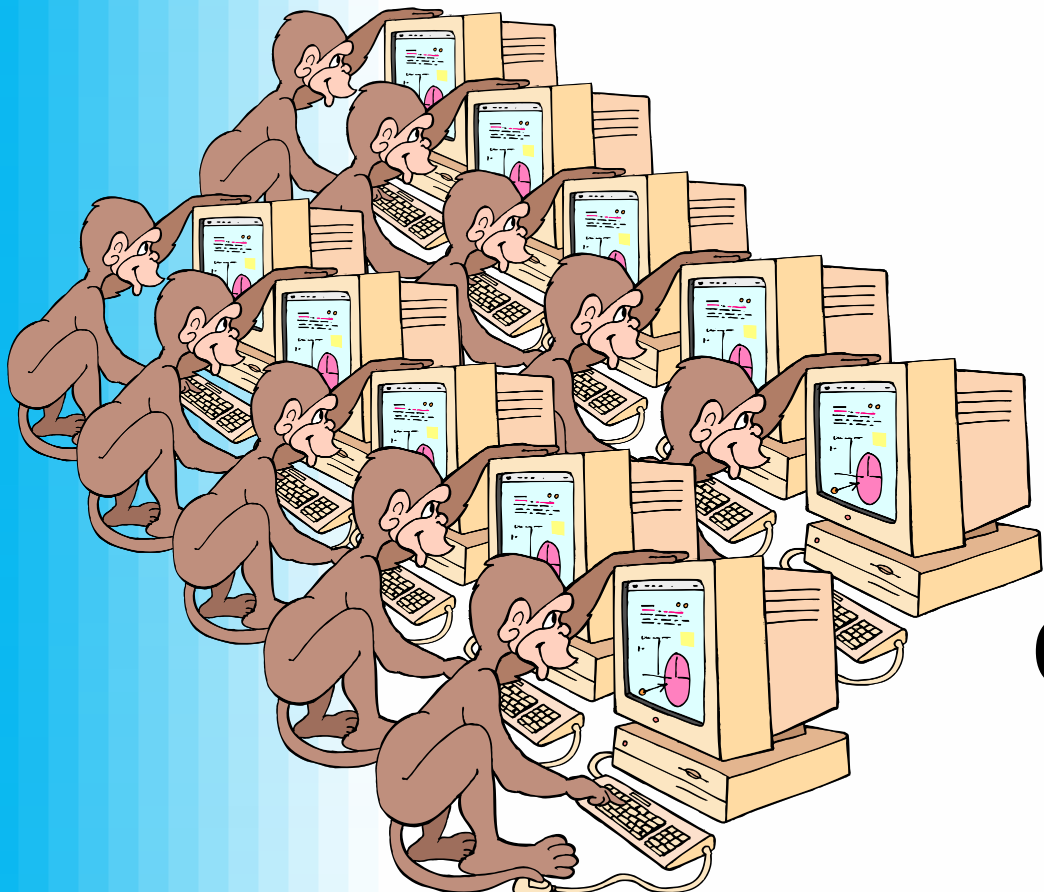
GPU Programming



- Graphics Past
- Graphics Present
- Graphics Future
- High-Level Shading Languages

CISC 440/640

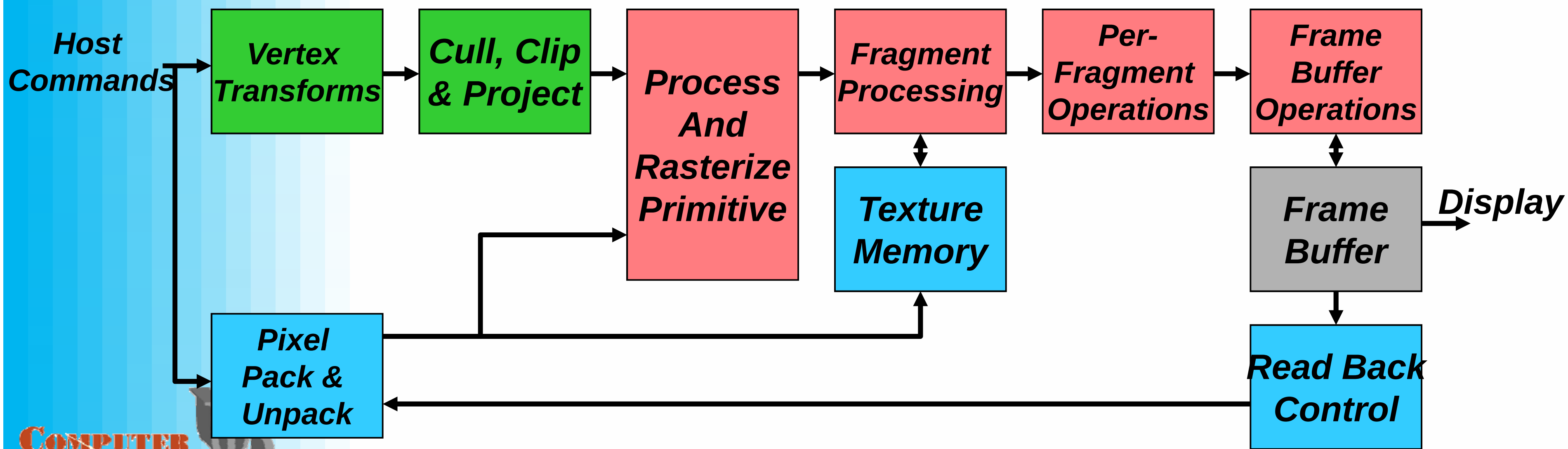
Spring 2013

Computer Graphics

Department of Computer and Information Science

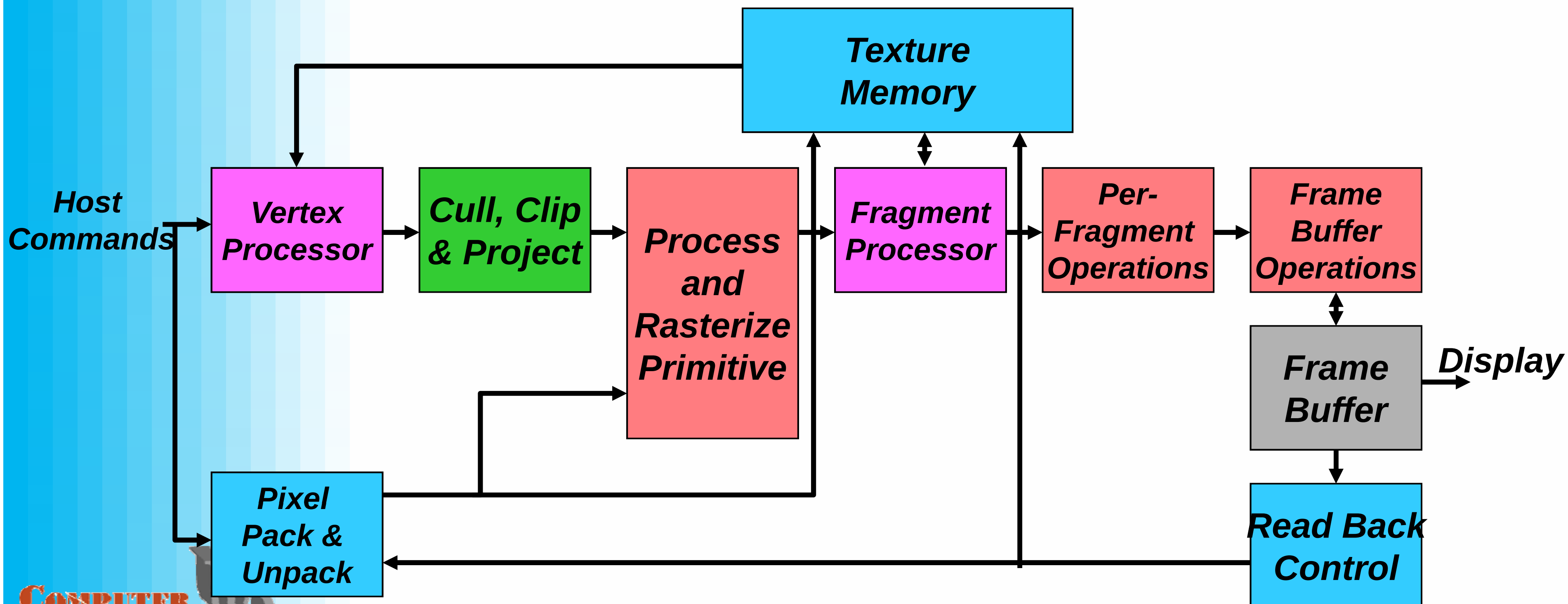
OpenGL 1.4 - Graphics Past

- Fixed-Function Graphics Pipeline with "every step neatly planned"
- PHILOSOPHY: Performance > Flexibility
- Extended by committee
- Why process anything other than polygons or the occasional pixel?



OpenGL 2.0 - Graphics Today

- Programmable Processing units
  (Exposing what was always there beneath the covers)
  - Programmable per-Vertex Processors
  - Programmable per-Fragment Processors
- Texture memory – general purpose data storage

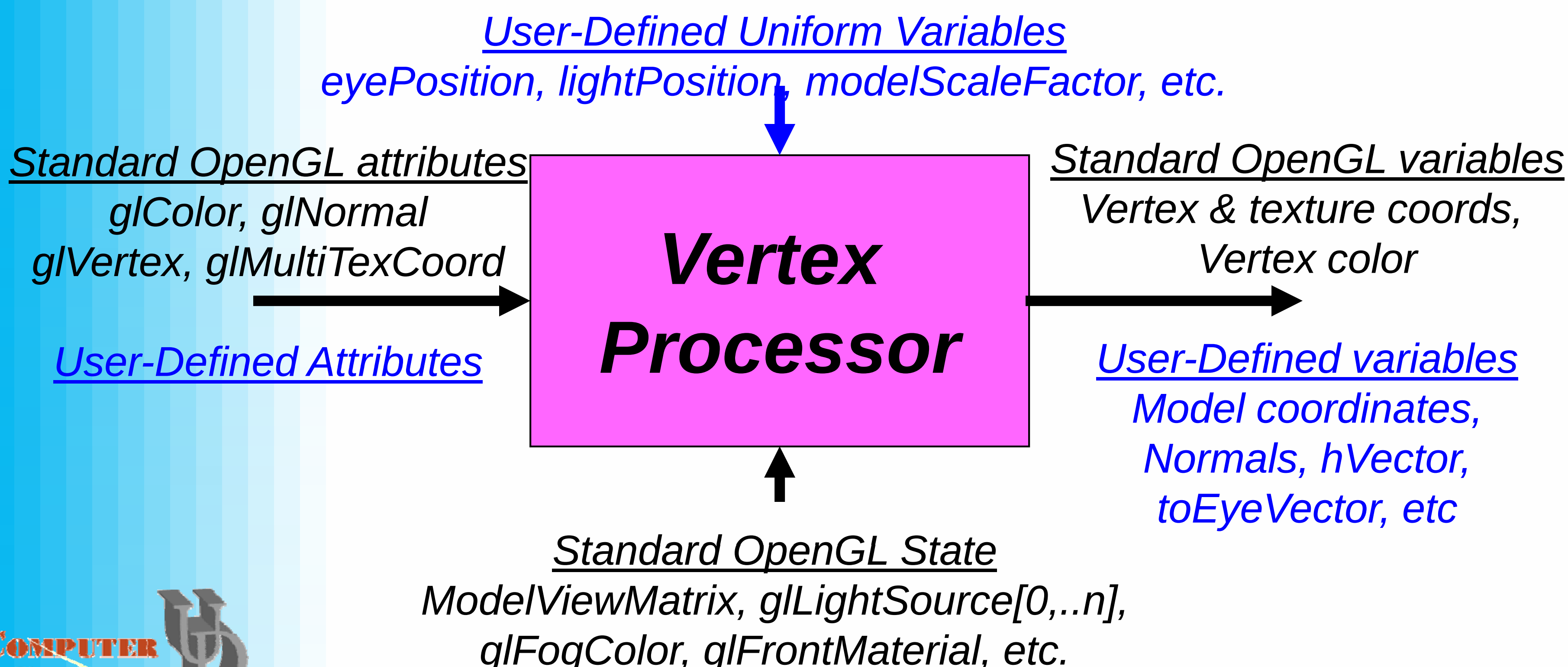


Vertex Processor Capabilities

- **Lighting, Material and Geometry flexibility**
- **Vertex programs replace the following parts of the pipeline:**
  - Vertex & Normal transformation
  - Normalization and rescaling
  - Per-Vertex Lighting Calculations
  - Color application & clamping
  - Texture coordinate generation & transformation
- **The vertex shader does NOT replace:**
  - Perspective divide and viewport (NDC) mapping
  - Clipping
  - Backface culling
  - Primitive assembly (Triangle setup, edge equations, etc.)

Vertex Processor Inputs & Outputs

- Vertex “Shader” has all of the primitive arguments available to it
- Fixed constants that are compiled into the shader
- Special variables that are rendering specific
- Writes its results into prearranged locations (registers) that are “understood” by later processing steps

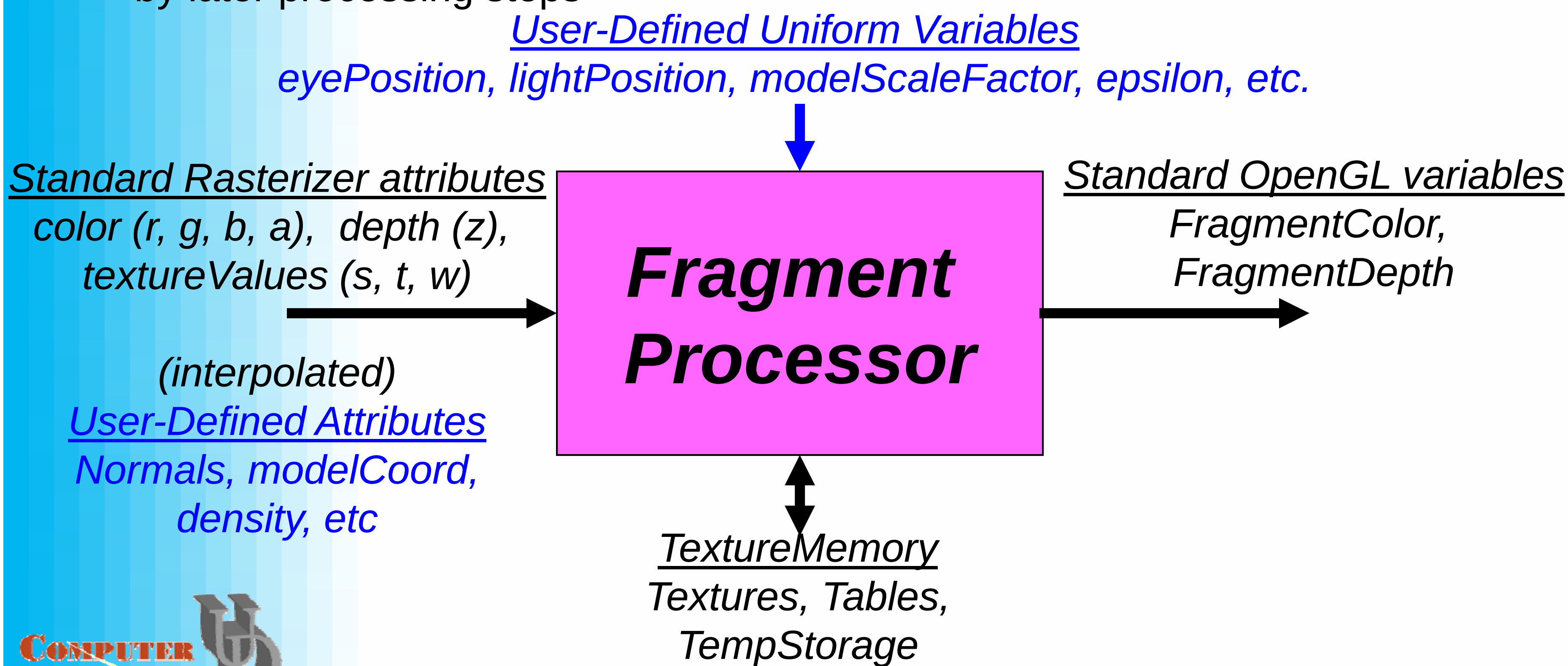


Fragment Processor Capabilities

- **Flexibility for texturing and per-pixel operations**
- **Fragment programs replace the following parts of the OpenGL pipeline:**
  - Operations on interpolated values
  - Texture access
  - Texture application (modulate, add)
  - Fog (color(depth))
  - Color sums (blends, mattes)
  - Perspective divide
  - Pixel zoom
  - Scale and bias
  - Color table lookup
  - Convolution
  - Color matrix
- **The Fragment shader does NOT replace:**
  - Scan Conversion
  - Coverage
  - Scissor
  - Alpha test
  - Stencil test
  - Logical ops
  - Plane masking
  - Histogram
  - Pixel packing and unpacking
  - Stipple
  - Depth test
  - Alpha blending
  - Dithering
  - Z-buffer replacement test

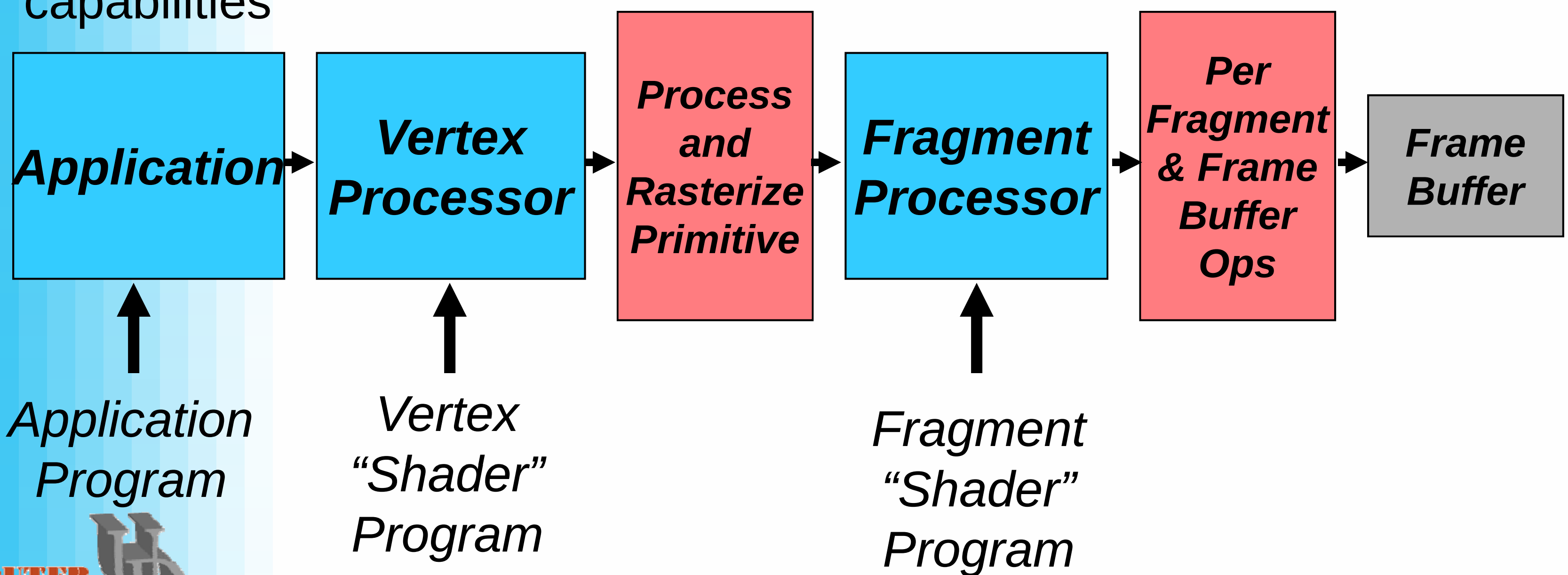
Fragment Processor Inputs & Outputs

- Fragment "Shader" has all of the rasterization arguments available to it
- Fixed constants that are compiled into the shader
- Special variables that are rendering specific
- Writes its results into prearranged locations (registers) that are "understood" by later processing steps



GPU Programmability

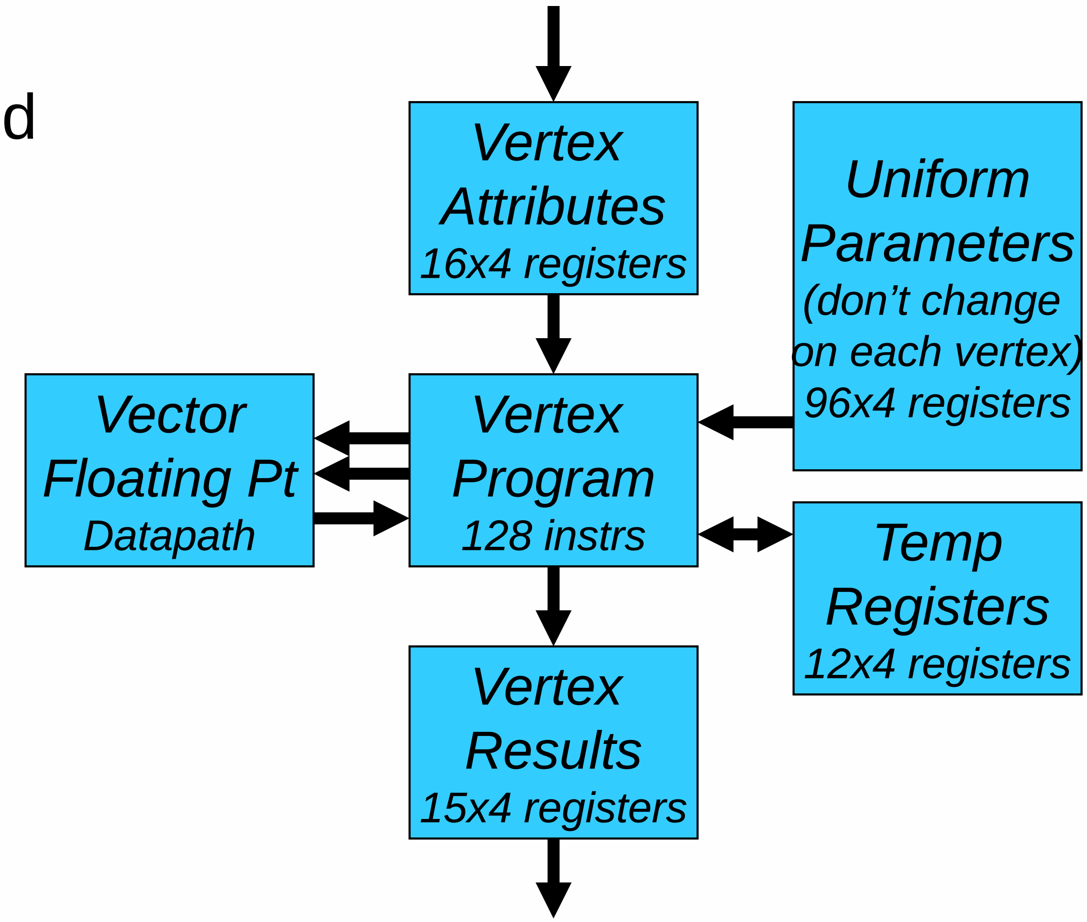
- The major innovation of the Vertex and Fragment Processors is the exposing of a programmable interface
- Initially, the Vertex and Fragment programs were written in a low-level H/W specific assembly languages, with specific capabilities (eg. floating point only in Vertex shaders, Fixed-point only in Fragment shaders)
- Trend is toward Higher-Level languages and more symmetric capabilities



Example: GeForce 3 Vertex Processor

- In the beginning, resources were limited
- It was difficult to do anything, even at the assembly level
- Useful macros
  - Vector-scalar mult
  - Vector-vector add
  - Dot-product
  - Normalize

became
the programming method of choice

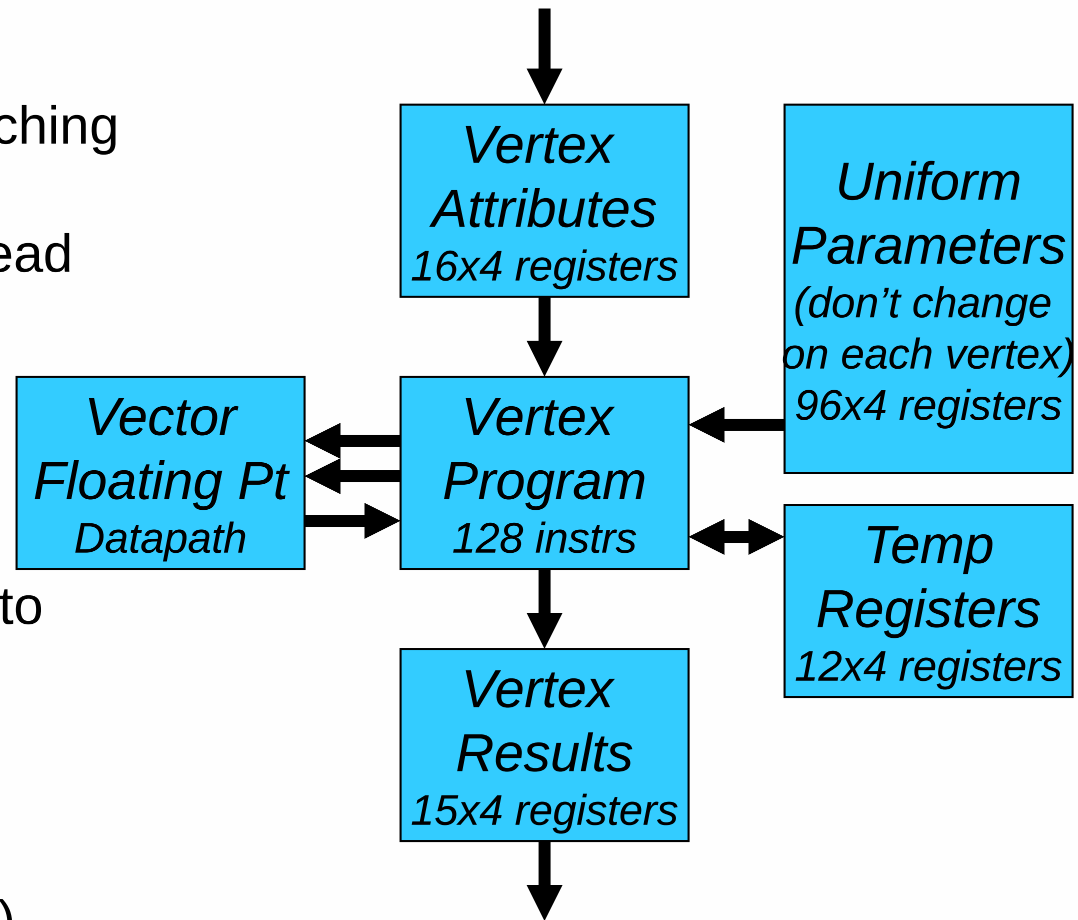


GPU/CPU Differences

- First GPUs offered no branching support
- Conditional operations instead

If (regA < 0)
    regB = regC

- No general indirect access to memory (i.e. lookup tables, textures, etc.)
- Limited Arrays (uniform parameters)
- Fixed vector sizes (2, 3 & 4)



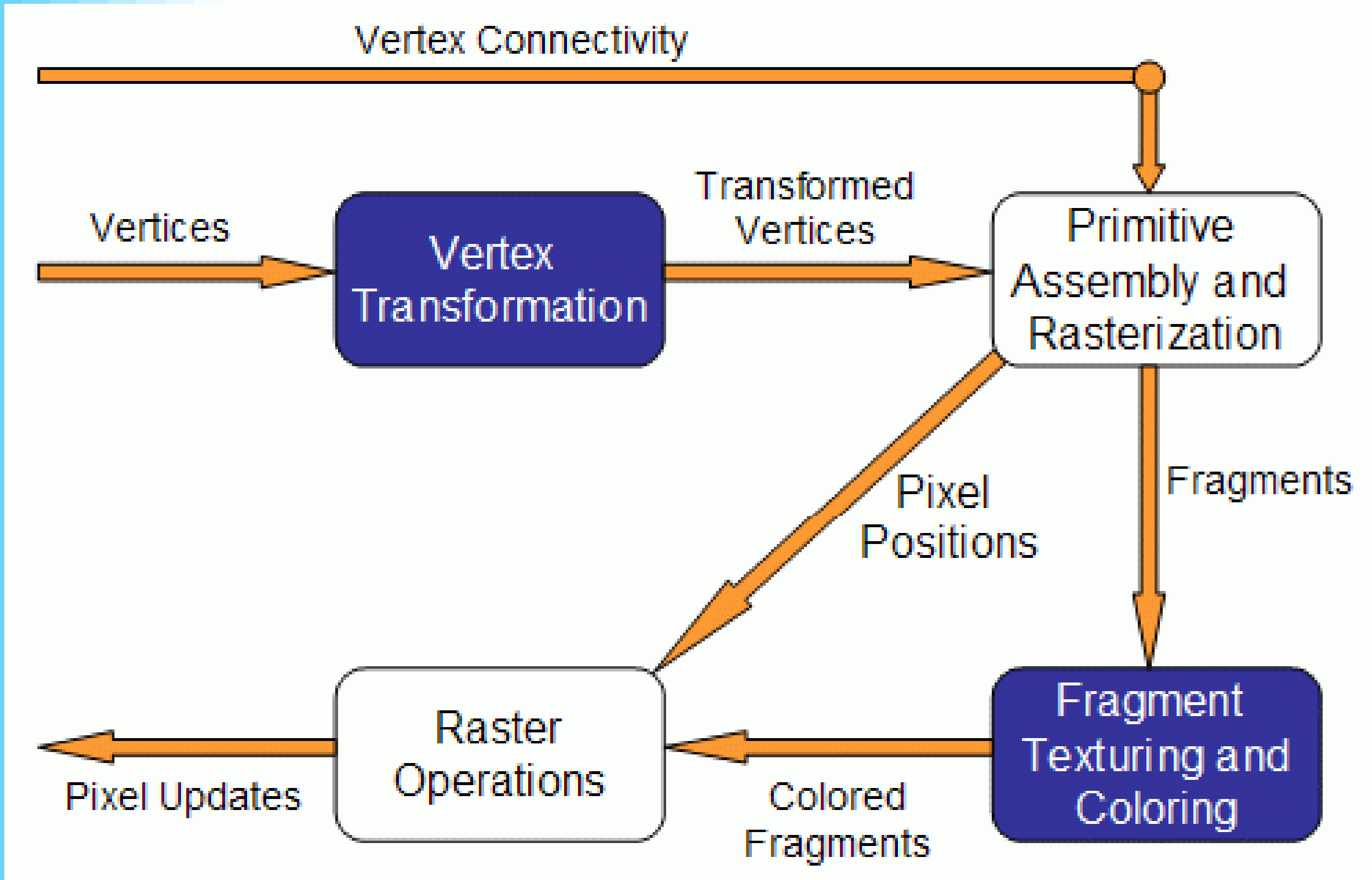
OpenGL Shading Language (GLSL)

- The end result is OpenGL Shading Language, which is a part of the OpenGL 2.0 standard (October 22, 2004)

- GLSL is commonly referred to as "*GLslang*"

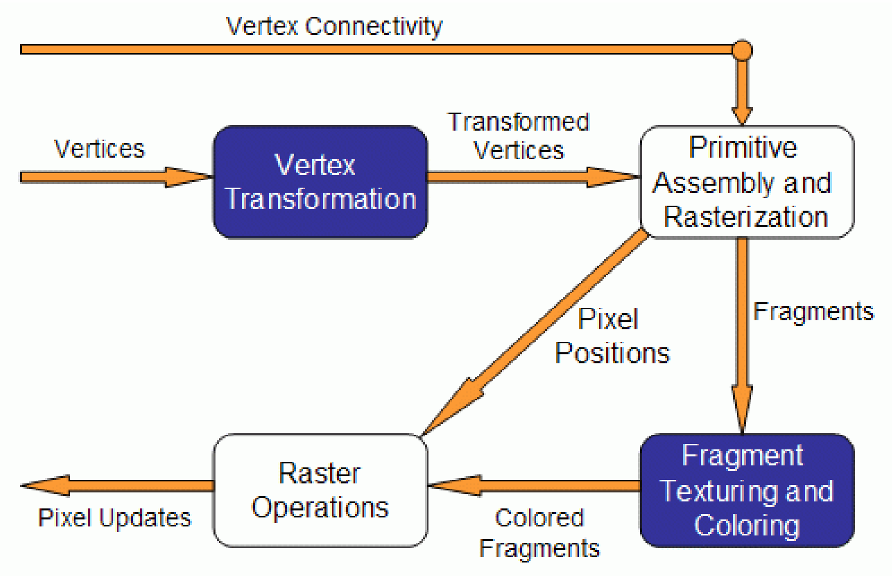
- GLSL and Cg are quite similar, with GLSL being a lot closer to OpenGL

The Graphics Pipeline



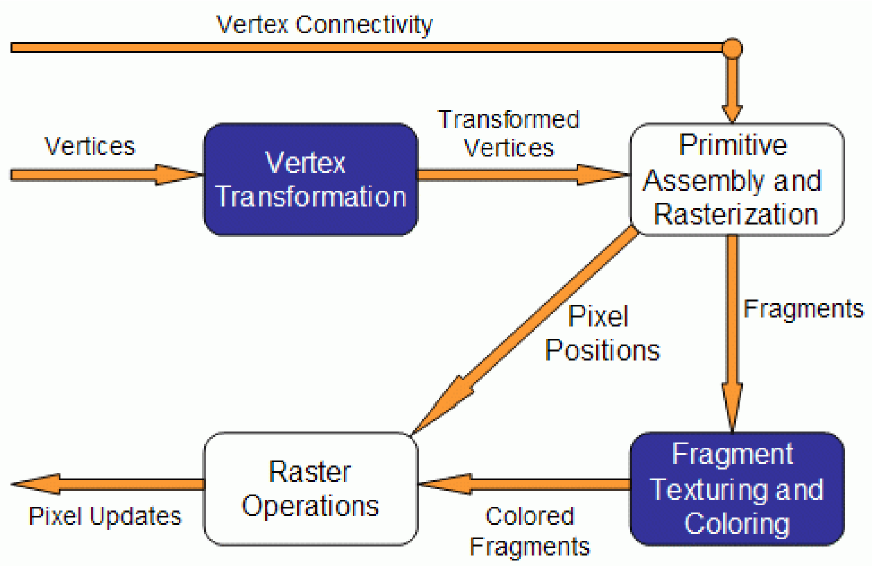
Fixed Functionality – Vertex Transformation

- A vertex is a set of attributes such as its location in space, color, normal, texture coordinates, etc.
- Inputs: individual vertices attributes.
- Operations:
  - Vertex position transformation
  - Lighting computations per vertex
  - Generation and transformation of texture coordinates



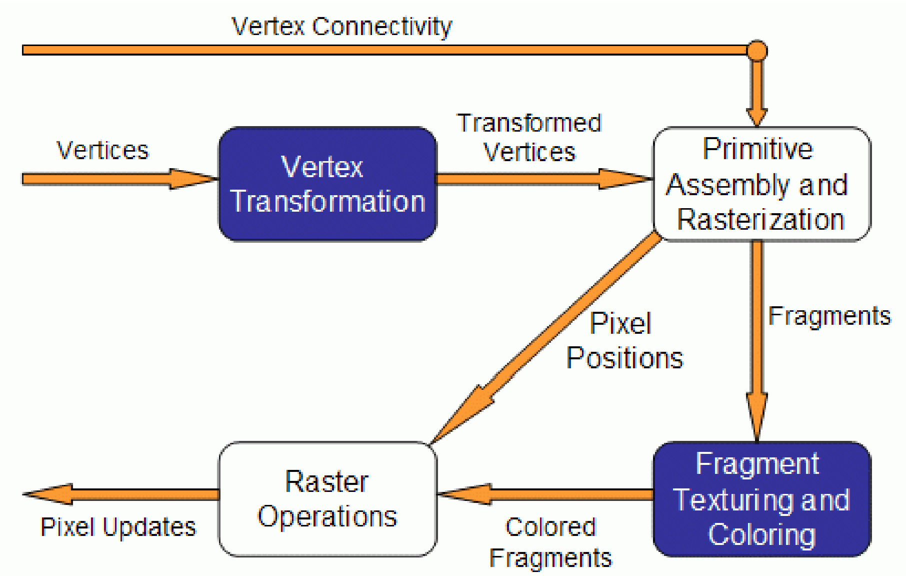
Fixed Functionality – Primitive Assembly and Rasterization

- Inputs: transformed vertices and connectivity information
- Op 1: clipping against view frustum and back face culling
- Op 2: the actual rasterization determines the fragments, and pixel positions of the primitive.
- Output:
  - position of the fragments in the frame buffer
  - interpolated attributes for each fragment



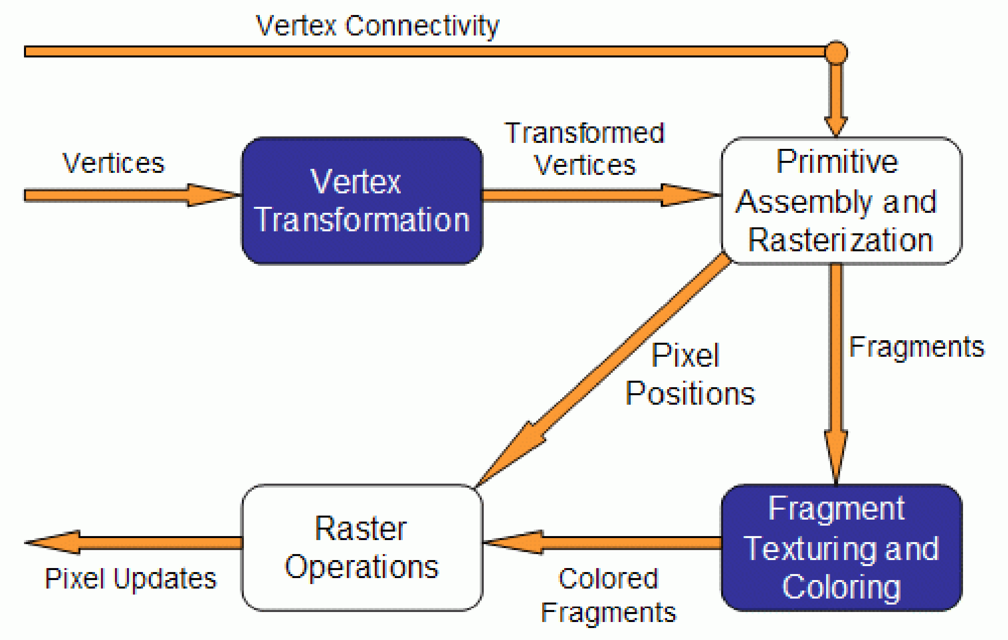
Fixed Functionality – Fragment Texturing and Coloring

- Input: interpolated fragment information
- A color has already been computed in the previous stage through interpolation, and can be combined with a texel
- Texture coordinates have also been interpolated in the previous stage. Fog is also applied at this stage.
- Output: a color value and a depth for each fragment.



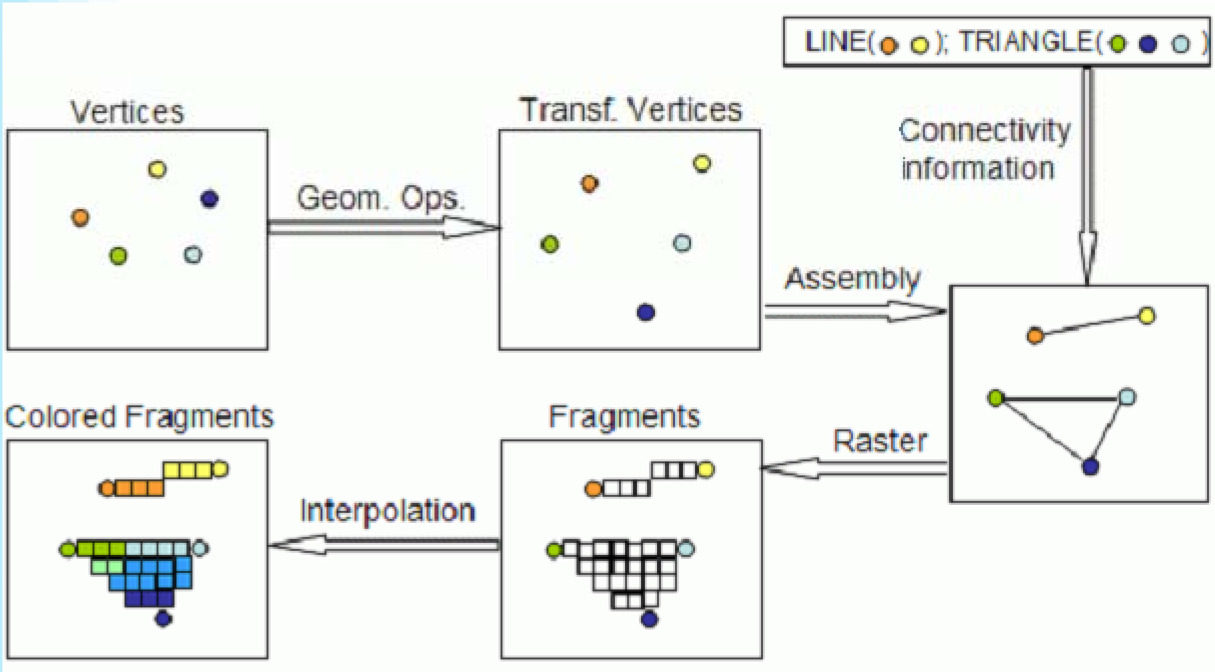
Fixed Functionality – Raster Operations

- Inputs:
  - pixels location
  - fragments depth and color values
- Operations:
  - Scissor test
  - Alpha test
  - Stencil test
  - Depth test



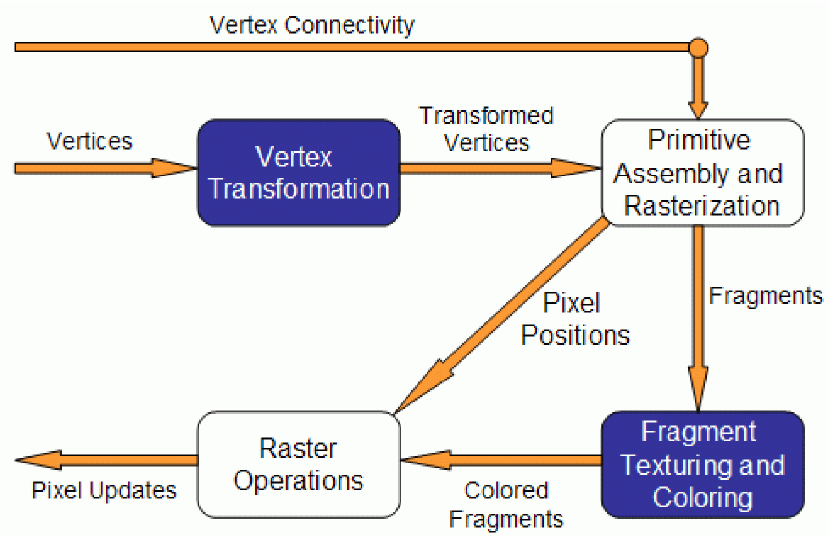
Fixed Functionality

- A summary (common jargons: T&L, Texturing etc.)



Replacing Fixed Functionalities

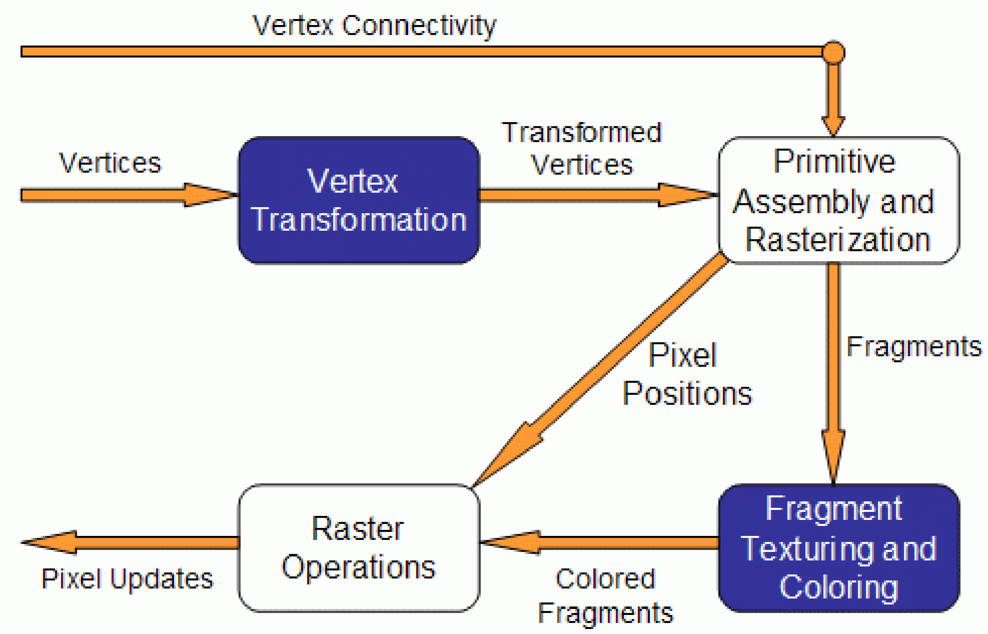
- Vertex Transformation stage: vertex shaders
- Fragment Texturing and Coloring stage: fragment shaders
- Obviously, if we are replacing fixed functionalities with programmable shaders, “stage” is not a proper term any more
- From here on, let’s call them vertex processors and fragment processors



Vertex Processors

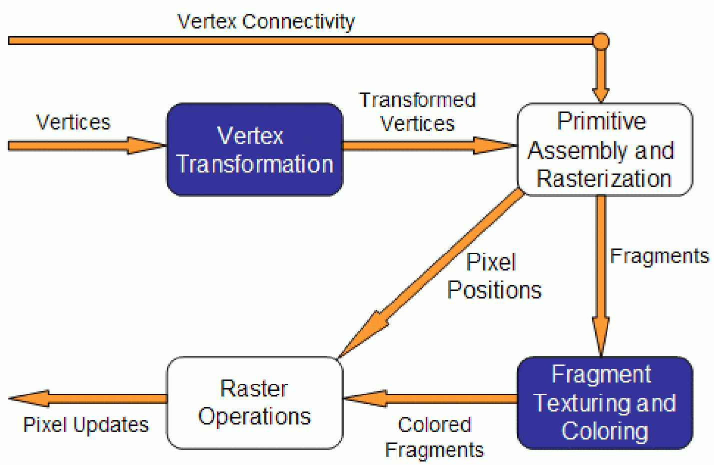
- The vertex processor is where the vertex shaders are run
- Input: the vertex data, namely its position, color, normals, etc, depending on what the OpenGL application sends
- A piece of code that sends the inputs to vertex shader:

```
glBegin(...);
glColor3f(0.2,0.4,0.6);
glVertex3f(-1.0,1.0,2.0);
glColor3f(0.2,0.4,0.8);
glVertex3f(1.0,-1.0,2.0);
glEnd();
```



Vertex Processors

- In vertex shaders, sample tasks to perform include:
  - vertex position transformation using the modelview and projection matrices
  - normal transformation, and if required its normalization
  - texture coordinate generation and transformation
  - lighting per vertex or computing values for lighting per pixel
  - color computation
- Note:
  - it is not required that your vertex shader does any particular task
  - no matter what vertex shader is provided, you have already replaced the entire fixed functionality for vertex transformation stage



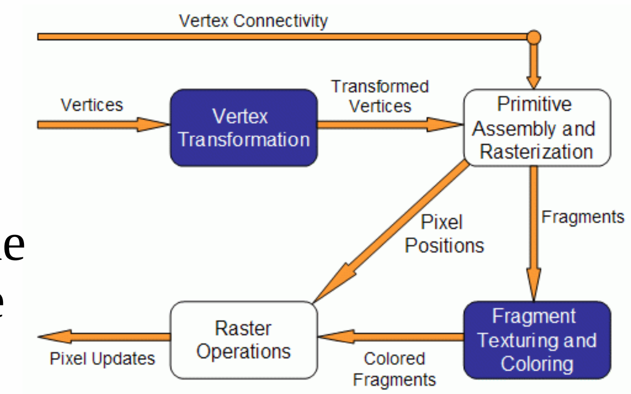
Vertex Processors

- The vertex processor processes vertices individually and has no information regarding connectivity, no operations that require topological knowledge can't be performed in here.
  – for example, no back face culling
- The vertex shader must write at least a variable: *gl_Position*
  – often transforming with modelview and projection matrices
- A vertex processor has access to OpenGL states
  – so it can do lighting and use materials.
- A vertex processor can access textures (not on all hardware).
- A vertex processor cannot access the frame buffer.

Fragment Processors

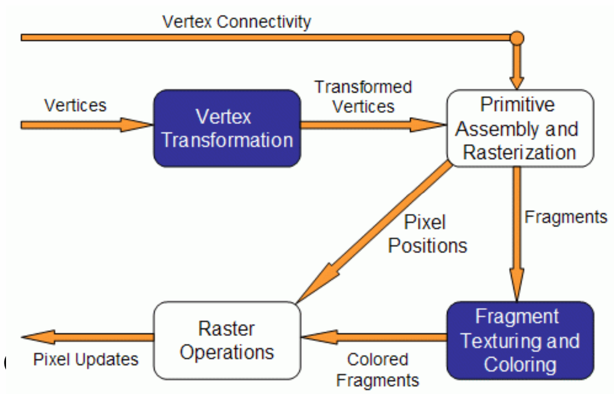
- Inputs: the interpolated values computed in the previous stage of the pipeline
  - e.g. vertex positions, colors, normals, etc...
- Note, in the vertex shader these values are computed per vertex. Here we're interpolating for the fragments
- When you write a fragment shader it replaces all the fixed functionality. The programmer must code all effects that the application requires.

- A fragment shader has two output options:
  - to discard the fragment, hence outputting nothing
  - to compute either *gl_FragColor* (the final color of the fragment), or *gl_FragData* when rendering to multiple targets.



Fragment Processors

- The fragment processor operates on single fragments, i.e. it has no clue about the neighboring fragments.
- The shader has access to OpenGL states
  - Note: a fragment shader has access to but cannot change the pixel coordinate. Recall that modelview, projection and viewport matrices are all used before the fragment processor.
- Depth can also be written but not required
- Note the fragment shader has no access to the frame buffer
- Operations such as blending occur only after the fragment shader has run.



Using GLSL

- If you are using OpenGL 2.0, GLSL is part of it
- If not, you need to have two extensions:

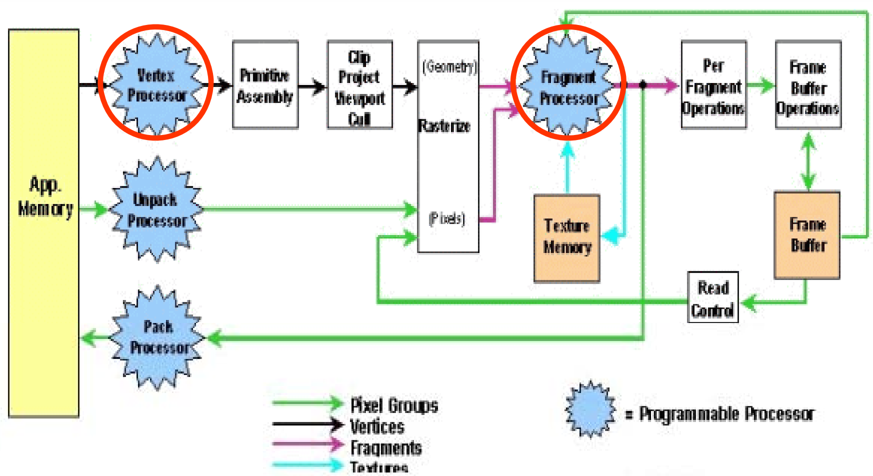
  GL_ARB_fragment_shader

  GL_ARB_vertex_shader

- In OGL 2.0, the involved functions and symbolic constants do not have "ARB" in the name any more.

Shader Review

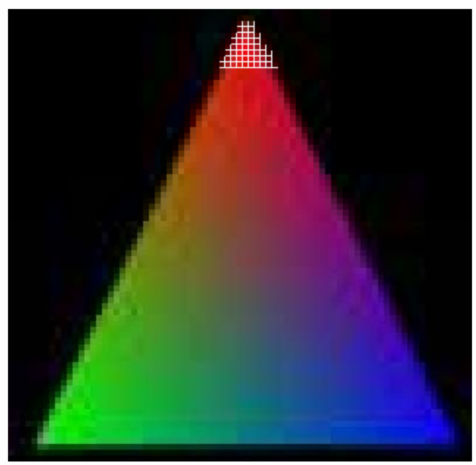
- Hardware
  - Video cards only [300,650]Mhz (CPUs are 2-4Ghz) but [2,16] vertex, [8,48] fragment processors
    - Fragment Programs: FX1000:8x300=2.4Ghz; 7800GT: 20x400Mhz=8.0Ghz
  - SLI for 2-4 video cards (www.tomshardware.com)



Shader Review

- Programming GPU:
  – Store data as texture (similar to 2D array)
  – RoT: data structures, kernels, matrices, reduce communication, reduce conditionals

```
int glutDisplay()
{
    glClear(GL_COLOR_BUFFER_BIT |
            GL_DEPTH_BUFFER_BIT);
    glLoadIdentity();
    glTranslatef(-1.5f,0.0f,-6.0f);
    glBegin(GL_TRIANGLES)
        glColor3f(1.0f,0.0f,0.0f);
        glVertex3f( 0.0f, 1.0f, 0.0f);
        glColor3f(0.0f,1.0f,0.0f);
        glVertex3f(-1.0f,-1.0f, 0.0f);
        glColor3f(0.0f,0.0f,1.0f);
        glVertex3f( 1.0f,-1.0f, 0.0f);
    glEnd();
}
```



Triangle
~3,042 pixels
Each pixel processed by fragment processor each frame

Shader Review

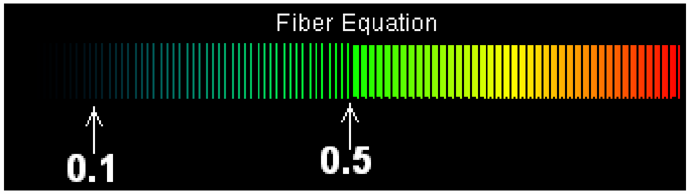
- GPU uses:
  - Games often use for custom lighting, dynamic contrast, etc.
  - Shader programs: 3-100 lines of code (10 avg.)
  - General uses: particle engines, illumination, signal processing, image compression, computer vision, sorting/searching

    (www.gpgpu.org)

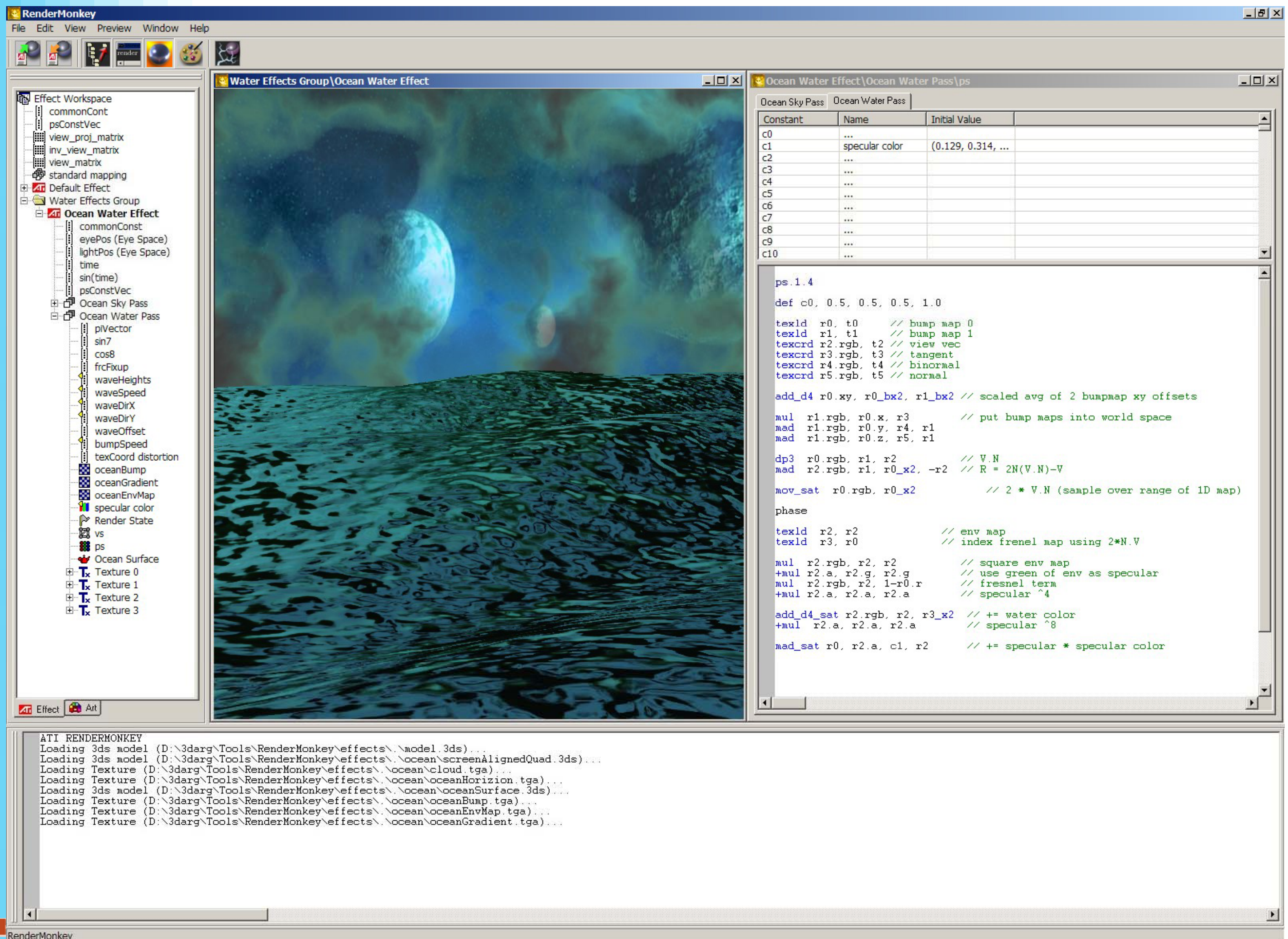
Example Shader

```
uniform int viewIndex;
uniform sampler1D clutTexture;
uniform float alphaThresh;

void main(void)
{
	vec4 color;
	float mainIndex;
	if(viewIndex==0)
		gl_FragColor=vec4 (0.95, 0.95, 0.95, 1.0);
	else if (viewIndex==4) {
		if(gl_TexCoord[0].x<0) discard;
		//Compute the RGBA color
		mainIndex = clamp(gl_TexCoord[0].x,0.0,1.0);
		color = vec4(
			texture1D(clutTexture, mainIndex));
		color.a = smoothstep(alphaThresh-0.4,
				alphaThresh,gl_FragColor.a);
		gl_FragColor = color;
	}
}
```



Enter the GPU IDE



ATI RenderMonkey

- Integrated Shader Development Environment
  - Interactive Preview window-- lets you see the impact of your shader changes immediately
  - Supports HLSL, Cg, and OpenGL Slang
  - Separate editor windows for vertex and fragment shading code
  - Support generation of artwork (textures, color palettes, MIPmaps)
  - Built-in host application that allows loading geometry
  - Built-in disassembler
  - Error checking but not Debugging
- Free download at
  - http://www.ati.com/developer/sdk/radeonSDK/html/Tools/RenderMonkey.html

ATI RenderMonkey

GLSL Data Types

- Three basic data types in GLSL:
  - float, bool, int
  - float and int behave just like in C,and bool types can take on the values of true or false.
- Vectors with 2,3 or 4 components, declared as:
  - vec{2,3,4}: a vector of 2, 3,or 4 floats
  - bvec{2,3,4}: bool vector
  - ivec{2,3,4}: vector of integers
- Square matrices 2x2, 3x3 and 4x4:
  - mat2
  - mat3
  - mat4

GLSL Data Types

- A set of special types are available for texture access, called sampler
  - sampler1D - for 1D textures
  - sampler2D - for 2D textures
  - sampler3D - for 3D textures
  - samplerCube - for cube map textures
- Arrays can be declared using the same syntax as in C, but can't be initialized when declared. Accessing array's elements is done as in C.
- Structures are supported with exactly the same syntax as C

```
struct dirlight
{
        vec3 direction;
        vec3 color;
};
```

GLSL Variables

- Declaring variables in GLSL is mostly the same as in C

```
float a,b; // two vector (yes, the comments are like in C)
int c = 2; // c is initialized with 2
bool d = true; // d is true
```

- Differences: GLSL relies heavily on constructor for initialization and type casting

```
float b = 2; // incorrect, there is no automatic type casting
float e = (float)2;// incorrect, requires constructors for type casting
int a = 2;
float c = float(a); // correct. c is 2.0
vec3 f; // declaring f as a vec3
vec3 g = vec3(1.0,2.0,3.0); // declaring and initializing g
```

- GLSL is pretty flexible when initializing variables using other variables

```
vec2 a = vec2(1.0,2.0);
vec2 b = vec2(3.0,4.0);
vec4 c = vec4(a,b) // c = vec4(1.0,2.0,3.0,4.0);
vec2 g = vec2(1.0,2.0);
float h = 3.0;
vec3 j = vec3(g,h);
```

GLSL Variables

- Matrices also follow this pattern

```
mat4 m = mat4(1.0)                 // initializing the diagonal of the matrix with 1.0
vec2 a = vec2(1.0,2.0);
vec2 b = vec2(3.0,4.0);
mat2 n = mat2(a,b);                // matrices are assigned in column major order
mat2 k = mat2(1.0,0.0,1.0,0.0); // all elements are specified
```

- The declaration and initialization of structures is demonstrated below

```
struct dirlight { // type definition
   vec3 direction;
   vec3 color;
};
dirlight d1;
dirlight d2 = dirlight(vec3(1.0,1.0,0.0),vec3(0.8,0.8,0.4));
```

GLSL Variables

- Accessing a vector can be done using letters as well as standard C selectors.

```
vec4 a = vec4(1.0,2.0,3.0,4.0);
float posX = a.x;
float posY = a[1];
vec2 posXY = a.xy;
float depth = a.w;
```

- One can the letters x,y,z,w to access vectors components; r,g,b,a for color components; and s,t,p,q for texture coordinates.
- As for structures the names of the elements of the structure can be used as in C

```
d1.direction = vec3(1.0,1.0,1.0);
```

GLSL Variable Qualifiers

- Qualifiers give a special meaning to the variable. In GLSL the following qualifiers are available:
  - const - the declaration is of a compile time constant
  - attribute – (only used in vertex shaders, and read-only in shader) global variables that may change per vertex, that are passed from the OpenGL application to vertex shaders
  - uniform – (used both in vertex/fragment shaders, read-only in both) global variables that may change per primitive (may not be set inside glBegin,/glEnd)
  - varying - used for interpolated data between a vertex shader and a fragment shader. Available for writing in the vertex shader, and read-only in a fragment shader.

GLSL Statements

- Control Flow Statements: pretty much the same as in C.

```
if (bool expression)
     ...
else
    ...

for (initialization; bool expression; loop expression)
    ...

while (bool expression)
   ...

do
  ...
while (bool expression)
```

Note: only “if” are available on most current hardware

GLSL Statements

- A few jumps are also defined:

•continue - available in loops, causes a jump to the next iteration of the loop

•break - available in loops, causes an exit of the loop

•Discard - can only be used in fragment shaders. It causes the termination of the shader for the current fragment without writing to the frame buffer, or depth.

GLSL Functions

- As in C, a shader is structured in functions. At least each type of shader must have a main function declared with the following syntax: void main()
- User defined functions may be defined.
- As in C a function may have a return value, and use the return statement to pass out its result. A function can be void. The return type can have any type, except array.
- The parameters of a function have the following qualifiers:
  - in - for input parameters
  - out - for outputs of the function. The return statement is also an option for sending the result of a function.
  - inout - for parameters that are both input and output of a function
  - If no qualifier is specified, by default it is considered to be *in*.

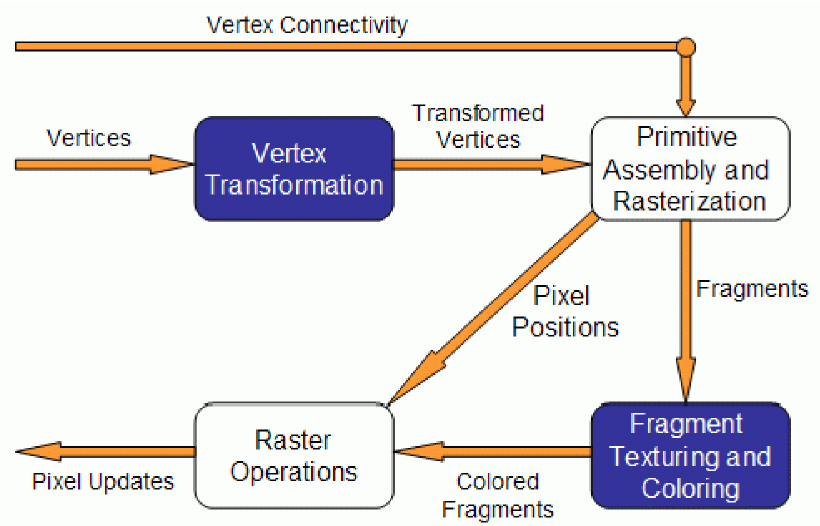
GLSL Functions

- A few final notes:
  - A function can be overloaded as long as the list of parameters is different.
  - Recursion behavior is undefined by specification.
- Finally, let's look at an example

```
vec4 toonify(in float intensity)
{
    vec4 color;
    if (intensity > 0.98)
        color = vec4(0.8,0.8,0.8,1.0);
    else if (intensity > 0.5)
        color = vec4(0.4,0.4,0.8,1.0);
    else if (intensity > 0.25)
        color = vec4(0.2,0.2,0.4,1.0);
    else color = vec4(0.1,0.1,0.1,1.0);
    return(color);
}
```

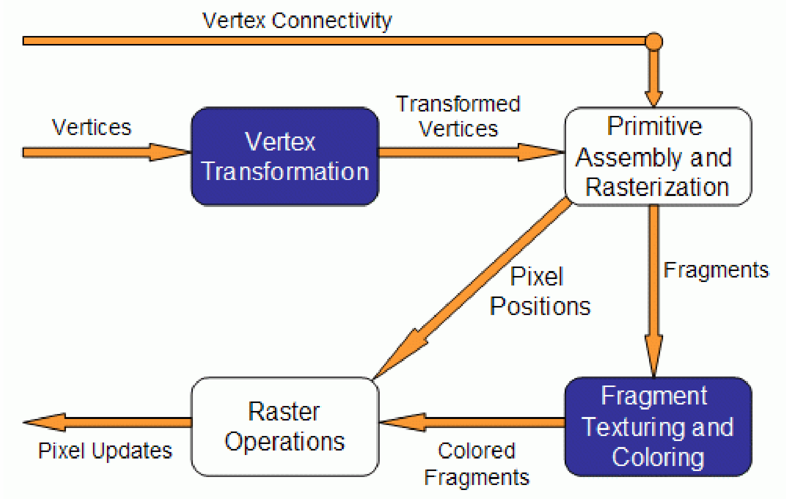
GLSL Varying Variables

- Let's look at a real case, shading
  - Current OGL does Gouraud Shading
  - Phong shading produces much higher visual quality, but turns out to be a big deal for hardware
- Illumination takes place in vertex transformation, then shading (color interpolation) goes in the following stage
- But Phong shading basically requires per fragment illumination



GLSL Varying Variables

- Varying variables are interpolated from vertices, utilizing topology information, during rasterization
- GLSL has some predefined varying variables, such as color, texture coordinates etc.
- Unfortunately, normal is not one of them
- In GLSL, to do Phong shading, let's make normal a varying variable

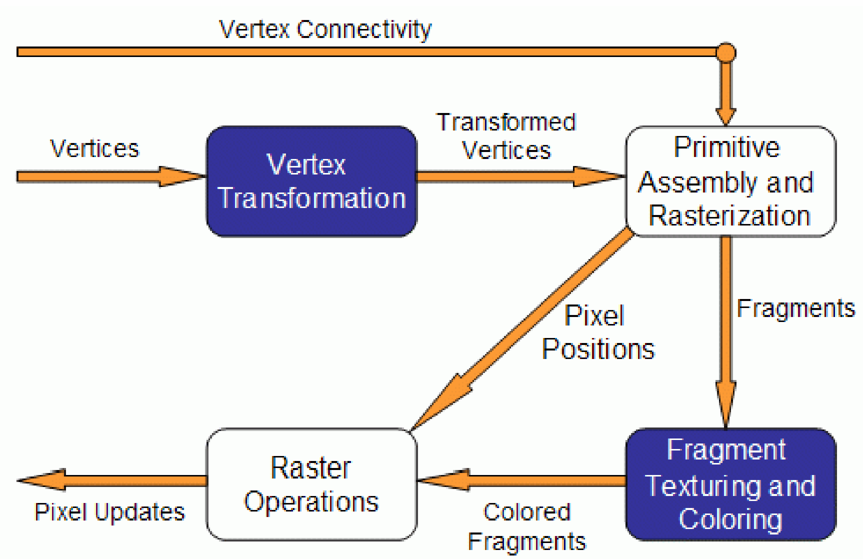


GLSL Varying Variables

- Define varying variables in both vertex and fragment shaders

```
varying vec3 normal;
```

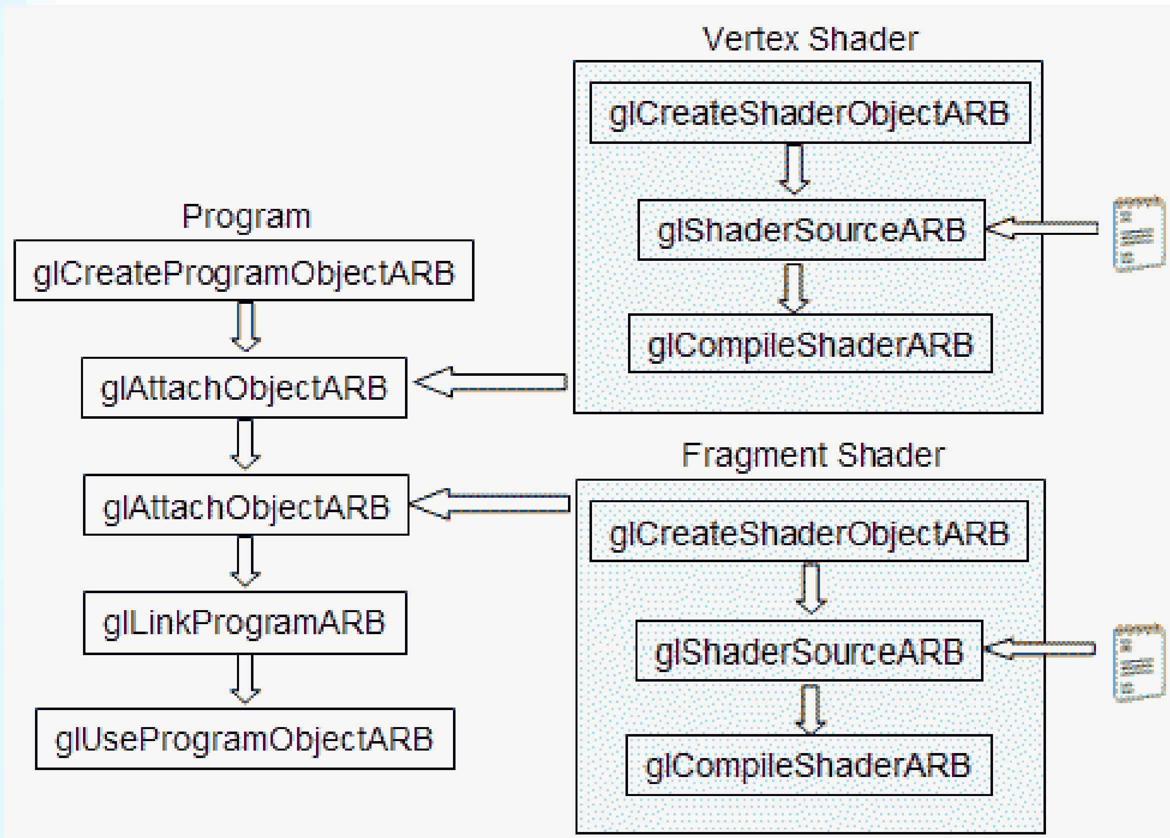
- Varying variables must be written in the vertex shader
- Varying variables can only be read in fragment shaders



More Setup for GLSL- Uniform Variables

- Uniform variables, this is one way for your C program to communicate with your shaders (e.g. what time is it since the bullet was shot?)
- A uniform variable can have its value changed by primitive only, i.e., its value can't be changed between a *glBegin* / *glEnd* pair.
- Uniform variables are suitable for values that remain constant along a primitive, frame, or even the whole scene.
- Uniform variables can be read (but not written) in both vertex and fragment shaders.

The Overall Process



Creating a Shader

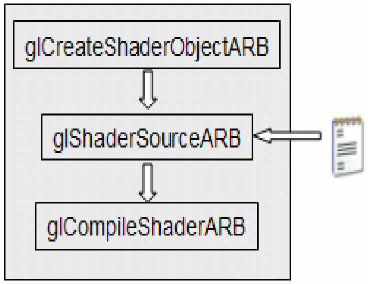
- The first step is creating an object which will act as a shader container. The function available for this purpose returns a handle for the container

  GLhandleARB glCreateShaderObjectARB(GLenum shaderType);

  Parameter:

  shaderType - GL_VERTEX_SHADER_ARB or GL_FRAGMENT_SHADER_ARB.

- You can create as many shaders as needed, but there can only be one single *main* function for the set of vertex shaders and one single *main* function for the set of fragment shaders in each single program.



Creating a Shader

- The second step is to add some source code (like this is a surprise ☺).
  - The source code for a shader is a string array, although you can use a pointer to a single string.
- The syntax of the function to set the source code for a shader is

```
void glShaderSourceARB(GLhandleARB shader, int numOfStrings, const char **strings, int *lenOfStrings);
```

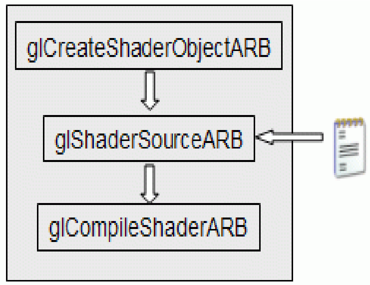
Parameters:

shader - the handler to the shader.

numOfStrings - the number of strings in the array.

strings - the array of strings.

lenOfStrings - an array with the length of each string, or NULL, meaning that the strings are NULL terminated.



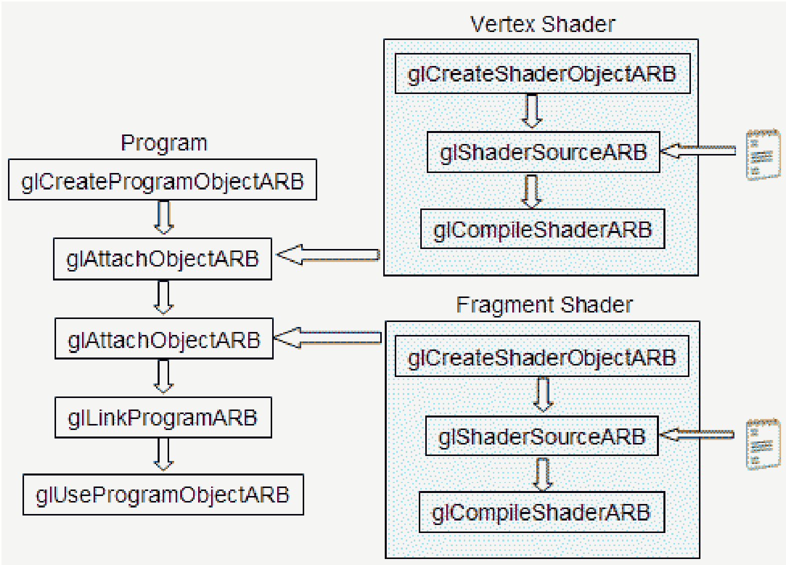
Creating a Shader

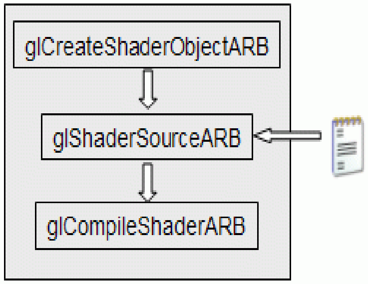
- The final step, the shader must be compiled.
- The function to achieve this is:

void glCompileShaderARB(GLhandleARB program);

Parameters:

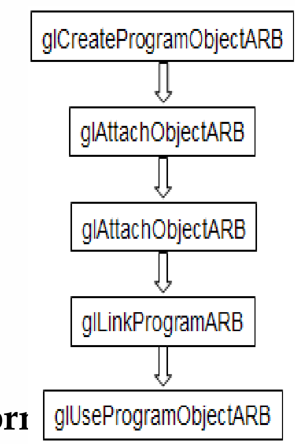
program - the handler to the program.





Creating a Program

- The first step is creating an object which will act as a program container.
- The function available for this purpose returns a handle for the container GLhandleARB glCreateProgramObjectARB(void);
- One can create as many programs as needed. Once rendering, you can switch from program to program, and even go back to fixed functionality during a single frame.
  - For instance one may want to draw a teapot with refraction and reflection shaders, while having a cube map displayed for background using OpenGL's fixed functionality.



Creating a Program

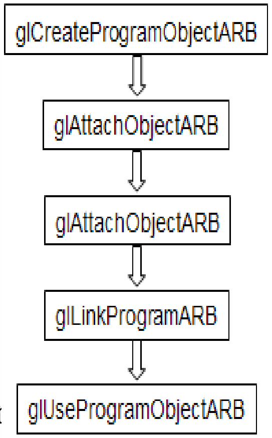
- The 2nd step is to attach the shaders to the program you've just created.
- The shaders do not need to be compiled nor is there a need to have src code. For this step only the shader container is required

```
void glAttachObjectARB(GLhandleARB program, GLhandleARB shader);
```

Parameters:

  program - the handler to the program.
  shader - the handler to the shader you want to attach.

- If you have a pair vertex/fragment of shaders you'll need to attach both to the program (call attach twice).
- You can have many shaders of the same type (vertex or fragment) attached to the same program (call attach many times)



•As in C, for each type of shader there can only be one shader with a *main* function. You can attach a shader to multiple programs, e.g. to use the same shader in several programs.

Creating a Program

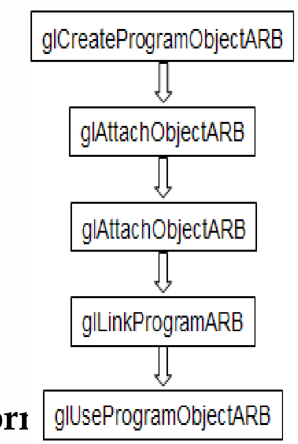
- The final step is to link the program. In order to carry out this step the shaders must be compiled as described in the previous subsection.

  void glLinkProgramARB(GLhandleARB program);

  Parameters:

  program - the handler to the program.

- After link, the shader's source can be modified and recompiled without affecting the program.



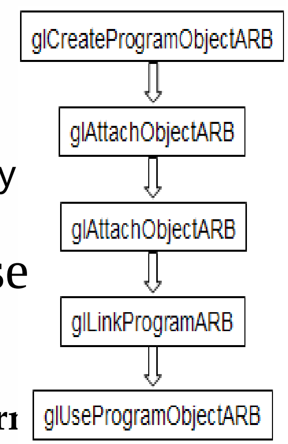
Using a Program

- After linking, the shader's source can be modified and recompiled without affecting the program.
- Because calling the function that actually load and use the program , *glUseProgramObjectARB*, causes a program to be actually loaded (the latest version then) and used.
- Each program is assigned an handler, and you can have as many programs linked and ready to use as you want (and your hardware allows).

void glUseProgramObjectARB(GLhandleARB prog);

Parameters:

prog - the handler to the program to use, or zero to return to fixed functionality



A program in use, if linked again, will automatically be placed in use again. No need to useprogram again.

Setting up - setShaders

- Here is a sample function to setup shaders. You can call this in your main function

```
void setShaders() /* GLhandleARB p,f,v; are declared as globals */
{
  char *vs,*fs;
  const char * vv = vs;
  const char * ff = fs;
  v = glCreateShaderObjectARB(GL_VERTEX_SHADER_ARB);
  f = glCreateShaderObjectARB(GL_FRAGMENT_SHADER_ARB);
  vs = textFileRead("toon.vert");
  fs = textFileRead("toon.frag");
  glShaderSourceARB(v, 1, &vv, NULL);
  glShaderSourceARB(f, 1, &ff, NULL);
  free(vs);  free(fs);
  glCompileShaderARB(v);
  glCompileShaderARB(f);
  p = glCreateProgramObjectARB();
  glAttachObjectARB(p,v);
  glAttachObjectARB(p,f);
  glLinkProgramARB(p);
  glUseProgramObjectARB(p);
}
```

textFileRead is provided in the class directory

Cleaning Up

- A function to detach a shader from a program is:

  ```
  void glDetachObjectARB(GLhandleARB program, GLhandleARB shader);
  ```

  Parameter:

  - program - The program to detach from.
  - shader - The shader to detach.

- Only shaders that are not attached can be deleted

- To delete a shader use the following function:

  ```
  void glDeleteShaderARB(GLhandleARB shader);
  ```

  Parameter:

  - shader - The shader to delete.

Getting Error

- There is an info log function that returns compile & linking information, errors

```
void glGetInfoLogARB(GLhandleARB object,
                     GLsizei maxLength,
                     GLsizei *length,G
                     GLcharARB *infoLog);
```

More Setup for GLSL- Uniform Variables

- The first thing you have to do is to get the memory location of the variable.
  - Note that this information is only available after you link the program. With some drivers you may be required to be using the program, i.e. *glUseProgramObjectARB* is already called
- The function to use is:

```
GLint glGetUniformLocationARB(GLhandleARB program, const char *name);
```

Parameters:

program - the handler to the program

name - the name of the variable.

The return value is the location of the variable, which can be used to assign values to it.

More Setup for GLSL- Uniform Variables

- Then you can set values of uniform variables with a family of functions.
- A set of functions is defined for setting float values as below. A similar set is available for int's, just replace "f" with "i"

```
void glUniform1fARB(GLint location, GLfloat v0);
void glUniform2fARB(GLint location, GLfloat v0, GLfloat v1);
void glUniform3fARB(GLint location, GLfloat v0, GLfloat v1, GLfloat v2);
void glUniform4fARB(GLint location, GLfloat v0, GLfloat v1, GLfloat v2, GLfloat v3);

GLint glUniform{1,2,3,4}fvARB(GLint location, GLsizei count, GLfloat *v);
```

Parameters:

location - the previously queried location.
v0,v1,v2,v3 - float values.
count - the number of elements in the array
v - an array of floats.

More Setup for GLSL- Uniform Variables

- Matrices are also an available data type in GLSL, and a set of functions is also provided for this data type:

GLint glUniformMatrix{2,3,4}fvARB(GLint location, GLsizei count, GLboolean transpose, GLfloat *v);

Parameters:

location - the previously queried location.

count - the number of matrices. 1 if a single matrix is being set, or *n* for an array of *n* matrices.

transpose - wheter to transpose the matrix values. A value of 1 indicates that the matrix values are specified in row major order, zero is column major order

v - an array of floats.

More Setup for GLSL- Uniform Variables

- Note: the values that are set with these functions will keep their values until the program is linked again.
- Once a new link process is performed all values will be reset to zero.

More Setup for GLSL- Uniform Variables

- A sample:

Assume that a shader with the following variables is being used:

```
uniform float specIntensity;
uniform vec4 specColor;
uniform float t[2];
uniform vec4 colors[3];
```

In the OpenGL application, the code for setting the variables could be:

```
GLint loc1,loc2,loc3,loc4;
float specIntensity = 0.98;
float sc[4] = {0.8,0.8,0.8,1.0};
float threshold[2] = {0.5,0.25};
float colors[12] = {0.4,0.4,0.8,1.0, 0.2,0.2,0.4,1.0, 0.1,0.1,0.1,1.0};
loc1 = glGetUniformLocationARB(p,"specIntensity");
glUniform1fARB(loc1,specIntensity);
loc2 = glGetUniformLocationARB(p,"specColor");
glUniform4fvARB(loc2,1,sc);
loc3 = glGetUniformLocationARB(p,"t");
glUniform1fvARB(loc3,2,threshold);
loc4 = glGetUniformLocationARB(p,"colors");
glUniform4fvARB(loc4,3,colors);
```

More Setup for GLSL- Attribute Variables

- Attribute variables also allow your C program to communicate with shaders
- Attribute variables can be updated at any time, but can only be read (not written) in a vertex shader.
- Attribute variables pertain to vertex data, thus not useful in fragment shader
- To set its values, (just like uniform variables) it is necessary to get the location in memory of the variable.
  - Note that the program must be linked previously and some drivers may require the program to be in use.

```
GLint glGetAttribLocationARB(GLhandleARB program,char *name);
```

Parameters:

program - the handle to the program.

name - the name of the variable

More Setup for GLSL- Attribute Variables

- As uniform variables, a set of functions are provided to set attribute variables (replacing "f" with "i" gives the API for int's)

```
void glVertexAttrib1fARB(GLint location, GLfloat v0);
void glVertexAttrib2fARB(GLint location, GLfloat v0, GLfloat v1);
void glVertexAttrib3fARB(GLint location, GLfloat v0, GLfloat v1,GLfloat v2);
void glVertexAttrib4fARB(GLint location, GLfloat v0, GLfloat v1,,GLfloat v2, GLfloat v3);
```

or

```
GLint glVertexAttrib{1,2,3,4}fvARB(GLint location, GLfloat *v);
```

Parameters:

location - the previously queried location.

v0,v1,v2,v3 - float values.

v - an array of floats.

More Setup for GLSL- Attribute Variables

- A sample snippet

Assuming the vertex shader has:

```
attribute float height;
```

In the main Opengl program, we can do the following:

```
loc = glGetAttribLocationARB(p,"height");
glBegin(GL_TRIANGLE_STRIP);
glVertexAttrib1fARB(loc,2.0);
glVertex2f(-1,1);
glVertexAttrib1fARB(loc,2.0);
glVertex2f(1,1);
glVertexAttrib1fARB(loc,-2.0);
glVertex2f(-1,-1);
glVertexAttrib1fARB(loc,-2.0);
glVertex2f(1,-1); glEnd();
```

Appendix

- Sample Shaders
- List of commonly used Built-in's of GLSL
- Shader Tools

Ivory – vertex shader

```
uniform vec4 lightPos;

varying vec3 normal;
varying vec3 lightVec;
varying vec3 viewVec;

void main(){
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
   vec4 vert = gl_ModelViewMatrix * gl_Vertex;

   normal   = gl NormalMatrix * gl Normal;
   lightVec = vec3(lightPos - vert);
   viewVec  = -vec3(vert);
}
```

Ivory – fragment shader

```
varying vec3 normal;
varying vec3 lightVec;
varying vec3 viewVec;

void main(){
    vec3 norm = normalize(normal);

    vec3 L = normalize(lightVec);
    vec3 V = normalize(viewVec);
    vec3 halfAngle = normalize(L + V);

    float NdotL = dot(L, norm);
    float NdotH = clamp(dot(halfAngle, norm), 0.0, 1.0);

    // "Half-Lambert" technique for more pleasing diffuse term
    float diffuse  = 0.5 * NdotL + 0.5;
    float specular = pow(NdotH, 64.0);

    float result = diffuse + specular;

    gl_FragColor = vec4(result);
}
```

Gooch – vertex shader

```
uniform vec4 lightPos;

varying vec3 normal;
varying vec3 lightVec;
varying vec3 viewVec;

void main(){
  gl_Position = gl_ModelViewProjectionMatrix *
  gl_Vertex;
  vec4 vert = gl_ModelViewMatrix * gl_Vertex;

  normal   = gl_NormalMatrix * gl_Normal;
  lightVec = vec3(lightPos - vert);
  viewVec  = -vec3(vert);
}
```

Gooch – fragment shader

```
uniform vec3 ambient;

varying vec3 normal;
varying vec3 lightVec;
varying vec3 viewVec;

void main(){
   const float b = 0.55;
   const float y = 0.3;
   const float Ka = 1.0;
   const float Kd = 0.8;
   const float Ks = 0.9;

   vec3 specularcolor = vec3(1.0, 1.0, 1.0);

   vec3 norm = normalize(normal);
   vec3 L = normalize (lightVec);
   vec3 V = normalize (viewVec);
   vec3 halfAngle = normalize (L + V);
```

Gooch – fragment shader (2)

```
    vec3 orange = vec3(.88,.81,.49);
    vec3 purple = vec3(.58,.10,.76);

    vec3 kCool = purple;
    vec3 kWarm = orange;

    float NdotL = dot(L, norm);
    float NdotH = clamp(dot(halfAngle, norm), 0.0, 1.0);
    float specular = pow(NdotH, 64.0);

    float blendval  = 0.5 * NdotL + 0.5;
    vec3 Cgooch = mix(kWarm, kCool, blendval);

    vec3 result = Ka * ambient + Kd * Cgooch + specularcolor * Ks *
    specular;

    gl_FragColor = vec4(result, 1.0);
}
```

Built-in variables

- Attributes & uniforms
- For ease of programming
- OpenGL state mapped to variables
- Some special variables are required to be written to, others are optional

Special built-ins

- Vertex shader

```
vec4  gl_Position;      // must be written
vec4  gl_ClipPosition;  // may be written
float gl_PointSize;     // may be written
```

- Fragment shader

```
float gl_FragColor;     // may be written
float gl_FragDepth;     // may be read/written
vec4  gl_FragCoord;     // may be read
bool  gl_FrontFacing;   // may be read
```

Attributes

- Built-in

```
attribute vec4  gl_Vertex;
attribute vec3  gl_Normal;
attribute vec4  gl_Color;
attribute vec4  gl_SecondaryColor;
attribute vec4  gl_MultiTexCoordn;
attribute float gl_FogCoord;
```

- User-defined

```
attribute vec3  myTangent;
attribute vec3  myBinormal;
Etc…
```

Built-in Uniforms

```
uniform   mat4  gl_ModelViewMatrix;
uniform   mat4  gl_ProjectionMatrix;
uniform   mat4  gl_ModelViewProjectionMatrix;
uniform   mat3  gl_NormalMatrix;
uniform   mat4  gl_TextureMatrix[n];

struct gl_MaterialParameters {
  vec4  emission;
  vec4  ambient;
  vec4  diffuse;
  vec4  specular;
  float shininess;
};
uniform gl_MaterialParameters gl_FrontMaterial;
uniform gl_MaterialParameters gl_BackMaterial;
```

Built-in Uniforms

```
struct gl_LightSourceParameters {
  vec4  ambient;
  vec4  diffuse;
  vec4  specular;
  vec4  position;
  vec4  halfVector;
  vec3  spotDirection;
  float spotExponent;
  float spotCutoff;
  float spotCosCutoff;
  float constantAttenuation
  float linearAttenuation
  float quadraticAttenuation
};
Uniform gl_LightSourceParameters
   gl_LightSource[gl_MaxLights];
```

Built-in Varyings

```
varying   vec4  gl_FrontColor        // vertex
varying   vec4  gl_BackColor;        // vertex
varying   vec4  gl_FrontSecColor;    // vertex
varying   vec4  gl_BackSecColor;     // vertex

varying   vec4  gl_Color;            // 
  fragment
varying   vec4  gl_SecondaryColor;   // 
  fragment

varying   vec4  gl_TexCoord[];       // both
varying   float gl_FogFragCoord;     // both
```

Built-in functions

- Angles & Trigonometry
  - **radians, degrees, sin, cos, tan, asin, acos, atan**
- Exponentials
  - **pow, exp2, log2, sqrt, inversesqrt**
- Common
  - **abs, sign, floor, ceil, fract, mod, min, max, clamp**

Built-in functions

- Interpolations
  - **mix**(x,y,a) **x*(1.0-a) + y*a**)
  - **step**(edge,x) **x <= edge ? 0.0 : 1.0**
  - **smoothstep**(edge0,edge1,x)

```
t = (x-edge0)/(edge1-edge0);
t = clamp( t, 0.0, 1.0);
return t*t*(3.0-2.0*t);
```

Built-in functions

- Geometric
  - **length, distance, cross, dot, normalize, faceForward, reflect**
- Matrix
  - **matrixCompMult**
- Vector relational
  - **lessThan, lessThanEqual, greaterThan, greaterThanEqual, equal, notEqual, any, all**

Built-in functions

- Texture
  - **texture1D, texture2D, texture3D, textureCube**
  - **texture1DProj, texture2DProj, texture3DProj, textureCubeProj**
  - **shadow1D, shadow2D, shadow1DProj, shadow2Dproj**
- Vertex
  - **ftransform**

Tools

- OpenGL Extensions Viewer
  - http://www.realtech-vr.com/glview/download.html
- Simple Shaders
  - ogl2brick (http://developer.3dlabs.com/downloads/glslexamples/)
  - Hello GPGPU (http://www.gpgpu.org/developer/)
- ShaderGen
  - http://developer.3dlabs.com/downloads/shadergen/
- Shader data structures – Brook, glift
- Recommended literature – OpenGL RedBook, OpenGL OrangeBook, GPU Gems 2