Computer Graphics

7 - Hierarchical Modeling, Mesh

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Topics Covered

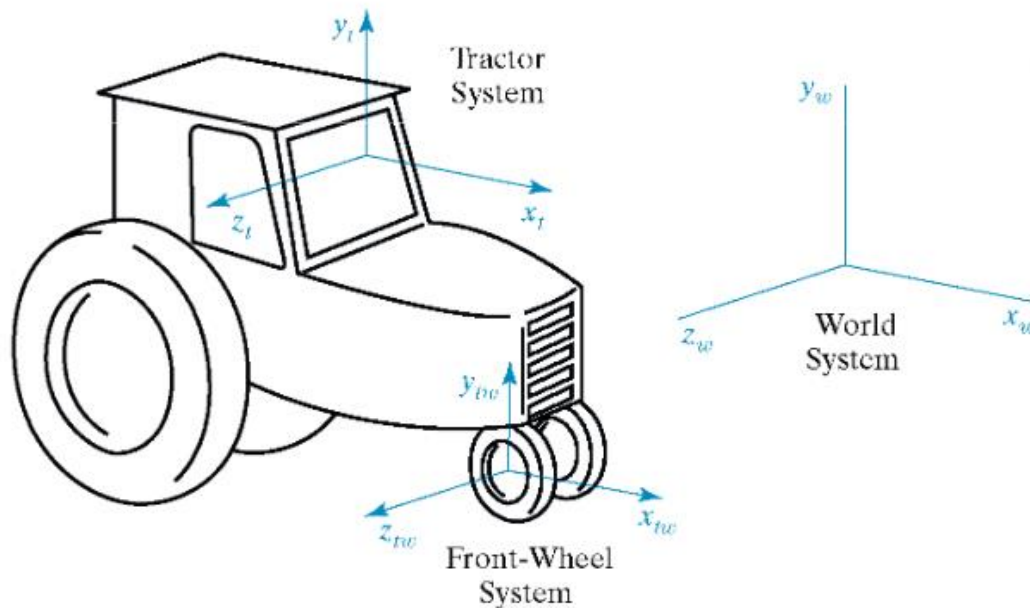
- Hierarchical Modeling
  - Concept of Hierarchical Modeling
  - OpenGL Matrix Stack

- Mesh
  - Polygon mesh & triangle mesh
  - Representations for triangle meshes
  - OpenGL vertex array
  - OBJ file format

Hierarchical Modeling

Hierarchical Modeling

- A hierarchical model is created by nesting the descriptions of subparts into one another to form a tree organization



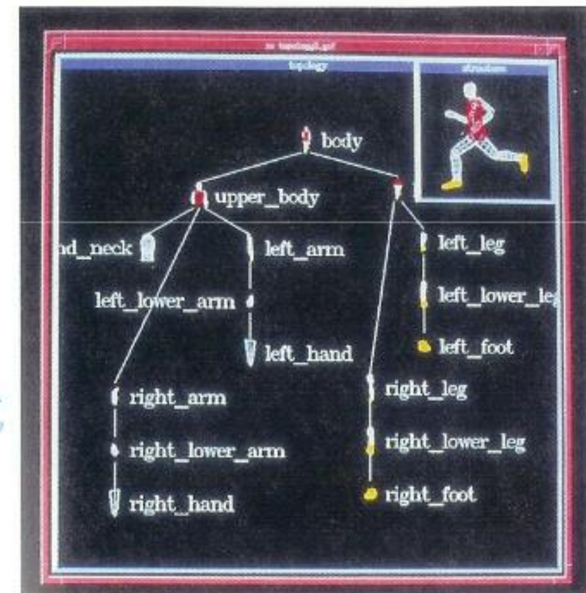
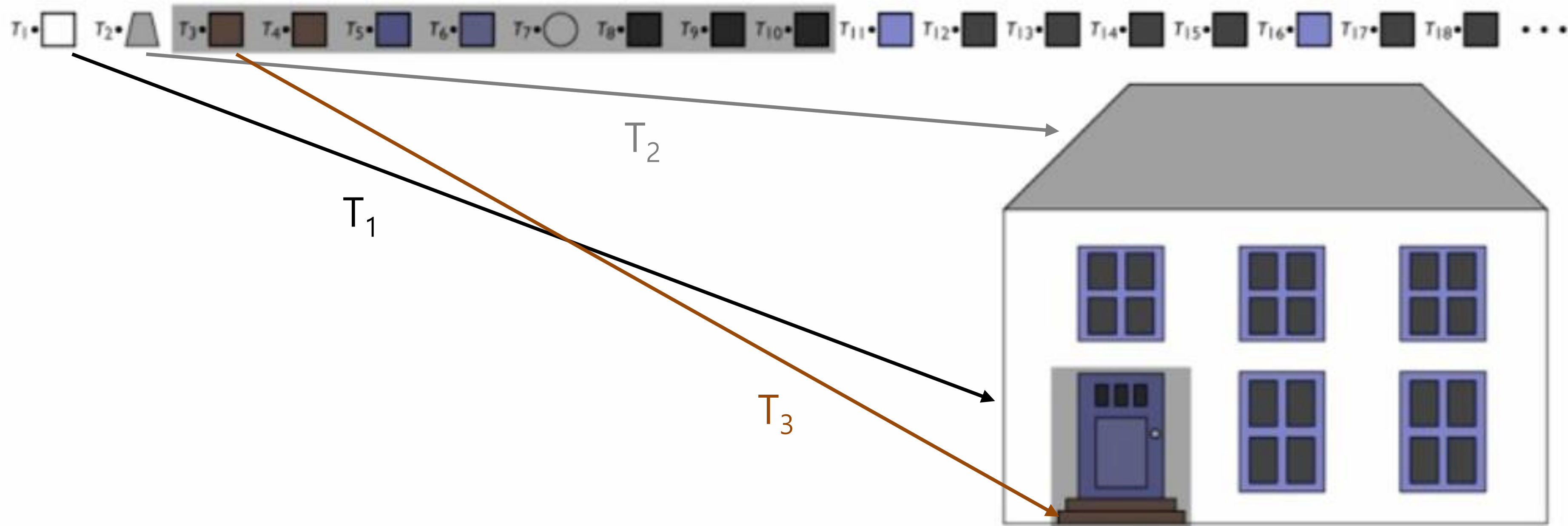


FIGURE 14-4 An object hierarchy generated using the PHIGS Toolkit package developed at the University of Manchester. The displayed object tree is itself a PHIGS structure. (*Courtesy of T. L. J. Howard, J. G. Williams, and W. T. Hewitt, Department of Computer Science, University of Manchester, United Kingdom.*)

Example

- Can represent drawing with flat list
  - but editing operations require updating many transforms



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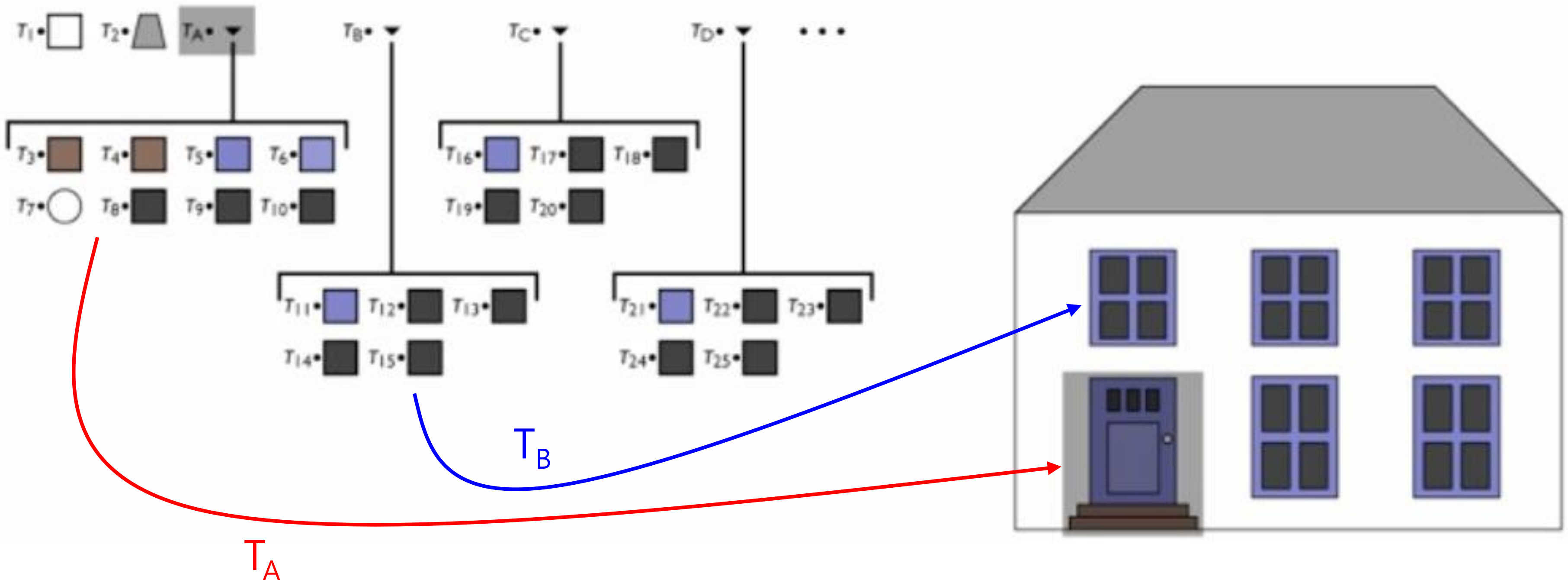
“Grouping”

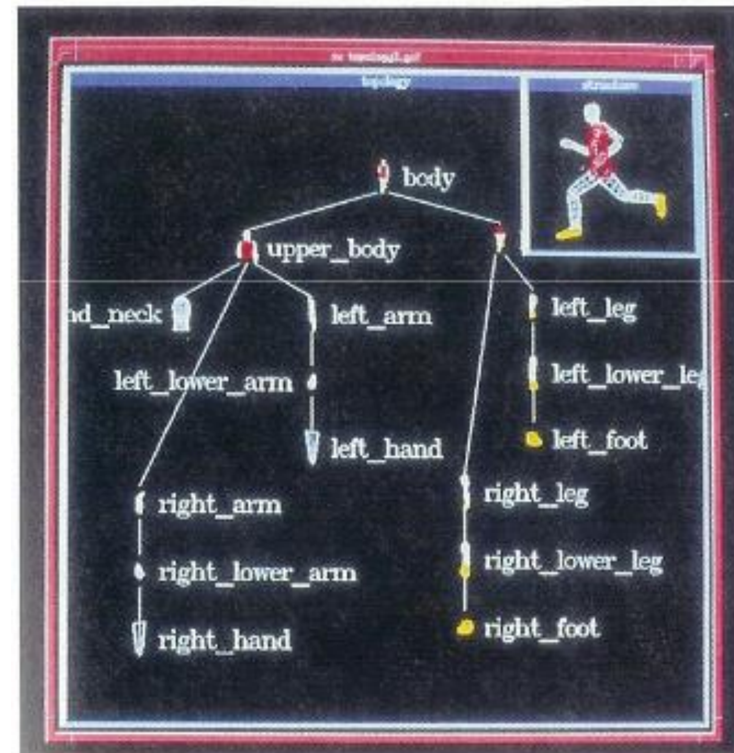
- Treat a set of objects as one
  - lets the data structure reflect the drawing structure
  - enables high-level editing by changing just one node



The Scene Graph (tree)

- A name given to various kinds of graph structures (nodes connected together) used to represent scenes
- Simplest form: tree
  - just saw this
  - every node has one parent

- Each node has its own transformation w.r.t. parent node's frame



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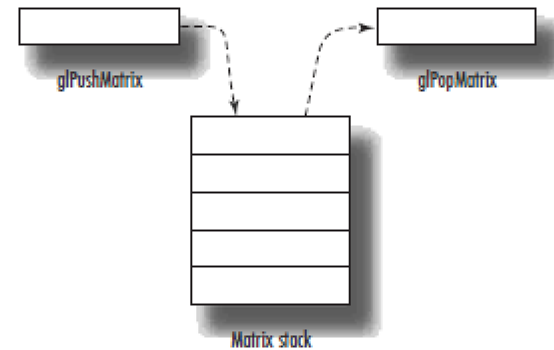
Hierarchical Modeling in OpenGL

- OpenGL provides a useful way of drawing objects in the hierarchical structure (scene graph)

- → **Matrix stack**

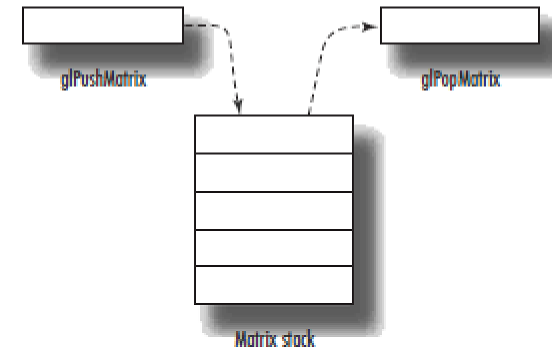
OpenGL Matrix Stack

- A *stack* for transformation matrices
  - Last In First Outs
- You can **save** the **current transformation matrix** and then **restore** it after some objects have been drawn
- Useful for traversing hierarchical data structures (i.e. scene graph or tree)



OpenGL Matrix Stack

- glPushMatrix()
  - Pushes **the current matrix** onto the stack.

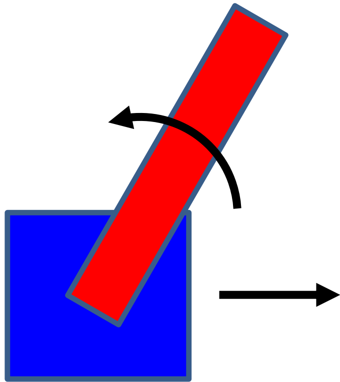


- glPopMatrix()
  - Pops the matrix off the stack.

- The **current matrix** is the matrix **on the top of the stack!**

- Keep in mind that the **numbers of glPushMatrix() calls and glPopMatrix() calls must be the same.**

A simple example



Bold text is the **current transformation matrix** (the one at the top of the matrix stack)

- Start with identity matrix

I

- glPushMatrix()

I
I

- glTranslate(T) # to translate base

T
I

- glPushMatrix()

T
T
I

- glScale(S) # to draw base

TS
T
I

- Draw a box
- glPopMatrix()

T
I

- glPushMatrix()

T
T
I

- glRotate(R) # to rotate arm

TR
T
I

- glPushMatrix()

TR
TR
T
I

- glScale(U) # to draw arm

TRU
TR
T
I

- Draw a box
- glPopMatrix()

TR
T
I

- glPopMatrix()

T
I

- glPopMatrix()

I

[Practice] Matrix Stack

```
import glfw
from OpenGL.GL import *
import numpy as np
from OpenGL.GLU import *

gCamAng = 0

def render(camAng):
    # enable depth test (we'll see
details later)
    glClear(GL_COLOR_BUFFER_BIT |
GL_DEPTH_BUFFER_BIT)
    glEnable(GL_DEPTH_TEST)

    glLoadIdentity()

    # projection transformation
    glOrtho(-1,1, -1,1, -1,1)

    # viewing transformation
    gluLookAt(.1*np.sin(camAng),.1,
.1*np.cos(camAng), 0,0,0, 0,1,0)

    drawFrame()

    t = glfw.get_time()
```

```
    # modeling transformation

    # blue base transformation
    glPushMatrix()
    glTranslatef(np.sin(t), 0, 0)

    # blue base drawing
    glPushMatrix()
    glScalef(.2, .2, .2)
    glColor3ub(0, 0, 255)
    drawBox()
    glPopMatrix()

    # red arm transformation
    glPushMatrix()
    glRotatef(t*(180/np.pi), 0, 0, 1)
    glTranslatef(.5, 0, .01)

    # red arm drawing
    glPushMatrix()
    glScalef(.5, .1, .1)
    glColor3ub(255, 0, 0)
    drawBox()
    glPopMatrix()

    glPopMatrix()
    glPopMatrix()
```

```
def drawBox():
    glBegin(GL_QUADS)
    glVertex3fv(np.array([1,1,0.]))
    glVertex3fv(np.array([-1,1,0.]))
    glVertex3fv(np.array([-1,-1,0.]))
    glVertex3fv(np.array([1,-1,0.]))
    glEnd()

def drawFrame():
    # draw coordinate: x in red, y in
green, z in blue
    glBegin(GL_LINES)
    glColor3ub(255, 0, 0)
    glVertex3fv(np.array([0.,0.,0.]))
    glVertex3fv(np.array([1.,0.,0.]))
    glColor3ub(0, 255, 0)
    glVertex3fv(np.array([0.,0.,0.]))
    glVertex3fv(np.array([0.,1.,0.]))
    glColor3ub(0, 0, 255)
    glVertex3fv(np.array([0.,0.,0]))
    glVertex3fv(np.array([0.,0.,1.]))
    glEnd()<
```

```
def key_callback(window, key, scancode, action,
mods):
    global gCamAng, gComposedM
    if action==glfw.PRESS or
action==glfw.REPEAT:
        if key==glfw.KEY_1:
            gCamAng += np.radians(-10)
        elif key==glfw.KEY_3:
            gCamAng += np.radians(10)

def main():
    if not glfw.init():
        return
    window =
glfw.create_window(640,640,"Hierarchy",
None,None)
    if not window:
        glfw.terminate()
        return
    glfw.make_context_current(window)
    glfw.set_key_callback(window, key_callback)
    glfw.swap_interval(1)

    while not glfw.window_should_close(window):
        glfw.poll_events()
        render(gCamAng)
        glfw.swap_buffers(window)

    glfw.terminate()

if __name__ == "__main__":
    main()
```

Quiz #1

- Go to https://www.slido.com/
- Join #cg-hyu
- Click “Polls”

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

- Note that you must submit all quiz answers in the above format to be checked for “attendance”.

OpenGL Matrix Stack Types

- Actually, OpenGL maintains four different types of matrix stacks:

- **Modelview matrix stack (GL_MODELVIEW)**
  - Stores model view matrices.
  - This is the default type (what we've just used)
- **Projection matrix stack (GL_PROJECTION)**
  - Stores projection matrices
- Texture matrix stack (GL_TEXTURE)
  - Stores transformation matrices to adjust texture coordinates. Mostly used to implement texture projection (like an image projected by a beam projector)
- Color matrix stack (GL_COLOR)
  - Rarely used. Just ignore it.

- You can switch the current matrix stack type using glMatrixMode()
  - e.g. glMatrixMode(GL_PROJECTION) to select the projection matrix stack

OpenGL Matrix Stack Types

- A common guide is something like:

```
/* Projection Transformation */
glMatrixMode(GL_PROJECTION);      /* specify the projection matrix */
glLoadIdentity();                 /* initialize current value to identity */
gluPerspective(...);              /* or glOrtho(...) for orthographic */
                                  /* or glFrustrum(...), also for perspective */

/* Viewing And Modelling Transformation */
glMatrixMode(GL_MODELVIEW);       /* specify the modelview matrix */
glLoadIdentity();                 /* initialize current value to identity */
gluLookAt(...);                   /* specify the viewing transformation */

glTranslate(...);                 /* various modelling transformations */
glScale(...);
glRotate(...);
...
```

- **Projection transformation** functions (gluPerspective(), glOrtho(), …) should be called with **glMatrixMode(GL_PROJECTION).**

- **Modeling & viewing transformation** functions (gluLookAt(), glTranslate(), …) should be called with **glMatrixMode(GL_MODELVIEW).**

- Otherwise, you'll get wrong lighting results.

[Practice] With Correct Matrix Stack Types

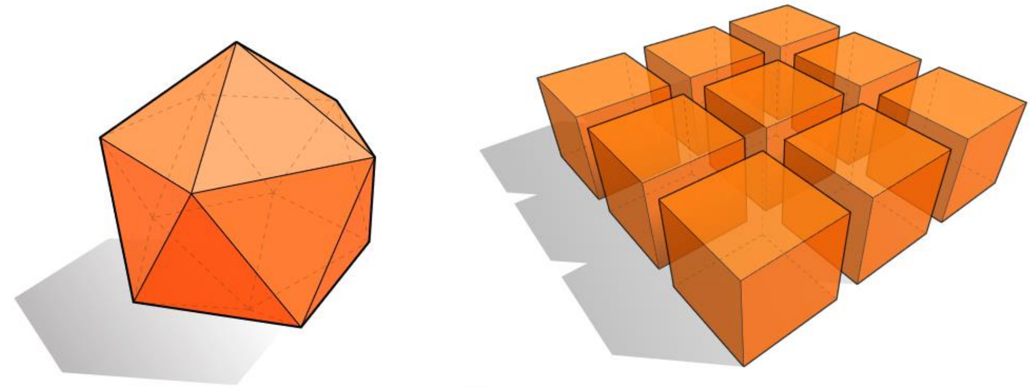
```
def render(camAng):
    # enable depth test (we'll see
details later)
    glClear(GL_COLOR_BUFFER_BIT |
GL_DEPTH_BUFFER_BIT)
    glEnable(GL_DEPTH_TEST)

    glMatrixMode(GL_PROJECTION)
    glLoadIdentity()

    # projection transformation
    glOrtho(-1,1, -1,1, -1,1)

    glMatrixMode(GL_MODELVIEW)
    glLoadIdentity()

    # viewing transformation
    gluLookAt(.1*np.sin(camAng),.1,
.1*np.cos(camAng), 0,0,0, 0,1,0)

    drawFrame()
    t = glfw.get_time()
```

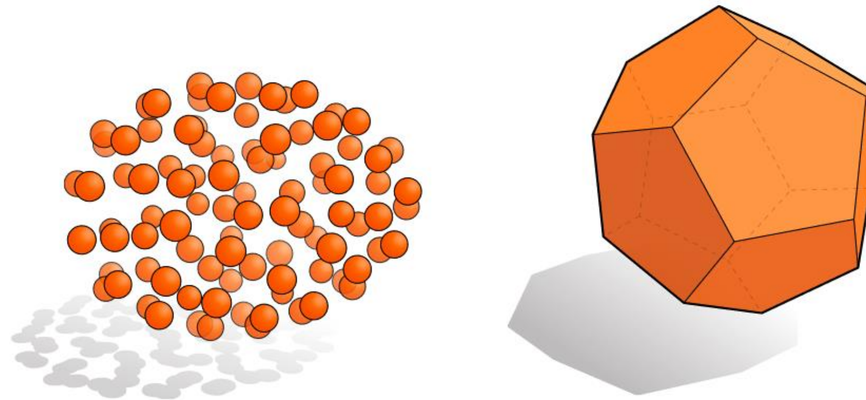
```
    # modeling transformation

    # blue base transformation
    glPushMatrix()
    glTranslatef(np.sin(t), 0, 0)

    # blue base drawing
    glPushMatrix()
    glScalef(.2, .2, .2)
    glColor3ub(0, 0, 255)
    drawBox()
    glPopMatrix()

    # red arm transformation
    glPushMatrix()
    glRotatef(t*(180/np.pi), 0, 0, 1)
    glTranslatef(.5, 0, .01)

    # red arm drawing
    glPushMatrix()
    glScalef(.5, .1, .1)
    glColor3ub(255, 0, 0)
    drawBox()
    glPopMatrix()

    glPopMatrix()
    glPopMatrix()
```

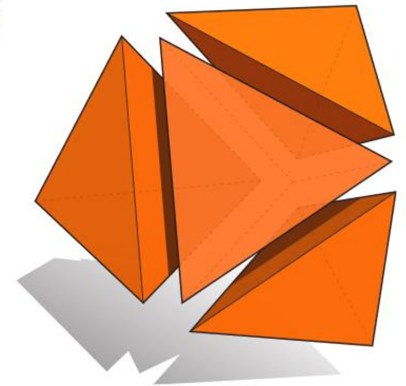
Mesh

Many ways to digitally encode geometry

- EXPLICIT
  - point cloud
  - polygon mesh
  - subdivision, NURBS
  - L-systems
  - ...
- IMPLICIT
  - level set
  - algebraic surface
  - ...
- Each choice best suited to a different task/type of geometry

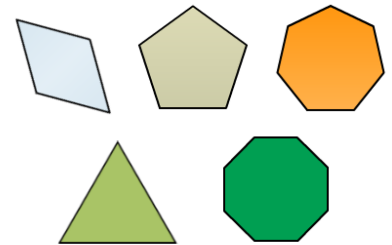






The Most Popular One : Polygon Mesh

- Because this can model any arbitrary complex shapes with relatively simple representations and can be rendered fast.

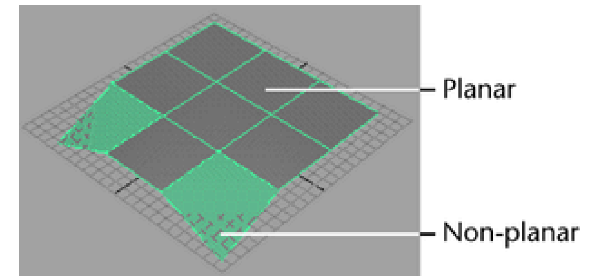


- **Polygon**: a "closed" shape with straight sides

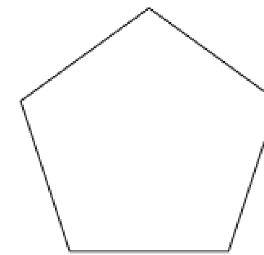
- **Polygon mesh**: a bunch of polygons in 3D space that are connected together to form a surface
  - Usually use *triangles* or *quads* (4 side polygon)

Triangle Mesh

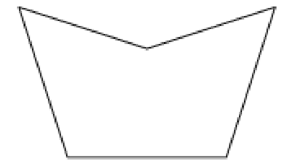
- A general N-polygon can be
  - Non-planar
  - Non-convex
- , which are not desirable for fast rendering.



- A triangle does not have such problems. It’s always planar & convex.



convex polygon



concave polygon

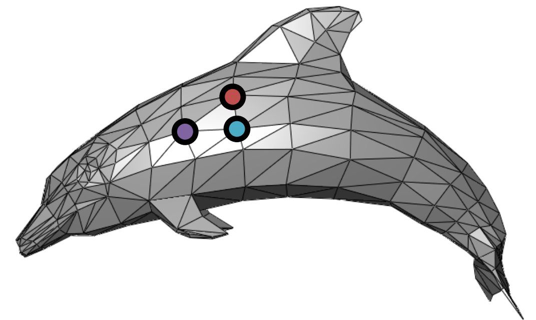
- and N-polygons can be composed of multiple triangles.

- That's why modern GPUs draw everything as a set of triangles.

- So, we'll focus on triangle meshes.

Representation for Triangle Mesh

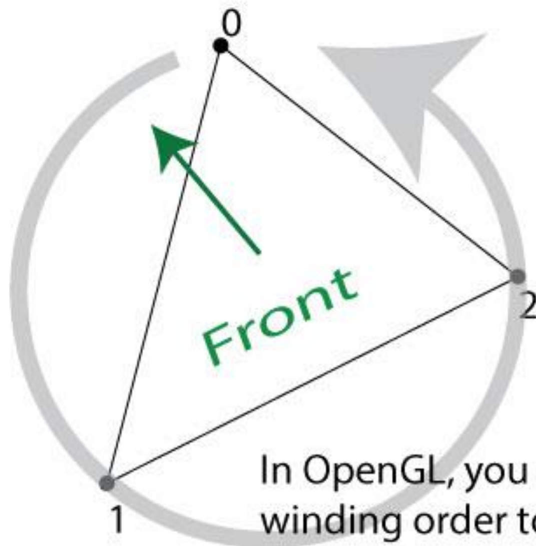
- It's about how to store
  - vertex positions
  - relationship between vertices (to make triangles)
- on memory.

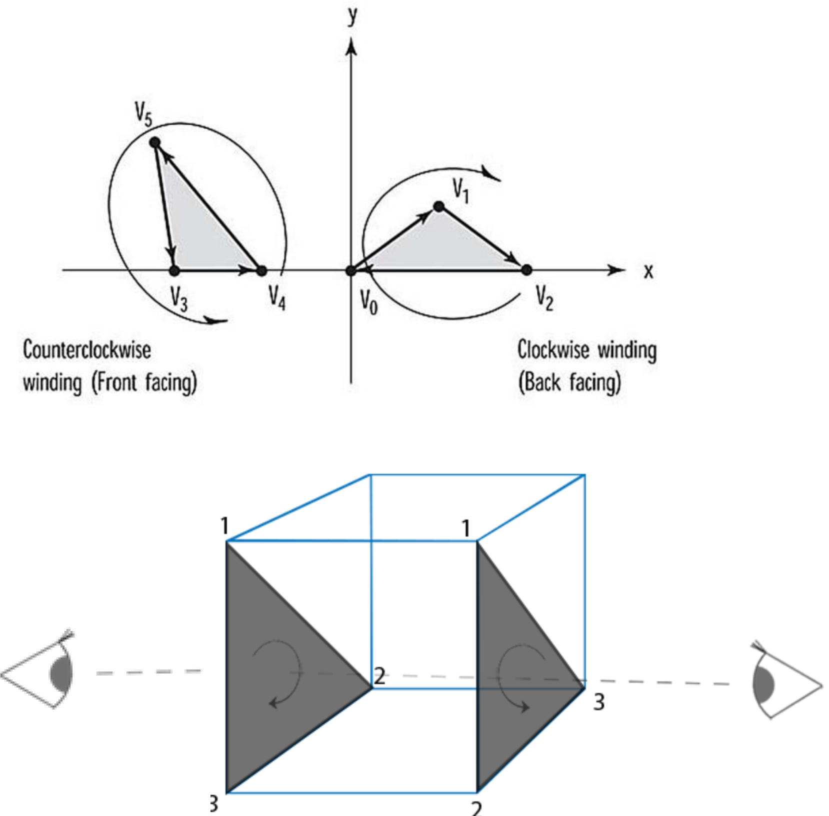


- We'll see
  - Separate triangles
  - Indexed triangle set

Vertex Winding Order

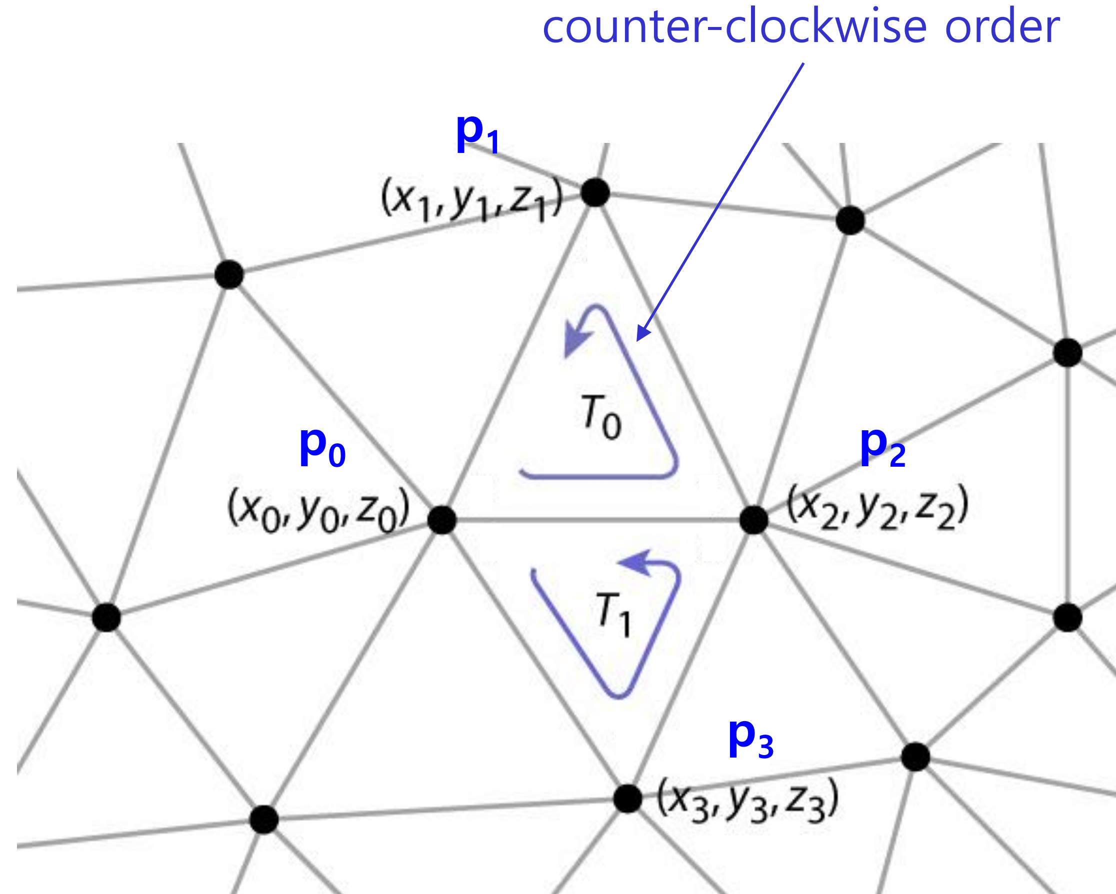
- In OpenGL, by default, polygons whose vertices appear in **counterclockwise** order on the screen is front-facing





Separate triangles

	[0]	[1]	[2]
tris[0]	x_0, y_0, z_0	x_2, y_2, z_2	x_1, y_1, z_1
tris[1]	x_0, y_0, z_0	x_3, y_3, z_3	x_2, y_2, z_2
	⋮	⋮	⋮



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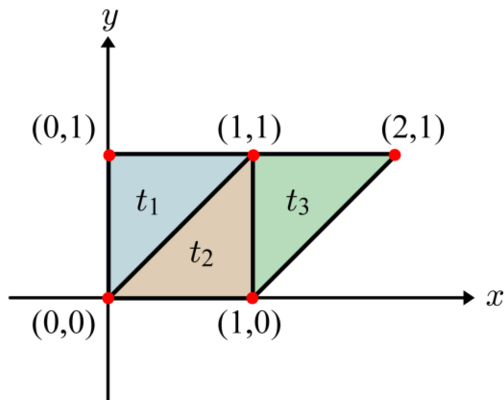
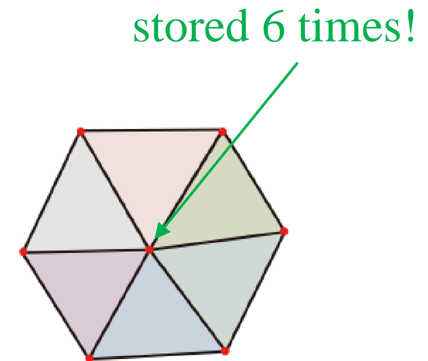
Separate Triangles

- Various problems
  - Wastes space
  - Cracks due to roundoff
  - Difficulty of finding neighbors



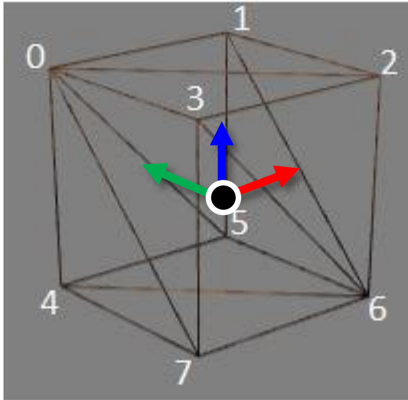
vertex buffer

vertex	triangle
(0,1)	t_1
(0,0)	t_1
(1,1)	t_1
(0,0)	t_2
(1,0)	t_2
(1,1)	t_2
(1,1)	t_3
(1,0)	t_3
(2,1)	t_3



(1,1) is stored 3 times!

Example: a cube of length 2

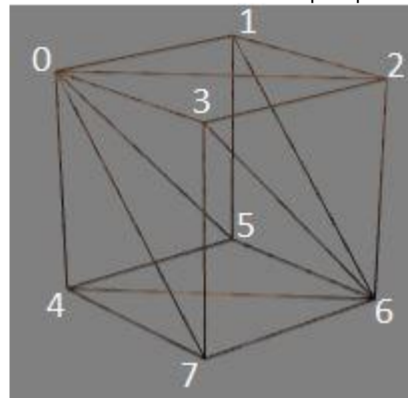


vertex index	position
0	(-1 , 1 , 1)
1	(1 , 1 , 1)
2	(1 , -1 , 1)
3	(-1 , -1 , 1)
4	(-1 , 1 , -1)
5	(1 , 1 , -1)
6	(1 , -1 , -1)
7	(-1 , -1 , -1)

Drawing Separate Triangles using glVertex*()

- You can use glVertex*() like this:

```
def drawCube_glVertex():
    glBegin(GL_TRIANGLES)
    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f(  1 , -1 ,  1 ) # v2
    glVertex3f(  1 ,  1 ,  1 ) # v1

    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f( -1 , -1 ,  1 ) # v3
    glVertex3f(  1 , -1 ,  1 ) # v2

    glVertex3f( -1 ,  1 , -1 ) # v4
    glVertex3f(  1 ,  1 , -1 ) # v5
    glVertex3f(  1 , -1 , -1 ) # v6

    glVertex3f( -1 ,  1 , -1 ) # v4
    glVertex3f(  1 , -1 , -1 ) # v6
    glVertex3f( -1 , -1 , -1 ) # v7

    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f(  1 ,  1 ,  1 ) # v1
    glVertex3f(  1 ,  1 , -1 ) # v5

    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f(  1 ,  1 , -1 ) # v5
    glVertex3f( -1 ,  1 , -1 ) # v4
```




```
    glVertex3f( -1 , -1 ,  1 ) # v3
    glVertex3f(  1 , -1 , -1 ) # v6
    glVertex3f(  1 , -1 ,  1 ) # v2

    glVertex3f( -1 , -1 ,  1 ) # v3
    glVertex3f( -1 , -1 , -1 ) # v7
    glVertex3f(  1 , -1 , -1 ) # v6

    glVertex3f(  1 ,  1 ,  1 ) # v1
    glVertex3f(  1 , -1 ,  1 ) # v2
    glVertex3f(  1 , -1 , -1 ) # v6

    glVertex3f(  1 ,  1 ,  1 ) # v1
    glVertex3f(  1 , -1 , -1 ) # v6
    glVertex3f(  1 ,  1 , -1 ) # v5

    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f( -1 , -1 , -1 ) # v7
    glVertex3f( -1 , -1 ,  1 ) # v3

    glVertex3f( -1 ,  1 ,  1 ) # v0
    glVertex3f( -1 ,  1 , -1 ) # v4
    glVertex3f( -1 , -1 , -1 ) # v7
    glEnd()
```

Vertex Array

- But from now on, let's use a more advanced method to draw polygons: *Vertex array*

- **Vertex array**: an array of vertex data including vertex positions, normals, texture coordinates and color information
  - For now, consider vertex positions only

- By using a vertex array, you can draw a whole mesh just by calling a OpenGL function **once**! (instead of a huge number of glVertex*() calls!)
- → Tremendous increase in rendering performance!

Drawing Separate Triangles using Vertex Array

- 1. Create a vertex array for your mesh
  - Using numpy.ndarray or python list

- 2. Specify “pointer” to this vertex array
  - Using glVertexPointer()

- 3. Render the mesh using the specified “pointer”
  - Using glDrawArrays()

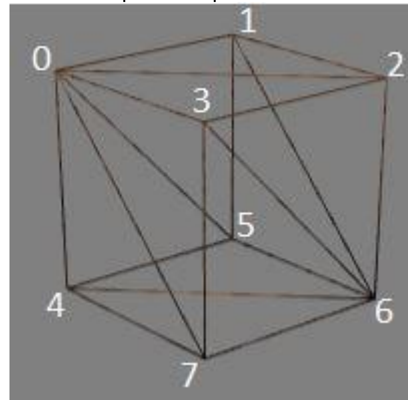
glVertexPointer() & glDrawArrays()

- **glVertexPointer(size, type, stride, pointer)**
- : specifies the location and data format of a vertex array
  - **size**: The number of vertex coordinates, 2 for 2D points, 3 for 3D points
  - **type**: The data type of each coordinate value in the array. GL_FLOAT, GL_SHORT, GL_INT or GL_DOUBLE.
  - **stride**: The byte offset to the next vertex
  - **pointer**: The pointer to the first coordinate of the first vertex in the array

- **glDrawArrays(mode , first , count)**
- : render primitives from the vertex array specified by glVertexPointer()
  - **mode**: The primitive type to render. GL_POINTS, GL_TRIANGLES, ...
  - **first**: The starting index in the array specified by glVertexPointer()
  - **count**: The number of vertices to be rendered (duplicate vertices also should be counted separately)

[Practice] Drawing Separate Triangles using Vertex Array

```
import glfw
from OpenGL.GL import *
import numpy as np
from OpenGL.GLU import *

gCamAng = 0
gCamHeight = 1.

def createVertexArraySeparate():
    varr = np.array([
            ( -1 ,  1 ,  1 ), # v0
            (  1 , -1 ,  1 ), # v2
            (  1 ,  1 ,  1 ), # v1

            ( -1 ,  1 ,  1 ), # v0
            ( -1 , -1 ,  1 ), # v3
            (  1 , -1 ,  1 ), # v2

            ( -1 ,  1 , -1 ), # v4
            (  1 ,  1 , -1 ), # v5
            (  1 , -1 , -1 ), # v6

            ( -1 ,  1 , -1 ), # v4
            (  1 , -1 , -1 ), # v6
            ( -1 , -1 , -1 ), # v7

            ( -1 ,  1 ,  1 ), # v0
            (  1 ,  1 ,  1 ), # v1
            (  1 ,  1 , -1 ), # v5

            ( -1 ,  1 ,  1 ), # v0
            (  1 ,  1 , -1 ), # v5
            ( -1 ,  1 , -1 ), # v4

            ( -1 , -1 ,  1 ), # v3
            (  1 , -1 , -1 ), # v6
            (  1 , -1 ,  1 ), # v2

            ( -1 , -1 ,  1 ), # v3
            ( -1 , -1 , -1 ), # v7
            (  1 , -1 , -1 ), # v6

            (  1 ,  1 ,  1 ), # v1
            (  1 , -1 ,  1 ), # v2
            (  1 , -1 , -1 ), # v6

            (  1 ,  1 ,  1 ), # v1
            (  1 , -1 , -1 ), # v6
            (  1 ,  1 , -1 ), # v5

            ( -1 ,  1 ,  1 ), # v0
            ( -1 , -1 , -1 ), # v7
            ( -1 , -1 ,  1 ), # v3

            ( -1 ,  1 ,  1 ), # v0
            ( -1 ,  1 , -1 ), # v4
            ( -1 , -1 , -1 ), # v7
            ], 'float32')
    return varr
```



```python
def render():
    global gCamAng, gCamHeight
    glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT)
    glEnable(GL_DEPTH_TEST)
    glPolygonMode( GL_FRONT_AND_BACK, GL_LINE )

    glLoadIdentity()
    gluPerspective(45, 1, 1,10)
    gluLookAt(5*np.sin(gCamAng),gCamHeight,5*np.cos(gCamAng), 0,0,0, 0,1,0)

    drawFrame()
    glColor3ub(255, 255, 255)

    # drawCube_glVertex()
    drawCube_glDrawArrays()


def drawCube_glDrawArrays():
    global gVertexArraySeparate
    varr = gVertexArraySeparate
    glEnableClientState(GL_VERTEX_ARRAY)  # Enable it to use vertex array
    glVertexPointer(3, GL_FLOAT, 3*varr.itemsize, varr)
    glDrawArrays(GL_TRIANGLES, 0, int(varr.size/3))
```

```python
gVertexArraySeparate = None
def main():
    global gVertexArraySeparate

    if not glfw.init():
        return
    window = glfw.create_window(640,640,'Lecture10', None,None)
    if not window:
        glfw.terminate()
        return
    glfw.make_context_current(window)
    glfw.set_key_callback(window, key_callback)

    gVertexArraySeparate = createVertexArraySeparate()

    while not glfw.window_should_close(window):
        glfw.poll_events()
        render()
        glfw.swap_buffers(window)

    glfw.terminate()

if __name__ == "__main__":
    main()
```

```
def drawFrame():
    glBegin(GL_LINES)
    glColor3ub(255, 0, 0)
    glVertex3fv(np.array([0.,0.,0.]))
    glVertex3fv(np.array([1.,0.,0.]))
    glColor3ub(0, 255, 0)
    glVertex3fv(np.array([0.,0.,0.]))
    glVertex3fv(np.array([0.,1.,0.]))
    glColor3ub(0, 0, 255)
    glVertex3fv(np.array([0.,0.,0]))
    glVertex3fv(np.array([0.,0.,1.]))
    glEnd()


def key_callback(window, key, scancode, action,
mods):
    global gCamAng, gCamHeight
    if action==glfw.PRESS or action==glfw.REPEAT:
        if key==glfw.KEY_1:
            gCamAng += np.radians(-10)
        elif key==glfw.KEY_3:
            gCamAng += np.radians(10)
        elif key==glfw.KEY_2:
            gCamHeight += .1
        elif key==glfw.KEY_W:
            gCamHeight += -.1
```

Quiz #2

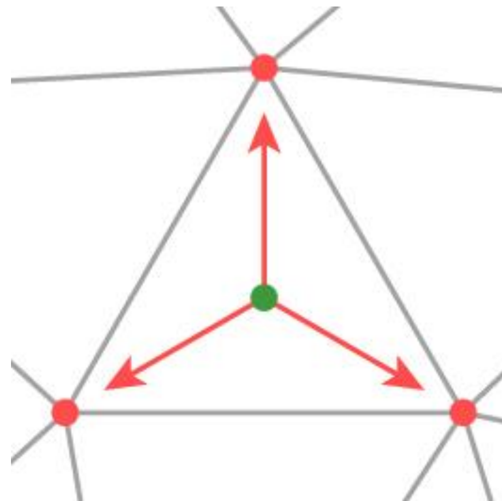
- Go to https://www.slido.com/
- Join #cg-hyu
- Click “Polls”

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

- Note that you must submit all quiz answers in the above format to be checked for “attendance”.

Indexed triangle set

- Store each vertex once
- Each triangle points to its three vertices



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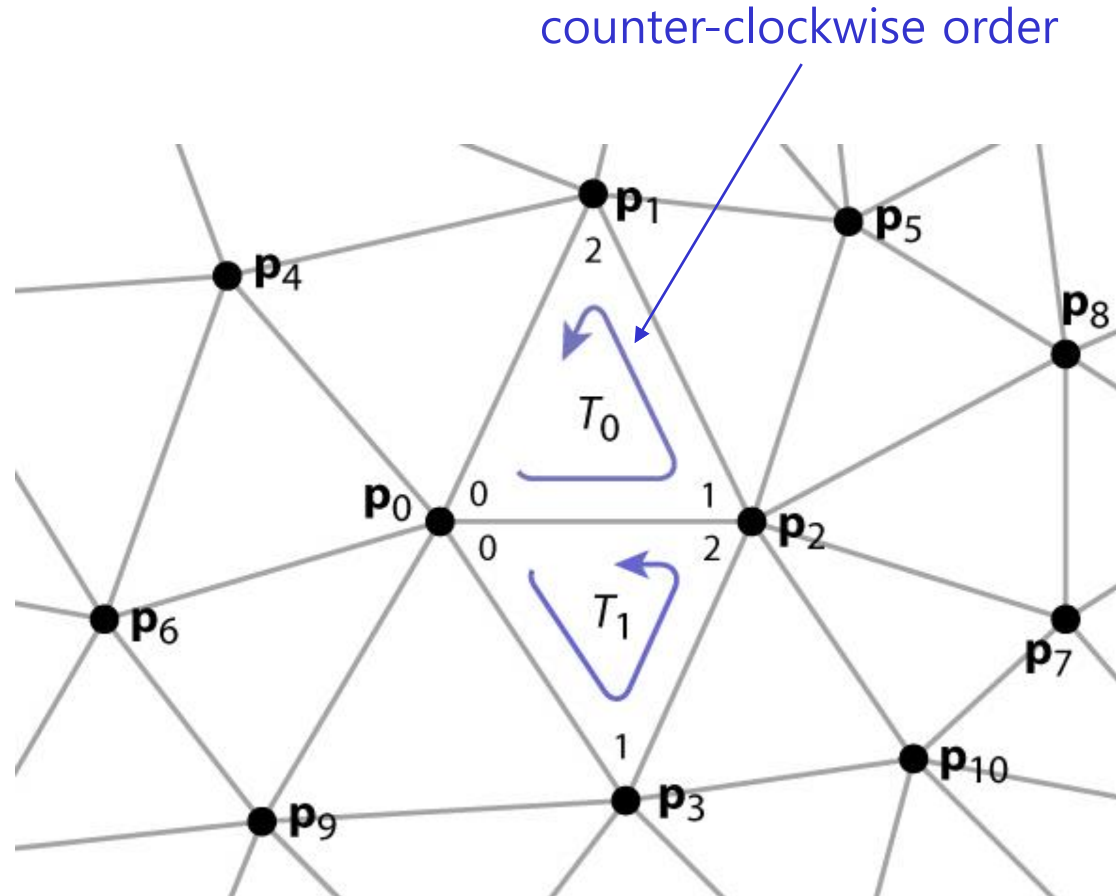
Indexed triangle set

vertex array

verts[0]	x_0, y_0, z_0
verts[1]	x_1, y_1, z_1
	x_2, y_2, z_2
	x_3, y_3, z_3
	⋮

index array

tInd[0]	0, 2, 1
tInd[1]	0, 3, 2
	⋮



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Indexed Triangle Set

- Memory efficient: each vertex position is stored only once.

- Represents topology and geometry separately.

- Finding neighbors is at least well defined.
  - Neighbor triangles share same vertex indices.

Drawing Indexed Triangles using Vertex & Index Array

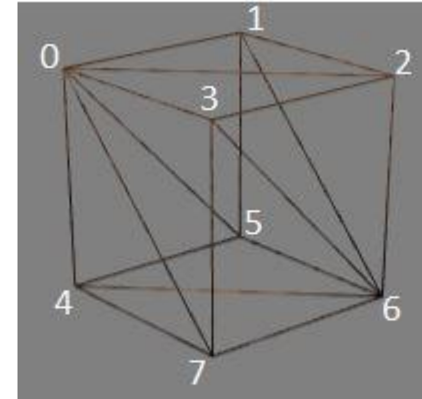
- 1. Create a vertex array & **index array** for your mesh
  - The vertex array **should not have duplicate vertex data**
- 2. Specify "pointer" to this vertex array
  - Same with the separate triangles case
- 3. Render the mesh using the specified "pointer" & **indices of vertices to render**
  - Using **glDrawElements()**

glDrawElements()

- **glDrawElements(mode , count , type , indices)**
- : render primitives from vertex & index array data
  - **mode**: The primitive type to render. GL_POINTS, GL_TRIANGLES, ...
  - **count**: The number of indices to be rendered
  - **type**: The type of the values in **indices**. GL_UNSIGNED_BYTE, GL_UNSIGNED_SHORT, or GL_UNSIGNED_INT
  - **indices**: The pointer to the index array

[Practice] Drawing Indexed Triangles using Vertex & Index Array

```
def createVertexAndIndexArrayIndexed():
    varr = np.array([
                ( -1 ,  1 ,  1 ), # v0
                (  1 ,  1 ,  1 ), # v1
                (  1 , -1 ,  1 ), # v2
                ( -1 , -1 ,  1 ), # v3
                ( -1 ,  1 , -1 ), # v4
                (  1 ,  1 , -1 ), # v5
                (  1 , -1 , -1 ), # v6
                ( -1 , -1 , -1 ), # v7
                ], 'float32')
    iarr = np.array([
                (0,2,1),
                (0,3,2),
                (4,5,6),
                (4,6,7),
                (0,1,5),
                (0,5,4),
                (3,6,2),
                (3,7,6),
                (1,2,6),
                (1,6,5),
                (0,7,3),
                (0,4,7),
                ])
    return varr, iarr
```



vertex index	position
0	(-1 , 1 , 1)
1	(1 , 1 , 1)
2	(1 , -1 , 1)
3	(-1 , -1 , 1)
4	(-1 , 1 , -1)
5	(1 , 1 , -1)
6	(1 , -1 , -1)
7	(-1 , -1 , -1)

```python
def render():
    # ...
    drawFrame()
    glColor3ub(255, 255, 255)
    drawCube_glDrawElements()


def drawCube_glDrawElements():
    global gVertexArrayIndexed, gIndexArray
    varr = gVertexArrayIndexed
    iarr = gIndexArray
    glEnableClientState(GL_VERTEX_ARRAY)
    glVertexPointer(3, GL_FLOAT, 3*varr.itemsize, varr)
    glDrawElements(GL_TRIANGLES, iarr.size, GL_UNSIGNED_INT, iarr)


# ...
gVertexArrayIndexed = None
gIndexArray = None

def main():
    # ...
    global gVertexArrayIndexed, gIndexArray

    # ...
    gVertexArrayIndexed, gIndexArray = createVertexAndIndexArrayIndexed()

    while not glfw.window_should_close(window):
    # ...
```

Quiz #3

- Go to https://www.slido.com/
- Join #cg-hyu
- Click "Polls"

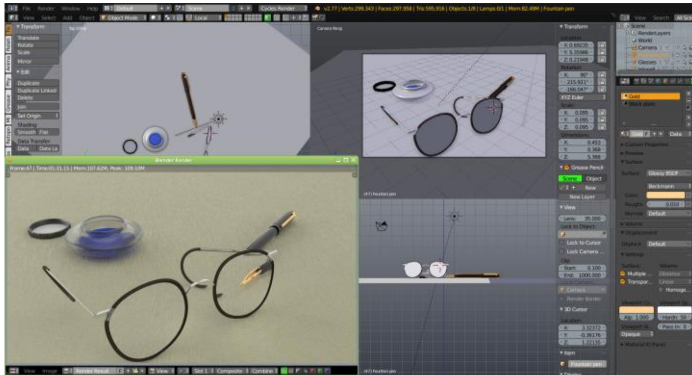
- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

- Note that you must submit all quiz answers in the above format to be checked for "attendance".

Do we need to hard-code all vertex positions and indices?

- Of course not

- An *object file* or *model file* storing polygon mesh data is usually created using 3D modeling tools.



Blender

Maya

- Applications usually load vertex and index data from an *object file* and draw the object using the loaded data.

3D File Formats

- **DXF – AutoCAD**
  - **Supports 2-D and 3-D; binary**
- **3DS – 3DS MAX**
  - **Flexible; binary**
- **VRML – Virtual reality modeling language**
  - **ASCII – Human readable (and writeable)**
- **OBJ – Wavefront OBJ format**
  - **ASCII**
  - **Extremely simple**
  - **Widely supported**

KAIST

OBJ File Tokens

- **File tokens are listed below**

 # some text

Rest of line is a comment

v *float float float*

A single vertex's geometric position in space

vn *float float float*

A normal

vt *float float*

A texture coordinate

KAIST

OBJ Face Varieties

f *int int int* ... **(vertex only)**

or

f *int/int int/int int/int* . . . **(vertex & texture)**

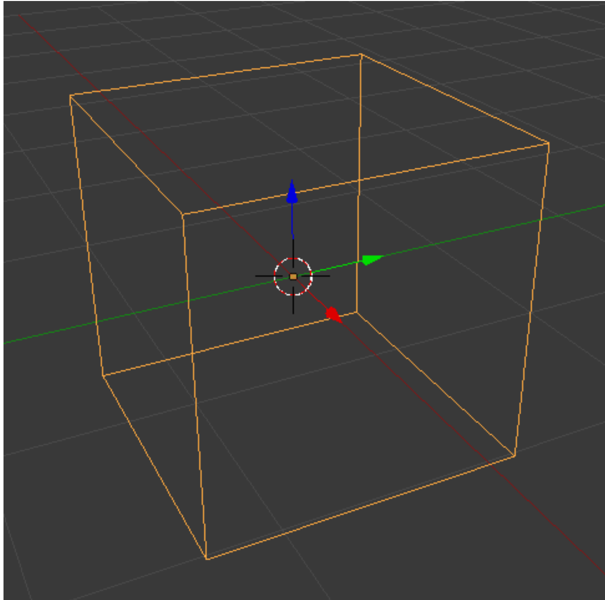
or

f *int/int/int int/int/int int/int/int* ... **(vertex, texture, & normal)**

- **The arguments are 1-based indices into the arrays**
  - **Vertex positions**
  - **Texture coordinates**
  - **Normals, respectively**

KAIST

An OBJ Example



```
# A simple cube
v 1.000000 -1.000000 -1.000000
v 1.000000 -1.000000 1.000000
v -1.000000 -1.000000 1.000000
v -1.000000 -1.000000 -1.000000
v 1.000000 1.000000 -1.000000
v 1.000000 1.000000 1.000000
v -1.000000 1.000000 1.000000
v -1.000000 1.000000 -1.000000
f 1 2 3 4
f 5 8 7 6
f 1 5 6 2
f 2 6 7 3
f 3 7 8 4
f 5 1 4 8
```

[Practice] Manipulate an OBJ file with Blender

- Blender
  - https://www.blender.org/
  - Open source
  - Full 3D modeling/rendering/animation tool

- Install & launch Blender

- Reference for basic mouse actions in Blender
  - https://en.wikibooks.org/wiki/Blender_3D:_Noob_to_Pro/3D_View_Windows#Changing_Your_Viewpoint,_Part_One

[Practice] Manipulate an OBJ file with Blender

- Save the obj example in the prev. page as cube.obj (using a text editor)
- Right click the "start-up" cube object in the Blender and press Del key to delete it.
- Import cube.obj into Blender (File-Import)
  - Press ‘z’ to render in wireframe mode
- Edit cube.obj somehow (using a text editor)
- Delete the loaded cube and re-import cube.obj into Blender again
- Press ‘tab’ to switch to *Edit mode*

[Practice] Manipulate an OBJ file with Blender

- Right click to select a vertex and move it by dragging red/blue/green arrows
- Export this mesh to cube.obj (File – Export)
- Open cube.obj using a text editor and check what is changed
- Reference for *Edit mode* in Blender
  - https://en.wikibooks.org/wiki/Blender_3D:_Noob_to_Pro/Mesh_Edit_Mode
- Reference for *Object mode* in Blender
  - https://en.wikibooks.org/wiki/Blender_3D:_Noob_to_Pro/Object_Mode

OBJ Sources

- https://free3d.com/
- https://www.cgtrader.com/free-3d-models

- You can download any .obj model files from these sites open them in Blender.

- OBJ file format is very popular:
  - Most modeling programs will export OBJ files
  - Most rendering packages will read in OBJ files

Next Time

- Lab in this week:
  - Lab assignment 7

- Next lecture (after the midterm exam):
  - 8 - Lighting & Shading

- Midterm exam: 10:00, April 22 (Mon), IT.BT Hall Room No. 911

- No lecture and lab next week.

- Acknowledgement: Some materials come from the lecture slides of
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  - Prof. Steve Marschner, Cornell Univ., http://www.cs.cornell.edu/courses/cs4620/2014fa/index.shtml
  - Prof. Kayvon Fatahalian and Keenan Crane, CMU, http://15462.courses.cs.cmu.edu/fall2015/