Basics of OpenGL

Topic 1: Introduction

OpenGL (Open Graphics Library) is a cross-platform, hardware-accelerated, language-independent, industrial standard API for producing 3D (including 2D) graphics. Modern computers have dedicated GPU (Graphics Processing Unit) with its own memory to speed up graphics rendering. OpenGL is the software interface to graphics hardware. In other words, OpenGL graphic rendering commands issued by your applications could be directed to the graphic hardware and accelerated.

We use 3 sets of libraries in our OpenGL programs:

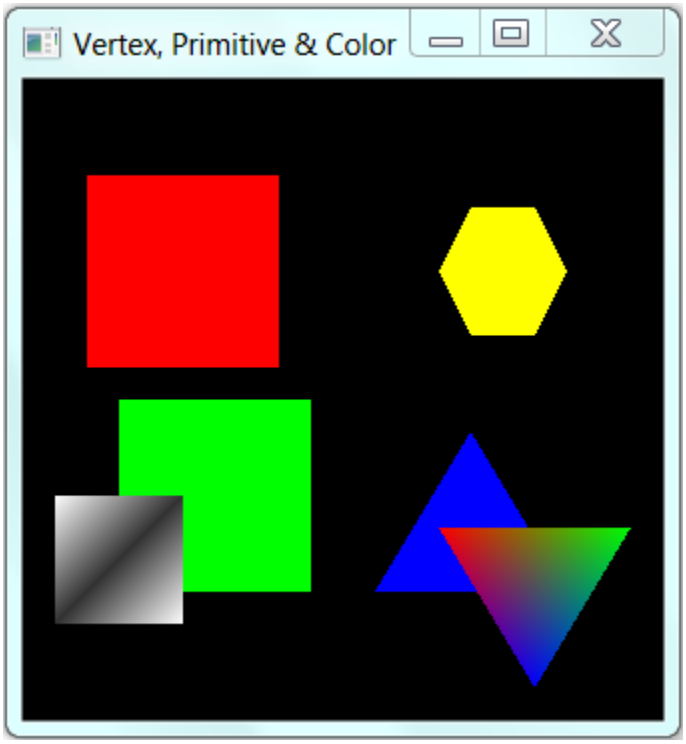
1. **Core OpenGL (GL)**: consists of hundreds of commands, which begin with a prefix "`gl`" (e.g., `glColor`, `glVertex`, `glTranslate`, `glRotate`). The Core OpenGL models an object via a set of geometric primitives such as point, line and polygon.
2. **OpenGL Utility Library (GLU)**: built on-top of the core OpenGL to provide important utilities (such as setting camera view and projection) and more building models (such as qradric surfaces and polygon tessellation). GLU commands start with a prefix "`glu`" (e.g., `gluLookAt`, `gluPerspective`).
3. **OpenGL Utilities Toolkit (GLUT)**: OpenGL is designed to be independent of the windowing system or operating system. GLUT is needed to interact with the Operating System (such as creating a window, handling key and mouse inputs); it also provides more building models (such as sphere and torus). GLUT commands start with a prefix of "`glut`" (e.g., `glutCreatewindow`, `glutMouseFunc`). GLUT is platform independent, which is built on top of platform-specific OpenGL extension such as GLX for X Window System, WGL for Microsoft Window, and AGL, CGL or Cocoa for Mac OS. Quoting from the opengl.org: "GLUT is designed for constructing small to medium sized OpenGL programs. While GLUT is well-suited to learning OpenGL and developing simple OpenGL applications, GLUT is not a full-featured toolkit so large applications requiring sophisticated user interfaces are better off using native window system toolkits. *GLUT is simple, easy, and small.*" Alternative of GLUT includes SDL, ...
4. **OpenGL Extension Wrangler Library (GLEW)**: "GLEW is a cross-platform open-source C/C++ extension loading library. GLEW provides efficient run-time mechanisms for determining which OpenGL extensions are supported on the target platform." Source and pre-build binary available at http://glew.sourceforge.net/. A standalone utility called "`glewinfo.exe`" (under the "`bin`" directory) can be used to produce the list of OpenGL functions supported by your graphics system.
5. Others.

Topic 2: Vertex, Primitive and Color

```
#include <windows.h>  // for MS Windows
#include <GL/glut.h>  // GLUT, include glu.h and gl.h

/* Initialize OpenGL Graphics */
void initGL() {
   // Set "clearing" or background color
   glClearColor(0.0f, 0.0f, 0.0f, 1.0f); // Black and opaque
}

/* Handler for window-repaint event. Call back when the window first appears and
   whenever the window needs to be re-painted. */
void display() {
   glClear(GL_COLOR_BUFFER_BIT);   // Clear the color buffer with current clearing
color

   // Define shapes enclosed within a pair of glBegin and glEnd
   glBegin(GL_QUADS);              // Each set of 4 vertices form a quad
      glColor3f(1.0f, 0.0f, 0.0f); // Red
      glVertex2f(-0.8f, 0.1f);     // Define vertices in counter-clockwise (CCW)
order
      glVertex2f(-0.2f, 0.1f);     //  so that the normal (front-face) is facing
you
      glVertex2f(-0.2f, 0.7f);
      glVertex2f(-0.8f, 0.7f);

      glColor3f(0.0f, 1.0f, 0.0f); // Green
      glVertex2f(-0.7f, -0.6f);
      glVertex2f(-0.1f, -0.6f);
      glVertex2f(-0.1f,  0.0f);
      glVertex2f(-0.7f,  0.0f);

      glColor3f(0.2f, 0.2f, 0.2f); // Dark Gray
      glVertex2f(-0.9f, -0.7f);
      glColor3f(1.0f, 1.0f, 1.0f); // White
      glVertex2f(-0.5f, -0.7f);
      glColor3f(0.2f, 0.2f, 0.2f); // Dark Gray
      glVertex2f(-0.5f, -0.3f);
      glColor3f(1.0f, 1.0f, 1.0f); // White
      glVertex2f(-0.9f, -0.3f);
   glEnd();
```

```
   glBegin(GL_TRIANGLES);          // Each set of 3 vertices form a triangle
      glColor3f(0.0f, 0.0f, 1.0f); // Blue
      glVertex2f(0.1f, -0.6f);
      glVertex2f(0.7f, -0.6f);
      glVertex2f(0.4f, -0.1f);

      glColor3f(1.0f, 0.0f, 0.0f); // Red
      glVertex2f(0.3f, -0.4f);
      glColor3f(0.0f, 1.0f, 0.0f); // Green
      glVertex2f(0.9f, -0.4f);
      glColor3f(0.0f, 0.0f, 1.0f); // Blue
      glVertex2f(0.6f, -0.9f);
   glEnd();

   glBegin(GL_POLYGON);            // These vertices form a closed polygon
      glColor3f(1.0f, 1.0f, 0.0f); // Yellow
      glVertex2f(0.4f, 0.2f);
      glVertex2f(0.6f, 0.2f);
      glVertex2f(0.7f, 0.4f);
      glVertex2f(0.6f, 0.6f);
      glVertex2f(0.4f, 0.6f);
      glVertex2f(0.3f, 0.4f);
   glEnd();

   glFlush();  // Render now
}

/* Main function: GLUT runs as a console application starting at main()  */
int main(int argc, char** argv) {
   glutInit(&argc, argv);          // Initialize GLUT
   glutCreateWindow("Vertex, Primitive & Color");  // Create window with the given
title
   glutInitWindowSize(320, 320);   // Set the window's initial width & height
   glutInitWindowPosition(50, 50); // Position the window's initial top-left corner
   glutDisplayFunc(display);         // Register callback handler for window re-
paint event
   initGL();                       // Our own OpenGL initialization
   glutMainLoop();                 // Enter the event-processing loop
   return 0;
}
```

Output:



Topic 3: OpenGL as a State Machine

OpenGL operates as a *state machine*, and maintain a set of *state variables* (such as the foreground color, background color, and many more). In a state machine, once the value of a state variable is set, the value persists until a new value is given.

For example, we set the "clearing" (background) color to black *once* in `initGL()`. We use this setting to clear the window in the `display()` *repeatedly* (`display()` is called back whenever there is a window re-paint request) - the clearing color is not changed in the entire program.

```
// In initGL(), set the "clearing" or background color
glClearColor(0.0f, 0.0f, 0.0f, 1.0f);  // black and opaque

// In display(), clear the color buffer (i.e., set background) with the current "clearing" color
glClear(GL_COLOR_BUFFER_BIT);
```

Another example: If we use `glColor` function to set the current foreground color to "red", then "red" will be used for all the subsequent vertices, until we use another `glColor` function to change the foreground color.

In a state machine, everything shall remain until you explicitly change it!

Topic 4: Naming Convention for OpenGL Functions

An OpenGL functions:

- begins with lowercase `gl` (for core OpenGL), `glu` (for OpenGL Utility) or `glut` (for OpenGL Utility Toolkit).
- followed by the purpose of the function, in *camel case* (initial-capitalized), e.g., `glColor` to specify the drawing color, `glVertex` to define the position of a vertex.
- followed by specifications for the parameters, e.g., `glColor3f` takes three `float` parameters. `glVectex2i` takes two `int` parameters. (This is needed as C Language does not support function overloading. Different versions of the function need to be written for different parameter lists.)

The convention can be expressed as follows:

```
returnType glFunction[234][sifd] (type value, ...);  // 2, 3 or 4 parameters
returnType glFunction[234][sifd]v (type *value);     // an array parameter
```

The function may take 2, 3, or 4 parameters, in type of `s` (`GLshort`), `i` (`GLint`), `f` (`GLfloat`) or `d` (`GLdouble`). The 'v' (for vector) denotes that the parameters are kept in an array of 2, 3, or 4 elements, and pass into the function as an array pointer.

OpenGL defines its own *data types*:

- Signed Integers: `GLbyte` (8-bit), `GLshort` (16-bit), `GLint` (32-bit).
- Unsigned Integers: `GLubyte` (8-bit), `GLushort` (16-bit), `GLuint` (32-bit).
- Floating-point numbers: `GLfloat` (32-bit), `GLdouble` (64-bit), `GLclampf` and `GLclampd` (between 0.0 and 1.0).
- `GLboolean` (unsigned char with 0 for false and non-0 for true).
- `GLsizei` (32-bit non-negative integers).
- `GLenum` (32-bit enumerated integers).

The OpenGL types are defined via `typedef` in "`gl.h`" as follows:

```
typedef unsigned int    GLenum;

typedef unsigned char   GLboolean;

typedef unsigned int    GLbitfield;

typedef void            GLvoid;

typedef signed char     GLbyte;         /* 1-byte signed */
typedef short           GLshort;        /* 2-byte signed */
typedef int             GLint;          /* 4-byte signed */
typedef unsigned char   GLubyte;        /* 1-byte unsigned */
typedef unsigned short  GLushort;       /* 2-byte unsigned */
typedef unsigned int    GLuint;         /* 4-byte unsigned */
typedef int             GLsizei;        /* 4-byte signed */
typedef float           GLfloat;        /* single precision float */
typedef float           GLclampf;       /* single precision float in [0,1] */
typedef double          GLdouble;       /* double precision float */
typedef double          GLclampd;       /* double precision float in [0,1] */
```

OpenGL's *constants* begins with "GL_", "GLU_" or "GLUT_", in uppercase separated with underscores, e.g., GL_COLOR_BUFFER_BIT.

For examples,

```
glVertex3f(1.1f, 2.2f, 3.3f);        // 3 GLfloat parameters
glVertex2i(4, 5);                    // 2 GLint paramaters
glColor4f(0.0f, 0.0f, 0.0f, 1.0f);   // 4 GLfloat parameters

GLdouble aVertex[] = {1.1, 2.2, 3.3};
glVertex3fv(aVertex);        // an array of 3 GLfloat values
```

Topic 5: One-time Initialization initGL()

The initGL() is meant for carrying out one-time OpenGL initialization tasks, such as setting the clearing color. initGL() is invoked once (and only once) in main().

Topic 6: Callback Handler display()

The function display() is known as a *callback event handler*. An event handler provides the *response* to a particular *event* (such as key-press, mouse-click, window-paint). The function display() is meant to be the handler for *window-paint* event. The OpenGL graphics system calls back display() in response to a window-paint request to re-paint the window (e.g., window first appears, window is restored after minimized, and window is resized). Callback means that the function is invoked by the system, instead of called by the your program.

The Display() runs when the window first appears and once per subsequent re-paint request. Observe that we included OpenGL graphics rendering code inside the display() function, so as to re-draw the entire window when the window first appears and upon each re-paint request.

Topic 7: GLUT - main()

GLUT provides high-level utilities to simplify OpenGL programming, especially in interacting with the Operating System (such as creating a window, handling key and mouse inputs). The following GLUT functions were used in the above program:

- glutInit: initializes GLUT, must be called before other GL/GLUT functions. It takes the same arguments as the main().

  ```
  void glutInit(int *argc, char **argv)
  ```

- glutCreateWindow: creates a window with the given title.

  ```
  int glutCreateWindow(char *title)
  ```

- glutInitWindowSize: specifies the initial window width and height, in pixels.

  ```
  void glutInitWindowSize(int width, int height)
  ```

- `glutInitWindowPosition`: positions the top-left corner of the initial window at (*x*, *y*). The coordinates (*x*, *y*), in term of pixels, is measured in window coordinates, i.e., origin (0, 0) is at the top-left corner of the screen; x-axis pointing right and y-axis pointing down.

```
void glutInitWindowPosition(int x, int y)
```

- `glutDisplayFunc`: registers the callback function (or event handler) for handling window-paint event. The OpenGL graphic system calls back this handler when it receives a window re-paint request. In the example, we register the function `display()` as the handler.

```
void glutDisplayFunc(void (*func)(void))
```

- `glutMainLoop`: enters the infinite event-processing loop, i.e, put the OpenGL graphics system to wait for events (such as re-paint), and trigger respective event handlers (such as `display()`).

```
void glutMainLoop()
```

In the `main()` function of the example:

```
glutInit(&argc, argv);
glutCreateWindow("Vertex, Primitive & Color");
glutInitWindowSize(320, 320);
glutInitWindowPosition(50, 50);
```

We initialize the GLUT and create a window with a title, an initial size and position.

```
glutDisplayFunc(display);
```

We register `display()` function as the callback handler for window-paint event. That is, `display()` runs when the window first appears and whenever there is a request to re-paint the window.

```
initGL();
```

We call the `initGL()` to perform all the one-time initialization operations. In this example, we set the clearing (background) color once, and use it repeatably in the `display()` function.

```
glutMainLoop();
```

We then put the program into the event-handling loop, awaiting for events (such as window-paint request) to trigger off the respective event handlers (such as `display()`).

Color

We use `glColor` function to set the *foreground color*, and `glClearColor` function to set the *background* (or *clearing*) color.

```
void glColor3f(GLfloat red, GLfloat green, GLfloat blue)
void glColor3fv(GLfloat *colorRGB)
```

```
void glColor4f(GLfloat red, GLfloat green, GLfloat blue, GLfloat alpha)
void glColor4fv(GLfloat *colorRGBA)

void glClearColor(GLclampf red, GLclampf green, GLclampf blue, GLclampf alpha)
   // GLclampf in the range of 0.0f to 1.0f
```

Notes:

- Color is typically specified in `float` in the range `0.0f` and `1.0f`.
- Color can be specified using RGB (Red-Green-Blue) or RGBA (Red-Green-Blue-Alpha) components. The 'A' (or alpha) specifies the transparency (or opacity) index, with value of 1 denotes opaque (non-transparent and cannot see-thru) and value of 0 denotes total transparent. We shall discuss alpha later.

In the above example, we set the background color via `glClearColor` in `initGL()`, with R=0, G=0, B=0 (black) and A=1 (opaque and cannot see through).

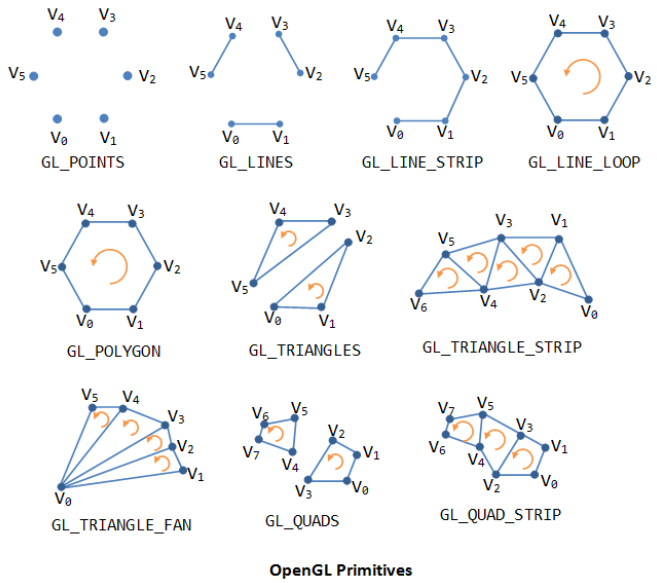
```
// In initGL(), set the "clearing" or background color
glClearColor(0.0f, 0.0f, 0.0f, 1.0f);  // Black and opague
```

In `display()`, we set the vertex color via `glColor3f` for subsequent vertices. For example, R=1, G=0, B=0 (red).

```
// In display(), set the foreground color of the pixel
glColor3f(1.0f, 0.0f, 0.0f);  // Red
```

Topic 8: Geometric Primitives

In OpenGL, an object is made up of geometric primitives such as triangle, quad, line segment and point. A primitive is made up of one or more vertices. OpenGL supports the following primitives:



OpenGL Primitives

A geometric primitive is defined by specifying its vertices via `glVertex` function, enclosed within a pair `glBegin` and `glEnd`.

```
void glBegin(GLenum shape)
   void glVertex[234][sifd] (type x, type y, type z, ...)
   void glVertex[234][sifd]v (type *coords)
void glEnd()
```

`glBegin` specifies the type of geometric object, such as `GL_POINTS`, `GL_LINES`, `GL_QUADS`, `GL_TRIANGLES`, and `GL_POLYGON`. For types that end with 'S', you can define multiple objects of the same type in each `glBegin`/`glEnd` pair. For example, for `GL_TRIANGLES`, each set of three `glVertex`'s defines a triangle.
The vertices are usually specified in `float` precision. It is because integer is not suitable for trigonometric operations (needed to carry out transformations such as rotation). Precision of `float` is sufficient for carrying out intermediate operations, and render the objects finally into pixels on screen (with resolution of says 800x600, integral precision). `double` precision is often not necessary.

In the above example:

```
glBegin(GL_QUADS);
   .... 4 quads with 12x glVertex() ....
glEnd();
```

we define 3 color quads (`GL_QUADS`) with 12x `glVertex()` functions.

```
glColor3f(1.0f, 0.0f, 0.0f);
glVertex2f(-0.8f, 0.1f);
glVertex2f(-0.2f, 0.1f);
glVertex2f(-0.2f, 0.7f);
glVertex2f(-0.8f, 0.7f);
```

We set the color to red (R=1, G=0, B=0). All subsequent vertices will have the color of red. Take note that in OpenGL, color (and many properties) is applied to vertices rather than primitive shapes. The color of the a primitive shape is *interpolated* from its vertices.

We similarly define a second quad in green.

For the third quad (as follows), the vertices have different color. The color of the quad surface is interpolated from its vertices, resulting in a shades of white to dark gray, as shown in the output.

```
glColor3f(0.2f, 0.2f, 0.2f);  // Dark Gray
glVertex2f(-0.9f, -0.7f);
glColor3f(1.0f, 1.0f, 1.0f);  // White
glVertex2f(-0.5f, -0.7f);
glColor3f(0.2f, 0.2f, 0.2f);  // Dark Gray
glVertex2f(-0.5f, -0.3f);
glColor3f(1.0f, 1.0f, 1.0f);  // White
glVertex2f(-0.9f, -0.3f);
```