HW1 Tutorial

Outline

Section 1. BASIC GLUT - About main() function in basicDraw.cpp

1-1 Document

1-2 OpenGL Architecture

1-3 Initialization and window

1-4 Callback Registration

1-5 Geometric Object Rendering

1-6 Beginning Event Processing

Outline

Section 2. BASIC DRAW - About display() function in basicDraw.cpp

2-1 Overview – Code explanation

2-2 Clear color buffer & Clear depth buffer

2-3 Enable depth test

2-4 Draw the triangles

2-5 Complete drawing

2-6 Face culling

2-7 More Information about OpenGL …

Outline

Section 3. BASIC DRAW - How to rotate the planet in OpenGL?

- 3-1 Overview
- 3-2 ModelView Matrix
- 3-3 Modeling Transformation
- 3-4 Projection Matrix
- 3-5 Viewport Matrix
- 3-6 Matrix Stack Mechanism
- 3-7 Example

Reference

1.BASIC GLUT

About **main()** function in basicDraw.cpp

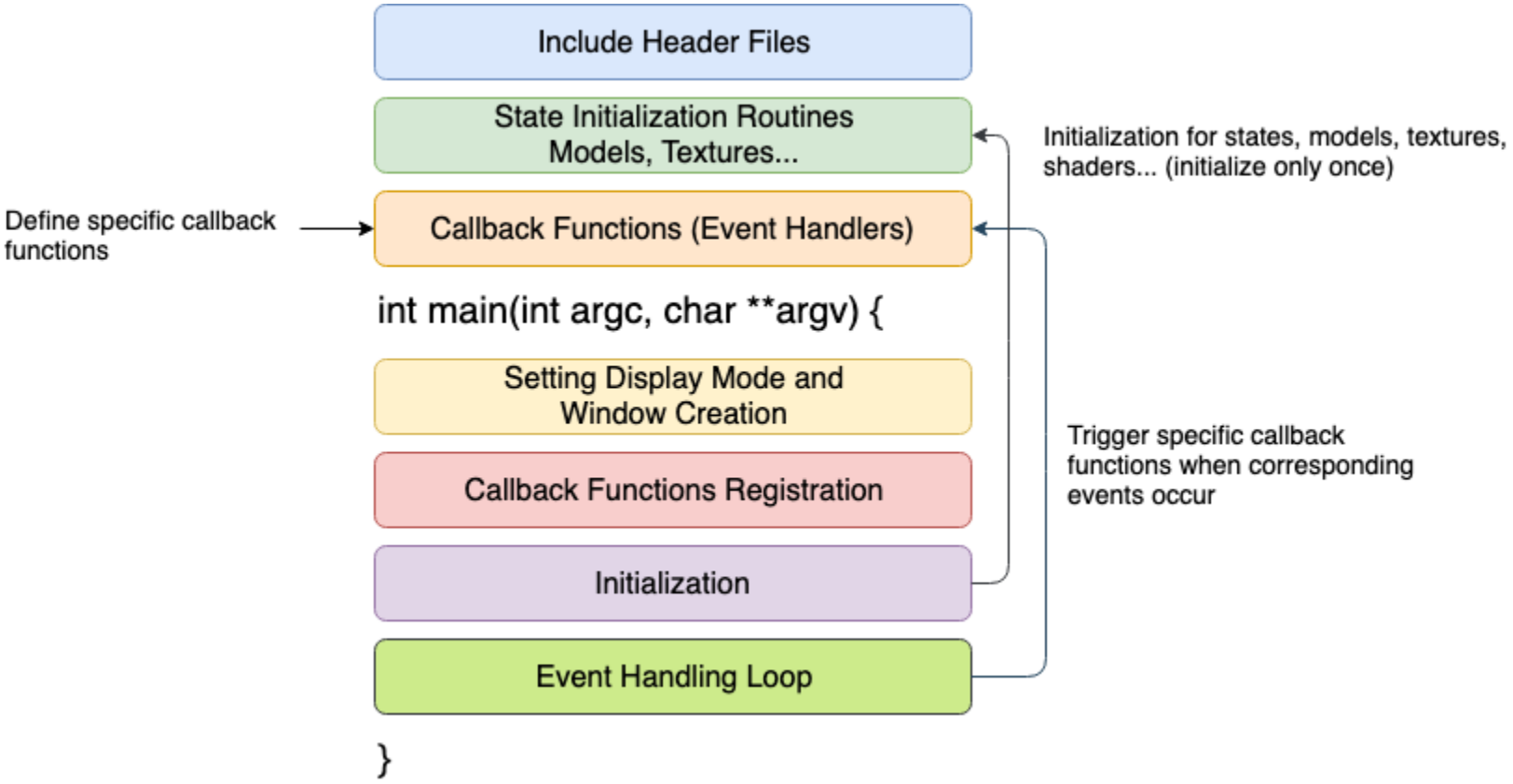
1-1 Document

- https://www.opengl.org/resources/libraries/glut/spec3/spec3.html

The OpenGL Utility Toolkit (GLUT) Programming Interface API Version 3

Mark J. Kilgard
Silicon Graphics, Inc.

1-2 OpenGL Architecture



1-3 Initialization and window

- void **glutInit**(int* argc, char **argv);
  - Initialize the GLUT library
  - Should be called before any GLUT functions
- void **glutInitDisplayMode**(unsigned int mode); (Red are commonly used parameters)
  - Specify a display mode for windows created
  - Color: GLUT_RGBA, GLUT_RGB or GLUT_INDEX
  - Framebuffer: GLUT_SINGLE or GLUT_DOUBLE
  - Buffer: GLUT_DEPTH, GLUT_STENCIL and GLUT_ACCUM

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

1-3 Initialization and window

- void **glutInitWindowSize**(int width, int height);
  - Set the initial window size
- void **glutInitWindowPosition**(int x, int y);
  - Set the initial window position
  - The actual position is left to the window system to determine
- int **glutCreateWindow**(char *name);
  - Create and open a window with previous settings

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

1-3 Initialization and window

- void **glutPostRedisplay**();
  - Mark the current window as needing to be redisplayed
  - The window‘s display callback will be called
- void **glutSwapBuffers**();
  - Swap the buffers of the current window
  - An implicit glFlush() is done by glutSwapBuffers()

```
void idle() {
    glutPostRedisplay();
}
```

```
glBegin(GL_TRIANGLES);
//red triangle (z = 0)
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(1.0f, 0.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 1.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 0.0f, 0.0f);
//blue triangle (z = -1)
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(1.0f, 0.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 1.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 0.0f, -1.0f);

glEnd();
// In display function
glutSwapBuffers();
```

1-4 Callback Registration

- void **glutDisplayFunc**(void (*func)(void));
  - Put whatever you want to render in the callback
  - The callback is called when the window need to be redisplayed
  - Call glutPostRedisplay() to trigger the callback
- void **glutReshapeFunc**(void (*func)(int width, int height));
  - The callback is called when a window is created, resized or moved
  - Always call glViewport() to resize your viewport
- void **glutIdleFunc**(void (*func)(void));
  - Perform background processing tasks or continuous animation when window system events are not being received
  - The idle callback is continuously called when events are not being received

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

1-4 Callback Registration

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

- void **glutKeyboardFunc**(void (*func)(unsigned char key, int x, int y));
  - Each key press generates a keyboard callback
  - key: The ASCII character generated by the pressed key
  - x and y: The mouse location in window relative coordinates when the key was pressed
- void **glutMouseFunc**(void (*func)(int button, int state, int x, int y));
  - Each press and each release mouse button in a window generates a mouse callback
  - button: GLUT_LEFT_BUTTON, GLUT_MIDDLE_BUTTO or GLUT_RIGHT_BUTTON
  - state: GLUT_UP or GLUT_DOWN
  - x and y: The mouse location in window relative coordinates when the mouse was pressed

1-4 Callback Registration

- void **glutMotionFunc**(void (*func)(int x, int y));
  - The callback is called when the mouse moves within the window while any mouse buttons are pressed
  - x and y: the mouse location in window relative coordinates
- void **glutPassiveMotionFunc**(void (*func)(intx, inty));
  - The callback is called when the mouse moves within the window while no mouse buttons are pressed
  - x and y: the mouse location in window relative coordinates

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

1-5 Geometric Object Rendering

- void **glutSolidSphere**(Gldouble size, GLint slices, GLint stacks);
- void **glutWireSphere**(Gldouble size, GLint slices, GLint stacks);
- void **gluCylinder**(GLUquadric* quad, GLdouble base, GLdouble top,
  GLdouble height, GLint slices, GLint stacks);
- void **glutSolidCube**(Gldouble size); void **glutWireCube**(Gldouble size);
- void **glutSolidCone**(Gldouble size); void **glutWireCone**(Gldouble size);
- void **glutSolidTorus**(Gldouble size);void **glutWireTorus**(Gldouble size);
- void **glutSolidTeapot**(Gldouble size); void **glutWireTeapot**(Gldouble size);

1-6 Beginning Event Processing

- void glutMainLoop();
  - Enter the GLUT event processing loop
  - Once called, this routine will never return

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(width, height);
    glutInitWindowPosition(0, 0);
    glutCreateWindow("WindowName");

    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mouseMotion);
    glutPassiveMotionFunc(passiveMouseMotion);
    glutIdleFunc(idle);

    glutMainLoop();

    return 0;
}
```

2.BASIC DRAW

About display() function in basicDraw.cpp

2-1. In the function **display()** of basicDraw.cpp,
We do the following things,

1. Set up the MVP matrix (Mentioned later in the Section. 3 OpenGL-Transform)

2. Before drawing, we need to clear the color buffer and depth buffer by **glClear()** with the values set by **glClearColor()** and **glClearDepth()**

3. Enable the option for depth test so the face behind other faces would not render in the front

4. Draw two triangles by glColor3f() and glVertex3f() between **glBegin(), glEnd()**

5. In the end, swap the buffers by **glutSwapBuffers()**

In the next pages, we will introduce the openGL functions used in these steps since step2. And if you want to know more detailed information about the functions, please go to the link:
https://www.khronos.org/registry/OpenGL-Refpages/gl2.1/

```
//ModelView Matrix
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(0.0f, 0.0f, 10.0f, 0.0f, 0.0f, 0.0f, 0.0f, 1.0f, 0.0f);
//Projection Matrix
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
gluPerspective(45, width / (GLfloat)height, 0.1, 1000);
//Viewport Matrix
glViewport(0, 0, width, height);

//
glMatrixMode(GL_MODELVIEW);
glClearColor(0.0f, 0.0f, 0.0f, 0.0f);
glClear(GL_COLOR_BUFFER_BIT);
glClearDepth(1.0);
glEnable(GL_DEPTH_TEST);    //depth test
glDepthFunc(GL_LEQUAL);
glClear(GL_DEPTH_BUFFER_BIT);

glBegin(GL_TRIANGLES);
//red triangle (z = 0)
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(1.0f, 0.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 1.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 0.0f, 0.0f);
//blue triangle (z = -1)
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(1.0f, 0.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 1.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 0.0f, -1.0f);

glEnd();

glutSwapBuffers();
```

STEP1
STEP2
STEP3
STEP4
STEP5

2-2. Clear color buffer & Clear depth buffer

Before we start a new render iteration, we need to clear our color buffer and depth buffer, otherwise you're stuck with the written color values and depth values from the last render iteration.
Here are the functions used for buffer cleaning:

```
//
glMatrixMode(GL_MODELVIEW);
glClearColor(0.0f, 0.0f, 0.0f, 0.0f);
glClear(GL_COLOR_BUFFER_BIT);
glClearDepth(1.0);
glEnable(GL_DEPTH_TEST);    //depth test
glDepthFunc(GL_LEQUAL);
glClear(GL_DEPTH_BUFFER_BIT);
```

- void **glClearColor**(GLfloat red,
  GLfloat green,
  GLfloat blue,
  GLfloat alpha);

Specify the red, green, blue, and alpha values used when the color buffers are cleared. The initial values are all 0. (black)

- void **glClearDepth**(GLdouble depth);

Specify the depth value used when the depth buffer is cleared. The initial value is 1. The depth is in the range [0, 1].

- void **glClear**(GLbitfield mask);

Clear the specified buffers to their current clearing values selected by glClearColor(), glClearDepth(), and glClearStencil().

mask: **GL_COLOR_BUFFER_BIT, GL_DEPTH_BUFFER_BIT,**
GL_STENCIL_BUFFER_BIT

EX:
glClear(GL_COLOR_BUFFER_BIT |GL_DEPTH_BUFFER_BIT);

2-3. Enable depth test

In order to prevent faces rendering to the front while they're behind other faces, we need to enable depth test before drawing:
Here are the functions for enabling depth test:

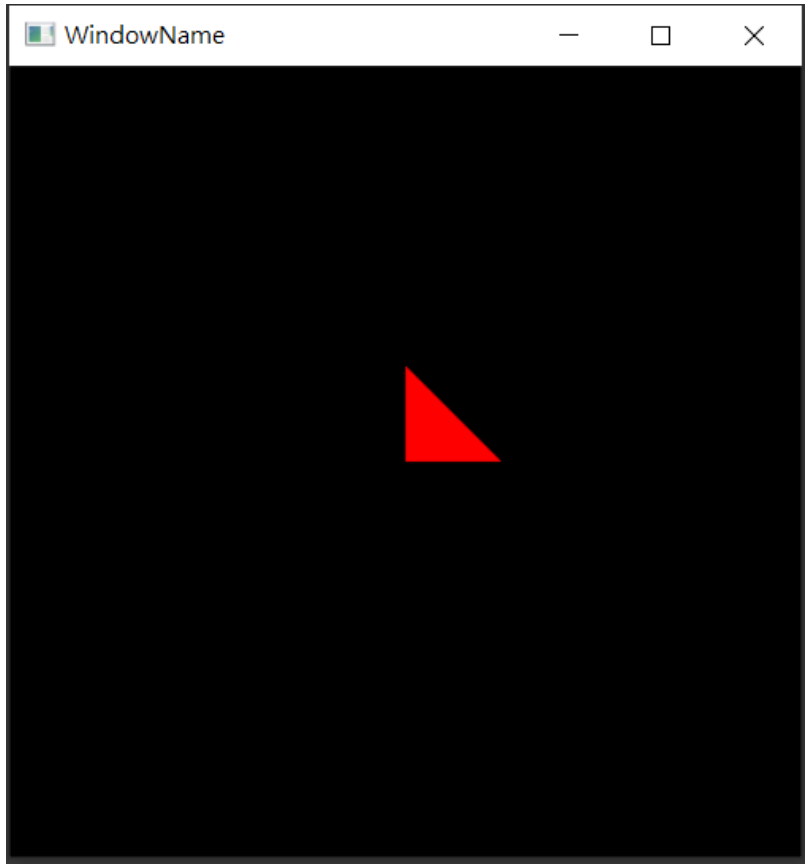
- **glEnable**(GL_DEPTH_TEST);

When depth test is enabled, OpenGL tests the depth value of a fragment against the content of the depth buffer. If this test passes, the depth buffer is updated with the new depth value. If the test fails, the fragment is discarded.

- void **glDepthFunc**(GLenum func);

Specify the depth comparison function for the depth test.
func: GL_NEVER, GL_LESS, GL_EQUAL, GL_LEQUAL, GL_GREATER... The initial value is GL_LESS
Ex. glDepthFunc(GL_LEQUAL); =>
if (fragment's depth value <= stored depth value) pass.

```
//
glMatrixMode(GL_MODELVIEW);
glClearColor(0.0f, 0.0f, 0.0f, 0.0f);
glClear(GL_COLOR_BUFFER_BIT);
glClearDepth(1.0);
glEnable(GL_DEPTH_TEST);    //depth test
glDepthFunc(GL_LEQUAL);
glClear(GL_DEPTH_BUFFER_BIT);
```



This is the output of the BasicDraw.cpp, what will happen if we don’t enable the depth test?
(Try to delete the glEnable() and run the code basicDraw.cpp by yourself.)

If you are interested in more information about depth test:

https://learnopengl.com/Advanced-OpenGL/Depth-testing

2-4. Draw the triangles

By the help of OpenGL, we can draw our triangles by simply setting the vertex data **between glBegin() and glEnd()**

- void **glBegin**(Glenum mode);

Marks the beginning of a vertex-data list.
Vertex-data include vertex's color, normal, position, etc.
The mode specifies the primitive or primitives that will be created from vertices presented between glBegin() and glEnd().

- void **glEnd**();

Marks the end of a vertex-data list

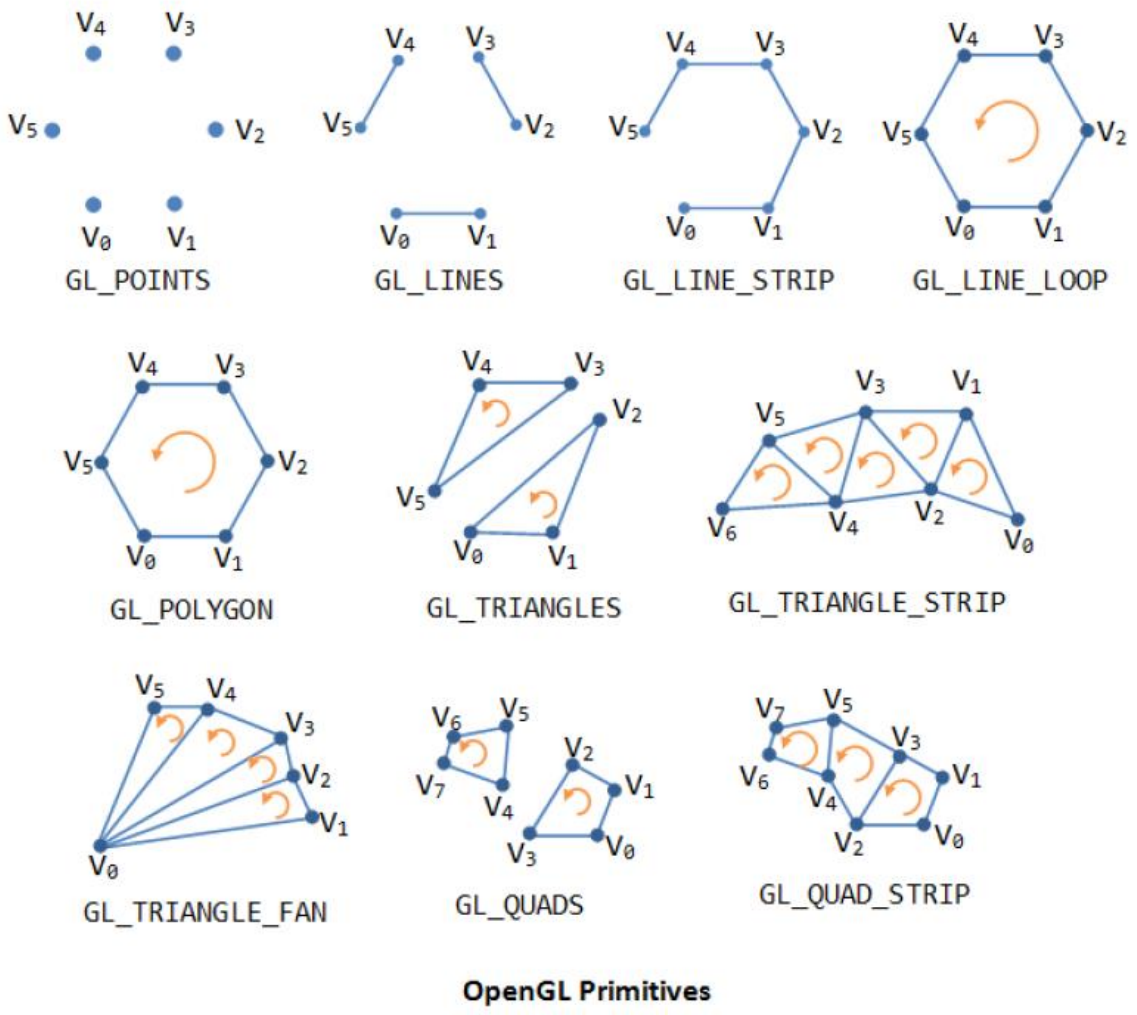
```
glBegin(GL_TRIANGLES);
//red triangle (z = 0)
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(1.0f, 0.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 1.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 0.0f, 0.0f);
//blue triangle (z = -1)
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(1.0f, 0.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 1.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 0.0f, -1.0f);

glEnd();

glutSwapBuffers();
```

2-4. Draw the triangles

mode of glBegin() :



OpenGL Primitives

2-4. Draw the triangles

Can only be effective between glBegin() and glEnd() pair

- void **glColor**{34}{sifd}[v](…);
  Set the current color

- void **glMaterialfv**(GLenum face,
  GLenum pname,
  const GLfloat *params);
  Specify material parameters for the lighting model
  (If HW1 use lighting, use this to set the color!)

- void **glNormal3**{bsifd}[v](…)
  Set the current normal vector

- void **glVertex**{234}{sifd}[v](…)
  Specify a vertex for use in describing a geometric object

You have to set vertex's attributes before glVertex

Ex: Use **glColor()** and **glNormal()** before **glVertex()** to set the vertex's color and normal.

```
glBegin(GL_TRIANGLES);
//red triangle (z = 0)
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(1.0f, 0.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 1.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 0.0f, 0.0f);
//blue triangle (z = -1)
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(1.0f, 0.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 1.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 0.0f, -1.0f);

glEnd();

glutSwapBuffers();
```

2-5. Complete drawing

Don’t forget to swap the buffers when you complete drawing

- void **glutSwapBuffers();**
  Swap the front and back buffers.

```
glBegin(GL_TRIANGLES);
//red triangle (z = 0)
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(1.0f, 0.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 1.0f, 0.0f);
glColor3f(1.0f, 0.0f, 0.0f);
glVertex3f(0.0f, 0.0f, 0.0f);
//blue triangle (z = -1)
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(1.0f, 0.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 1.0f, -1.0f);
glColor3f(0.0f, 0.0f, 1.0f);
glVertex3f(0.0f, 0.0f, -1.0f);

glEnd();

glutSwapBuffers();
```

2-6 Face culling

OpenGL checks and renders all the faces that are front facing towards the viewer while discarding all the back face.

- **glEnable**(GL_CULL_FACE);

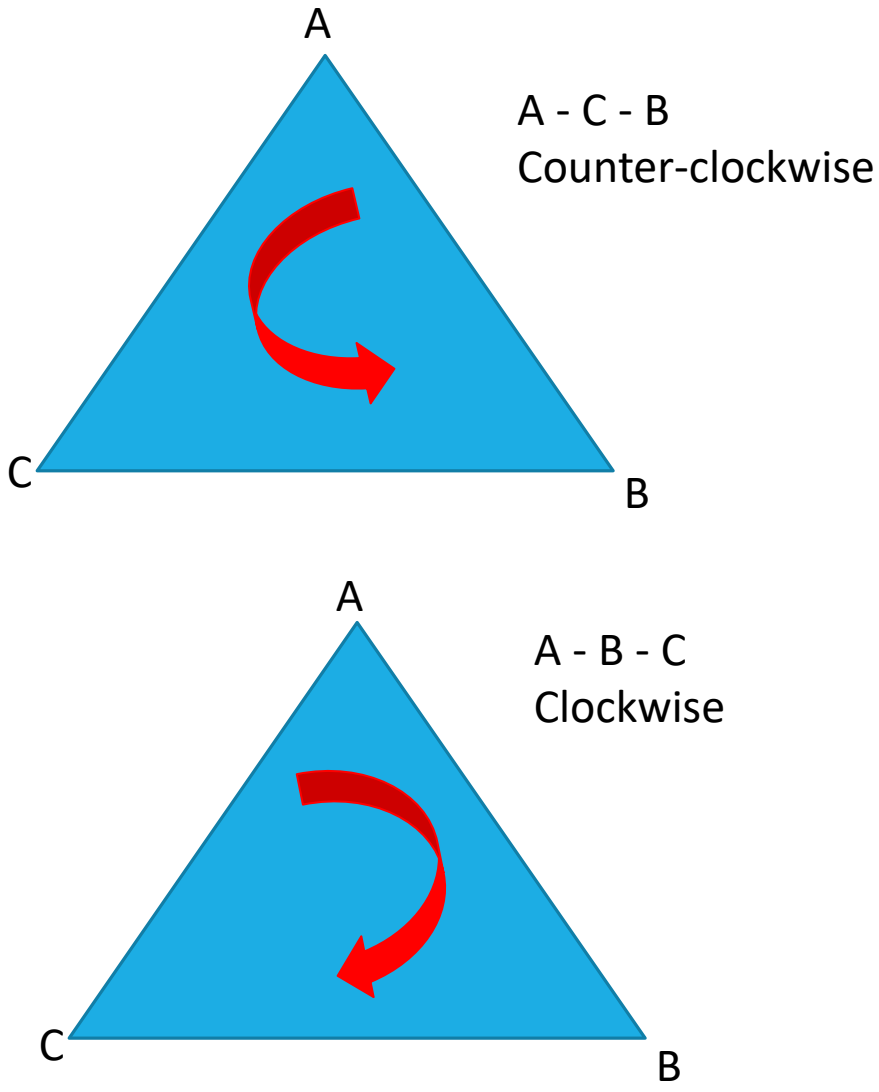
  Enable OpenGL's GL_CULL_FACE option.

- void **glCullFace** (GLenum mode)

  Specify whether front or back facing faces can be culled.
  mode: GL_BACK,GL_FRONT,GL_FRONT_AND_BACK
  Ex. glCullFace(GL_BACK) culls only the back faces. OpenGL allows us to change the type of face that we want to cull as well.

- void **glFrontFace** (GLenum mode);

  Define front and back facing polygons
  mode: GL_CW, GL_CCW. The default value is GL_CCW.
  Ex. glFrontFace(GL_CCW) =>counter-clockwise ordering



2-7 More Information about OpenGL …
OpenGL data type

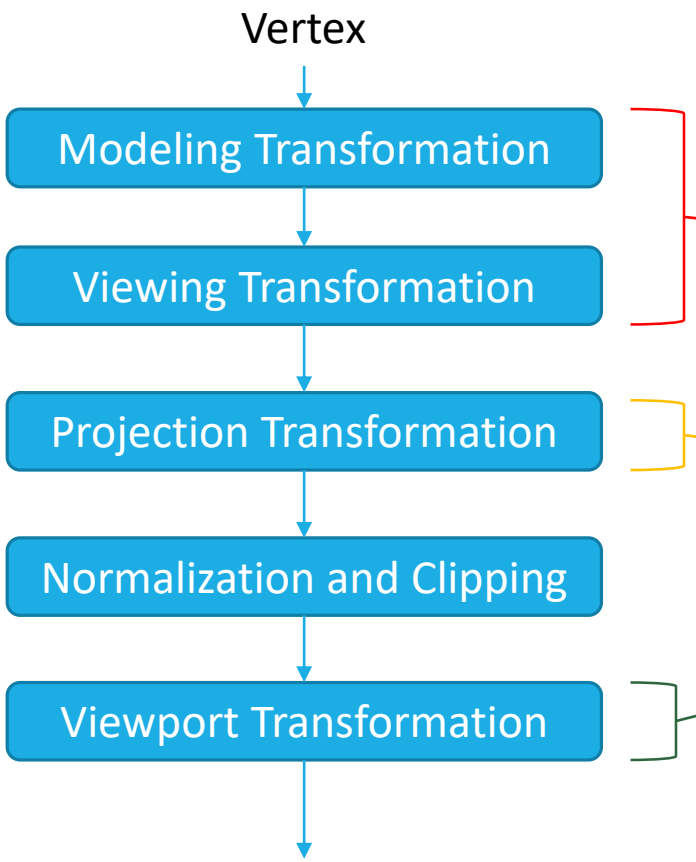
Table 3-2 OpenGL variable types and corresponding C data types

OpenGL Data Type	Internal Representation	Defined as C Type	C Literal Suffix
GLbyte	8-bit integer	Signed char	b
GLshort	16-bit integer	Short	s
GLint, GLsizei	32-bit integer	Long	I
GLfloat, GLclampf	32-bit floating point	Float	f
GLdouble, GLclampd	64-bit floating point	Double	d
GLubyte, GLboolean	8-bit unsigned integer	Unsigned char	ub
GLushort	16-bit unsigned integer	Unsigned short	us
GLuint, GLenum, GLbitfield	32-bit unsigned integer	Unsigned long	ui

OpenGL-Transform

How to rotate the planet in OpenGL?

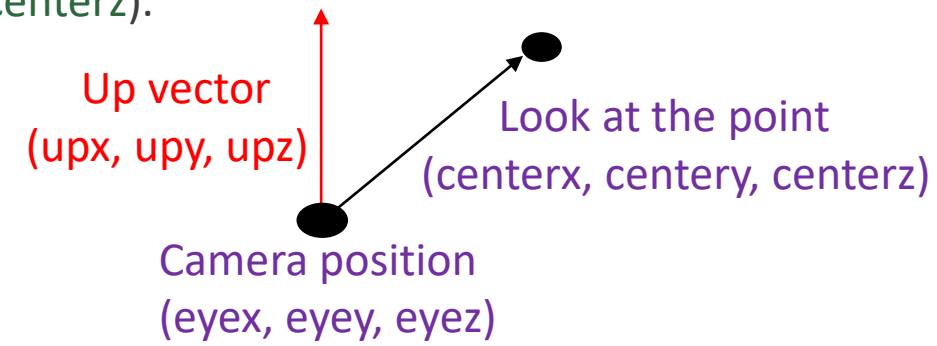
3-1 Overview




```
void display()
{
    //ModelView Matrix
    glMatrixMode(GL_MODELVIEW);
    glLoadIdentity();
    gluLookAt(0.0f, 0.0f, 10.0f, 0.0f, 0.0f, 0.0f, 0.0f, 1.0f, 0.0f);
    //Projection Matrix
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    gluPerspective(45, width / (GLfloat)height, 0.1, 1000);
    //Viewport Matrix
    glViewport(0, 0, width, height);
```

3-2 ModelView Matrix

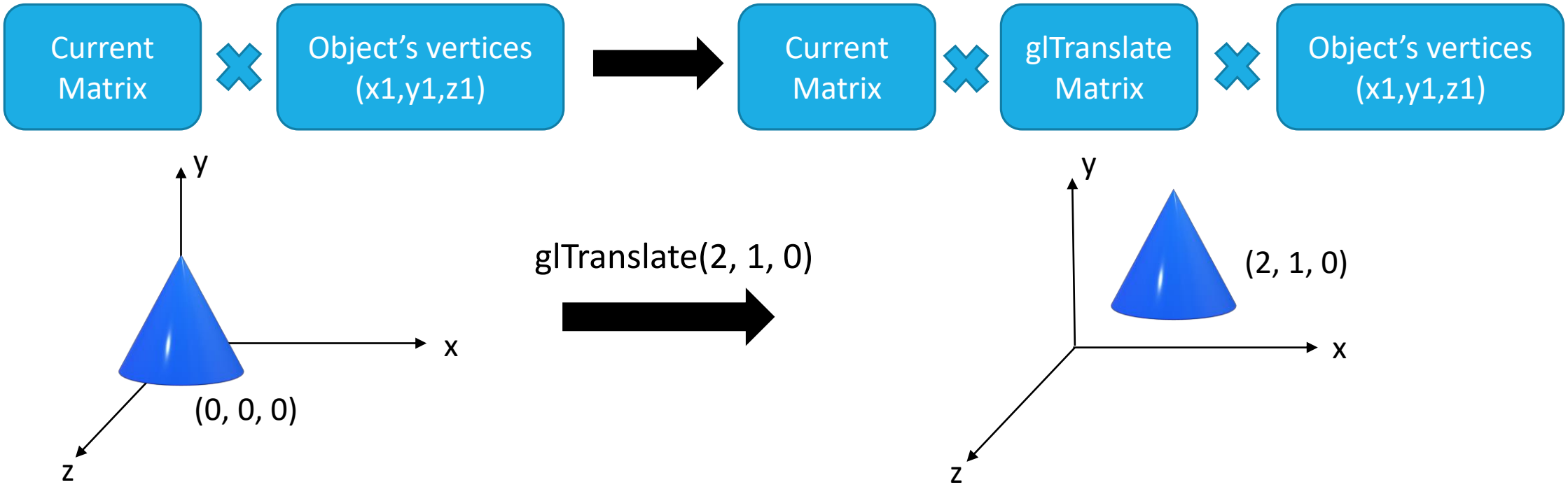
- void **glMatrixMode** (GLenum mode);
  - There are three different modes : GL_MODELVIEW, GL_PROJECTION, or GL_TEXTURE.
  - Each mode has its corresponding matrix stack, and only one matrix stack is active at a time.
- void **glLoadIdentity** (void);
  - Replace the current matrix with the identity matrix.
- void **gluLookAt** (GLdouble eyex, GLdouble eyey, GLdouble eyez, GLdouble centerx, GLdouble centery, GLdouble centerz, GLdouble upx, GLdouble upy, GLdouble upz);
  - Viewing direction is from (eyex, eyey, eyez) to (centerx, centery, centerz).
  - Camera's up vector is (upx, upy, upz).
  - Changing the parameters in gluLookAt() means changing the camera's position, not the object's position.



3-3 Modeling Transformation

➢void **glTranslate{fd}** (TYPE x, TYPE y, TYPE z);

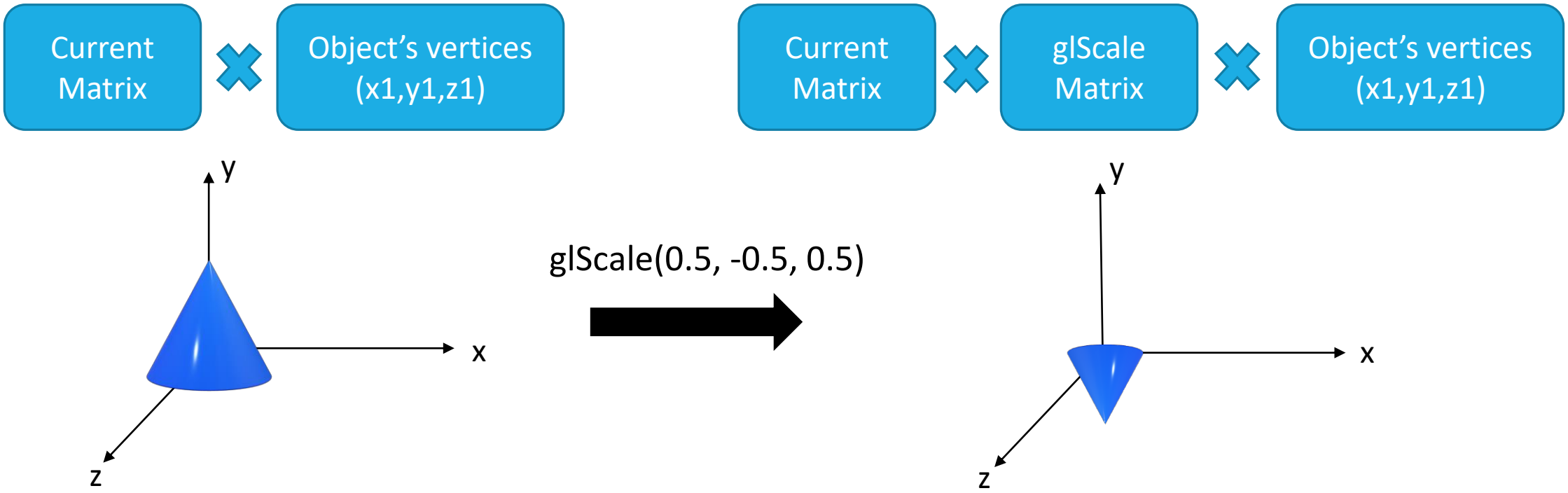
It will translate the object's vertices by the given x, y, z values.



3-3 Modeling Transformation

➢void **glScale{fd}**(TYPE x, TYPE y, TYPE z);

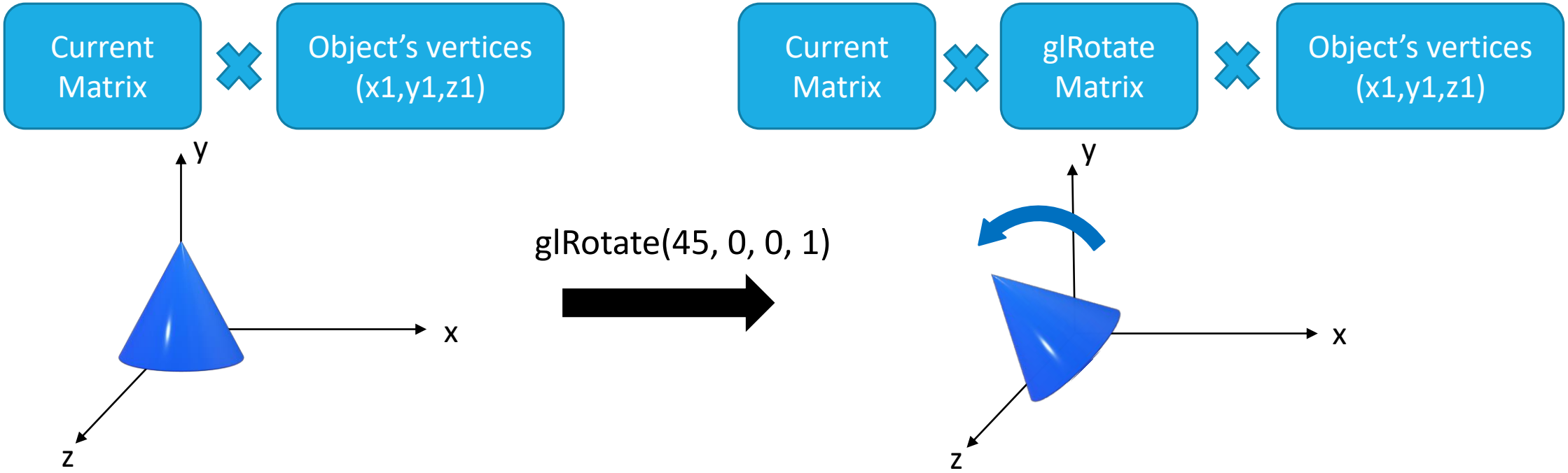
It will scale the object along the x, y, or z axes.



3-3 Modeling Transformation

➢void **glRotate{fd}**(TYPE angle, TYPE x, TYPE y, TYPE z);

It will rotate the object in a counterclockwise direction. The angle parameter is the angle of rotation in degrees. The rotating axis is from the origin to the point (x, y, z).



3-3 Modeling Transformation

In OpenGL, matrices multiplications are in reverse order when applied to the vertices.

……

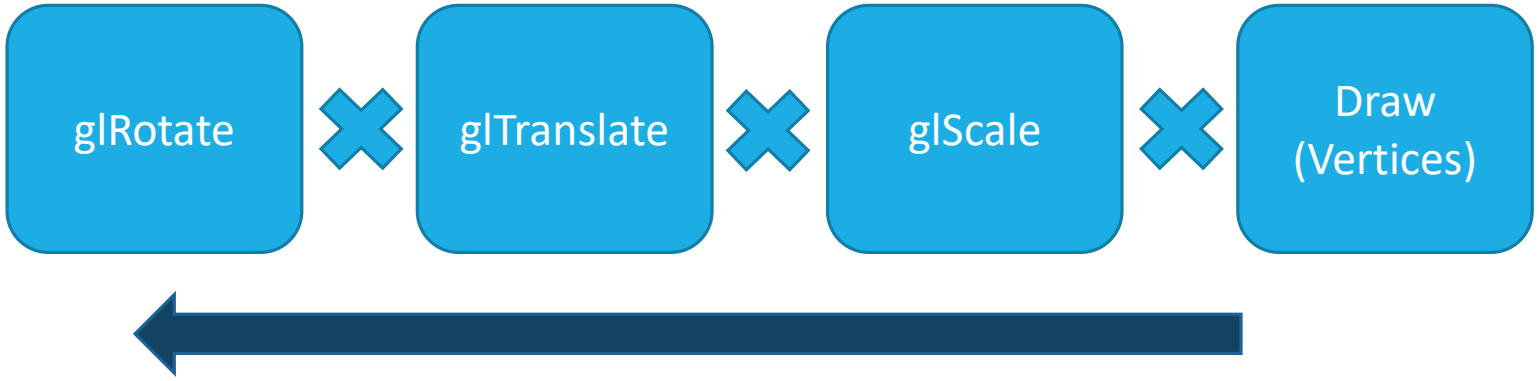
glRotate();

glTranslate();

glScale();

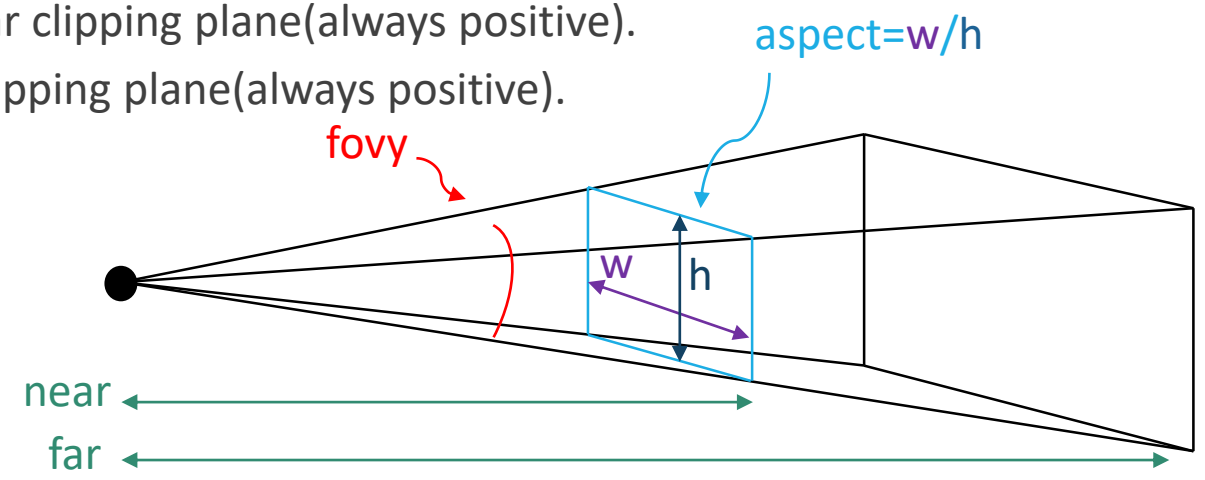
Draw();

……



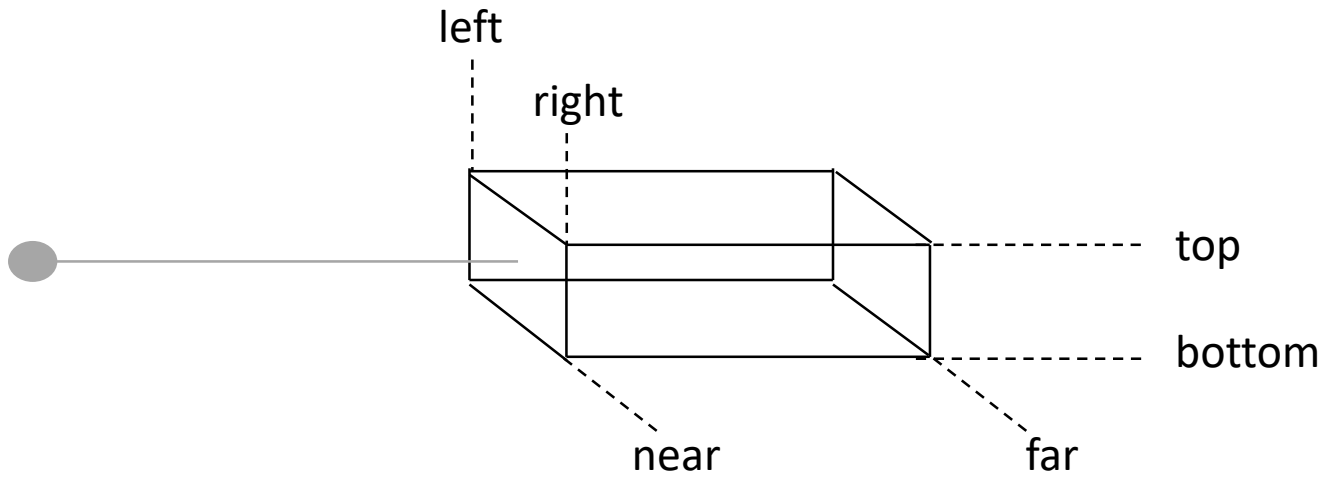
3-4 Projection Matrix --- Perspective Projection

- **glMatrixMode**(GL_PROJECTION);
- **glLoadIdentity**();
- void **gluPerspective** (GLdouble fovy, GLdouble aspect, GLdouble near, GLdouble far);
  - fovy : the angle of the field of view in the y direction.(in degrees)
  - aspect : the aspect ratio(w/h) that determines the field of view.
  - near : the distance between the viewer to the near clipping plane(always positive).
  - far : the distance between the viewer to the far clipping plane(always positive).



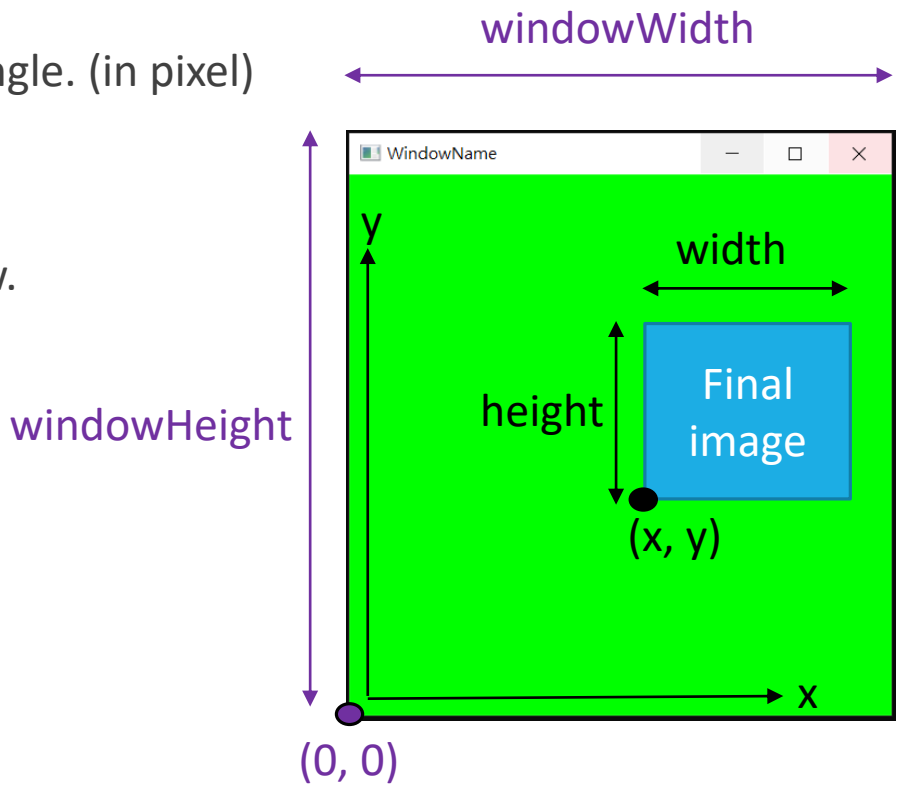
3-4 Projection Matrix --- Orthographic Projection

- void **glOrtho** (GLdouble left, GLdouble right, GLdouble bottom, GLdouble top, GLdouble near, GLdouble far);
  - left, right : the coordinates of the left and right vertical clipping planes.
  - bottom, top : the coordinates of the bottom and top horizontal clipping planes.
  - near, far : the coordinates of the near and far depth clipping planes.



3-5 Viewport Matrix

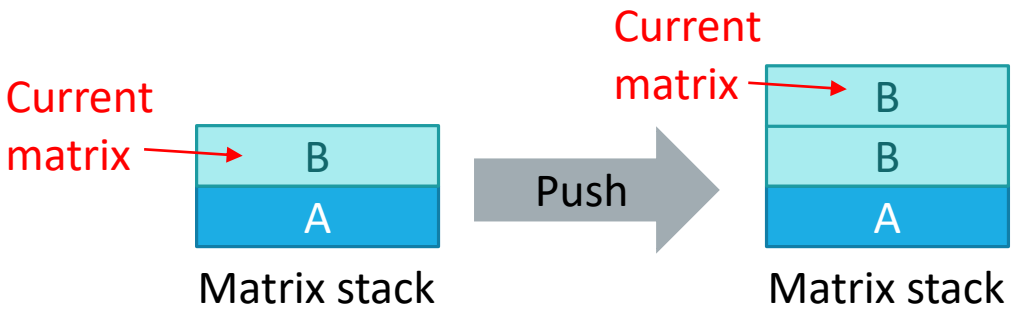
- void **glViewport** (GLint x, GLint y, GLsizei width, GLsizei height);
  - Map the final image to some region of the window.
  - The point (x, y) : the lower-left corner of the viewport rectangle. (in pixel)
  - width, height : the size of the viewport rectangle.
  - default value : (0, 0, windowWidth, windowHeight)
  - windowWidth and windowHeight are the size of the window.



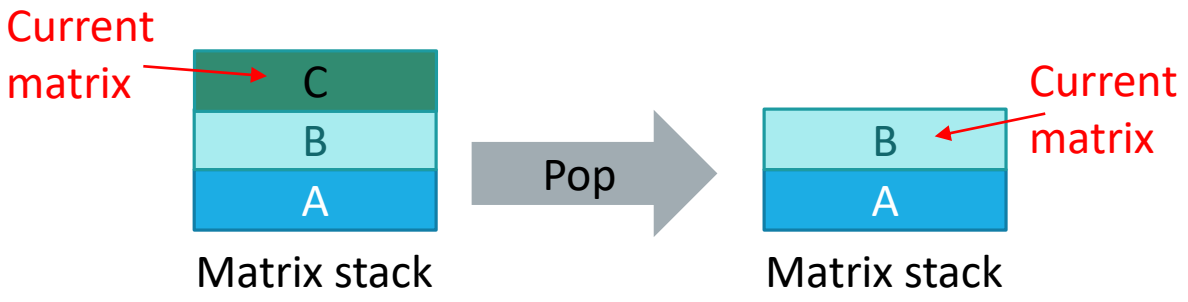
3-6 Matrix Stack Mechanism

- You can store certain transformation matrix on the matrix stack and easily get it when you want to reuse.
- The top of the matrix stack is the current matrix.
- Use **glPushMatrix()** and **glPopMatrix()** to manage the stack.

void **glPushMatrix()** :
Push the current matrix on the top of the stack.



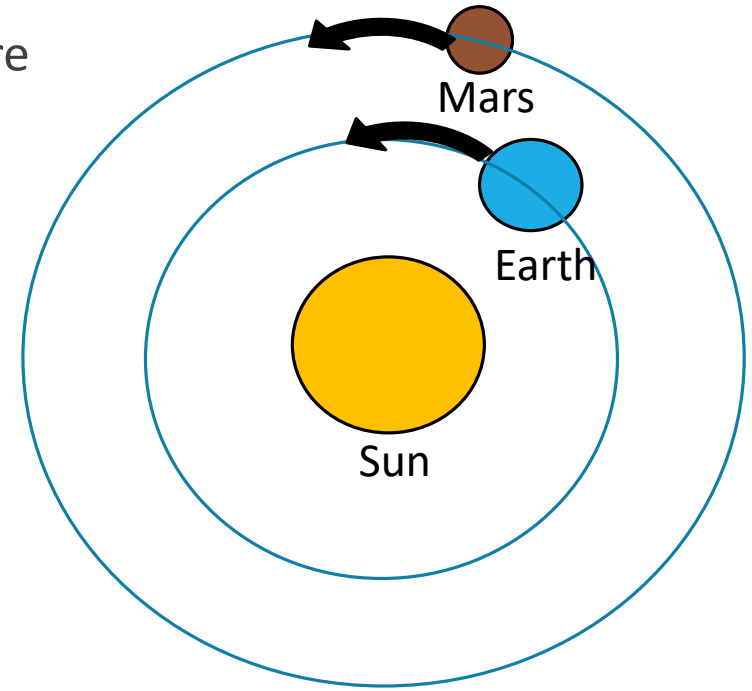
void **glPopMatrix()** :
Pop the top matrix off the matrix stack.



3-7 Example

- How to draw a solar system?

The sun is in the center, and the Earth and the Mars are rotating around the sun.



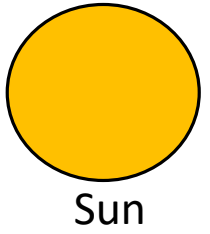
Step 1


```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(…….); //matrix M
glMatrixMode(GL_PROJECTION);
……
```

Set up default transform matrices.

Step 2


```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(…….); //matrix M
glMatrixMode(GL_PROJECTION);
……
glMatrixMode(GL_MODELVIEW);
drawSun();
```

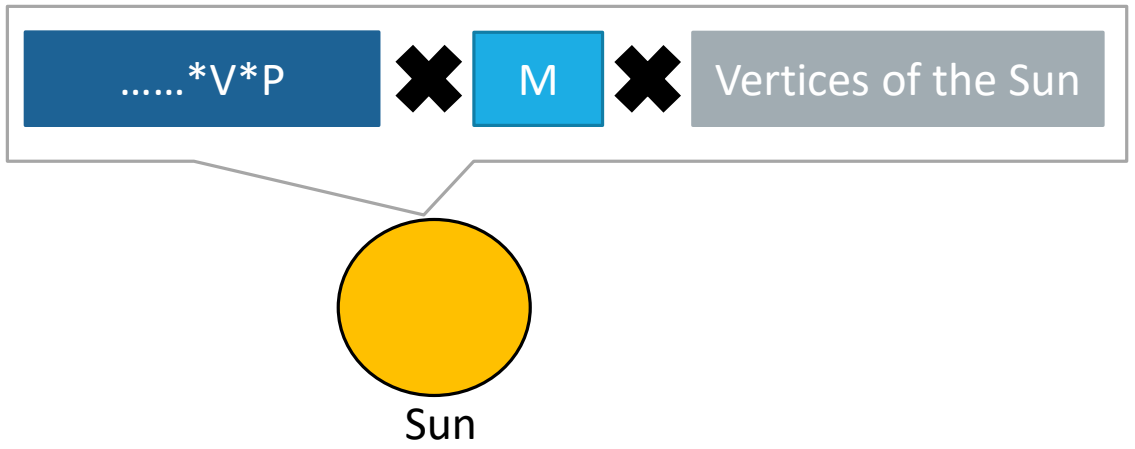


Activate the matrix stack of the MODELVIEW, and draw the Sun at the default position.

Step 2

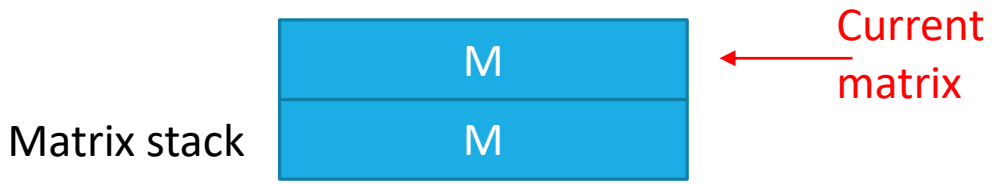

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(…….); //matrix M
glMatrixMode(GL_PROJECTION);
……
glMatrixMode(GL_MODELVIEW);
drawSun();
```

```
glBegin();
…… //vertex data list
……
glEnd();
```

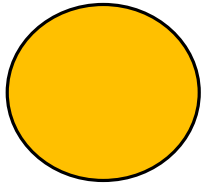


In the function drawSun(), it set up the vertex data list.

Step 3



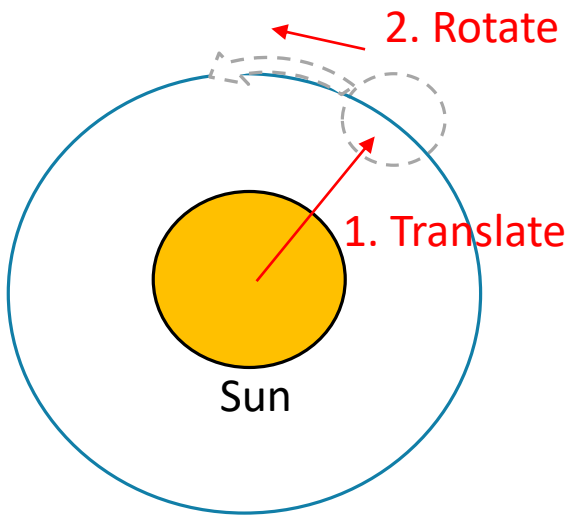

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(…….); //matrix M
glMatrixMode(GL_PROJECTION);
……
glMatrixMode(GL_MODELVIEW);
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
```



Use glPushMatrix() to store the position of the Sun.

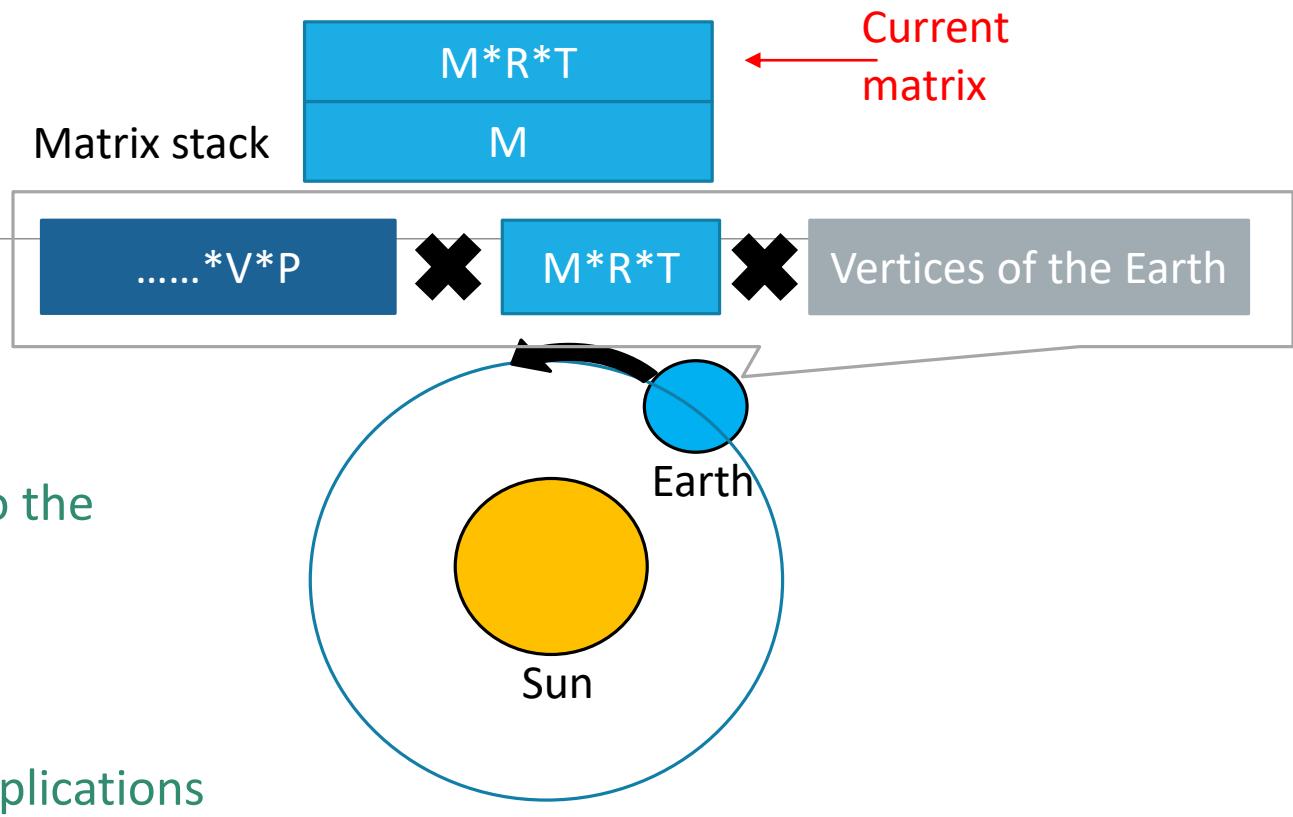
Step 4


```
……..
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
glRotate();
glTranslate(); //remember that matrices multiplications
are in reverse order
```



To draw the Earth rotating around the Sun, we first translate it to certain position and then rotate it.

Step 5

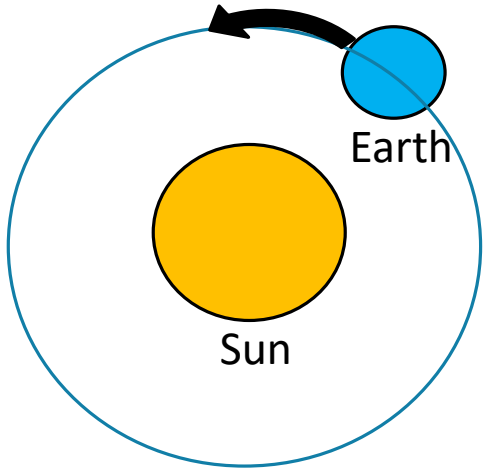



```
……..
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
glRotate();
glTranslate(); //remember that matrices multiplications
are in reverse order
drawEarth();
```

Use drawEarth() to draw on the window.

Step 6


```
……….
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
glRotate();
glTranslate(); //remember that matrices multiplications
are in reverse order
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
```

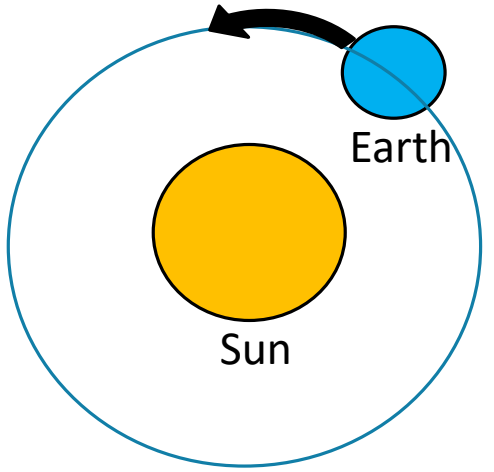


We want to draw the Mars which was also rotating around the Sun, so we need to pop off the current matrix(matrix M*R*T) to get the Sun position(matrix M)

Step 6

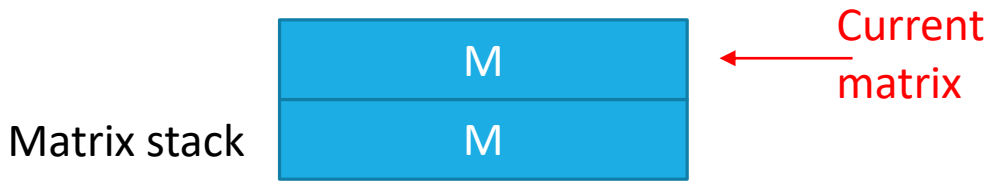
Matrix stack M*R*T*T*R ← Current matrix

```
……..
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
glRotate(a);
glTranslate(b); //remember that matrices multiplications
are in reverse order
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
glTranslate(-b);  glRotate(-a);   //inverse
```

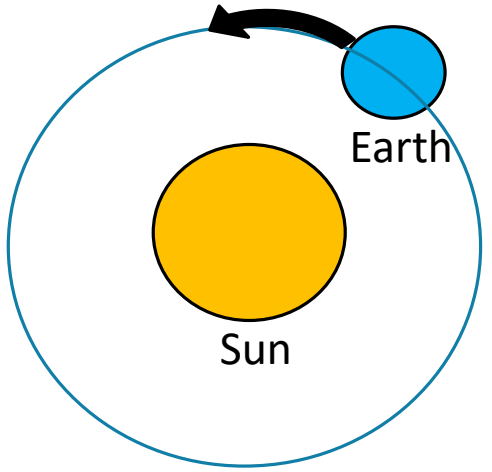


However, If you don't use glPushMatrix() and glPopMatrix() in your code, then you need to multiply the inverse matrix of Rotate and Translate to get the Sun position.

Step 7



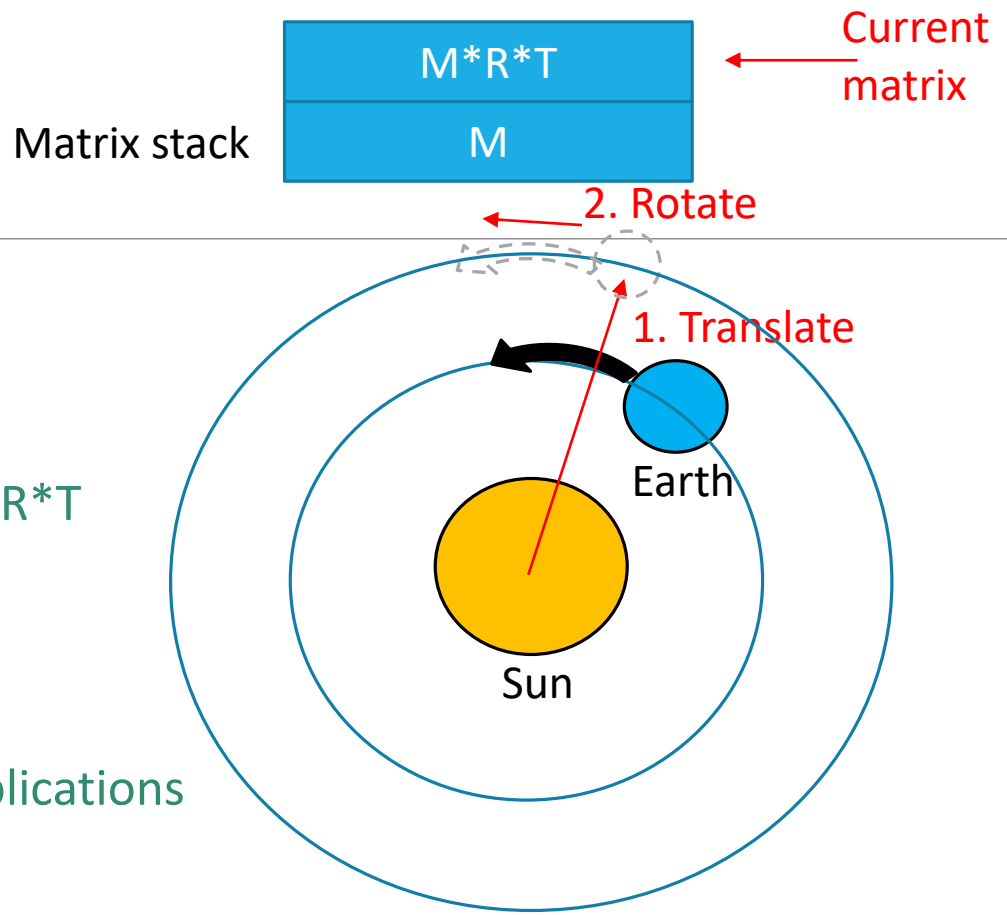

```
……….
drawSun();
glPushMatrix();//push the current matrix M to the
 top of the matrix stack
glRotate();
glTranslate(); //remember that matrices multiplications
are in reverse order
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
glPushMatrix();//store the Sun again
```



Same as before, we use glPushMatrix() to store the Sun again.

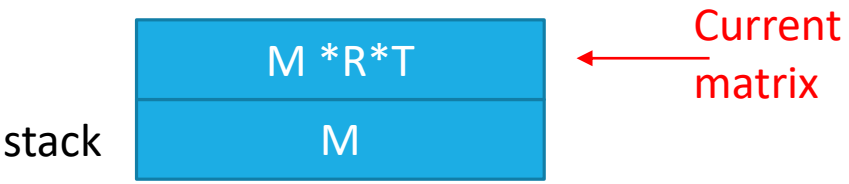
Step 8

```
……
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
glPushMatrix();//store the Sun again
glRotate();
glTranslate(); //remember that matrices multiplications
are in reverse order
```



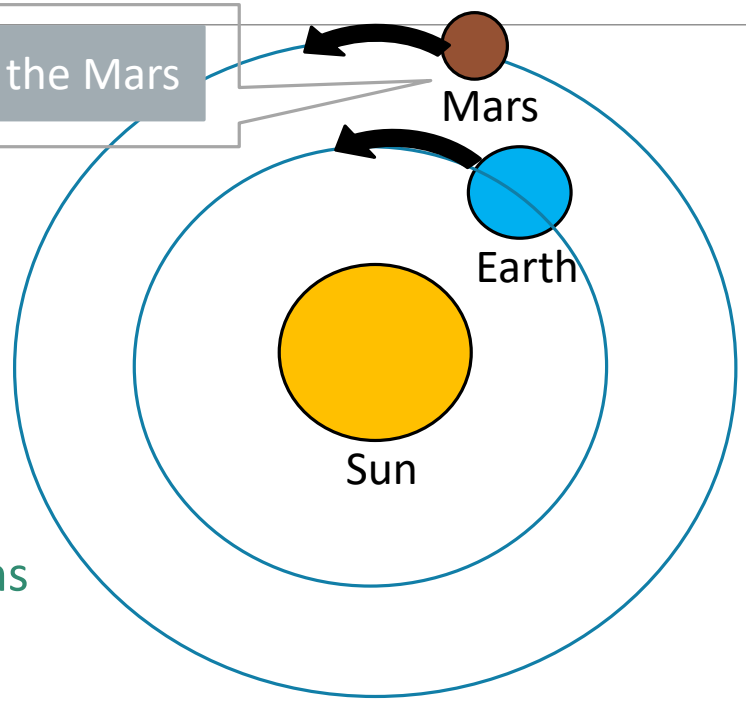
Same as before, we translate it to certain position and then rotate it.

Step 9



……

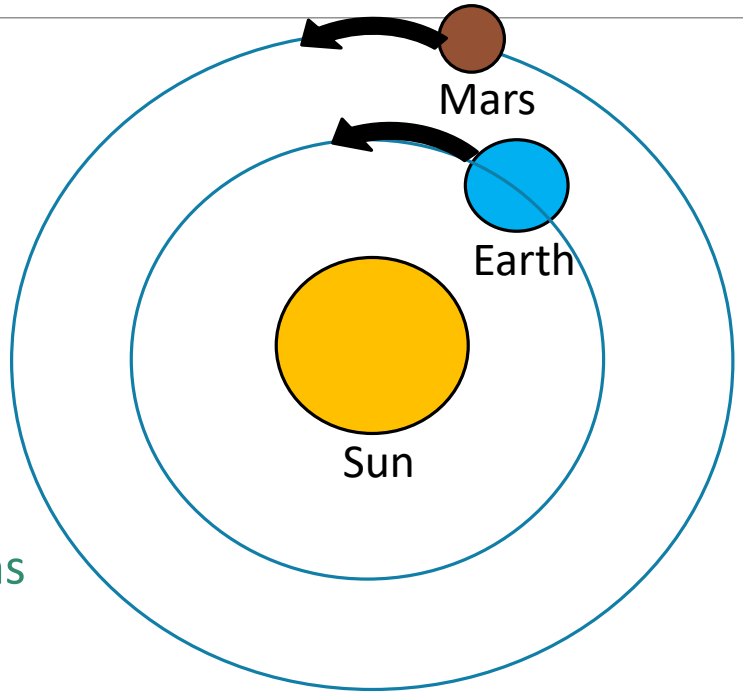
```
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
glPushMatrix();//store the Sun again
glRotate();
glTranslate(); //remember that matrices multiplications are in reverse order
drawMars();
```



Use drawMars() to draw on the window.

Step 10


```
……
drawEarth();
glPopMatrix(); //pop off the current matrix M*R*T
glPushMatrix();//store the Sun again
glRotate();
glTranslate(); //remember that matrices multiplications are in reverse order
drawMars();
glPopMatrix(); //pop off the current matrix M*R*T
```



Pop off the current matrix(matrix M*R*T) to get the Sun position(matrix M), if you want to draw other planets.

Reference

https://www.khronos.org/registry/OpenGL-Refpages/gl2.1/

https://learnopengl.com/

http://opengl.czweb.org/ch03/031-034.html