Programming with OpenGL Part 3: Shaders

CS 432 Interactive Computer Graphics
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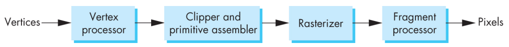
Objectives

- Simple Shaders
  - Vertex shader
  - Fragment shaders
- Programming shaders with GLSL
- Finish first program


Vertices → Vertex processor → Clipper and primitive assembler → Rasterizer → Fragment processor → Pixels

Vertex Shader Applications

- Moving vertices
  - Transformations
    - Modeling
    - Projection
  - Morphing
  - Wave motion
  - Fractals
  - Particle systems
- Lighting
  - More realistic shading models
  - Cartoon shaders

Fragment Shader Applications

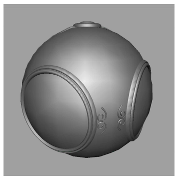
Per fragment lighting calculations

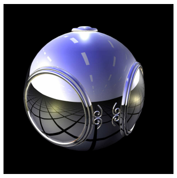
per vertex lighting

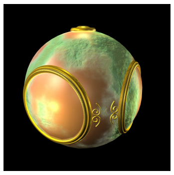
per fragment lighting

Fragment Shader Applications

Texture mapping


smooth shading


environment mapping


bump mapping

Writing Shaders

- First programmable shaders were programmed in an assembly-like manner
- OpenGL extensions added for vertex and fragment shaders
- Cg (C for graphics) C-like language for programming shaders
  - Works with both OpenGL and DirectX
  - Interface to OpenGL complex
- OpenGL Shading Language (GLSL)

GLSL

- OpenGL Shading Language
- Part of OpenGL 2.0 and up
- High level C-like language
- New data types
  - Matrices
  - Vectors
  - Samplers
- As of OpenGL 3.1, application ***must*** provide shaders

Simple Vertex Shader

input from application (GLSL 1.5)

```
in vec4 vPosition;
void main(void)
{
   gl_Position = vPosition;
}
```

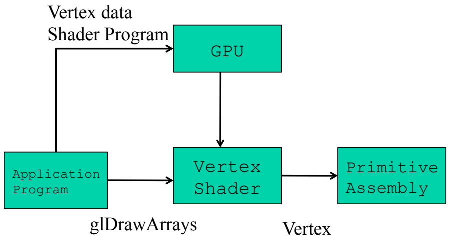
must link to variable in application

Simple pass-through

built in variable

Use “attribute vec4 vPosition” for GLSL 1.4

Execution Model

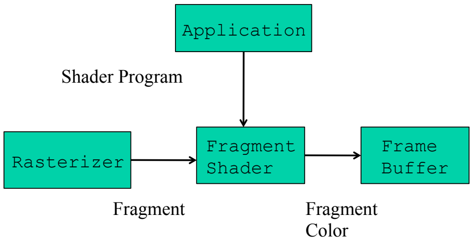


Simple Fragment Program

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

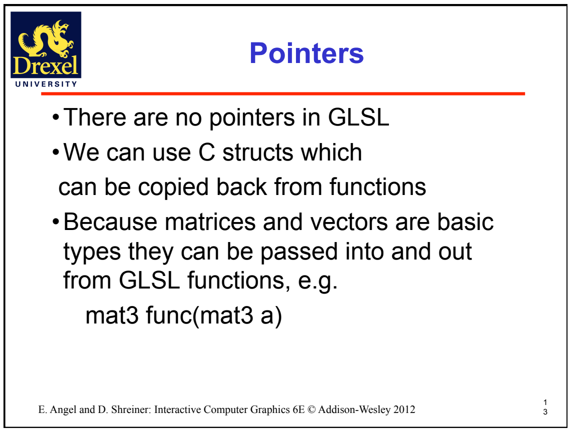
Every fragment simply colored red

Execution Model



Data Types

- C types: int, float, bool, uint, double
- Vectors:
  - float vec2, vec3, vec4
  - Also int (ivec), boolean (bvec), uvec, dvec
- 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)



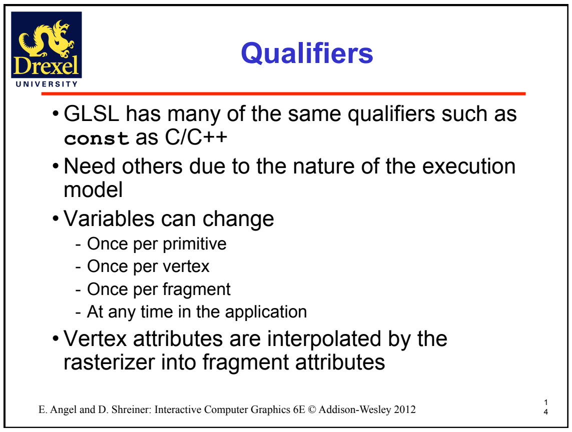
Pointers

- There are no pointers in GLSL
- We can use C structs which

can be copied back from functions

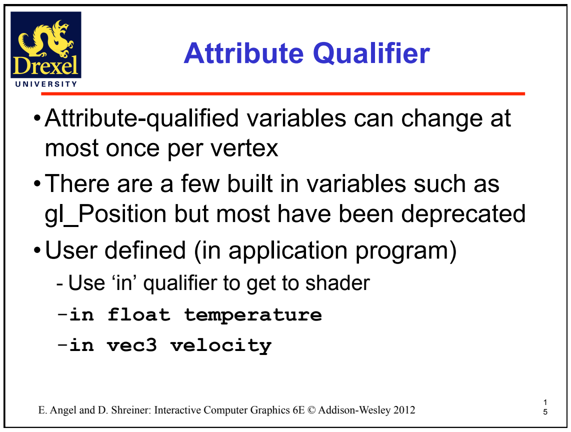
- Because matrices and vectors are basic types they can be passed into and out from GLSL functions, e.g.

    mat3 func(mat3 a)



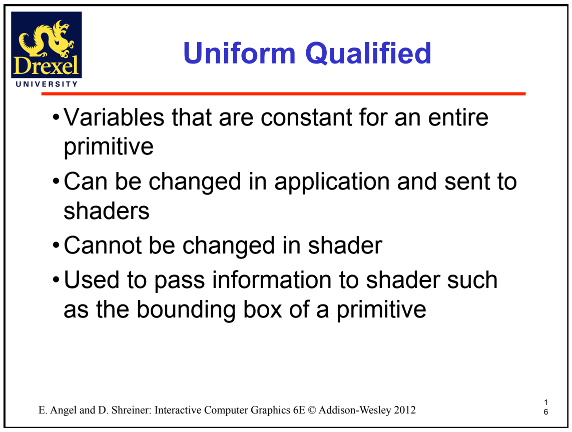
Qualifiers

- 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



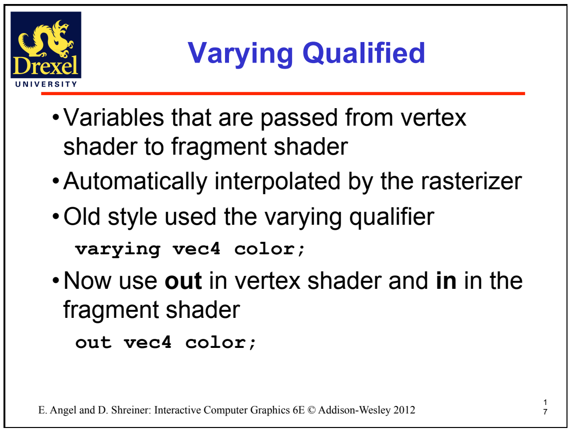
Attribute Qualifier

- Attribute-qualified variables can change at most once per vertex
- There are a few built in variables such as gl_Position but most have been deprecated
- User defined (in application program)
  - Use ‘in’ qualifier to get to shader
  - `in float temperature`
  - `in vec3 velocity`



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 bounding box of a primitive



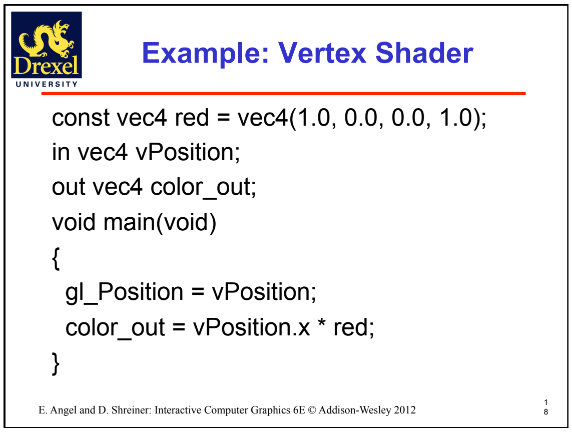
Varying Qualified

- Variables that are passed from vertex shader to fragment shader
- Automatically interpolated by the rasterizer
- Old style used the varying qualifier

```
varying vec4 color;
```

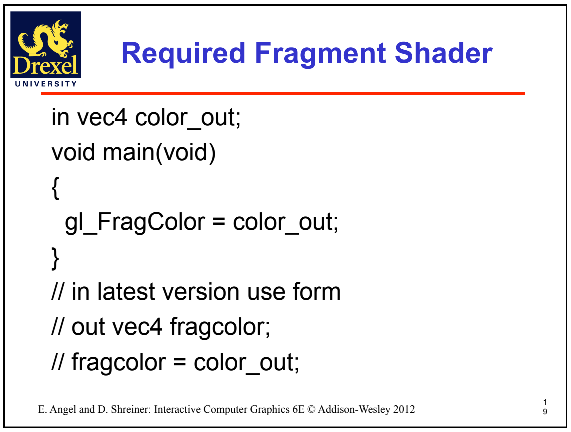
- Now use **out** in vertex shader and **in** in the fragment shader

```
out vec4 color;
```



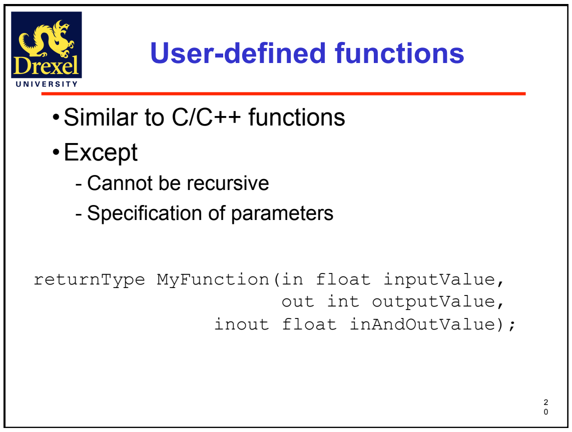
Example: Vertex Shader

```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
in vec4 vPosition;
out vec4 color_out;
void main(void)
{
  gl_Position = vPosition;
  color_out = vPosition.x * red;
}
```



Required Fragment Shader

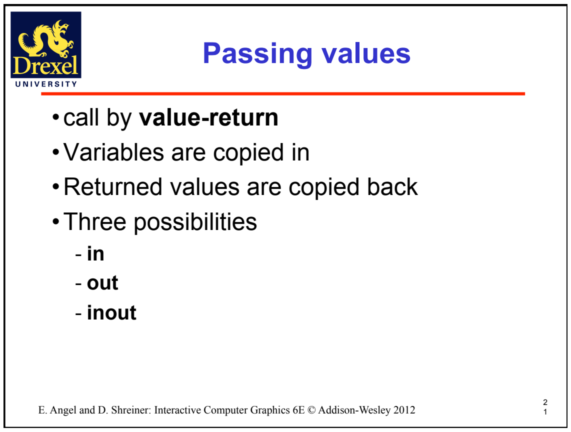
```
in vec4 color_out;
void main(void)
{
  gl_FragColor = color_out;
}
// in latest version use form
// out vec4 fragcolor;
// fragcolor = color_out;
```



User-defined functions

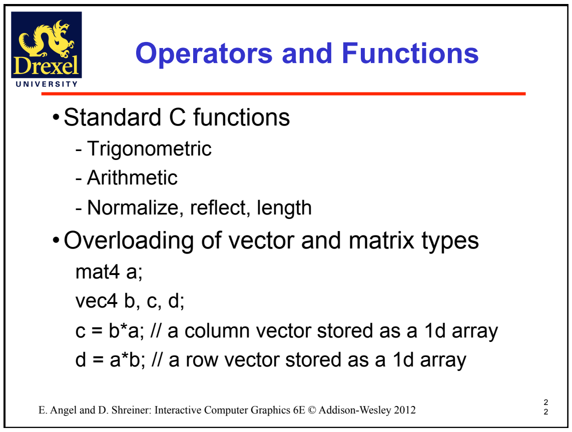
- Similar to C/C++ functions
- Except
  - Cannot be recursive
  - Specification of parameters

```
returnType MyFunction(in float inputValue,
                      out int outputValue,
                   inout float inAndOutValue);
```



Passing values

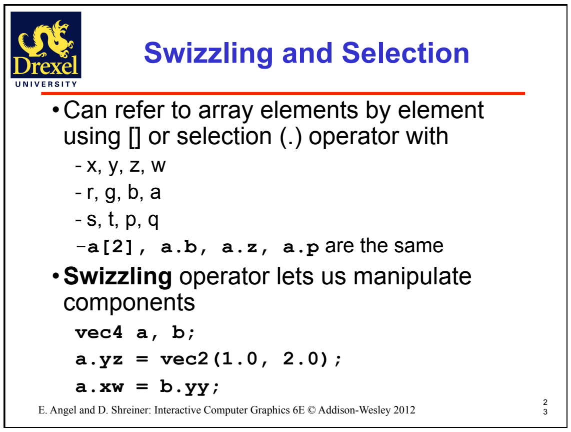
- call by **value-return**
- Variables are copied in
- Returned values are copied back
- Three possibilities
  - **in**
  - **out**
  - **inout**



Operators and Functions

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

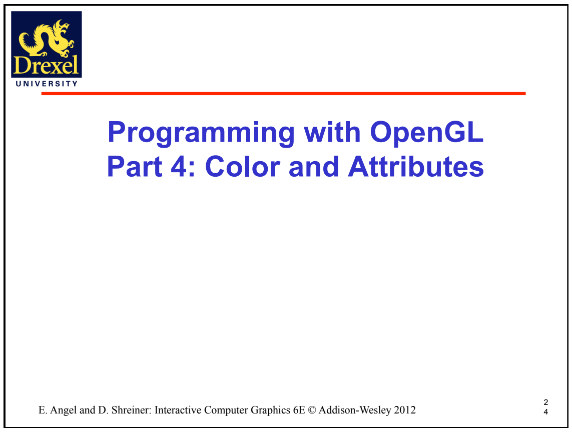
```
mat4 a;
vec4 b, c, d;
c = b*a; // a column vector stored as a 1d array
d = a*b; // a row vector stored as a 1d array
```



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** operator lets us manipulate components

```
vec4 a, b;
a.yz = vec2(1.0, 2.0);
a.xw = b.yy;
```

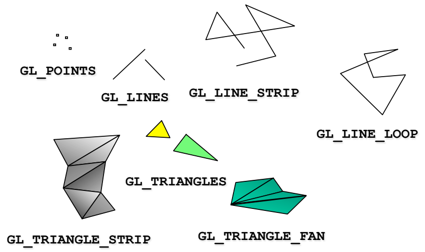


Programming with OpenGL Part 4: Color and Attributes

Objectives

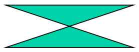
- Expanding primitive set
- Adding color
- Vertex attributes
- Uniform variables

OpenGL Primitives

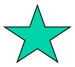


Polygon Issues

- OpenGL will only display triangles
  - Simple: edges cannot cross
  - Convex: All points on line segment between two points in a polygon are also in the polygon
  - Flat: all vertices are in the same plane
- Application program must tessellate a polygon into triangles (triangulation)
- OpenGL 4.1 contains a tessellator



nonsimple polygon



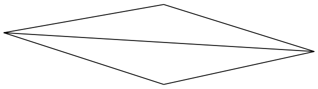
nonconvex polygon

Polygon Testing

- Conceptually simple to test for simplicity and convexity
- Time consuming
- Earlier versions assumed both and left testing to the application
- Present version only renders triangles
- Need algorithm to triangulate an arbitrary polygon

Good and Bad Triangles

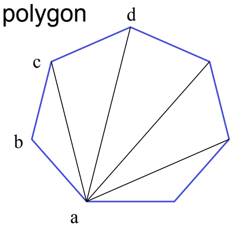
- Long thin triangles render badly



- Equilateral triangles render well
- Maximize minimum angle
- Delaunay triangulation for unstructured points

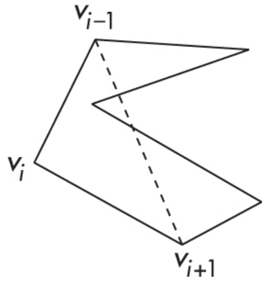
Triangularization

- Convex polygon



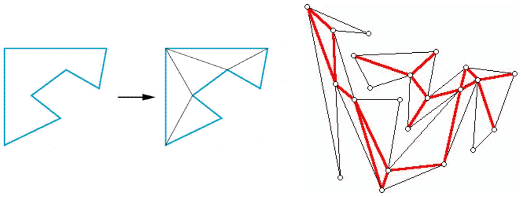
- Start with abc, remove b, then acd, ….

Non-convex (concave)



Recursive Division

- There are a variety of recursive algorithms for subdividing concave polygons

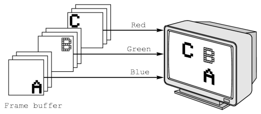


Attributes

- Attributes determine the appearance of objects
  - Color (points, lines, polygons)
  - Size and width (points, lines)
  - Stipple pattern (lines, polygons)
  - Polygon mode
    - Display as filled: solid color or stipple pattern
    - Display edges
    - Display vertices
- Only a few (glPointSize) are supported by OpenGL functions

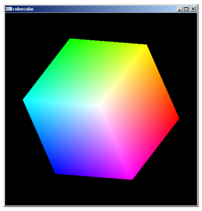
RGB color

- Each color component is stored separately in the frame buffer
- Usually 8 bits per component in buffer
- Color values can range from 0.0 (none) to 1.0 (all) using floats or over the range from 0 to 255 using unsigned bytes



Smooth Color

- Default is *smooth* shading
  - OpenGL interpolates vertex colors across visible polygons
- Alternative is *flat shading*
  - Color of first vertex determines fill color
  - Handle in shader



Setting Colors

- Colors are ultimately set in the fragment shader but can be determined in either shader or in the application
- Application color: pass to vertex shader as a uniform variable (next lecture) or as a vertex attribute
- Vertex shader color: pass to fragment shader as varying variable (next lecture)
- Fragment color: can alter via shader code