Shader Programming

Technical Game Development II

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“The Orange Book”
Also take CS 4731 – Computer Graphics

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Shader Programming

- graphics hardware has replaced (1st generation) 
  fixed functionality with programmability in:
  - vertex processing (geometry)
    - transformation
    - lighting
  - fragment (per-pixel) processing
    - reading from texture memory
    - procedurally computing colors, etc.

- OpenGL Shading Language (GLSL) is a open standard for programming such hardware
  - other languages, e.g., RenderMan, ShaderLab, HLSL (Unreal)
  - all have same basic principles
OpenGL “Fixed Functionality” Pipeline

OpenGL Programmable Processors
**Vertex (Geometry) Processor**

- Built-in attribute variables:
  - gl_Color
  - gl_NumVertices
  - gl_Vertex
  - gl_MultiTexCoord0
  - etc.

- User-defined attribute variables

- Special input variables:
  - gl_Unt
  - gl_TexCoord
  - gl_COordinate

- Vertex Processor

- Built-in variable variables:
  - ModelViewMatrix
  - Normal
  - ModelView

- Fragment Processor

- Special output variables:
  - Normal
  - ModelView

- User-defined output variables

- User-defined uniform variables:
  - ModelViewMatrix
  - Epsilon
  - Radius
  - etc.

- Fragment (Pixel) Processor

- Built-in varying variables:
  - gl_Color
  - gl_PointCoord
  - gl_FragCoord

- Special input variables:
  - gl_Uniform
  - gl_FragData

- User-defined varying variables

- User-defined uniform variables:
  - ModelViewMatrix
  - Epsilon
  - Radius
  - etc.

- Fragment Processor

- Special output variables:
  - Normal
  - ModelView

- User-defined output variables

- User-defined uniform variables:
  - ModelViewMatrix
  - Epsilon
  - Radius
  - etc.

-< Interpolated from vertices

- Provided directly by application

- Provided indirectly by application

- Provided by the vertex processor

- Provided by the fragment processor
GLSL Language

- Similar to C, C++
- Built-in vector and matrix operations:
  - vec2, vec3, vec4
  - mat2, mat3, mat4
- Texture memory lookup
  - sampler1D, sampler2D, sampler3D

Simple Shader Program Example

- Surface temperature coloring – “false color”
  - Assume temperature (user defined variable) is known at each vertex in model
  - Smoothly color surface to indicate temperature at every pixel (using interpolation)
  - Uses both a vertex and a fragment shader program working together (typical)

- Does coloring in parallel on GPU (much faster than using CPU)
### Vertex Shader

// global parameters read from application
uniform float CoolestTemp;
uniform float TempRange;

// user-defined incoming property of this vertex
attribute float VertexTemp;

// “output” variable to communicate to the fragment shader
// (via interpolation – see scaling below)
varying float Temperature;

void main()
{
// communicate this vertex’s temperature scaled to [0.0, 1.0]
    Temperature = (VertexTemp - CoolestTemp) / TempRange;

// don’t move this vertex
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}

### Fragment Shader

// global parameters read from application
uniform vec3 CoolestColor;
uniform vec3 HottestColor;

// interpolated value from vertex shader
varying float Temperature;

void main()
{
// compute a color using built-in mix() function
    vec3 color = mix(CoollestColor, HottestColor, Temperature);

// set this pixel’s raw color (with alpha blend of 1.0)
    gl_FragColor = vec4(color, 1.0);
}
Shader Execution

- Vertex shader is run once per vertex
- Vertex values are *interpolated* to get fragment values
- Fragment shader is run once per pixel
- Many such executions can happen *in parallel*
- *No* communication or ordering between parallel executions
  - no vertex-to-vertex
  - no pixel-to-pixel

Another Example: Adding Noise

- Using shader to change geometry (!)
- Moving vertices randomly a bit to simulate roughness
- More complicated vertex shader
- "No-op" fragment shader
### Vertex Shader

```glsl
uniform vec3 LightPosition; // global application parameters
uniform vec3 SurfaceColor;
uniform vec3 Offset;
varying vec4 Color; // output color for pixel shader
uniform float ScaleIn; // for this shader only
uniform float ScaleOut; // for this shader only

void main()
{
    vec3 normal = gl_Normal;
    // move vertex randomly
    vec3 vertex = gl_Vertex.xyz +
                   noise3(Offset + gl_Vertex.xyz * ScaleIn) * ScaleOut;

    // redo default color calculation based on new vertex location
    normal = normalize(gl_NormalMatrix * normal);
    vec3 position = vec3(gl_ModelViewMatrix * vec4(vertex,1.0));
    vec3 lightVec = normalize(LightPosition - position);
    float diffuse = max(dot(lightVec, normal), 0.0);
    if (diffuse < 0.125) diffuse = 0.125;
    Color = vec4(SurfaceColor * diffuse, 1.0);
    gl_Position = gl_ModelViewProjectionMatrix * vec4(vertex,1.0);
}
```

### “No-Op” Fragment Shader

```glsl
varying vec4 Color;

void main()
{
    gl_FragColor = Color;
}
```
Fragment Shader for Stripes

```glsl
uniform vec3 StripeColor; // global application parameters
uniform vec3 BackColor;   // that define striping pattern
uniform vec3 Width;
uniform float Fuzz;
uniform float Scale;

varying vec3 DiffuseColor; // inputs from vertex shader
varying vec3 SpecularColor;

void main()
{
    float scaledT = fract(gl_TexCoord[0].t * Scale);
    float frac1 = clamp(scaledT / Fuzz, 0.0, 1.0);
    float frac2 = clamp((scaledT - Width) / Fuzz, 0.0, 1.0);
    frac1 = frac1 * (1.0 - frac2);
    frac1 = frac1 * frac1 * (3.0 - (2.0 * frac1));
    vec3 finalColor = mix(BackColor, StripeColor, frac1);
    finalColor = finalColor * DiffuseColor + SpecularColor;
    gl_FragColor = vec4(finalColor, 1.0);
}
```
### Lots More You Can Do With Shaders

- **Procedural Textures**
  - patterns (stripes, etc.)
  - bump mapping
- **Lighting Effects**
- **Shadows**
- **Surface Effects**
  - refraction, diffraction
- **Animation**
  - morphing
  - particles

### Lots More ...

- **Anti-aliasing**
- **Non-photorealistic effects**
  - hatching, meshes
  - technical illustration
- **Imaging**
  - sharpen, smooth, etc.
- **Environmental effects (RealWorldz)**
  - terrain
  - sky
  - ocean
Screen shot of the SolidWorks application, showing a jigsaw rendered with OpenGL shaders to simulate a chrome body, galvanized steel housing, and cast iron blade. (Courtesy of SolidWorks Corporation)

Different glyphs applied to a cube using the glyph bombing shader described in Section 10.6. (3Dlabs, Inc.)
The lattice shader presented in Section 11.3 is applied to the cow model. (3Dlabs, Inc.)

A simple box and a torus that have been bump-mapped using the procedural method described in Section 11.4. (3Dlabs, Inc.)
A variety of materials rendered with Ward's BRDF model (see Section 14.3) and his measured/fitted material parameters.

Brick shader with and without antialiasing. On the left, the results of the brick shader presented in Chapter 6. On the right, results of antialiasing by analytic integration using the brick shader described in Section 17.4.5. (3Dlabs, Inc.)
A variety of screen shots from the 3Dlabs RealWorldz demo. Everything in this demo is generated procedurally using shaders written in the OpenGL Shading Language. This includes the planets themselves, the terrain, atmosphere, clouds, plants, oceans, and rock formations. Planets are modeled as mathematical spheres, not height fields. These scenes are all rendered at interactive rates on current generation graphics hardware.

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**Shader Programming - Summary**

- Seems to lie on the boundary between art and tech
- programming is hard-core (parallel algorithms)
- but intended result is often mostly aesthetic