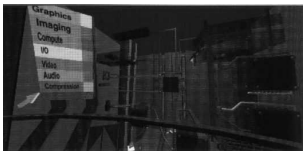
Realtime 3D Computer Graphics & Virtual Reality



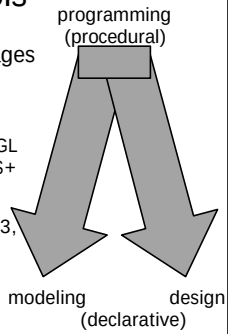
OpenGL Introduction

VR-programming

- Input and display devices are the main hardware interface to users
- Immersion embeds users through the generation of live-like sensory experiences
- *But how is the programmers/designers view?*

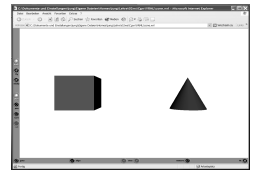
VR-programming tools

- Direct rendering and gfx packages
  - OpenGL, Direct3D, GKS (3D)
- Scene graph based tools
  - VRML, OpenGL Performer, OpenGL Optimizer, Open Inventor, PHIGS+
- VR modeling toolkits
  - AVANGO, World toolkit, Masive1-3, Dive, Lightning, game engines



A Scene Graph Language: VRML

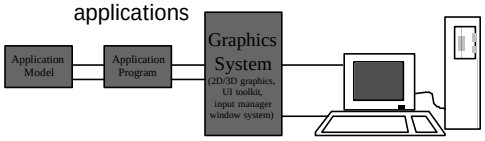
```
#VRML V2.0 utf8
Transform {
  translation -3 0 0
  children Shape {
    geometry Box { }
    appearance Appearance {
      material Material { diffuseColor .8 .2 .2 } }
  }
}
Transform {
  translation 3 0 0
  children Shape {
    geometry Cone { }
    appearance Appearance {
      material Material { diffuseColor .2 .2 .8 } }
  }
}
```



More VRML later in this course!

What is a gfx package?

- software
  - that takes user input and passes it to applications
  - that displays graphical output for applications



An Interactive Introduction to OpenGL Programming

Partly based on SIGGRAPH course notes by Dave Shreiner, Ed Angel and Vicki Shreiner

What You'll See

- General OpenGL Introduction
- Rendering Primitives
- Rendering Modes
- Lighting
- Texture Mapping
- Additional Rendering Attributes
- Imaging

Goals

- Demonstrate enough OpenGL to write an interactive graphics program with
  - custom modeled 3D objects or imagery
  - lighting
  - texture mapping
- Introduce advanced topics for future investigation
- Generate knowledge to understand high-level scene graph based engines for VE-design

OpenGL and GLUT Overview

OpenGL and GLUT Overview

- What is OpenGL & what can it do for me?
- OpenGL in windowing systems
- Why GLUT
- A GLUT program template

What Is OpenGL?

- OpenGL – Open Graphics Library
- Graphics rendering API
  - high-quality color images composed of geometric and image primitives
  - window system independent
  - operating system independent
  - hardware independent layer to different acceleration designs (supporting software modes as well)

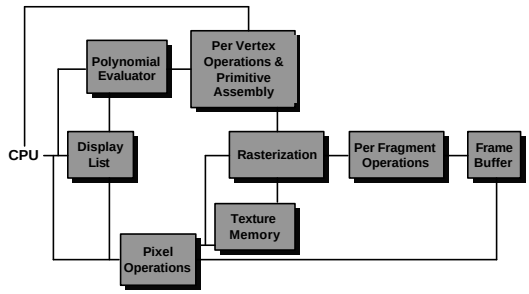
What Is OpenGL?

- Introduced 1992 by SGI
- Based on IRIS GL, an API for the SGI personal IRIS workstation and follow-ups
- Now an open standard that is widely adopted for all types of applications
- Under the supervision of the OpenGL architecture review board

OpenGL Design Goals

- SGI's design goals for OpenGL:
  - High-performance (hardware-accelerated) graphics API
  - Some hardware independence
  - Natural, terse API with some built-in extensibility
- OpenGL has become a standard because:
  - It doesn't try to do too much
    - Only renders the image, doesn't manage windows, etc.
    - No high-level animation, modeling, sound (!), etc.
  - It does enough
    - Useful rendering effects + high performance
  - It is promoted by SGI (& Microsoft, half-heartedly)

OpenGL Architecture



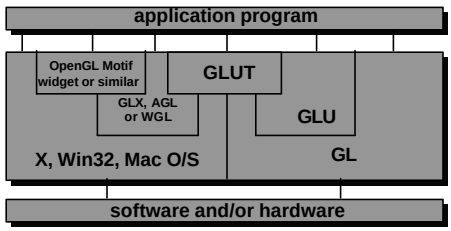
OpenGL as a Renderer

- Geometric primitives
  - points, lines and polygons
- Image Primitives
  - images and bitmaps
  - separate pipeline for images and geometry
    - linked through texture mapping
- Rendering depends on state
  - colors, materials, light sources, etc.

Related APIs

- AGL, GLX, WGL
  - glue between OpenGL and windowing systems
- GLU (OpenGL Utility Library)
  - part of OpenGL
  - NURBS, tessellators, quadric shapes, etc.
- GLUT (OpenGL Utility Toolkit)
  - portable windowing API
  - not officially part of OpenGL

OpenGL and Related APIs



OpenGL: Conventions

- Functions in OpenGL start with **`gl`**
  - Most functions just **`gl (`**e.g., **`glColor())`**
  - Functions starting with **`glu`** are utility functions **`(`**e.g., **`gluLookAt() )`**
  - Functions starting with **`glx`** are for interfacing with the X Windows system (e.g., in gfx.c)

OpenGL: Conventions

- Variables written in CAPITAL letters
  - Example: GLUT_SINGLE, GLUT_RGB
  - usually constants
  - use the bitwise or command (x | y) to combine constants

Preliminaries

- Headers Files
  - #include <GL/gl.h>
  - #include <GL/glu.h>
  - #include <GL/glut.h>
- Compile with libraries
  - cc myapp.c –o myapp –lgl –lglu –lglut –lm –lX11
  - Adopt different library places using e.g. –L/usr/...

Preliminaries

- Simple make looks like

```
CC = cc
LDLIBS = -lglut –lgl –lglu –lX11 –lm –L/usr/...
.c:
    $(CC)    $@.c $(LDLIBS) –o $@
```

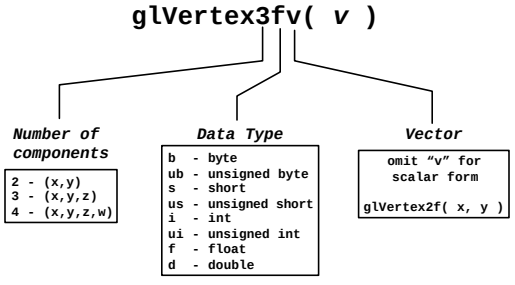
- Enumerated Types
  - OpenGL defines numerous types for compatibility between different systems
    - GLfloat, GLint, GLenum, etc.

Preliminaries

- Enumerated Types

Char	C-type	OpenGL type
b	signed char	GLbyte
s	short	GLshort
i	int	Glint, GLsizei
f	float	GLfloat, GLclampf
d	double	GLdouble, GLclampd
ub	unsigned char	GLubyte, GLboolean
us	unsigned char	GLushort
ui	unsigned int	GLuint, GLenum, GLbitfield
	void	GLvoid

OpenGL Command Formats



GLUT Basics

- Application Structure
  - Configure and open window
  - Initialize OpenGL state
  - Register input callback functions
    - render
    - resize
    - input: keyboard, mouse, etc.
  - Enter event processing loop

Basic OpenGL template

```
/* simple program template for
   OpenGL progs */

#include <GL/glut.h>

void myDisplay()
{
   /* clear the window */
   glClear(GL_COLOR_BUFFER_BIT);
   /* draw something */
   glBegin(GL_LINES);
        glVertex2f(-0.5, -0.5);
        glVertex2f(0.5, 0.5);
   glEnd();
   glFlush();
}
```

```
int main (int argc,
          char** argv)
{
   glutInit(&argc, argv);
   glutCreateWindow("basic
   template 1");
   glutDisplayFunc(myDisplay);
   glutMainLoop();
}
```

Sample Program

```
void main( int argc, char** argv )
{
  glutInit( argc, argv );
  int mode = GLUT_RGB|GLUT_SINGLE;
  glutInitDisplayMode( mode );
  glutCreateWindow( argv[0] );
  init();
  glutDisplayFunc( display );
  glutKeyboardFunc( key );
  glutMouseFunc( mouse );
  glutIdleFunc( idle );
  glutMainLoop();
}
```

OpenGL Initialization

- Set up whatever state you're going to use

```
void init( void )
{
  glClearColor( 0.0, 0.0, 0.0, 1.0 );
  glColor3f( 1.0, 1.0, 1.0);
  glClearDepth( 1.0 );
  glEnable( GL_LIGHT0 );
  glEnable( GL_LIGHTING );
  glEnable( GL_DEPTH_TEST );
}
```

GLUT Callback Functions

- A callback is a routine to call when something happens
  - window resize or redraw
  - user input
  - animation

GLUT Callback Functions

- "Register" callbacks with GLUT

```
glutDisplayFunc( display );
glutIdleFunc( idle );
glutResizeFunc( resize );
glutKeyboardFunc( keyboard );
glutSpecialFunction( special )
glutMouseFunc( mouse );
glutMotionFunc( mouse_motion );
glutPassiveMotionFunc( mouse_pmotion );
glutEntryFunc( on_focus_change );
```

Rendering Callback

- **Do all of your drawing here**

```
glutDisplayFunc( display );
```

```
void display( void )
{
  glClear( GL_COLOR_BUFFER_BIT );
  glBegin( GL_LINES );
    glVertex2f( 50.0, 50.0 );
    glVertex2f( 100.0, 100.0 );
    glVertex2f( 70.0, 10.0 );
    glVertex2f( 100.5, 70.1 );
  glEnd();
  glFlush();
}
```

Idle Callbacks

- Use for animation and continuous update

```
glutIdleFunc( idle );

void idle( void )
{
  t += dt;
  glutPostRedisplay();
}
```

“smart” update

```
glutPostRedisplay();
```

- Requests that the display callback be executed
- Allows the implementation to be smarter in deciding when to carry out the display callback
  - As GLUT goes through the event loop, more than one event can require a redraw which should only be carried out once during the loop

Idle callback and smart update

- Processing an animation should be done with respect to the elapsed time
  - t += dt;
- No hint when the update occurs
- How can we achieve a minimal simulation and frame rate using this application structure?

User Input Callbacks

- Process user keyboard input

```
glutKeyboardFunc( keyboard );

void keyboard( char key, int x, int y )
{
  switch( key ) {
    case ‘q’ : case ‘Q’ :
      exit( EXIT_SUCCESS );
      break;
    case ‘r’ : case ‘R’ :
      rotate = GL_TRUE;
      break;
  }
}
```

User Input Callbacks

- Process user special keyboard input

```
glutSpecialFunction( special );

void special( char key, int x, int y )
{
  if( key == GLUT_KEY_F1)    help();
  if( key == GLUT_KEY_UP)    up();
  if( key == GLUT_KEY_DOWN)  down();
  if( key == GLUT_KEY_LEFT)  left();
  if( key == GLUT_KEY_RIGHT) right();
}
```

User Input Callbacks

- Process user mouse input

```
glutMouseFunc( mouse );

void mouse( int button, int state,
  int x, int y )
{
  if (state == GLUT_DOWN &&
      button == GLUT_LEFT_BUTTON)
        exit(EXIT_SUCCESS);
}
```

User Input Callbacks

- Process user mouse motion input with a pressed button

```
glutMotionFunc( mouse_motion );

void mouse_motion( int x, int y )
{
  if (first_time_called)
     glBegin();
     …
     glEnd();
     first_time_called = GL_false;
}
```

User Input Callbacks

- Process user mouse motion input without a button pressed

```
glutPassiveMotionFunc( mouse_pmotion );

void mouse_pmotion( int x, int y )
{
  last_points_visited.push(pair(x,y));
  if( last_points_visited.size() > 100)
    last_points_visited.remove_last();
}
```

User Input Callbacks

- Process leaving and entering the OpenGL window with the mouse

```
glutEntryFunc( on_focus_change );

void on_focus_change( int state )
{
 if (state == GLUT_ENTERED)
   beep();
 if (state == GLUT_LEFT)
   exit(EXIT_SUCCESS);
}
```