

## Programmable Graphics Hardware

OpenGL Extensions  
Shading Languages  
Vertex Program  
Fragment Program  
[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 4.1
- 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)

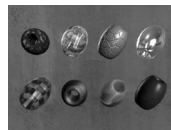
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## OpenGL 2.0 Added Shaders

- 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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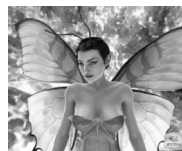
## Shaders Enable Many New Effects



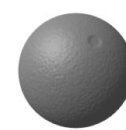
Complex materials



Shadowing



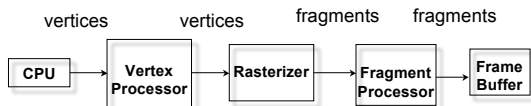
Lighting environments



Advanced mapping

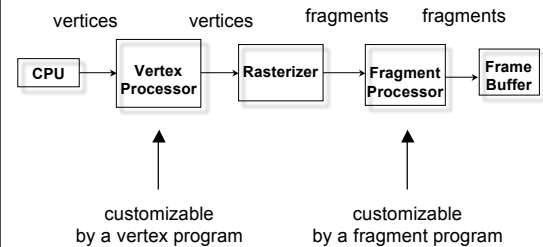
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## The Rendering Pipeline



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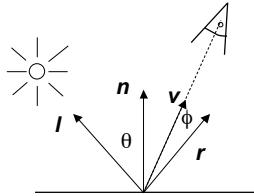
## Example: Phong Shader ("per-pixel lighting")

- 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

- No good automatic debugging tools exist
- 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(If)ARB (GLhandleARB shader, GLenum whatToCheck, GLfloat \* statusVals)
- Subtle Problems
  - Type overflow
  - 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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