Announcement

- Self attendance check!
- OpenGL skeleton code is uploaded
  - Course Materials
- Assignment 1 is uploaded
  - Assignments and Tests

COSE436

Lecture 5: OpenGL Basics

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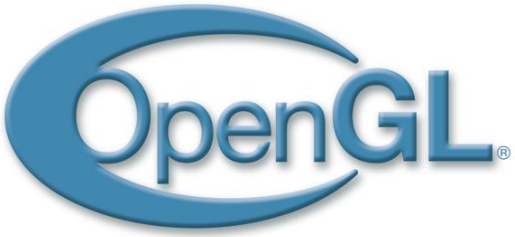
KOREA UNIVERSITY

Outline

- OpenGL History
- How to create OpenGL application
- How to set up OpenGL camera
- How to pass the data to the GPU
- How to display onto screen
- How to make realistic 3D rendering

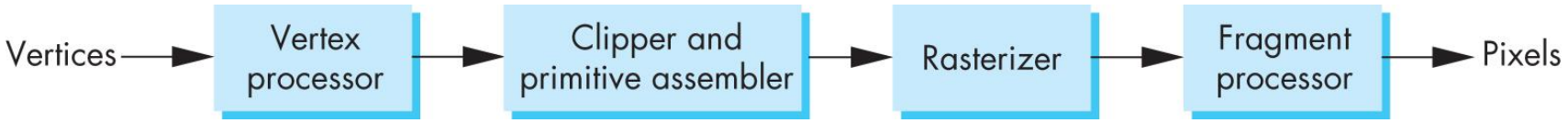
OpenGL

- OpenGL is a platform-independent API for graphics, first introduced in 1992
  - Interface for graphics hardware
- OpenGL is concerned only with rendering into a framebuffer and reading values in it
  - Easy to use
  - Platform independent
  - User interface is omitted
  - Windows system independent



Modern OpenGL

- Performance is achieved by using GPU rather than CPU
- Control GPU through programs called shaders
- Application's job is to send data to GPU
- GPU does all rendering



OpenGL Evolution

- OpenGL 1.x : fixed pipeline
- OpenGL 2.x : programmable pipeline
- OpenGL 3.x : deprecated APIs
- The latest version is 4.6
- Most of fixed stages and global state model are removed
  - Still available through GL_ARB_compatibility extension

Other GL Versions

- OpenGL ES
  - Embedded systems (Android, iPad,…)
  - Version 1.0 simplified OpenGL 2.1
  - Version 2.0 simplified OpenGL 3.1
    - Shader based
  - Version 3.0 simplified OpenGL 4.3
- WebGL
  - Javascript implementation of OpenGL ES
  - Supported on newer browsers

GLUT

- OpenGL Utility Toolkit (GLUT)
  - Platform-independent window management library
    - Create a GL window
    - Get input from mouse and keyboard
    - Menus
- freeglut adds new functionalities to original GLUT

GLEW

- OpenGL Extension Wrangler Library
- Makes it easy to access OpenGL extensions available on a particular system
- Avoids having to have specific entry points in Windows code
- Application needs only to include glew.h and run a glewInit()

```
Download: http://glew.sourceforge.net
```

Software Organization

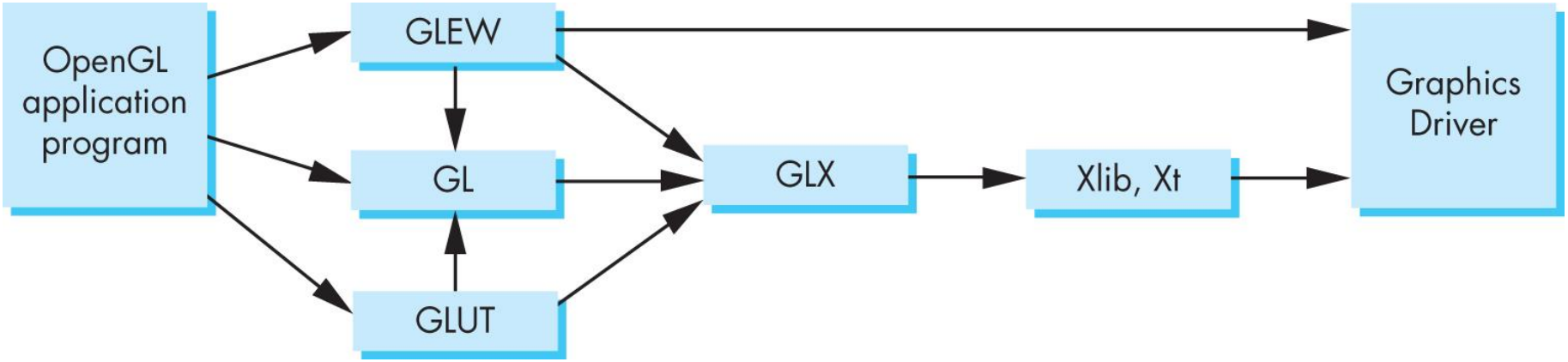


Image Courtesy of Angel

OpenGL is a Client-Server Model

- Host process (CPU)
  - Client
  - Send commands and data to server
  - Interconnect: PCIe
- Graphics hardware (GPU)
  - Server
  - Performs functions directed by the client

OpenGL Elements

- States
  - Snapshot of global parameters
  - GL context
- Primitives
  - Group of vertices
- Commands
  - Execution of graphics functions

Start with Skeleton Code

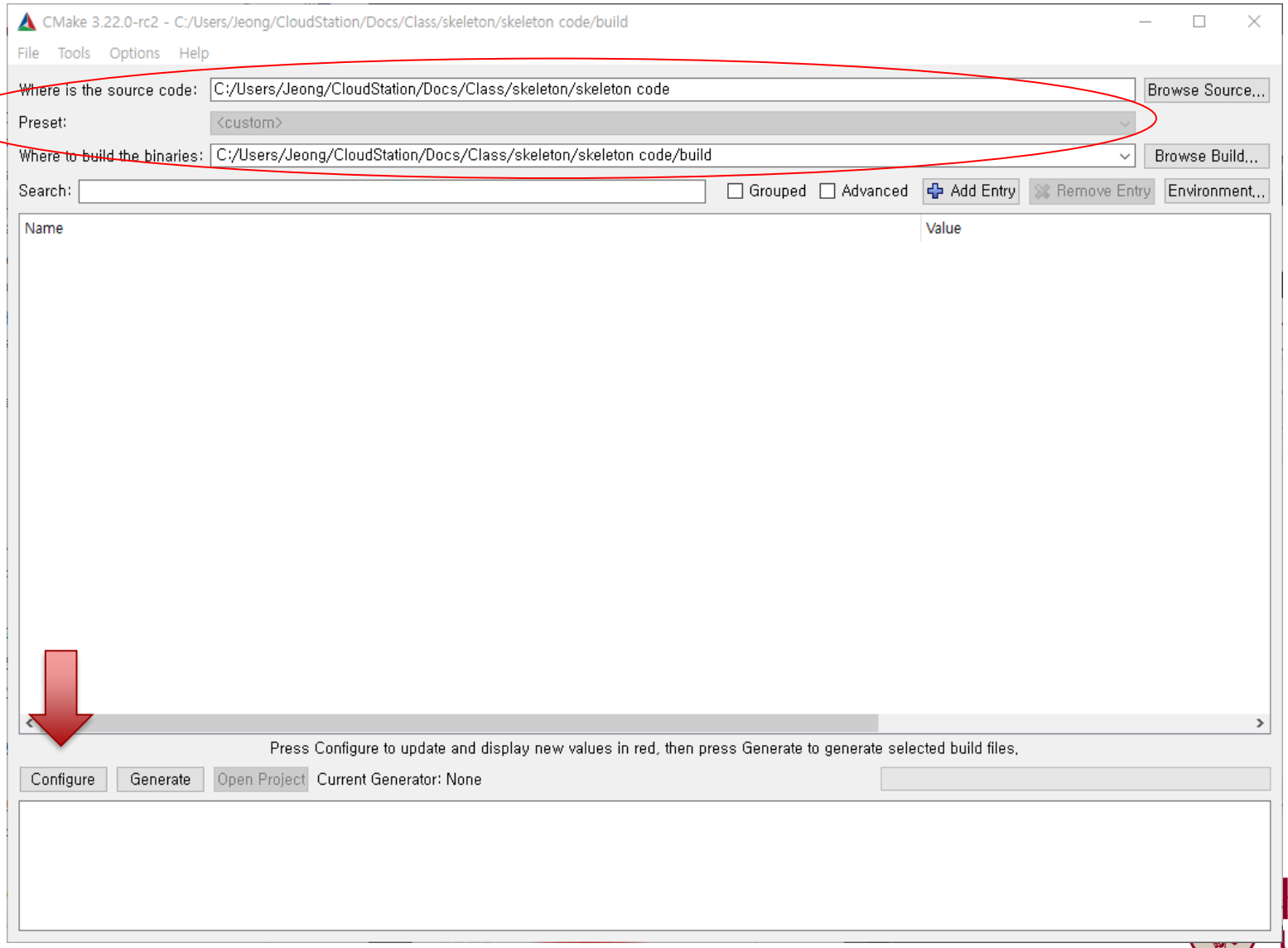
- MS Visual Studio 2022 (community ver.)
  - https://visualstudio.microsoft.com/ko/
  - Visual Studio Download-> Select "community 2022"
- Download from blackboard
  - glew
  - CMake
  - OpenGL Skeleton Code

Check OpenGL Version

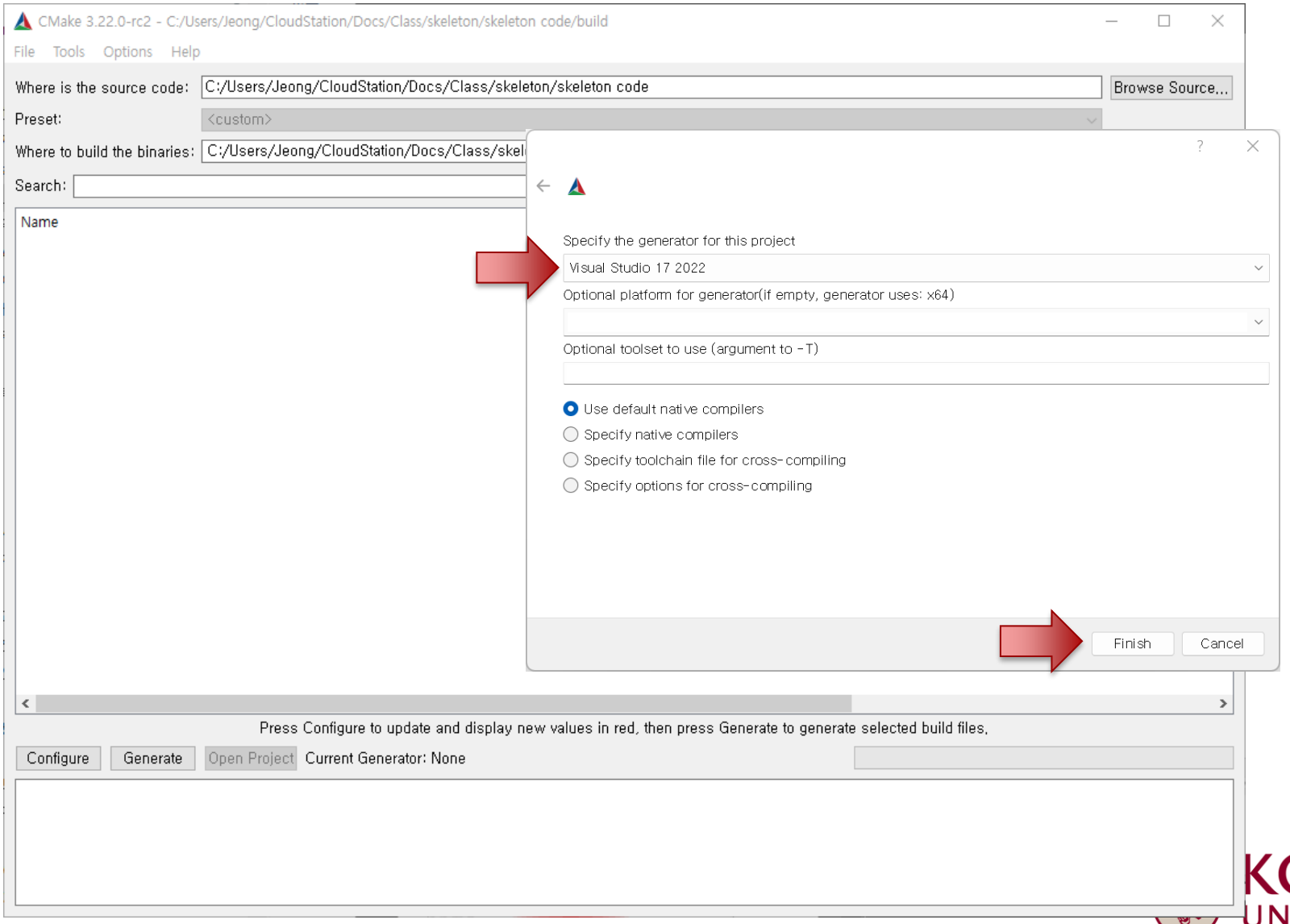
- glewinfo

```
--------------------------
    GLEW Extension Info
--------------------------

GLEW version 2.1.0
Reporting capabilities of pixelformat 3
Running on a Intel(R) HD Graphics 620 from Intel
OpenGL version 4.4.0 - Build 21.20.16.4550 is supported

GL_VERSION_1_1:                                                 OK
---------------

GL_VERSION_1_2:                                                 OK
---------------
  glCopyTexSubImage3D:                                          OK
  glDrawRangeElements:                                          OK
  glTexImage3D:                                                 OK
  glTexSubImage3D:                                              OK

GL_VERSION_1_2_1:                                               OK
-----------------

GL_VERSION_1_3:                                                 OK
---------------
  glActiveTexture:                                              OK
  glClientActiveTexture:                                        OK
  glCompressedTexImage1D:                                       OK
  glCompressedTexImage2D:                                       OK
```

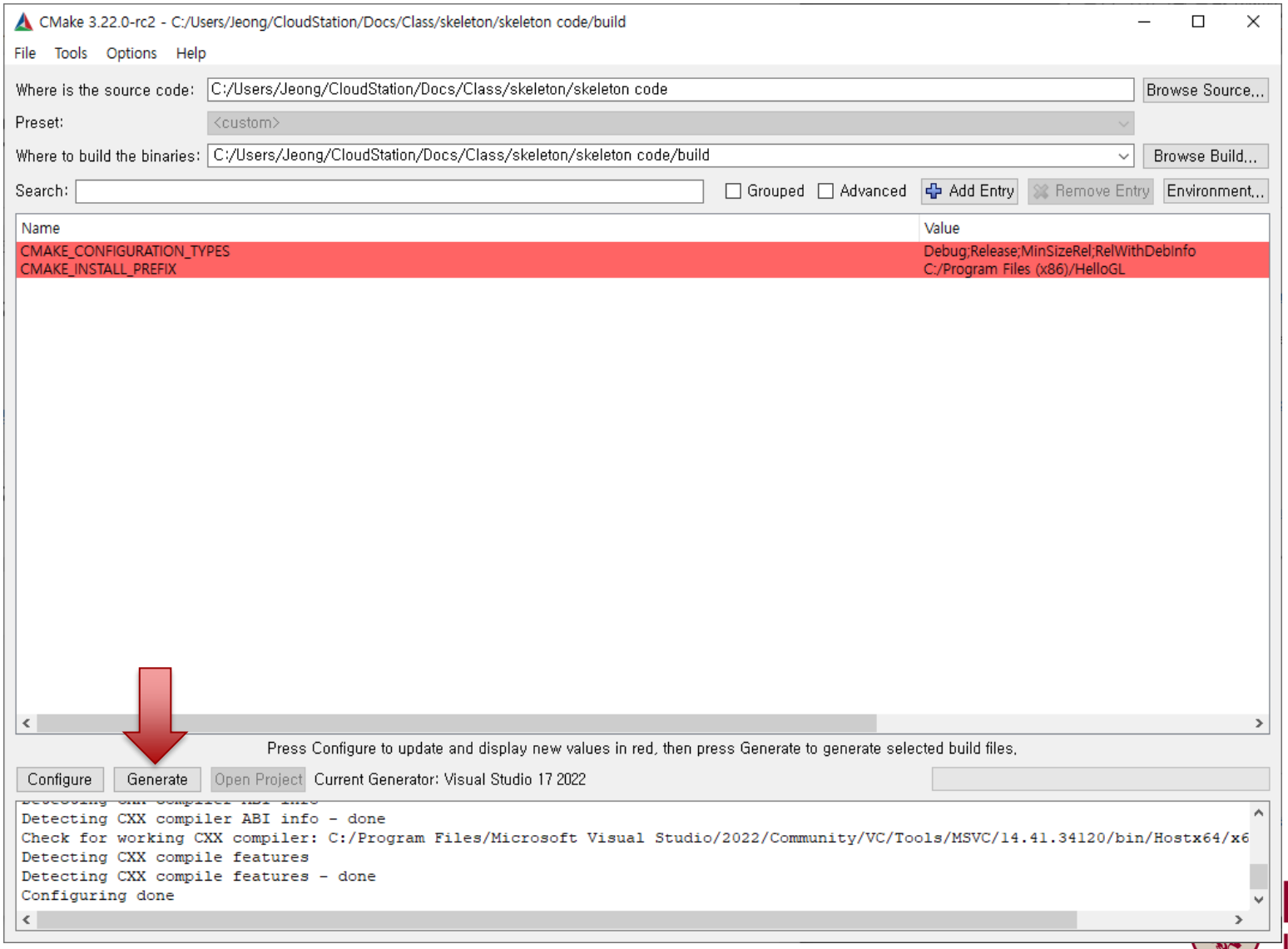
Run CMake to Create VS Project



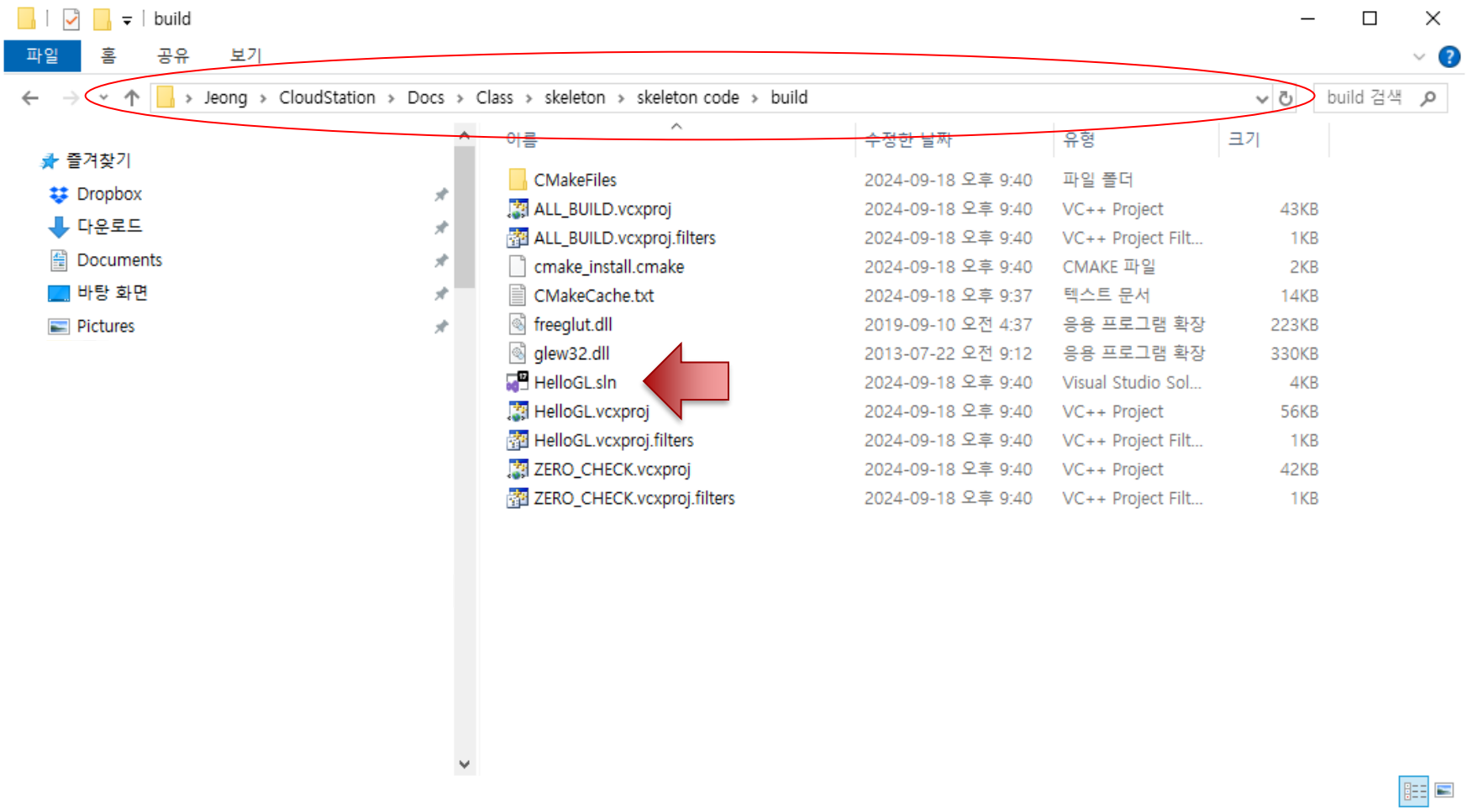
Run CMake to Create VS Project

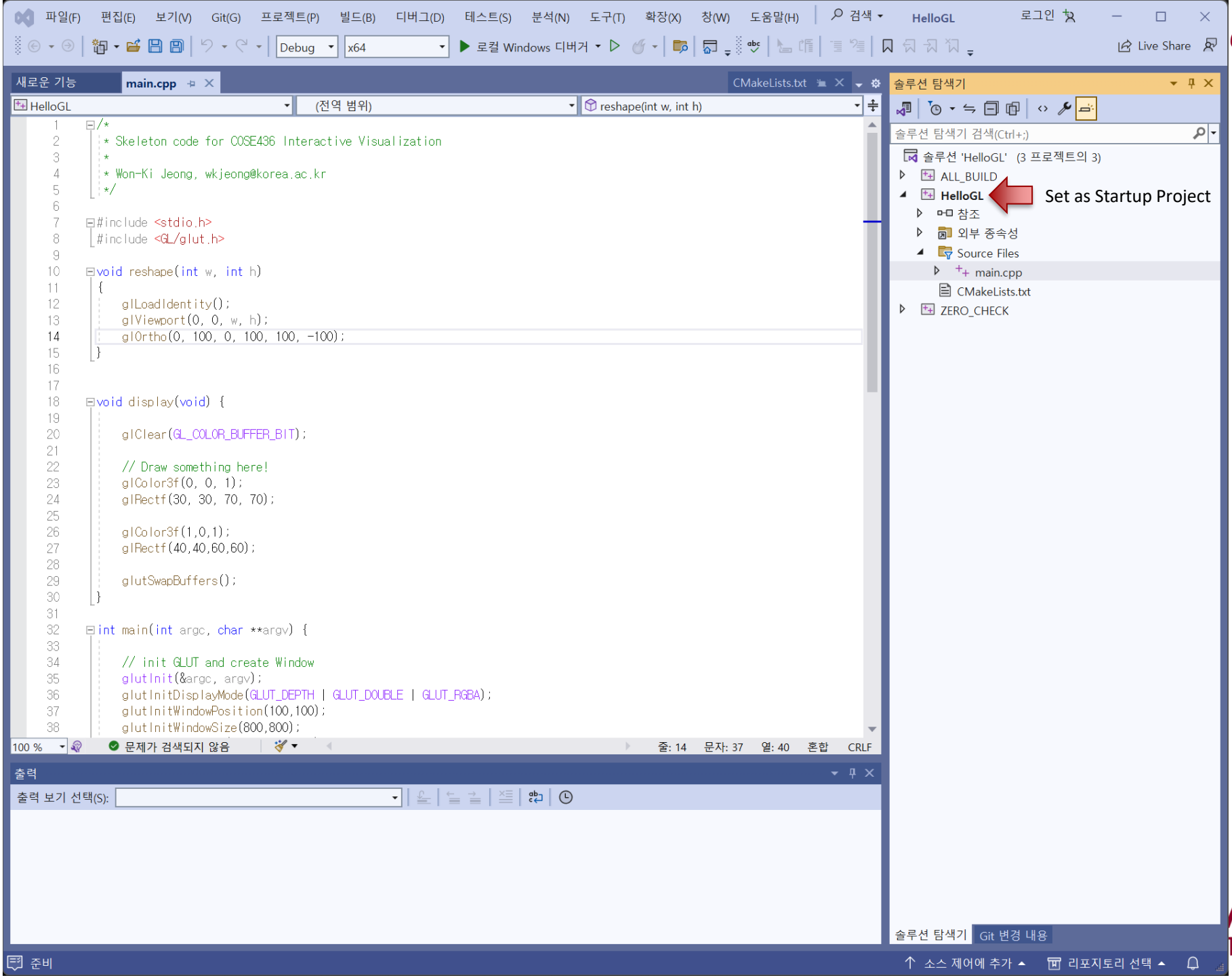


Run CMake to Create VS Project



Location of .sln File




파일(F) 편집(E) 보기(V) Git(G) 프로젝트(P) 빌드(B) 디버그(D) 테스트(S) 분석(N) 도구(T) 확장(X) 창(W) 도움말(H)
검색
HelloGL
로그인
Debug
x64
로컬 Windows 디버거
Live Share
새로운 기능
main.cpp
CMakeLists.txt
HelloGL
(전역 범위)
reshape(int w, int h)
/*
* Skeleton code for COSE436 Interactive Visualization
*
* Won-Ki Jeong, wkjeong@korea.ac.kr
*/
#include <stdio.h>
#include <GL/glut.h>
void reshape(int w, int h)
{
glLoadIdentity();
glViewport(0, 0, w, h);
glOrtho(0, 100, 0, 100, 100, -100);
}
void display(void) {
glClear(GL_COLOR_BUFFER_BIT);
// Draw something here!
glColor3f(0, 0, 1);
glRectf(30, 30, 70, 70);
glColor3f(1,0,1);
glRectf(40,40,60,60);
glutSwapBuffers();
}
int main(int argc, char **argv) {
// init GLUT and create Window
glutInit(&argc, argv);
glutInitDisplayMode(GLUT_DEPTH | GLUT_DOUBLE | GLUT_RGBA);
glutInitWindowPosition(100,100);
glutInitWindowSize(800,800);
100 %
문제가 검색되지 않음
줄: 14 문자: 37 열: 40 혼합 CRLF
출력
출력 보기 선택(S):
솔루션 탐색기
솔루션 탐색기 검색(Ctrl+;)
솔루션 'HelloGL' (3 프로젝트의 3)
ALL_BUILD
HelloGL
Set as Startup Project
참조
외부 종속성
Source Files
main.cpp
CMakeLists.txt
ZERO_CHECK
솔루션 탐색기
Git 변경 내용
준비
소스 제어에 추가
리포지토리 선택

Hello World GL

- Use GLUT to handle GL windows and event
  - You do not need to use OS specific windows handling APIs
- GLUT is event-driven, callback function is called
  - When your screen is changed
  - When you press a keyboard
  - When you move mouse
  - When you are not doing anything

Create GL Window using GLUT

- Main window management and registering callback functions

```
int main(int argc, char** argv)
{
   glutInit(&argc, argv);
   glutInitDisplayMode (GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
   glutInitWindowSize (250, 250);
   glutInitWindowPosition (100, 100);
   glutCreateWindow (argv[0]);
   glutReshapeFunc(reshape);       // reshape callback
   glutDisplayFunc(display);       // display callback
   glutKeyboardFunc(keyboard);     // keyboard callback
   glutMouseFunc(mouse);           // Mouse callback
   glutMainLoop();
   return 0;
}
```

GLUT Functions

- **`glutInit`** allows application to get command line arguments and initializes system
- **`gluInitDisplayMode`** requests properties for the window (the *rendering context*)
  - RGB color
  - Double buffering
  - Use depth buffer
- **`glutWindowSize`** window size in pixels
- **`glutWindowPosition`** top-left corner position of display
- **`glutCreateWindow`** create window with title
- **`glutDisplayFunc`** display callback
- **`glutMainLoop`** enter infinite event loop

Adapted from Angel

GLUT Callback Example

- glutKeyboardFunc(void(*f)(key, x, y)

```
void keyboard(unsigned char key, int x, int y)
{
    switch(key)
    {
        case 'Q' :
        case 'q' :
        case 27 : // ESC
            exit(0);
            break;
    }
}
```

Example: Hello World GL

```
#include <glut.h>

void reshape(int w, int h)
{
  glLoadIdentity();
  glViewport(0,0,w,h);
  glOrtho(0, 100, 0 ,100 , 100, -100);
}

void display(void)
{
  glClear(GL_COLOR_BUFFER_BIT);
  glColor3f(0,0,1);
  glRectf(30,30,70,70);
  glColor3f(1,0,1);
  glRectf(40,40,60,60);
  glutSwapBuffers();
}

int main(int argc, char** argv)
{
  glutInit(&argc, argv);
  glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB);
  glutCreateWindow("Hello World");
  glutReshapeFunc(reshape);
  glutDisplayFunc(display);
  glutMainLoop();

  return 0;
}
```

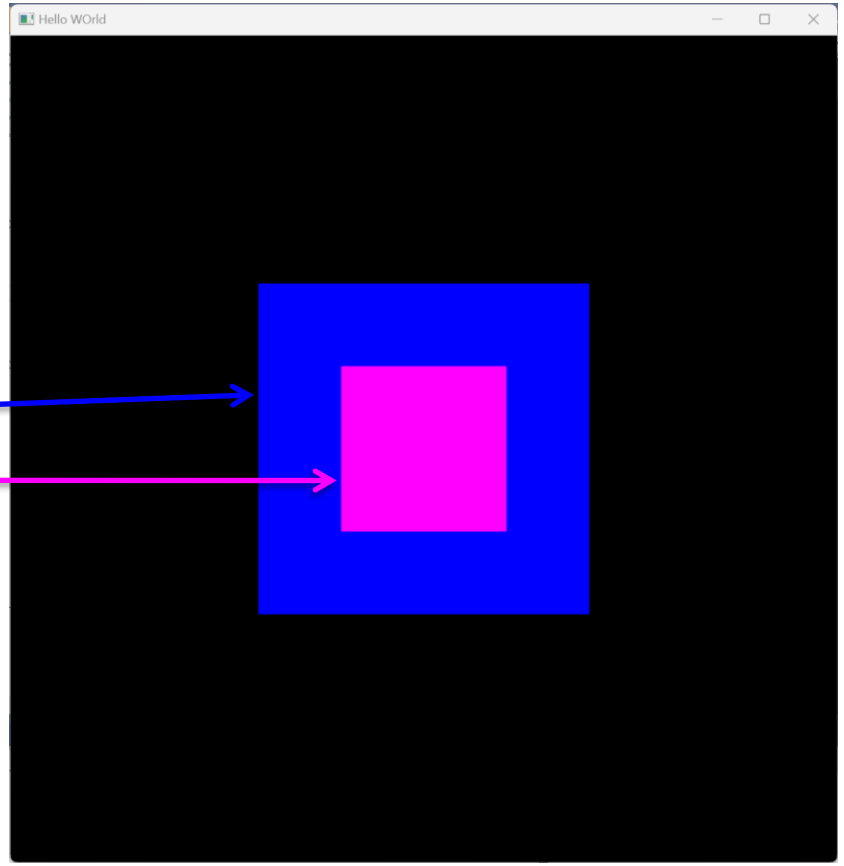
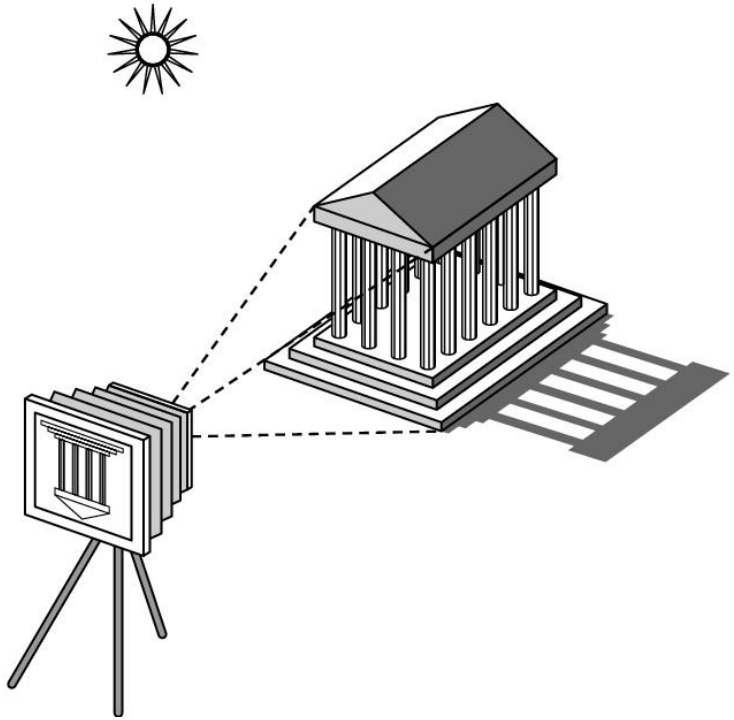


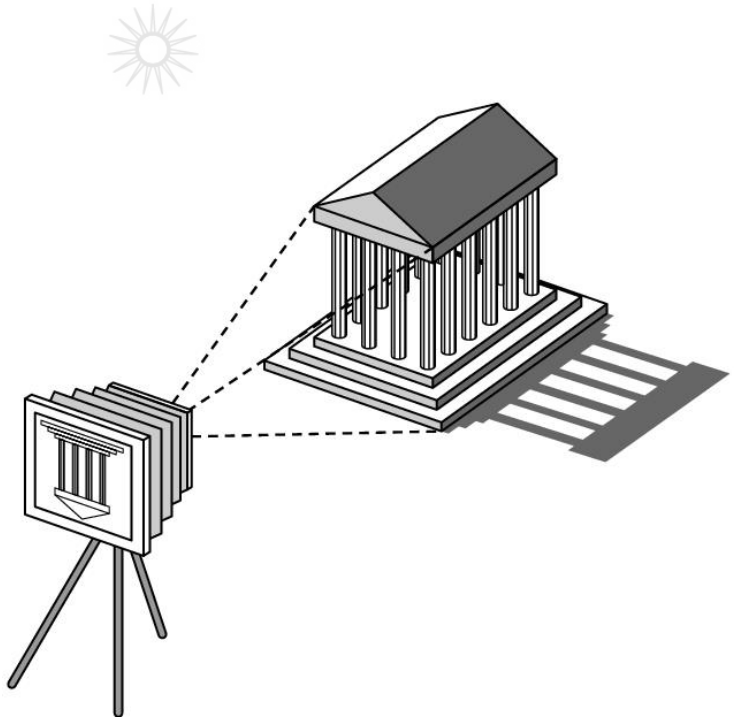
Image Formation

- Object
- Viewer
- Light sources



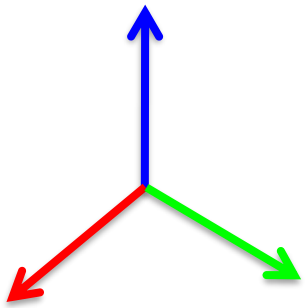
Today: Image Formation in GL

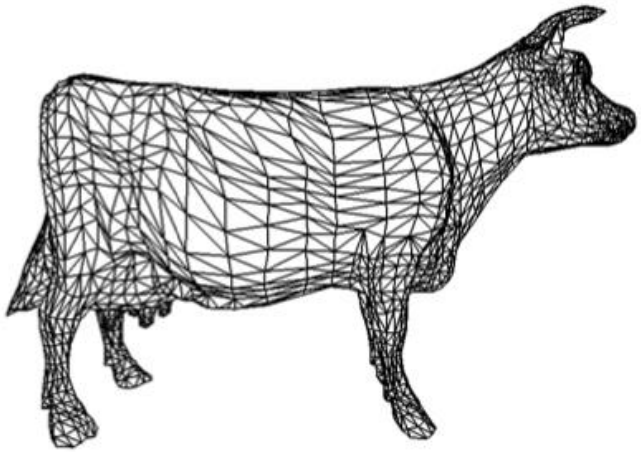
- Object
- Viewer
- Light sources



Object in OpenGL

- How to place objects in 3D space?
  - Represent object as 3D polygons
  - Assign coordinate per vertex





Handling GL Data

- Immediate mode
  - Transfer data when rendering
  - Copy from CPU to GPU per render call
  - Expensive for large datasets

- Buffer objects
  - Data reside in GPU memory
  - Fast and flexible

Vertex Array

- Use array as vertex attributes
- Single GL draw command
- Stored in client's memory space
- Transfer data from client to host for rendering
  - Immediate mode

```
GLfloat vertices[] = {...};
...
glEnableClientState(GL_VERTEX_ARRAY);
glVertexPointer(3,GL_FLOAT,0,vertices);

glDrawArrays(GL_TRIANGLES, 0, n);

glDisableClientState(GL_VERTEX_ARRAY);
```

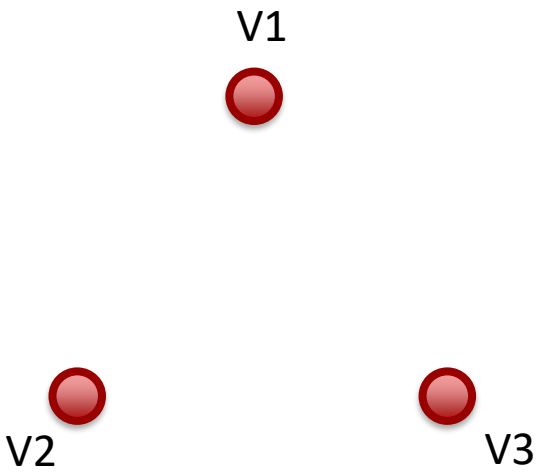
Primitives

- From vertices to 3D objects
- How to tessellate (connect) vertices
- Point, Line, Polygon, 3D shapes

```
glDrawArrays(GL_TRIANGLES, 0, n);
```

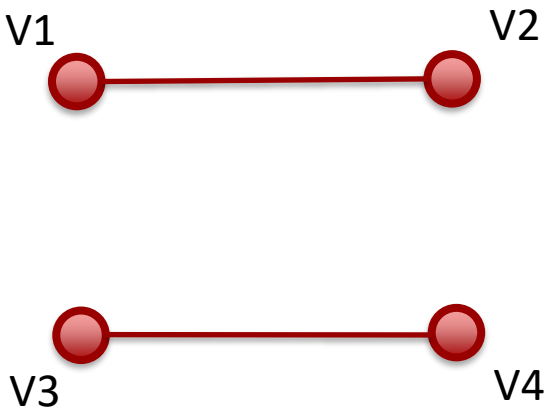
Point

- GL_POINTS



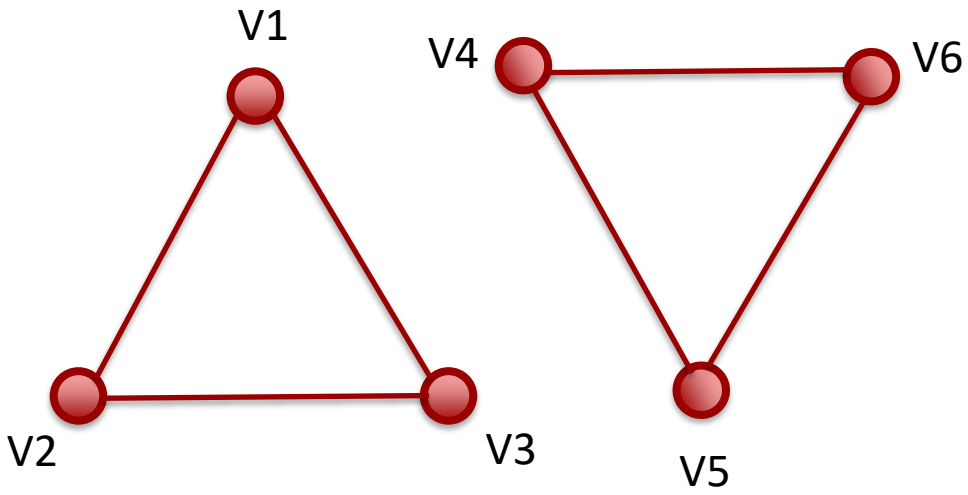
Line

- GL_LINES
  - Group every two vertices for a line segment



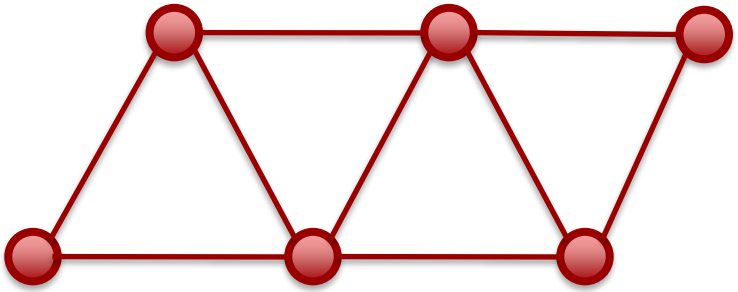
Triangle

- GL_TRIANGLES
  - Group every three vertices for a triangle

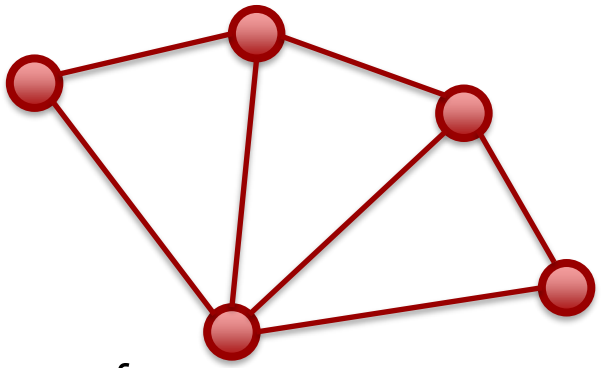


Other Primitives

- GL_LINE_STRIP, GL_LINE_LOOP
- GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN
- GL_QUADS, GL_QUAD_STRIP
- GL_POLYGON



strip



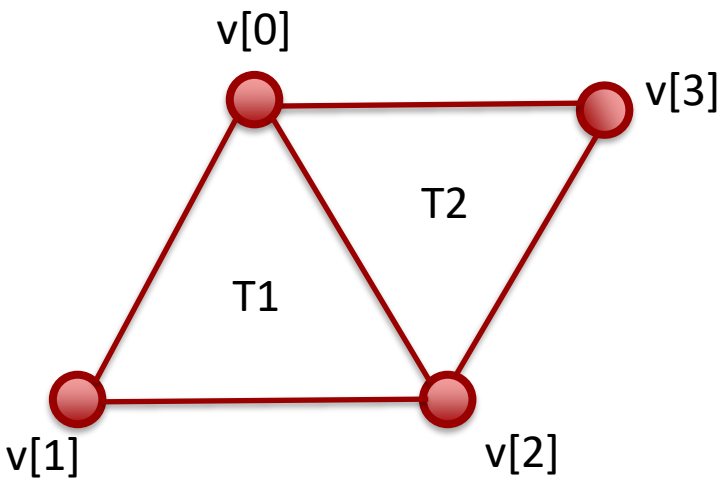
fan

Handling Vertex Attributes

```
// two coords (x,y) per 2D vertex
float coords[6] = { 25,25, 75,50, 50,75 };

// three RGB values per vertex
float colors[9] = { 1,0,0,  0,1,0,  0,0,1 };

// Set data type and location
glVertexPointer( 2, GL_FLOAT, 0, coords );
glColorPointer( 3, GL_FLOAT, 0, colors );

// Enable arrays
glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );

// Draw triangle using 3 vertices, start with vertex 0
glDrawArrays( GL_TRIANGLES, 0, 3 );
```

Handling Redundant Vertices

- Use index array




```
// Coords for 3D vertices
float v[] = { 1.0,1.0,1.0,
              2.0,4.0,1.0,
              3.0,1.0,1.0,
              4.0,4.0,1.0 };

// Two triangles (T1, T2)
int idx = { 0,1,2, 0,2,3 };
```

Handling Vertex Index

```
// Cube example
// 8 vertices (3 coords/colors per vertex)
// 6 faces (4 indices per face)
float vertexCoords[24] = { ... };
float vertexColors[24] = { ... };
int indexArray[24] = { ... };

glVertexPointer( 3, GL_FLOAT, 0, vertexCoords );
glColorPointer( 3, GL_FLOAT, 0, vertexColors );

glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );

glDrawElements( GL_QUADS, 24, GL_UNSIGNED_INT, indexArray );
```

Vertex/Index Buffer Object (VBO/IBO)

- Store vertices in server's memory space
- No transfer between client to server for rendering
- Most efficient method

Vertex Buffer Object

- Create buffer, bind buffer, copy data

```
float vertices[] = {....};  // n vertices
Gluint buffer;
glGenBuffers(1, &buffer);
glBindBuffer(GL_ARRAY_BUFFER, buffer);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices,
             GL_STATIC_DRAW);

glEnableClientState(GL_VERTEX_ARRAY);
glVertexPointer(3, GL_FLOAT, 0, 0);

glDrawArrays(GL_TRIANGLES, 0, n);
```

use currently bound buffer

# of vertices to draw

Index Buffer Object

- Create buffer, bind buffer, copy data

```
GLuint indices[] = {....};  // indices for n vertices
Gluint ibo;
glGenBuffers(1, &ibo);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, ibo);
glBufferData(GL_ ELEMENT_ARRAY_BUFFER, sizeof(indices),
             indices,GL_STATIC_DRAW);

glDrawElements(GL_TRIANGLES, n, GL_UNSIGNED_INT, 0 );
```

Pre-defined 3D Shapes

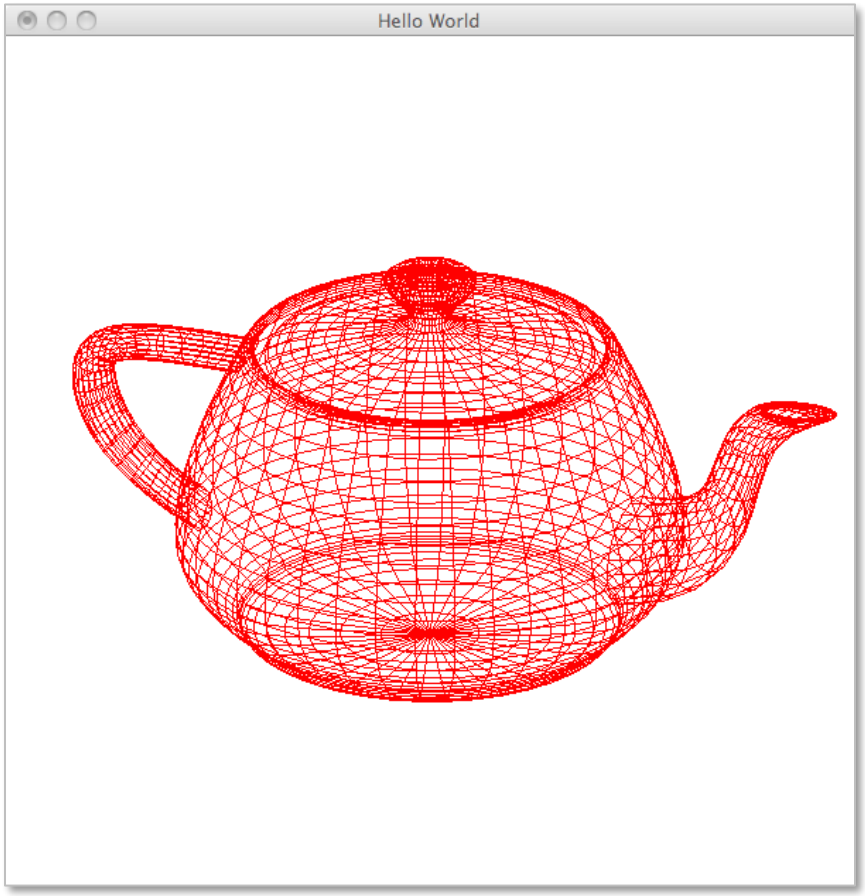
- glut functions (solid, wire)
  - glut***Cube
  - glut***Tetrahedron
  - glut***Icosahedron
  - glut***Sphere
  - glut***Torus
  - glut***Cone
  - glut***Teapot

glPolygonMode(face,mode)

- Polygon rasterization mode
- face
  - GL_FRONT
  - GL_BACK
  - GL_FRONT_AND_BACK
- mode
  - GL_POINT
  - GL_LINE
  - GL_FILL

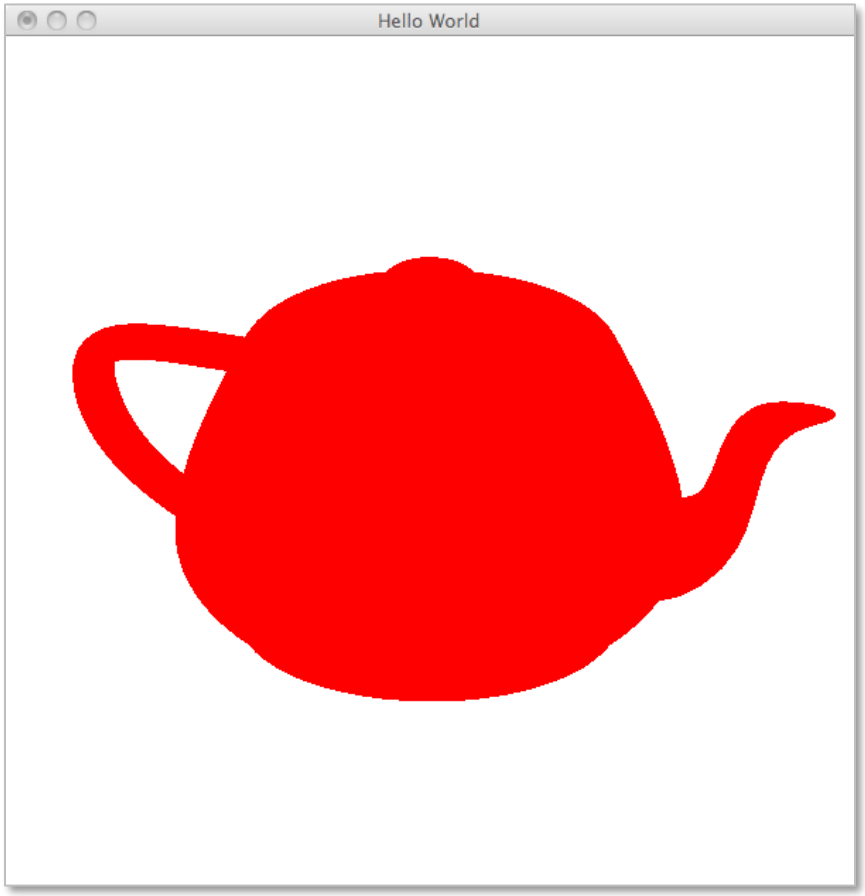
Wireframe Rendering

- glPolygonMode(GL_FRONT_AND_BACK, GL_LINE)



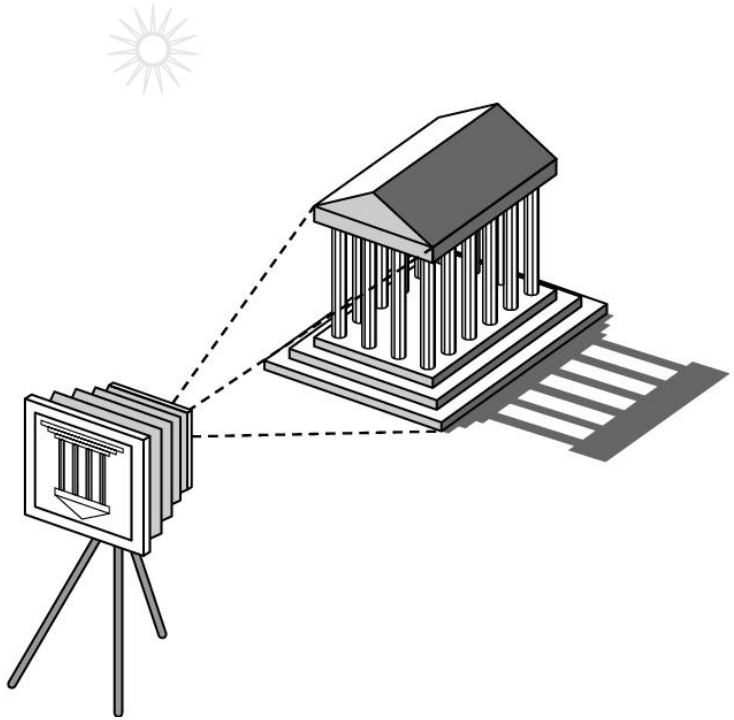
Solid Rendering

- glPolygonMode(GL_FRONT_AND_BACK, GL_FILL)



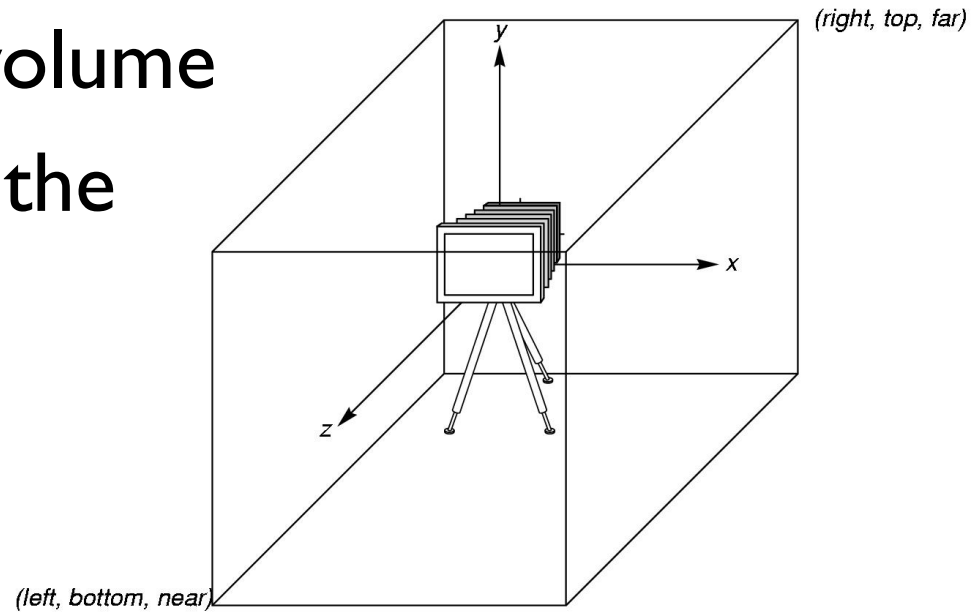
Today: Image Formation in GL

- Object
- Viewer
- Light sources



OpenGL Camera

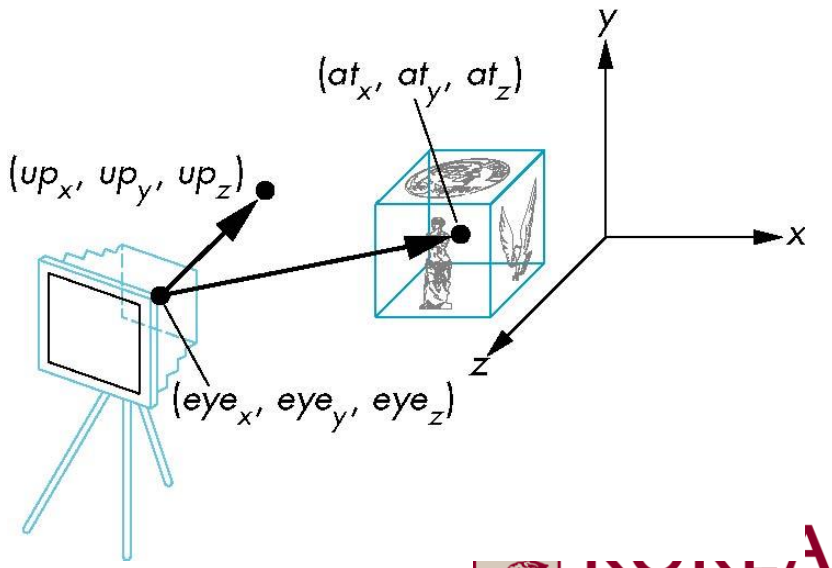
- OpenGL places a camera at the origin in object space pointing in the negative z direction
- The default viewing volume is a box centered at the origin with sides of length 2



Adapted from Angel

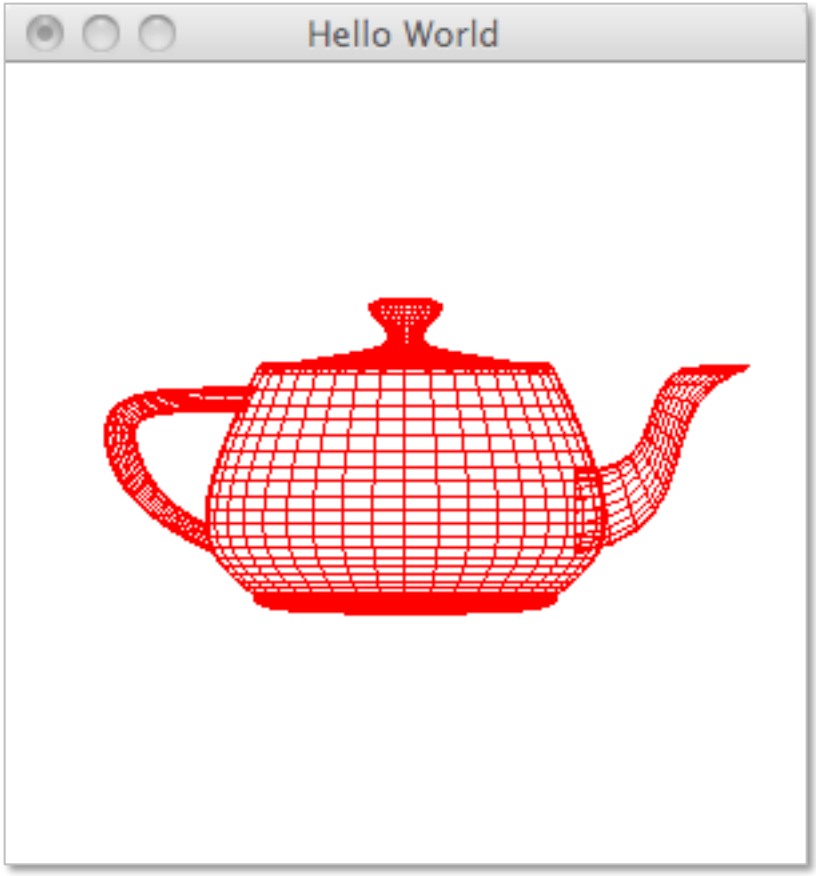
OpenGL Camera Commands

- Orientation
  - `LookAt`
- Field of view
  - `Orthogonal/Perspective Projection`
- Film/CCD
  - `Buffers`



LookAt

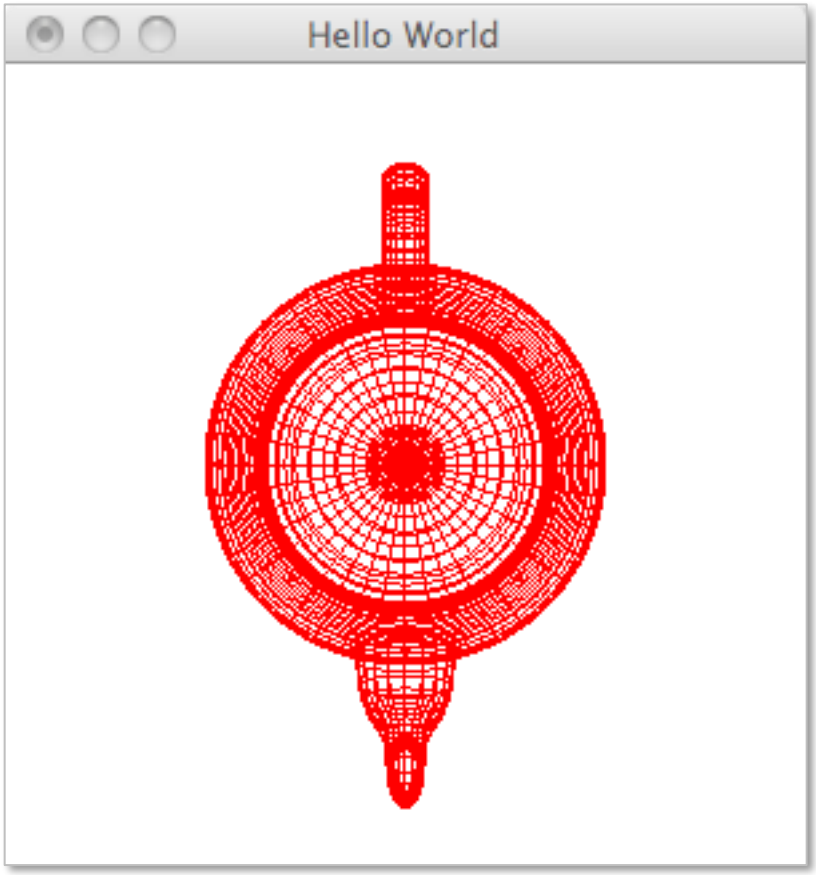
- Eye position, viewing direction, up vector




```
gluLookAt(0,0,100,  0,0,0,  0,1,0);
```

LookAt

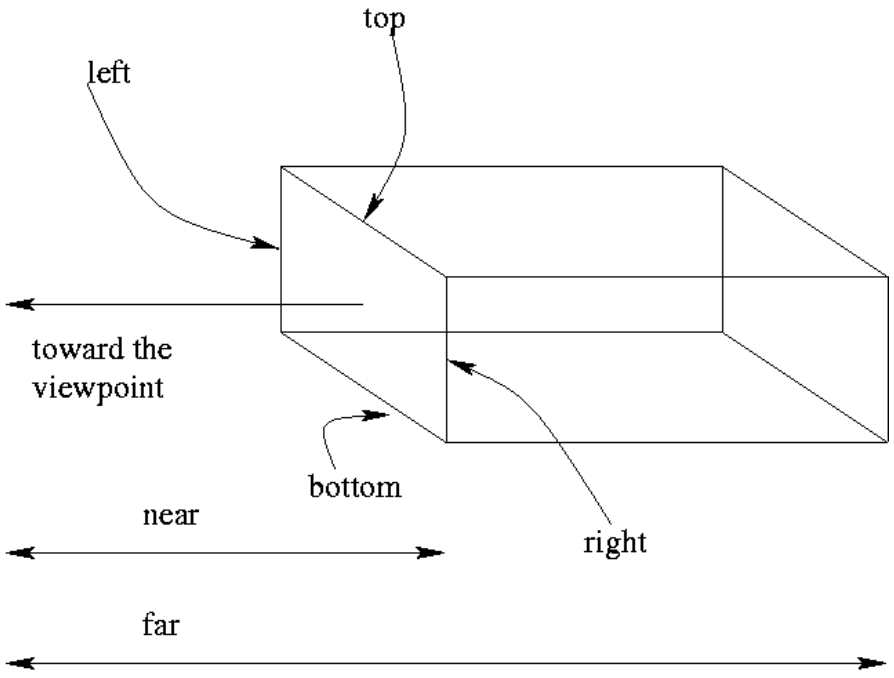
- Eye position, viewing direction, up vector




```
gluLookAt(0,100,0,  0,0,0,  -1,0,0);
```

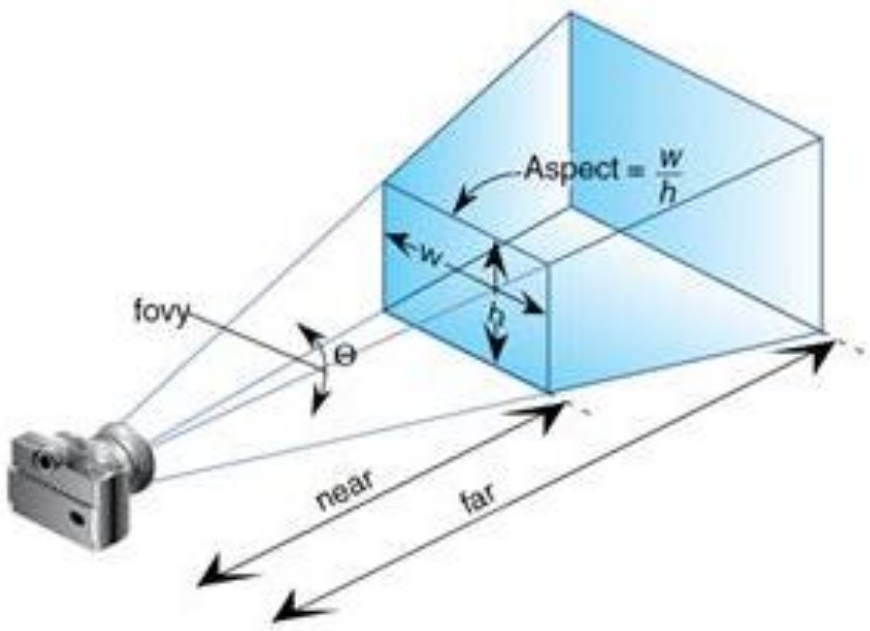
Orthogonal Projection

- left, right, bottom, top, near, far



Perspective Projection

- fovy, aspect, near, far



OpenGL Framebuffer

- Color buffers
  - Store pixel colors
  - Front, back, left, right, auxiliary
- Depth buffer
  - Store per-pixel depth value
- Stencil buffer
  - Mask for stencil test
- Accumulation buffer
  - Blend pixel values

Clear Buffers

- Set the clearing value for buffer
  - glClearColor, glClearIndex
  - glClearDepth
  - glClearStencil
  - glClearAccum

```
glClearColor(1,1,1,0);
glClear(GL_COLOR_BUFFER_BIT);

glClearDepth(1.0);
glClear(GL_DEPTH_BUFFER_BIT);
```

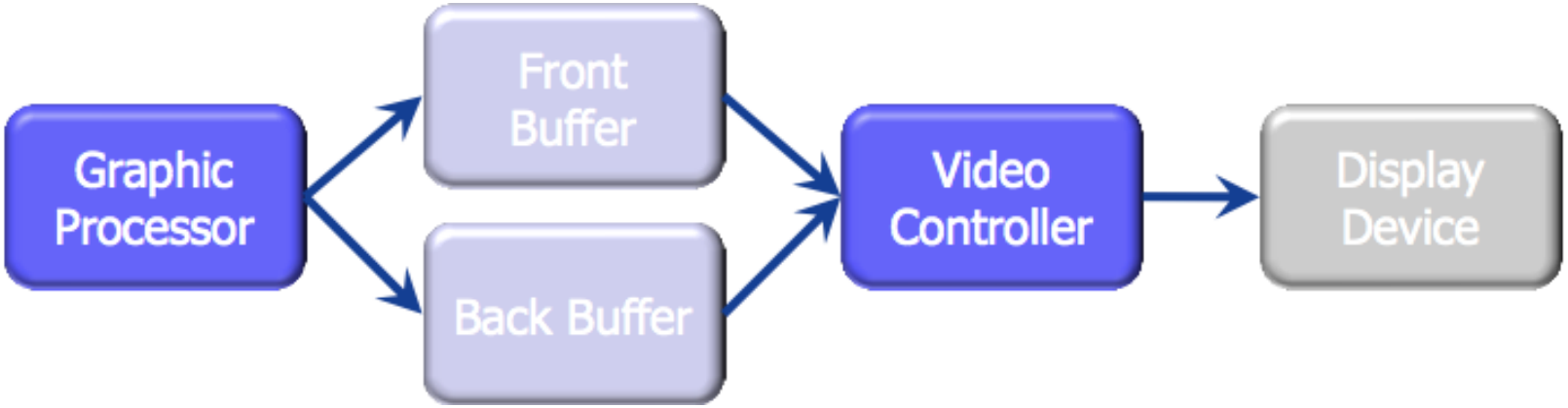
- Clear specific buffers
  - glClear(mask)
    - GL_COLOR_BUFFER_BIT, GL_DEPTH_BUFFER_BIT...

Select Buffers

- glDrawBuffer(mode)
  - Select target buffer to render onto
- glReadBuffer(mode)
  - Select buffer to read

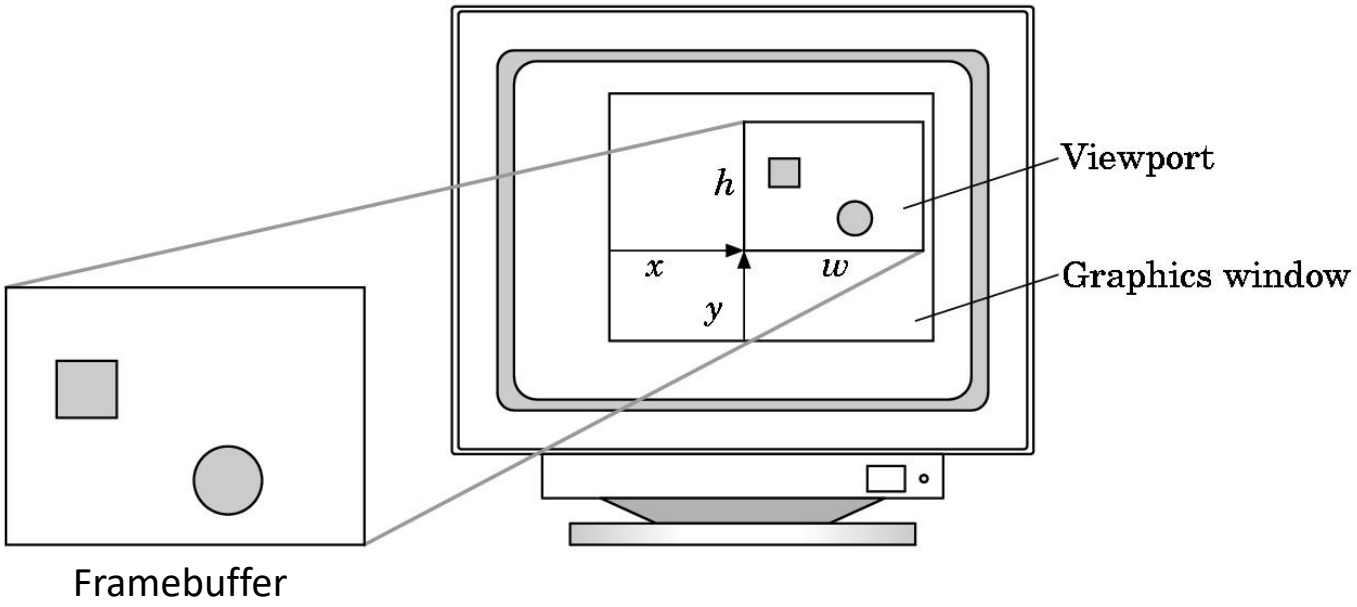
Double Buffering

- Rendering to framebuffer is slower than copying framebuffer to screen
- Use two buffers, GL_FRONT and GL_BACK
- Render to back buffer and swap
- Fast, reduce flickering and tearing



Viewport

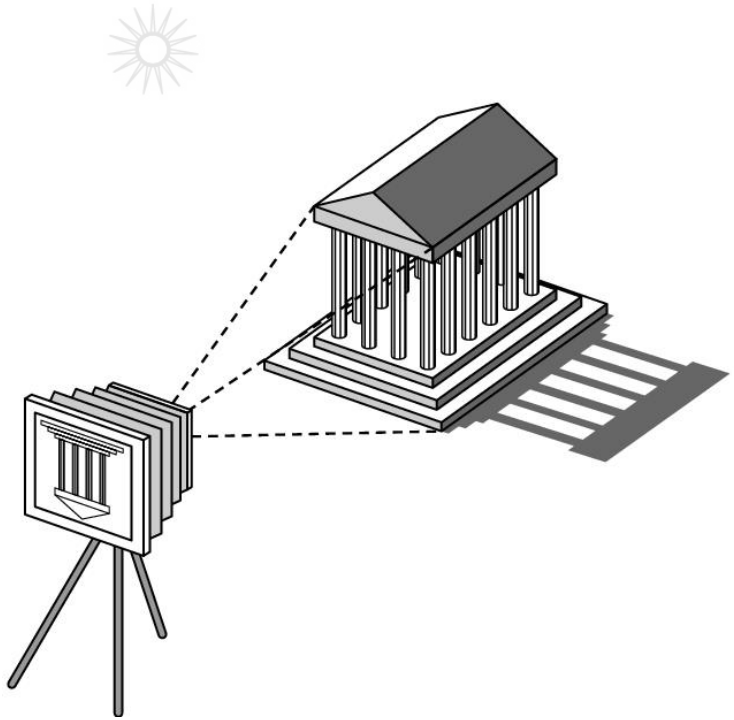
- Mapping framebuffer to screen
  - `glViewport(x,y,w,h)`



Adapted from Angel

Today: Image Formation in GL

- Object
- Viewer
- Light sources



Enable Lighting

```
GLfloat lightPos[] = {200, 100, 200, 1};
GLfloat diffuse[] = {0.9,0.0,0.0,1};
GLfloat specular[] = {1,1,1,1};
GLfloat ambient[] = {1,1,1,1};

glEnable(GL_LIGHTING);

glEnable(GL_LIGHT0);
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffuse);
glLightfv(GL_LIGHT0, GL_SPECULAR, specular);
glLightfv(GL_LIGHT0, GL_AMBIENT, ambient);
glLightfv(GL_LIGHT0, GL_POSITION, lightPos);
```

You can do this on your own in **shaders** without using OpenGL lighting functions!

Shading Model

- Flat shading
  - Per-polygon shading
  - Constant color for a polygon

Shading Model

- Smooth shading
  - Per-vertex shading or per-pixel shading

Why?

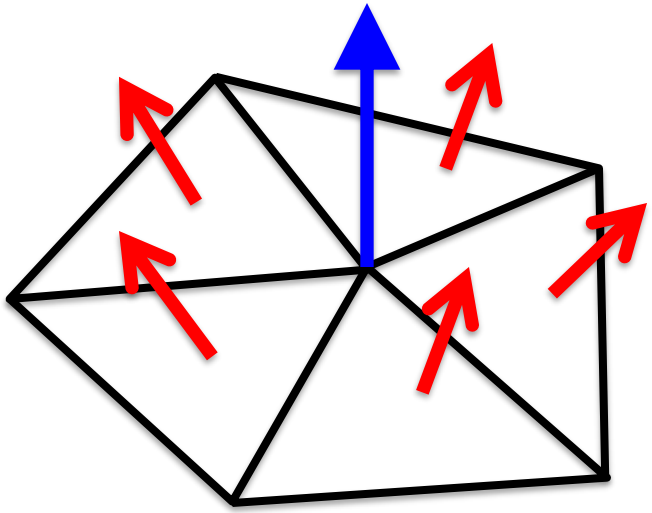
Depth Test

- Triangle rendering order is arbitrary
- You must discard fragments that are not visible

```
// once
glutInitDisplayMode(GLUT_DEPTH | ...);
glEnable(GL_DEPTH_TEST);

...

// Before drawing something
glClearDepth(1.0);
glClear(GL_DEPTH_BUFFER_BIT | ...)
```

Note

- You need to calculate per-vertex normals and assign them as vertex attribute
- Per-vertex normal can be an average of neighbor triangle normals



Questions?

"Brave" Image courtesy of Disney/Pixar