

Introduction to OpenGL

**CSCI 4229/5229
Computer Graphics
Fall 2022**

OpenGL by Example

- Learn OpenGL by reading
- nehe.gamedev.net
- lighthouse3d.com
 - Excellent free tutorials
- OpenGL: A Primer (3ed) by Edward Angel
 - Short and sweet
- OpenGL Programming Guide (Vermillion Book)
 - Free older editions as PDF
- OpenGL Superbible
 - Theory and Applications

What is OpenGL?

- Sometimes called a library, actually an Application Programming Interface (API)
- Specification is controlled by Khronos
- Multiple implementations by different vendors
 - Mesa & FreeGLUT free implementations
- OpenGL just does real time graphics
 - Need GLX/WGL/AGL for windowing and input
 - Limited font support (in GLUT)
 - No sound, printing, etc. support

OpenGL Versions

- 1.0 Initial release (1992)
- 1.1 Major upgrade (1997)
 - Latest version on some Windows system
- 1.2 Improves textures (1998)
- 1.3-1.5 Incremental improvements (2001-2003)
- 2.0 Relaxes restrictions, adds shader (2004)
- 2.1-2.3 Incremental improvement (2006-7)
- 3.0 Support advanced hardware features (2008)
- 3.1-3.3 Improved shaders (2009)
- 4.0 Merge desktop and devices (2010)
- 4.1-4.x Additional shaders

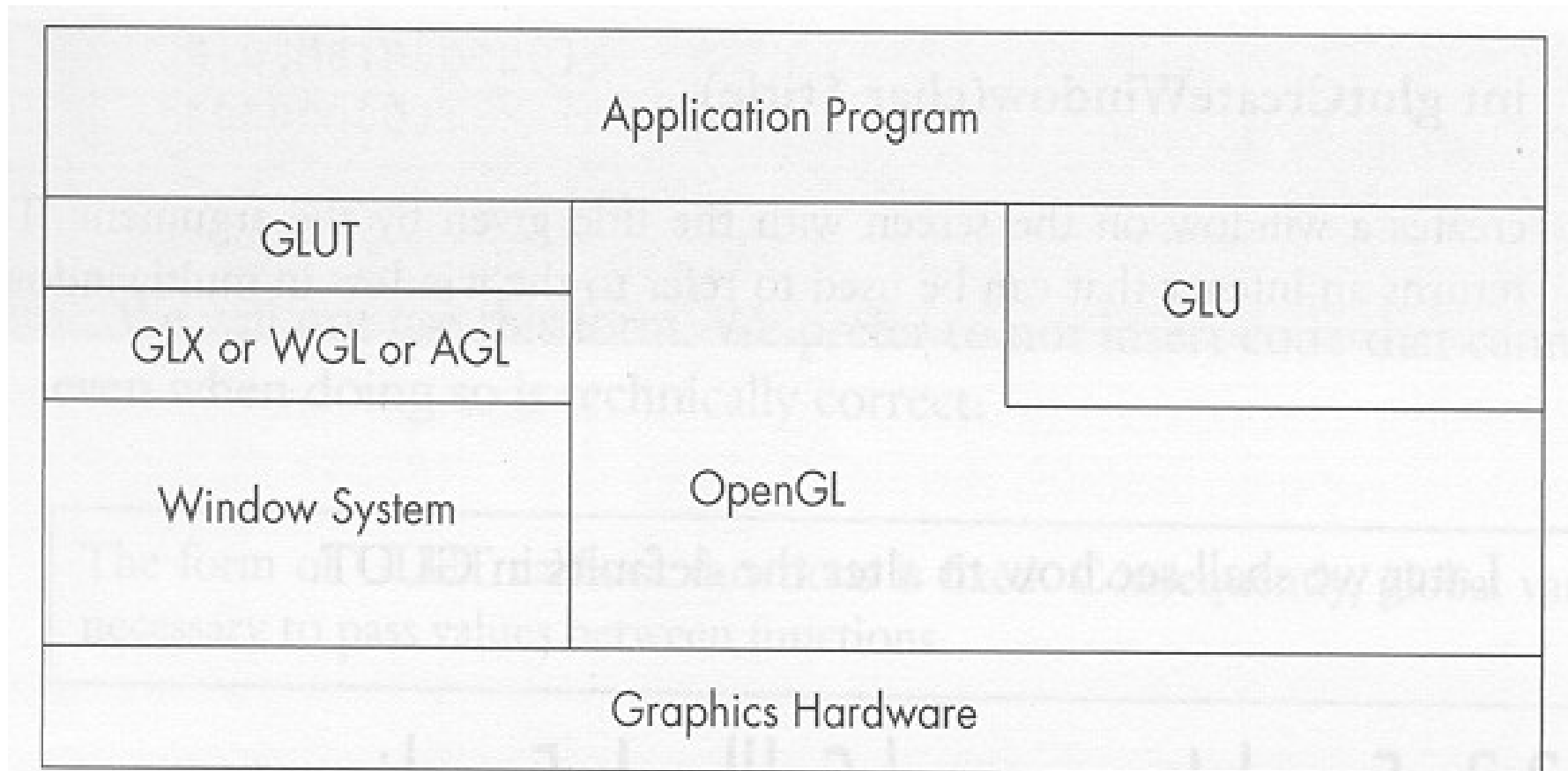
OpenGL Deprecation

- I will mostly use OpenGL 2.0
 - Feature rich, flat learning curve
 - I will use GL3 or GL4 only as needed
- OpenGL Core Profile concentrates on rendering
 - Improved execution time performance
- User must provide deprecated functionality
 - Steepens the learning curve
 - Deprecated features in Compatibility Profile
 - Increases reliance on third party libraries
 - Adds development time until tools mature

OpenGL APIs

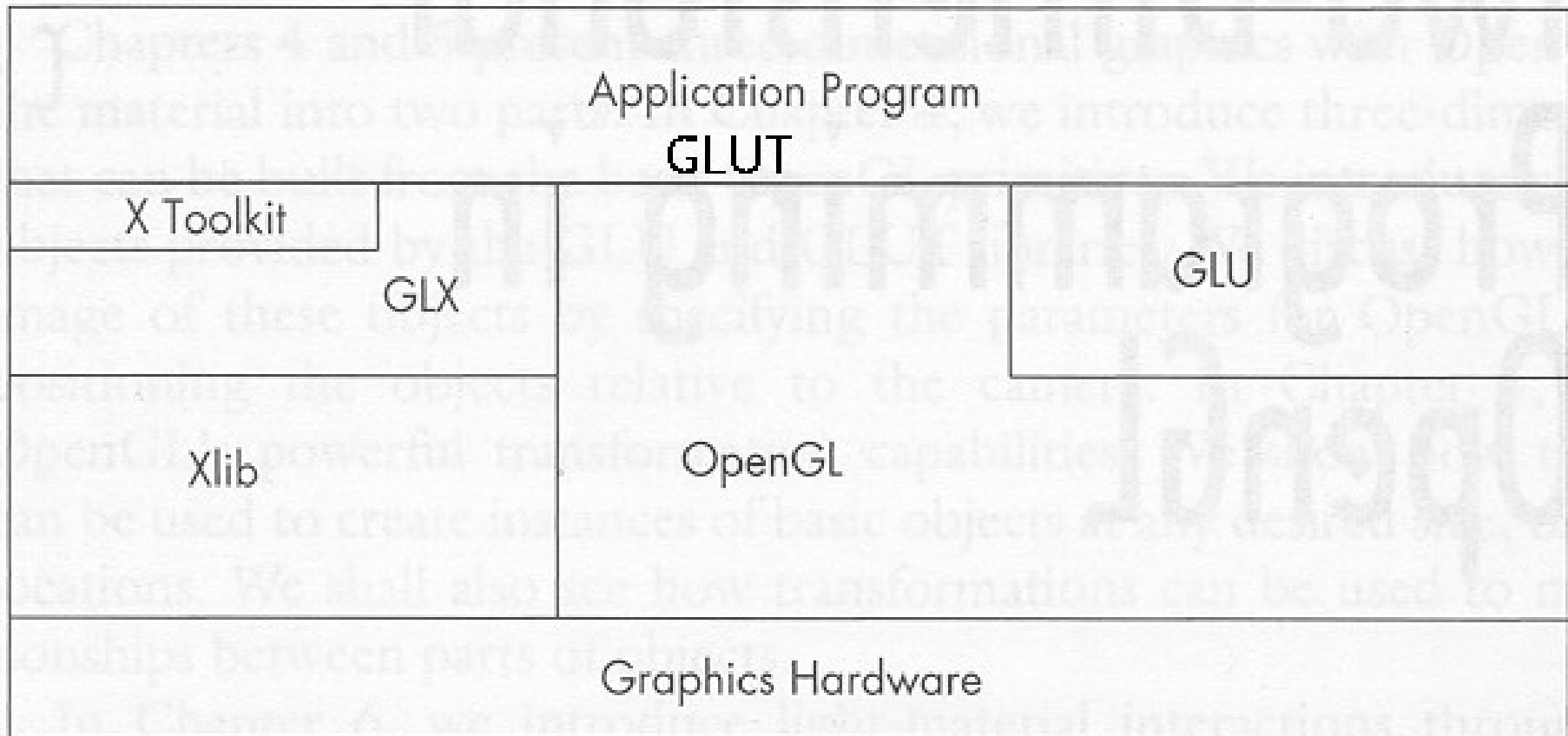
- Languages
 - C, C++, C#
 - FORTRAN
 - Java
 - Perl
 - Python
 - Ada
- Packages
 - Qt (QOpenGLWidget)
 - SDL, glfw, etc
 - Many others

OpenGL and Friends



From *OpenGL: A Primer*

OpenGL on X11



From *OpenGL: A Primer*

GLU: OpenGL Utility

- Higher Level and Convenience Functions
 - Projections
 - Creating texture maps
 - NURBS, quadrics, tessalation
 - Predefined objects (sphere, cylinder, teapot)
- Collections of calls for convenience
- Standard with all OpenGL implementations

GLUT: GL Utility Toolkit

- Provides access to OS and Window System
 - Open windows and setting size and capabilities
 - Register and triggers callbacks
 - Keyboard and mouse interaction
 - Elementary fonts
- Not part of OpenGL, but provides a portable abstraction of the OS
 - FreeGLUT
 - OpenGLUT
- Alternatives: SDL, Qt, glfw, ...

Header Files and Libraries

- Usually you only need
 - `#define GL_GLEXT_PROTOTYPES`
 - `#include <GL/glut.h>`
- Header file locations
 - `/usr/include/GL` on most systems
- Linking may only need
 - `-l glut -l GLU -l GL`
- Special cases
 - OS/X separates GL and GLUT
 - Windows differs depending on the compiler

OpenGL Naming Convention

- glSomethingNt()
 - *Something* is the name of the function
 - N is 2 or 3 or 4 for the dimension
 - t is for the the variable type
 - b GLbyte (signed char) 8 bit
 - s GLshort (signed short) 16 bit
 - i GLint (signed int) 32 bit
 - ub GLubyte (unsigned char) 8 bit
 - us GLushort (unsigned short) 16 bit
 - ui GLuint (unsigned int) 32 bit
 - f GLfloat (float) 32 bit
 - d GLdouble (double) 64 bit

OpenGL Naming Example

- Vertex
 - glVertex3i(0 , 0 , 1)
 - glVertex2d(27.34 , 88.12)
 - glVertex3dv(array)
- Few functions return a value
- Most functions created by name mangling
- Constants are GL_SOMETHING
- Variable types are GLsomething

GLUT and GLU Naming

- Functions
 - glutSomething
 - gluSomething
- Constants
 - GLUT_SOMETHING
 - GLU_SOMETHING
- You can always tell by the name which API supplies a function or constant
- Avoid things starting with glx, wgl & agl

GLUT: GL Utility Toolkit

- Supplies interface to OS
 - Windowing
 - Interaction
- Hello World in GLUT (well sorta)

```
int main(int argc,char* argv[ ])
{
    glutInit(&argc,argv);
    glutCreateWindow("Hello World");
    glutDisplayFunc(display);
    glutMainLoop();
}
```

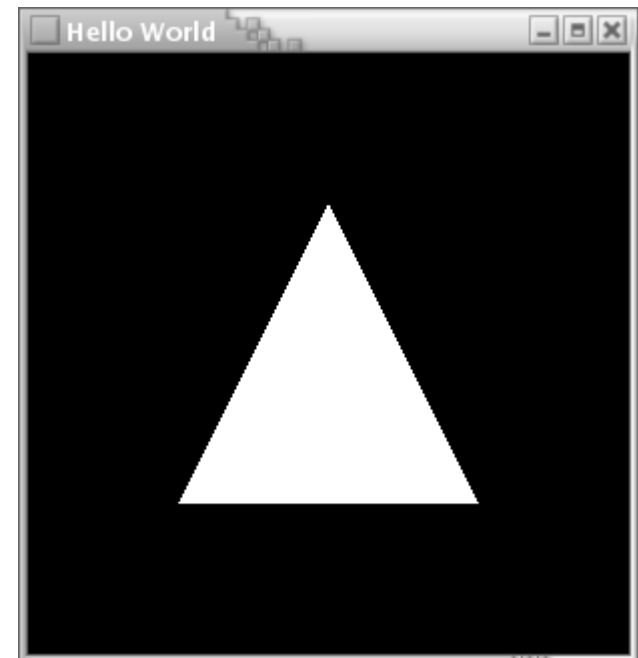
Completing Hello World

- Draw a triangle

```
#include <GL/glut.h>
void display()
{
    glClear(GL_COLOR_BUFFER_BIT);
    glBegin(GL_POLYGON);
    glVertex2f(0.0,0.5);
    glVertex2f(0.5,-0.5);
    glVertex2f(-0.5,-0.5);
    glEnd();
    glFlush();
}
```


Compile, link and run

- `gcc -Wall -o ex1 ex1.c -lglut -lGL`
- Heavily relies on defaults
 - Window
 - Viewport
 - Projection
 - Color



Event Driven Programming

- Don't call us, we'll call you
 - register callbacks corresponding to events
 - similar to interrupt driven programs
- DO NOT explicitly call `display()`
 - request redisplay using `glutPostRedisplay()`
- NEVER call `sleep()`
 - use global/static variables and wall time for timing
 - use `glutTimerFunc()` for regular events
- Return control as soon as possible

Types of Objects

- glBegin(type)
 - GL_POINTS points
 - GL_LINES lines between pairs of points
 - GL_LINE_STRIP series of line segments
 - GL_LINE_LOOP closed GL_LINE_STRIP
 - GL_POLYGON simple polygon
 - GL_TRIANGLES triangles between triples of points
 - GL_TRIANGLE_STRIP series of triangles
 - GL_TRIANGLE_FAN fan of triangles
- Set coordinates with glVertex
- glEnd()

Qualifiers

- `glPointSize(float size)`
 - POINT size in pixels (default 1)
- `glLineWidth(float width)`
 - LINE width in pixels (default 1)
- `glLineStipple(int factor, unsigned short pattern)`
 - LINE type
 - Requires `glEnable(GL_LINE_STIPPLE)`

Color

- Default is RGB color
 - X11 TrueColor
 - R,G,B 0-1 or integer range
 - `glColor3f(1.0 , 0.0 .0.0)`
 - `glColor3b(127 , 0 , 0);`
 - `glColor3ub(255 , 0 , 0);`
 - `glColor3fv(rgbarray);`
- Color can also contain transparency (alpha)
 - `glColor4f(1.0 , 0.0 . 0.0 , 0.5);`
 - Default alpha=1 (opaque)
- Stays in effect until you change color

Indexed Color

- X11 Direct Color
 - Based on a colormap
- Set color using `glIndexi(27)`
- Need to load colors into color map using `glutSetColor()`
- Use RGB color unless hardware constrain
- Deprecated in OpenGL 3 since it really is obsolete

Displaying a scene

- Register using `glutDisplayFunc()`
- `glClear()`
- *Draw Something*
- `glFlush()`
- `glutSwapBuffers()`
- Schedule using `glutPostRedisplay()`

Transformations

- Transformation apply to everything that follows
- Transformations are cumulative
 - Call `glLoadIdentity()` in `display()`
- Primitive operations
 - `glLoadIdentity();`
 - `glTranslate[fd](dx , dy , dz)`
 - `glScale[fd](Sx , Sy , Sz)`
 - `glRotate[fd](angle , Ux , Uy , Uz)`
- Compatibility profile in OpenGL4 still useful


```
glTranslate[fd](dx , dy , dz);
```

- Move an object in three dimensions
- Allows you to easily produce multiple copies of an object
- Always takes 3D coordinates (float or double)

glScale[fd](Sx , Sy , Sz)

- Change the scale along the axes
- Multiplicative factors
 - $|S| < 1$ shrink
 - $|S| > 1$ expand
 - Negative values creates mirror image
- Allows you to easily create multiple copies of the same type at different sizes

glRotate[fd](angle , Ux , Uy , Uz)

- Rotates around the origin and axis (Ux,Uy,Uz)
- Angle is measured in degrees
- The axis often a primary axis, but may be any axis
 - Undefined behavior if $Ux=Uy=Uz=0$
- Allows you to create multiple copies of the same object viewed from different sides, or to view the scene from different positions

Temporary Transformations

- `glPushMatrix()`
 - Saves the current transformation
- `glPopMatrix()`
 - Resets the transformation to what it was when you did the push
- Allows you to build complex transformations and then get them back

Compound Transformations

- Rotate angle around the point (X,Y,Z) and axis (U_x,U_y,U_z)
 - `glTranslated(-X,-Y,-Z)`
 - `glRotated(angle,U_x,U_y,U_z)`
 - `glTranslated(X,Y,Z)`
- OpenGL does this intelligently

Projections

- Orthographic
 - `glOrtho(left,right,bottom,top,near,far)`
 - Same size regardless of distance
 - Easiest to use
- Perspective
 - `glFrustum(left,right,bottom,top,near,far)`
 - Closer objects are bigger
 - GLU convenience functions
 - `gluPerspective(fov,aspect,Znear,Zfar)`
 - `gluLookAt(Ex,Ey,Ez , Cx,Cy,Cz , Ux,Uy,Uz)`

Text

- OpenGL provides only hooks for fonts
- Stroked fonts
 - Lines and fills write the characters
- Bitmap (raster) fonts
 - Characters are raster images
- Orientation, size, etc. treated just like any other drawing elements

Text using GLUT

- `glutBitmapCharacter(GLUT_FONTTYPE,ch)`
 - Single character
 - Limited font selection
- `glRasterPos3d(x,y,z)`
 - Sets position to write text in (x,y,z) coordinates
- `glWindowPos2i(x,y)`
 - Sets position to write text in pixels coordinates

Registering Callbacks

- Display
 - glutDisplayFunc() Draw the scene
 - glutReshapeFunc() Window resized
 - glutIdleFunc() Nothing more scheduled
- User input
 - glutKeyboardFunc() Key pressed
 - glutSpecialFunc() Special key pressed
 - glutMouseFunc() Mouse button
 - glutMotionFunc() Mouse motion
- Many more

Keyboard Input

- `special(int key,int x,int y)`
 - Cursor keys `GLUT_KEY_LEFT`, `GLUT_KEY_UP`,...
 - Function keys `GLUT_KEY_Fx`
 - Basically anything not an ASCII key
- `keyboard(char ch,int x,int y)`
 - Regular ASCII keystrokes
- `(x,y)` is the mouse position in pixels

Setting Modes

- `glutInitDisplayMode`
 - Interfaces with the window manager to get the right kind of window (BE CAREFUL ABOUT DEFAULTS)
- `glEnable()` & `glDisable()`
 - Switches OpenGL into various modes
 - `GL_DEPTH_TEST`
 - `GL_ALPHA_TEST`
 - `GL_CULL_FACE`
 - `GL_LIGHTING`
 - Different modes for different objects

Checking for Errors

- OpenGL fails silently
- Functions do not return an error code
- `glGetError()` must be called explicitly to check for errors
- A black screen is a sure signal of an error