OpenGL/GLSL Shader Programing

CSE 5542

OpenGL Shading Language (GLSL)

- Platform independent
  - Compared to Cg (nVidia) or HLSL (Microsoft)
- A C-like language and incorporated into OpenGL 2.0
- Used to write
  - Vertex/fragment shader programs
  - Geometry/tessellation shader programs

OpenGL/GLSL shader programs

- Let's look at a very simple shader example
  - do_nothing.vert, do_nothing.frag
- How to import the shader program and link to your OpenGL program
  - SDcubeSimple.C; shaderSetup.C
- How to pass the vertex attributes from VBOs to a shader program
  - SDcubeSimple.C

do_nothing.vert

- A very simple shader program
- Replace vertex processing in the fixed function pipeline
- Does nothing except passing the vertex position and color to the fragment shader
- This program does not even perform local to clip space transformation. It assumes that the input vertex position is already in clip space
  - This is not a norm; typically you will at least transform the vertex position to the clip space

do_nothing.vert

```
attribute vec4 position;  // the vertex position and color are passed from an opengl program
attribute vec4 color;

varying vec4 pcolor;  // this is the output variable to the fragment shader

// this shader just pass the vertex position and color along, doesn't actually do anything
// Note that this means the vertex position is assumed to be already in clip space
//
void main(){
    gl_Position = position;
    pcolor = color;
}
```

do_nothing.frag

- Replace fragment processing in the fixed function pipeline
- The input to the fragment program are interpolated attributes from the vertices for the fragment
- This fragment program essentially does nothing except passing the fragment color to the frame buffer

do_nothing.frag

```
varying vec4 pcolor;    // Need to match the name with the desired variable from
                        //  the vertex program
//
// This fragment shader just passes the already interpolated fragment color
//
void main() {
    gl_FragColor = pcolor;  // note that gl_FragColor is a default name for
                            // the final fragment color
}
```

Why do you want me to look at these simple shader programs??

- I want you to learn how to import and link the shader program with an OpenGL program
- I want you to learn how to pass the vertex attributes (position and color in this example) to the shader

Setup of Shader Prgorams

- A shader is defined as an array of strings
- Steps to use shaders
    1. Create a shader program
    2. Create **shader objects** (vertex and fragment)
    3. Send **source code** to the shader objects
    4. **Compile** the shader

1. Create **program object** by linking compiled shaders together
2. Use the linked program object

Create Shader Program and Shader Objects

- Create a shader program
- Later a vertex and a fragment shader will be attached to this shader program

```
GLuint programObject;
programObject = glCreateProgram();  // create an overall shader program

if (programObject == 0) {  // error checking
  printf(" Error creating shader program object.\n");
  exit(1);
}
else printf(" Succeeded creating shader program object.\n");
```

Create Shader Program and Shader Objects (cont'd)

- Create vertex and fragment shader objects

```
GLuint vertexShaderObject;
GLuint fragmentShaderObject;

vertexShaderObject = glCreateShader(GL_VERTEX_SHADER);
if (vertexShaderObject == 0) {  // error checking
  printf(" Error creating vertex shader object.\n");
  exit(1);
}
else printf(" Succeeded creating vertex shader object.\n");

fragmentShaderObject = glCreateShader(GL_FRAGMENT_SHADER);
if (fragmentShaderObject == 0) {  // error checking
  printf(" Error creating fragment shader object.\n");
  exit(1);
}
else printf(" Succeeded creating fragment shader object.\n");
```

Send the source to the shader and compile

- You need to read the source (.vert and .frag files in ascii format) into strings first
  - For example, into the following char arrays

    GLchar *vertexShaderSource;

    GLchar *fragmentShaderSource;
- Remember how to use C fopen and fread? something like

```
 fh = fopen(name, "r");
if (fh==NULL)  return -1;
//
// Get the shader from a file.
 fseek(fh, 0, SEEK_SET);
 count = fread(shaderText, 1, size, fh);
shaderText[count] = '\0';
if (ferror(fh))   count = 0;
fclose(fh);
```

- Check shaderSetup.C in the example

Send the source to the shader and compile (con’td)

- Now compile the shaders

```
//  After reading the shader files,  send the source to the shader objects
glShaderSource(vertexShaderObject,1,(co  nst GLchar**)&vertexShaderSource,NULL);
glShaderSource(fragmentShaderObject,1,(const GLchar**)&fragmentShaderSource,NULL);

// now compile the shader code; vertex shader first, followed by fragment shader
glCompileShader(vertexShaderObject);
glCompileShader(fragmentShaderObject);
```

- Remember you need to do some error checking, check shaderSetup.C to see how to do it

Finally, attach and link the shader program

- Attach the vertex and fragment shader objects to the shader program and link together

```
glAttachShader(programObject, vertexShaderObject);
glAttachShader(programObject, fragmentShaderObject);
glLinkProgram(programObject);
```

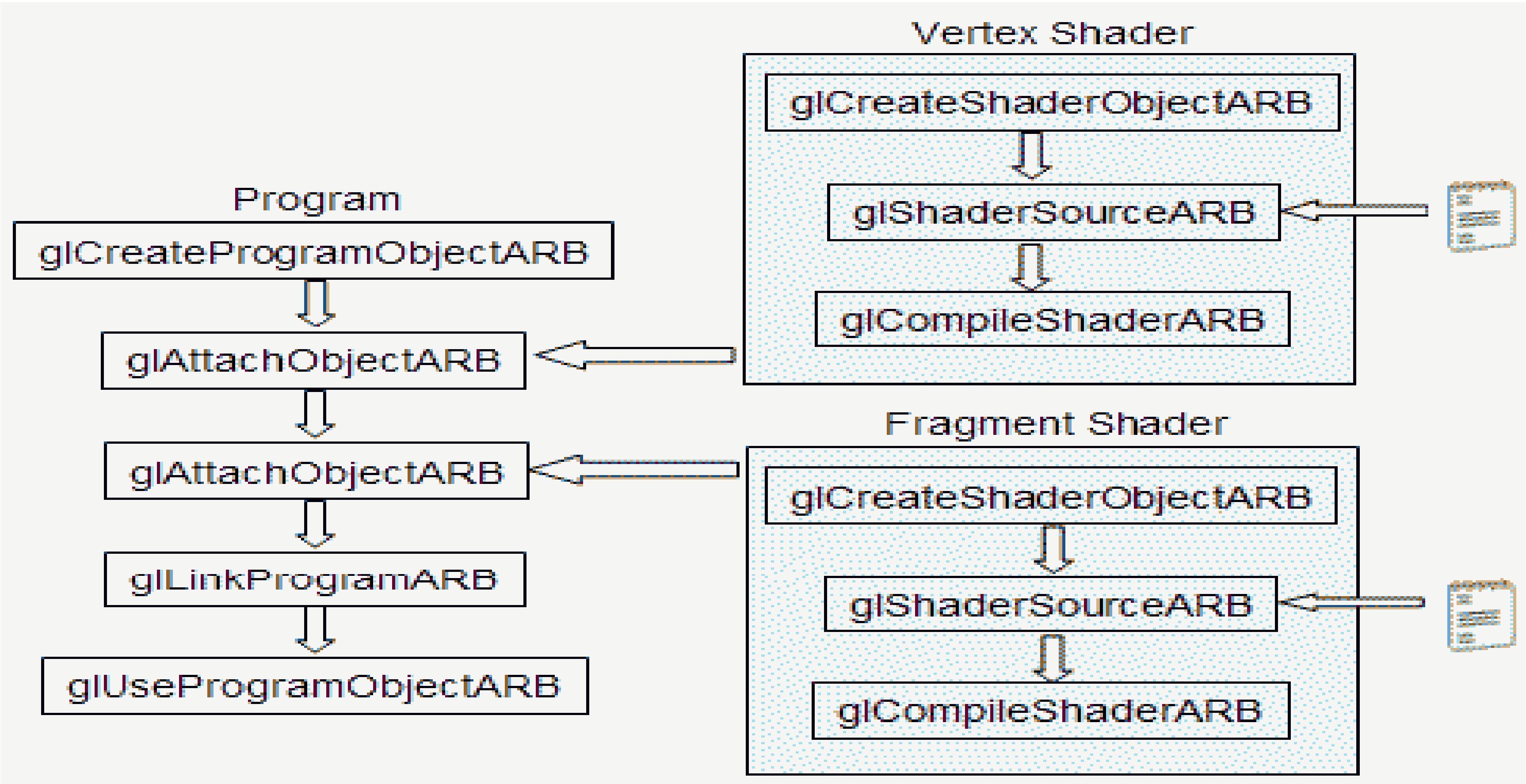
- Later you can use the shader program any time before you render your geometry (See SDcubeSimple.C)

```
...
glUseProgram(programObject);
… // OpenGL drawing
```

Shaders Setup Summary

```
GLhandle glCreateProgramObject();
Glhandle glCreateShaderObject(GL_VERTEX_SHADER);
GLhandle glCreateShaderObjectARB(GL_FRAGMENT_SHADER);
void glShaderSource(GLhandle shader, GLsizei nstrings, const
    GLchar **strings, const GLint *lengths)
      //if lengths==NULL, assumed to be null-terminated
void glCompileShader(GLhandle shader);
void glAttachObjectARB(GLhandle program, GLhandle shader);
      //twice, once for vertex shader & once for fragment shader

void glLinkProgram(GLhandle program);
    //program now ready to use

void glUseProgramObject(GLhandle program);
    //switches on shader, bypasses FFP
    //if program==0, shaders turned off, returns to FFP
```

Shaders Setup Summary



Let’s go back to look at the shaders

- How to pass the vertex attributes to the vertex shader?

```
attribute vec4 position;  //input:  the vertex position and color,  passed from an opengl program
attribute vec4 color;
varying vec4 pcolor;  // this is the output  to the fragment shader

void main(){
    gl_Position = position;
    pcolor = color;
}
```

Passing vertex attributes to the (vertex) shader

- In your OpenGL program, do the following:
  1. ID = Query the location of the shader variable
  2. Enable the attribute array
  3. Map the attribute array to ID

```
GLuint c0 = glGetAttribLocation(programObject, "position");
GLuint c1 = glGetAttribLocation(programObject, "color")
…
glEnableVertexAttribArray(c0);
glEnableVertexAttribArray(c1);
…
glVertexAttribPointer(c0,4,GL_FLOAT, GL_FALSE, sizeof(Vertex),(char*) NULL+0)
glVertexAttribPointer(c1,4,GL_FLOAT, GL_FALSE, sizeof(Vertex),(char*) NULL+16);
…
glDrawElements(GL_TRIANGLES, 36, GL_UNSIGNED_BYTE, (char*) NULL+0);
```

Setup of *Attribute* Variables

Return type	Function Name	Parameters
GLint	glGetAttribLocation	GLuint program const GLchar * name
void	glVertexAttribPointer	GLuint index, GLint size GLenum type Glboolean normalized, GLsizei stride const GLvoid * pointer
void	glEnableVertexAttribArray	GLuint index

1. Get ID of the attribute
2. Map the pointer to the array of per-vertex attribute to this ID
3. Enable this attribute

How do vertex and fragment shaders communicate?

- Through the **varying** variable

```
attribute vec4 position;
attribute vec4 color;

varying vec4 pcolor

void main()
{
      gl_Position = position;
      pcolor = color;
}
```

Vertex Program

```
varying vec4 pcolor;

void main()
 {
     gl_FragColor = pcolor;
}
```

Fragment Program

Let’s make the vertex shader do more

- Transform the vertex position from local space to clip space
  - Any vertex program is expected to perform the transformation
- Assume you use the OpenGL fixed function pipeline (like in Lab 2) and set up GL_MODELVIEW and GL_PROJECTION

```
attribute vec4 position;
attribute vec4 color;
varying vec4 pcolor;

void main(){
    pcolor = color;
    gl_Position = gl_ModelViewProjectionMatrix * position;
}
```

Use your own transformation matrix

- Need to pass the modelview projection matrix (projection*modelview) to the vertex shader
- Let's look at the vertex program first

```
attribute vec4 position;
attribute vec4 color;
uniform mat4 local2clip;   // this is the concatenated modlview projection matrix passed from your
                           // OpenGL program

varying vec4 pcolor;

void main(){
    pcolor = color1;
    gl_Position = local2clip * position;

}
```

How to pass the matrices to the vertex shader

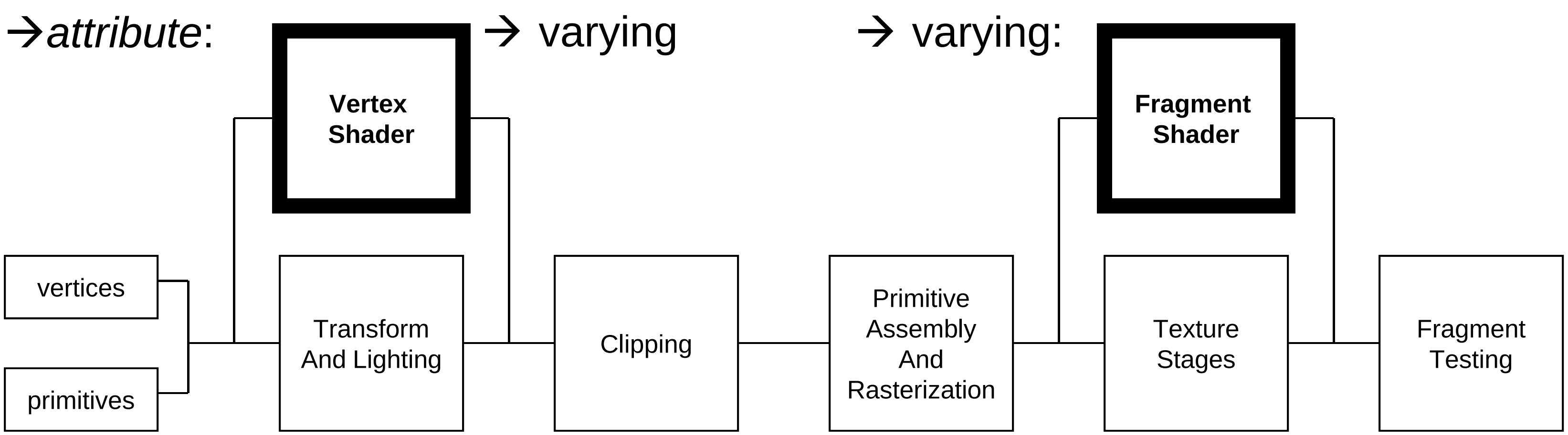
- You can pass any matrices to the shader as desired
  - For example, modeling matrix, viewing matrix, projection matrix, modelview matrix, or modelviewprojection matrix
- These matrices are *uniform* variable
- Uniform variables remain the same values for all vertices/fragments
  - i.e., you cannot change their values between vertices (between glBegin/glEnd or within VBOs

Set the values of uniform variables to shaders (a glm example)

```
glUseProgram(programObject);
…
// get the location of the uniform variable in the shader
GLuint m1 = glGetUniformLocation(programObject, "local2clip");
…
glm::mat4 projection = glm::perspective(60.0f,1.0f,.1f,100.0f);
glm::mat4 view = glm::lookAt(glm::vec3(0.0, 0.0, 5.0),
                             glm::vec3(0.0, 0.0, 0.0),
                             glm::vec3(0.0, 1.0, 0.0));
glm::mat4 model = glm::mat4(1.0f);
model = glm::rotate(model, x_angle, glm::vec3(0.0f, 1.0f, 0.0f));
model = glm::rotate(model, y_angle, glm::vec3(1.0f, 0.0f, 0.0f));
model = glm::scale(model, scale_size, scale_size, scale_size);

// construct the modelview and modelview projection matrices
glm::mat4 modelview = view * model;
glm::mat4 modelview_projection = projection * modelview;

// pass the modelview_projection matrix to the shader as a uniform
glUniformMatrix4fv(m1, 1, GL_FALSE, &modelview_projection[0][0]);
```

Setup of *Uniform* Variable

Uniform Variable: The Same Content for all Vertices/Fragments



Return type	Function Name	Parameters
GLint	glGetUniformLocation	GLuint program const GLchar * name
void	glUniformXX	GLint location Depends on XX

Vertex Shader: From *attribute* to *varying*

→*attribute*:

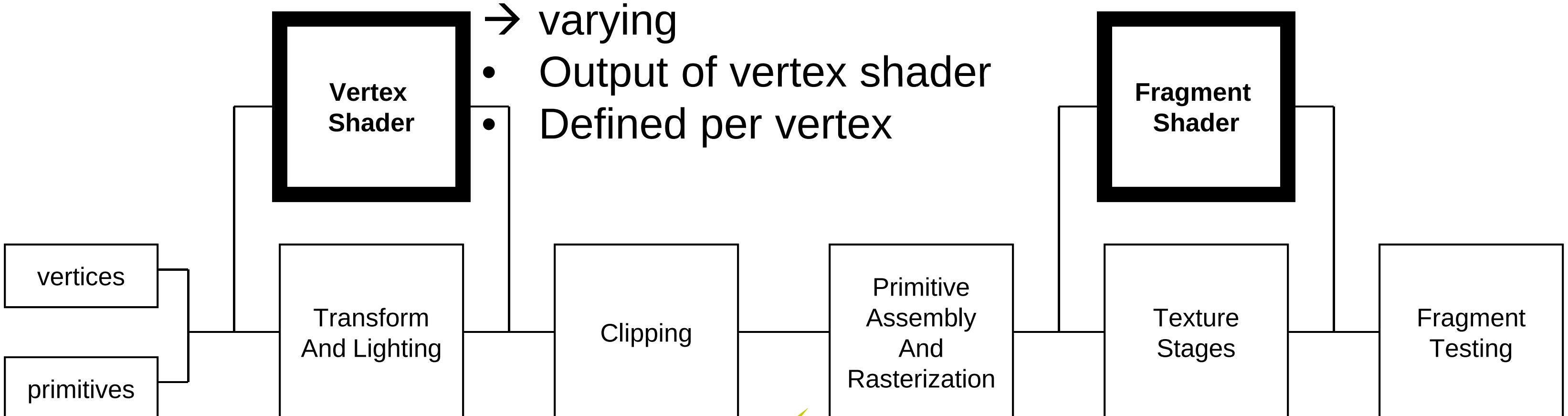
- input to the vertex shader;
- Defined per vertex;

→ varying:

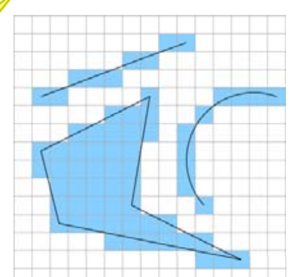
Input of fragment shader per fragment

→ varying

- Output of vertex shader
- Defined per vertex



varying variables will be *interpolated* in a perspective-correct fashion across the primitives



Rasterization of Lines/Polygons

http://iloveshaders.blogspot.com/2011/05/how-rasterization-process-works.html

Lighting Example
Vertex Shader

```
varying vec4 diffuseColor;
varying vec3 fragNormal;
varying vec3 lightVector;

uniform vec3 eyeSpaceLightVector;

void main(){

   vec3 eyeSpaceVertex= vec3(gl_ModelViewMatrix *
   gl_Vertex);
   lightVector= vec3(normalize(eyeSpaceLightVector -
   eyeSpaceVertex));
   fragNormal = normalize(gl_NormalMatrix * gl_Normal);

   diffuseColor = gl_Color;
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;

}
```

Lighting Example Fragment Shader

```
varying vec4 diffuseColor;
varying vec3 lightVector;
varying vec3 fragNormal;

void main(){

   float
   perFragmentLighting=max(dot(lightVector,fragNormal),0.0)
   ;

   gl_FragColor = diffuseColor * lightingFactor;

}
```

Toon Shading Example

- Toon Shading
  - Characterized by abrupt change of colors
  - Vertex Shader computes the vertex intensity (declared as varying)
  - Fragment Shader computes colors for the fragment based on the interpolated intensity

Vertex Shader

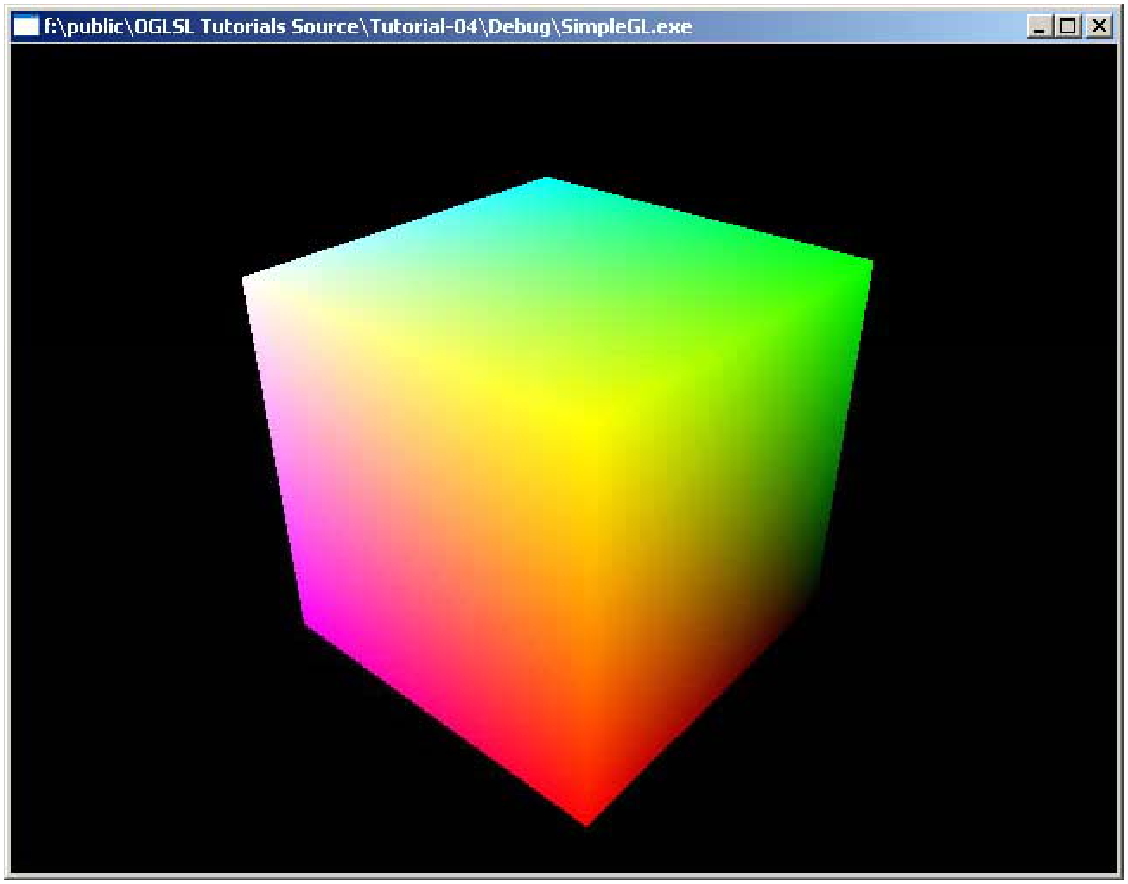
```
uniform vec3 lightDir;
varying float intensity;
void main() {
  vec3 ld;
  intensity = dot(lightDir,gl_Normal);
  gl_Position = ftransform();
}
```

Fragment Shader

```
varying float intensity;

void main() {
   vec4 color;
   if (intensity > 0.95) color = vec4(1.0,0.5,0.5,1.0);
   else if (intensity > 0.5) color = vec4(0.6,0.3,0.3,1.0);
   else if (intensity > 0.25) color = vec4(0.4,0.2,0.2,1.0);
   else color = vec4(0.2,0.1,0.1,1.0);
   gl_FragColor = color;
}
```

Varying Variable Example

Determine color based on x y z coordinates



Vertex Shader

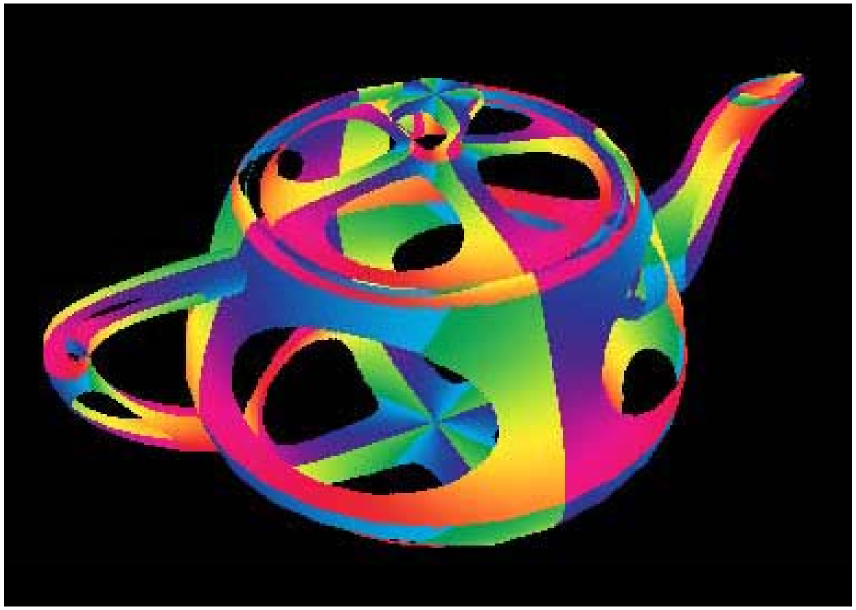
```
varying float xpos;
varying float ypos;
varying float zpos;

void main(void) {
   xpos = clamp(gl_Vertex.x,0.0,1.0);
   ypos = clamp(gl_Vertex.y,0.0,1.0);
   zpos = clamp(gl_Vertex.z,0.0,1.0);
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Fragment Shader

```
varying float xpos;
varying float ypos;
varying float zpos;

void main (void) {
    gl_FragColor = vec4 (xpos, ypos, zpos, 1.0);
}
```

Color Key Example

- Set a certain color (say FF00FF as transparent



Vertex Shader

```
void main(void) {
    gl_TexCoord[0] = gl_MultiTexCoord0;
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Fragment Shader

```
uniform sampler2D myTexture;

#define epsilon 0.0001

void main (void) {
        vec4 value = texture2D(myTexture, v
        ec2(gl_TexCoord[0]));
        if (value[0] > 1.0-epsilon) && (value[2] > 1.0-epsilon))
                discard;
        gl_FragColor = value;
}
```

Color Map Example

- Suppose you want to render an object such that its surface is colored by the temperature.
  - You have the temperatures at the vertices.
  - You want the color to be interpolated between the coolest and the hottest colors.
- Previously, you would calculate the colors of the vertices in your program, and say glColor().
- Now, lets do it in the vertex and pixel shaders…

Vertex shader

```
// uniform qualified variables are changed at most once
// per primitive
uniform float CoolestTemp;
uniform float TempRange;

// attribute qualified variables are typically changed per vertex
attribute float VertexTemp;

// varying qualified variables communicate from the vertex
// shader to the fragment shader
varying float Temperature;
```

Vertex shader

```
void main()
{
    // compute a temperature to be interpolated per fragment,
    // in the range [0.0, 1.0]
    Temperature = (VertexTemp - CoolestTemp) / TempRange;
    /*
    The vertex position written in the application using glVertex() can
    be read from the built-in variable gl_Vertex. Use this value and
    the current model view transformation matrix to tell the rasterizer
    where this vertex is. Could use ftransform(). */
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Fragment Shader

```
// uniform qualified variables are changed at most
// once per primitive by the application, and vec3
// declares a vector of three floating-point numbers
uniform vec3 CoolestColor;
uniform vec3 HottestColor;

// Temperature contains the now interpolated
// per-fragment value of temperature set by the
// vertex shader
varying float Temperature;
```

Fragment Shader

```
void main()
{
    // get a color between coolest and hottest colors, using
    // the mix() built-in function
    vec3 color = mix(CoolestColor, HottestColor, Temperature);
    // make a vector of 4 floating-point numbers by appending an
    // alpha of 1.0, and set this fragment’s color
    gl_FragColor = vec4(color, 1.0);
}
```

Additional GLSL Info

- Built-in names for accessing OpenGL states and for communicating with OpenGL fixed functionality
  - gl_Position
  - gl_FragCoord/gl_FrontFacing/gl_ClipDistance[]/gl_PointCoord/gl_PrimitiveID/gl_SampleID/gl_SamplePosition/gl_SampleMaskIn[];
- Type qualifiers *attribute*, *uniform*, and *varying*
  - Or *in/out* in OpenGL 3.X/4.X

Types

- Vector types are supported for floats, integers, and booleans
  - Can be 2-, 3-, or 4- components
  - float, vec2, vec3, vec4
  - int, ivec2, ivec3, ivec4
  - bool, bvec2, bvec3, bvec4

- Matrix types
  - mat2, mat3, mat4

- Texture access
  - sampler1D, sampler2D, sampler3D

❖ The complete list of GLSL data types functions are in Section 4 of GLSL Spec 4.2.

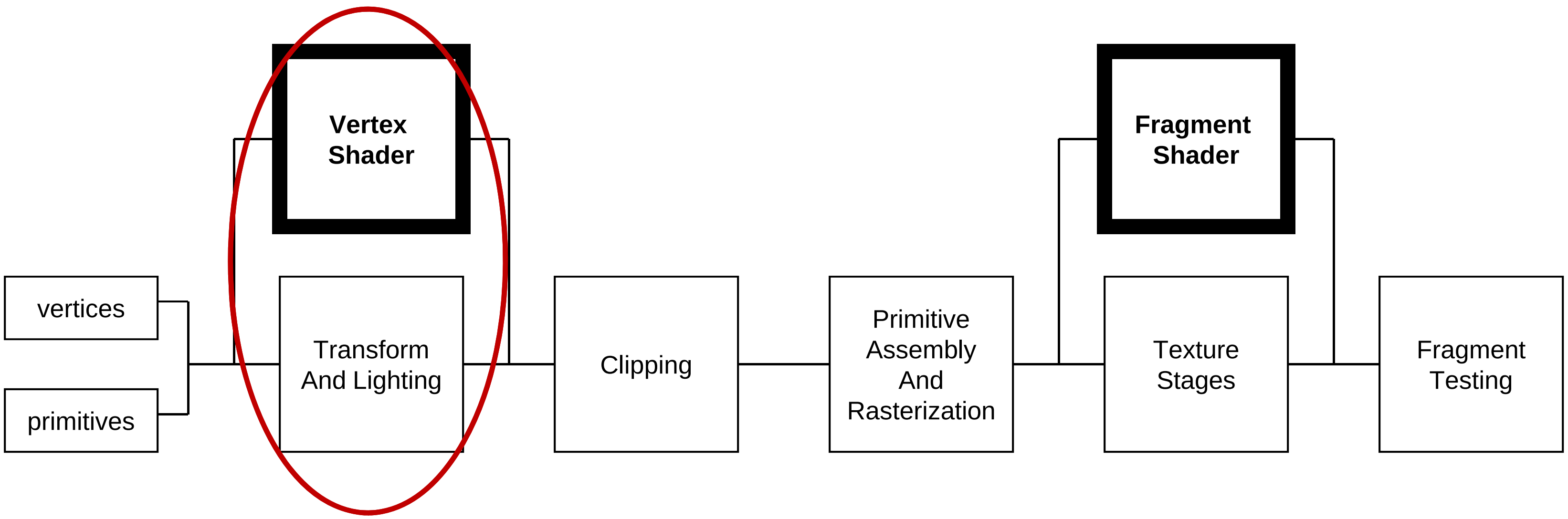
Built-in Functions

Trigonometry/angle	radians, degrees, sin, cos, tan, asin, acos, atan
Exponential	pow, exp2, log2, sqrt, inversesqrt
Geometric and matrix	length, distance, dot, cross, normalize, ftransform, faceforward, reflect, matrixCompMult
Misc	abs, sign, floor, ceil, fract, mod, min, max, clamp, mix, step, smoothstep

❖ The complete list of build-in functions are in Section 8 of GLSL Spec 4.2.

Vertex Program Capabilities

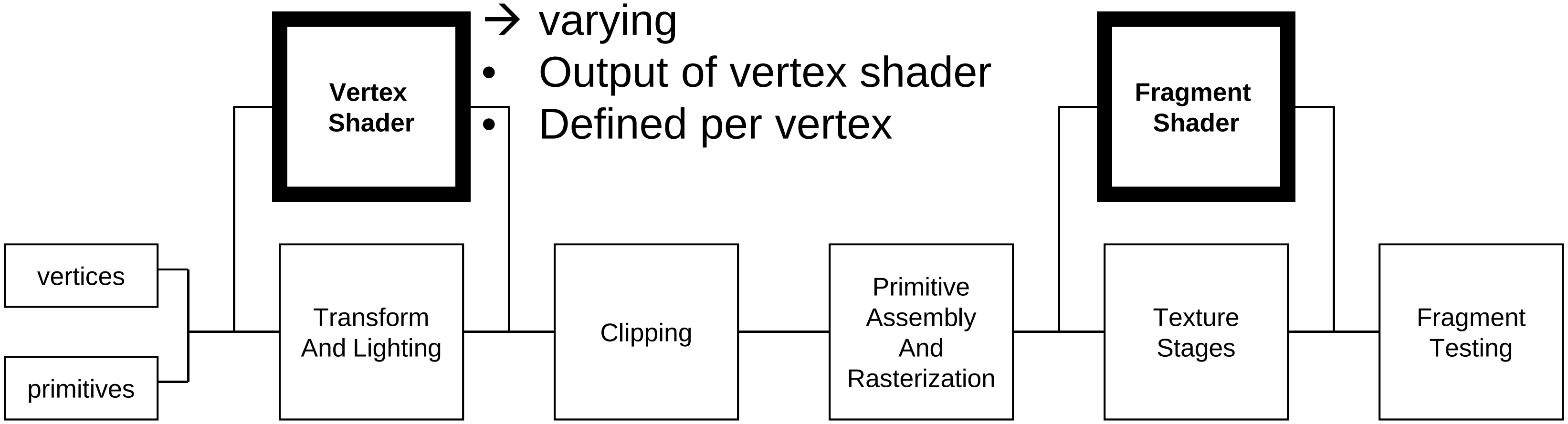
- Vertex program can do general processing, including things like:
  - Vertex transformation
  - Normal transformation, normalization and rescaling
  - Lighting
  - Color material application
  - Clamping of colors
  - Texture coordinate generation
  - Texture coordinate transformation



Varialbe Qualifies: From *attribute* to *varying* under *uniform*

→*attribute*:
- input to the vertex shader;
- Defined per vertex;
- E.g vertex color/normal/coordinates

→ varying
- Output of vertex shader
- Defined per vertex



→Uniform: The same information used by all vertices/fragment.
e.g ModelView transformation matrices

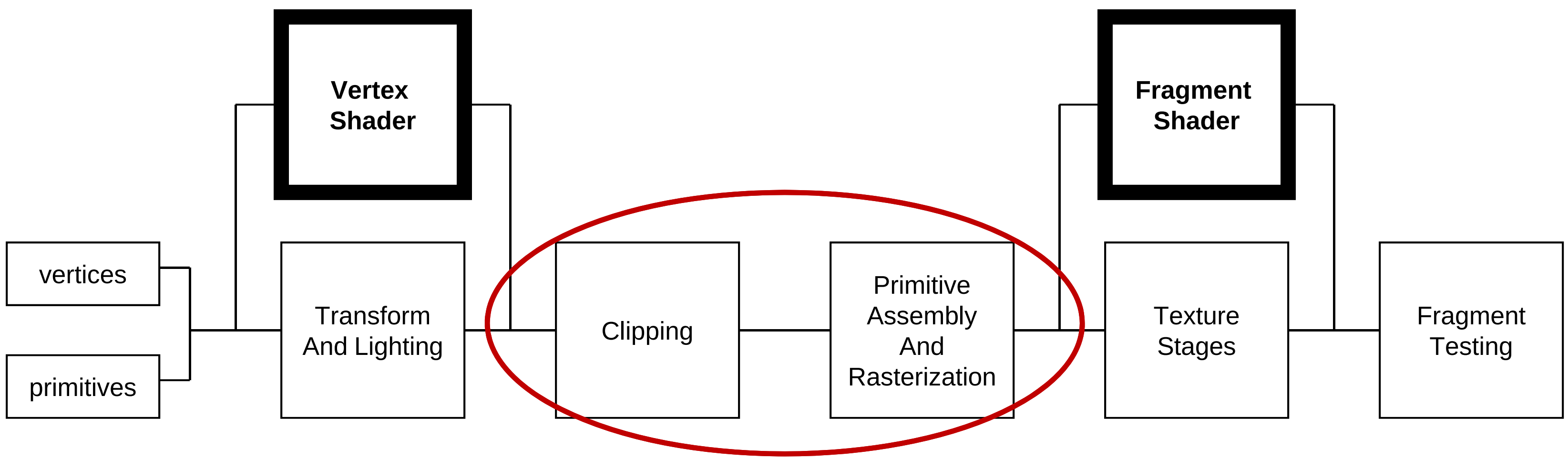
Vertex shader: Example Usage of Attribute/Varying/Uniform

```
// uniform qualified variables are changed at
      most once
// per primitive
uniform float CoolestTemp;
uniform float TempRange;

// attribute qualified variables are typically
      changed per vertex
attribute float VertexTemp;

// varying qualified variables communicate from
      the vertex
// shader to the fragment shader
varying float Temperature;
```

```
void main()
{
      /*
      compute a temperature to be interpolated
      per fragment,
      in the range [0.0, 1.0]
      */
      Temperature = (VertexTemp - CoolestTemp)
      / TempRange;

      gl_Position = ftransform();
}
```

Intervening Fixed Functionality

- Results from vertex processing undergo:
  - Perspective division on clip coordinates
  - Viewport mapping
  - Clipping, including user clipping
  - Color clamping or masking (for built-in varying variables that deal with color, but not user-defined varying variables)
  - Depth range
  - Front face determination and culling
  - Interpolate colors, texture coordinate, and user-defined varying variables
  - Etc.



Intervening Fixed Functionality: Rasterization

Rasterization of Lines[1]

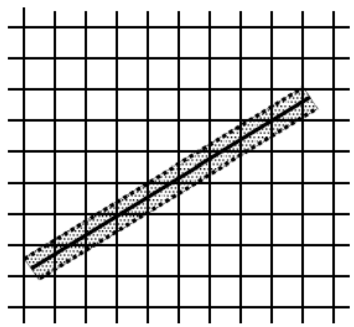
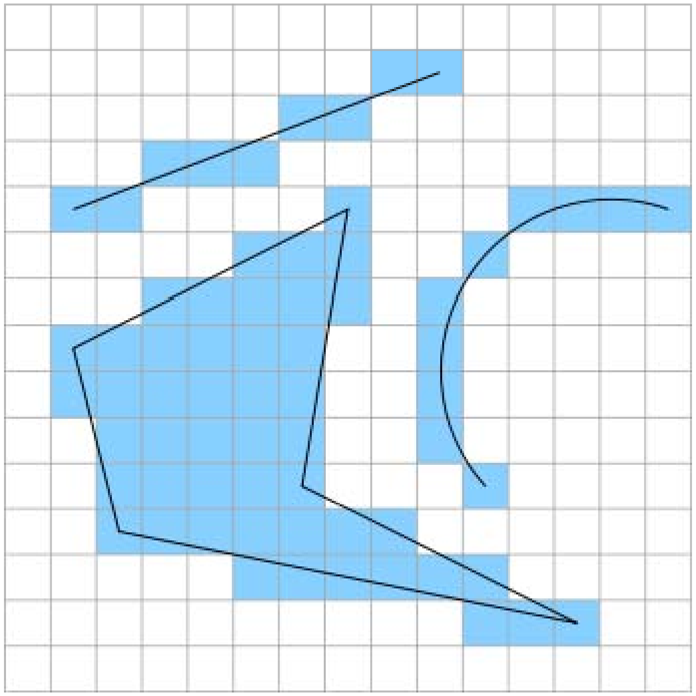


Figure 3.3. The region used in rasterizing and finding corresponding coverage values for an antialiased line segment (an x-major line segment is shown).

Rasterization of Lines/Polygons[2]

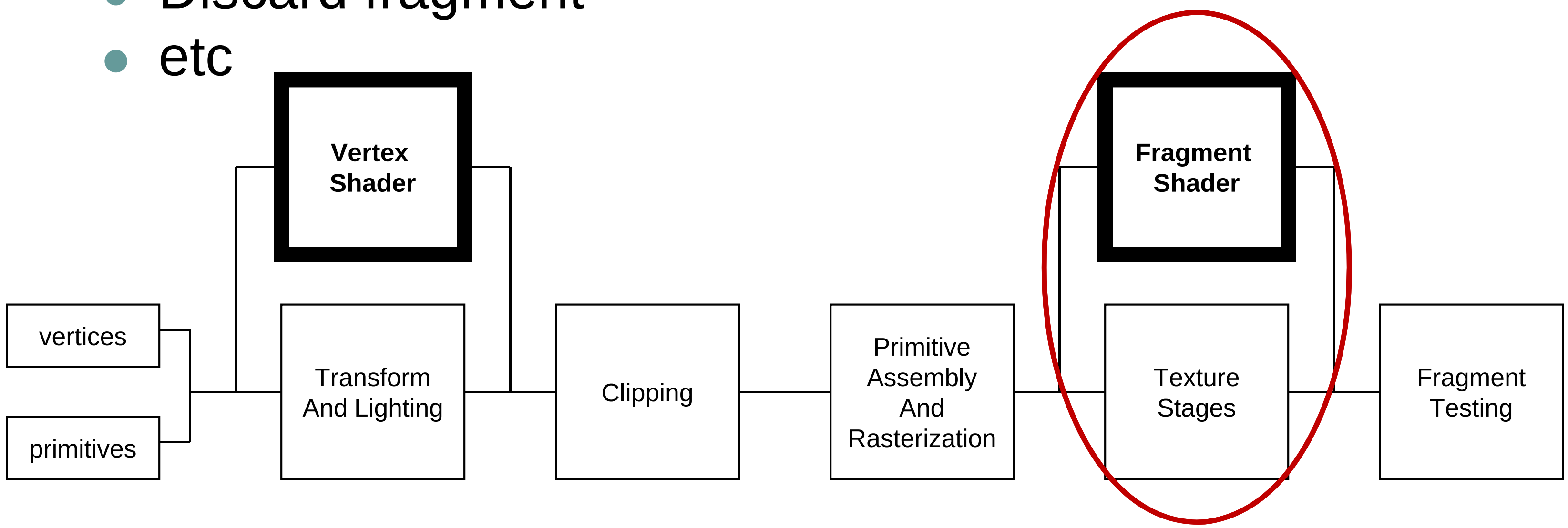


1. OpenGL 4.2 SPEC, 08/22/2011.
2. http://iloveshaders.blogspot.com/2011/05/how-rasterization-process-works.html

Fragment Program Capabilities

Fragment shader can do general processing, like:

- Operations on interpolated values
- Texture access
- Texture application
- Fog
- Color sum
- Color matrix
- Discard fragment
- etc



Fragment Program

- Output of vertex shader is the input to the fragment shader
  - Compatibility is checked when linking occurs
  - Compatibility between the two is based on varying variables that are defined in both shaders and that match in type and name

- Fragment shader is executed for each fragment produced by rasterization

- For each fragment, fragment shader has access to the interpolated value for each varying variable
  - Color, normal, texture coordinates, arbitrary values

Fragment Processor Output

- In OpenGL 2.X
  - Output of the fragment processor goes on to the fixed function fragment operations and frame buffer operations using built-in variables
  - gl_FragColor – computed R, G, B, A for the fragment
  - gl_FragDepth – computed depth value for the fragment
  - gl_FragData[n] – arbitrary data per fragment, stored in multiple render targets

Fragment Shader: Example

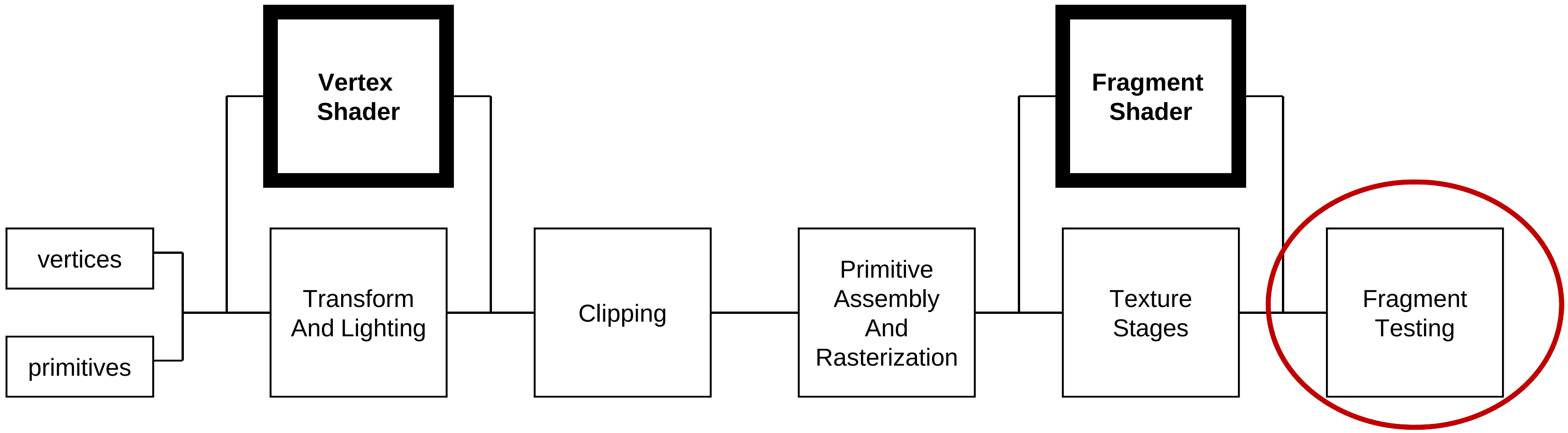
```
// uniform qualified variables are changed at
    most
// once per primitive by the application, and vec3
// declares a vector of three floating-point
    numbers
uniform vec3 CoolestColor;
uniform vec3 HottestColor;

// Temperature contains the now interpolated
// per-fragment value of temperature set by the
// vertex shader
varying float Temperature;
```

```
void main()
{
    // get a color between coolest and hottest
    colors, using
    // the mix() built-in function
    vec3 color = mix(CoolestColor, HottestColor,
    Temperature);
    // make a vector of 4 floating-point numbers
    by appending an
    // alpha of 1.0, and set this fragment’s color
    gl_FragColor = vec4(color, 1.0);
}
```

Fragment Program Capabilities

- Pass the fragment shader output to framebuffers for the following test
  - Scissor test/Alpha test/Depth test/Stencil test/Blending, etc.
  - Values are destined for writing into the frame buffer if all back end tests (stencil, depth etc.) pass

- Clamping or format conversion to the target buffer is done automatically outside of the fragment shader



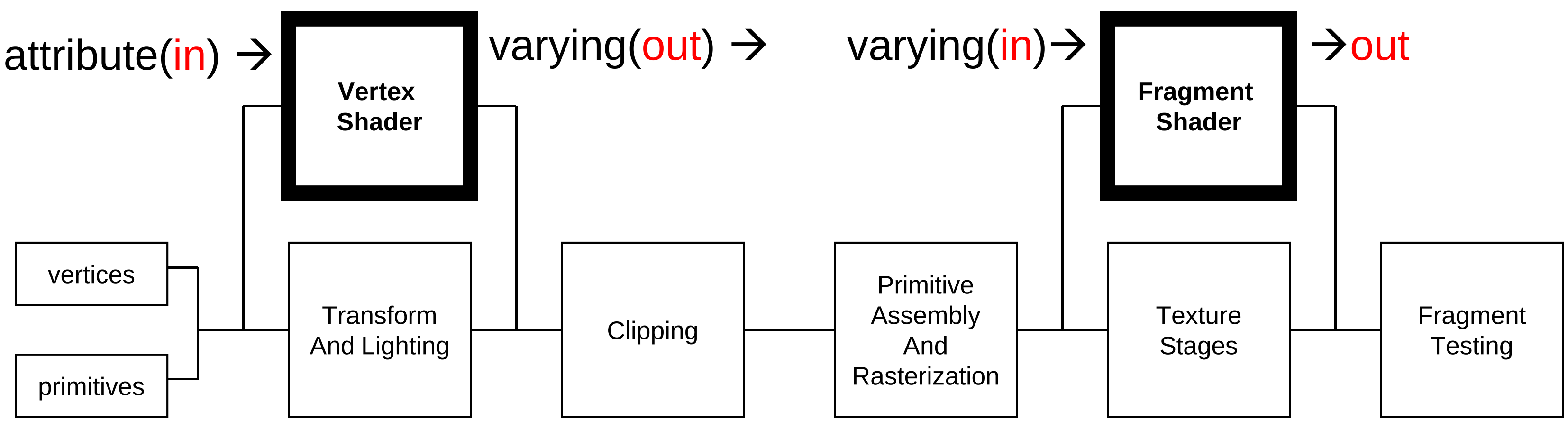
GLSL for OpenGL 3.X/4.X

- Two profiles for shader languages
  - Compatibility (1.X/2.X)
  - Core (3.X/4.X)
- Main changes
  - Reduction of built-in states
    - No transformation matrix,
    - No lighting,
    - No built-in attributes for vertex/colors/normals, etc
- Change of type qualifiers
- Additional programmable stages
  - Geometry/Tessellation shader
- Much more …

❖ The features for compatibility profile are listed in GLSL Spec 4.2.

OpenGL 3.X: Type Qualifiers

- *in*
  - for function parameters copied into a function, but not copied out
- *out*
  - for function parameters copied out of a function, but not copied in
- Can be combined with auxiliary storage qualifiers *centroid/sample/patch*



❖ The complete list of GLSL data types functions are in Section 4.3 of GLSL Spec 4.2.