Remember

- Midterm: Next Thursday (Feb 7)
- More on that next week
Other Camera Controls

- The LookAt function is only for positioning camera
- Other ways to specify camera position/movement
  - Yaw, pitch, roll
  - Elevation, azimuth, twist
  - Direction angles
Flexible Camera Control

- Sometimes, we want camera to move
- Like controlling a airplane’s orientation
- Adopt aviation terms:
  - **Pitch**: nose up-down
  - **Roll**: roll body of plane
  - **Yaw**: move nose side to side
Similarly, yaw, pitch, roll with a camera
Flexible Camera Control

- Create a **camera** class

```cpp
class Camera
{
private:
    Point3 eye;
    Vector3 u, v, n;.... etc
}
```

- Camera functions to specify pitch, roll, yaw. E.g

```cpp
    cam.slide(-1, 0, -2); // slide camera forward -2 and left -1
    cam.roll(30);        // roll camera 30 degrees
    cam.yaw(40);         // yaw it 40 degrees
    cam.pitch(20);       // pitch it 20 degrees
```
Recall: Final LookAt Matrix

- Slide along u, v or n
- Changes eye position
- Affects these components

\[
\begin{bmatrix}
ux & uy & uz \\
vx & vy & vz \\
xn & ny & nz \\
0 & 0 & 0
\end{bmatrix}
- e \cdot u
- e \cdot v
- e \cdot n
\begin{bmatrix}
0 & 0 & 0 \\
1
\end{bmatrix}
\]

- Pitch, yaw, roll rotates u, v or n
- Changes changes these components
Implementing Flexible Camera Control

- Camera class: maintains current \( (u,v,n) \) and eye position

```cpp
class Camera
private:
    Point3 eye;
    Vector3 u, v, n;.... etc
```

- User inputs desired roll, pitch, yaw angle or slide
  1. Roll, pitch, yaw: calculate modified vector \( (u', v', n') \)
  2. Slide: Calculate new eye position
  3. Update lookAt matrix, Load it into CTM
Load Matrix into CTM

void Camera::setModelViewMatrix(void)
{
    // load modelview matrix with camera values
    mat4 m;
    Vector3 eVec(eye.x, eye.y, eye.z); // eye as vector
    m[0] = u.x; m[4] = u.y; m[8] = u.z; m[12] = -dot(eVec, u);
    m[2] = n.x; m[6] = n.y; m[10] = n.z; m[14] = -dot(eVec, n);
    CTM = m; // Finally, load matrix m into CTM Matrix
}

• Call setModelViewMatrix after slide, roll, pitch or yaw
• Slide changes eVec,
• roll, pitch, yaw, change u, v, n
Example: Camera Slide

- User changes eye by delU, delV or delN
- eye = eye + changes (delU, delV, delN)
- Note: function below combines all slides into one

```c
void camera::slide(float delU, float delV, float delN)
{
    eye.x += delU*u.x + delV*v.x + delN*n.x;
    eye.y += delU*u.y + delV*v.y + delN*n.y;
    eye.z += delU*u.z + delV*v.z + delN*n.z;
    setModelViewMatrix( );
}
```

E.g moving camera by \( \mathbf{D} \) along its u axis = \( \mathbf{eye} + \mathbf{D} \mathbf{u} \)
Example: Camera Roll

void Camera::roll(float angle)
{
    // roll the camera through angle degrees
    float cs = cos(3.142/180 * angle);
    float sn = sin(3.142/180 * angle);
    Vector3 t = u; // remember old u
    u.set(cs*t.x - sn*v.x, cs*t.y - sn*v.y, cs*t.z - sn*v.z);
    v.set(sn*t.x + cs*v.x, sn*t.y + cs*v.y, sn*t.z + cs*v.z);
    setModelViewMatrix( );
}

\[ u' = \cos(\alpha)u + \sin(\alpha)v \]
\[ v' = -\sin(\alpha)u + \cos(\alpha)v \]
Recall: 3D Viewing and View Volume

Previously:
Lookat( ) to set camera position

Now:
Set view volume
Recall: Different View Volume Shapes

- Different view volume => different look
- Foreshortening? Near objects bigger
View Volume Parameters

- Need to set view volume parameters
  - **Projection type**: perspective, orthographic, etc.
  - Field of view and aspect ratio
  - Near and far clipping planes
Field of View

- View volume parameter
- Determines how much of world in picture (vertically)
- Larger field of view = smaller objects drawn
Near and Far Clipping Planes

- Only objects between near and far planes drawn
Viewing Frustum

- Near plane + far plane + field of view = Viewing Frustum
- Objects outside the frustum are clipped
Setting up View Volume/Projection Type

- Previous OpenGL projection commands deprecated!!
  - Perspective view volume/projection:
    - `gluPerspective(fovy, aspect, near, far)` or
    - `glFrustum(left, right, bottom, top, near, far)`
  - Orthographic:
    - `glOrtho(left, right, bottom, top, near, far)`
- Useful functions, so we implement similar in `mat.h`:
  - `Perspective(fovy, aspect, near, far)` or
  - `Frustum(left, right, bottom, top, near, far)`
  - `Ortho(left, right, bottom, top, near, far)`

What are these arguments? Next!
Perspective(fovy, aspect, near, far)

- Aspect ratio used to calculate window width

\[ \text{AspectRatio} = \frac{w}{h} \]

![Diagram showing perspective settings and aspect ratio calculation](image)
Frustum(left, right, bottom, top, near, far)

- Can use `Frustum()` in place of `Perspective()`
- Same view volume shape, different arguments

```
x
y
z
```

```
left
top
bottom
right
```

```
near  far
```

near and far measured from camera
Ortho(left, right, bottom, top, near, far)

- For orthographic projection

`near` and `far` measured from camera
Example Usage:
Setting View Volume/Projection Type

```c
void display()
{
    // clear screen
    glClear(GL_COLOR_BUFFER_BIT);

    // Set up camera position
    LookAt(0,0,1,0,0,0,0,1,0);

    // set up perspective transformation
    Perspective(fovy, aspect, near, far);

    // draw something
    display_all(); // your display routine
}
```
Perspective Projection

- After setting view volume, then projection transformation
- Projection?
  - **Classic**: Converts 3D object to corresponding 2D on screen
  - How? Draw line from object to projection center
  - Calculate where each cuts projection plane
Orthographic Projection

- How? Draw parallel lines from each object vertex
- The projection center is at infinite
- In short, use (x,y) coordinates, just drop z coordinates
Demo

- Nate Robbins demo on projection
Default View Volume/Projection?

- What if you user does not set up projection?
- Default OpenGL projection is orthogonal (Ortho( ));
- To project points within default view volume

\[
x_p = x \\
y_p = y \\
z_p = 0
\]
Homogeneous Coordinate Representation

\[ x_p = x \]
\[ y_p = y \]
\[ z_p = 0 \]
\[ w_p = 1 \]

Vertices before Projection

Vertices after Projection

default orthographic projection

\[ \mathbf{p}_p = \mathbf{M} \mathbf{p} \]

\[
\mathbf{M} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

Default Projection Matrix

In practice, can let \( \mathbf{M} = \mathbf{I} \), set the z term to zero later
The Problem with Classic Projection

- Keeps \((x,y)\) coordinates for drawing, drops \(z\)
- We may need \(z\). Why?

\[
\begin{align*}
  x_p &= x \\
  y_p &= y \\
  z_p &= 0
\end{align*}
\]

Classic Projection
Loses \(z\) value
Normalization: Keeps z Value

- Most graphics systems use *view normalization*
- **Normalization**: convert all other projection types to orthogonal projections with the *default view volume*
References