

Fall 2018

CSCI 420: **Computer Graphics**

12.2 Programmable Graphics Hardware



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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, 11
 - ▶ OpenGL 2, 3, 4
- This lecture:
 - programmable pipeline and shaders**

OpenGL Extensions

- Initial OpenGL version was 1.0 (1992)
- Current OpenGL version is 4.5 (Aug. 2014)
- As graphics hardware improved, new capabilities were added to OpenGL
 - multitexturing
 - multisampling
 - non-power-of-two textures
 - shaders
 - and many more

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)

Deprecation

- New functionality added to OpenGL for ~20 years
- Difficult to maintain/implement drivers
- Many different ways to render same effects:
 - e.g. immediate mode, display lists, vertex buffer objects
- OpenGL 3.2 introduced core/compatibility profiles:
 - Core: deprecated functionality removed
 - Compatibility: backwards compatible w/ earlier versions
- When creating OpenGL context, can request compatibility profile (may not be supported)

Core Profile

- Removes immediate mode (e.g. glVertex*())
- Removes matrix stack (e.g. glTranslate*())
 - Must pass matrices directly to shaders
 - External libs like GLM, Eigen can handle matrix math
- Compatibility profile easier to learn, still widely supported (for now)
- Most of what follows will use OpenGL 2.0 API

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)

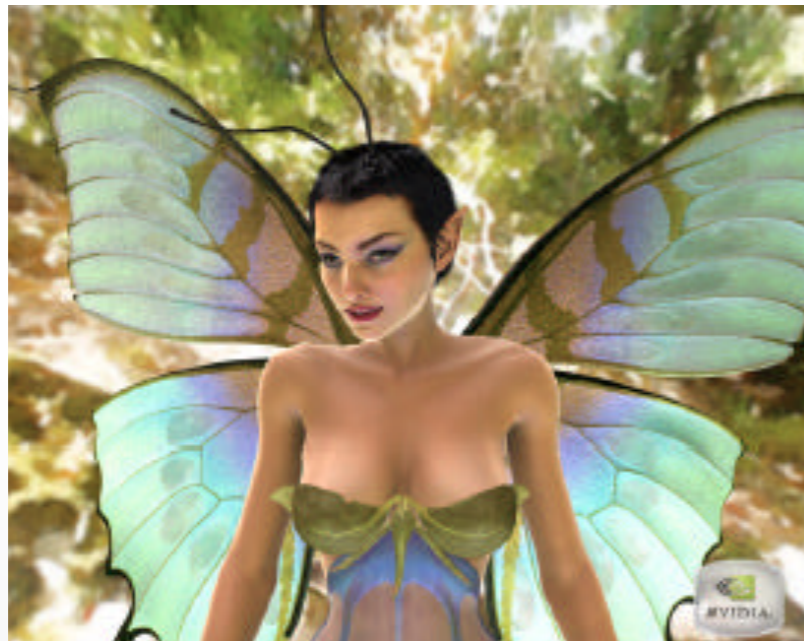
Shaders Enable Many New Effects



Complex materials



Shadowing

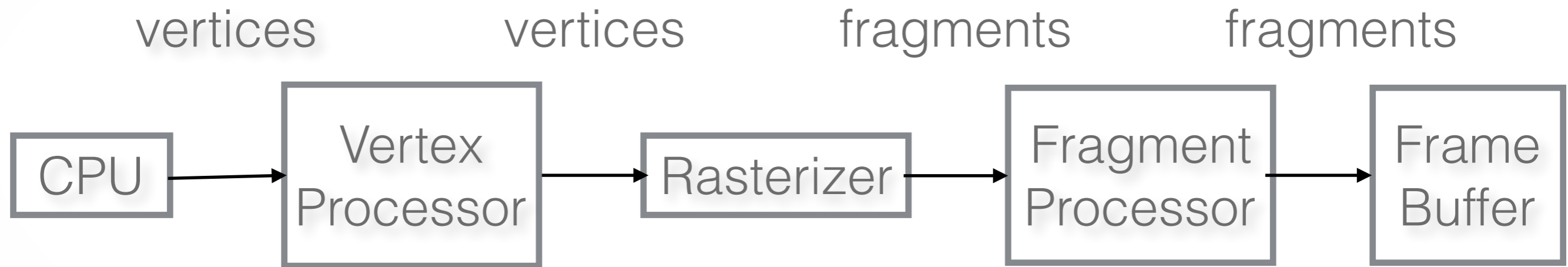


Lighting environments

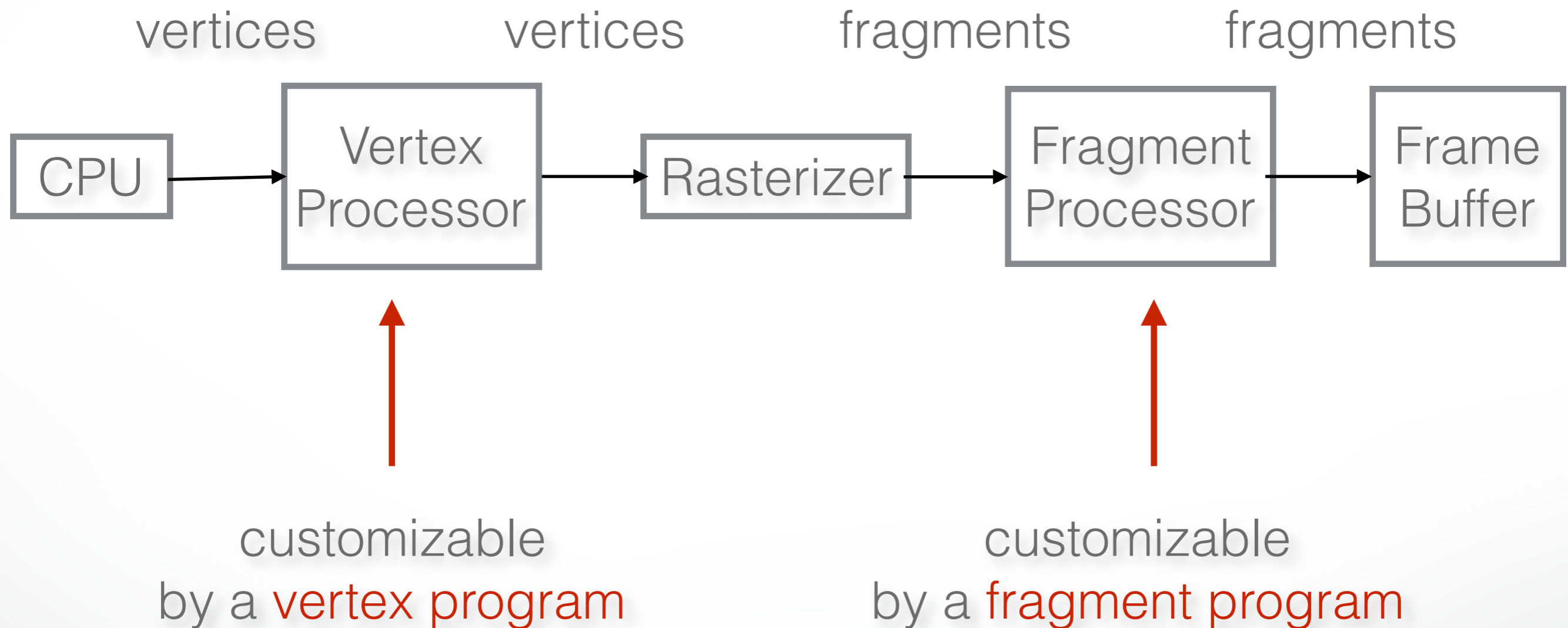


Advanced mapping

The Rendering Pipeline



Shaders Replace Part of the Pipeline



Shaders

- Vertex shader (= vertex program)
- Fragment shader (= fragment program)
- Geometry shader (recent addition)
- Tessellation shaders (more recent addition)
- Default shaders are provided in OpenGL 2.0
(fixed-function pipeline)
- Programmer can install her own shaders
as needed

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++

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

Simple Vertex Program in GLSL (OpenGL 2.0)

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


Simple Vertex Program in GLSL (Core)

```
/* pass-through vertex shader */  
  
uniform mat4 ProjectionMatrix;  
uniform mat4 ModelViewMatrix;  
  
in vec3 Vertex;  
void main()  
{  
    gl_Position = ProjectionMatrix  
    * (ModelViewMatrix * vec4(Vertex, 1.0));  
}
```

- In C/C++ code, set values of matrices and vertex position

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

Simple Fragment Program (OpenGL 2.0)

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

Simple Fragment Program #2 (OpenGL 2.0)

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

Simple Fragment Program #2 (Core)

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

- In C/C++ code, call:

```
glBindFragDataLocation(ShaderProgram, 0, "FragColor");
```

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

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;`

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
```

GLSL: Global Qualifiers

- Attribute
 - Information specific to each vertex/pixel passed to vertex/fragment shader
 - No integers, booleans, structs, or arrays

Example:
Vertex Color
- Uniform
 - Constant information passed to vertex/fragment shader
 - Cannot be written to in a shader

Example:
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 shader

Example:
Vertex Color
Texture Coords
- Const
 - To declare non-writable, constant variables

Example:
 π , e , 0.480

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;
}
```

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

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

GLSL: Accessing OpenGL State

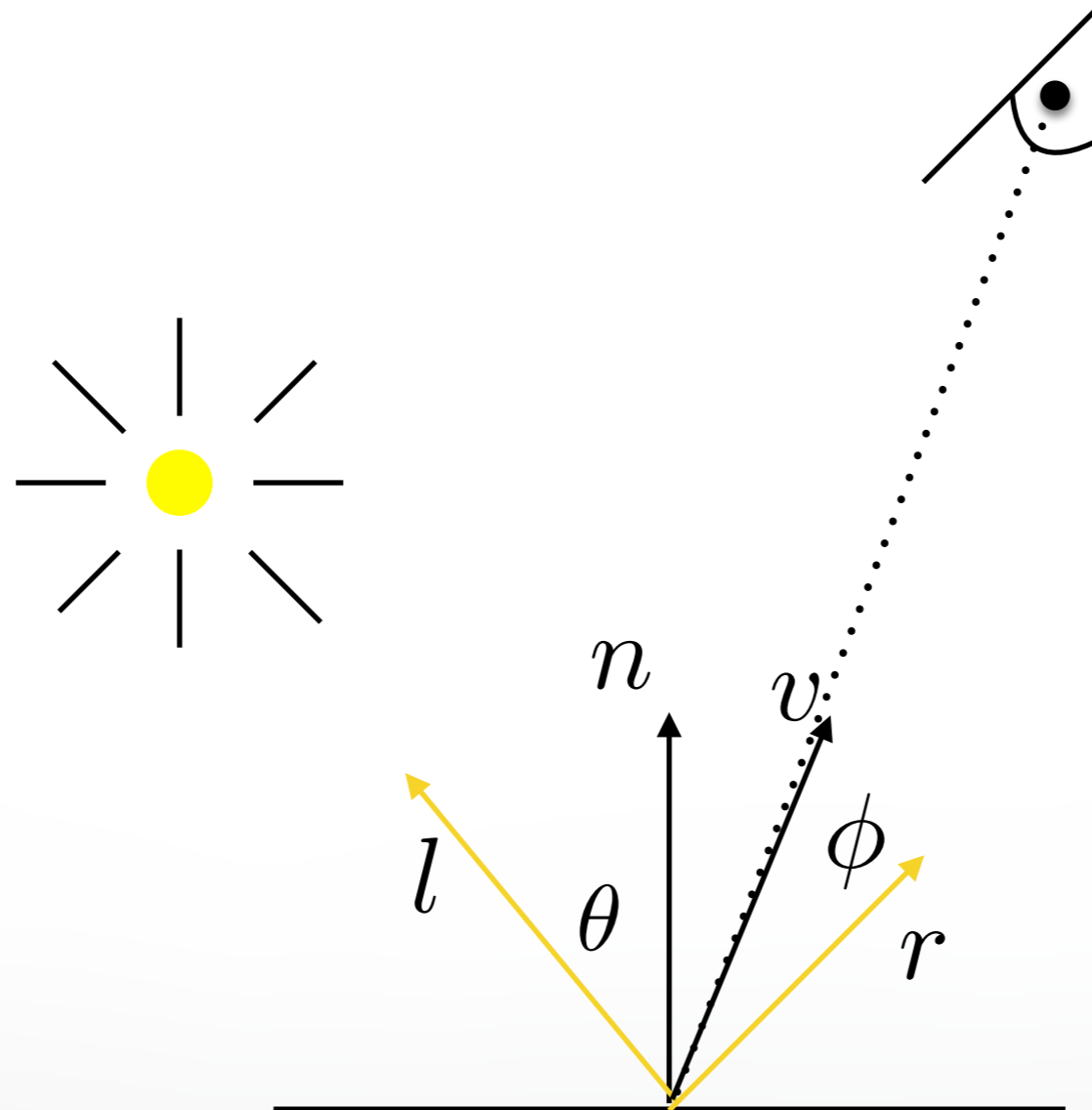
- Vertex Shader:
 - Have access to several vertex attributes:
`gl_Color`, `gl_Normal`, `gl_Vertex`, etc.
 - Also write to special output variables:
`gl_Position`, `gl_PointSize`, etc.
- Fragment Shader:
 - Have access to special input variables:
`gl_FragCoord`, `gl_FrontFacing`, etc.
 - Also write to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

Example: Phong Shader (“per-pixel lighting”)

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

Phong Shading Review

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



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

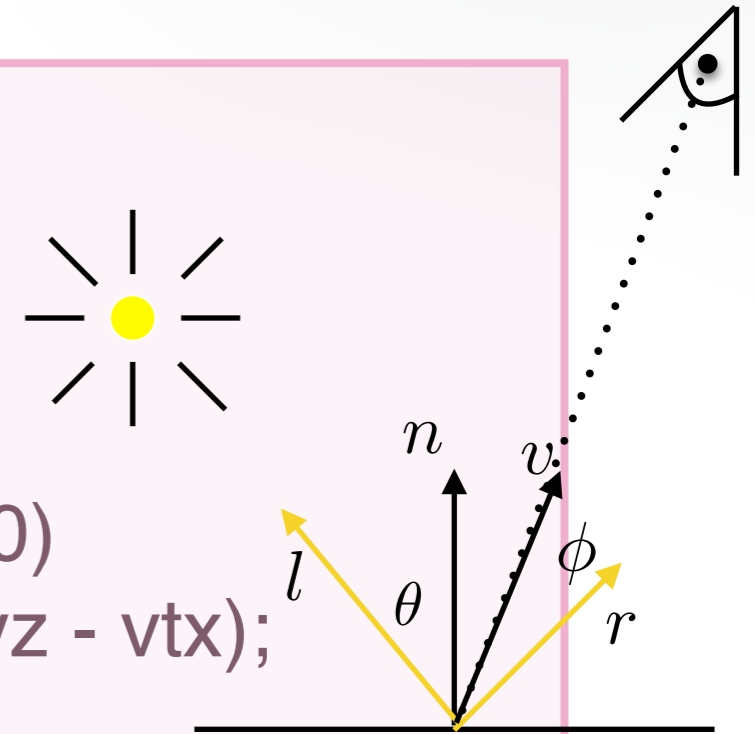
Phong Shader: Vertex Program

```
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)

Phong Shader: Fragment Program

```
varying vec3 n;      } interpolated
varying vec3 vtx;    } from vertex program
void main (void)     } outputs
{
    // 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 Idiff = gl_FrontLightProduct[0].diffuse * max(dot(n,l), 0.0);
    vec4 Ispec = gl_FrontLightProduct[0].specular
        * pow(max(dot(r,v),0.0), gl_FrontMaterial.shininess);
    // write total color:
    gl_FragColor = gl_FrontLightModelProduct.sceneColor +
        lamb + Idiff + Ispec;
}
```



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}vARB` (GLhandleARB shader, GLenum whatToCheck, GLfloat * statusVals)
- Subtle Problems
 - Shader too long
 - Use too many registers

Summary

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

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Thanks!

