Introduction to OpenGL

Computer Graphics
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OpenGL

- **IRIS GL (Graphics Library):**
  - Silicon Graphics (SGI) revolutionized the graphics workstation by implementing the pipeline approach in hardware (1982).

- **OpenGL (Open Graphics Library):**
  - The success of IRIS GL led to OpenGL (1992).
  - A platform-independent ***rendering*** API
  - Close enough to the hardware/driver to get excellent performance
  - Extensible for platform-specific features through extension mechanics
  - Still, it is an industry standard for 3D graphics.

OpenGL Management Consortium

KHRONOS GROUP
CONNECTING SOFTWARE TO SILICON

- **Originally controlled by Architectural Review Board (ARB)**
  - Members includes: SGI, MS, NVIDIA, HP, Apple, 3DLabs, IBM, …
- **Now managed by Khronos group (www.khronos.org)**
  - Current promoter members (board of directors)
  - Active standards

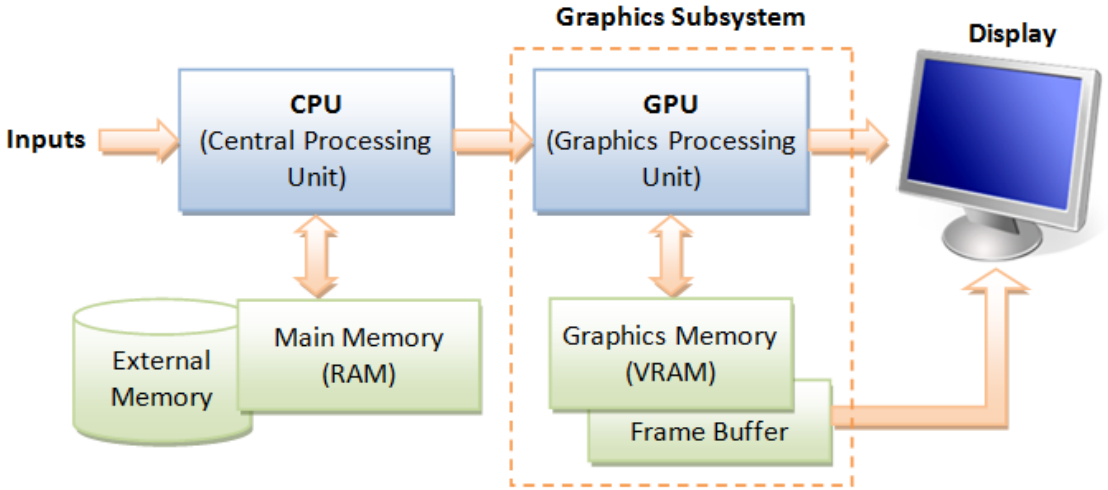
Old-Style OpenGL

- **Through version 2.5 (more strictly up to version 3.1)**
  - was relatively ***stable*** and ***backward-compatible***
  - The features were fixed, and impossible to modify
    - So, the pipeline is called the "***fixed-pipeline***," which simulates the basic transformation/projection (in vertex shader) and Blinn-Phong shading (in fragment shader).

  - Now, many of the architecture are deprecated in modern-style OpenGL (since version 3.2).

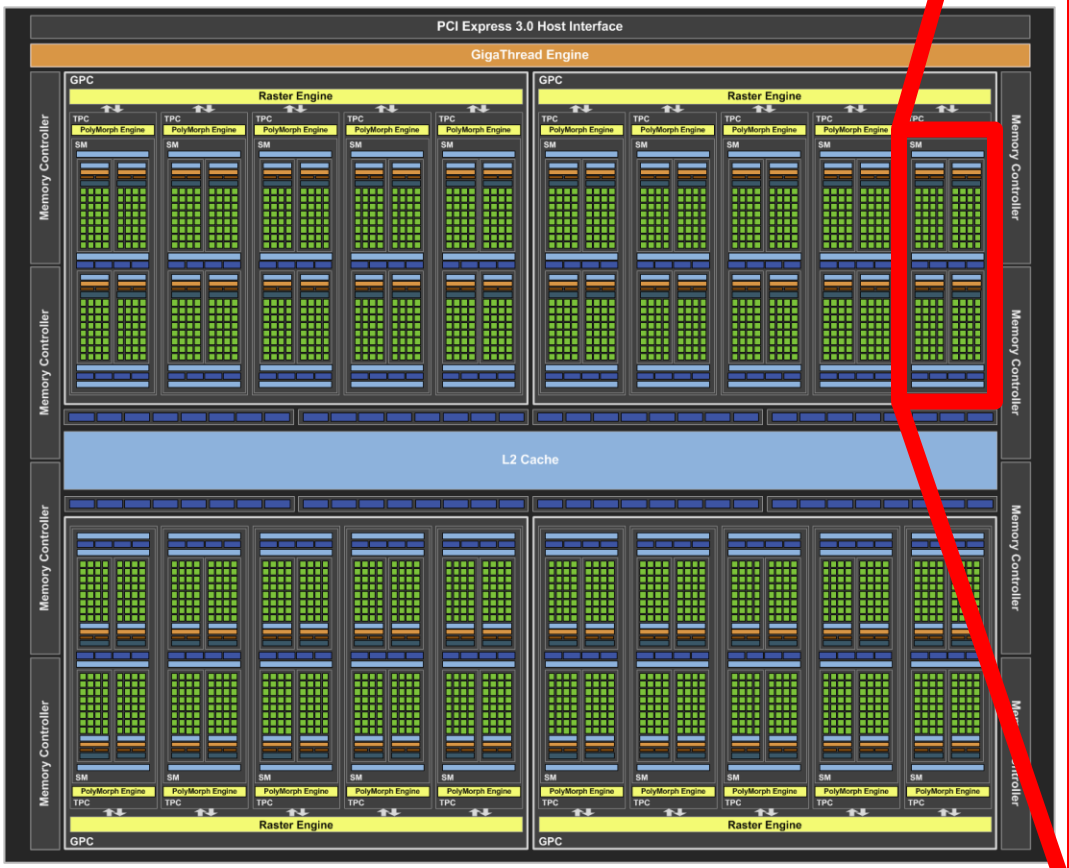
Graphics Hardware

- **GPU (Graphics Processing Unit)**
  - Modern computer has dedicated Graphics Processing Unit (GPU) to produce images for the display.
  - GPU is a special complete parallel computing system which has thousands of cores with its own graphics memory hierarchy (or Video RAM or VRAM).



Graphics Hardware

- **Example: NVIDIA GTX 1080**
  - 2560 CUDA Cores (1.6 GHz)
  - 160 Texture units, 8GB Memory



Modern-Style OpenGL

- **Modern-style OpenGL:**
  - OpenGL *since version 3.2* is called "modern-style OpenGL".

- **Using Powerful GPUs**
  - Intensively using GPU rather than CPU for high performance
  - Application's job is only to send data to GPU.
  - GPU does all rendering (as well as some computing).

- **This course will focus only on modern-style OpenGL.**
  - Basically, old-style OpenGL stuffs (many available on the web) are not allowed here.
  - Even, I will not let you know what the old-style was to avoid confusion.

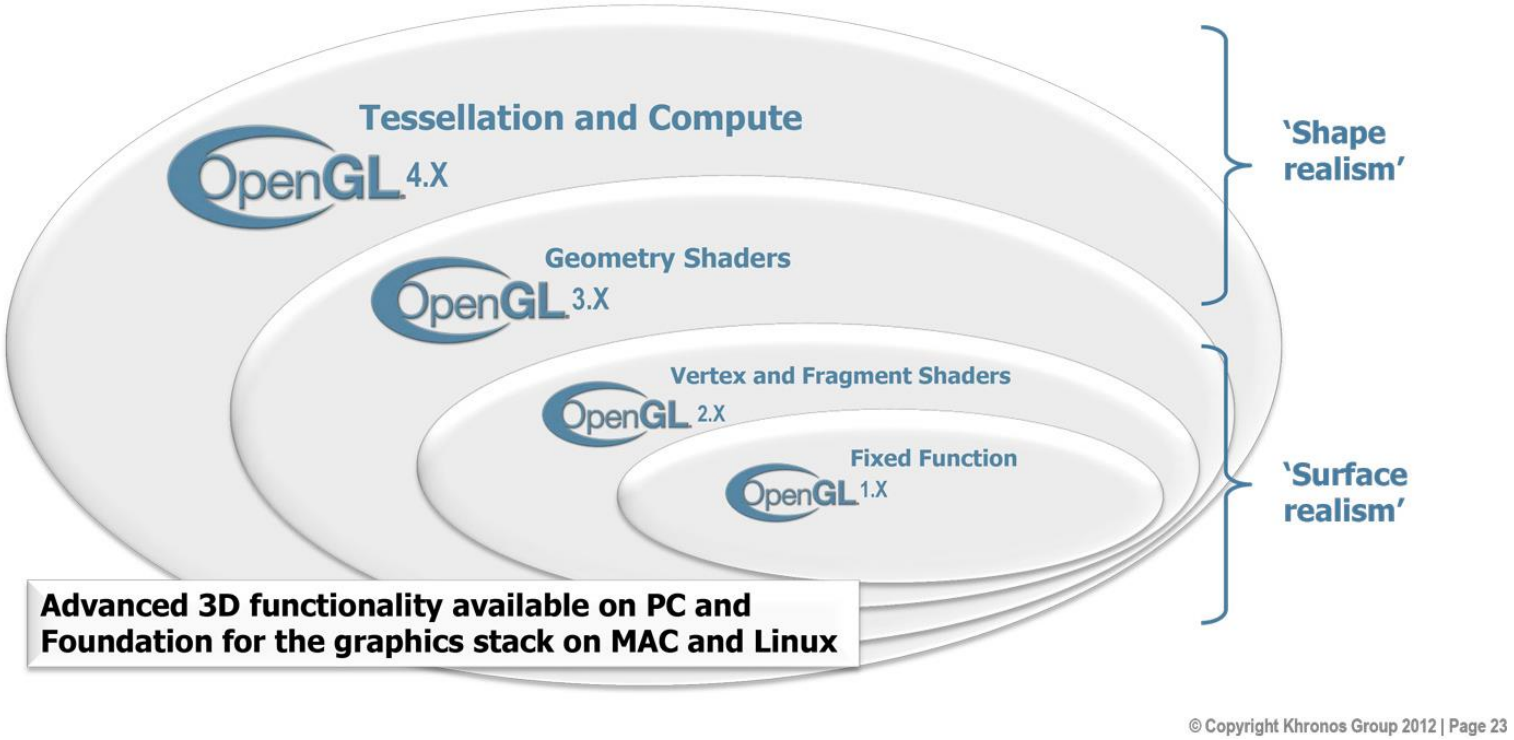
Modern-Style OpenGL

- **User-programmable pipeline**
  - Now, user can modify the vertex and fragment processing stages.
  - This is possible by GPU programs called ***shaders***.

- **Totally shader-based**
  - No default shaders (as fixed pipeline) available
  - Each application must provide both a vertex and a fragment shader
  - ***Most 2.5 and previous functions deprecated.***

Modern-Style OpenGL

- **OpenGL for each Hardware generation**



Introduction to OpenGL API

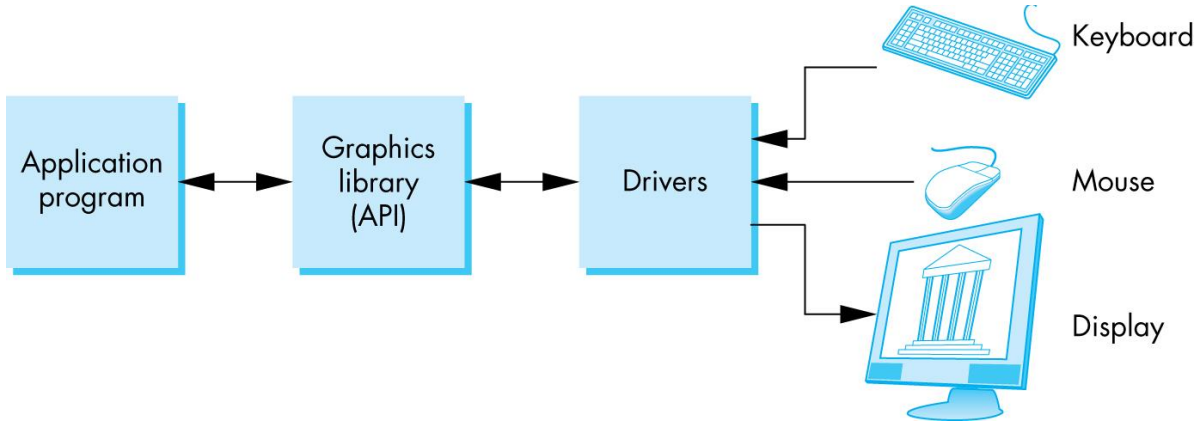
API?

- **Application Programming Interface (API)**
  - A protocol intended to be used as an interface by software/hardware components to communicate with each other.
  - A library that may include specification for routines, data structures, object classes, and variables.

- **Examples:**
  - POSIX (for Unix-like programming)
  - Microsoft Windows API (for windows programming)
  - C++ Standard Template Library (STL)

OpenGL API

- **OpenGL API:**
  - Allows us to interact with graphics hardware and other software platform via abstract forms of function calls.
  - Cross-language, cross-platform API
    - Languages: **C**/C++, Java, C#, Fortran 90, Perl, Python, Delphi, Ada, …
    - Platforms: Windows, Linux, Apple, …
  - Windowing support not exists for cross-platform API
    - 3rd-party libraries necessary (e.g., GLUT, freeGLUT, GLFW)

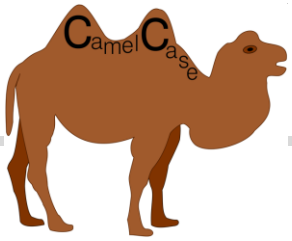


OpenGL API: Lack of Object Orientation

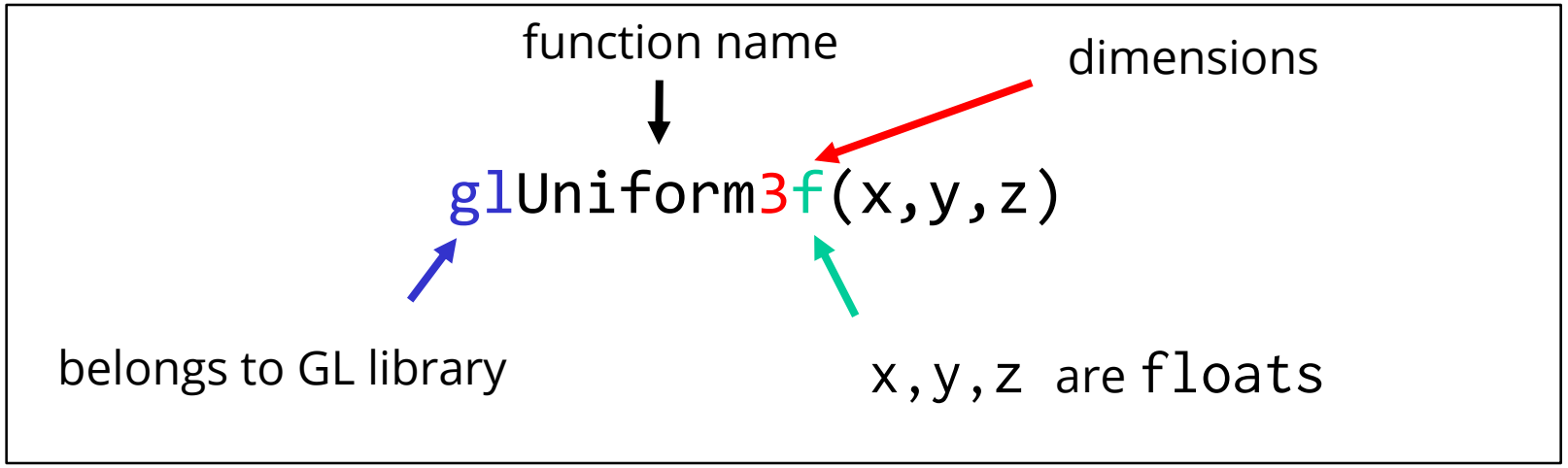
- **It's a pure "C" API.**
  - There are multiple functions for a given logical function.
    - e.g., glUniform3f(), glUniform2i(), glUniform3dv()
  - Underlying storage mode is the same
  - Easy to create overloaded functions in C++ but an issue is efficiency.
  - However, in practice, many of third-party libraries use OpenGL API with their C++ APIs.

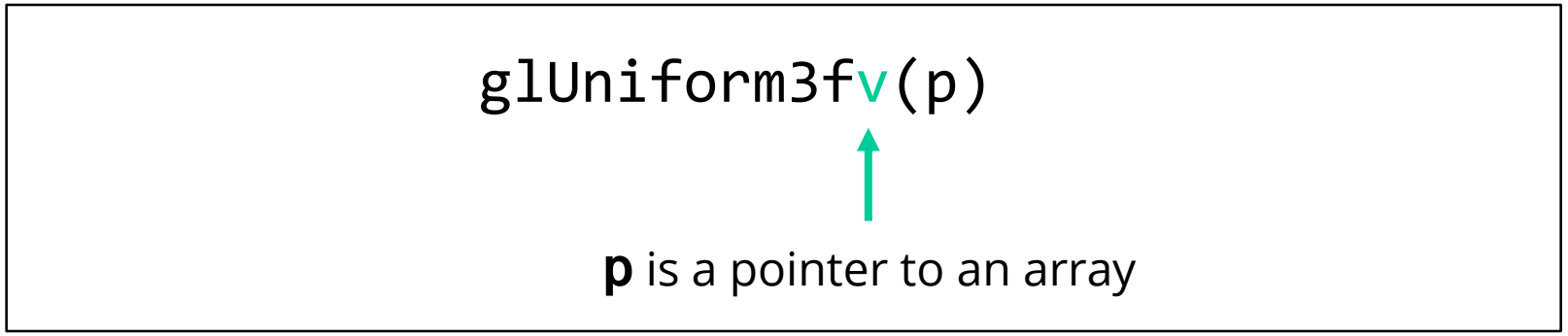
- **OpenGL is a state machine**
  - Since it does not use OOP, many of the API states are stored internally.
  - You can access it by query functions (e.g., glGetSomething())

OpenGL API: Function Format



- **It uses a (lower) camel-case style with variable types.**





Prerequisites:
How to Use Third-Party Libraries

Precompiled Binary Distribution

- **Most of binary distribution of 3rd-party libraries are structured like this:**
  - include/libname.h
  - lib/libname.lib (libname.a for Linux)
  - bin/libname.dll (libname.so for Linux)

- **DLL (or SO in Linux)?**
  - Dynamic Linking Library (Shared Object)
  - Precompiled binary objects that can be used for other programs.

- **Example:**
  - include/glfw3.h **// have declaration of functions**
  - lib/glfw3dll.lib **// have linking entry points of functions**
  - bin/glfw3.dll **// have binary objects of functions**

Installation

- **Assumed platform:**
  - Windows + Visual Studio (32-bit builds)

- **How to get Visual Studio (Community Edition)**
  - Download a community edition of Visual Studio from Microsoft, freely available for college students.
  - The community version is fully functional as a professional version does.
  - Never use an illegal copy of the software.

Installation: Local Copy

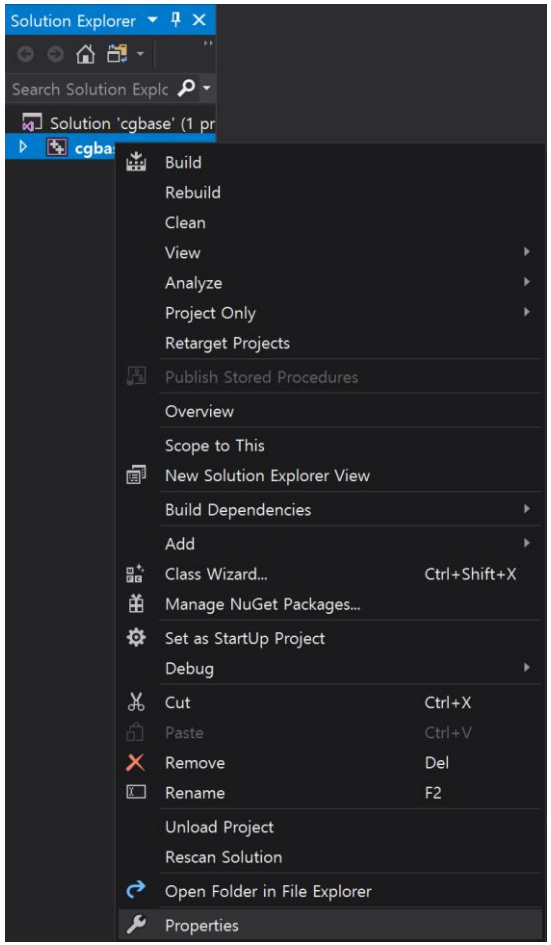
- **Global installation to VC's h/lib/bin directories is *not recommended*, because:**
  - You will not be able to re-compile the source code on other platforms.
  - You also need to distribute DLL files, too.

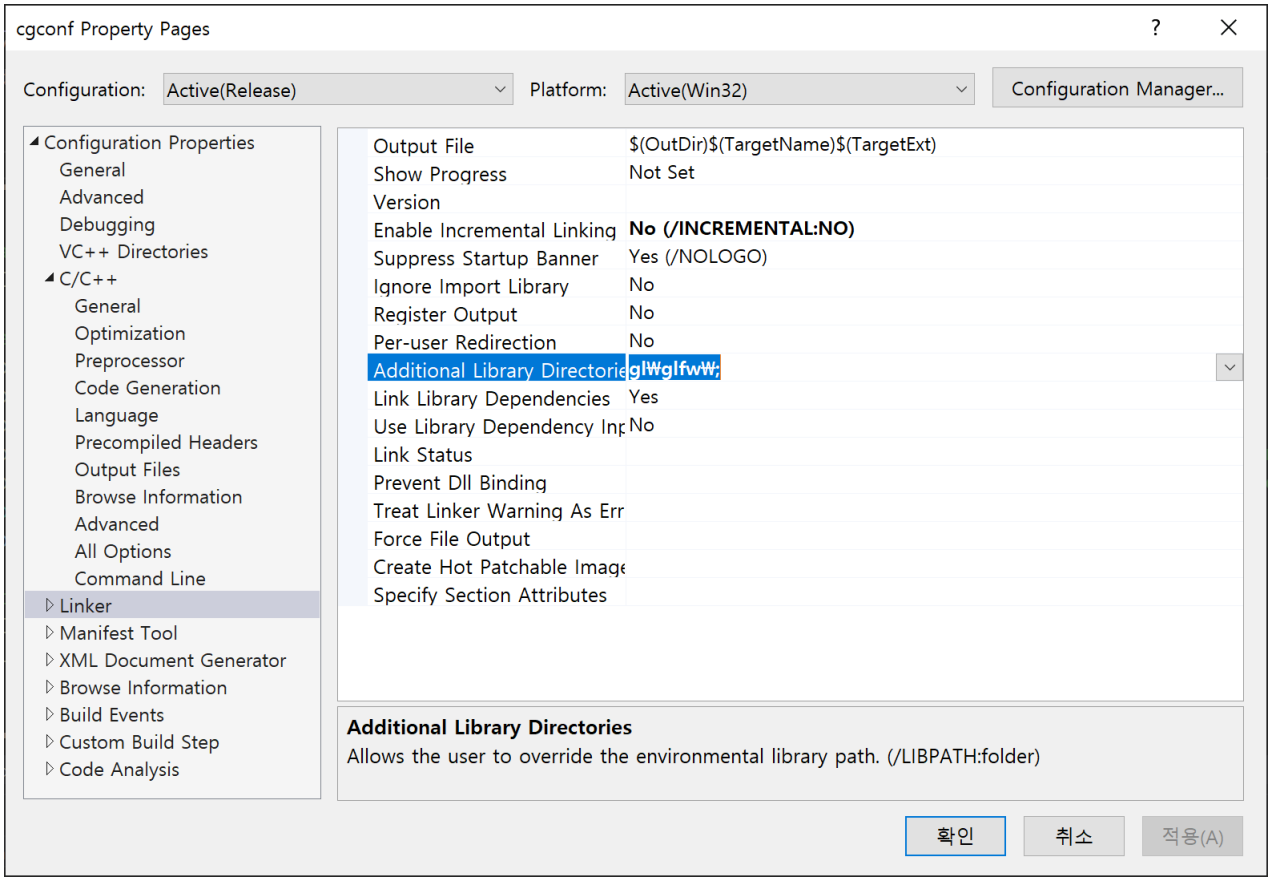
- **Instead, copy your library files to your project directory.**
  - Put LIBNAME.h and LIBNAME.lib to .\hello\src\gl\
  - Put LIBNAME.dll to .\hello\bin\
    - Binary files (*.dll) are loaded at run time.

- **This local copy is *recommended*, because:**
  - You do not need to worry about a compiler system where the libraries are not installed.
  - You can easily distribute your binaries in /bin/ directory (just copy it).

Things to Do in Visual Studio

- **Add additional library directories that have *.lib files**
  - In Visual Studio:





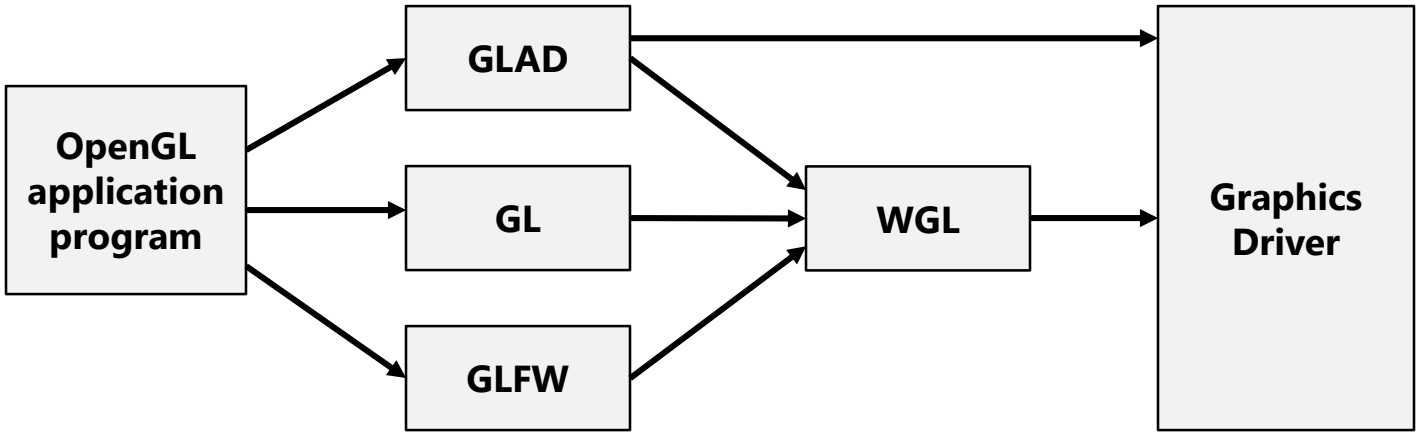
vcpkg: Building libraries on your own

- **Build the source code directly**
  - You can basically build libraries on your own from the original source.
- **vcpkg:**
  - Visual Studio now provides a good package manger, which is similar to:
  - scoop or chocolatey or sudo apt-get install (in Ubuntu)
- **Examples: static build for x64:**
  - > vcpkg install glfw3:x64-windows-static // static build for x64
  - > vcpkg install glad:x86-windows // dynamic build for x86
- **Still, I recommend you copying the build to local directories**
  - You can find the libraries in:
  - For example: /vcpkg/installed/x64-windows-static/

Installation of GL and 3rd-Party Libraries

OpenGL Software Organization

- **OpenGL Software organization on Windows**



OpenGL Core

- **OpenGL core library (i.e., drivers)**
  - It's already installed on your compiler systems when your are installing display drivers for your OS.
  - Implementations are available through graphics drivers.

- **Linking with window system**
  - WGL for Windows
  - GLX for Linux

- **In your code,**
  - You do not need to do anything, because GLFW and GLAD do everything instead.

GLFW: https://www.glfw.org/

- **GLFW: An Open Source, multi-platform library for**
  - creating windows with OpenGL contexts and receiving input and events.
  - written in C and has native support for Windows, OS X and many Unix-like systems using the X Window System, such as Linux and FreeBSD.
  - Modern alternative to old-school OpenGL Utility Toolkit (GLUT)
  - You can download the source and build on your own.
    - However, the course example will provide in-house pre-built binaries.

- **In your code,**
  - #include “GL/glfw3.h”
  - #pragma comment(lib, “glfw3.lib") // or glfw3dll.lib for dynamic lib
  - copy “glfw3.dll" to your program binary directory (/bin/)
    - *This is only necessary when you are using dll version*.

GLAD: https://github.com/Dav1dde/glad/

- **GLAD: OpenGL Extension Loader Generator Library**
  - Web service: https://glad.dav1d.de/
  - Makes it easy to access OpenGL extensions
  - Avoids having to have specific entry points in Windows code

- **In your code,**
  - #include “GL/glad.h”
  - embed “glad.c” into your source project for implementation
  - Application needs only to run `gladLoadGL()`
  - That’s it; very simple C library

How to configure OpenGL for Linux

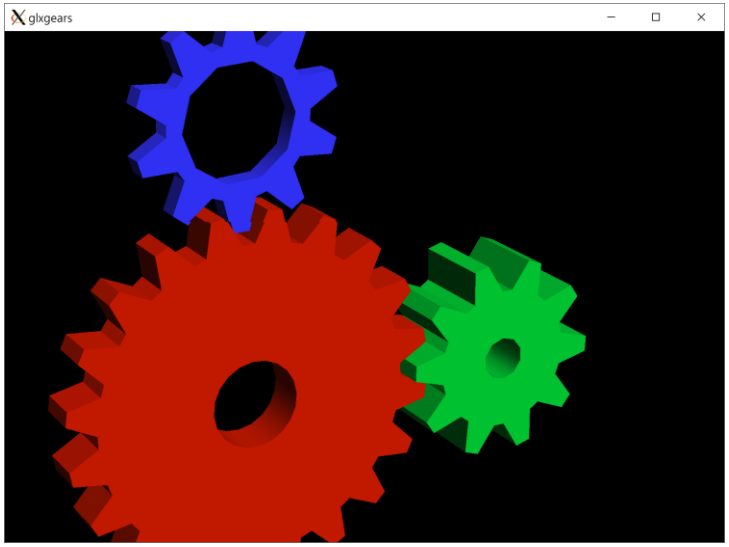
Install MESA and GLFW

- **Install/update essential packages**
  - >> sudo apt-get install –y build-essential
  - >> sudo apt-get update
- **Install the latest MESA via ppa (personal package archive)**
  - >> sudo add-apt-repository ppa:ubuntu-x-swat/updates
  - >> sudo apt-get dist-upgrade
  - >> sudo apt-get install mesa-utils
- **Install GLFW**
  - >> sudo apt-get install libglfw3-dev

Install MESA and GLFW

- **Find GL version and test glxgears**
  - >> glxinfo | grep version
  - >> glxgears

- **If you find version is 1.4 or similar,**
  - Try this in ~/.bashrc
    - export LIBGL_ALWAYS_INDIRECT=0
    - this bypasses X's handling of OpenGL



Makefile

- **Most of the source files are distributed with makefile.**
  - You can simply copy the source code directories to your Linux env.

- **Simply run 'make'**
  - >> cd ~/gl-01-hello/src/
  - >> make
  - >> ../bin/hello.out

- **You can find the resulting executable in /bin/**

Putting it all together: Hello OpenGL (cgconf)

Example

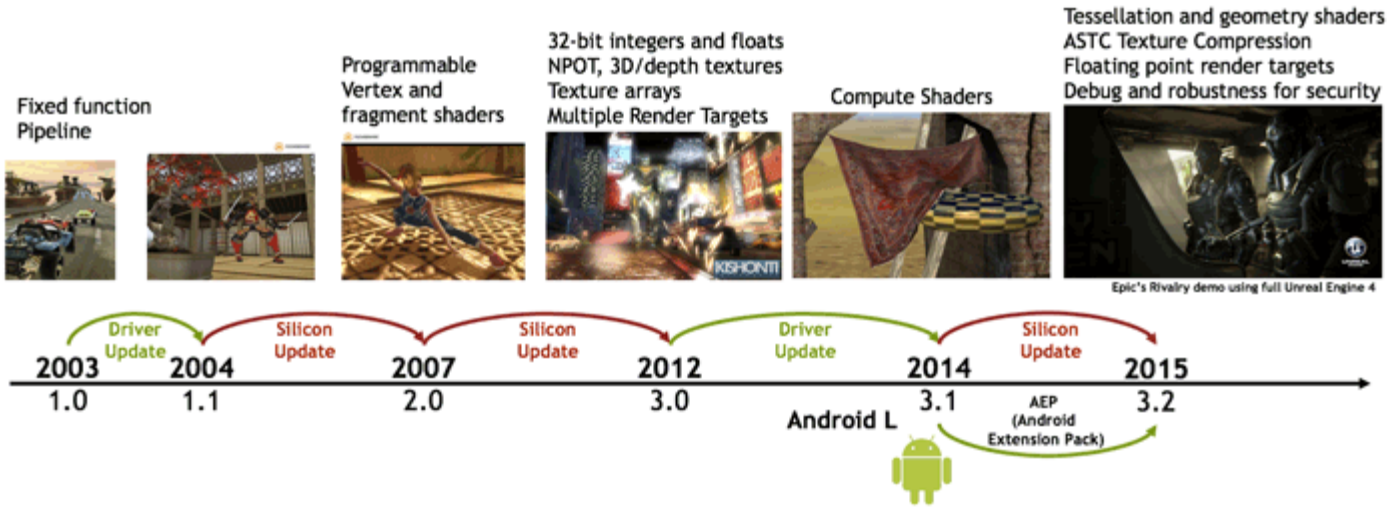
```c
#include "gl/glad/glad.h"   // https://github.com/Dav1dde/glad
#define GLFW_INCLUDE_NONE
#include "gl/glfw/glfw3.h"  // http://www.glfw.org
#include <stdio.h>

int main()
{
    printf( "Hello OpenGL!\n\n" );

    // initialization
    if(!glfwInit()){ printf( "[error] failed in glfwInit()\n" ); return 1; }

    // create invisible window for OpenGL context
    glfwWindowHint( GLFW_VISIBLE, GL_FALSE );
    glfwWindowHint( GLFW_CONTEXT_VERSION_MAJOR, 3 );                    // minimum requirement for modern OpenGL (3)
    glfwWindowHint( GLFW_CONTEXT_VERSION_MINOR, 3 );                    // minimum requirement for modern OpenGL (3.3)
    glfwWindowHint( GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE );              // core profile (>=3.3) allow only forward-compatible profile
    glfwWindowHint( GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE );    // create core profile; all legacy deprecated
    GLFWwindow* window = glfwCreateWindow( 100, 100, "cgconf - Hello OpenGL", nullptr, nullptr );
    if(!window){ printf( "Failed to create GLFW window.\n" ); glfwTerminate(); return 1; }

    // make the current context and load GL extensions
    glfwMakeContextCurrent(window);
    if(!gladLoadGL()){ printf( "Failed in gladLoadGLLoader()\n" ); glfwTerminate(); return 1; }

    // check renderer and vendor
    printf( "You are using\n" );
    printf( " - OpenGL %s\n", glGetString(GL_VERSION) );
    printf( " - OpenGL Shading Language %s\n", glGetString(GL_SHADING_LANGUAGE_VERSION) );
    printf( " - GPU: %s\n", glGetString(GL_RENDERER) );
    printf( " - Vendor: %s\n", glGetString(GL_VENDOR) );

    glfwDestroyWindow(window);
    glfwTerminate();

    return 0;
}
```

Advanced:
OpenGL ES and Other APIs

OpenGL ES

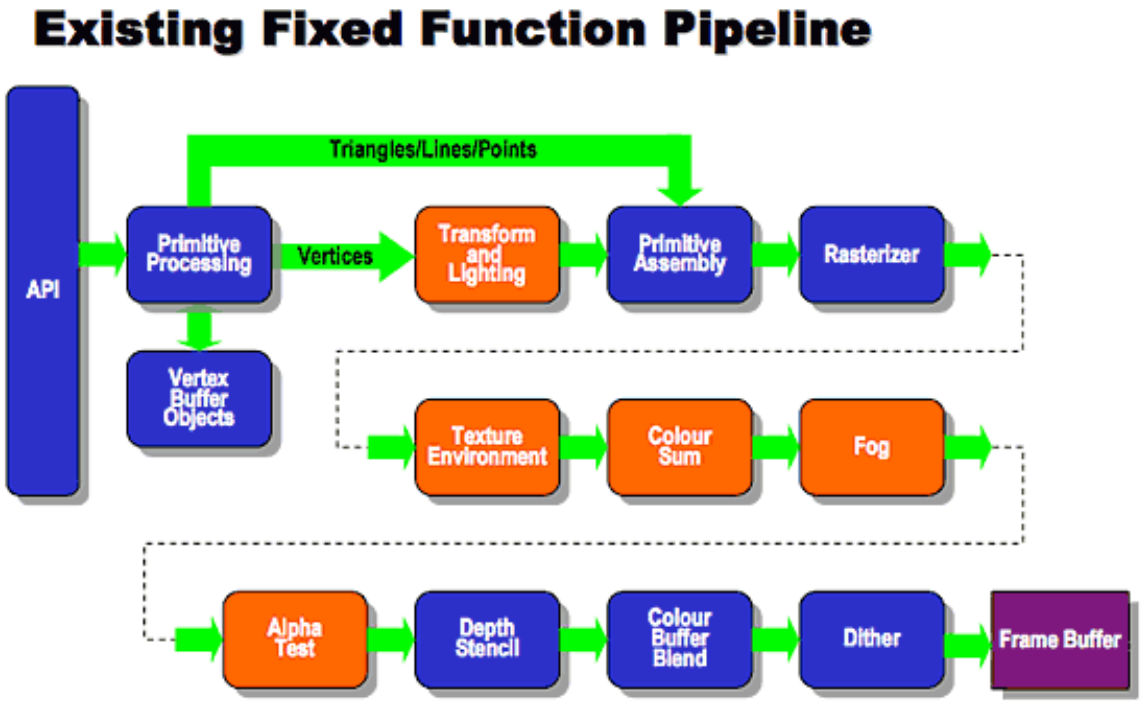
- **OpenGL ES (Embedded Systems)**
  - Well-defined subsets of desktop OpenGL, essential in mobile applications.
  - Includes profiles for floating-point and fixed-point systems and EGL.

- **Roadmap for OpenGL ES**



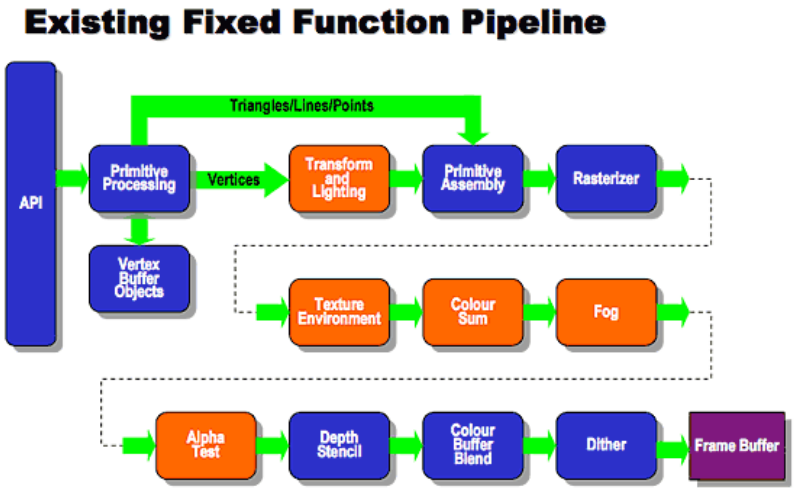
OpenGL ES 1.x

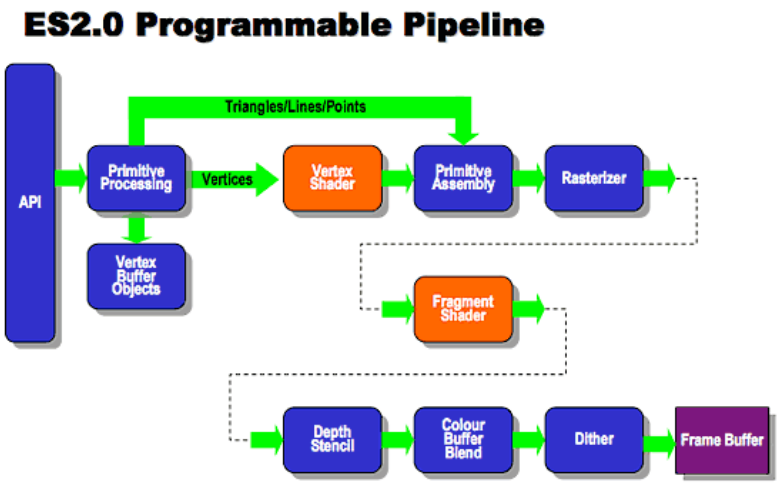
- **OpenGL ES 1.x**
  - Defined for fixed-function hardware, but now deprecated in later versions.
  - OpenGL ES 1.0 is derived from OpenGL 1.3 (old style GL)
  - OpenGL ES 1.1 is derived from OpenGL 1.5 (old style GL)



OpenGL ES 2.0

- **OpenGL ES 2**
  - Defined relative to OpenGL 2.0 (old style but near to modern style)
  - Programmable pipeline with vertex/fragment shaders.
  - Does not support fixed-function transformation and fragment pipeline of OpenGL ES 1.x





OpenGL ES 2.0

- **OpenGL ES Shading Language 1.0 (ESSL 1.0, 2009)**
  - Adds the same shading language used in OpenGL 2.0 but adapted for embedded platforms.
  - Precision qualifier should be specified in the shader program.

- **Minimum precisions required in any platforms**
  - Vertex shader: 16-bit precision (in range $[-2^{62},+2^{62}]$ for fp)
  - Fragment shader: 10-bit precision (in range $[-2^{14},+2^{14}]$ for fp)

OpenGL ES 2.0

- **Precision Qualifiers**
  - *highp*, *mediump*, *lowp*
  - range/precision:

Qualifier	Floating Point Range	Floating Point Magnitude Range	Floating Point Precision	Integer Range
highp	$(-2^{62}, 2^{62})$	$(2^{-62}, 2^{62})$	Relative: 2^{-16}	$(-2^{16}, 2^{16})$
mediump	$(-2^{14}, 2^{14})$	$(2^{-14}, 2^{14})$	Relative: 2^{-10}	$(-2^{10}, 2^{10})$
lowp	$(-2, 2)$	$(2^{-8}, 2)$	Absolute: 2^{-8}	$(-2^{8}, 2^{8})$

OpenGL ES 3.x

- **OpenGL ES 3.x is fully compatible with OpenGL 4.3**

- **OpenGL ES 3.0**
  - Multiple render targets
  - Occlusion queries, transform feedback, instanced rendering
  - ETC2/EA texture compression
  - A new ESSL with 32-bit integers and floats
  - Textures: NPOT, floating-point, 3D, 2D array
  - Swizzle, LOD, mip level clamps, seamless cube maps, and sampler objects

OpenGL ES 3.x

- **OpenGL ES 3.1**
  - Computer shaders
  - Indirect draw commands

- **OpenGL ES 3.2**
  - Geometry and tessellation shaders
  - Floating-point render targets
  - ASTC (adaptive scalable texture compression)
  - Enhanced blending and handling of multiple color attachments
  - Advanced texture targets: texture buffers, multisample 2D array, cubemap arrays
  - Debug and robustness for security

- **EGL (Khronos Native Platform Graphics Interface)**
  - Interface specification between Khronos rendering APIs (e.g., OpenGL and OpenGL ES) and the underlying native windowing platform.
  - Handles graphics context management, surface/buffer binding, rendering synchronization, and mixed-mode 2D and 3D rendering.
  - Prior to EGL 1.2, it was OpenGL ES Native Platform Graphics Interface.

- **Similar interfaces**
  - WGL: for windows
  - CGL (Core OpenGL): for OS X
  - GLX: for X11
  - WSI (Window System Interface) : for Vulkan

Other APIs

- **WebGL**
  - Javascript implementation of OpenGL ES 2.0
  - Supported on most modern browsers (e.g., Chrome, FireFox, Safari, Opera)

- **Vulkan**
  - The next-generation graphics API: the successor of OpenGL 4
  - Designed for high-performance graphics and computing with less driver overhead
  - Useful for low-level graphics developers