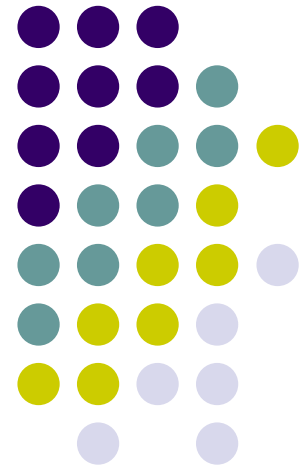


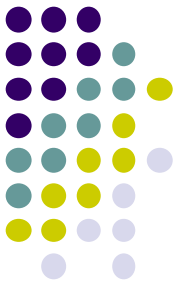
Computer Graphics (CS 4731)

Lecture 2: Introduction to OpenGL/GLUT (Part 1)

Prof Emmanuel Agu

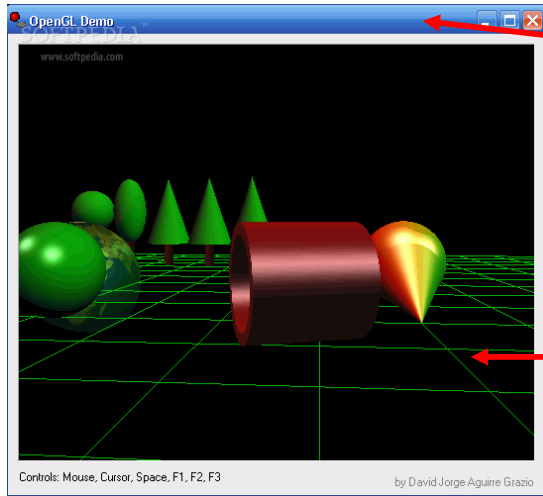
*Computer Science Dept.
Worcester Polytechnic Institute (WPI)*





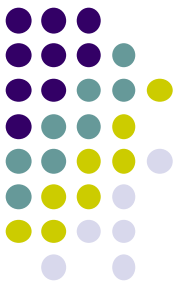
OpenGL/GLUT Installation

- **OpenGL:** Specific version (e.g. 4.3) on your graphics card hardware
 - Just check OpenGL version on your graphics card
- **GLUT:** software that needs to be installed
 - already installed in zoolab machines



GLUT: **install it!**

OpenGL: **already on graphics card**



glInfo: Finding out about your Graphics Card

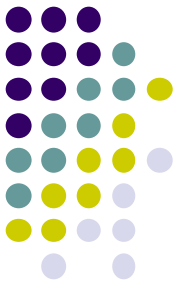
- Software tool to find out OpenGL version and extensions your graphics card supports
- This class? Need graphics card with OpenGL 4.3 or later

The screenshot shows the GLInfo application window with a dark blue background and yellow text. The window title is "GLInfo". On the left is a sidebar with menu items: "Driver info", "Extension lists", "Implementation specifics", "Extension specifics", "Reports", and "About". The "Extension lists" item is highlighted with a white box and a red arrow pointing to the text "OpenGL extensions on Graphics card". The main area displays the following information:

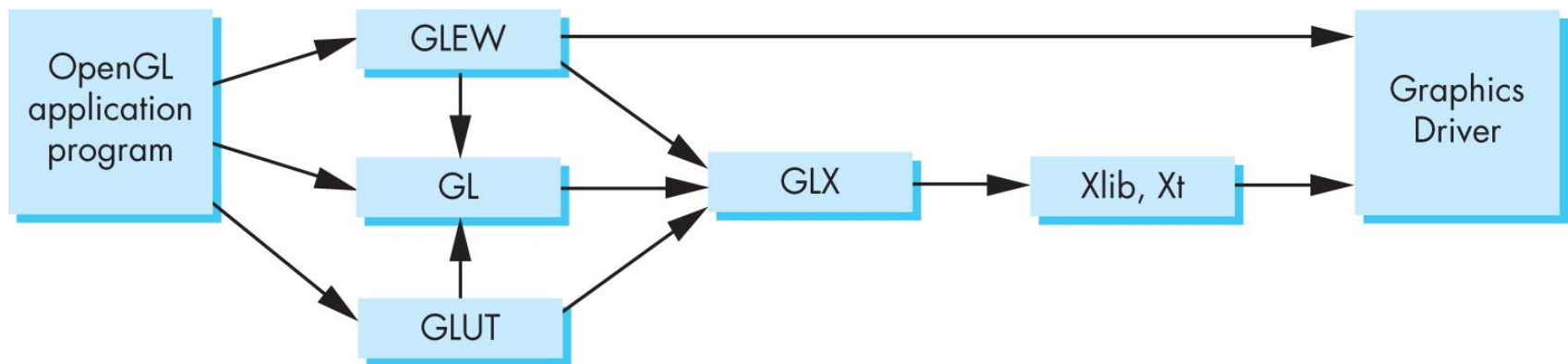
Driver version:	Unknown
Vendor:	Intel
Renderer:	Intel(R) HD Graphics
OpenGL version:	2.1.0 - Build 8.15.10.2202

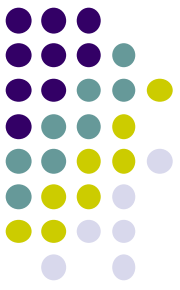
The "OpenGL version:" line is highlighted with a white box and a red arrow pointing to the text "OpenGL version on Graphics card".

OpenGL Extension Wrangler Library (GLEW)



- **OpenGL extensions:** card manufacturers may implement new proprietary features after latest OpenGL version released
 - Published, made available as extension to latest OpenGL
- **GLEW:** library to access OpenGL extensions on a graphics card
- We will install GLEW as well





Windows Installation of GLUT, GLEW

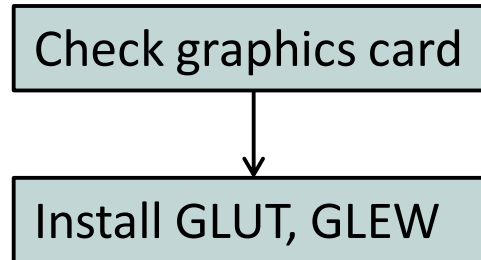
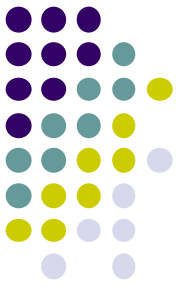
1. Install Visual Studio (e.g 2015)
2. Download freeglut **32-bit** (GLUT implementation)
 - <http://freeglut.sourceforge.net/>
3. Download **32-bit** GLEW
 - <http://glew.sourceforge.net/>
4. Unzip GLUT, GLEW => .lib, .h, .dll files
 - E.g. freeglut 3.0.0, files:
 - freeglut.dll
 - glut.h
 - freeglut.lib

Check graphics card

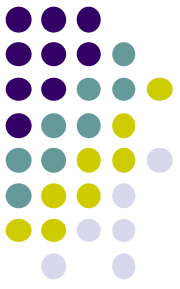


Install GLUT, GLEW

Windows Installation of GLUT, GLEW



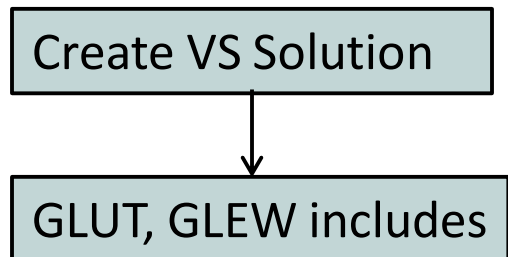
- Install .lib, .h, .dll files (for GLUT and GLEW) from zip files. Put
 - .dll files in **C:\windows\system**
 - .h files in c:\Visual Studio... **\include** directory
 - .lib files in c:\Visual Studio.... **\lib** directory



Getting Started: Writing .cpp In Visual studio

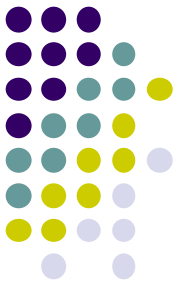
1. Create empty project,
2. Create blank console application (C program)
3. Include **glew.h** and **glut.h** at top of your program

```
#include <glew.h>  
#include <GL/glut.h>
```



Note: **GL/** is sub-directory of compiler **include/** directory

- OpenGL drawing functions in **gl.h**
- **glut.h** contains GLUT functions, also includes **gl.h**



Getting Started: More #includes

- Most OpenGL applications use standard C library (e.g `printf`), so

```
#include <glew.h>
```

```
#include <GL/glut.h>
```

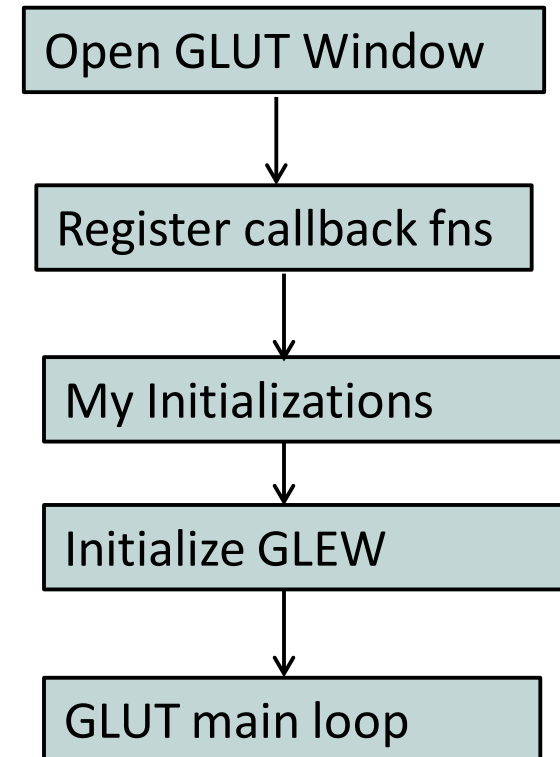
```
#include <stdlib.h>
```

```
#include <stdio.h>
```




OpenGL/GLUT Program Structure

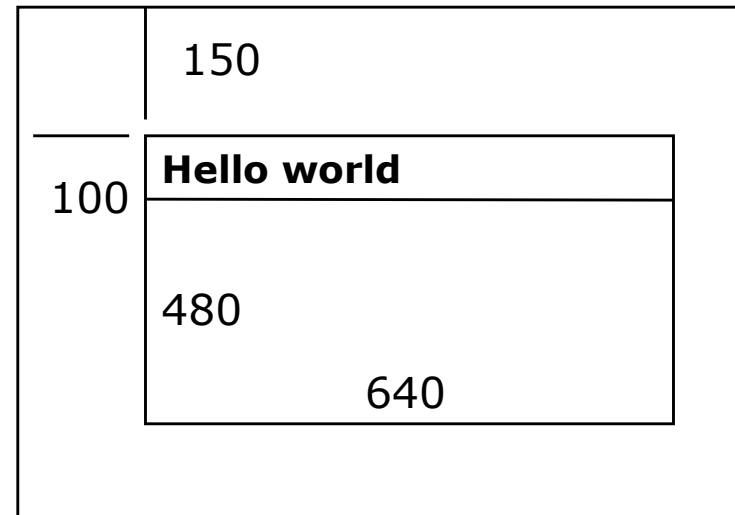
- Open window (GLUT)
 - Configure display mode, window position/size
- Register GLUT callback functions (GLUT)
 - Render, resize, input: keyboard, mouse, etc
- Custom initialization
 - Set background color, clear color, etc
 - Generate points to be drawn
 - Initialize shaders
- Initialize GLEW
- glutMainLoop()
 - Waits here infinitely till event

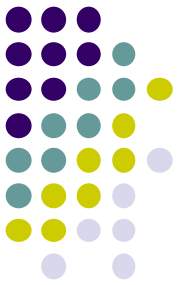




Opening a GLUT window

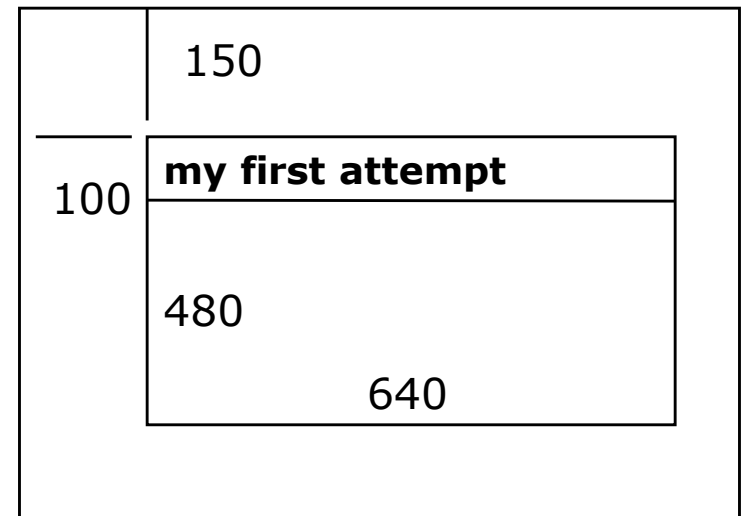
- GLUT Commands used
 - `glutInit(&argc, argv);`
 - Initializes GLUT
 - `glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);`
 - sets display mode (e.g. single framebuffer with RGB colors)
 - `glutInitWindowSize(640, 480);`
 - sets window size (Width x Height) in pixels
 - `glutInitPosition(100, 150);`
 - sets location of upper left corner of window
 - `glutCreateWindow("Hello world");`
 - open window with title "Hello world"
- Then initialize GLEW
 - `glewInit();`





OpenGL Skeleton

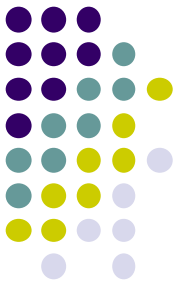
```
void main(int argc, char** argv){  
    // First initialize toolkit, set display mode and create window  
  
    glutInit(&argc, argv);    // initialize toolkit  
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);  
    glutInitWindowSize(640, 480);  
    glutInitWindowPosition(100, 150);  
    glutCreateWindow("my first attempt");  
    glewInit( );  
  
    // ... then register callback functions,  
    // ... do my initialization  
    // .. wait in glutMainLoop for events  
  
}
```





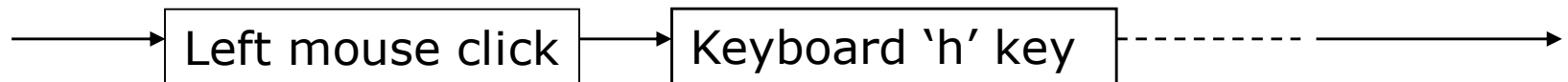
Sequential Vs Event-driven

- OpenGL programs are event-driven
- Sequential program
 - Start at `main()`
 - Perform actions 1, 2, 3.... *N*
 - End
- Event-driven program
 - Start at `main()`
 - Initialize
 - Wait in infinite loop
 - Wait till defined event occurs
 - Event occurs => Take defined actions
- What is world's most widely used event-driven program?



OpenGL: Event-driven

- Program only responds to events
- Do nothing until event occurs
- Example Events:
 - Redraw “stuff” in OpenGL window
 - mouse clicks,
 - keyboard stroke
- Programmer defines:
 - Events that program should respond to
 - Actions to be taken when event occurs
- System (e.g. Windows):
 - Receives event, maintains event queue

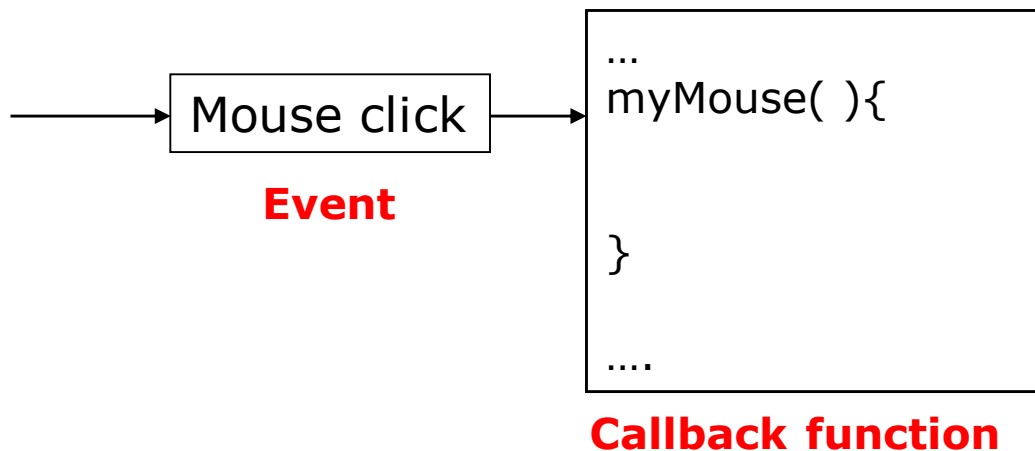


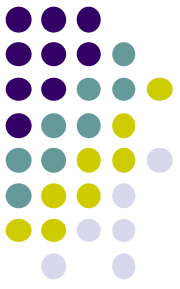
- Calls functions defined by programmer for specific event



OpenGL: Event-driven

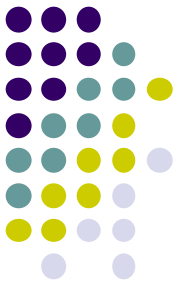
- How in OpenGL?
 - Programmer declares, registers callback functions (event handler)
 - Callback function called when event occurs
- Example: Programmer
 1. Declare function *myMouse*, to be called on mouse click
 2. Register it: `glutMouseFunc(myMouse);`
- When OS receives mouse click, calls callback function **myMouse**





GLUT Callback Functions

- Register callbacks for all events your program will react to
- No registered callback = no action
- Example: if no registered keyboard callback function, hitting keyboard keys generates **NO RESPONSE!!**



GLUT Callback Functions

- GLUT Callback functions in skeleton
 - `glutDisplayFunc (myDisplay)` : Initial drawing put here
 - `glutReshapeFunc (myReshape)` : called when window is reshaped
 - `glutMouseFunc (myMouse)` : called when mouse button pressed
 - `glutKeyboardFunc (mykeyboard)` : called when keyboard is pressed or released
- `glutMainLoop ()` :
 - program draws initial picture (by calling myDisplay function once)
 - Enters infinite loop till event



OpenGL Skeleton

```
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( );

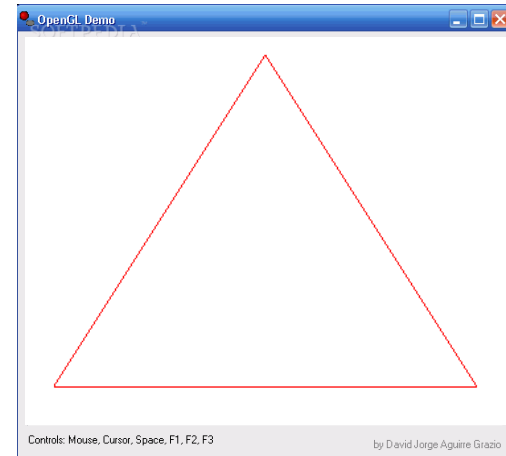
    // ... now register callback functions
    glutDisplayFunc(myDisplay);    ←--Next... how to draw in myDisplay
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

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



Example: Draw in function myDisplay

- **Task:** Draw red triangle on white background



- **Rendering steps:**

1. Generate triangle corners (3 vertices)
2. Create GPU buffer for vertices
3. Move array of 3 vertices from CPU to GPU buffer
4. Draw 3 points from array on GPU using **glDrawArray**



Example: Retained Mode Graphics

- **Rendering steps:**

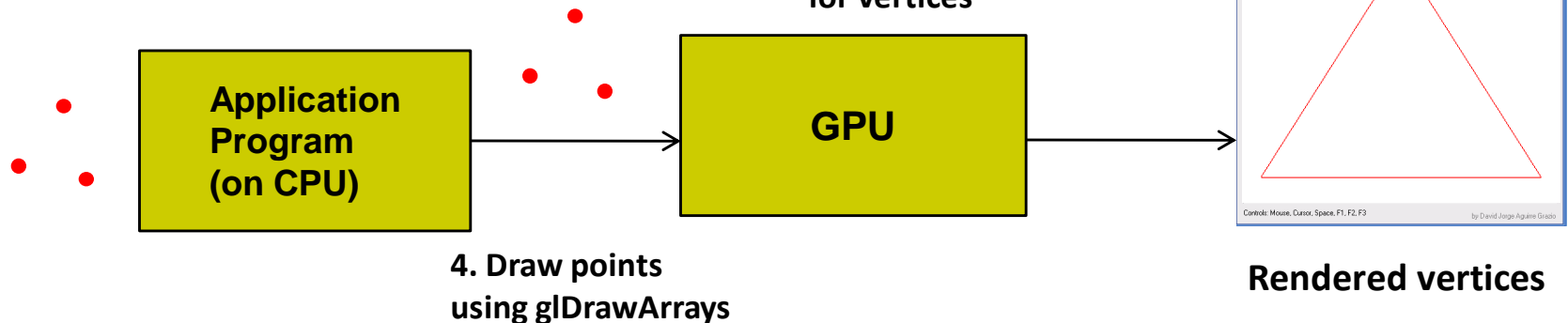
1. Generate triangle corners (3 vertices)
2. Create GPU buffer for vertices
3. Move array of 3 vertices from CPU to GPU buffer
4. Draw 3 points from array on GPU using `glDrawArray`

- **Simplified Execution model:**

1. Generate 3 triangle corners

3. Move array of 3 vertices from CPU to GPU buffer

2. Create GPU buffers for vertices





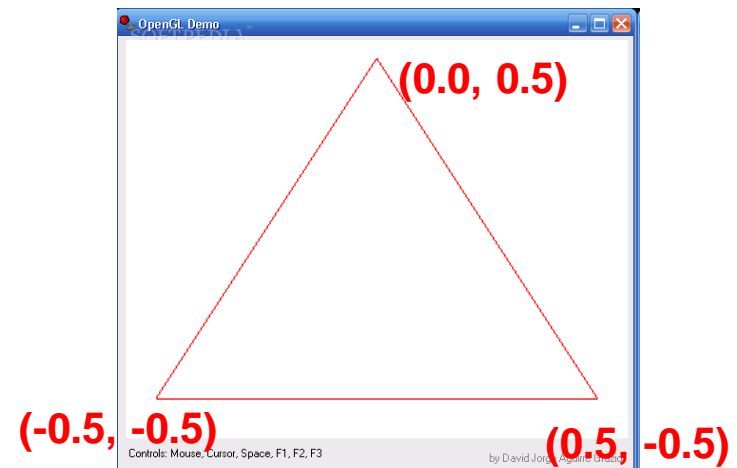
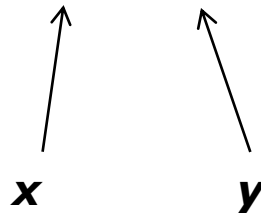
1. Generate triangle corners (3 vertices)

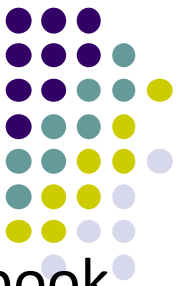
```
// declare array of 3 points
```

```
point2 points[3];
```

```
// generate 3 triangle vertices + store in points array
```

```
void generateGeometry( void ){  
    points[0] = point2( -0.5, -0.5 );  
    points[1] = point2( 0.0, 0.5 );  
    points[2] = point2( 0.5, -0.5 );  
}
```





Declare some Types for Points, vectors

- Useful declarations (homegrown) in *header file* **vec.h** from book
 - **point2** for (x,y) locations
 - **vec3** for (x,y,z) vector coordinates

- Need to include header “vec.h”

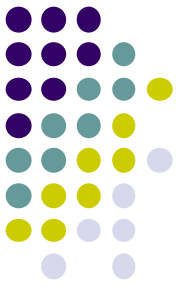
- Example usage:

```
#include "vec.h"
```

```
vec3 vector1; ← Declares (x, y, z) coordinates of a vector
```

- **Note:** You will be given file Angel.h from book. It includes vec.h

OpenGL Skeleton: Where are we?



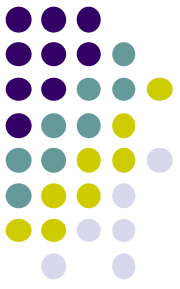
```
void main(int argc, char** argv){
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

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

    glewInit( );
    generateGeometry( );

    glutMainLoop( );
}
```

```
// generate 3 triangle vertices + store in array
void generateGeometry( void ){
    points[0] = point2( -0.5, -0.5 );
    points[1] = point2( 0.0, 0.5 );
    points[2] = point2( 0.5, -0.5 );
}
```



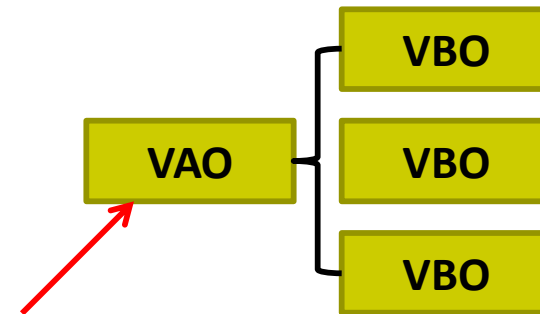
2. Create GPU Buffer for Vertices

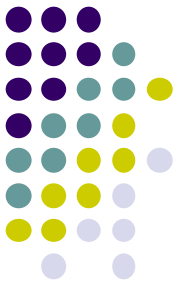
- Rendering from GPU memory significantly faster. Move data there
- Fast GPU (off-screen) memory for data called **Vertex Buffer Objects (VBO)**
- Array of VBOs (called **Vertex Array Object (VAO)**) usually created
- Example use: vertex positions in VBO 1, color info in VBO 2, etc

- So, first create the VAO

```
GLuint vao;
```

```
glGenVertexArrays( 1, &vao ); // create VAO  
glBindVertexArray( vao ); // make VAO active
```





2. Create GPU Buffer for Vertices

- Next, create a buffer object in two steps
 1. Create VBO and give it name (unique ID number)

GLuint buffer;

glGenBuffers(1, &buffer); // create one VBO

Number of Buffer Objects to return



2. Make created VBO currently active one

glBindBuffer(GL_ARRAY_BUFFER, buffer);

Data is array of values



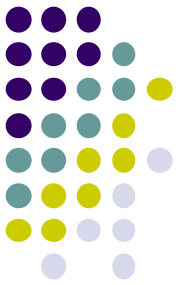
3. Move points GPU memory

3. Move `points` to VBO

```
glBufferData(GL_ARRAY_BUFFER, buffer, sizeof(points),  
points, GL_STATIC_DRAW ); //data is array
```

**Data to be transferred to GPU
memory (generated earlier)**

- **GL_STATIC_DRAW**: buffer object data will not be changed. Specified once by application and used many times to draw
- **GL_DYNAMIC_DRAW**: buffer object data will be changed. Specified repeatedly and used many times to draw



Put it Together:

2. Create GPU Buffer for Vertices

3. Move points GPU memory

```
void initGPUBuffers( void )  
{
```

```
    // Create a vertex array object
```

```
    GLuint vao;
```

```
    glGenVertexArrays( 1, &vao );
```

```
    glBindVertexArray( vao );
```



```
    // Create and initialize a buffer object
```

```
    GLuint buffer;
```

```
    glGenBuffers( 1, &buffer );
```

```
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
```

```
    glBufferData( GL_ARRAY_BUFFER, sizeof(points),  
                 points, GL_STATIC_DRAW );
```

```
}
```

OpenGL Skeleton: Where are we?



```
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( );
```



```
glutMainLoop( );
```

```
}
```

```
void initGPUBuffers( void )
{
    // Create a vertex array object
    GLuint vao;
    glGenVertexArrays( 1, &vao );
    glBindVertexArray( vao );

    // Create and initialize a buffer object
    GLuint buffer;
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER,
                  sizeof(points), points, GL_STATIC_DRAW );
}
```



4. Draw points (from VBO)

```
glDrawArrays (GL_POINTS, 0, N);
```

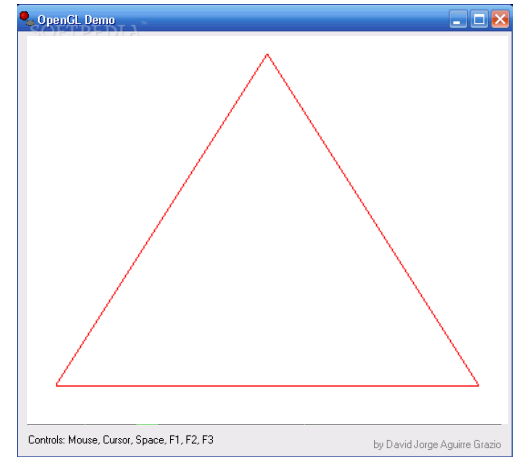
Render buffered
data as points

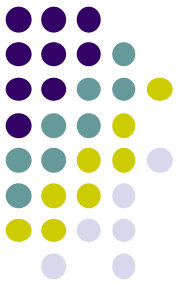
Starting
index

Number of
points to be
rendered

- Display function using `glDrawArrays`:

```
void mydisplay(void) {  
    glClear(GL_COLOR_BUFFER_BIT);           // clear screen  
    glDrawArrays(GL_LINE_LOOP, 0, 3);      // draw the points  
    glFlush( );                             // force rendering  
}
```





References

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