Intro to GPU Programming (OpenGL Shading Language)

Cliff Lindsay

Ph.D. Student CS-WPI

Talk Summary

Topic Coverage

- Define Shading Languages (loosely)
- High Level View of GPU
- Functional Aspects of GPU
- Example Shaders (GPU programs)

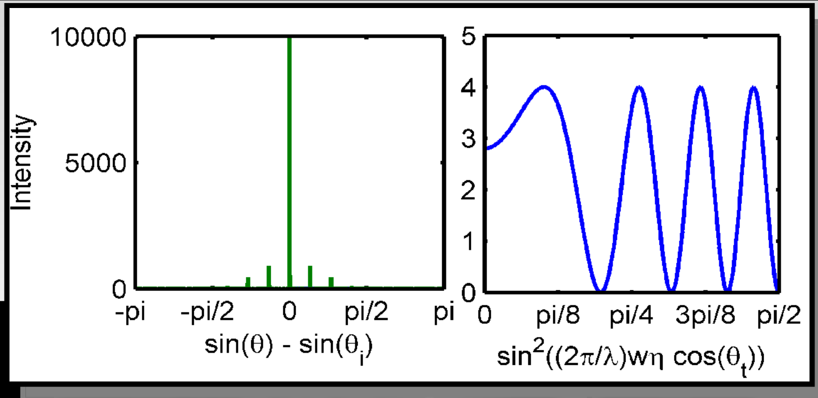
Who Am I?

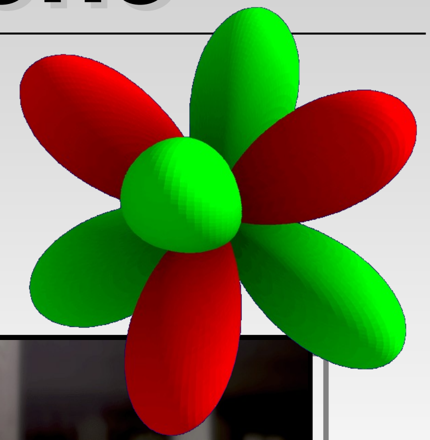
- Ph.D. Student @ WPI
- Advisor = Emmanuel
- Interests:
  - *Computational Photography*
  - *Real-time Rendering*
  - *Photorealistic Rendering*
  - *GPU Algorithms*

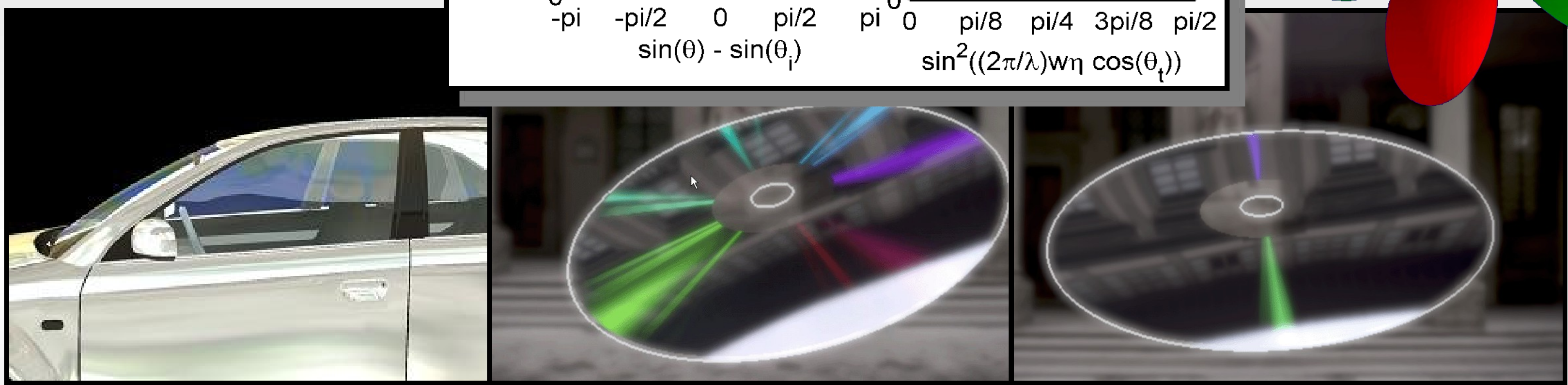
- Done: Published Papers, M.S. Thesis

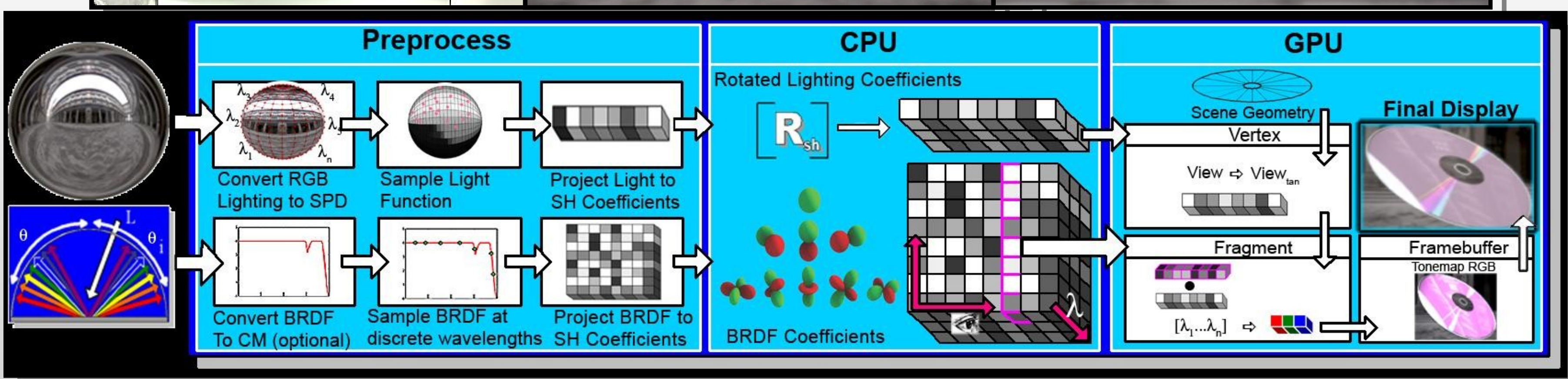
Some Work We've Done

Samples









Back To Lecture

Q: What is a Programmable GPU & Why do we need it?

A:

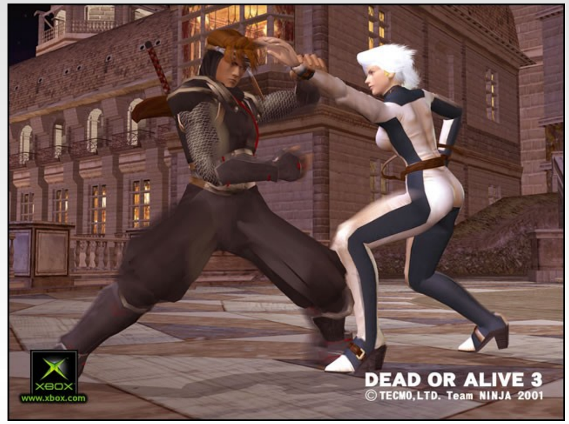
- OpenGL Fixed Function: Can only select from pre-defined effects (90's)
  - E.g. Only two shading models pre-defined
- Industry needs *flexibility* (new effects)
- GPU Shaders = programmability + access to GPU internals

History Of Real-Time Graphics

Virtua Fighter
(SEGA Corporation)

NV1
50K triangles/sec
1M pixel ops/sec

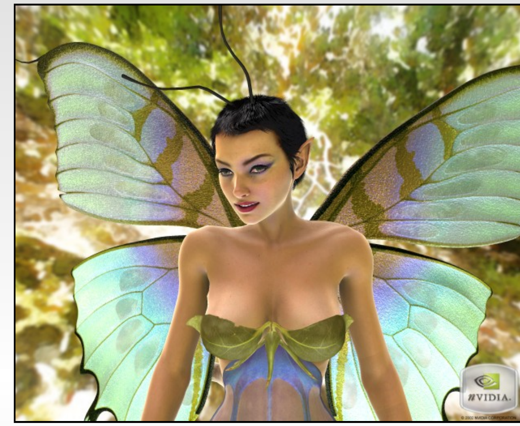
1995



Dead or Alive 3
(Tecmo Corporation)

Xbox (NV2A)
100M triangles/sec
1G pixel ops/sec

2001



Dawn
(NVIDIA Corporation)

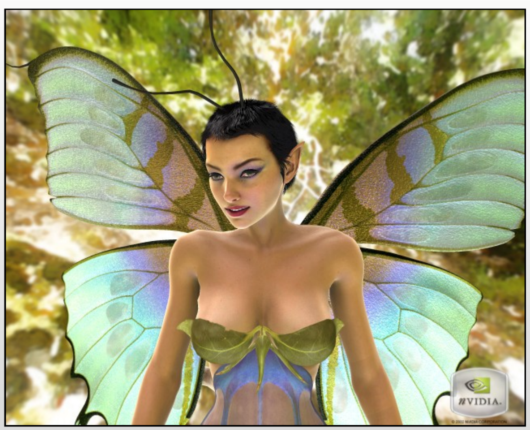
GeForce FX (NV30)
200M triangles/sec
2G pixel ops/sec

2003

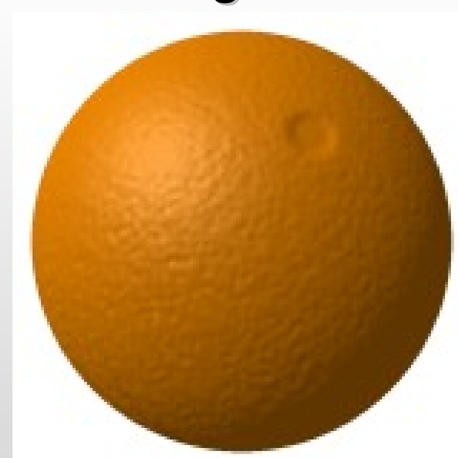
Examples of New Effects

Complex Materials

Shadowing



Lighting Environments



Advanced Mapping

History of Shading Languages

Big Players

- **RenderMan** – Pixar, software based in toy story
- **Cg** – nVidia, 1st commercial SL
- **HLSL** – M$/NVidia, Cg & Xbox project (Cg/HLSL Fork)
- **GLSL** – SGI, ARB/3DLabs
- **Stanford RTSL** - Academic SLs

Several others more recently

The Motivation for Shading Languages

- Graphics hardware has become **increasingly more powerful**
- Programming powerful hardware with **assembly code is hard**
- Most GPUs supports programs **more than 1,000 assembly instructions long**
- Programmers need the benefits of a **high-level language**:
  - Easier programming
  - Easier code reuse
  - Easier debugging

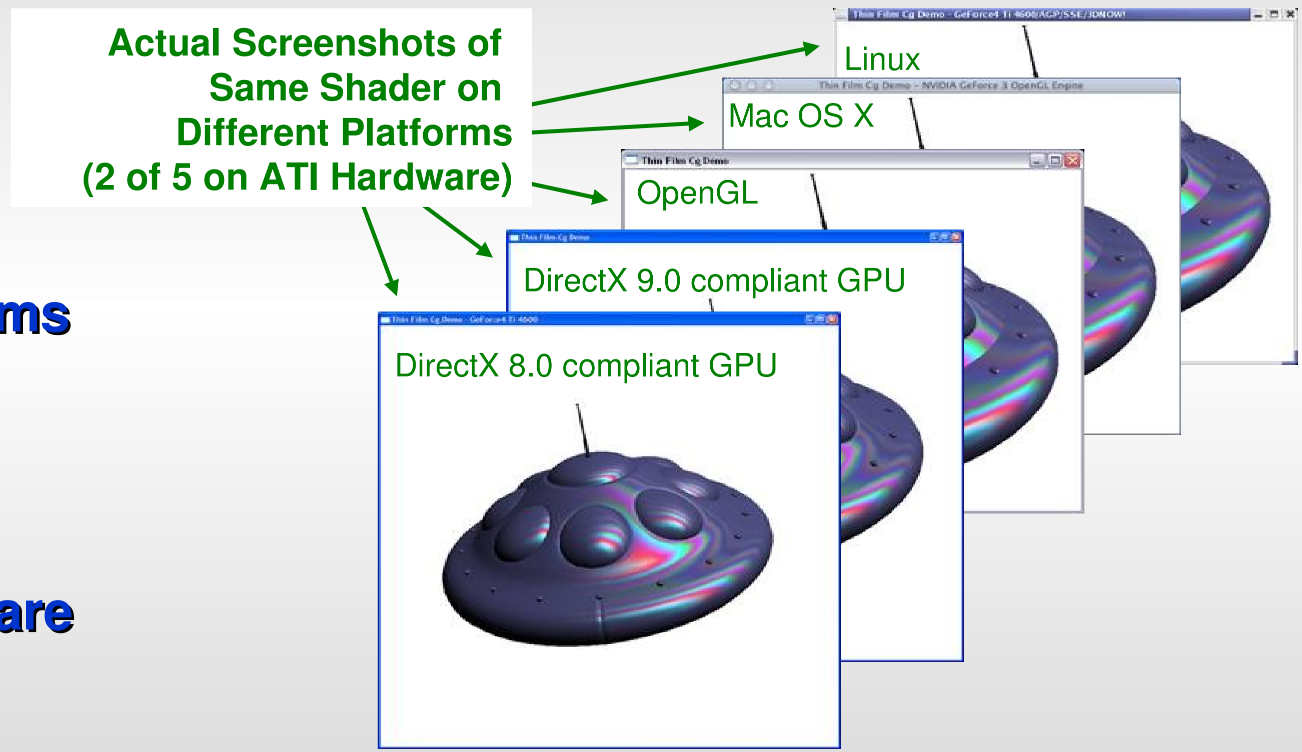
Assembly

```
…
DP3 R0, c[11].xyzx, c[11].xyzx;
RSQ R0, R0.x;
MUL R0, R0.x, c[11].xyzx;
MOV R1, c[3];
MUL R1, R1.x, c[0].xyzx;
DP3 R2, R1.xyzx, R1.xyzx;
RSQ R2, R2.x;
MUL R1, R2.x, R1.xyzx;
ADD R2, R0.xyzx, R1.xyzx;
DP3 R3, R2.xyzx, R2.xyzx;
RSQ R3, R3.x;
MUL R2, R3.x, R2.xyzx;
DP3 R2, R1.xyzx, R2.xyzx;
MAX R2, c[3].z, R2.x;
MOV R2.z, c[3].y;
MOV R2.w, c[3].y;
LIT R2, R2;
...
```

```
float3 cSpecular = pow(max(0, dot(Nf, H)),
                       phongExp).xxx;
float3 cPlastic = Cd * (cAmbient + cDiffuse) +
                  Cs * cSpecular;
```

Where Can I Use Shader Programming

- Students who learn Cg can apply their skills in a variety of situations
  - **Graphics APIs**
    - OpenGL
    - DirectX
  - **Operating Systems**
    - Windows
    - Linux
    - Mac OS
  - **Graphics Hardware**
    - NVIDIA GPUs
    - ATI GPUs
    - Other GPUs that support OpenGL and DirectX 9



Shader Pipeline

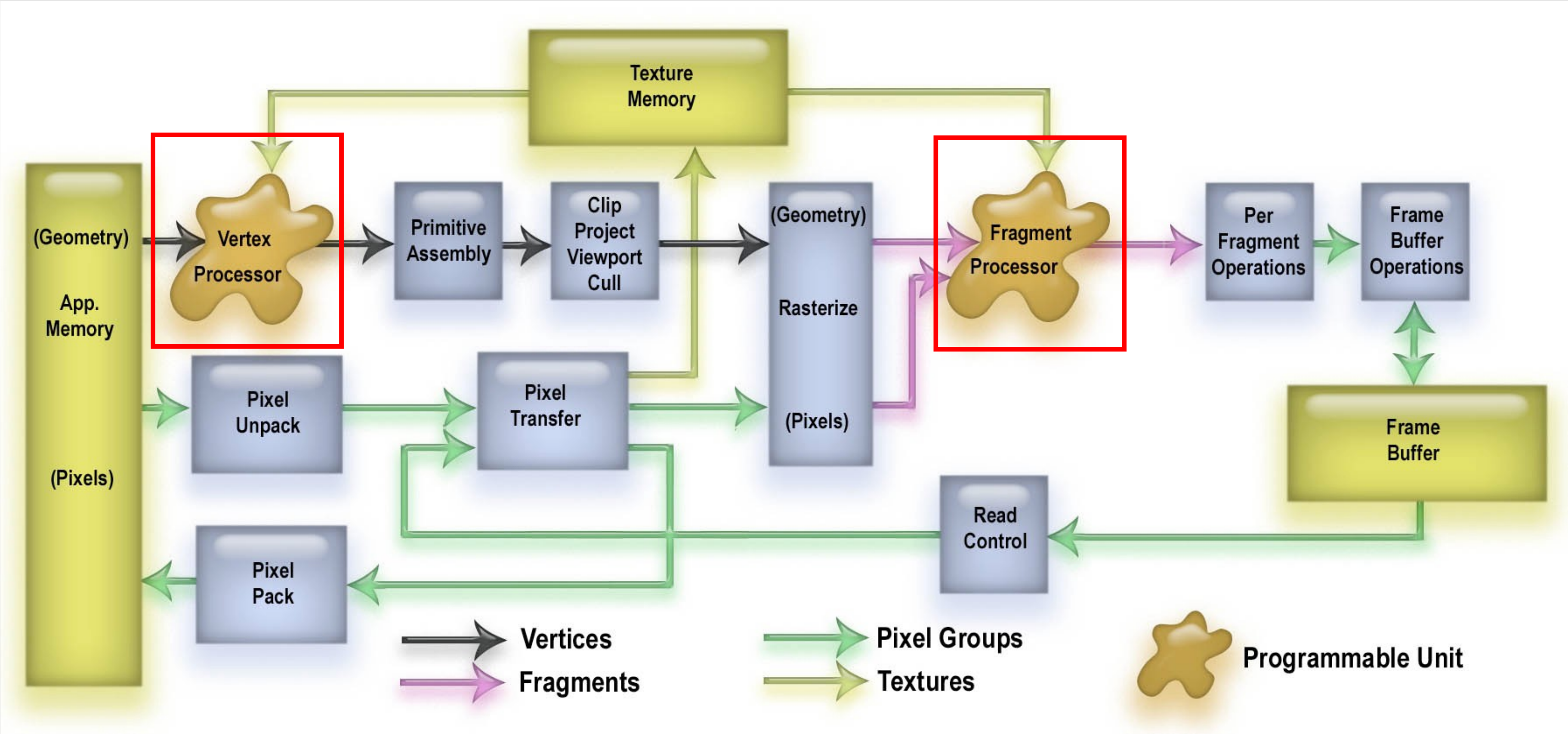
Like Traditional Hardware Graphics Pipeline

But:

- Has Programmable Stages
- Control Primitives In Pipeline
  - e.g. Skinning, Animation
- Not Limited In Rendering Style
  - Whatever Material Desired
- Decouple Rendering From Application

Shader Pipeline

Programmable Graphics Pipeline



Programmable Pipeline

Programmable Functionality

- **Exposed via small programs**
- **Language similar to c/c++**
- **Hardware support highly variable**

Vertex Shaders

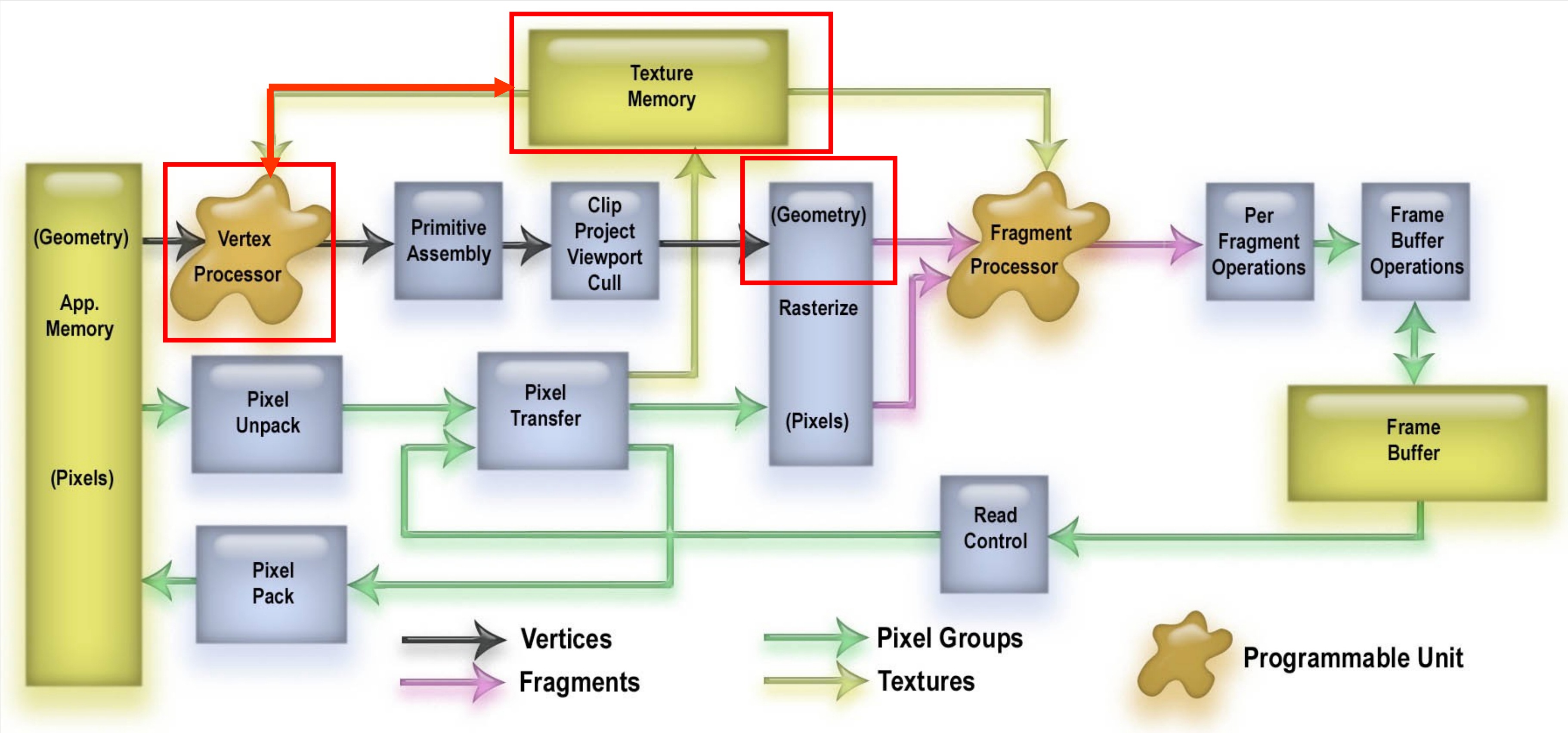
- Input: Application geometry & per vertex attributes
- Transform input in a meaningful way

Fragment Shaders

- Input: Perspective Correct Attributes (interpolated)
- Transform input into color or discard

Recent Advances

- Geometry Shaders
- Texture Fetching Within Vertex Shaders



In General

Some Fixed Functions Are Bypassed

Vertex Tasks

- Vertex Transformation
- Normal Transformation, Normalization
- Lighting
- Texture Coordinate Generation and Transformation

Fragment Tasks

- Texture accesses
- Fog
- Discard Fragment

Rendering Pipeline

- **All Operations Performed By Programmer**
- **Same Stages As Fixed Function**
- **Inject Code: Vertex & Fragment Programs**

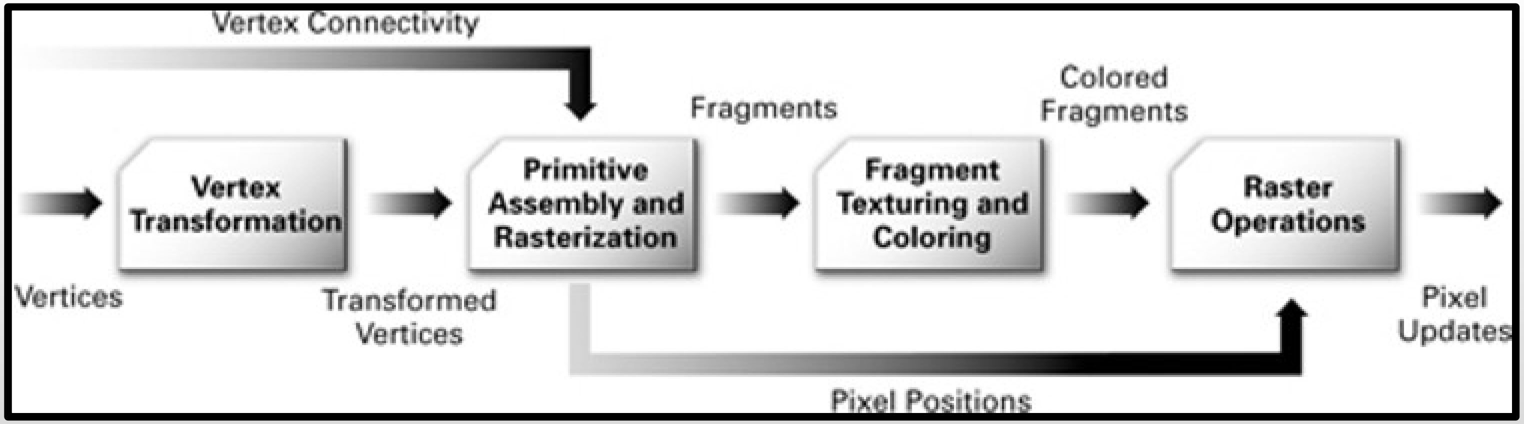


Image courtesy of Nvidia

Rendering Pipeline

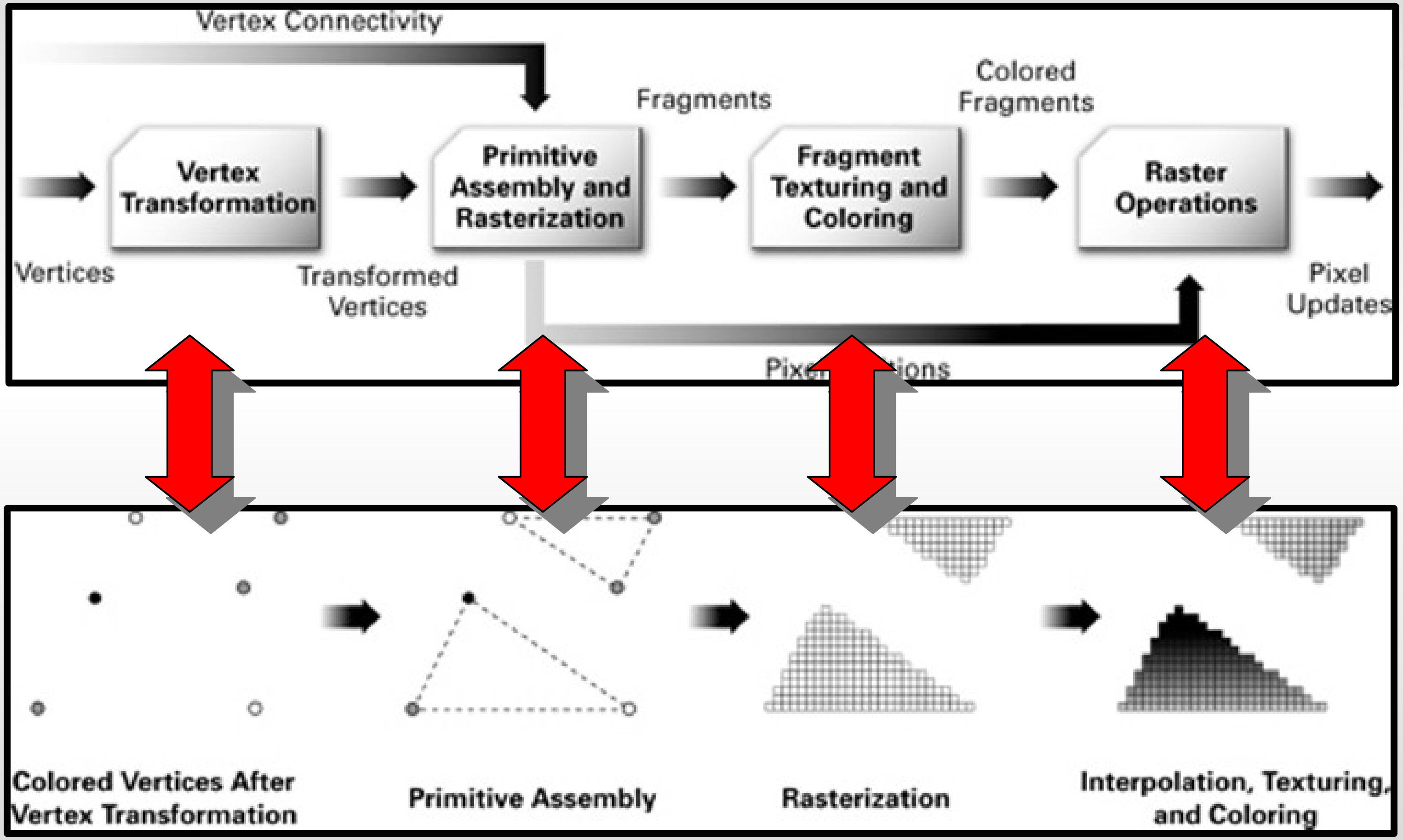


Image courtesy of Nvidia

Anatomy Of GLSL: OpenGL State

Built-in Variables

- Always prefaced with gl_
- Accessible to both vertex and fragment shaders

Uniform Variables

- Matrices (i.e. 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

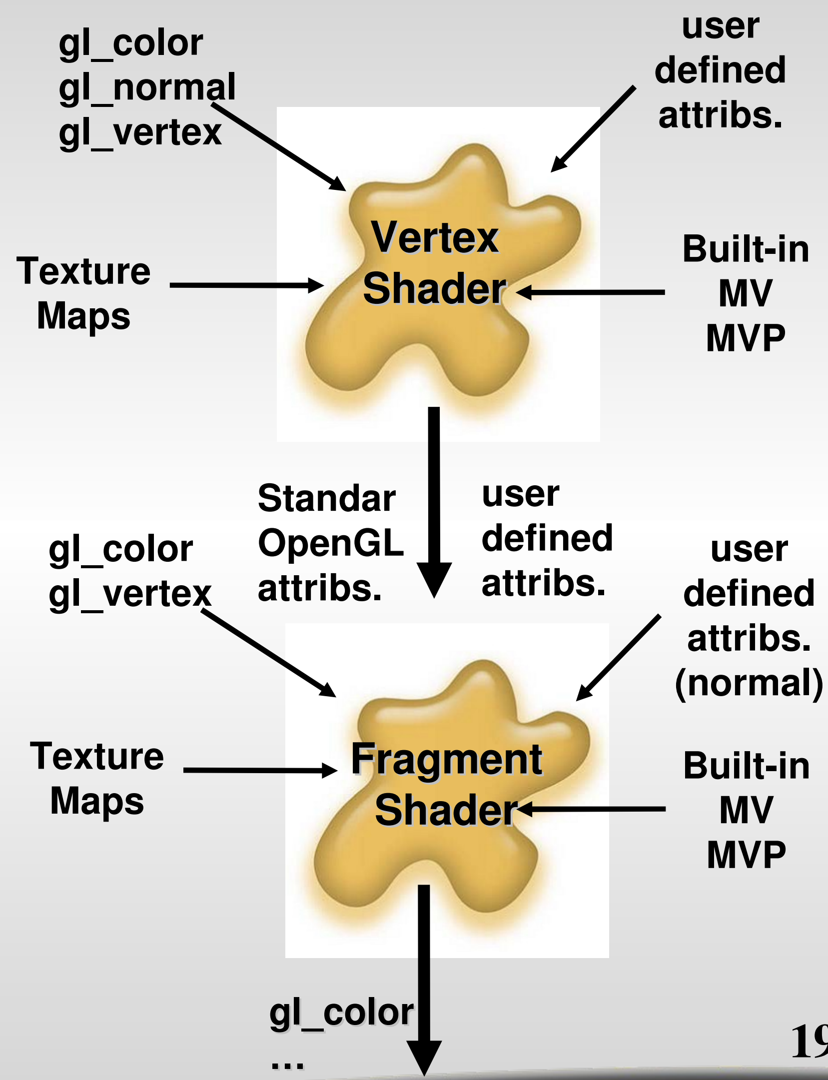
Anatomy Of GLSL: Special Vars

Vertex Shaders

- 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 Shaders

- 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

Questions?

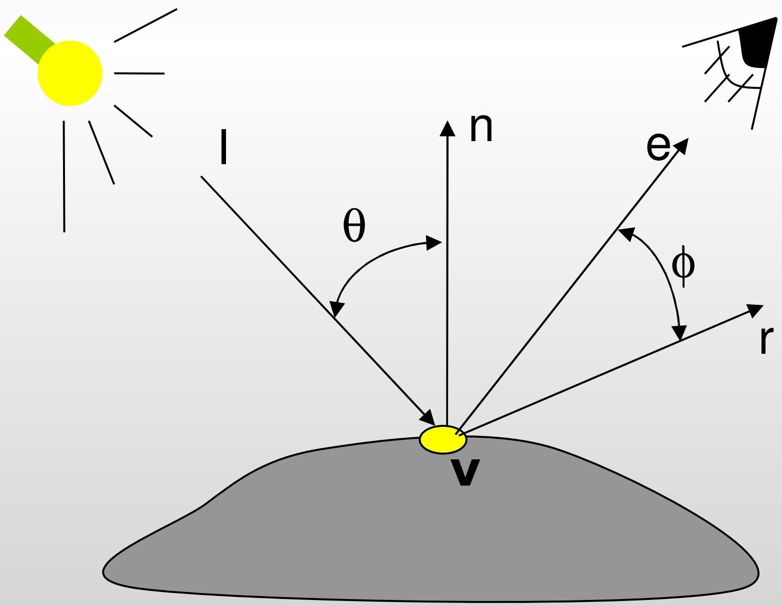
Goals

- Phong Illumination Review (1 slide)
- C/C++ Application Setup
- Vertex Shader
- Fragment Shader
- Debugging

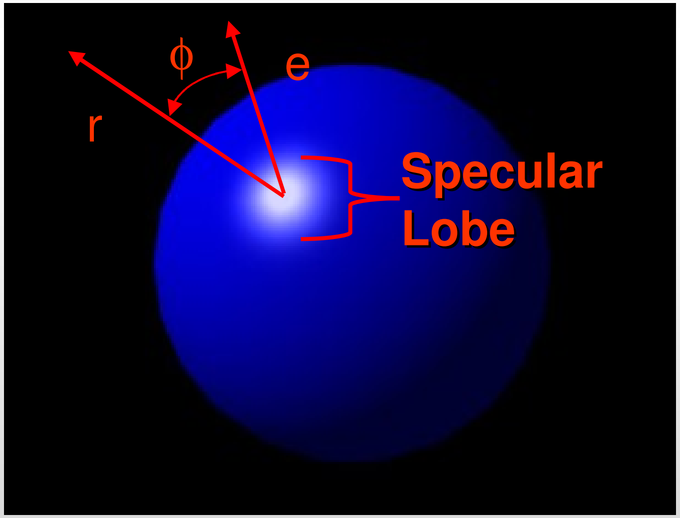
Phong Shader Review

Illum = ambient + diffuse + specular

$= Ka \times I + Kd \times I \times (\cos \theta) + Ks \times I \times \cos^n(\phi)$



[Diagram Courtesy of E. Agu]



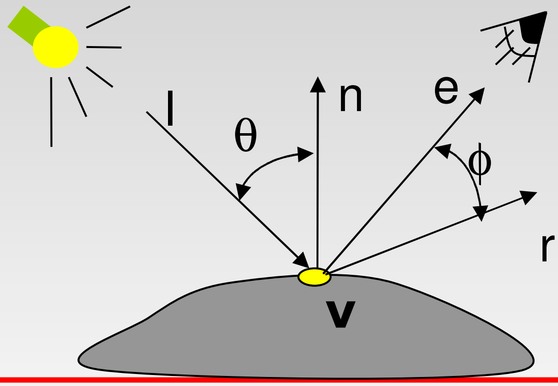
Phong Shader: Setup Steps

- **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 obj via handle
- **Step 6: Link Shaders to Programs**
  - Another step similar to attach
- **Step 7: Enable Program**
  - Finally, let GPU know shaders are ready

Phong Shader: App Setup

```
GLhandleARB phongVS, phongkFS, phongProg; // handles to objects

// Step 1: Create a vertex & fragment shader object
phongVS = glCreateShaderObjectARB(GL_VERTEX_SHADER_ARB);
phongFS = glCreateShaderObjectARB(GL_FRAGMENT_SHADER_ARB);

// Step 2: Load source code strings into shaders
glShaderSourceARB(phongVS, 1, &phongVS_String, NULL);
glShaderSourceARB(phongFS, 1, &phongFS_String, NULL);

// Step 3: Compile the vertex, fragment shaders.
glCompileShaderARB(phongVS);
glCompileShaderARB(phongFS);

// Step 4: Create a program object
phongProg = glCreateProgramObjectARB();

// Step 5: Attach the two compiled shaders
glAttachObjectARB(phongProg, phongVS);
glAttachObjectARB(phongProg, phongFS);

// Step 6: Link the program object
glLinkProgramARB(phongProg);

// Step 7: Finally, install program object as part of current state
glUseProgramObjectARB(phongProg);
```

Phong Shader: Vertex



This Shader Does

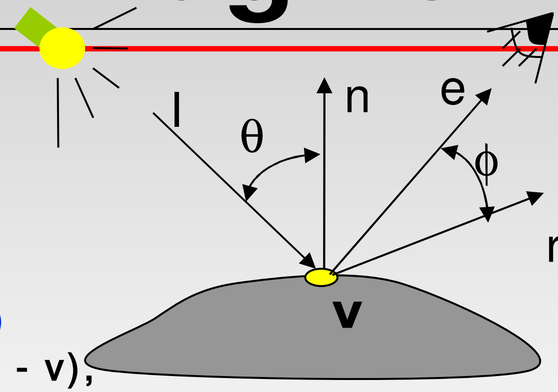
- Gives eye space location for v
- Transform Surface Normal
- Transform Vertex Location

```
varying vec3 N;
varying vec3 v;

void main(void)
{
   v = vec3(gl_ModelViewMatrix * gl_Vertex);
   N = normalize(gl_NormalMatrix * gl_Normal);

   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Created For Use Within Frag Shader

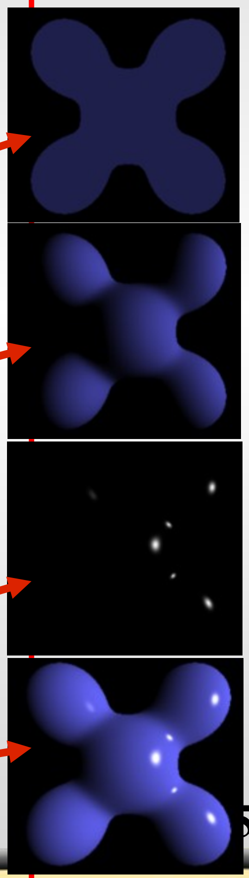
(Update OpenGL Built-in Variable for Vertex Position)

Phong Shader: Fragment




```
varying vec3 N;
varying vec3 v;

void main (void)
{
   // we are in Eye Coordinates, so EyePos is (0,0,0)
   vec3 L = normalize(gl_LightSource[0].position.xyz - v);
   vec3 E = normalize(-v);
   vec3 R = normalize(-reflect(L,N));

   //calculate Ambient Term:
   vec4 Iamb = gl_FrontLightProduct[0].ambient;

   //calculate Diffuse Term:
   vec4 Idiff = gl_FrontLightProduct[0].diffuse * max(dot(N,L), 0.0);

   // calculate Specular Term:
   vec4 Ispec = gl_FrontLightProduct[0].specular
            * pow(max(dot(R,E),0.0), gl_FrontMaterial.shininess);

   // write Total Color:
   gl_FragColor = gl_FrontLightModelProduct.sceneColor + Iamb + Idiff + Ispec;
}
```

Passed in From VS



Phong Shader: Debugging

****Many things will silently fail during setup****

- No good automatic debugging tools for GLSL yet 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{I|f}vARB (GLhandleARB shader, GLenum whatToCheck, GLfloat *statusVals)
- Subtle Problems
  - Type over flow
  - Shader too long
  - Use too many registers

Phong Shader: Demo

Click Me!

GPU: More Than RT Pipeline

- Character Animation
- Ray Tracing
- General Purpose Programming
- Game Physics

Future Of GPUs

- Super Computers On The Desktop
  - GPUs = Order Of Magnitude Than CPUs
- Mobile Computing
  - Realistic Rendering On Phones
  - Mobile Applications:
    - Automotive Computing
    - Wearable Computers
    - Cameras, Phones, E-paper, Bots, ...

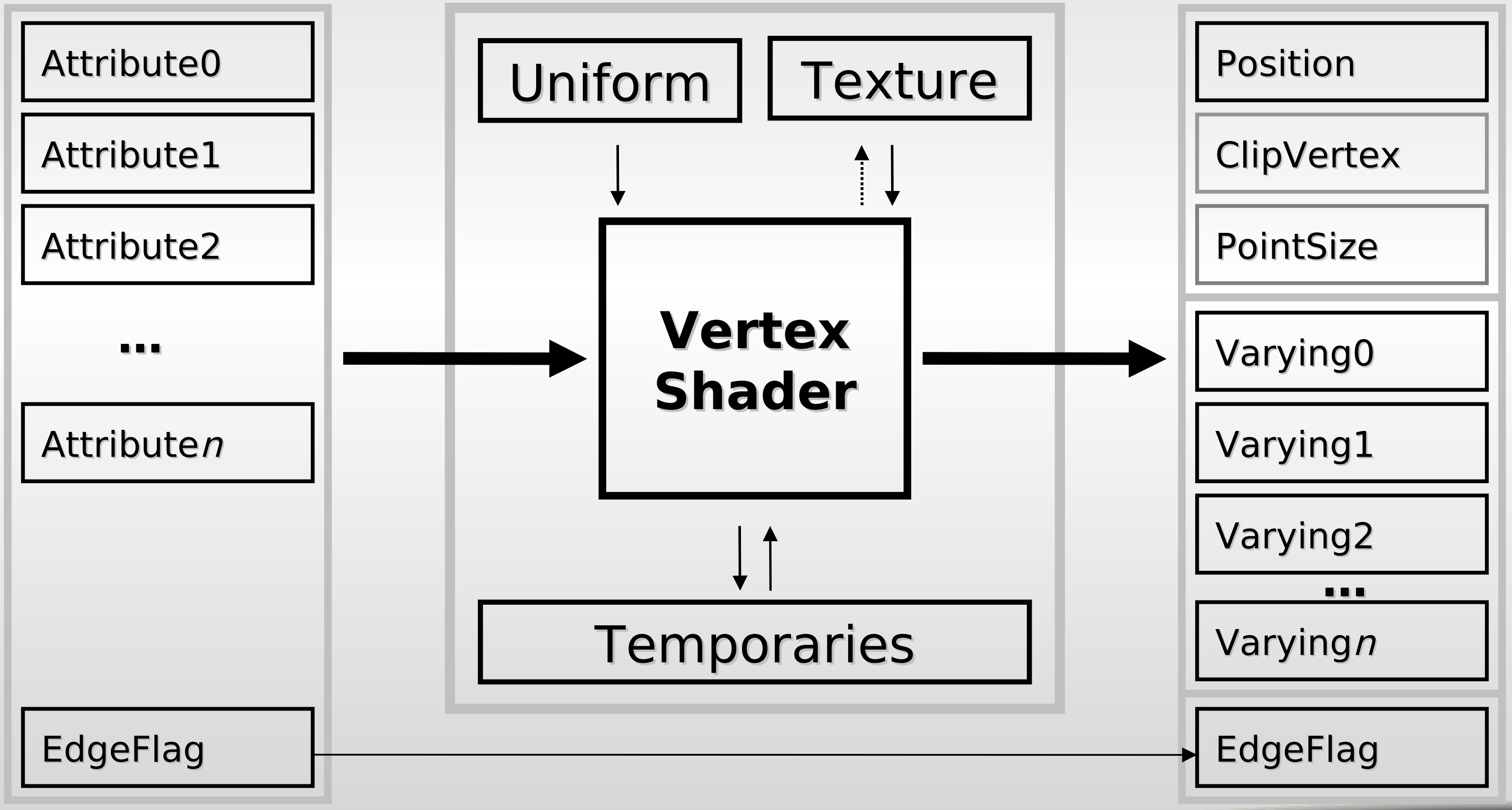
Questions?

References

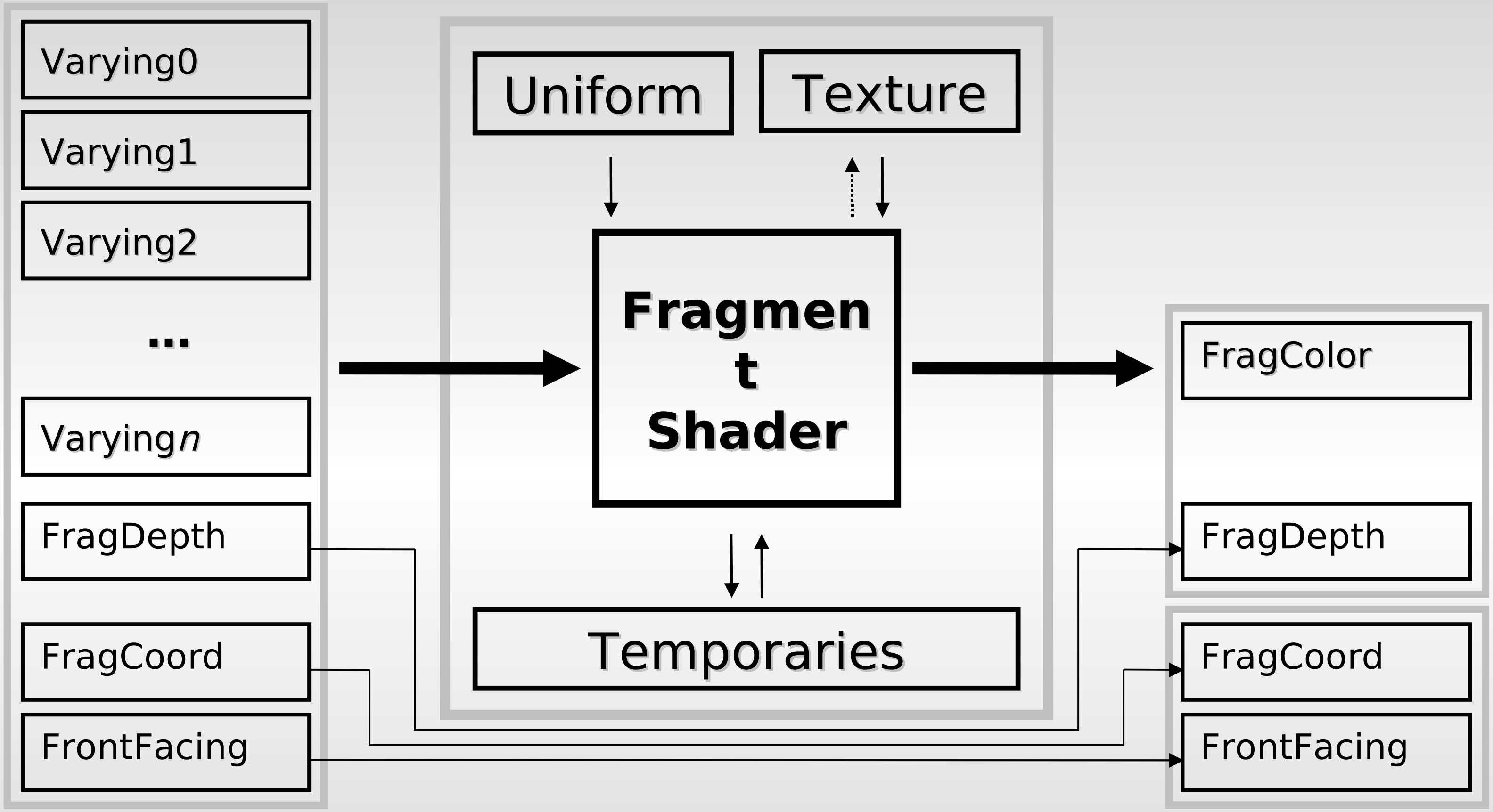
- OpenGL Shading Language (Orange Book), Randi Rost, 2004
- Intro GLSL, Talk Slides Randi Rost 3DLabs, 2005
- Intro GLSL, Teaching Slide, Mike Bailey (my ugrad graphics teacher) U of O, 2006
- Intro GLSL, Teaching Slides, Keith O'connor, GV2 (U of Dublin)
- OpenGL Shading Language, Teaching Slides, Jerry Talton, Stanford, 2006
- Real-time Shading, John Hart, 2002, AK Peters
- OpenGL 2.0 Specification, OpenGL ARB, 2004, OpenGL.org
- OpenGL Shading Language Specification, 2004, OpenGL.org
- The Cg Tutorial: The Definitive Guide to Programmable Real-Time Graphics, Randima Fernando, Mark Kilgard, 2003

Shader Vertex Processing

All value are inputs to Shaders



Shader Fragment Processing



Same as vertex, all values are input into shader