Components of a Graphics Software System

Introduction to OpenGL

Basic Components of a Graphics Software System

- Examples from: Windows GDI and OpenGL

1. Output Primitives

- Building blocks for drawing pictures
- **Plotting a pixel**--most primitive
- Windows CDC:

```
COLORREF colref;
SetPixel(x,y,colref);  // Windows--plots pixel
colref = GetPixel(x,y);  // returns pixel  color
```

- OpenGL:

```
glBegin (GL_POINTS);   // OpenGL
    glVertex2f (x, y);   // 2==>2D, f==>floating pt
glEnd();   // current drawing is color used
```

  - In general:

```
glVertex{234}{sifd} (TYPE coords,…);
glVertexv{234}{sifd} (TYPE *coord array);
   // glPointSize(size); before Begin/End to set size in pixels
```

- **Lines**

Windows CDC:

```
MoveTo(x1,y1);     // Set Curr. Pos., one endpoint
LineTo(x2,y2);     // line from CP to (x2,y2)
                   // current pen is used
```

OpenGL:

```
glBegin (GL_LINES);  // OpenGL
    glVertex2f(x1,y1);  // 2D endpoint vertices
    glVertex2f(x2,y2);  // appear in pairs
glEnd()                 // current glLineWidth & glColor
```

Polylines and Polygons

– Windows CDC:

```
Polyline(lppts,num_pts); // Windows
Polygon(lppts,num_pts);
        // parameters: POiNT array, number of points
```

– OpenGL:

```
glBegin (GL_POLYGON); // OpenGL
    glVertex2f(x1,y1); // first polygon vertex
    glVertex2f(x2,y2); // second polygon vertex
    …                  // more vertices
glEnd();           // current glColor & glPolygonMode are used
```

Other primitives

– Windows CDC:

- Lots of other primitives
- See prior notes on Windows programming
  - Especially Help on CDC class

– OpenGL:

- GL_TRIANGLES, GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN, GL_LINE_STRIP, GL_QUADS, etc. ---- lots more

Text

- Windows CDC:

  TextOut(x,y,lpszStr,cStrLngth);

- OpenGL:
  - Design a font set using bitmap functions in the core library
  - Use GLUT character-generation library functions

```
char* str = “abcde”;
glRasterPos2i(10,10);
for (int k=0; k<5; k++)
    glutBitmapCharacter(GLUT_BITMAP_9_BY_15, str[k]);
```

3-D primitives

- Windows has nothing
- OpenGL:
  - GLU graphics library
    - sphere, cube, cone, etc.

2. Attributes (State Variables)

- Properties of primitives
  - how they appear
  - e.g., color, line style, text style, fill patterns
- Usually modal
  - values retained until changed
- Windows –
  - see prior notes (e.g., pens, brushes)
- OpenGL-- gl*Property*();
  - '*Property*' is state variable to set, e.g.

```
glColor3f (1.0, 0.0, 0.0);  // bright red
glLineWidth(3.0);           // 3 pixels wide
glPolygonMode(GL_FRONT_AND_BACK,GL_LINE);
```

3. Transformations

- Done with matrix math
- Setting windows/viewports
  - Window-to-viewport transformation
- Moving objects
  - Geometric Transformations
  - e.g., translation, rotation, scaling
- Changing coordinate system
- Changing viewpoint
- Different types of projections

- Windows
  - window-to-viewport transformation
    - done with Mapping Modes
  - programmer must implement others
- OpenGL is very rich
  - glLoadMatrix(), glRotatef(), glTranslatef(), glScalef(), glViewport(), glFrustum(), glOrtho2D(), gluPerspective(), etc.

4. Segmentation

- Dividing scene into component parts for (later) manipulation
- Windows: GDI strictly immediate mode
  - But there are Metafiles (can be played back)
- OpenGL has Display lists:
  - Groups of OpenGL commands that have been stored for later execution
  - Can be hierarchical
- PHIGS uses hierarchical segments

5. Input/Interaction

- Obtain data from input devices or graphics system
  - So user can manipulate scene interactively
- Windows:
  - Built into event-driven, message-based paradigm

5. Input/Interaction in OpenGL

- Obtain data from input devices/system and respond to events
- Auxiliary libraries (GLX, WGL, AGL)
  - All use the underlying windowing system
- Or GLUT callback functions
  - All take pointers to an event handler function, e.g.
    - Window must be redrawn: glutDisplayFunc (mydisplay)
      - Then write: mydisplay ( ) function;
    - Keyboard: glutKeyboardFunc (mykey)
      - Then write: mykey (key, xmouse, ymouse) function
    - Mouse events: glutMouseFunc (mymouse)
      - Then write: mymouse (button, action, xmouse, ymouse)
    - Mouse motion: glutMotionFunc (mymotion)
      - Then write: mymotion (xmouse, ymouse)

6. Control/Housekeeping

- Initialize system, create window, etc.
- Windows: Extensive support
  - RegisterClass(), CreateWindow(), etc.
  - Mostly hidden in MFC framework
- OpenGL:
  - Use GLUT library functions
    - glutInit(&argc,argv); glutInitDisplayMode(mode); glutInitWindowSize(w,h); glutInitWindowPosition(x,y); glutCreateWindow("Title"); glutMainLoop();
  - Or use WGL functions under Windows

7. Storing/retrieving/manipulating bitmapped Images

- BitBLT -- Bit Block Transfer
- Windows:
  - Device Dependent Bitmaps
    - BitBlt(), StretchBlt(), StretchDIBits()etc.
  - But very slow
  - Device Independent Bitmaps--faster
  - DirectX -- flipping surfaces--fastest!
- OpenGL:
  - glReadPixels(); glDrawPixels(); glCopyPixels();

8. Rendering/Photorealism

- Hidden surfaces, lighting, shading, reflection properties, etc.
- Windows GDI: Very little support
  - DirectX (Direct3D)--Quite a bit of support
- OpenGL: A lot of support!
  - e.g., light sources, lighting models, material properties, blending, antialiasing, fog, depth buffer (hidden surface removal), texturing, etc.

Introduction to OpenGL

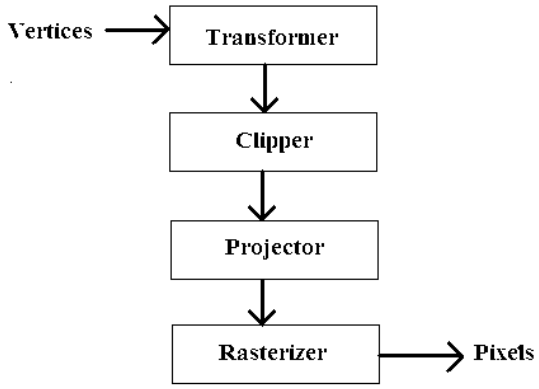
The OpenGL API

- A basic library of functions for specifying 2-D and 3-D graphics primitives, attributes, transformations, viewing setups, and many other operations
- Hardware and platform independent
  - All functions in OpenGL library are device independent
  - So many operations (windowing, I/O, etc.) are not included in basic core library
  - Many auxiliary libraries for these
- Close enough to hardware so that programs written in OpenGL run efficiently
- Easy to learn and use

Three Views of OpenGL

- Programmer's view
  - Specify a set of output primitives to render
  - Describe properties (attributes) of these objects
  - Define how these objects should be viewed
- OpenGL state machine with functions to:
  - Specify inputs to state machine
  - Change the state of the machine
  - Both determine the machine's outputs
- The OpenGL Pipeline

The OpenGL Pipeline



Related Libraries

- GLU: utility library provides routines for working with viewing/projection matrices, approximating complex 3D objects with polygons, displaying quadrics & splines, surface rendering, and much more
  - GLU functions begin with glu
  - All OpenGL implementations include the GLU library

Windowing Support Libraries

- Windowing systems are platform dependent
- Support libraries:
  - GLX: OpenGL Extension to the X Window System, functions begin with glX
  - WGL: Microsoft Windows-to-OpenGL interface, functions begin with wgl
    - Comes with Microsoft Visual Studio
  - AGL: Apple GL, functions begin with agl
  - GLUT: OpenGL Utility Toolkit
    - A library of functions for interacting with screen-windowing system, functions begin with glut
    - Works with many different platforms
    - Doesn't come with Visual Studio, but easily obtained

OpenGL for Microsoft Windows

- Industry standard for high-quality 3-D graphics applications
- Available on many HW and OS platforms
- "Thin" software interface to underlying graphics HW
  - Implies very good performance
- Implementing on Windows brings workstation-class graphics to PC
- Real 3-D graphics for Windows

Using OpenGL from Microsoft Windows

- Two approaches:
  - WGL
    - Underlying Windows functionality does most of the work
    - Can be used from either Win32 API or MFC
  - GLUT
    - Contains functions to create and manage windows
    - Others to set up handler functions for user-initiated events
    - Applications more easily ported to other platforms
    - Win32 API

Using the GLUT in OpenGL Windows Applications -Visual Studio 2005-

- Download the Windows version from:
  - http://www.xmission.com/~nate/glut.html
- Copy files to following directories:
  - glut32.dll to: Windows\system32
  - glut32.lib to: Program Files\Microsoft Visual Studio 8\VC\PlatformSDK\lib
  - glut.h to: Program Files\Microsoft Visual Studio 8\VC\PlatformSDK\include\gl

Using GLUT from VS 2008

- Download the GLUT libraries and header files
- Put them in the correct directories
- Go to the following website:
  - http://tempvariable.blogspot.com/2008/02/installing-freeglut-on-visual-studio.html
- Follow the instructions given there to download the files and copy them to the indicated directories:

Creating a GLUT-based Win32 API Application

- Create a Win32 API Application (Empty)
  - Under Project Properties:
    - Configuration Properties / Linker / Input / Additional Dependencies, add:
      - opengl32.lib glu32.lib glut32.lib
    - Under Linker / Advanced / Entry Point, set to:
      - mainCRTStartup

Header Files

- #include <GL/glut.h>
  - gl.h and glu.h not needed if we're using the GLUT
  - May need other C/C++ standard header files:
    - stdio.h, stdlib.h, math.h, time.h, etc.

Main Program

- Just like regular C/C++ app -- entry point is:
  - void main(int &argc, char** argv)
- In main() do following:
  - 1. Initialize the GLUT with
    - glutInit(&argc, argv);
  - 2. Set the display mode
    - Specify kind of buffering, color mode, etc:
      - glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
  - 3. Set initial window position on screen:
    - glutInitWindowPosition(x,y);
  - 4. Set initial window size on screen
    - glutInitWindowSize(w,h);
  - 5. Create the window:
    - glutCreateWindow("title");

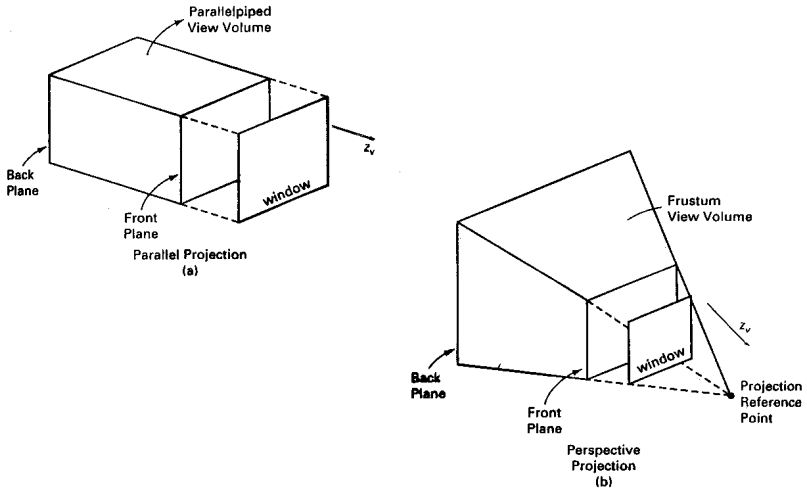
Setting the Background Color

- Set background color for display window
  - glClearColor(1.0,1.0,1.0,0.0); //white
    - Assigns a color, but does not paint it, Use:
    - glClear(GL_COLOR_BUFFER_BIT);
      - Causes values in color buffer to be set to values given in glClearColor()

More Initiazlization: Projection Type, Viewing Transformation, Clipping

- OpenGL designed for 3D graphics
- Must project onto a 2D window
- Also do window-to-viewport transformation
  - with clipping
- For 2D graphics, use an orthogonal projection
  - gluOrtho2D(xmin,xmax,ymin,ymax)
    - Evquivalent to taking z=0 & setting a “window” with clipping boundaries: xmin<=x<=xmax, ymin<=y<=ymax
      - Will be mapped to entire client area of physical window
    - Since projection transformations are done with matrices, must first set the matrix mode and initialize the matrix:
      - glMatarixMode(GL_PROJECTION);
      - glLoadIdentity();

Projections: orthogonal/perspective



After Initialization

- Specify what to display in display window
  - Create the picture in a display "callback" function using OpenGL drawing functions
  - Pass the address of that callback function to the GLUT routine glutDisplayFunc(callback_ftn);
  - Subsequently callback_ftn gets called any time client area of display window is exposed
    - Like MFC OnDraw(), callback_ftn is called in response to WM_PAINT messages
    - Place code there that specifies what is to be displayed
    - End with glFlush() to force buffered commands to execute
- Finally start the message loop in main():
  - glutMainLoop();
  - Must be last statement in main()

Example GLUT Windows Application

- See Section 2-9 of the text book (Hearn and Baker)
- Modified Program listing on page 80
  - See First OpenGL program using GLUT (ogl-pgm1-cc) link on “Example Programs” web page
  - Just draws two diagonal red straight lines
  - And some text

Using OpenGL with Microsoft Windows: WGL Approach

Steps in Using OpenGL in Windows Applications – WGL Approach

- Get a DC for a rendering location (window)
- Choose & set a "pixel format" for the DC
  - Describes desired HW capabilities
- Create a Rendering Context (RC) for the DC
  - Links OpenGL calls to the DC associated with a window client area
- Associate (bind) the RC with the DC
- Draw using OpenGL function calls
- Release the RC & DC

Rendering Context (RC)

- OpenGL equivalent of Windows GDI Device Context
- Mechanism by which OpenGL calls are rendered to the device via a DC
- Links OpenGL calls to a window client area through the associated DC
  - RC Must be compatible with a window's DC
- Keeps track of current values of OpenGL state variables
  - Just like DC does for GDI state variables
    - Attributes, drawing objects, etc.

Pixel Format

Translation layer between OpenGL ftn. calls & Windows physical rendering operation

Describe things like:

- If using single or double buffering
- If direct or indirect color
- If drawing to a window or offscreen bitmap
- Color depth (# of bit planes)
- ZBuffer depth
- Lots of others

PIXELFORMATDESCRIPTOR

- Data structure used to set the Pixel Format
- Some fields:
  - dwFlags: “OR” of properties constants, e.g.
    - doublebuffered, stereo, window or bitmap, etc.
  - iPixelType
    - color type (RGBA or indexed)
  - cColorBits: # of bitplanes
  - cRedBits: # of bits in red color channel
  - cRedShift: where red bits are
  - cDepthBits: depth of Z-buffer (hidden surface removal)
  - etc.
- See online help: PIXELFORMATDESCRIPTOR

Choosing and Setting the Pixel Format

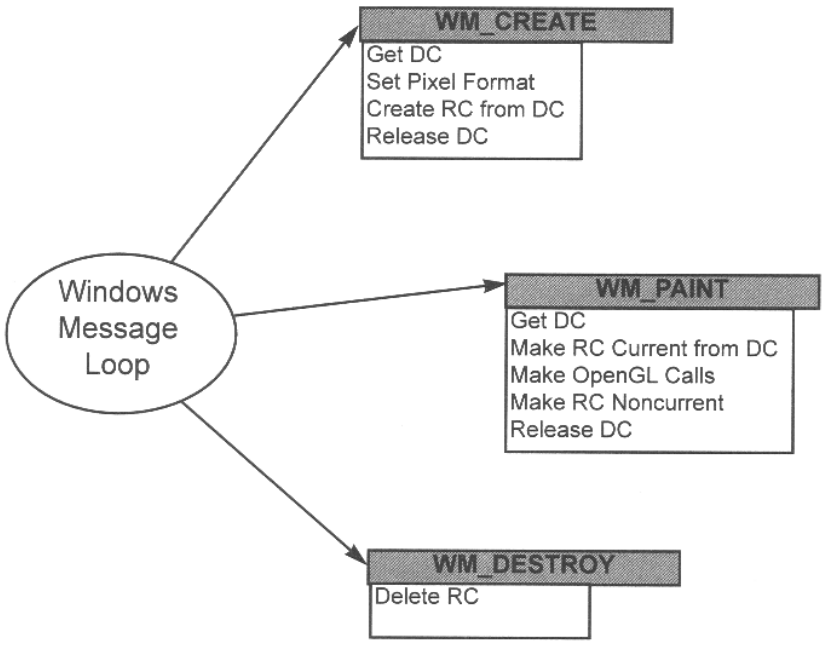
- Set up a PIXELFORMATDESCRIPTOR variable (e.g., pfd)
- pf_index=ChoosePixelFormat(hDC,&pfd)
  - gets DC's pixel format that's the closest match to the desired PFD
  - returns an integer (e.g., pf_index)
- SetPixelFormat(hDC, pf_index, &pfd)
  - Set that pixel format into the DC

Creating and Using a Rendering Context

- Use WGL function to create an RC:
  - hRC = wglCreateContext(hDC);
  - Returns a handle to an OpenGL Rendering Context:
    - HGLRC hRC
  - Will have all capabilities of selected pfd
- Make the RC "Current" [bind RC to DC]
  - wglMakeCurrent(hDC, hRC);
  - Binds the RC to the window's DC and the current thread of execution
- Now we can draw with OpenGL calls

Cleanup

- Make RC non-current (Unbind RC from DC)
  - wglMakeCurrent(hDC, NULL);
- Get rid of the DC
  - ReleaseDC() in a Win32 API app.
  - Done automatically in MFC when OnDraw() returns
- Get rid of the RC
  - wglDeleteContext(hRC);



Building a Windows/OpenGL App using the WGL Interface

- Includes in .h file:
  - <gl\gl.h> // OpenGL interface
  - <gl\glu.h> // OpenGL utility library interface
    - Note we're not using the GLUT
- Must add opengl32.lib & glu32.lib to Linker's Object library modules
  - Under .NET:
    - 'Project' | 'Properties' | 'Configuration Properties' | 'Linker' | 'Input' | 'Additional Dependencies'
    - Type in: opengl32.lib glu.lib

MINOGL Example Program

- Displays a rectangle in different shades of red
- See online listing of CView class of minogl example OpenGL program
  - Look on CS-460/560 "Sample Programs" Page
  - Link:
    - MINOGL: A Simple OpenGL Example Program for Windows MFC (minoglView.cpp)