GLSL

Lots of handy math functions

They know it's for graphics!

Limited control structures

parallel execution means all the same

Conditional functions

step, softstep, …