COSE436

Lecture 6:
OpenGL Transformation

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Outline

- OpenGL transformation
- Virtual trackball

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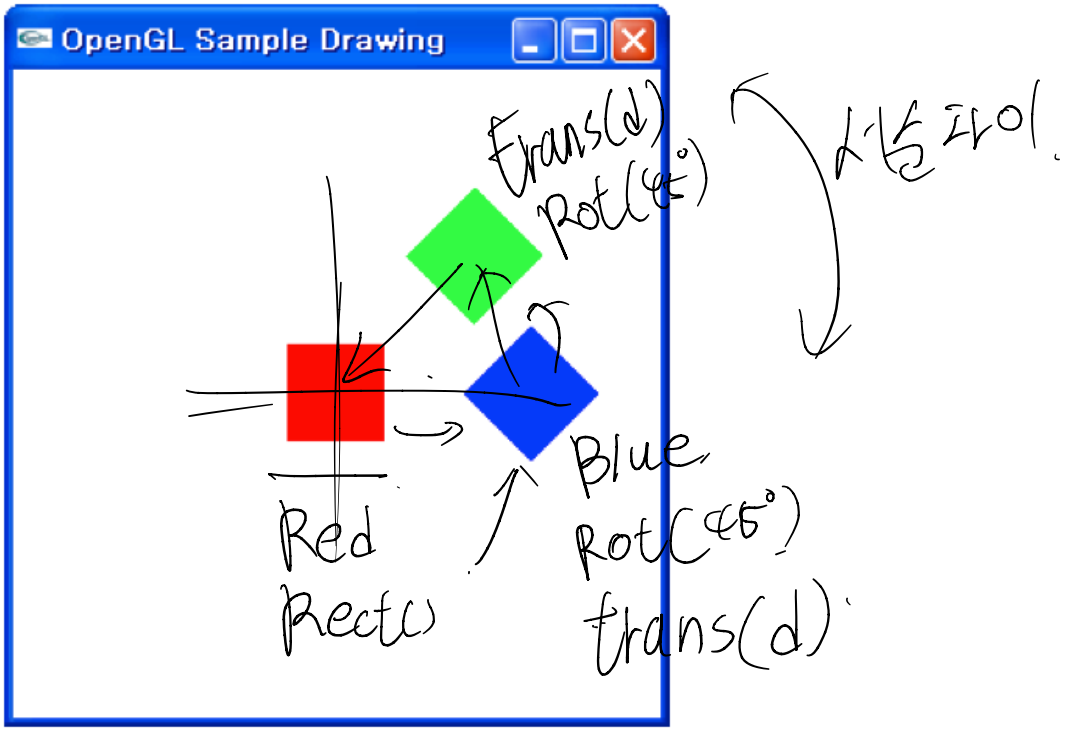
- Virtual trackball

Modeling Transformation ⇒ object transform

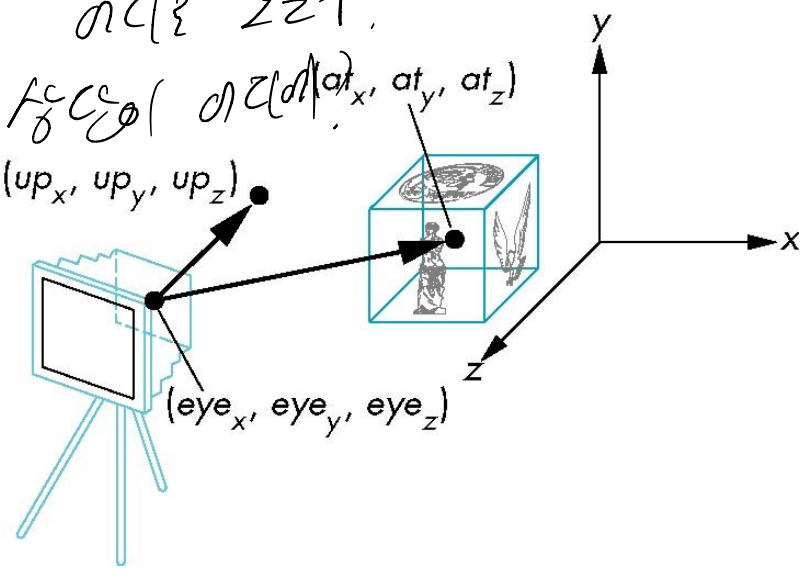
= Object

- Local to global coordinate transform
- Rotate, Translate, Scale



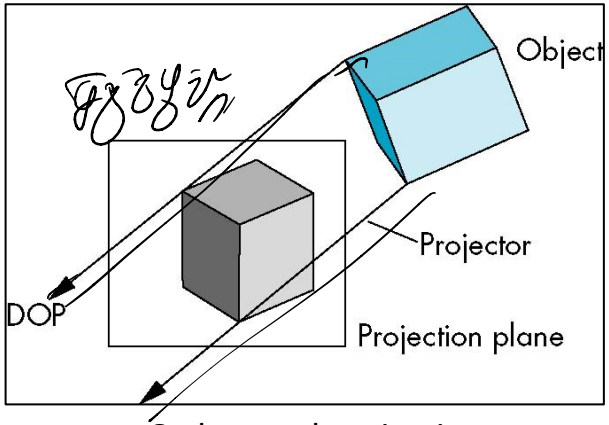
Viewing Transformation

- Global to 3D viewing coordinate transform
- Set eye position and viewing direction
- LookAt(eyex/y/z, atx/y/z, upx/y/z)
  - eye x/y/z : eye position (x,y,z)
  - at x/y/z : viewing direction
  - up x/y/z : up vector

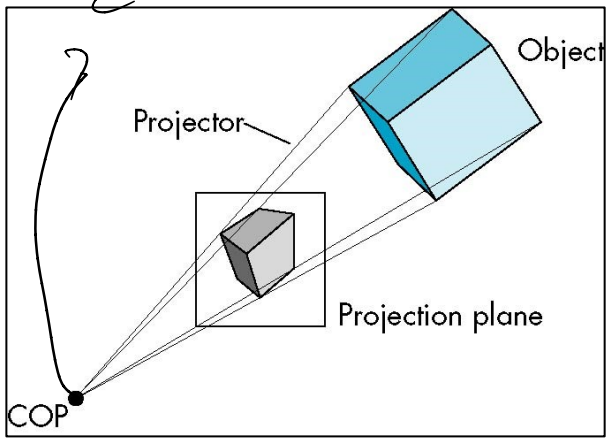


Projection Transformation

- 3D to 2D viewing coordinate transform
- Define clipping volume
- Projection types
  - Orthogonal
  - Perspective



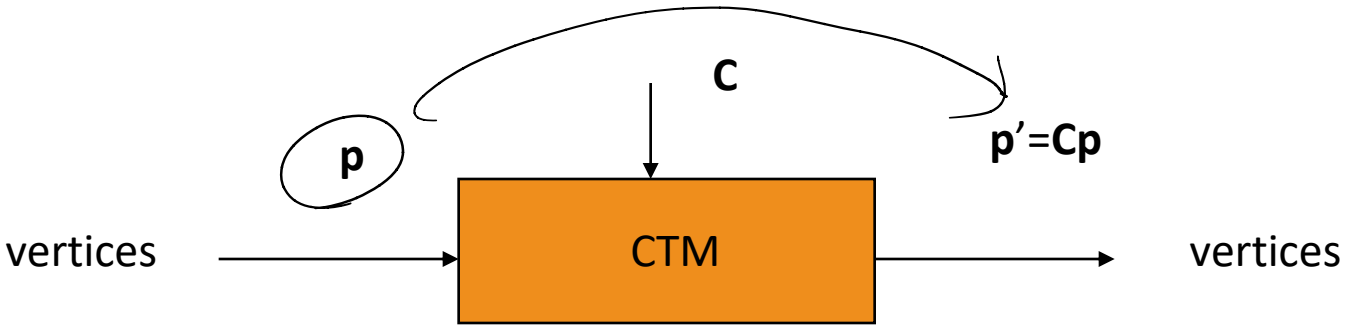
Orthogonal projection



Perspective projection

Current Transformation Matrix

- Conceptually there is a 4 x 4 homogeneous coordinate matrix, the *current transformation matrix* (CTM) that is part of the state and is applied to all vertices that pass down the pipeline
- The CTM is defined in the user program and loaded into a transformation unit



CTM Operations

General Graphics. OpenGL.

Load an identity matrix: **C** = **I**
Load an arbitrary matrix: **C** = **M**

Load a translation matrix: **C** = **T**
Load a rotation matrix: **C** = **R**
Load a scaling matrix: **C** = **S**

CTM ↓ C = C · M

Postmultiply by an arbitrary matrix: **C** = **CM**
Postmultiply by a translation matrix: **C** = **CT**
Postmultiply by a rotation matrix: **C** = **C R**
Postmultiply by a scaling matrix: **C** = **C S**

Matrix Order is Reversed

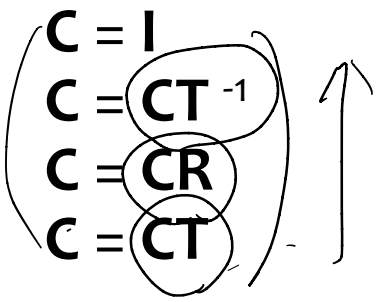
- Example: Rotation about a fixed point
  - Start with identity matrix: $\mathbf{C} = \mathbf{I}$
  - Move fixed point to origin: $\mathbf{C} = \mathbf{CT}$
  - Rotate: $\mathbf{C} = \mathbf{CR}$
  - Move fixed point back: $\mathbf{C} = \mathbf{CT}^{-1}$
  - Result: $\mathbf{C} = \mathbf{TR}\,\mathbf{T}^{-1}$ which is **backwards!**

$(C \cdot T) \cdot R$

$\Rightarrow (C\,T\,R) \cdot C \cdot T^{-1} \Rightarrow C = T \cdot R \cdot T^{-1}$

Correct Matrix Order

We want $\mathbf{C = T^{-1} R T}$
so we must do the operations in the following order



Each operation corresponds to one function call in the program

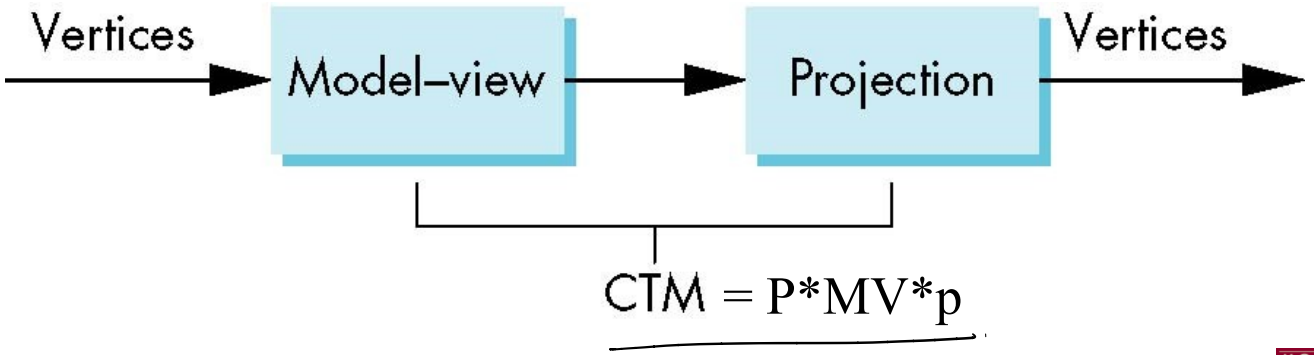
Note that the last operation specified is the first executed in the program

CTM in OpenGL with Shader

- The CTM in OpenGL is defined in the user program and passed down to the vertex processor
  - Vertex shader will multiply the matrix to vertex coordinates
- Programmers should create and manage them in their own applications
- Matrix / vector class can help
  - mat.h, vec.h (textbook source code)
    - Error corrected version of vector class (vec_fixed.h) is included in assign_1 skeleton code

ModelView/Projection Matrix

- In OpenGL, the model-view matrix is used to
  - Position the camera
    - Can be done by rotations and translations but is often easier to use the lookAt function in mat.h
  - Build models of objects
- The projection matrix is used to define the view volume and to select a camera lens



Basic Matrix Functions (mat.h)

- Create an identity matrix

```
mat4 m = Identity();
```

- Fill it with components

```
mat4 m = mat4(0,1,2,3,4,5,6,7,
              8,9,10,11,12,13,14,15);
```

- By vectors

```
mat4 m = mat4( vec4(0,1,2,3),
               vec4(4,5,6,7),
               vec4(8,9,10,11),
               vec4(12,13,14,15) );
```

Rotation, Translation, Scaling

- Multiply on right by rotation matrix of **`theta`** in degrees where (**`vx, vy, vz`**) define axis of rotation:

```
mat4 r = Rotate(theta, vx, vy, vz)
m = m * r
```

- Also have rotateX, rotateY, rotateZ.
- Do same with translation and scaling:

```
mat4 s = Scale(sx, sy, sz)
mat4 t = Translate(dx, dy, dz);
m = m*s*t;
```

Rotation about A Fixed Point using mat.h

- Fixed point: (4, 5, 6)
- Rotation angle: 45 degrees
- Rotation axis: the line through the origin and the point (1, 2, 3)
- Remember that last matrix specified in the program is the first applied

```
mat4 m = Identity();
m = Translate(4.0, 5.0, 6.0)*
    Rotate(45.0, 1.0, 2.0, 3.0)*
    Translate(-4.0, -5.0, -6.0);
```

How to pass matrix to shader?

- GL Shader

```
#version 150
in  vec4 vPosition;
in  vec4 vColor;
out vec4 color;
uniform mat4 model_view;
uniform mat4 projection;
void main()
{
    gl_Position = projection*model_view*vPosition;
    color = vColor;
}
```

How to pass matrix to shader?

- User code (C++)

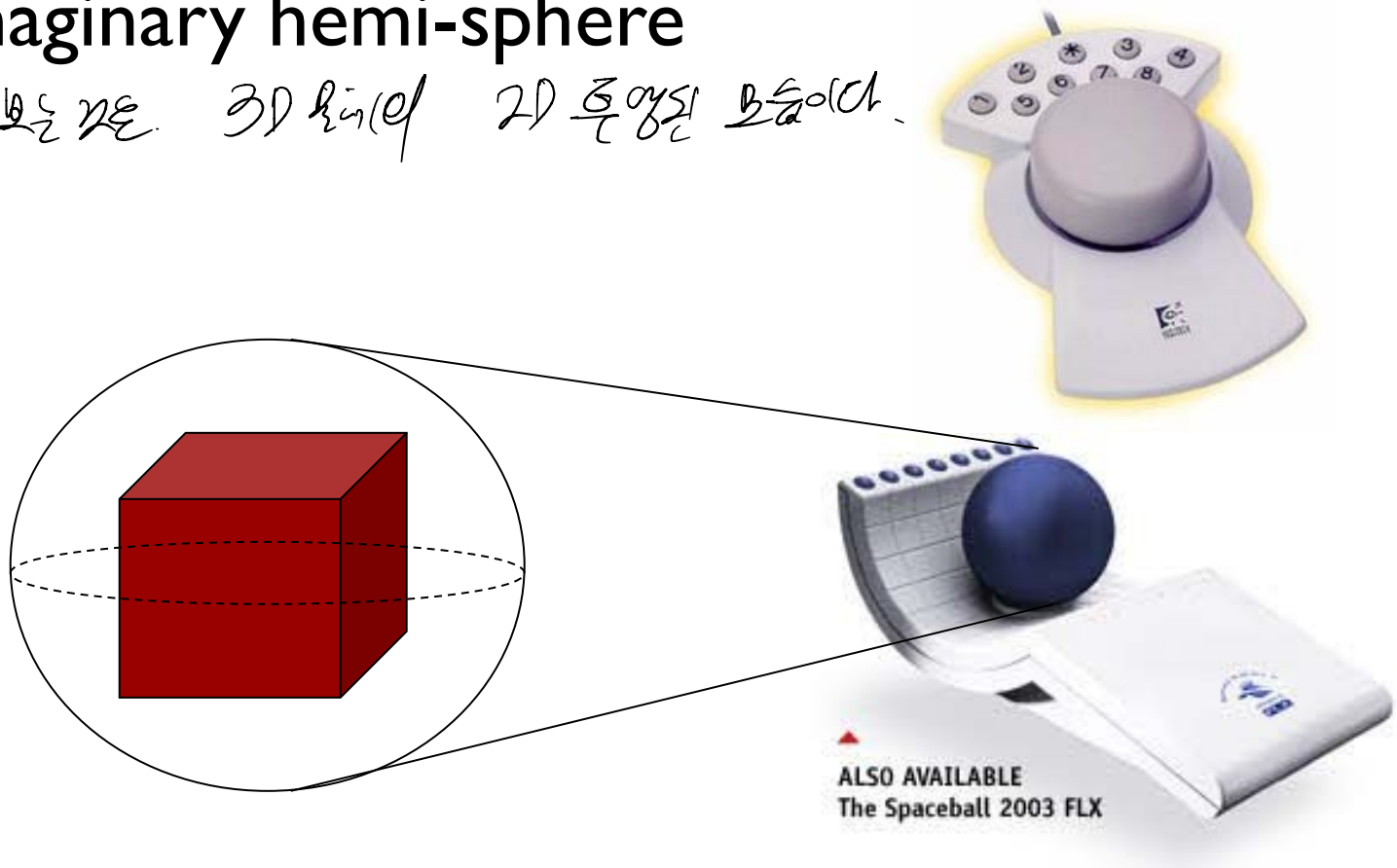
```
void display( void )
{
    glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );
    point4  eye( 0, 0, -100,  1.0 );
    point4  at( 0.0, 0.0, 0.0, 1.0 );
    vec4    up( 0.0, 1.0, 0.0, 0.0 );
    mat4  mv = LookAt( eye, at, up );
    glUniformMatrix4fv( model_view, 1, GL_TRUE, mv );
    mat4  p = Perspective( fovy, aspect, zNear, zFar );
    glUniformMatrix4fv( projection, 1, GL_TRUE, p );
    glDrawArrays( GL_TRIANGLES, 0, NumVertices );
    glutSwapBuffers();
}
```

Outline

- OpenGL transformation
- Virtual trackball

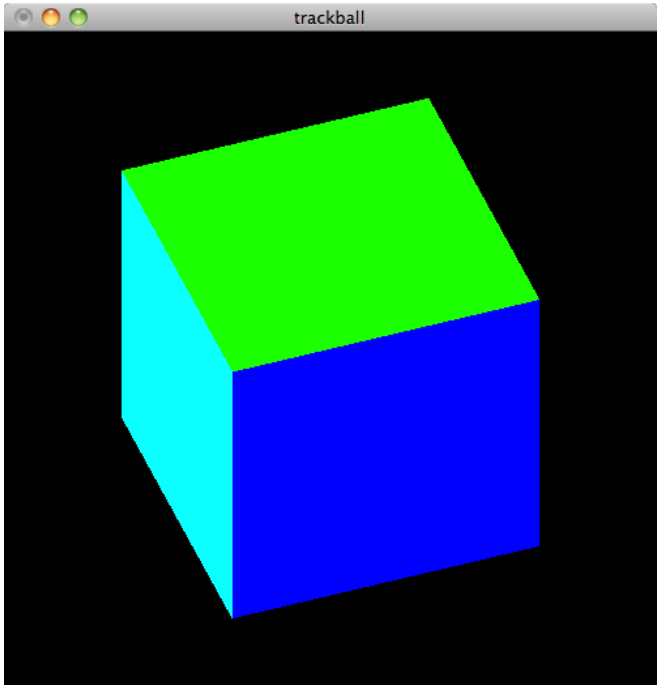
3D Rotations with Trackball

- Imagine the objects are rotated along with a imaginary hemi-sphere



Virtual Trackball ⇒ 마우스의 회전을 보여준다.

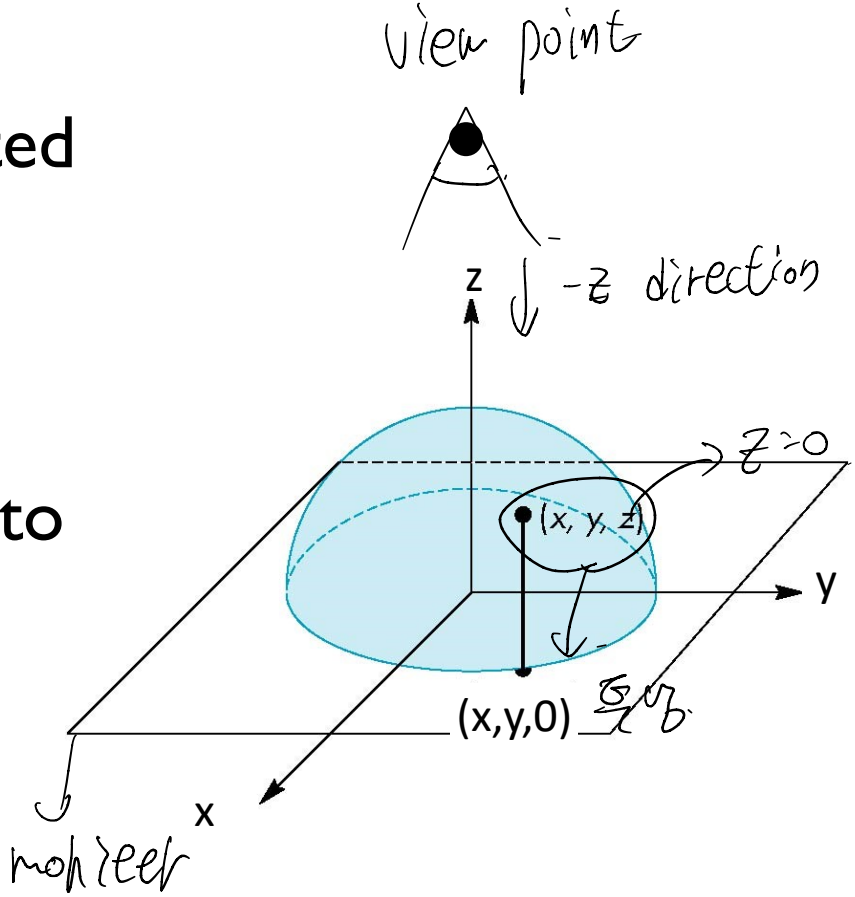
- Allow the user to define 3D *rotation* using mouse click in 2D windows
- Work similarly like the hardware trackball devices



Virtual Trackball

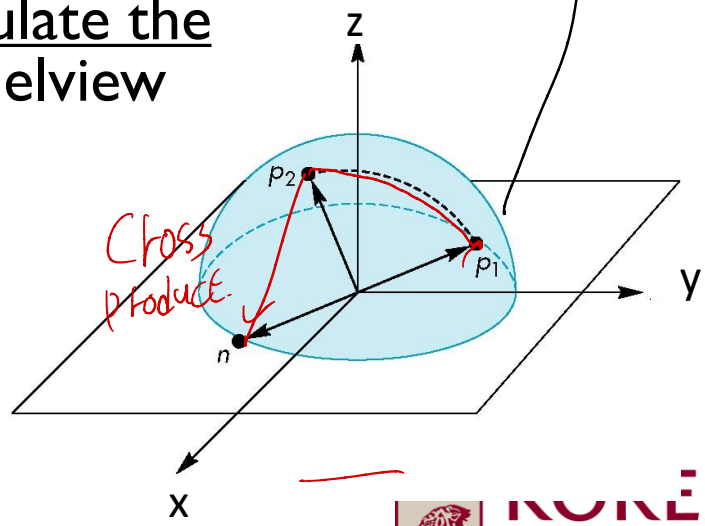
- Superimpose a hemi-sphere onto the viewport
- This hemi-sphere is projected to a circle inscribed to the viewport
- The mouse position is projected orthographically to this hemi-sphere

half - sphere



Virtual Trackball

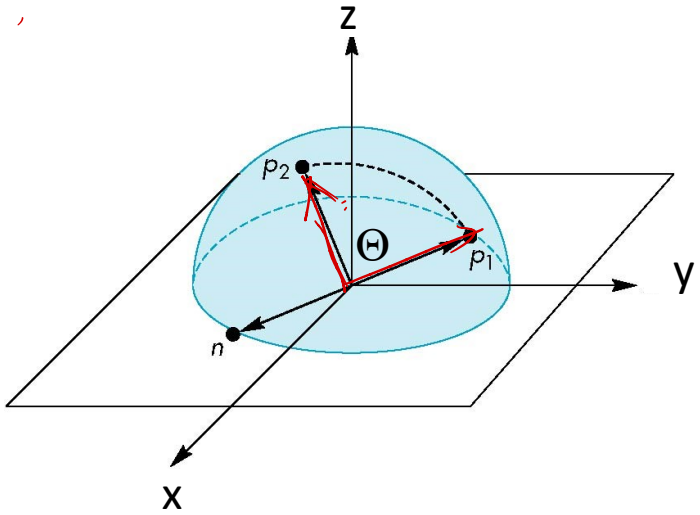
- Keep track the previous mouse position and the current position
- Calculate their projection positions p1 and p2 to the virtual hemi-sphere
- We then rotate the sphere from p1 to p2 by finding the proper rotation axis and angle
- You should also remember to accumulate the current rotation to the previous modelview matrix



Virtual Trackball

- The axis of rotation is given by the normal to the plane determined by the origin, **p**1 , and **p**2

$$\mathbf{n} = \mathbf{p}_1 \times \mathbf{p}_2$$

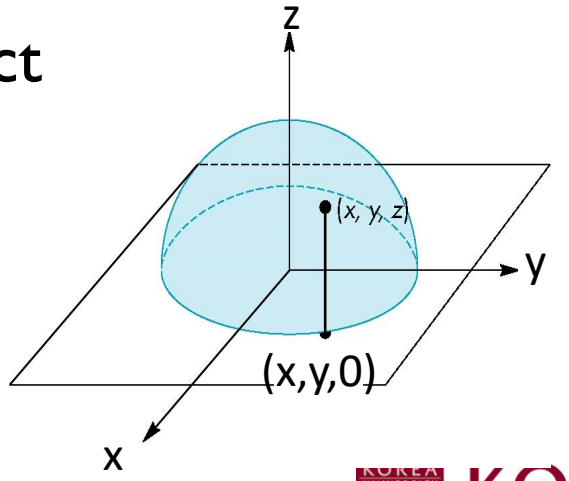


Virtual Trackball

- How to calculate p1 and p2?
- Assuming the mouse position is (x,y), then the sphere point P also has x and y coordinates equal to x and y
- Assume the radius of the hemi-sphere is *r*. Then the z coordinate of P is

$$\sqrt{r^2 - x^2 - y^2}$$

- If a point is outside the circle, project it to the nearest point on the circle (set z to 0 and renormalize (x,y))



glut Callback Functions

- glutMouseFunc(mouseButton)
  - Mouse click (UP/DOWN)
- glutMotionFunc(mouseMotion)
  - Mouse move
  - You need to count only when mouse is moving while mouse button is pressed

Mouse Callback Example

own func

```
void mouseButton(int button, int state, int x, int y)
{
  if(button==GLUT_LEFT_BUTTON) switch(state)
  {
     case GLUT_DOWN:
          startMotion(x,y);
          break;
     case GLUT_UP:
          stopMotion(x,y);
          break;
   }
 }
```

glutMotionFunc Example

```
Void mouseMotion(int x, int y)
{
      float curPos[3],
      dx, dy, dz;

      /* compute position on hemisphere */
      trackball_ptov(x, y, winWidth, winHeight, curPos);

      if(trackingMouse)
      {
         /* compute the change in position
               on the hemisphere */
         dx = curPos[0] - lastPos[0];
         dy = curPos[1] - lastPos[1];
         dz = curPos[2] - lastPos[2];

                        :
                        :
```

glutMotionFunc Example

```
void trackball_ptov(int x, int y, int width, int height,
  float v[3])
{
   float d, a;

   /* project x,y onto a hemi-sphere centered within width,
  height */
   v[0] = (2.0F*x - width) / width;
   v[1] = (height - 2.0F*y) / height;
   d = (float) sqrt(v[0]*v[0] + v[1]*v[1]);
   v[2] = (float) cos((M_PI/2.0F) * ((d < 1.0F) ? d : 1.0F));
   a = 1.0F / (float) sqrt(v[0]*v[0] + v[1]*v[1] + v[2]*v[2]);
   v[0] *= a;
   v[1] *= a;
   v[2] *= a;
}
```

glutMotionFunc Example

```
    if (dx || dy || dz)
    {
      /* compute theta and cross product */
      angle = 90.0 * sqrt(dx*dx + dy*dy + dz*dz);
      axis[0] = lastPos[1]*curPos[2] -
           lastPos[2]*curPos[1];
      axis[1] = lastPos[2]*curPos[0] -
           lastPos[0]*curPos[2];
      axis[2] = lastPos[0]*curPos[1] -
           lastPos[1]*curPos[0];
      /* update position */
      lastPos[0] = curPos[0];
      lastPos[1] = curPos[1];
      lastPos[2] = curPos[2];
      }
    }
    glutPostRedisplay();
}
```

Update Rotation Matrix

- Order is important!
  - rot * cmt for right-side multiplication

```
mat4 cmt; // current matrix

...

mat4 rot = Rotate(alpha, vx, vy, vz));

cmt = rot*cmt;
```

Notes about Glew

glew

- glewInit() must be called before any OpenGL command and after glutDisplayFunc()

```
int main(int argc, char **argv)
{
    glutInit(&argc, argv)
    glutInitDisplayMode(...)
    ...
    glutCreateWindow(..)

    glewInit();

    glutMainLoop();
    return 1;
}
```

glew

- glew.h must be included before glut.h

```
#include <GL/glew.h>

#include <GL/glut.h>

....
```

glutPostRedisplay() ⇒ refresh screen

- Update framebuffer
  - Call display callback function registered by `glutDisplayFunc()`
- Do not call `glutPostRedisplay()` inside display callback function! (= glut displayfunc)
  - Infinite loop
- Call when you need to manually refresh screen
  - After mouse or keyboard events

glutSwapBuffers()

- Swap back and front buffers
- Render target must be back buffer
  - `glDrawBuffer(GL_BACK)`
- Call only once per each render pass
  - Only at the end of the display callback function

Questions?

Refraction Effect using Vertex Shader (Wikipedia)