Computer Graphics (COMP0027) 2022/23

OpenGL

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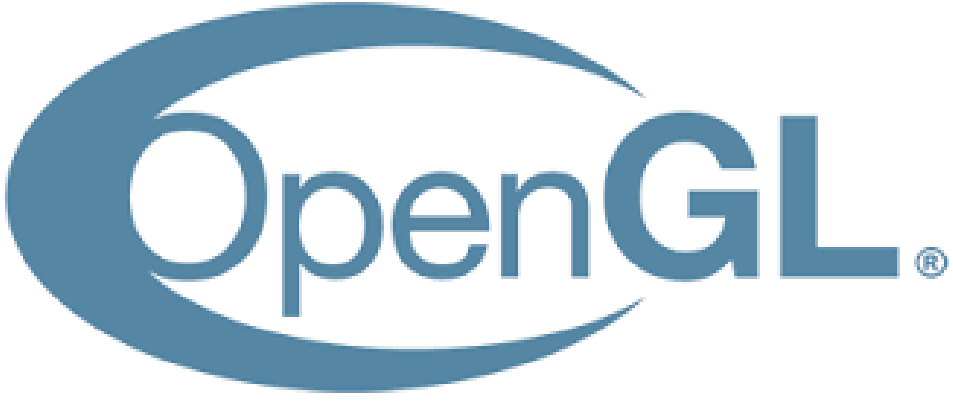
UCL

Overview

- OpenGL idea
- Pipeline overview
- Individual stages
- Example code
- Deprecated OpenGL



OpenGL: Hard or easy?

- Old-fashioned (deprecated) GL is didactical
- Easy to explain
- But
  - This is not what is out there
  - This is not what we will do here
  - We will try to see how it is in 2017

OpenGL Philosophy

- Platform and language-independent
- Rendering-only
- Aims to be real-time
- Supports Graphics Hardware (GPUs)
- State system
- Client-server system
- Extendable (OpenGL Extensions)

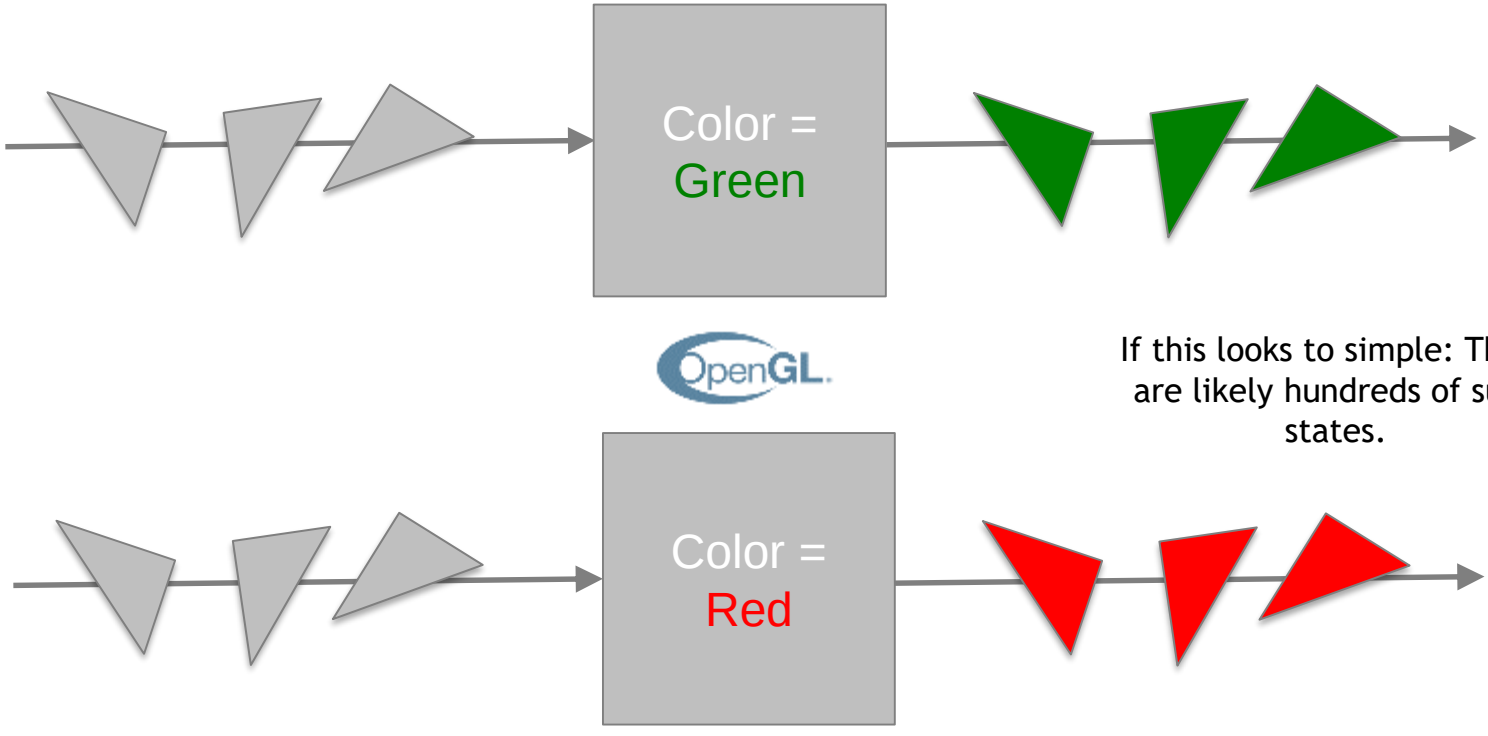
OpenGL

- OpenGL is
  - .. a specification to create images in a frame buffer
  - .. an API to access that mechanism
  - .. well specified

OpenGL

- OpenGL is not
  - .. a window system
  - .. a user interface
  - .. a display mechanism
  - .. a library
  - .. modeling cameras, materials or lights

What is a state system?

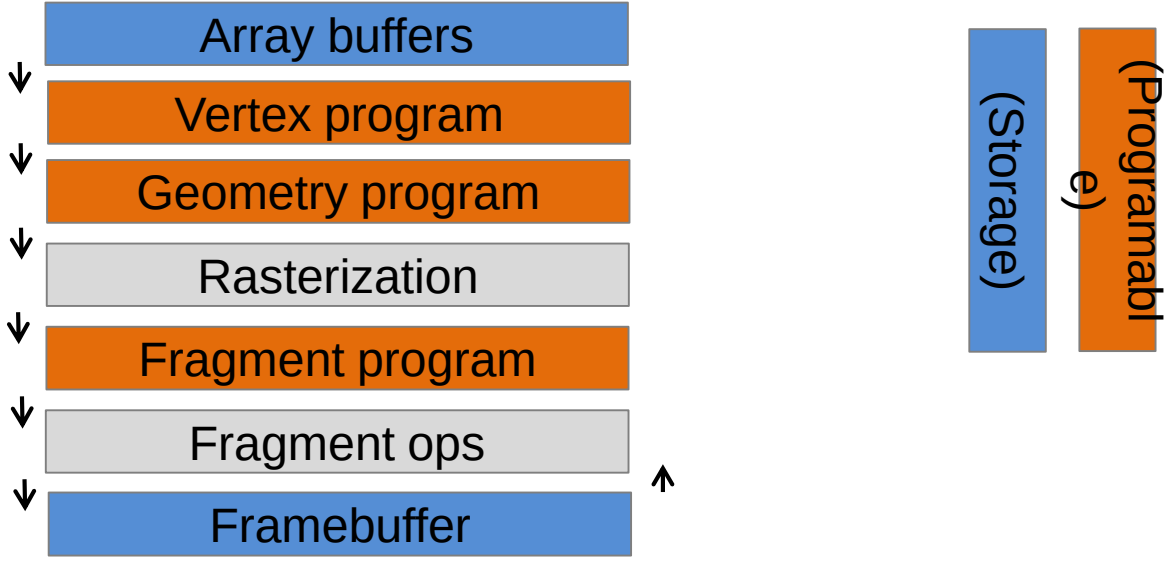


If this looks to simple: There are likely hundreds of such states.

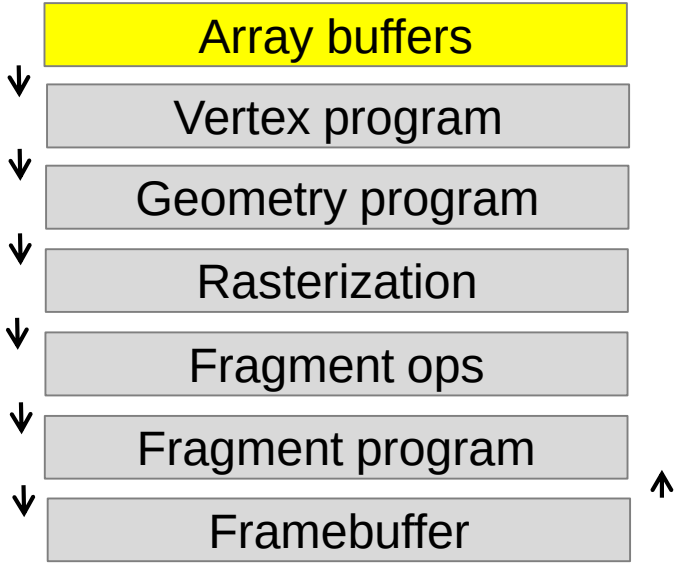
How to program OpenGL

- We will here use WebGL in JavaScript
- A subset of the specification
  - More restricted (-)
  - More modern (+)
  - Runs on all devices (+)
  - Easy to run and compile (+)

OpenGL Pipeline



The OpenGL Pipeline


Array buffers
Vertex program
Geometry program
Rasterization
Fragment ops
Fragment program
Framebuffer

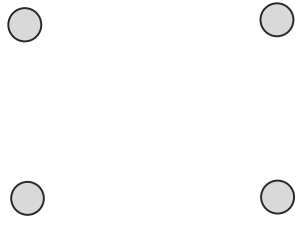
Array Buffers

- Just arrays of memory on the GPU
- It will take batches of data from those arrays and feed them into the pipeline
- Instead of using `new()` or `malloc()` we use gl functions like `bufferData()` to manage these.
- For now, assume they define vertices of a polygonal mesh
- Don’t upload every frame. That is slow.

Array Buffer: Example 1

```
{0, 0, 2, 0, 2, 1, 0, 1}
{x, y, x, y, x, y, x, y}
```

Vertex 0 Vertex 1 Vertex 2 Vertex 3



Array Buffer: Example 2

```
{0, 0,   2, 0,   2, 1,   0, 1}
{x, y,   x, y,   x, y,   x, y}

{0, 0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 0}
{r, g, b, r, g, b, r, g, b, r, g, b}
```

Color 0 Color 1 Color 2 Color 3

Array Buffer Example Uses

- Positions
- Colors
- Normals
- (Multiple) u, v texture coords
- Motion flow
- Tangent spaces for bump mapping
- Fully flexible .. no semantic!

Array Buffer Code

```
var positionBuffer = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, positionBuffer);
gl.bufferData(
 gl.ARRAY_BUFFER,
 new Float32Array(getVertices()),
 gl.STATIC_DRAW);
```

Element Arrays

- Special type of arrays
- They are used to compose vertices into polygonal primitives
- Only triangles in modern GL

Element Arrays: Example

```
{0, 0,   2, 0,   2, 1,   0, 1}
{x, y,   x, y,   x, y,   x, y}

{0, 0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 0}
{r, g, b, r, g, b, r, g, b, r, g, b}

{0, 1, 2, 1, 2, 3}
{a, b, c, a, b, c}
```

Element array: Code

```
var indexBuffer = gl.createBuffer();
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, indexBuffer);
gl.bufferData(
 gl.ELEMENT_ARRAY_BUFFER,
 new Uint16Array(getIndices()),
 gl.STATIC_DRAW);
```

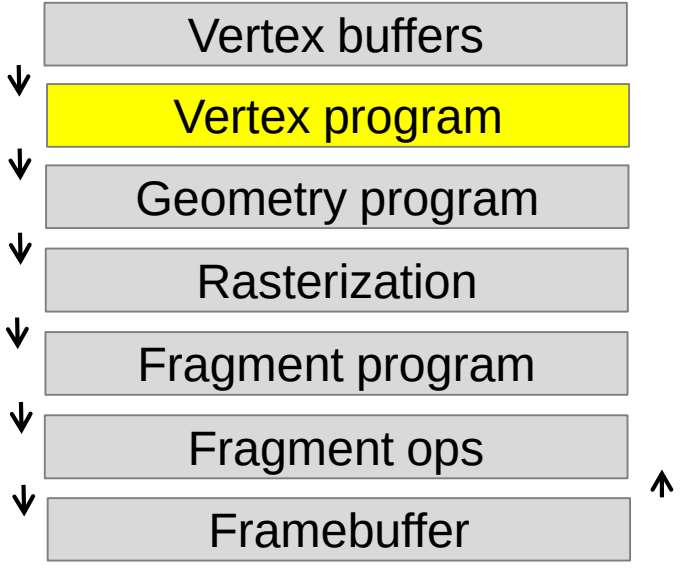
DEMO

Definitions and changing a few array values

Issuing a draw call

- Issue draw call with an element array buffers

```
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, tri);
gl.drawElements(gl.TRIANGLES,
 tri.numItems,
 gl.UNSIGNED_SHORT,
 0);
```


Vertex buffers
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Vertex program

- Also called “shader”
- There are so many things that can happen to a vertex, that this needs a full programming language: GLSL
- Executed
  - at every vertex
  - in parallel

Vertex program

- Input:
  - Vertices from array buffers now called **attributes**
  - Some **uniforms** that are the same for all vertices
- Output:
  - The clip space **coordinate** of that vertex (before division with w)
  - Every VS output you plan to use per-pixel called **varyings**

What array goes into which attribute?

- Everything possible
- Programmable mapping
- Example for 6 positions of cube:

```
   gl.bindBuffer(gl.ARRAY_BUFFER, buffer);
   var location = gl.getAttribLocation(shaderProgram, "position”);
gl.enableVertexAttribArray(location);
gl.vertexAttribPointer(location, 6, gl.FLOAT, false,  0,   0);
```

Vertex program: Example

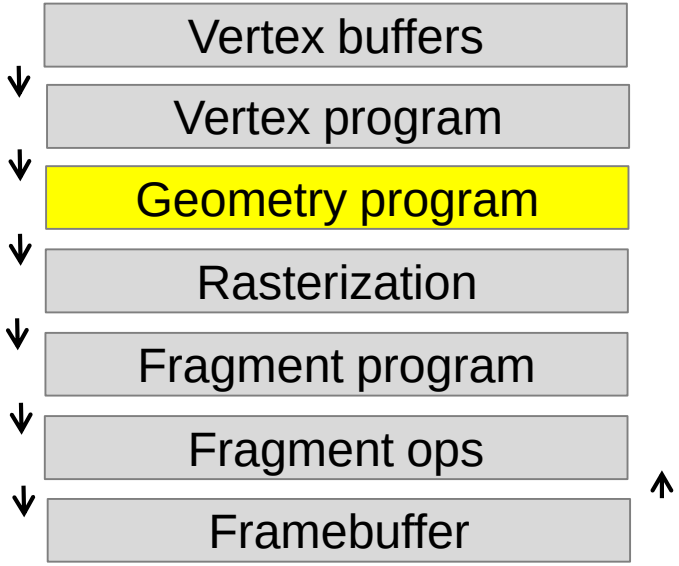
- Input:
  - attribute `position`
  - uniform `direction`
  - uniform matrix
- Output:
  - Clip-space coordinate
  - varying `color`

```
uniform vec3 direction;
uniform mat4 matrix;
attribute vec3 position;
varying color;

void main() {
 gl_Vertex = matrix * position
 color = vec3(dot(position, direction);
}
```

DEMO

Code-walk VS, adding a bit of animation via uniform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Geometry programs

- So far have processed single **vertices**, not **primitives**
- Remember: Use element array to turn vertices into primitives
- **Geometry** programs can change entire primitives
- Not yet in WebGL implementations. So no demo.

Geometry program

- Input:
  - All attributes (e.g. 3) that form a primitive
- Output:
  - One or multiple new primitives

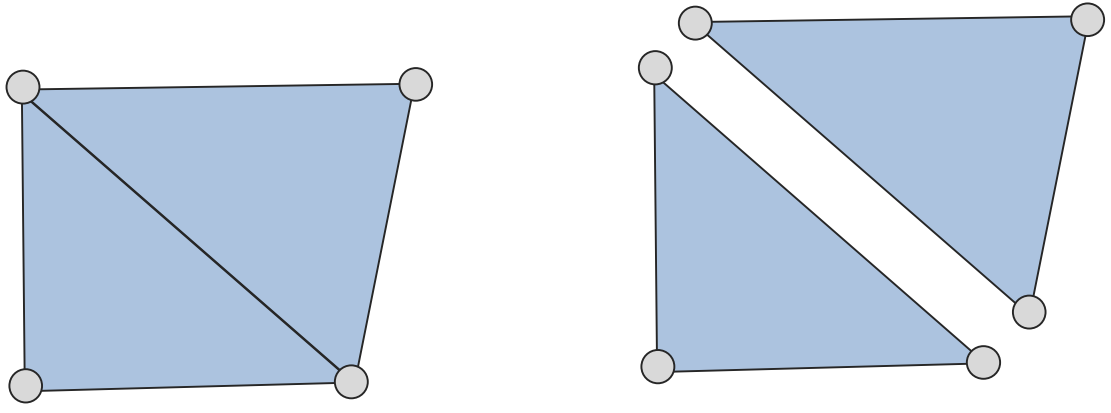
Geometry program: Example

- Input:
  - Tri positions
  - Tri normals
  - A magic jump
- Output:
  - The same, just changed

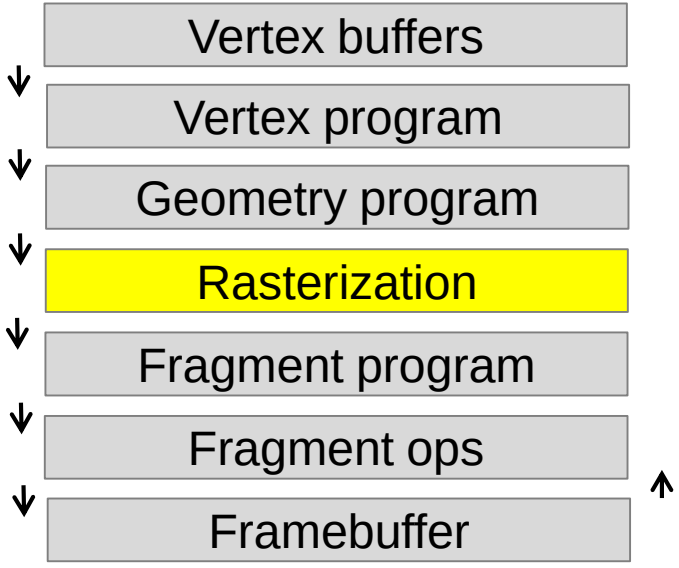
```
in vec3 ip[3]; in vec3 in[3];
out vec3 op[3]; out vec3 on[3];
uniform float jump;

void main() {
 for(int i = 0; i<3; i++) {
  op[i] = ip[i] + jump * in[i];
 }
 on = in;
}
```

Geometry program: Example result



Quiz: Why is this so interesting, could a VS do that?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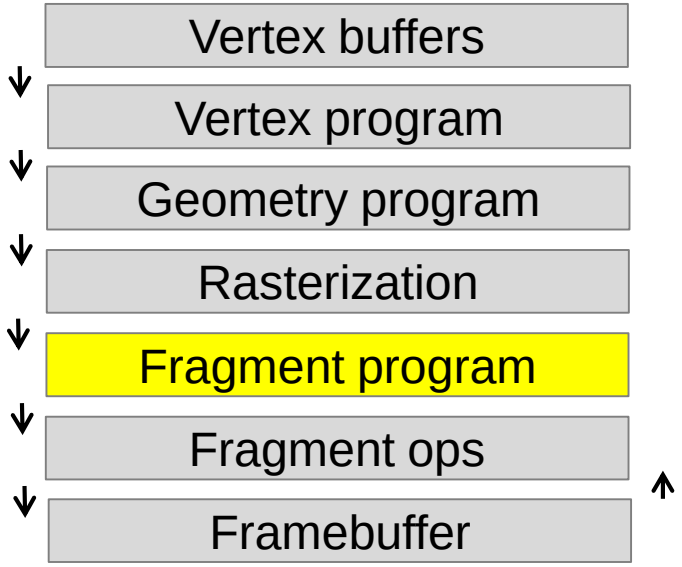
Rasterization

- Does what you learned
  - Clipping
  - Projective division
  - Culling
  - (perspective) Interpolation
- Can turn on and off culling and some other things

DEMO

Culling on and off (without depth buffering)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Fragment program

- The most important one
- Executed for every “fragment” (lots of)
- Without antialiasing a fragment is a pixel
- With anti-aliasing, multiple fragments go into a pixel

Fragment program

- Input
  - All the varyings the geometry shader outputs
  - The fragment coordinate
  - Uniforms
  - Samplers (GL name for textures)
- Output
  - A fragment color `gl_FragColor`
  - Optionally, depth `gl_FragDepth`
  - Can also `discard` fragments

Fragment program: Example

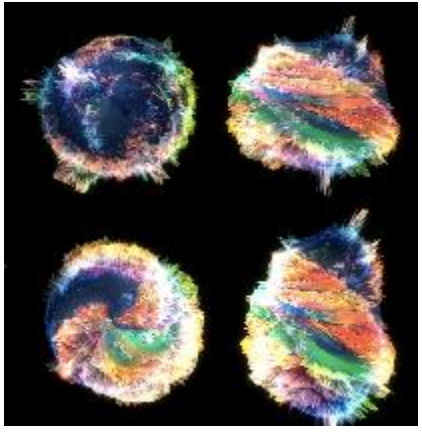
- Input:
  - varying `texCoord`
  - Sampler `texture`
- Output:
  - Color
  - Depth

```
varying vec2 texCoord;
uniform sampler2d testSampler;

void main() {
 gl_FragColor.rgb = texture(
  testSampler,
  texCoord).rgb;
 gl_FragDepth = texture(
  testSampler,
  texCoord).a;
}
```

Shader Examples



DEMO

Pixel shading code, replace with some overly simplified ones

Textures

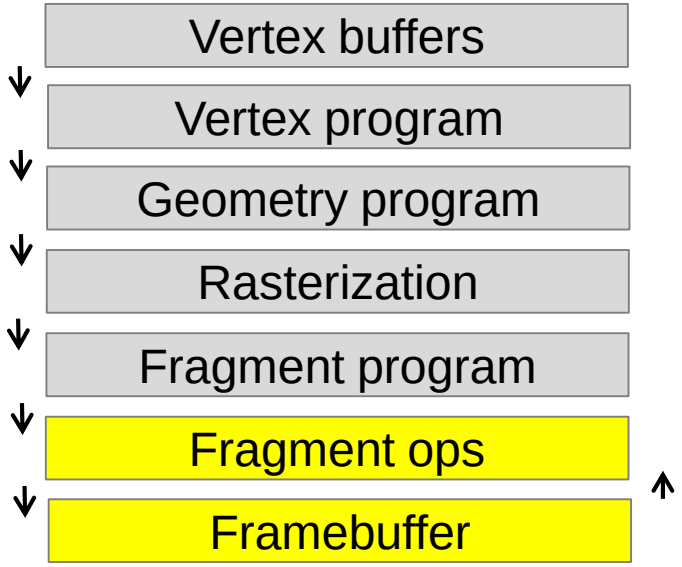
- Textures are storage objects like array buffers
- Have to allocate and fill them with specific calls
- Have the filtering modes explained in last lecture
- Read in every program stage using the function

`texture(sampler, ivec2 texCoord)` w. `texCoord` $0..1$

`texelFetch(sampler, ivec2 texCoord)` w. `texCoord` $0..N$

DEMO

Texture allocation & turning it on in fragment program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Framebuffer

- How fragment colors affects the frame buffer color
- Configurable, but nor programmable
  - Depth test
  - Blending
  - Multiple render targets / render-to-texture

Depth test

- As you would expect
- Need to allocate and clear the depth buffer to use it
- *Off* by default

DEMO

Turing on and off depth test (with culling off, ideally)

Blending

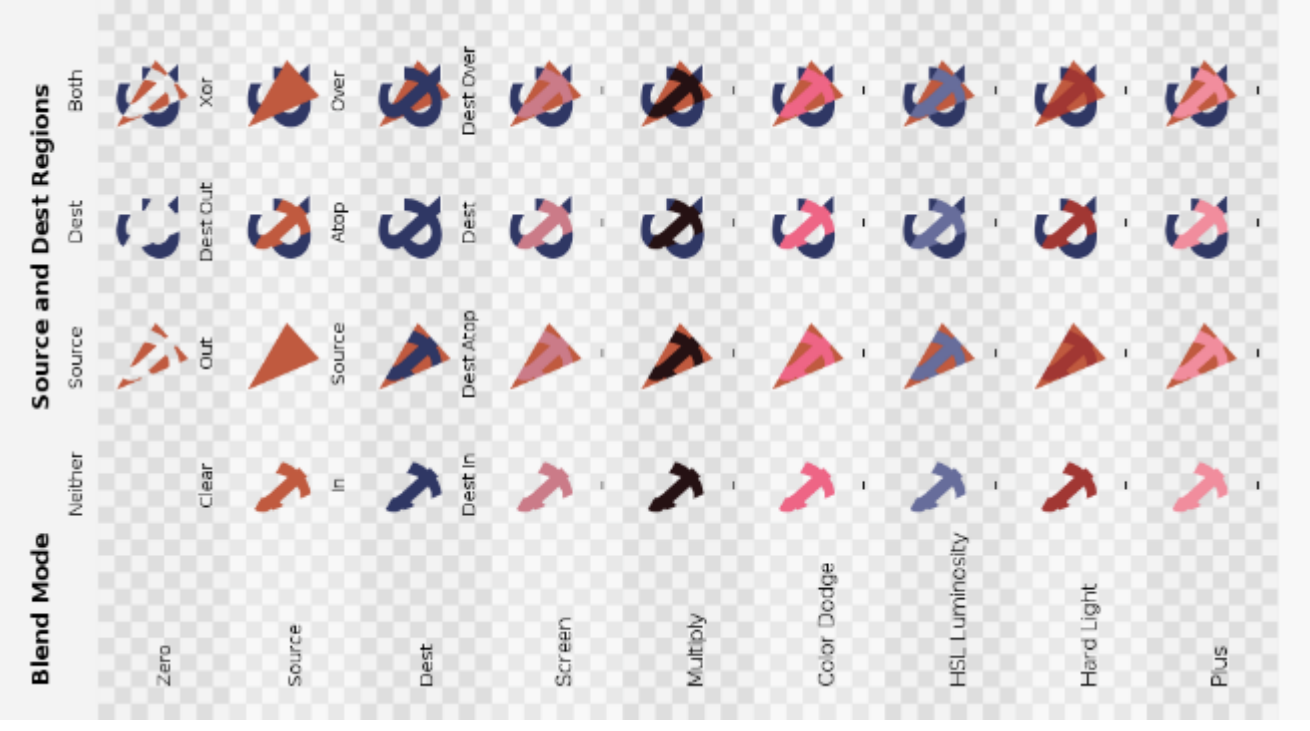
- If depth test passes, GL does not just replace the color such as we do in our coursework
- Instead, it evaluates an equation involving old and new color, including alpha

Blending

```
x_out = x_op(x_src * x_SrcFac, x_dest * x_DestFac)
```

- `x` can be RGB or ALPHA
- `x_out` result
- `x_src` fragment program output
- `x_dest` current frame buffer content
- Can configure `x_op`, `x_src` and `x_dest`

Blending: Example



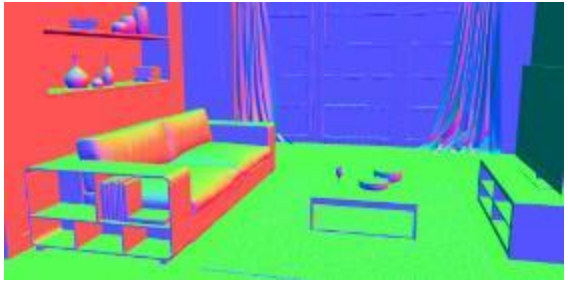
DEMO

Additive blending

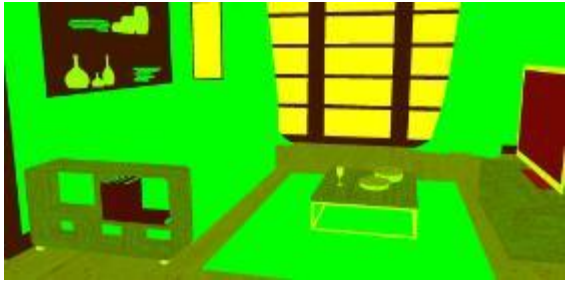
Multiple render targets

- No reason to output only a single color
- Can output multiple colors
- Each goes into its own framebuffer
- This frame buffer can the again be used as input texture in a new shader
- Example: Deferred shading
- First fill framebuffer, then only shade what you see

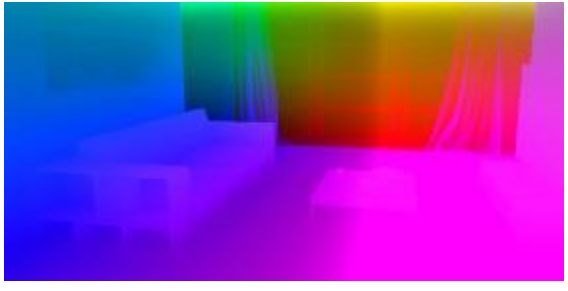
Multiple render targets



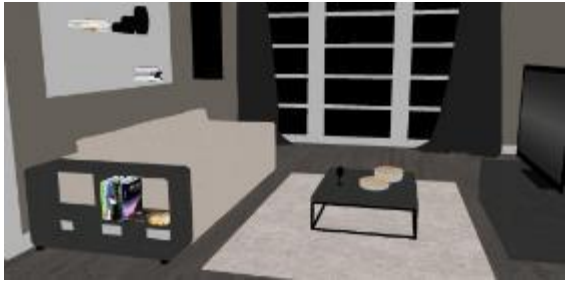
Position



Material



Normal



Reflectance

Deprecated OpenGL

- Modern GL does not do some things old GL did:
  - `glVertex` / `glColor` / …
  - `glMatrix` & Matrix stack
  - `glLight`
  - `glMaterial`
  - `GL_QUAD` / `GL_POLYGON`
- Will make many tutorials or courses out there break

Conclusion

- OpenGL is an specification
- Implements the rasterization pipeline we know
- Allows to configure many stages
- Allows to program some stages
- It turns primitives from buffers into a frame buffer using other buffers and programs