Implementation: Simple Drawing

Introduction to Computer Graphics

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Library

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Library

- **GLEW: The OpenGL Extension Wrangler Library (link)**
  - A cross-platform open-source C/C++ extension loading library
  - Provide efficient run-time mechanisms for determining which OpenGL extensions are supported on the target platform
- **GLM: OpenGL Mathematics (link)**
  - A **header-only** C++ mathematics library for graphics software based on the **OpenGL Shading Language (GLSL) specifications**

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Program Overview

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Goals

- Draw a point
- Draw a circle (ellipse)
- Draw a triangle

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Draw a Single Point

```
int main(int argc, char** argv)
{
    // Setting window properties.
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGBA | GLUT_DEPTH);
    glutInitWindowSize(640, 360);
    glutInitWindowPosition(100, 100);
    glutCreateWindow("OpenGL Renderer");

    // Initialize GLEW.
    // Must be done after glut is initialized!
    GLenum res = glewInit();
    if (res != GLEW_OK) {
        std::cerr << "GLEW initialization error: "
                  << glewGetErrorString(res) << std::endl;
        return 1;
    }

    // Initialization.
    SetupRenderState();
    SetupScene();

    // Register callback functions.
    glutDisplayFunc(RenderSceneCB);
```

```
// OpenGL and FreeGlut headers.
#include <glew.h>
#include <freeglut.h>
```


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Draw a Single Point (cont.)

```
// Global variables.
GLuint vbo;

void SetupScene()
{
    // Draw a single point.
    float VertexPosition[3] = {0.0f, 0.0f, 0.0f};
    // Generate the vertex buffer.
    glGenBuffers(1, &vbo);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glBufferData(GL_ARRAY_BUFFER, sizeof(VertexPosition), VertexPosition, GL_STATIC_DRAW);
}

void RenderSceneCB()
{
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // Render a point on screen.
    glEnableVertexAttribArray(0);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
    glDrawArrays(GL_POINTS, 0, 1);
    glDisableVertexAttribArray(0);

    glutSwapBuffers();
}
```


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Vertex Buffer

- A buffer storing the **vertex attribute data**
- Possible vertex attributes include (but are not limited to)
  - Vertex position
  - Vertex normal
  - Texture coordinate
  - Tangent
- Will be passed to GPU for rendering

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Vertex Buffer

- **Generate a buffer**
  - *void **glGenBuffers**(GLsizei n, GLuint * buffers);*
- **Upload data into the buffer**
  - *void **glBindBuffer**(GLenum target, GLuint buffer);* [Link]
  - *void **glBufferData**(* [Link]
    GLenum target, GLsizeiptr size,
    *const void * data, GLenum usage);*

```
// Generate the vertex buffer.
glGenBuffers(1, &vbo);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glBufferData(GL_ARRAY_BUFFER, sizeof(VertexPosition), VertexPosition, GL_STATIC_DRAW);
```


Vertex Buffer (cont.)

- **Render with the vertex buffer**
  - *void **glEnableVertexAttribArray**(GLuint index);*
  - *void **glVertexAttribPointer**(*
    GLuint index, — The index of the attribute E.g., 0 for position, 1 for normal, etc.
    GLint size, — Number of components of the attribute
    GLenum type, — Type of the attribute component
    GLboolean normalized ,
    GLsizei stride , — The byte offset to the same attribute of the next vertex
    *const void * pointer* — The byte offset of the first component
    );

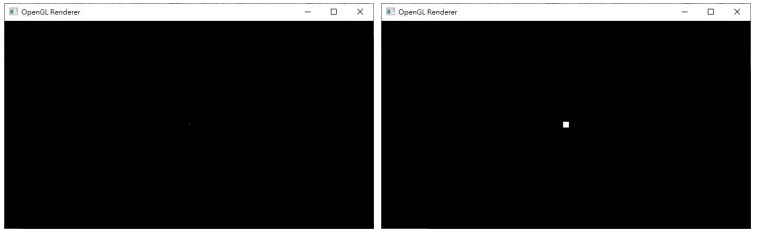
Vertex Buffer (cont.)

- *void **glDrawArrays**(*
  GLenum mode, — The type of the primitive E.g., GL_POINTS, GL_LINE_LOOP, GL_TRIANGLES, etc.
  GLint first, — The start index
  GLsizei count — The number of **indices** to be rendered
  );
- *void **glDisableVertexAttribArray**(GLuint index);*

```
// Render a point on screen.
glEnableVertexAttribArray(0);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
glDrawArrays(GL_POINTS, 0, 1);
glDisableVertexAttribArray(0);
```


Change the Point Size

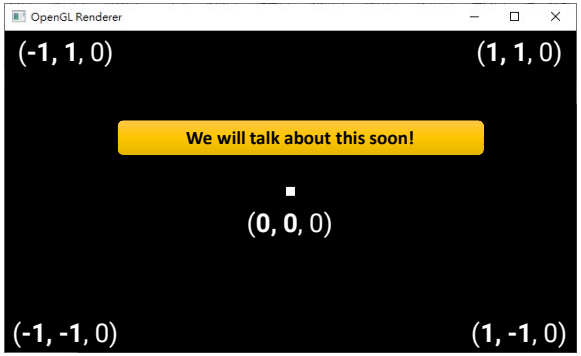
- *void **glPointSize**(GLfloat size)*




```
void SetupRenderState()
{
    // Default.
    glPointSize(1);
}
```

```
void SetupRenderState()
{
    glPointSize(10);
}
```

Insight: Coordinate



What about the *z* coordinate? You can find the point will only be visible if its *z* value is within ***[-1, 1]***

Avoid Deprecated APIs

- Although it seems convenient, do **NOT** use

```
glBegin(GL_POINTS/GL_LINES/GL_TRIANGLES);
    glVertex3f(…);
    glVertex3f(…);
    glVertex3f(…);
glEnd();
```

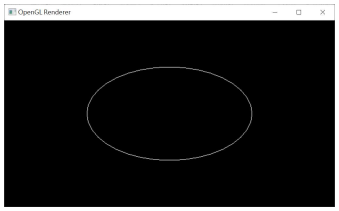
- These APIs have been deprecated since OpenGL 3.2 due to the performance issue

Draw a Circle (Ellipse)

```
// C++ STL headers.
#include <iostream>
#include <vector>
#define _USE_MATH_DEFINES
#include <math.h>

// Global variables.
GLuint vbo;
const int numCircleSamples = 36;

void SetupScene()
{
    // Draw a circle.
    float VertexPosition[numCircleSamples * 3];
    const float thetaOffset = 2.0f * M_PI / (float)numCircleSamples;
    float startTheta = 0.0f;
    float r = 0.5f;
    for (int i = 0; i < numCircleSamples; ++i) {
        float theta = startTheta + i * thetaOffset;
        VertexPosition[3 * i + 0] = r * std::cos(theta);    // x.
        VertexPosition[3 * i + 1] = r * std::sin(theta);    // y.
        VertexPosition[3 * i + 2] = 0.0f;                   // z.
    }

    // Generate the vertex buffer.
    glGenBuffers(1, &vbo);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glBufferData(GL_ARRAY_BUFFER, sizeof(VertexPosition), VertexPosition, GL_STATIC_DRAW);
}
```

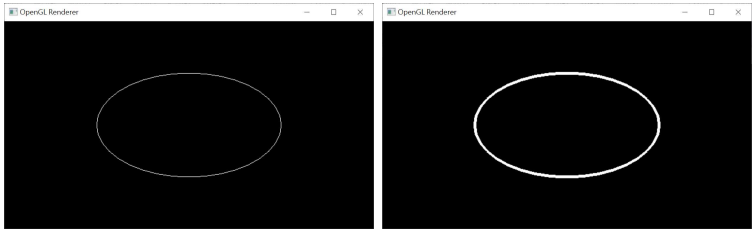

Draw a Circle (Ellipse)

```
void RenderSceneCB()
{
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // Render a point on screen.
    glEnableVertexAttribArray(0);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
    glDrawArrays(GL_LINE_LOOP, 0, numCircleSamples);
    glDisableVertexAttribArray(0);

    glutSwapBuffers();
}
```



Change the Line Width

- *void **glLineWidth**(GLfloat width)*




```
void SetupRenderState()
{
    glLineWidth(5);
}
```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The GLM Library

- In computer graphics, we need a data structure to store and manipulate **multi-dimensional data**, such as position, normal, texture coordinate, and color
- The GLM library provides an elegant way to process multi-dimensional data
  - Support **operator overloading**
  - Match the syntax of OpenGL shading language (GLSL)
  - Support **alias** of components
    - For position or normal, we used to use *(x, y, z, w)*
    - For texture coordinate, we used to use *(u, v, s, t)*
    - For color, we used to use *(r, g, b, a)*

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The GLM Library Examples

- The most common data types are three/four-dimensional vectors and four-by-four matrices
- Example: compute the average direction of three vectors

```
glm::vec3 dir1 = glm::vec3(1.0f, 0.0f, 0.0f);
glm::vec3 dir2 = glm::vec3(0.0f, 1.0f, 0.0f);
glm::vec3 dir3 = glm::vec3(0.0f, 0.0f, 1.0f);
glm::vec3 avgDir = (dir1 + dir2 + dir3) / 3.0f;
```


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Draw a Triangle

```
void SetupScene()
{
    // Draw a triangle.
    glm::vec3 VertexPosition[3];
    VertexPosition[0] = glm::vec3(-1.0f, -1.0f, 0.0f);
    VertexPosition[1] = glm::vec3( 0.0f,  1.0f, 0.0f);
    VertexPosition[2] = glm::vec3( 1.0f, -1.0f, 0.0f);

    // Generate the vertex buffer.
    glGenBuffers(1, &vbo);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glBufferData(GL_ARRAY_BUFFER, sizeof(VertexPosition), VertexPosition, GL_STATIC_DRAW);
}
void RenderSceneCB()
{
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // Render a point on screen.
    glEnableVertexAttribArray(0);
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
    glDrawArrays(GL_TRIANGLES, 0, 3);
    glDisableVertexAttribArray(0);

    glutSwapBuffers();
}
```


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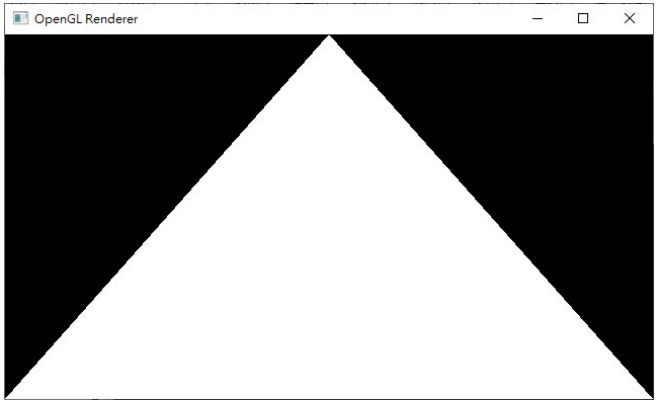
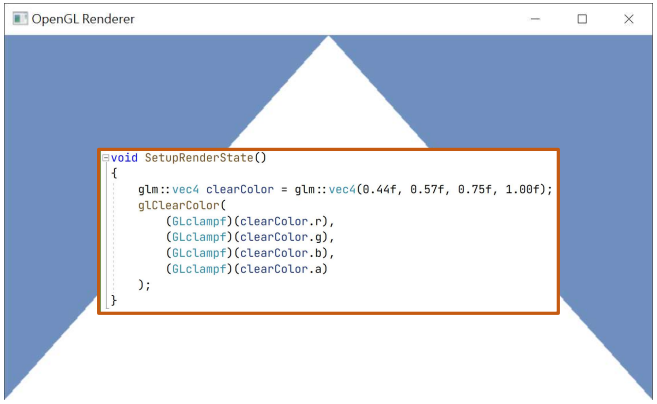
Draw a Triangle (cont.)

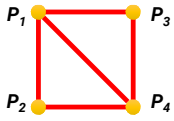


GLM Vector for Representing Color



Index Buffer

- When drawing multiple triangles, lots of the vertices are reused
- We can use an index buffer to identify the vertex defined in the vertex buffer
- Example: a quad with 2 triangles

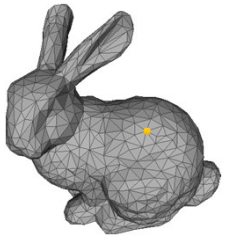


Vertex Buffer

P_1 x	P_1 y	P_1 z	P_2 x	P_2 y	P_2 z	P_3 x	P_3 y	P_3 z	P_4 x	P_4 y	P_4 z

Index Buffer

1	2	4	1	4	3



Index Buffer

- **Generate a buffer and upload data**
  - Use the same functions as we create the vertex buffer, but with different parameters

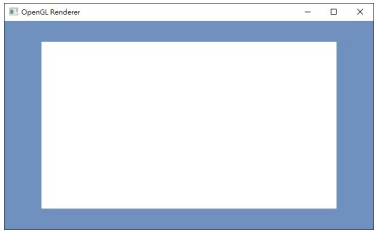
```
// Draw a quad with indexed triangles.
glm::vec3 vertexPosition[4];
vertexPosition[0] = glm::vec3(-0.8f,  0.8f, 0.0f);
vertexPosition[1] = glm::vec3(-0.8f, -0.8f, 0.0f);
vertexPosition[2] = glm::vec3( 0.8f,  0.8f, 0.0f);
vertexPosition[3] = glm::vec3( 0.8f, -0.8f, 0.0f);
// Generate the vertex buffer.
glGenBuffers(1, &vbo);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertexPosition), vertexPosition, GL_STATIC_DRAW);

unsigned int vertexIndices[6] = { 0, 1, 3, 0, 3, 2 };
// Generate the index buffer.
glGenBuffers(1, &ibo);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, ibo);
glBufferData(GL_ELEMENT_ARRAY_BUFFER, sizeof(vertexIndices), vertexIndices, GL_STATIC_DRAW);
```

Index Buffer (cont.)

- **Render with the vertex buffer and index buffer**

```
// Render a quad on screen.
glEnableVertexAttribArray(0);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, ibo);
glDrawElements(GL_TRIANGLES, 6, GL_UNSIGNED_INT, 0);
glDisableVertexAttribArray(0);
```



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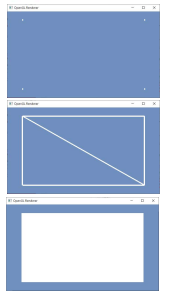
Change Polygon Render Mode

- OpenGL provides API for changing polygon render mode
  - *void **glPolygonMode**(GLenum face, GLenum mode);*

```
void ProcessSpecialKeysCB(int key, int x, int y)
{
    // Handle special (functional) keyboard inputs such as F1, spacebar, page up, etc.
    switch (key) {
    case GLUT_KEY_F1:
        // Render with point mode.
        glPointSize(5);
        glPolygonMode(GL_FRONT_AND_BACK, GL_POINT);
        break;
    case GLUT_KEY_F2:
        // Render with line mode.
        glLineWidth(5);
        glPolygonMode(GL_FRONT_AND_BACK, GL_LINE);
        break;
    case GLUT_KEY_F3:
        // Render with fill mode.
        glPolygonMode(GL_FRONT_AND_BACK, GL_FILL);
        break;
    default:
        break;
    }
}
```



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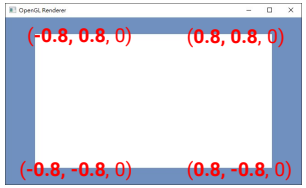
Where is the Camera and Projection?

- The typical flow of bringing a 3D point to the 2D screen involves the **camera projection**
- For now, we specify neither the camera nor the projection, so you can consider that we set the **"projected"** positions of the vertices directly
- In the next implementation slides, we will go through the full transformation



A rectangle?
Why not a square?

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Any Questions?

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