

Programmable Graphics Hardware

OpenGL Extensions
Shading Languages
Vertex Program
Fragment Program
[Angel Ch. 9]

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Introduction

- Recent major advance in real time graphics is the *programmable* pipeline:
 - First introduced by NVIDIA GeForce 3 (in 2001)
 - Supported by all modern high-end commodity cards
 - NVIDIA, ATI
 - Software Support
 - Direct X 8 , 9, 10
 - OpenGL
- This lecture:
programmable pipeline and shaders

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OpenGL Extensions

- Initial OpenGL version was 1.0
- Current OpenGL version is 4.4
- As graphics hardware improved, new capabilities were added to OpenGL
 - multitexturing
 - multisampling
 - non-power-of-two textures
 - shaders
 - and many more

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OpenGL Grows via Extensions

- Phase 1: vendor-specific: GL_NV_multisample
- Phase 2: multi-vendor:
GL_EXT_multisample
- Phase 3: approved by OpenGL's review board
GL_ARB_multisample
- Phase 4: incorporated into OpenGL (v1.3)

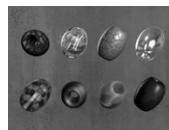
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OpenGL 2.0 Added Shaders

- Shaders are customized programs that replace a part of the OpenGL pipeline
- They enable many effects not possible by the fixed OpenGL pipeline
- Motivated by Pixar's Renderman (offline shader)

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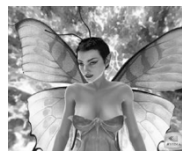
Shaders Enable Many New Effects



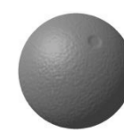
Complex materials



Shadowing



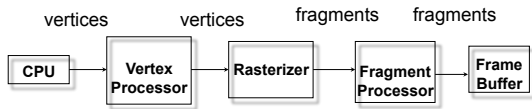
Lighting environments



Advanced mapping

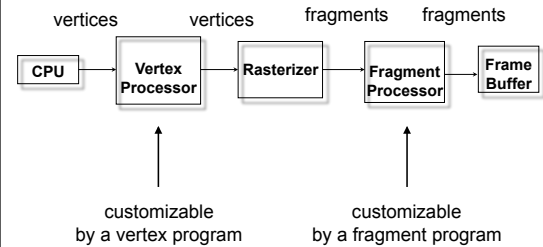
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The Rendering Pipeline



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Shaders Replace Part of the Pipeline



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Shaders

- Vertex shader (= vertex program)
- Fragment shader (= fragment program)
- Geometry shader (recent addition)
- Default shaders are provided by OpenGL (*fixed-function pipeline*)
- Programmer can install her own shaders as needed

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Shaders Are Written in Shading Languages

- Early shaders: assembly language
- Since ~2004: high-level shading languages
 - OpenGL Shading Language (GLSL)
 - highly integrated with OpenGL
 - Cg (NVIDIA and Microsoft), very similar to GLSL
 - HLSL (Microsoft), almost identical to Cg
 - All of these are simplified versions of C/C++

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Vertex Program

- Input: vertices, and per-vertex attributes:
 - color
 - normal
 - texture coordinates
 - many more
- Output:
 - vertex location in clip coordinates
 - vertex color
 - vertex normal
 - many more are possible

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Simple Vertex Program in GLSL

```
/* pass-through vertex shader */  
  
void main()  
{  
    gl_Position = gl_ProjectionMatrix  
        * (gl_ModelViewMatrix * gl_Vertex);  
}
```

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Fragment Program

- Input: pixels, and per-pixel attributes:
 - color
 - normal
 - texture coordinates
 - many more are possible
- Inputs are outputs from vertex program, interpolated (by the GPU) to the pixel location !
- Output:
 - pixel color
 - depth value

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Simple Fragment Program

```
/* pass-through fragment shader */  
  
void main()  
{  
    gl_FragColor = gl_Color;  
}
```

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Simple Fragment Program #2

```
/* all-red fragment shader */  
  
void main()  
{  
    gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);  
}
```

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GLSL: Data Types

- Scalar Types
 - float - 32 bit, very nearly IEEE-754 compatible
 - int - at least 16 bit
 - bool - like in C++
- Vector Types
 - vec[2 | 3 | 4] - floating-point vector
 - ivec[2 | 3 | 4] - integer vector
 - bvec[2 | 3 | 4] - boolean vector
- Matrix Types
 - mat[2 | 3 | 4] - for 2x2, 3x3, and 4x4 floating-point matrices
- Sampler Types
 - sampler[1 | 2 | 3]D - to access texture images

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GLSL: Operations

- Operators behave like in C++
- Component-wise for vector & matrix
- Multiplication on vectors and matrices
- Examples:
 - Vec3 t = u * v;
 - float f = v[2];
 - v.x = u.x + f;

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GLSL: Swizzling

- Swizzling is a convenient way to access individual vector components

```
vec4 myVector;  
myVector.rgba; // is the same as myVector  
myVector.xy; // is a vec2  
myVector.b; // is a float  
myVector[2]; // is the same as myVector.b  
myVector.xb; // illegal  
myVector.xxx; // is a vec3
```

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GLSL: Global Qualifiers

- Attribute
 - Information specific to each vertex/pixel passed to vertex/fragment shader
 - No integers, bools, structs, or arraysExample: Vertex Color
- Uniform
 - Constant information passed to vertex/fragment shader
 - Cannot be written to in a shaderExample: Light Position
Eye Position
- Varying
 - Info passed from vertex shader to fragment shader
 - Interpolated from vertices to pixels
 - Write in vertex shader, but only read in fragment shaderExample: Vertex Color
Texture Coords
- Const
 - To declare non-writable, constant variablesExample: pi, e, 0.480

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GLSL: Flow Control

- Loops
 - C++ style if-else
 - C++ style for, while, and do
- Functions
 - Much like C++
 - Entry point into a shader is void main()
 - No support for recursion
 - Call by value-return calling convention
- Parameter Qualifiers
 - in - copy in, but don't copy out
 - out - only copy out
 - inout - copy in and copy out

Example function:

```
void ComputeTangent(
  in vec3 N,
  out vec3 T,
  inout vec3 coord)
{
  if((dot(N, coord)>0)
    T = vec3(1,0,0);
  else
    T = vec3(0,0,0);
  coord = 2 * T;
}
```

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GLSL: Built-in Functions

- Wide Assortment
 - Trigonometry (cos, sin, tan, etc.)
 - Exponential (pow, log, sqrt, etc.)
 - Common (abs, floor, min, clamp, etc.)
 - Geometry (length, dot, normalize, reflect, etc.)
 - Relational (less than, equal, etc.)
- Need to watch out for common reserved keywords
- Always use built-in functions, don't implement your own
- Some functions aren't implemented on some cards

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GLSL: Accessing OpenGL State

- Built-in Variables
 - Always prefaced with gl_
 - Accessible to both vertex and fragment shaders
- Uniform Variables
 - Matrices (ModelViewMatrix, ProjectionMatrix, inverses, transposes)
 - Materials (in MaterialParameters struct, ambient, diffuse, etc.)
 - Lights (in LightSourceParameters struct, specular, position, etc.)
- Varying Variables
 - FrontColor for colors
 - TexCoord[] for texture coordinates

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GLSL: Accessing OpenGL State

- Vertex Shader:
 - Have access to several vertex attributes: gl_Color, gl_Normal, gl_Vertex, etc.
 - Also write to special output variables: gl_Position, gl_PointSize, etc.
- Fragment Shader:
 - Have access to special input variables: gl_FragCoord, gl_FrontFacing, etc.
 - Also write to special output variables: gl_FragColor, gl_FragDepth, etc.

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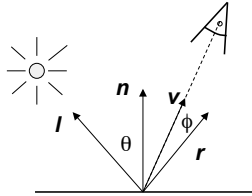
Example: Phong Shader ("per-pixel lighting")

- Questions ?
- Goals:
 - C/C++ Application Setup
 - Vertex Shader
 - Fragment Shader
 - Debugging

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Phong Shading Review

$$I = \frac{1}{a + bq + cq^2} (k_d L_d (l \cdot n) + k_s L_s (r \cdot v)^\alpha) + k_a L_a$$



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Phong Shader: Setup Steps

- Step 1: Create Shaders
 - Create handles to shaders
- Step 2: Specify Shaders
 - load strings that contain shader source
- Step 3: Compiling Shaders
 - Actually compile source (check for errors)
- Step 4: Creating Program Objects
 - Program object controls the shaders
- Step 5: Attach Shaders to Programs
 - Attach shaders to program objects via handle
- Step 6: Link Shaders to Programs
 - Another step similar to attach
- Step 7: Enable Shaders
 - Finally, let OpenGL and GPU know that shaders are ready

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Phong Shader: Vertex Program

```

varying vec3 n;
varying vec3 vtx;
void main(void)
{
    // transform vertex position to eye coordinates:
    vtx = vec3(gl_ModelViewMatrix * gl_Vertex);
    // transform normal:
    n = normalize(gl_NormalMatrix * gl_Normal);
    // transform vertex position to clip coordinates:
    gl_Position = gl_ModelViewProjectionMatrix *
        gl_Vertex;
}
    
```

these will be passed to fragment program (interpolated by hardware)

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Phong Shader: Fragment Program

```

varying vec3 n;
varying vec3 vtx;
void main(void)
{
    // we are in eye coordinates, so eye pos is (0,0,0)
    vec3 l = normalize(gl_LightSource[0].position.xyz - vtx);
    vec3 v = normalize(-vtx);
    vec3 r = normalize(-reflect(l,n));
    //calculate ambient, diffuse, specular terms:
    vec4 lamb = gl_FrontLightProduct[0].ambient;
    vec4 ldiff = gl_FrontLightProduct[0].diffuse * max(dot(n,l), 0.0);
    vec4 lspec = gl_FrontLightProduct[0].specular *
        pow(max(dot(r,v),0.0), gl_FrontMaterial.shininess);
    // write total color:
    gl_FragColor = gl_FrontLightModelProduct.sceneColor +
        lamb + ldiff + lspec;
}
    
```

interpolated from vertex program outputs

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Debugging Shaders

- More difficult than debugging C programs
- Common show-stoppers:
 - Typos in shader source
 - Assuming implicit type conversion
 - Attempting to pass data to undeclared varying/uniform variables
- Extremely important to check error codes, use status functions like:
 - glGetObjectParameter{I|f|v}ARB (GLhandleARB shader, GLenum whatToCheck, GLfloat * statusVals)
- Subtle Problems
 - Shader too long
 - Use too many registers

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Summary

- OpenGL Extensions
- Shading Languages
- Vertex Programs
- Fragment Programs
- Phong Shading in GLSL

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