CSE 167:
Introduction to Computer Graphics
Lecture #12: GLSL

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University of California, San Diego
Spring Quarter 2015

Announcements

- Project 6 due Friday at 1pm
- Monday: Midterm discussion

- SDSU student Richard Lheureux, `rlheureux15 AT gmail.com`
  - Looking for students to join team to make system for photorealistic real-estate walkthroughs

Duke Medicine GLASS

VITRIUM

Summer 2015 Recruiting

Vitrium Health is a Duke Medicine backed healthtech startup developing software for wearable-enabled automation of surgical data capture. Our innovative solutions are the only to leverage the hands-free capability of Google Glass to address the need for a sterile automation medium in surgery.

Given the upcoming release of Glass 2.0, and Google's revised focus on Glass for enterprise, we are seeking a number of talented software engineering interns to join us this summer. Interns will work with our technical team, which has been featured in the New York Times for their pioneering use of Glass. Interns will receive weekly assignments requiring a 20 – 40 hour per week time commitment.

Minimum Qualifications › Computer Science coursework, Java Experience

Preferred Qualifications › Android, Glass, or NoSQL (database) experience

Location & hours › Remote location, 20-40 hours/week

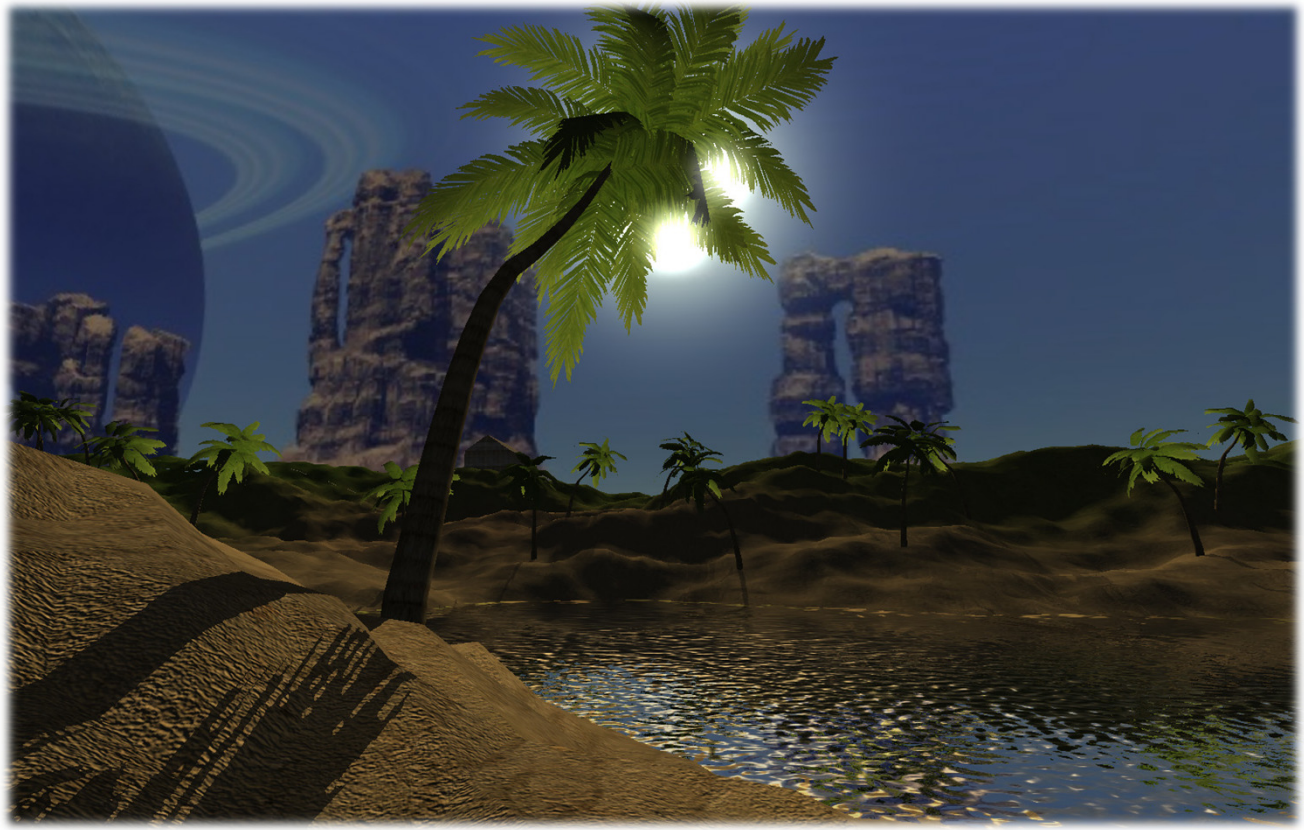
Compensation › Equity shares in the startup, deferred cash compensation + interest upon venture financing

To apply, simply email your resume to alex.payson@vitriumhealth.com

VITRIUM HEALTH » Durham, NC › (919) 923-8276 › www.vitriumhealth.com

GLSL

- Real Time 3D Demo C++/OpenGL/GLSL Engine
  http://www.youtube.com/watch?v=9N-kgCqy2xs



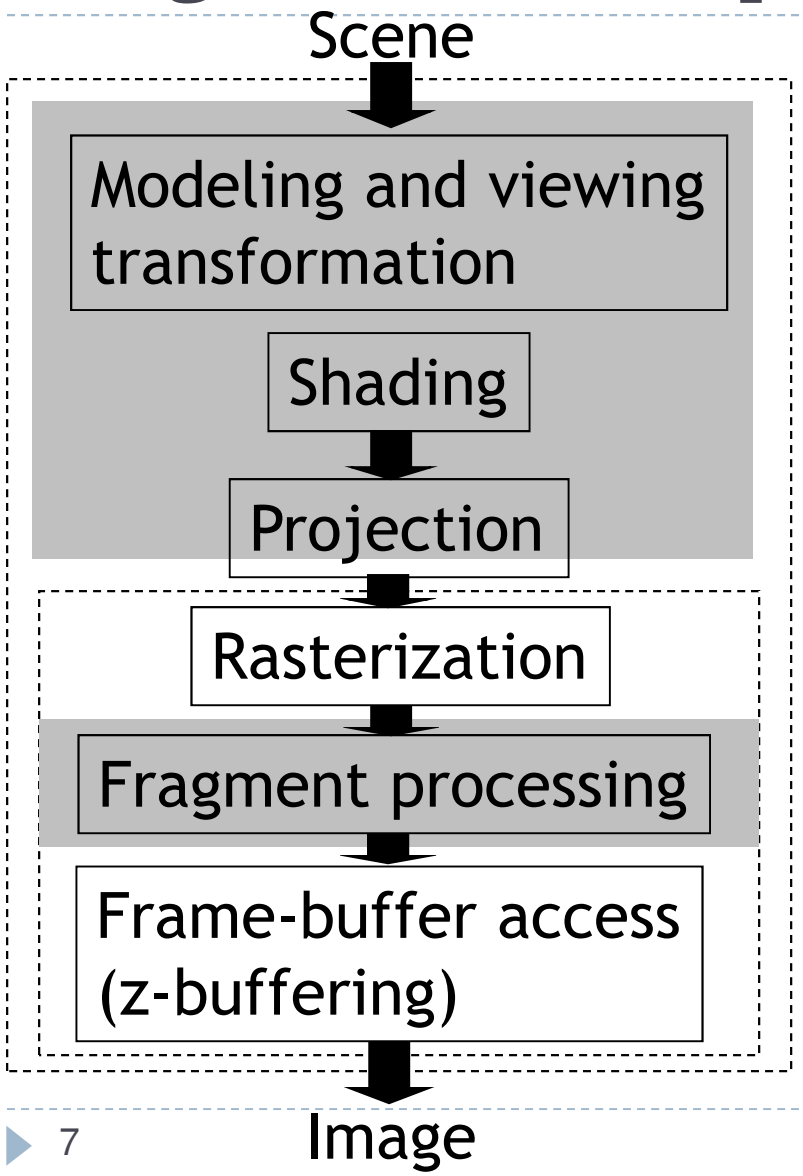
Lecture Overview

- Programmable Shaders
  - Vertex Programs
  - Fragment Programs
  - GLSL

Shader Programs

- Programmable shaders consist of shader programs
- Written in a shading language
  - Syntax similar to C language
- Each shader is a separate piece of code in a separate ASCII text file
- Shader types:
  - Vertex shader
  - Tessellation shader
  - Geometry shader
  - Fragment shader (a.k.a. pixel shader)
- The programmer can provide any number of shader types to work together to achieve a certain effect
- If a shader type is not provided, OpenGL's fixed-function pipeline is used

Programmable Pipeline



- Executed once per vertex:
  - Vertex Shader
  - Tessellation Shader
  - Geometry Shader
- Executed once per fragment:
  - Fragment Shader

Vertex Shader

- Executed once per vertex
- Cannot create or remove vertices
- Does not know the primitive it belongs to
- Replaces functionality for
  - Model-view, projection transformation
  - Per-vertex shading
- If you use a vertex program, you need to implement behavior for the above functionality in the program!
- Typically used for:
  - Character animation
  - Particle systems

Tessellation Shader

- Executed once per primitive
- Generates new primitives by subdividing each line, triangle or quad primitive
- Typically used for:
  - Adapting visual quality to the required level of detail
    - For instance, for automatic tessellation of Bezier curves and surfaces
  - Geometry compression: 3D models stored at coarser level of resolution, expanded at runtime
  - Allows detailed displacement maps for less detailed geometry

Geometry Shader

- Executed once per primitive (triangle, quad, etc.)
- Can create new graphics primitives from output of tessellation shader (e.g., points, lines, triangles)
  - Or can remove the primitive
- Typically used for:
  - Per-face normal computation
  - Easy wireframe rendering
  - Point sprite generation
  - Shadow volume extrusion
  - Single pass rendering to a cube map
  - Automatic mesh complexity modification (depending on resolution requirements)

Fragment Shader

- A.k.a. Pixel Shader
- Executed once per fragment
- Cannot access other pixels or vertices
  - Makes execution highly parallelizable
- Computes color, opacity, z-value, texture coordinates
- Typically used for:
  - Per-pixel shading (e.g., Phong shading)
  - Advanced texturing
  - Bump mapping
  - Shadows

GLSL Data Types

- float
  - vec2, vec3, vec4: floating point vector in 2D, 3D, 4D
  - mat2, mat3, mat4: 2x2, 3x3, 4x4 floating point matrix
- int
  - ivec2, ivec3, ivec4: integer vector
- bool
  - bvec2, bvec3, bvec4: boolean vector
- sampler: represent textures
  - sampler1D, sampler2D, sampler3D: 1D, 2D and 3D texture
  - samplerCube: Cube Map texture
  - sampler1Dshadow, sampler2Dshadow: 1D and 2D depth-component texture

Lecture Overview

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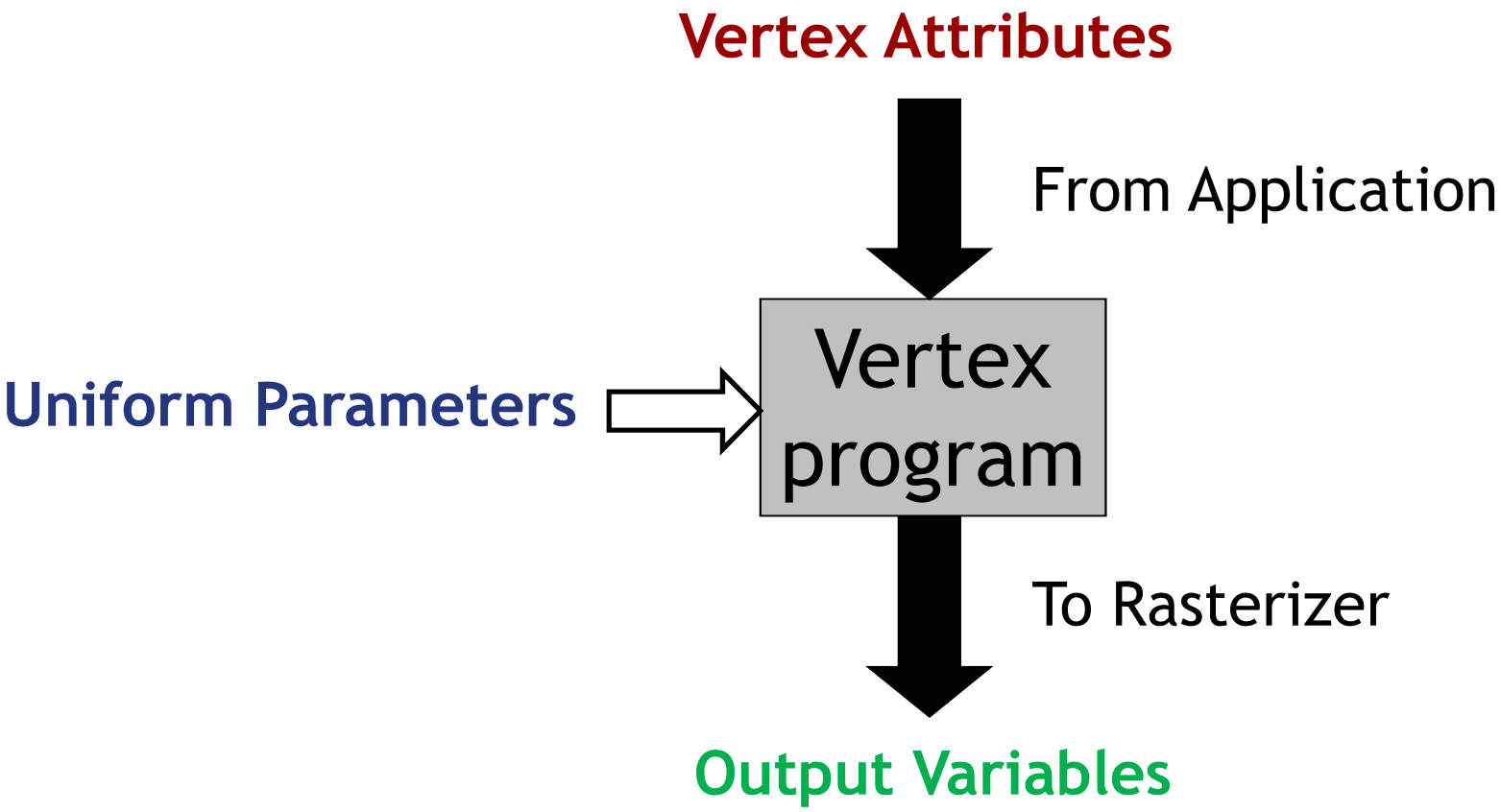
  - Vertex Programs
  - Fragment Programs
  - GLSL

Vertex Programs



Vertex Attributes

- Declared using the `attribute` storage classifier
- Different for each execution of the vertex program
- Can be modified by the vertex program
- Two types:
  - Pre-defined OpenGL attributes. Examples:
    ```
    attribute vec4 gl_Vertex;
    attribute vec3 gl_Normal;
    attribute vec4 gl_Color;
    ```
  - User-defined attributes. Example:
    ```
    attribute float myAttrib;
    ```

Uniform Parameters

- Declared by `uniform` storage classifier
- Normally the same for all vertices
- Read-only
- Two types:
  - Pre-defined OpenGL state variables
  - User-defined parameters

Uniform Parameters: Pre-Defined

- Provide access to the OpenGL state
- Examples for pre-defined variables:

```
uniform mat4 gl_ModelViewMatrix;
uniform mat4 gl_ModelViewProjectionMatrix;
uniform mat4 gl_ProjectionMatrix;
uniform gl_LightSourceParameters
        gl_LightSource[gl_MaxLights];
```

- `uniform mat4 gl_NormalMatrix; // inverse transpose model-view matrix`

Uniform Parameters: User-Defined

- Parameters that are set by the application
- Should not be changed frequently
  - Especially not on a per-vertex basis!
- To access, use `glGetUniformLocation, glUniform*` in application
- Example:
  - In shader declare
    ```
    uniform float a;
    ```
  - Set value of `a` in application:
    ```
    GLuint p;
    int i = glGetUniformLocation(p,"a");
    glUniform1f(i, 1.0f);
    ```

Vertex Programs: Output Variables

- Required output: homogeneous vertex coordinates
  `vec4 gl_Position`
- **`varying`** output variables
  - Mechanism to send data to the fragment shader
  - Will be interpolated during rasterization
  - Fragment shader gets interpolated data
- Pre-defined `varying` output variables, for example:

```
varying vec4 gl_FrontColor;
varying vec4 gl_TexCoord[];
```

  Any pre-defined output variable that you do not overwrite will have the value of the OpenGL state.
- User-defined `varying` output variables, e.g.:

```
varying vec4 vertex_color;
```

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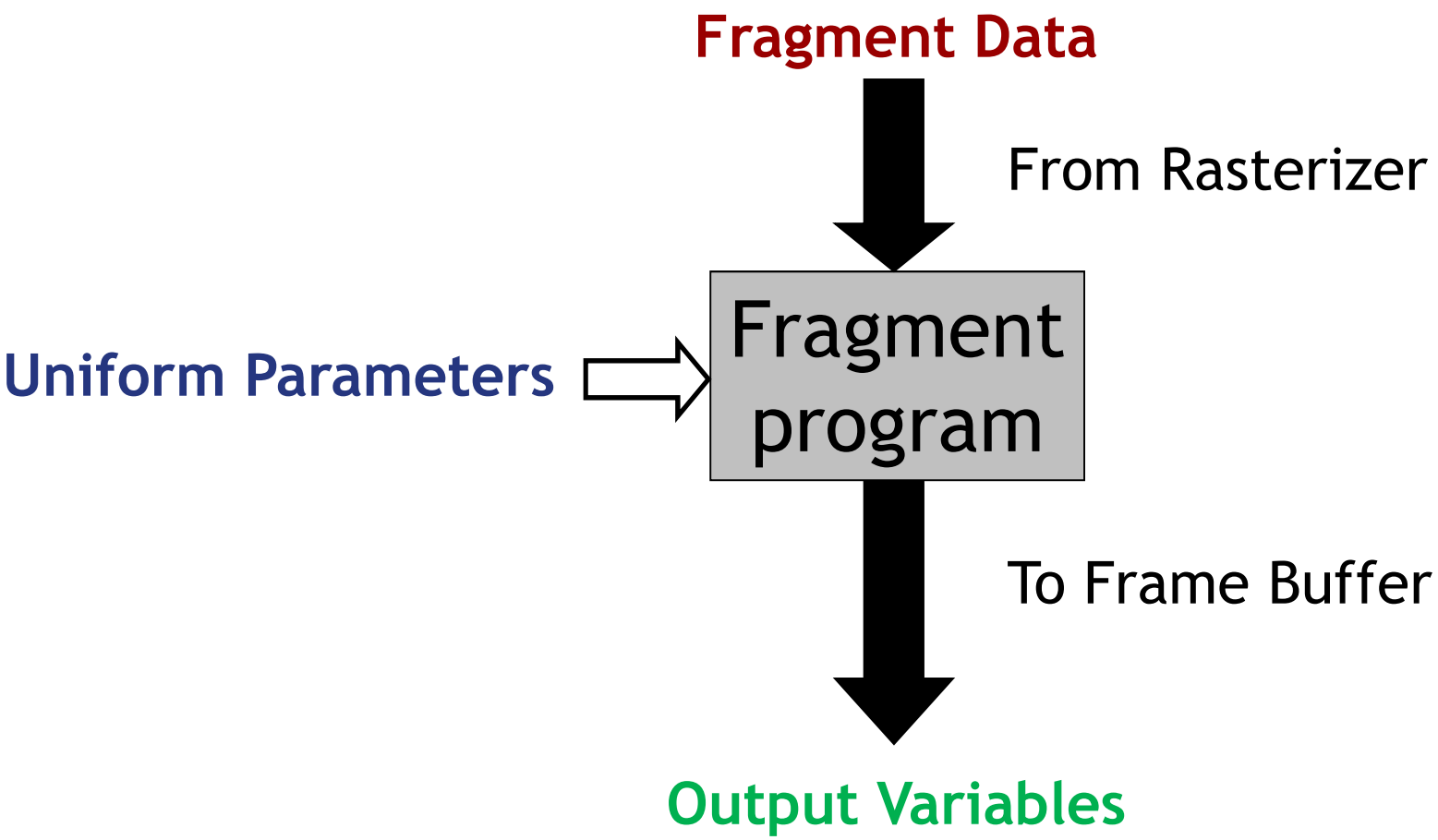
Fragment Programs



Fragment Data

- Changes for each execution of the fragment program
- Fragment data includes:
  - Interpolated standard OpenGL variables for fragment shader, as generated by vertex shader, for example:
    ```
    varying vec4 gl_Color;
    varying vec4 gl_TexCoord[];
    ```
  - Interpolated `varying` variables from vertex shader
    - Allows data to be passed from vertex to fragment shader

Uniform Parameters

- Same as in vertex programs

Output Variables

- Pre-defined output variables:
  - `vec4 gl_FragColor`
  - `float gl_FragDepth`
- OpenGL writes these to the frame buffer
- Result is undefined if you do not set these variables!

Built-In GLSL Functions

- dot: dot product
- cross: cross product
- texture2D: used to sample a texture
- normalize: normalize a vector
- clamp: clamping a vector to a minimum and a maximum

Simple GLSL Shader Example

Vertex Shader

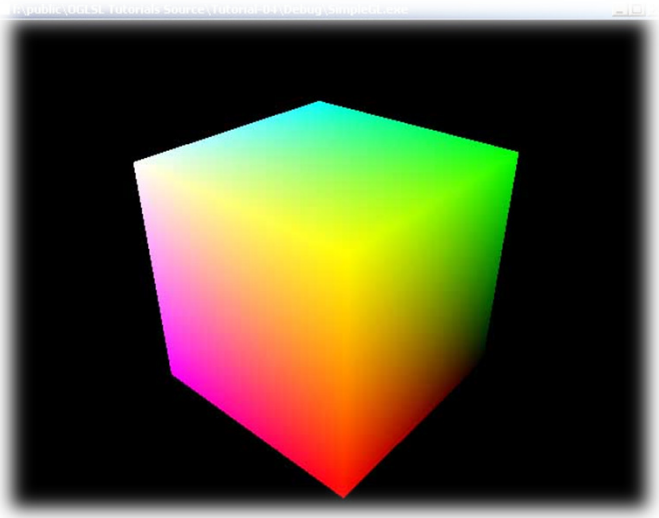
```
varying float xpos;
varying float ypos;
varying float zpos;
void main(void)
{
    xpos = clamp(gl_Vertex.x,0.0,1.0);
    ypos = clamp(gl_Vertex.y,0.0,1.0);
    zpos = clamp(gl_Vertex.z,0.0,1.0);

    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Fragment Shader

```
varying float xpos;
varying float ypos;
varying float zpos;

void main (void)
{
     gl_FragColor = vec4 (xpos, ypos, zpos, 1.0);
}
```



William H. Hsu
Department of Computing and Information Sciences, KSU

Diffuse Shader: Vertex Shader

```
varying vec3 normal;
varying vec3 vertex_to_light_vector;

void main()
{
  // Transforming the vertex
  gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;

  // Transforming the normal to ModelView space
  normal = gl_NormalMatrix * gl_Normal;

  // Transforming the vertex position to ModelView space
  vec4 vertex_in_modelview_space =
    gl_ModelViewMatrix * gl_Vertex;

  // Calculating the vector from the vertex position to the
  // light position
  vertex_to_light_vector = vec3(gl_LightSource[0].position
    vertex_in_modelview_space);
}
```

F. Rudolf, NeHe Productions

Diffuse Shader: Fragment Shader

```
varying vec3 normal;
varying vec3 vertex_to_light_vector;

void main()
{
  // Defining the material colors
  const vec4 AmbientColor = vec4(0.1, 0.0, 0.0, 1.0);
  const vec4 DiffuseColor = vec4(1.0, 0.0, 0.0, 1.0);

  // Scaling the input vector to length 1
  vec3 normalized_normal = normalize(normal);
  vec3 normalized_vertex_to_light_vector =
    normalize(vertex_to_light_vector);

  // Calculating the diffuse term and clamping it to [0;1]
  float DiffuseTerm = clamp(dot(normalized_normal,
    normalized_vertex_to_light_vector), 0.0, 1.0);

  // Calculating the final color
  gl_FragColor = AmbientColor + DiffuseColor * DiffuseTerm;
}
```

F. Rudolf, NeHe Productions

Exercise

Vertex Shader

```
void main(void)
{
   vec4 a = gl_Vertex;
   a.x = a.x * 0.5;
   a.y = a.y * 0.5;
   gl_Position = gl_ModelViewProjectionMatrix * a;
}
```

Q: What does this do?
A: Incoming x and y components are scaled with a factor 0.5;
Scaled vertex is transformed with concatenated modelview and projection matrix.

Fragment Shader

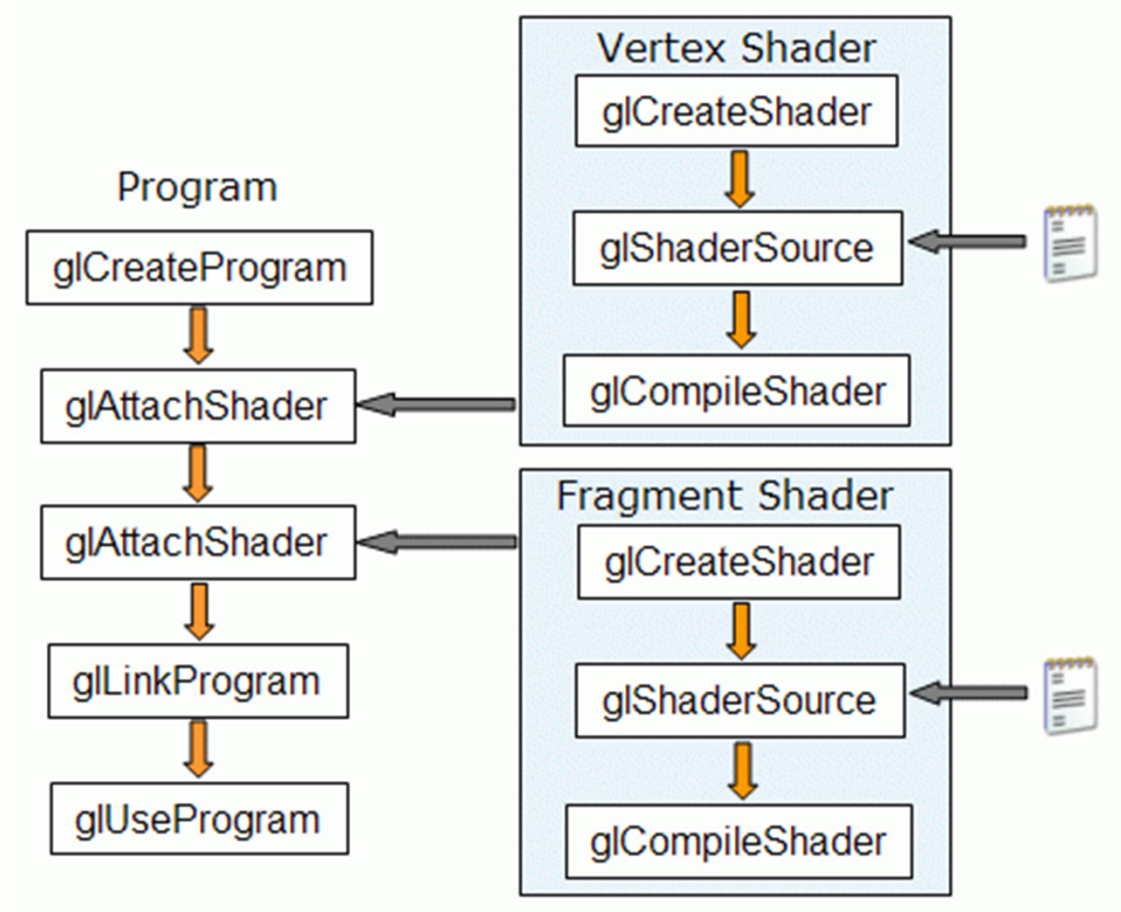
```
void main (void)
{
   gl_FragColor = vec4 (0.0, 1.0, 0.0, 1.0);
}
```

Q: What does this do?
A: Makes everything green!

M. Christen, ClockworkCoders.com

UCSD

Loading Shaders in OpenGL



Gabriel Zachmann, Clausthal University

GLShader.h

```
#ifndef GLSHADER_H
#define GLSHADER_H

#include "GL/glew.h"  // http://glew.sourceforge.net

GLuint LoadShader(const char *vertex_path, const char
*fragment_path);

#endif
```

Source: Nexcius.net

GLShader.cpp

```
#include "GLShader.h"

#include <string>
#include <iostream>
#include <fstream>
#include <vector>
#include <algorithm>

std::string readFile(const char *filePath)
{
    std::string content;
    std::ifstream fileStream(filePath, std::ios::in);
    if(!fileStream.is_open())
    {
        std::cerr << "Could not read file " << filePath << ". File does not exist." <<
           std::endl;
        return "";
    }

    std::string line = "";
    while(!fileStream.eof())
    {
        std::getline(fileStream, line);
        content.append(line + "\n");
    }

    fileStream.close();
    return content;
}
```

Source: Nexcius.net

GLShader.cpp

```
GLuint LoadShader(const char *vertex_path, const char *fragment_path)
{
    GLuint vertShader = glCreateShader(GL_VERTEX_SHADER);
    GLuint fragShader = glCreateShader(GL_FRAGMENT_SHADER);

    // Read shaders
    std::string vertShaderStr = readFile(vertex_path);
    std::string fragShaderStr = readFile(fragment_path);
    const char *vertShaderSrc = vertShaderStr.c_str();
    const char *fragShaderSrc = fragShaderStr.c_str();

    GLint result = GL_FALSE;
    int logLength;

    // Compile vertex shader
    std::cerr << "Compiling vertex shader." << std::endl;
    glShaderSource(vertShader, 1, &vertShaderSrc, NULL);
    glCompileShader(vertShader);

    // Compile fragment shader
    std::cerr << "Compiling fragment shader." << std::endl;
    glShaderSource(fragShader, 1, &fragShaderSrc, NULL);
    glCompileShader(fragShader);

    std::cerr << "Linking program" << std::endl;
    GLuint program = glCreateProgram();
    glAttachShader(program, vertShader);
    glAttachShader(program, fragShader);
    glLinkProgram(program);

    glGetProgramiv(program, GL_LINK_STATUS, &result);
    glGetProgramiv(program, GL_INFO_LOG_LENGTH, &logLength);
    std::vector<char> programError( (logLength > 1) ? logLength : 1 );
    glGetProgramInfoLog(program, logLength, NULL, &programError[0]);
    std::cerr << &programError[0] << std::endl;

    glDeleteShader(vertShader);
    glDeleteShader(fragShader);

    return program;
}
```

Source: Nexcius.net

main.cpp

```
GLuint program =
  LoadShader("shader.vert", "shader.frag");
glUseProgram(program);
```

Source: Nexcius.net

Tutorials and Documentation

- OpenGL and GLSL Specifications
  - https://www.opengl.org/registry/
- GLSL Tutorials
  - http://www.lighthouse3d.com/opengl/glsl/
  - http://www.clockworkcoders.com/oglsl/tutorials.html
- OpenGL Programming Guide (Red Book)
  - http://www.glprogramming.com/red/
- OpenGL Shading Language (Orange Book)
  - http://wiki.labomedia.org/images/1/10/Orange_Book_-_OpenGL_Shading_Language_2nd_Edition.pdf
- OpenGL 3.2 API Reference Card
  - http://www.opengl.org/sdk/docs/reference_card/opengl32-quick-reference-card.pdf