CIS 441/541: Introduction to Computer Graphics
Lecture 15: shaders

March 12th, 2019
Hank Childs, University of Oregon
Talk _more_ about the test
Project G

- Blender
- WebGL #1
- WebGL #2
- CUDA
- Bezier
- Computer Vision
- Shaders
Schedule

- Upcoming:
  - Today: shaders, live code
  - Thursday: test re-take
Late Passes

- Will bring forms to final
Hank OH

- Primary purpose of Hank’s OH is now to help with self-defined projects
- Also can help with 1A-1F, 2A, 2B
- Friday OH: 11am-12noon
Final Presentations

- 3 minutes each
- Make sure to make it clear what you did
- Try to impress judges
  - What is cool about what you did?
- Format
  - PowerPoint
  - Demo
  - PowerPoint + Demo
- Connect A/V to Rm 220 project before 9am as test
Shaders

- Shader: computer program used to do “shading”
- “Shading”: general term that covers more than just shading/lighting
  - Used for many special effects
- Increased control over:
  - position, hue, saturation, brightness, contrast
- For:
  - pixels, vertices, textures
Motivation: Bump Mapping

- **Idea:**
  - typical rasterization, calculate fragments
  - fragments have normals (as per usual)
  - also interpolate texture on geometry & fragments
    - use texture for “bumps”
    - take normal for fragment and displace it by “bump” from texture

*Image from Wikipedia*
Bump Mapping Example

Concept

BumpMapping allows designers to express their creativity through a 100,000+ polygons creature. Once art is done, a low poly model (5000 polygons) is automatically generated along with a normal map.

At runtime, details are added back by combining the low model with the normal map.

credit: http://www.fabiensanglard.net/bumpMapping/
Bump Mapping Example
How to do Bump Mapping?

- Answer: easy to imagine doing it in your Project 1A-1F infrastructure
  - You have total control

- But what OpenGL commands would do this?
  - Not possible in V1 of the GL interface, which is what we have learned

- It is possible with various extensions to OpenGL
  - We will learn to do this with shaders
Shading Languages

- Shading language: programming language for graphics, specifically shader effects
- Benefits: increased flexibility with rendering
- OpenGL (as we know it so far): fixed transformations for color, position, of pixels, vertices, and textures.
- Shader languages: custom programs, custom effects for color, position of pixels, vertices, and textures.
ARB assembly language

- ARB: low-level shading language
  - at same level as assembly language
- Created by OpenGL Architecture Review Board (ARB)
- Goal: standardize instructions for controlling GPU
- Implemented as a series of extensions to OpenGL
- You don’t want to work at this level, but it was an important development in terms of establishing foundation for today’s technology
GLSL: high-level shading language

- also called GLSLang
- syntax similar to C

- Purpose: increased control of graphics pipeline for developers, but easier than assembly
  - This is layer where developers do things like “bump mapping”

- Benefits:
  - Benefits of GL (cross platform: Windows, Mac, Linux)
  - Support over GPUs (NVIDIA, ATI)
  - HW vendors support GLSL very well
Other high-level shading languages

- Cg (C for Graphics)
  - based on C programming language
  - outputs DirectX or OpenGL shader programs
  - deprecated in 2012

- HLSL (high-level shading language)
  - used with MicroSoft Direct3D
  - analogous to GLSL
  - similar to CG

- RSL (Renderman Shading Language)
  - C-like syntax
  - for use with Renderman: Pixar’s rendering engine
## Relationship between GLSL and OpenGL

### Versions

GLSL versions have evolved alongside specific versions of the OpenGL API. It is only with OpenGL versions 3.3 and above that the GLSL and OpenGL major and minor version numbers match. These versions for GLSL and OpenGL are related in the following table:

<table>
<thead>
<tr>
<th>GLSL Version</th>
<th>OpenGL Version</th>
<th>Date</th>
<th>Shader Preprocessor</th>
</tr>
</thead>
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<td>April 2004</td>
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<td>4.3</td>
<td>August 2012</td>
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<tr>
<td>4.50</td>
<td>4.5</td>
<td>August 2014</td>
<td>#version 450</td>
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</table>

Source: wikipedia
4 Types of Shaders

- Vertex Shaders
- Fragment Shaders
- Geometry Shaders
- Tessellation Shaders

- It is common to use multiple types of shaders in a program and have them interact.
How Shaders Fit Into the Graphics Pipeline

- Transform Vertices from World Space to Device Space
- Rasterize
- Contribute Fragments to Buffers

- Vertex shaders: custom implementation
- Fragment shaders: custom implementation
- Geometry & tessellation shaders: create new geometry before rasterized

You can have 0 or 1 of each shader type

- Vertex & fragment: very common
- Geometry & tessellation: less common
  - adaptive meshing
Vertex Shader

- Run once for each vertex
- Can: manipulate position, color, texture
- Cannot: create new vertices
- Primary purpose: transform from world-space to device-space (+ depth for z-buffer).
  - However: A vertex shader replaces the transformation, texture coordinate generation and lighting parts of OpenGL, and it also adds texture access at the vertex level
- Output goes to geometry shader or rasterizer
Geometry Shader

- Run once for each geometry primitive
- Purpose: create new geometry from existing geometry.
- Output goes to rasterizer
- Examples: glyphing, mesh complexity modification
- Formally available in GL 3.2, but previously available in 2.0+ with extensions

- Tessellation Shader: doing some of the same things
- Available in GL 4.0
Fragment Shader

- Run once for each fragment
- Purpose: replaces the OpenGL 1.4 fixed-function texturing, color sum and fog stages
- Output goes to buffers
- Example usages: bump mapping, shadows, specular highlights
- Can be very complicated: can sample surrounding pixels and use their values (blur, edge detection)
- Also called pixel shaders
How to Use Shaders

- You write a shader program: a tiny C-like program
- You write C/C++ code for your application
- Your application loads the shader program from a text file
- Your application sends the shader program to the OpenGL library and directs the OpenGL library to compile the shader program
- If successful, the resulting GPU code can be attached to your (running) application and used
- It will then supplant the built-in GL operations
How to Use Shaders: Visual Version

- **Project2B’ C++ code**
  - Compiled by `g++` to a **binary**.
  - The **OpenGL** library compiles the program and creates a binary specific to the current execution.
  - The program reads a text file when running.
  - The program is used on the GPU to support the **Project2B’ binary**.
  - A **shader program** is a binary.

- Sends “char *” version of the program to GL via function call.
Compiling Shader

GLuint vertexShader = glCreateShader(GL_VERTEX_SHADER);
std::string vertexProgram = loadFileToString("vs.glsl");
const char *vertex_shader_source = vertexProgram.c_str();
GLint const vertex_shader_length = strlen(vertex_shader_source);
glShaderSource(vertexShader, 1, &vertex_shader_source, &vertex_shader_length);
glCompileShader(vertexShader);
GLint isCompiledVS = 0;
glGetShaderiv(vertexShader, GL_COMPILE_STATUS, &isCompiledVS);
Compiling Shader: inspect if it works

if(isCompiledVS == GL_FALSE)
{
    cerr << "Did not compile VS" << endl;

    GLint maxLength = 0;
    glGetShaderiv(vertexShader, GL_INFO_LOG_LENGTH, &maxLength);

    // The maxLength includes the NULL character
    std::vector<GLchar> errorLog(maxLength);
    glGetShaderInfoLog(vertexShader, maxLength, &maxLength, &errorLog[0]);
    cerr << "Vertex shader log says " << &errorLog[0] << endl;
    exit(EXIT_FAILURE);
}
Compiling Multiple Shaders

```cpp
GLuint vertexShader = glCreateShader(GL_VERTEX_SHADER);
std::string vertexProgram = loadFileToString("vs.glsl");
const char *vertex_shader_source = vertexProgram.c_str();
GLint const vertex_shader_length = strlen(vertex_shader_source);
glShaderSource(vertexShader, 1, &vertex_shader_source, &vertex_shader_length);
glCompileShader(vertexShader);
GLint isCompiledVS = 0;
glGetShaderiv(vertexShader, GL_COMPILE_STATUS, &isCompiledVS);

if(isCompiledVS == GL_FALSE)
{
    cerr << "Did not compile VS" << endl;
    GLint maxLength = 0;
    glGetShaderiv(vertexShader, GL_INFO_LOG_LENGTH, &maxLength);

    // The maxLength includes the NULL character
    std::vector<GLchar> errorLog(maxLength);
    glGetShaderInfoLog(vertexShader, maxLength, &maxLength, &errorLog[0]);
    cerr << "Vertex shader log says " << &errorLog[0] << endl;
    exit(EXIT_FAILURE);
}

GLuint fragmentShader = glCreateShader(GL_FRAGMENT_SHADER);
std::string fragmentProgram = loadFileToString("fs.glsl");
const char *fragment_shader_source = fragmentProgram.c_str();
GLint const fragment_shader_length = strlen(fragment_shader_source);
glShaderSource(fragmentShader, 1, &fragment_shader_source, &fragment_shader_length);
glCompileShader(fragmentShader);
GLint isCompiledFS = 0;
glGetShaderiv(fragmentShader, GL_COMPILE_STATUS, &isCompiledFS);
```
Attaching Shaders to a Program

```c
GLInt program = glGenProgram();
glAttachShader(program, vertexShader);
glAttachShader(program, fragmentShader);

glLinkProgram(program);

glDetachShader(program, vertexShader);
glDetachShader(program, fragmentShader);
```
Inspecting if program link worked...

GLint isLinked = 0;
gGetProgramiv(program, GL_LINK_STATUS, (int *)&isLinked);
if(isLinked == GL_FALSE)
{
    GLint maxLength = 0;
gGetProgramiv(program, GL_INFO_LOG_LENGTH, &maxLength);

    //The maxLength includes the NULL character
    std::vector<GLchar> infoLog(maxLength);
gGetProgramInfoLog(program, maxLength, &maxLength, &infoLog[0]);
cerr << "Couldn't link" << endl;
cerr << "Log says " << &infoLog[0] << endl;
exit(EXIT_FAILURE);
}
BUT: this doesn’t work in VTK…

- VTK has its own shader handling, and it doesn’t play well with the GL calls above...

```cpp
vtkSmartPointer<vtkShaderProgram2> pgm = vtkShaderProgram2::New();
pgm->SetContext(renWin);

vtkSmartPointer<vtkShader2> vertexShader=vtkShader2::New();
vertexShader->SetType(VTK_SHADER_TYPE_VERTEX);
std::string vertexProgram = loadFileToString("v_vs.glsl");
vertexShader->SetSourceCode(vertexProgram.c_str());
vertexShader->SetContext(pgm->GetContext());

pgm->GetShaders()->AddItem(vertexShader);

vtkSmartPointer<vtkShader2> fragmentShader=vtkShader2::New();
fragmentShader->SetType(VTK_SHADER_TYPE_FRAGMENT);
std::string fragmentProgram = loadFileToString("v_fs.glsl");
fragmentShader->SetSourceCode(fragmentProgram.c_str());
fragmentShader->SetContext(pgm->GetContext());

pgm->GetShaders()->AddItem(fragmentShader);

((vtkOpenGLProperty*)win3Actor->GetProperty())->SetPropProgram(pgm);
```

note: VTK6.1 much better for shaders than 6.0
void main(void)
{
    gl_Position = gl_ModelViewProjectionMatrix*gl_Vertex;
}

Many built-in variables.
Some are input.
Some are required output (gl_Position).
VTK uses special names
propFuncVS: vertex shader
propFuncFS: fragment shader
somehow it changes these into “main” just in time…
Bump-mapping with GLSL

bump map texture

output
Will need to load a texture...

// from swiftless.com
GLuint LoadTexture( const char * filename, int width, int height )
{
    GLint texture;
    unsigned char * data;
    FILE * file;

    //The following code will read in our RAW file
    file = fopen( filename, "rb" );

    if ( file == NULL ) return 0;
    data = (unsigned char *)malloc( width * height * 3 );
    fread( data, width * height * 3, 1, file );

    fclose( file );

    glGenTextures( 1, &texture ); //generate the texture with the loaded data
    glBindTexture( GL_TEXTURE_2D, texture ); //bind the texture to it's array
    glTexParameteri( GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_MODULATE ); //set texture environment parameters

    //And if you go and use extensions, you can use Anisotropic filtering textures which are of an
    //even better quality, but this will do for now.
    glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);

    //Here we are setting the parameter to repeat the texture instead of clamping the texture
    //to the edge of our shape.
    glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT );
    glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT );

    //Generate the texture
    glTexImage2D( GL_TEXTURE_2D, 0, GL_RGB, width, height, 0, GL_RGB, GL_UNSIGNED_BYTE, data);

    free( data ); //free the texture

    return texture; //return whether it was successful
}
Need to put 2D textures on our triangles...

class Triangle {
public:
    double X[3];
    double Y[3];
    double Z[3];
    double Tu[3];
    double Tv[3];
};

void DrawSphere() {
    int recursionLevel = 3;
    Triangle t;
    t.X[0] = 1;
    t.Y[0] = 0;
    t.Z[0] = 0;
    t.Tu[0] = 0;
    t.Tv[0] = 0;
    t.X[1] = 0;
    t.Y[1] = 1;
    t.Z[1] = 0;
    t.Tu[1] = 1;
    t.Tv[1] = 0;
    t.X[2] = 0;
    t.Y[2] = 0;
    t.Tu[2] = 1;
    t.Tv[2] = 1;
    std::vector<Triangle> list;
    list.push_back(t);
    for (int r = 0; r < recursionLevel; r++) {
        list = SplitTriangle(list);
    }
}

std::vector<Triangle> SplitTriangle(std::vector<Triangle> &list) {
    std::vector<Triangle> output(4*list.size());
    for (unsigned int i = 0; i < list.size(); i++) {
        double mid1[5], mid2[5], mid3[5];
        mid1[0] = (list[i].X[0]+list[i].X[1])/2;
        mid1[1] = (list[i].Y[0]+list[i].Y[1])/2;
        mid1[2] = (list[i].Z[0]+list[i].Z[1])/2;
        mid1[3] = (list[i].Tu[0]+list[i].Tu[1])/2;
        mid1[4] = (list[i].Tv[0]+list[i].Tv[1])/2;
        mid2[0] = (list[i].X[1]+list[i].X[2])/2;
        mid2[3] = (list[i].Tu[1]+list[i].Tu[2])/2;
        mid2[4] = (list[i].Tv[1]+list[i].Tv[2])/2;
        mid3[0] = (list[i].X[0]+list[i].X[2])/2;
        mid3[1] = (list[i].Y[0]+list[i].Y[2])/2;
        mid3[2] = (list[i].Z[0]+list[i].Z[2])/2;
        mid3[3] = (list[i].Tu[0]+list[i].Tu[2])/2;
        mid3[4] = (list[i].Tv[0]+list[i].Tv[2])/2;
        output[4*i+0].X[0] = list[i].X[0];
        output[4*i+0].Y[0] = list[i].Y[0];
        output[4*i+0].Z[0] = list[i].Z[0];
        output[4*i+0].Tu[0] = list[i].Tu[0];
        output[4*i+0].Tv[0] = list[i].Tv[0];
        output[4*i+0].X[1] = mid1[0];
        output[4*i+0].Y[1] = mid1[1];
        output[4*i+0].Z[1] = mid1[2];
        output[4*i+0].Tu[1] = mid1[3];
        output[4*i+0].Tv[1] = mid1[4];
        output[4*i+0].X[2] = mid3[0];
        output[4*i+0].Y[2] = mid3[1];
        output[4*i+0].Z[2] = mid3[2];
        output[4*i+0].Tu[2] = mid3[3];
        output[4*i+0].Tv[2] = mid3[4];
        output[4*i+1].X[0] = list[i].X[1];
        output[4*i+1].Y[0] = list[i].Y[1];
        output[4*i+1].Z[0] = list[i].Z[1];
        output[4*i+1].Tu[0] = list[i].Tu[1];
        output[4*i+1].Tv[0] = list[i].Tv[1];
    }
    return output;
}
Need to set up shaders and textures...

```cpp
vtkSmartPointer<vtkShaderProgram2> pgm = vtkShaderProgram2::New();
pgm->SetContext(renWin);

vtkSmartPointer<vtkShader2> vertexShader = vtkShader2::New();
vertexShader->SetType(VTK_SHADER_TYPE_VERTEX);
//std::string vertexProgram = loadFileToString("vs.glsl");
std::string vertexProgram = loadFileToString("v_vs.glsl");
vertexShader->SetSourceCode(vertexProgram.c_str());
vertexShader->SetContext(pgm->GetContext());

pgm->GetShaders()->AddItem(vertexShader);

vtkSmartPointer<vtkShader2> fragmentShader = vtkShader2::New();
fragmentShader->SetType(VTK_SHADER_TYPE_FRAGMENT);
//std::string fragmentProgram = loadFileToString("light_fs.glsl");
std::string fragmentProgram = loadFileToString("v_fs.glsl");
fragmentShader->SetSourceCode(fragmentProgram.c_str());
fragmentShader->SetContext(pgm->GetContext());

pgm->GetShaders()->AddItem(fragmentShader);

((vtkOpenGLProperty*)win3Actor->GetProperty())->SetPropProgram(pgm);
win3Actor->GetProperty()->ShadingOn();

GLuint texture = LoadTexture("normal_map.raw", 256, 256);
glEnable(GL_TEXTURE_2D);
int texture_location = glGetUniformLocation(fragmentShader->GetId(), "color_texture");
glUniform1i(texture_location, 0);
glBindTexture(GL_TEXTURE_2D, texture);
```
So what is the vertex shader program?

```c
void propFuncVS(void)
{
    gl_TexCoord[0] = gl_MultiTexCoord0;

    // Set the position of the current vertex
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```
And what is the fragment shader program?

```cpp
uniform sampler2D color_texture;
uniform sampler2D normal_texture;

void propFuncFS(void)
{
    // Extract the normal from the normal map
    vec3 normal = normalize(texture2D(normal_texture, gl_TexCoord[0].st).rgb * 2.0 - 1.0);

    // Determine where the light is positioned (this can be set however you like)
    vec3 light_pos = normalize(vec3(1.0, 1.0, 1.5));

    // Calculate the lighting diffuse value
    float diffuse = max(dot(normal, light_pos), 0.0);

    vec3 color = diffuse * texture2D(color_texture, gl_TexCoord[0].st).rgb;

    // Set the output color of our current pixel
    gl_FragColor = vec4(color, 1.0);
}
```