# Computer Graphics (CS 543) Lecture 1b: Introduction to OpenGL/GLUT (Part 1)

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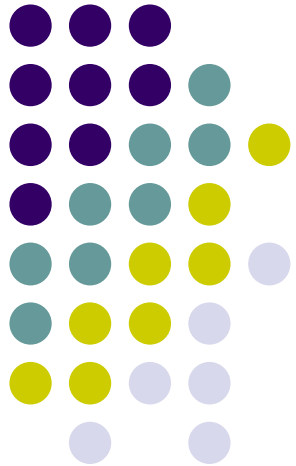
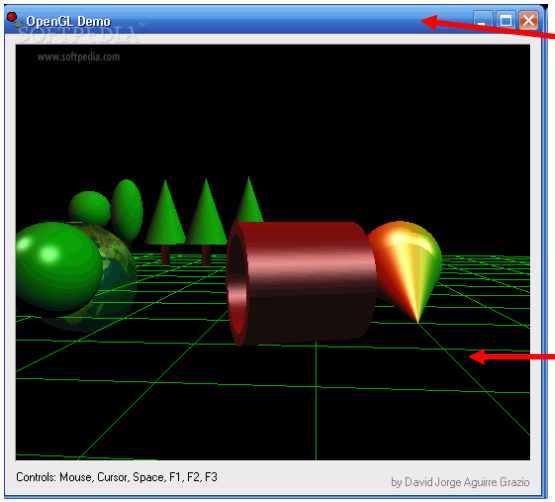


# OpenGL/GLUT Installation

- **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




**GLUT: install it!**

**OpenGL: already on graphics card**

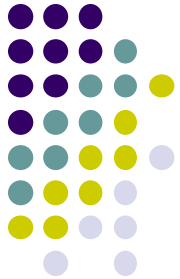
# glInfo: Finding out about your Graphics Card

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

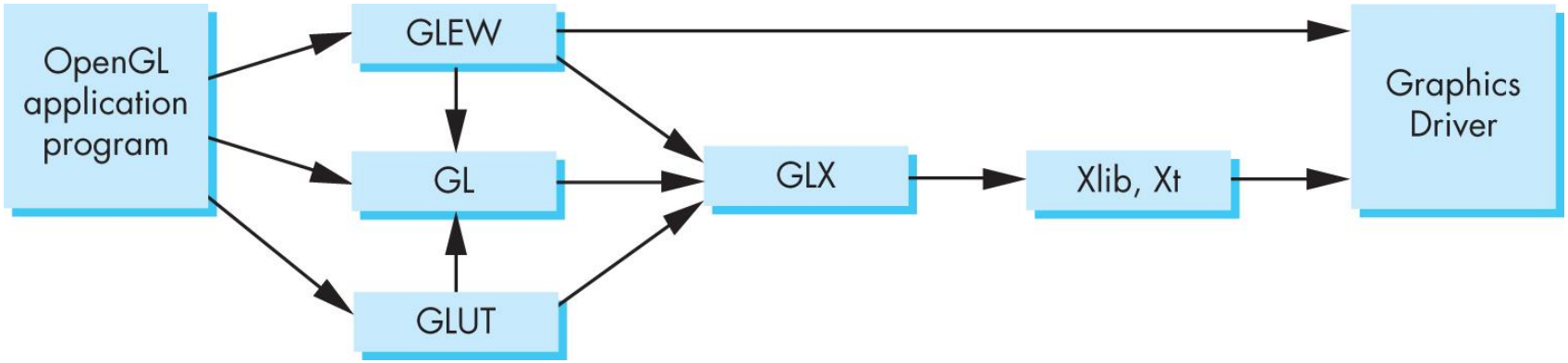

OpenGL extensions on Graphics card

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 extensions to latest OpenGL
- **GLEW:** library to access OpenGL extensions on a graphics card
- We will install GLEW as well



# Windows Installation of GLUT, GLEW

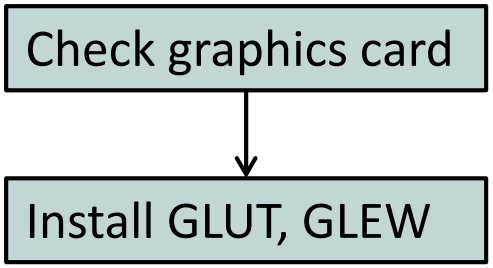
- **Note:** GLUT, GLEW already installed in zoolab. Can just go there
- The following instructions only useful if you want to install on your home machine

1. Install Visual Studio (e.g 2017)

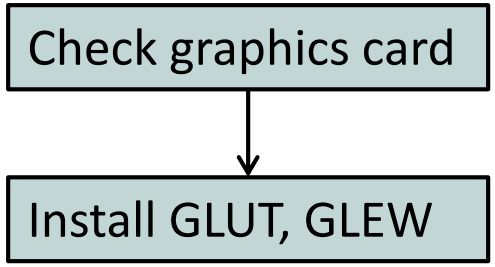
2. Download freeglut **32-bit** (GLUT implementation)
   - http://freeglut.sourceforge.net/

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

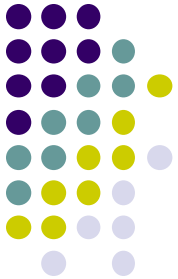


# Windows Installation of GLUT, GLEW



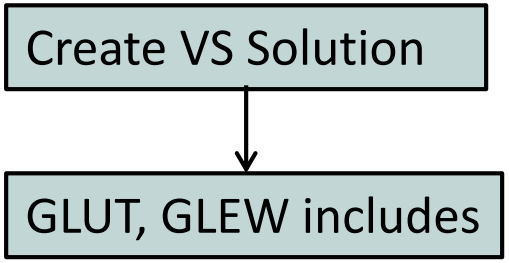

- Install .lib, .h, .dll files (for GLUT and GLEW) from zip files. Put
  - **.dll** files in **c:\windows\system**
  - **.h** files in c:\Visual Studio… **\include** directory
  - **.lib** files in c:\Visual Studio…. **\lib** directory

# 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

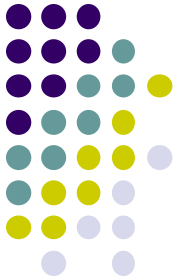
```
#include <glew.h>
#include <GL/glut.h>
```




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

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

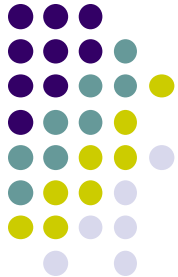
# Getting Started: More #includes



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

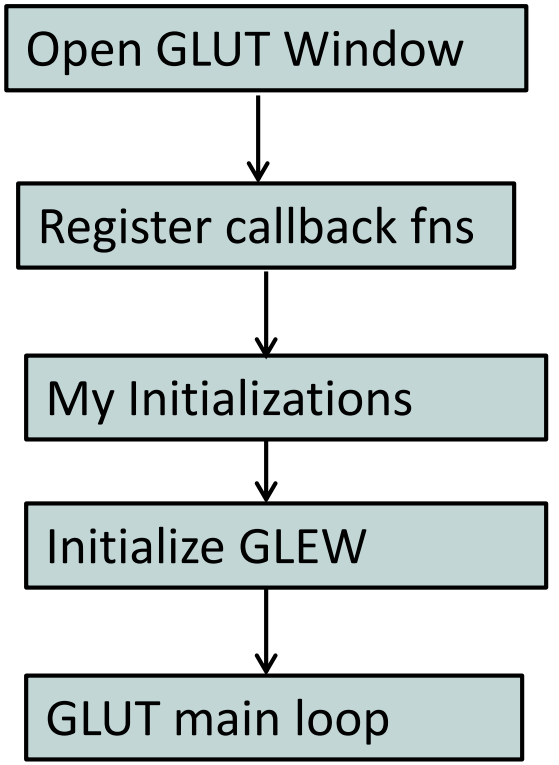
```
#include <glew.h>
#include <GL/glut.h>

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

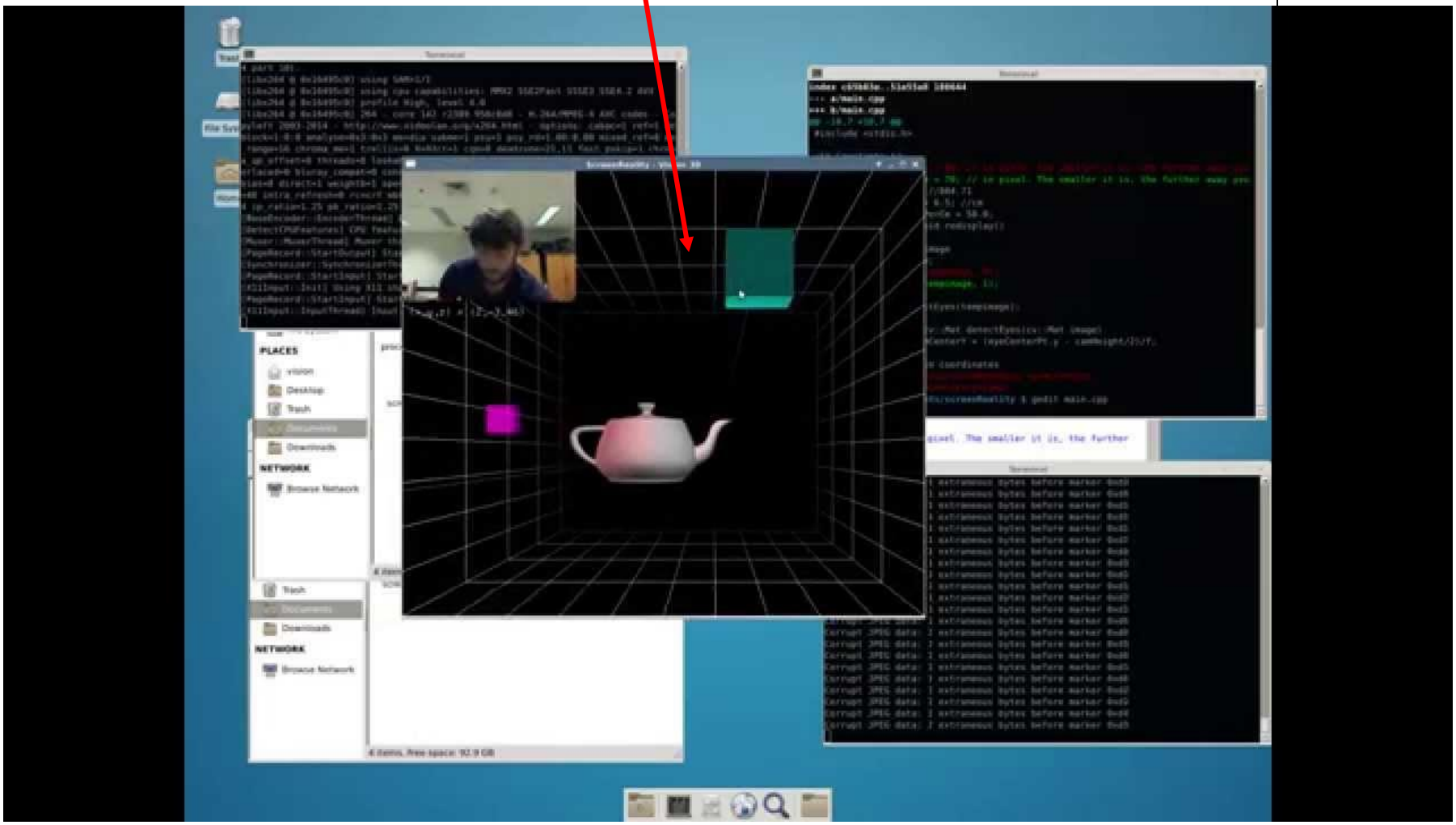


# OpenGL/GLUT Program Structure

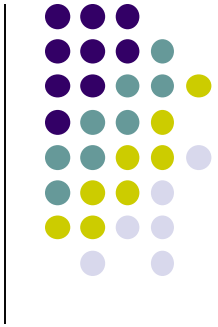
- Open window (GLUT)
  - Configure display mode, window position/size
- Register GLUT callback functions (GLUT)
  - Render, resize, input: keyboard, mouse, etc
- Custom initialization
  - Set background color, clear color, etc
  - Generate points to be drawn
  - Initialize shaders
- Initialize GLEW
-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



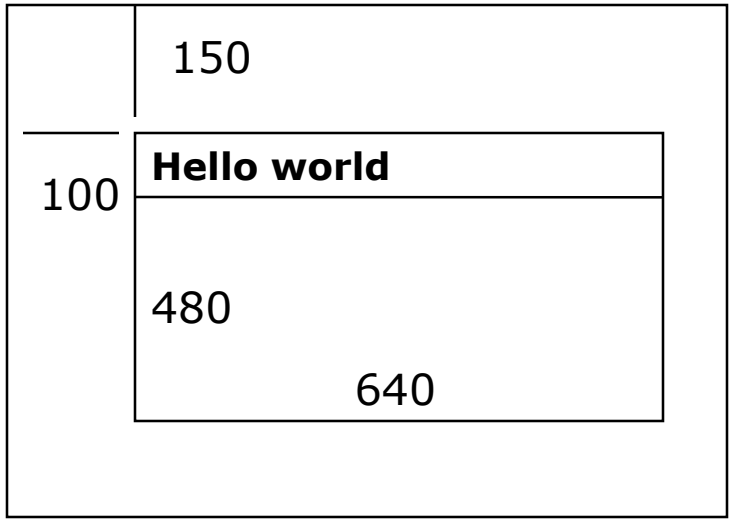
# OpenGL Drawing Window?



# 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( );`**



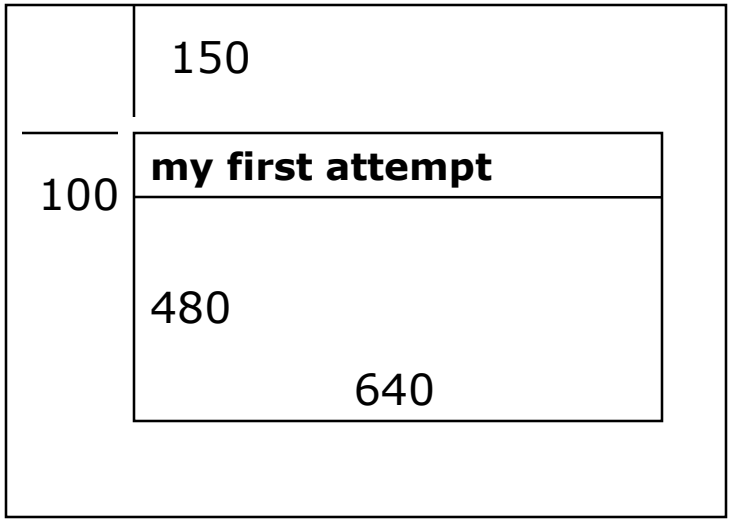
# OpenGL Skeleton

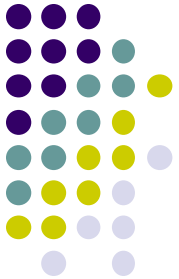
```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window

    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

}
```

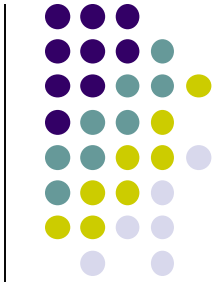




# Sequential Vs Event-driven

- 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

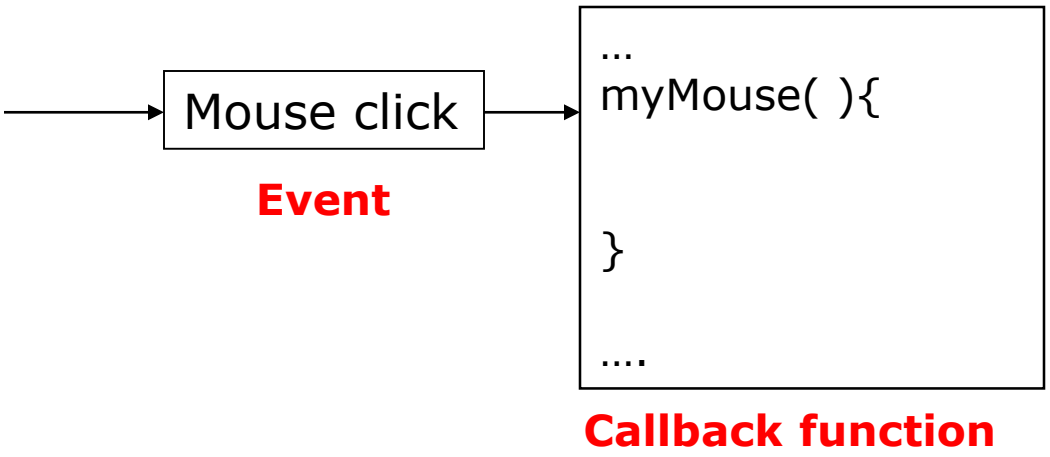


- Program only responds to events
- Do nothing until event occurs
- Example Events:
  - **Redraw “scene” in OpenGL window**
  - **mouse clicks,**
  - **keyboard stroke**
- Programmer defines:
  - Events that program should respond to
  - Actions to be taken when event occurs
- Operating system (e.g.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

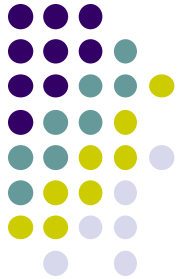

  - Calls functions defined by programmer for specific event

# 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**

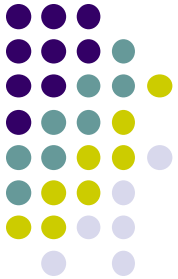


# GLUT Callback Functions

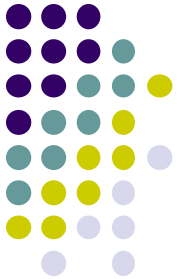


- Register callbacks for all events your program will react to
- No registered callback = no action
- Example: if no registered keyboard callback function, hitting keyboard keys generates NO RESPONSE!!

# 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 occurs



# OpenGL Skeleton

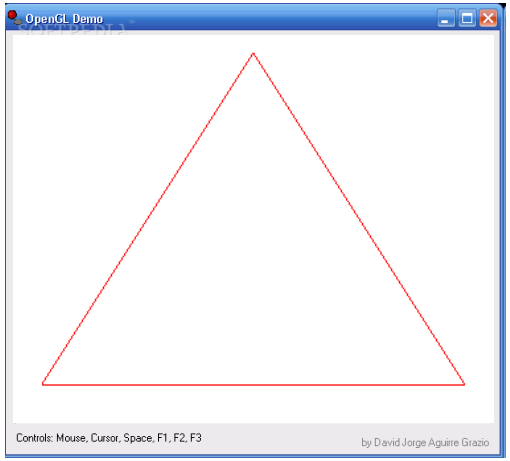
```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my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

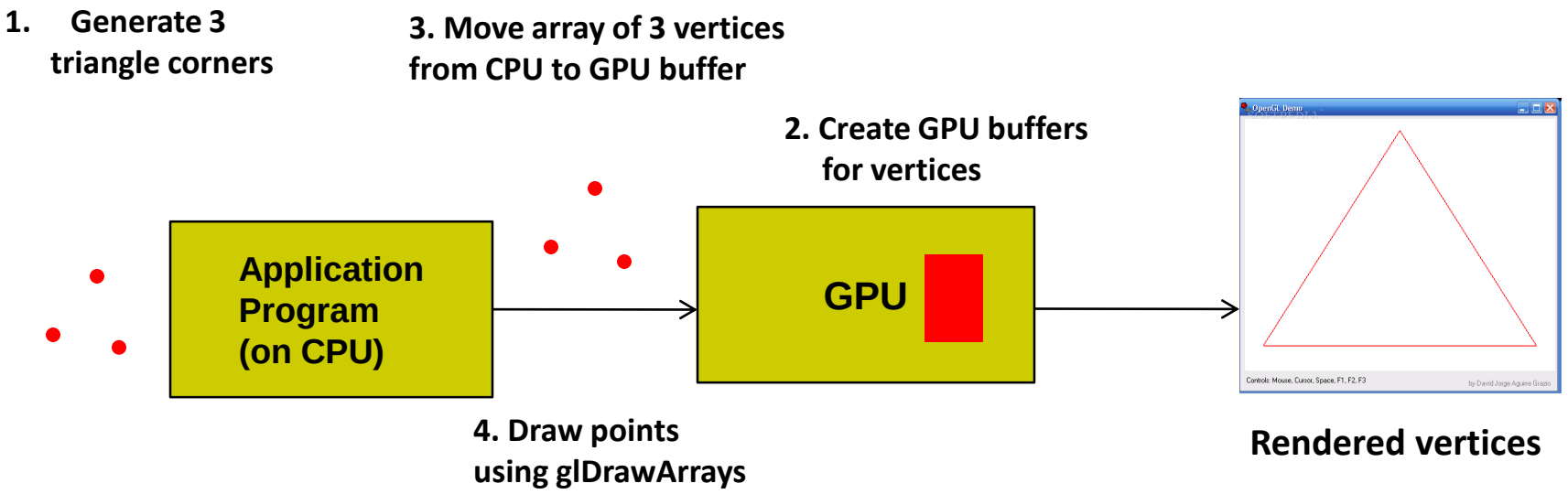



- **Rendering steps:**
  1. Generate triangle corners (3 vertices), initially on CPU
  2. Create GPU buffer for vertices
  3. Move array of 3 vertices from CPU to GPU buffer
  4. Draw 3 points from array on GPU using **`glDrawArray`**

# 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:**

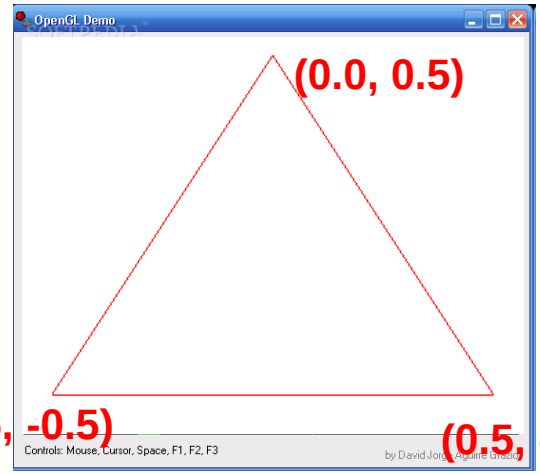


# 1. Generate triangle corners (3 vertices)

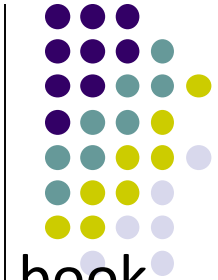
```
// declare array of 3 points
point2 points[3];

// 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 );
}
```

*x* *y*



# 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:

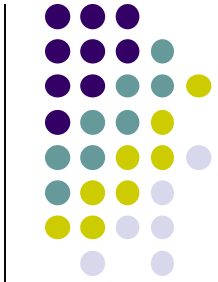
```
#include "vec.h"

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?



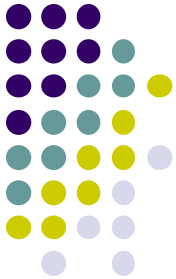
```
void main(int argc, char** argv){
   glutInit(&argc, argv);   // initialize toolkit
   glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutInitWindowPosition(100, 150);
   glutCreateWindow("my first attempt");
   glewInit( );

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

   glewInit( );
   generateGeometry( );

   glutMainLoop( );
}
```

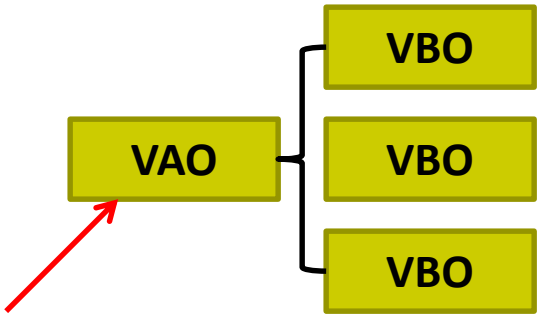
```
// generate 3 triangle vertices + store in array
void generateGeometry( void ){
          points[0] = point2( -0.5, -0.5 );
          points[1] = point2( 0.0, 0.5 );
          points[2] = point2( 0.5, -0.5 );
}
```



# 2. Create GPU Buffer for Vertices

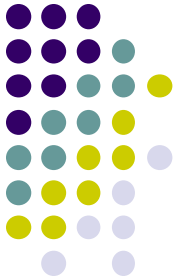
- Rendering from GPU memory significantly faster. Move data there
- Fast GPU (off-screen) memory for data called ***Vertex Buffer Objects (VBO)***
- Array of VBOs (called ***Vertex Array Object (VAO)***) usually created
- Example use: vertex positions in VBO 1, color info in VBO 2, etc

- So, first create the VAO




```
GLuint vao;

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

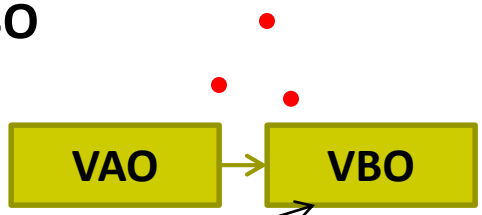


# 2. Create GPU Buffer for Vertices

- 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
```

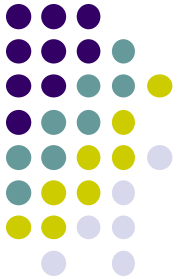
**Number of Buffer Objects to return**




  2. Make created VBO currently active one

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

**Data is array of values**



# 3. Move points GPU memory

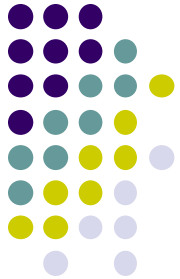
3. Move `points` to VBO

**Destination GPU buffer**

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

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

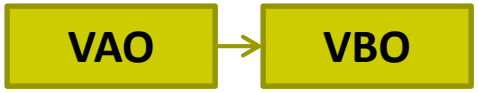
- **`GL_STATIC_DRAW:`** buffer object data will not be changed. Specified once by application and used many times to draw
- **`GL_DYNAMIC_DRAW:`** buffer object data will be changed. Specified repeatedly and used many times to draw



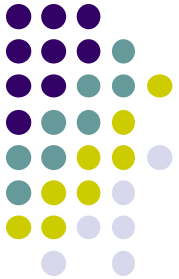
## Put it Together:
## 2. Create GPU Buffer for Vertices
## 3. Move points GPU memory

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

        // Create GPU buffer object, move points to GPU
        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?

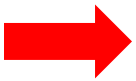


```
void main(int argc, char** argv){
   glutInit(&argc, argv);   // initialize toolkit
   glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutInitWindowPosition(100, 150);
   glutCreateWindow("my first attempt");
   glewInit( );

   // … 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 );
}
```

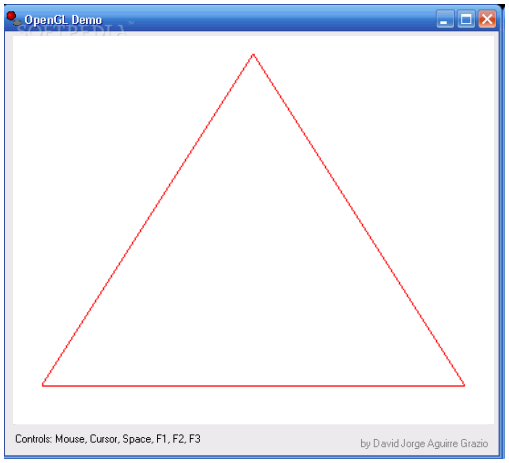
# 4. Draw points (from VBO)

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

**Render buffered data as points**

**Starting index**

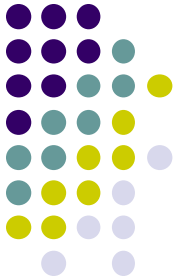
**Number of points to be rendered**




- 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