Computer Graphics (CS 543) Lecture 2 (Part 3): Interaction, Shader Setup & GLSL Introduction

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Adding Interaction

- So far, OpenGL programs just render images
- Can add user interaction
- Examples:
  - User hits ‘h’ on keyboard -> Program draws house
  - User clicks mouse left button -> Program draws table

Types of Input Devices

- **String:** produces string of characters e.g. keyboard

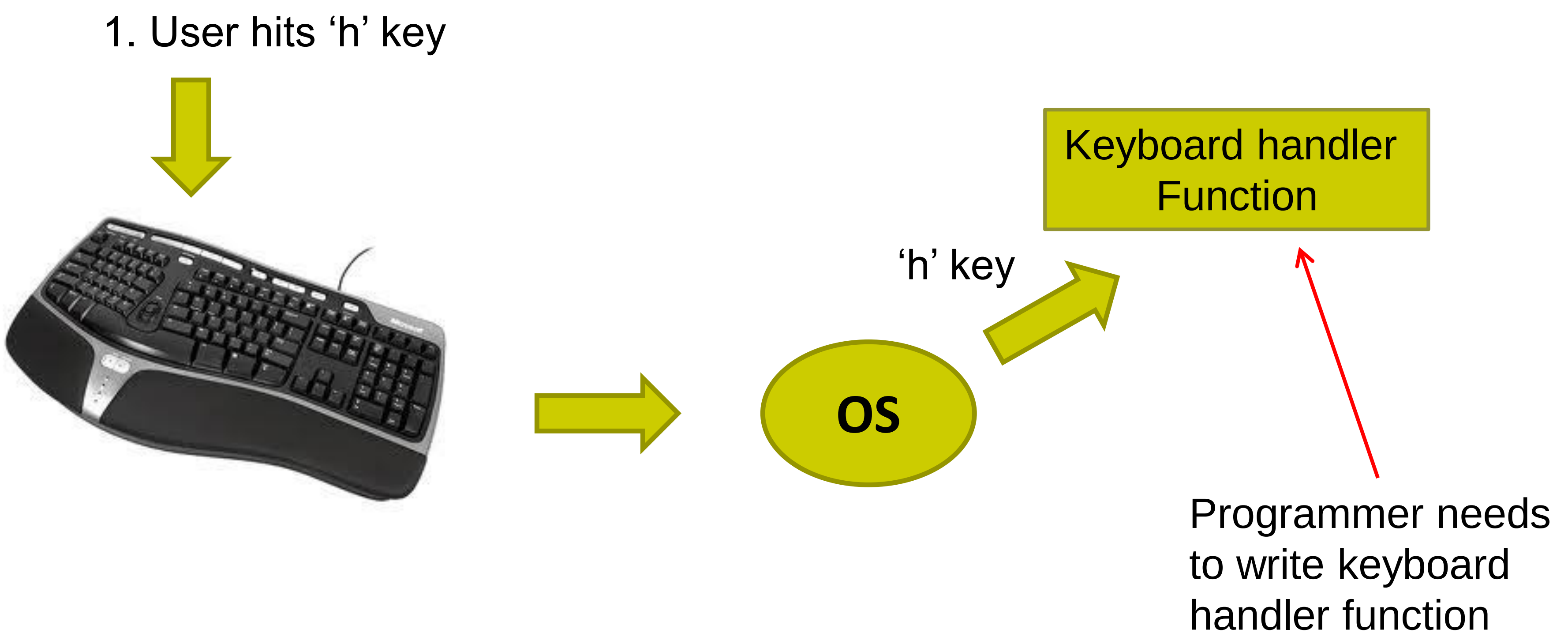
- **Locator:** User points to position on display. E.g mouse

Types of Input Devices

- **Valuator:** generates number between 0 and 1.0 (proportional to how much it is turned)
- **Pick:** User selects location on screen (e.g. touch screen in restaurant, ATM)

GLUT: How keyboard Interaction Works

- Example: User hits ‘h’ on keyboard -> Program draws house



Using Keyboard Callback for Interaction

```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);   // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // … now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}
```

1. Register keyboard Function

2. Implement keyboard function

ASCII character of pressed key

x,y location of mouse

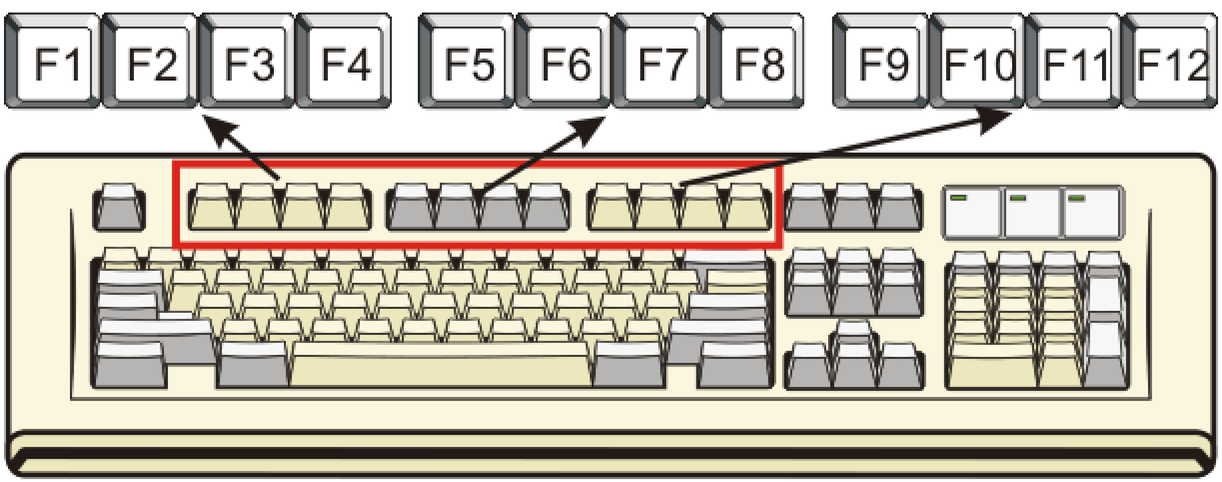
```
void myKeyboard(char key, int x, int y )
{    // put keyboard stuff here
     ……….
       switch(key){    // check which key
          case 'f':
            // do stuff
          break;

          case 'k':
            // do other stuff
          break;

       }
     ……………
}
```

Note: Backspace, delete, escape keys checked using their ASCII codes

Special Keys: Function, Arrow, etc

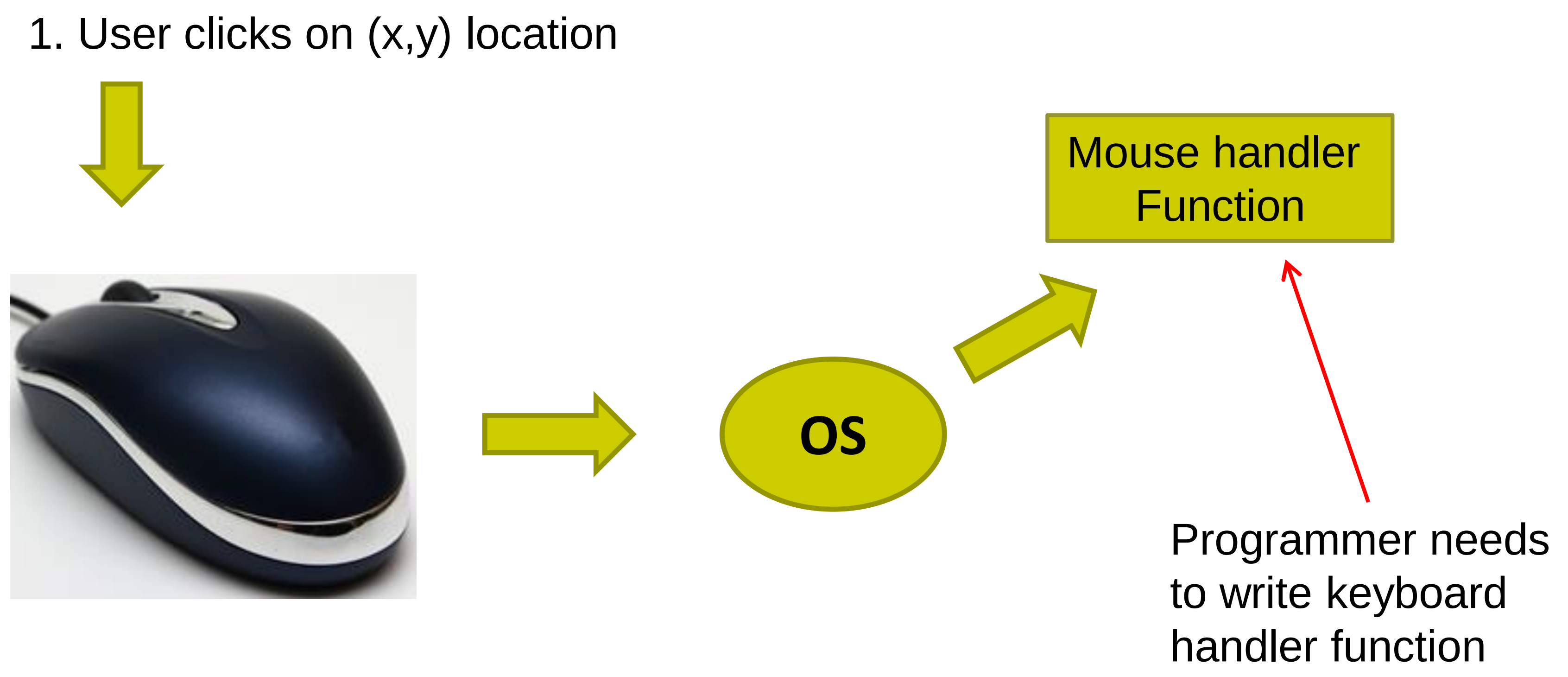
```
glutSpecialFunc (specialKeyFcn);
……
Void specialKeyFcn (Glint specialKey, GLint, xMouse,
                                        Glint yMouse)
```

- Example: if (`specialKey == GLUT_KEY_F1`) // F1 key pressed
  - `GLUT_KEY_F1, GLUT_KEY_F12, ….` for function keys
  - `GLUT_KEY_UP, GLUT_KEY_RIGHT, ….` for arrow keys keys
  - `GLUT_KEY_PAGE_DOWN, GLUT_KEY_HOME, ….` for page up, home keys
- Complete list of special keys designated in `glut.h`



GLUT: How Mouse Interaction Works

- Example: User clicks on (x,y) location in drawing window -> Program draws a line



Using Mouse Callback for Interaction

```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // … now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}
```

1. Register keyboard Function

2. Implement mouse function

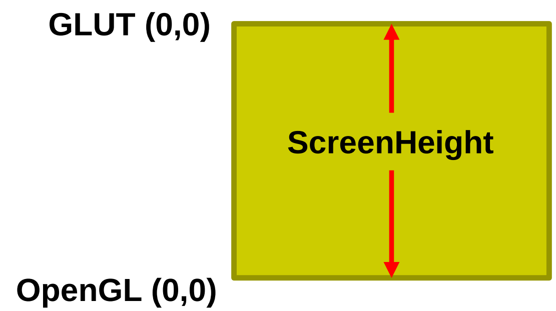
```
void myMouse(int button, int state, int
    x, int y)
{    // put mouse stuff here



        ...............
        }
```

Mouse Interaction

- Declare prototype
  - **`myMouse(int button, int state, int x, int y)`**
  - **`myMovedMouse`**
- Register callbacks:
  - **`glutMouseFunc(myMouse):`** mouse button pressed
  - **`glutMotionFunc(myMovedMouse):`** mouse moves with button pressed
  - **`glutPassiveMotionFunc(myMovedMouse):`** mouse moves with no buttons pressed
- Button returned values:
  - GLUT_LEFT_BUTTON, GLUT_MIDDLE_BUTTON, GLUT_RIGHT_BUTTON
- State returned values:
  - GLUT_UP, GLUT_DOWN
- X,Y returned values:
  - x,y coordinates of mouse location

Mouse Interaction Example

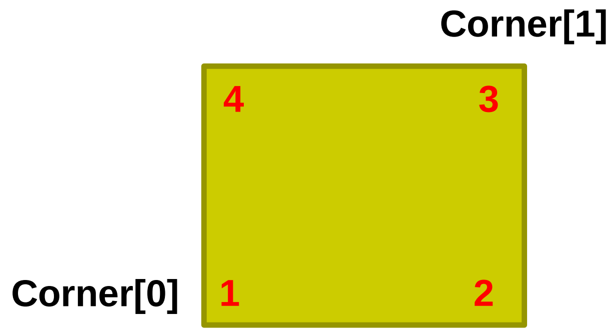
- **Example:** draw (or select) rectangle on screen
- Each mouse click generates separate events
- Store click points in **global** or **static** variable in mouse function




```
void myMouse(int button, int state, int x, int y)
{
   static GLintPoint corner[2];
   static int numCorners = 0;   // initial value is 0
   if(button == GLUT_LEFT_BUTTON && state == GLUT_DOWN)
   {
        corner[numCorners].x = x;
        corner[numCorners].y = screenHeight – y; //flip y coord
        numCorners++;
```

Screenheight is height of drawing window

Mouse Interaction Example (continued)

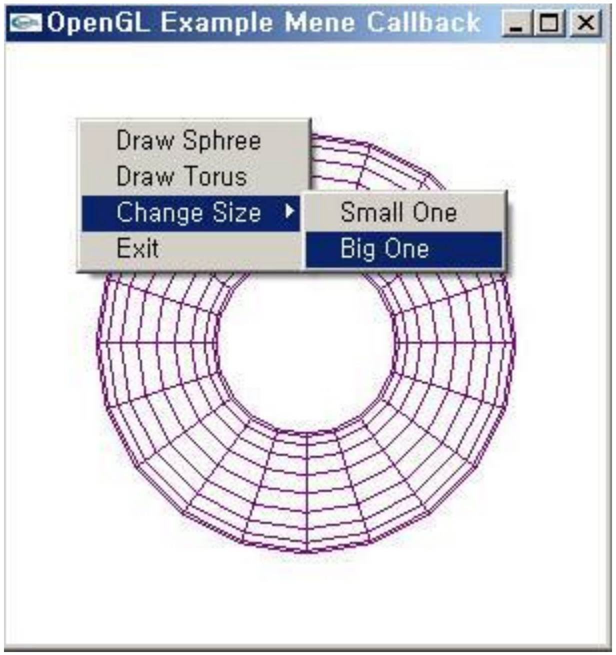



```
    if(numCorners == 2)
    {
        // draw rectangle or do whatever you planned to do
        Point3 points[4] = corner[0].x, corner[0].y,   //1
                           corner[1].x, corner[0].y,   //2
                           corner[1].x, corner[1].y,   //3
                            corner[0].x, corner[1].y);  //4

         glDrawArrays(GL_QUADS, 0, 4);

        numCorners == 0;
    }
    else if(button == GLUT_RIGHT_BUTTON && state == GLUT_DOWN)
        glClear(GL_COLOR_BUFFER_BIT); // clear the window
    glFlush( );
}
```

Menus

- Adding menu that pops up on mouse click

1. Create menu using **`glutCreateMenu(myMenu);`**
2. Use **`glutAddMenuEntry`** adds entries to menu
3. Attach menu to mouse button (left, right, middle) using **`glutAttachMenu`**



Menus

- Example:

Shows on menu

Checked in mymenu

```
glutCreateMenu(myMenu);
 glutAddMenuEntry(“Clear Screen”, 1);
 glutAddMenuEntry(“Exit”, 2);
 glutAttachMenu(GLUT_RIGHT_BUTTON);

 ….

 void mymenu(int value){
     if(value == 1){
          glClear(GL_COLOR_BUFFER_BIT);
          glFlush( );
     }
     if (value == 2) exit(0);
}
```

Clear Screen	1
Exit	2

GLUT Interaction using other input devices

- Tablet functions (mouse cursor must be in display window)

```
glutTabletButton (tabletFcn);
…. .
void tabletFcn(Glint tabletButton, Glint action, Glint
   xTablet, Glint yTablet)
```

- Spaceball functions
- Dial functions
- Picking functions: use your finger
- Menu functions: minimal pop-up windows within your drawing window
- Reference: *Hearn and Baker, 3rd edition (section 20-6)*

OpenGL function format

function name

Number of arguments

`glUniform3f(x,y,z)`

belongs to GL library

`x,y,z` are `floats`

`glUniform3fv(p)`

Argument is array of values

`p` is a pointer to array

Lack of Object Orientation

- OpenGL is not object oriented
- Multiple versions for each command
  - `glUniform3f`
  - `glUniform2i`
  - `glUniform3dv`

OpenGL Data Types

C++	**OpenGL**
Signed char	GLByte
Short	GLShort
Int	GLInt
Float	GLFloat
Double	GLDouble
Unsigned char	GLubyte
Unsigned short	GLushort
Unsigned int	GLuint

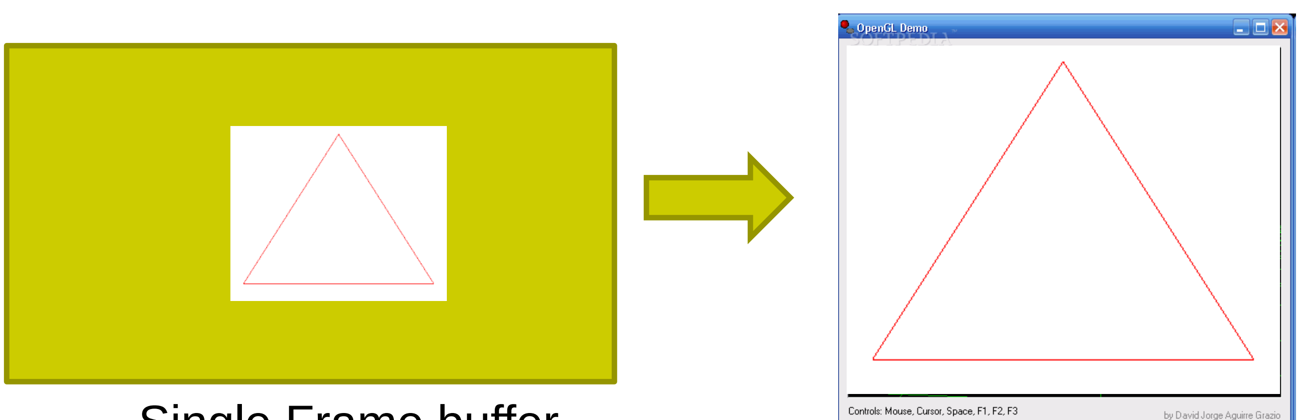
Example: Integer is 32-bits on 32-bit machine
but 64-bits on a 64-bit machine

Recall: Single Buffering

- If display mode set to single framebuffers
- Any drawing into framebuffer is seen by user. How?
    - `glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);`
        - Single buffering with RGB colors
- Drawing may not be drawn to screen until call to `glFlush( )`

```
void mydisplay(void){
      glClear(GL_COLOR_BUFFER_BIT); // clear screen
      glDrawArrays(GL_POINTS, 0, N);
      glFlush( );
}
```

← Drawing sent to screen



Single Frame buffer

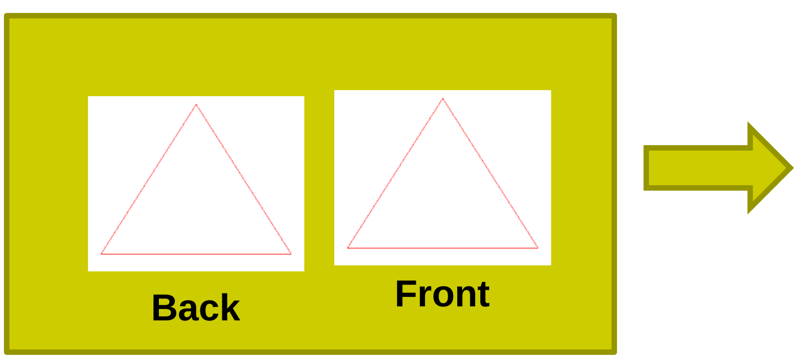
Double Buffering

- Set display mode to double buffering (create front and back framebuffers)
  - `glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB);`
    - Double buffering with RGB colors
    - Double buffering is good for animations, avoids tearing artifacts

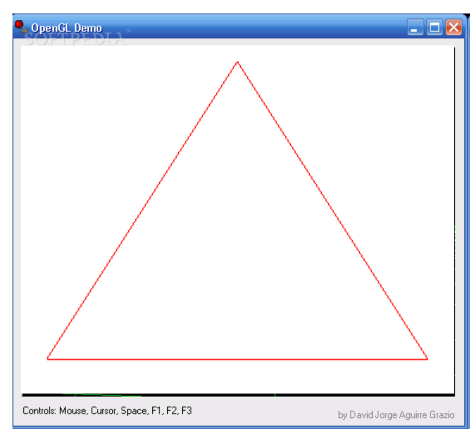
- Front buffer displayed on screen, back buffers not displayed
- Drawing into back buffers (not displayed) until swapped in using **`glutSwapBuffers( )`**

```
void mydisplay(void){
        glClear(GL_COLOR_BUFFER_BIT); // clear screen
        glDrawArrays(GL_POINTS, 0, N);
        glutSwapBuffers( );
}
```

Back buffer drawing swapped in, becomes visible here



Double Frame buffer



Recall: OpenGL Skeleton

```
void main(int argc, char** argv){
   glutInit(&argc, argv);   // initialize toolkit
   glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutInitWindowPosition(100, 150);
   glutCreateWindow("my first attempt");
   glewInit( );


   // … now register callback functions
   glutDisplayFunc(myDisplay);
   glutReshapeFunc(myReshape);
   glutMouseFunc(myMouse);
   glutKeyboardFunc(myKeyboard);

   glewInit( );
   generateGeometry( );
   initGPUBuffers( );
   void shaderSetup( );

   glutMainLoop( );
}
```

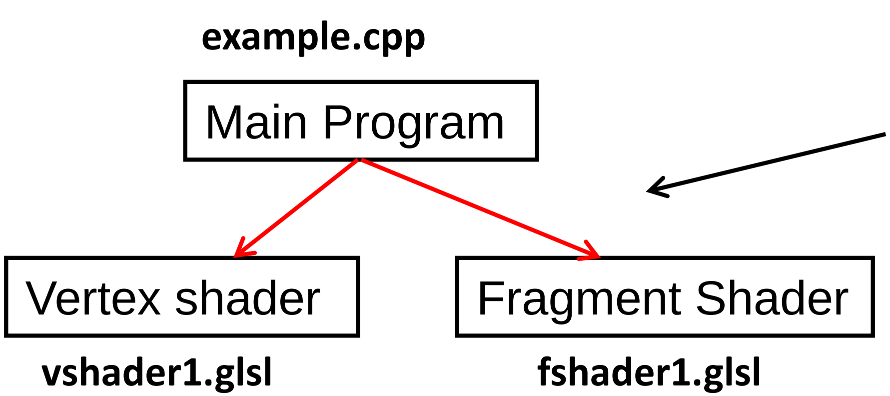
```
void shaderSetup( void )
{
  // Load shaders and use the resulting shader program
   program = InitShader( "vshader1.glsl", "fshader1.glsl" );
   glUseProgram( program );

   // Initialize vertex position attribute from vertex shader
   GLuint loc = glGetAttribLocation( program, "vPosition" );
   glEnableVertexAttribArray( loc );
   glVertexAttribPointer( loc, 2, GL_FLOAT, GL_FALSE, 0,
                                           BUFFER_OFFSET(0) );


   // sets white as color used to clear screen
   glClearColor( 1.0, 1.0, 1.0, 1.0 );
}
```

Recall: OpenGL Program: Shader Setup

- `initShader( )`: our homegrown shader initialization
  - Used in main program, connects and link vertex, fragment shaders
  - Shader sources read in, compiled and linked

```
Gluint = program;
```

```
GLuint program = InitShader( "vshader1.glsl", "fshader1.glsl" );
glUseProgram(program);
```



What's inside **initShader??**
Next!

Coupling Shaders to Application (initShader function)

1. Create a program object
2. Read shaders
3. Add + Compile shaders
4. Link program (everything together)
5. Link variables in application with variables in shaders
   - Vertex attributes
   - Uniform variables

Step 1. Create Program Object

- Container for shaders
  - Can contain multiple shaders, other GLSL functions

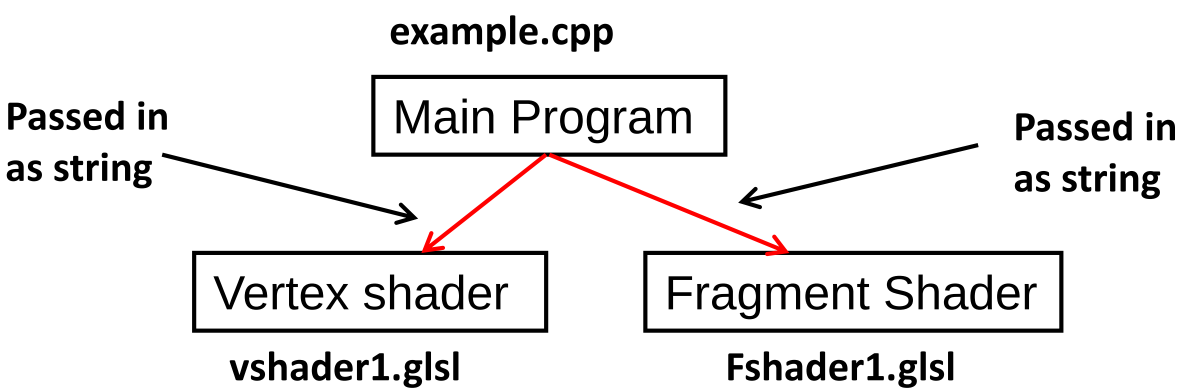
```
GLuint myProgObj;

myProgObj = glCreateProgram();
```

Create container called **Program Object**

Main Program

Step 2: Read a Shader

- Shaders compiled and added to program object



- Shader file code passed in as null-terminated string using the function **`glShaderSource`**
- Shaders in files (vshader.glsl, fshader.glsl), write function **`readShaderSource`** to convert shader file to string

Shader Reader Code?

```c
#include <stdio.h>

static char* readShaderSource(const char* shaderFile)
{
    FILE* fp = fopen(shaderFile, "r");

    if ( fp == NULL ) { return NULL; }

    fseek(fp, 0L, SEEK_END);
    long size = ftell(fp);

    fseek(fp, 0L, SEEK_SET);
    char* buf = new char[size + 1];
    fread(buf, 1, size, fp);

    buf[size] = '\0';
    fclose(fp);

    return buf;
}
```

Shader file name (e.g. vshader.glsl) → **readShaderSource** → String of entire shader code

Step 3: Adding + Compiling Shaders

```
GLuint myVertexObj;
Gluint myFragmentObj;
```

Declare shader object (container for shader)

```
GLchar* vSource = readShaderSource("vshader1.glsl");
GLchar* fSource = readShaderSource("fshader1.glsl");
```

Read shader files, Convert code to string

```
myVertexObj = glCreateShader(GL_VERTEX_SHADER);
myFragmentObj = glCreateShader(GL_FRAGMENT_SHADER);
```

Create empty Shader objects

example.cpp

Main Program

Vertex shader

vshader1.glsl

Fragment Shader

fshader1.glsl

Step 3: Adding + Compiling Shaders
Step 4: Link Program

Read shader code strings into shader objects

```
glShaderSource(myVertexObj, 1, vSource, NULL);
glShaderSource(myFragmentObj, 1, fSource, NULL);
```

```
glCompileShader(myVertexObj);
glCompileShader(myFragmentObj);
```

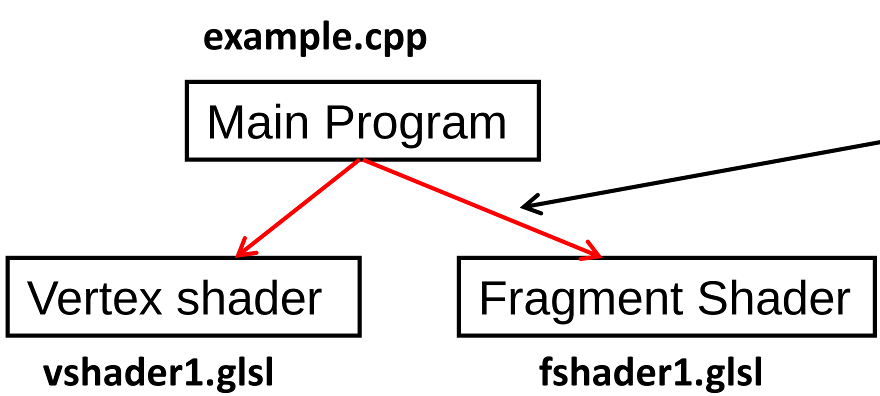
Compile shader objects

```
glAttachShader(myProgObj, myVertexObj);
glAttachShader(myProgObj, myFragmentObj);
```

Attach shader objects to program object

```
glLinkProgram(myProgObj);
```

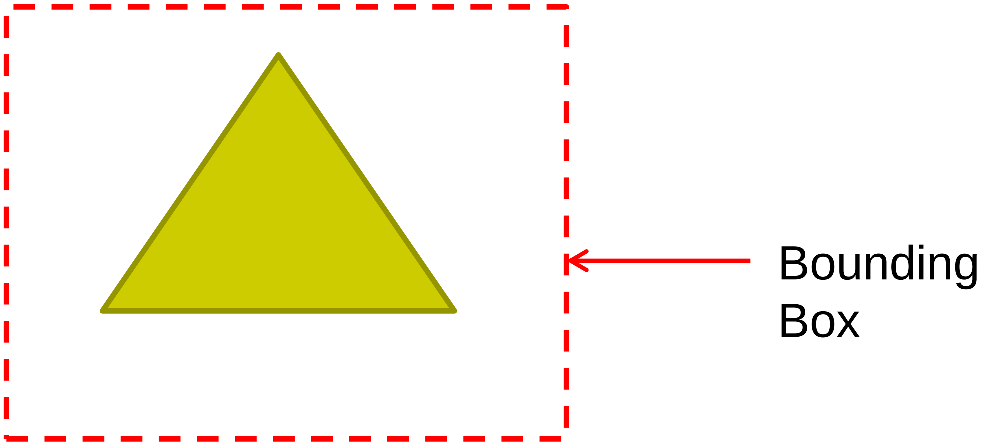
Link Program



Attach shader objects to program object

Uniform Variables

- Variables that are **constant** for an entire primitive
- Can be changed in application and sent to shaders
- Cannot be changed in shader
- Used to pass information to shader
  - **Example:** bounding box of a primitive



Uniform variables

- Sometimes want to connect uniform variable in OpenGL application to uniform variable in shader
- Example?
  - Check “elapsed time” variable (etime) in OpenGL application
  - Use elapsed time variable (time) in shader for calculations

Uniform variables

- First declare **etime** variable in OpenGL application, get time

```
float etime;

etime = 0.001*glutGet(GLUT_ELAPSED_TIME);
```

Elapsed time since program started

- Use corresponding variable **time** in shader

```
uniform float time;
attribute vec4 vPosition;

main( ){
    vPosition.x  += (1+sin(time));
    gl_Position = vPosition;
}
```

- Need to connect **etime** in application and **time** in shader!!

Connecting **etime and time**

- Linker forms table of shader variables, each with an index
- Application can get index from table, tie it to application variable
- In application, find location of shader **time** variable in linker table

```
Glint timeLoc;

timeLoc = glGetUniformLocation(program, “time”);
```

423	time

- Connect: **location** of shader variable **time** to **etime**!

```
glUniform1(timeLoc, etime);
```

423	etime

Location of shader variable time

Application variable, etime

GL Shading Language (GLSL)

- GLSL: high level C-like language
- Main program (e.g. example1.cpp) program written in C/C++
- Vertex and Fragment shaders written in GLSL
- From OpenGL 3.1, application must use shaders

What does keyword out mean?

```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Example code of vertex shader

gl_Position not declared
Built-in types (already declared, just use)

Passing values

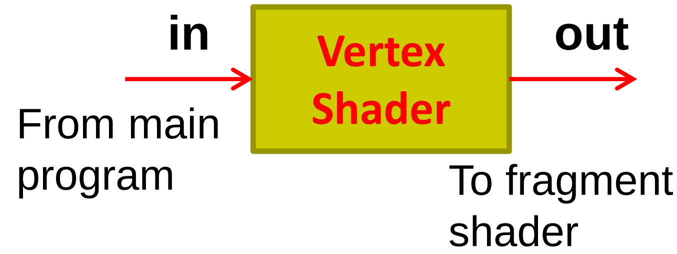
- Variable declared **out** in vertex shader can be declared as **in** in fragment shader and used
- Why? To pass result of vertex shader calculation to fragment shader

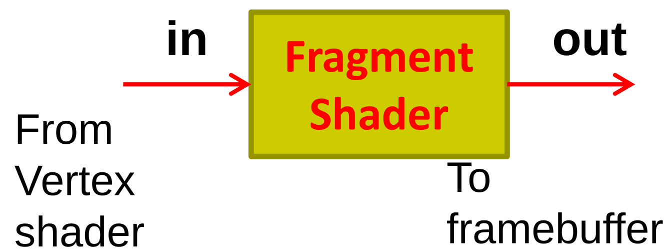
```
const vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Vertex shader

```
in vec3 color_out;

void main(void){
  // can use color_out here.
}
```

Fragment shader





Data Types

- **C types:** `int, float, bool`
- **GLSL types:**
  - `float vec2: e.g. (x,y)          // vector of 2 floats`
  - `float vec3: e.g. (x,y,z) or (R,G,B) // vector of 3 floats`
  - `float vec4: e.g. (x,y,z,w)      // vector of 4 floats`

```
Const float vec4 red = vec4(1.0, 0.0, 0.0, 1.0);
out float vec3 color_out;

void main(void){
  gl_Position = vPosition;
  color_out = red;
}
```

Vertex shader

C++ style constructors

- Also:
  - int (ivec2, ivec3, ivec4) and
  - boolean (bvec2, bvec3,bvec4)

Data Types

- Matrices: mat2, mat3, mat4
  - Stored by columns
  - Standard referencing m[row][column]
- Matrices and vectors are basic types
  - can be passed in and out from GLSL functions
- E.g

  mat3 func(mat3 a)
- **No pointers** in GLSL
- Can use C structs that are copied back from functions

Operators and Functions

- Standard C functions
  - **Trigonometric:** cos, sin, tan, etc
  - **Arithmetic:** log, min, max, abs, etc
  - Normalize, reflect, length
- Overloading of vector and matrix types

```
mat4 a;
vec4 b, c, d;
c = b*a;     // a column vector stored as a 1d array
d = a*b;    // a row vector stored as a 1d array
```

Swizzling and Selection

- **Selection:** Can refer to array elements by element using [] or selection (.) operator with
  - x, y, $\boxed{\text{z}}$, w
  - r, g, $\boxed{\text{b}}$, a
  - s, t, $\boxed{\text{p}}$, q
  - **`vec4 a;`**
  - **`a[2], a.b, a.z, a.p`** are the same
- **Swizzling** operator lets us manipulate components

```
a.yz = vec2(1.0, 2.0);
```

References

- Angel and Shreiner, Interactive Computer Graphics, 6th edition, Chapter 2
- Hill and Kelley, Computer Graphics using OpenGL, 3rd edition, Chapter 2