Computer Graphics (CS 543) Lecture 6 (Part 2): Viewing & Camera Control

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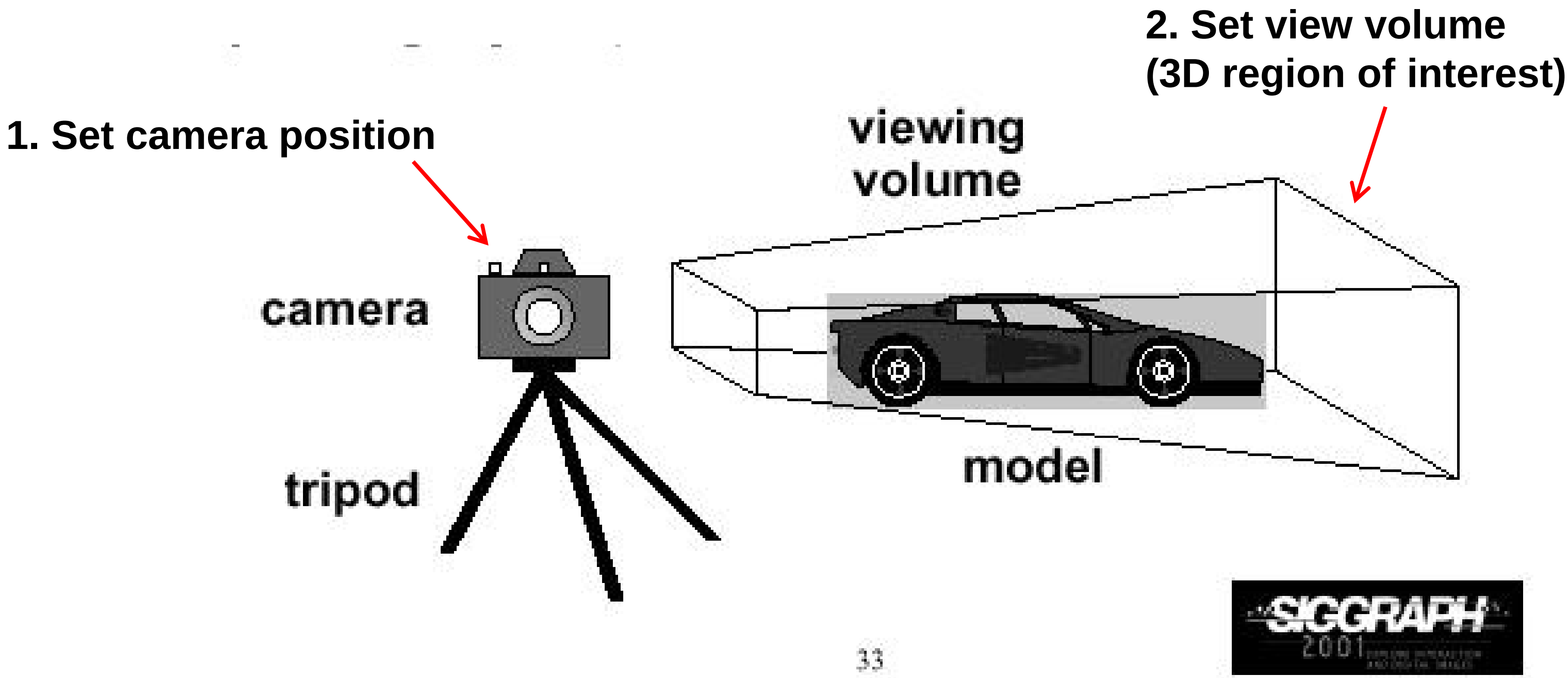
Objectives

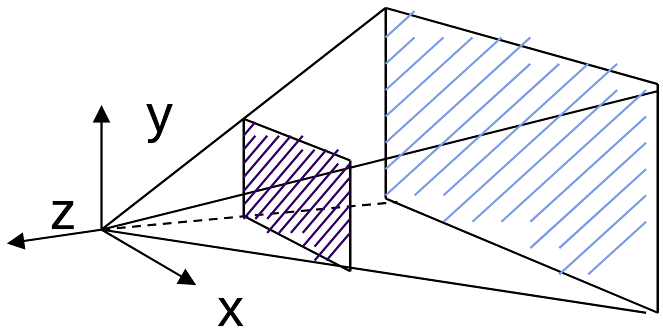
- Introduce viewing functions
- Look at enhanced camera controls

3D Viewing?

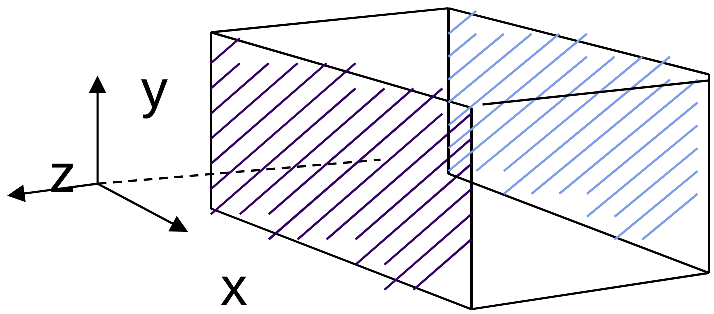
- Scene objects **inside** view volume show up on screen
- Objects outside view colume **clipped!**



Different View Volume Shapes



Perspective view volume

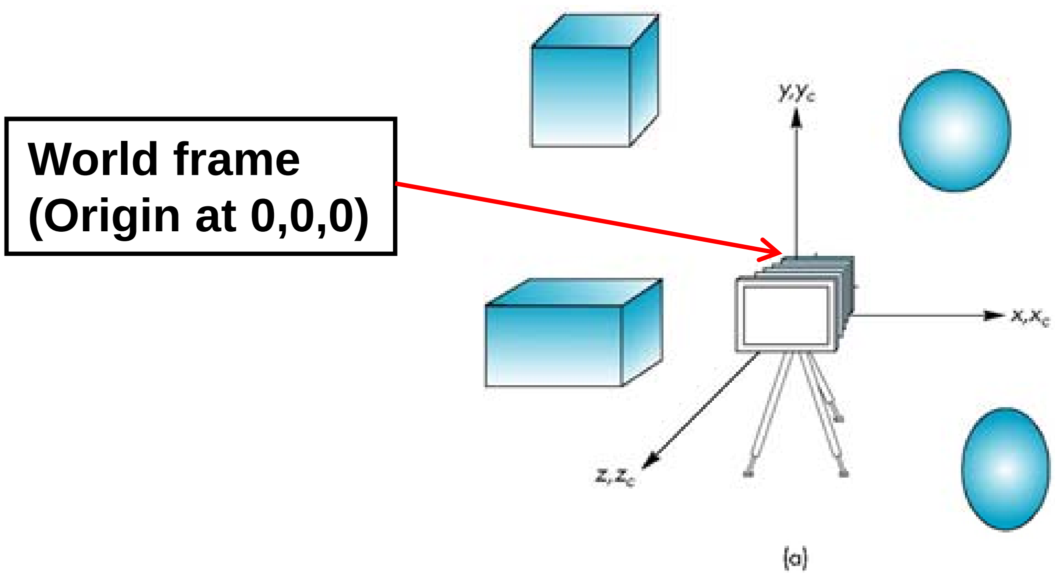


Orthogonal view volume

- **Foreshortening?** Near objects bigger
- Perpective projection has **foreshortening**
- Orthogonal projection: no foreshortening

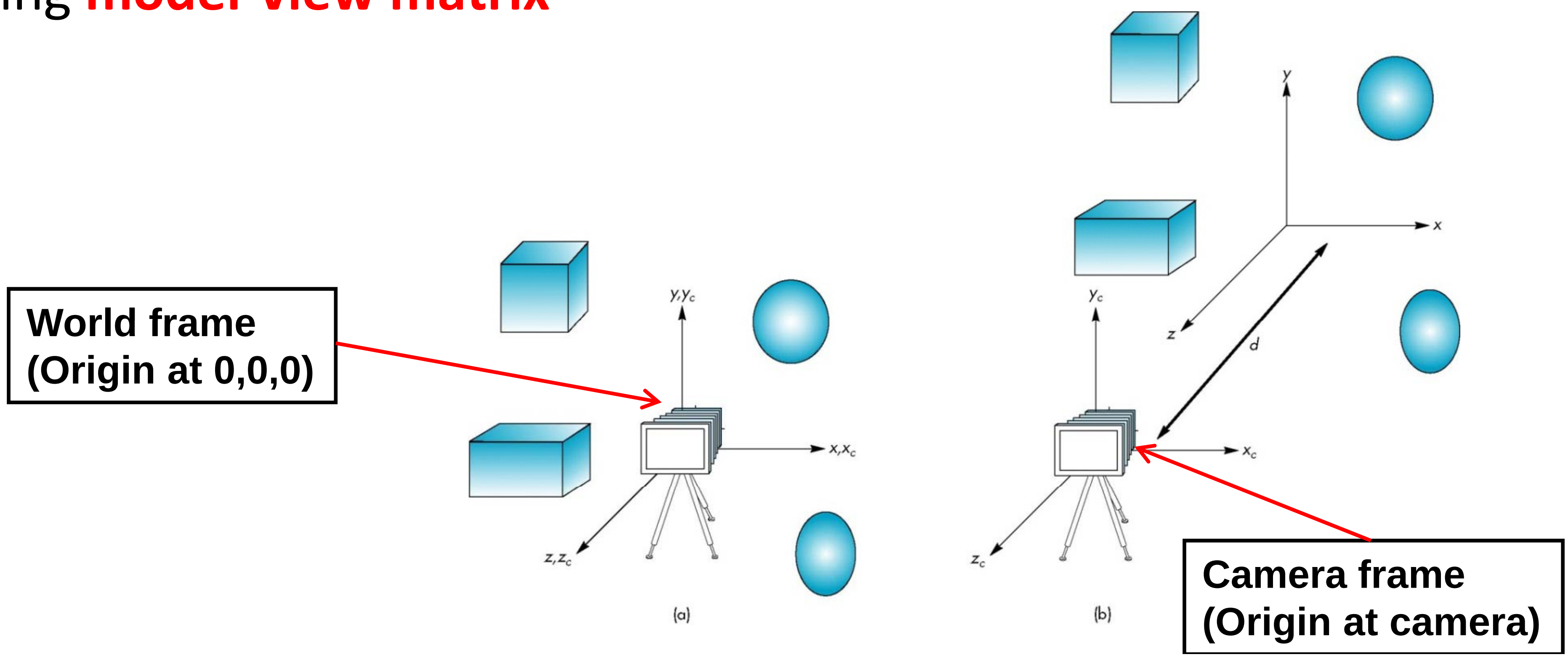
The World Frames

- Objects/scene initially defined in **world frame**
- Transformations (translate, scale, rotate) applied to objects in **world frame**



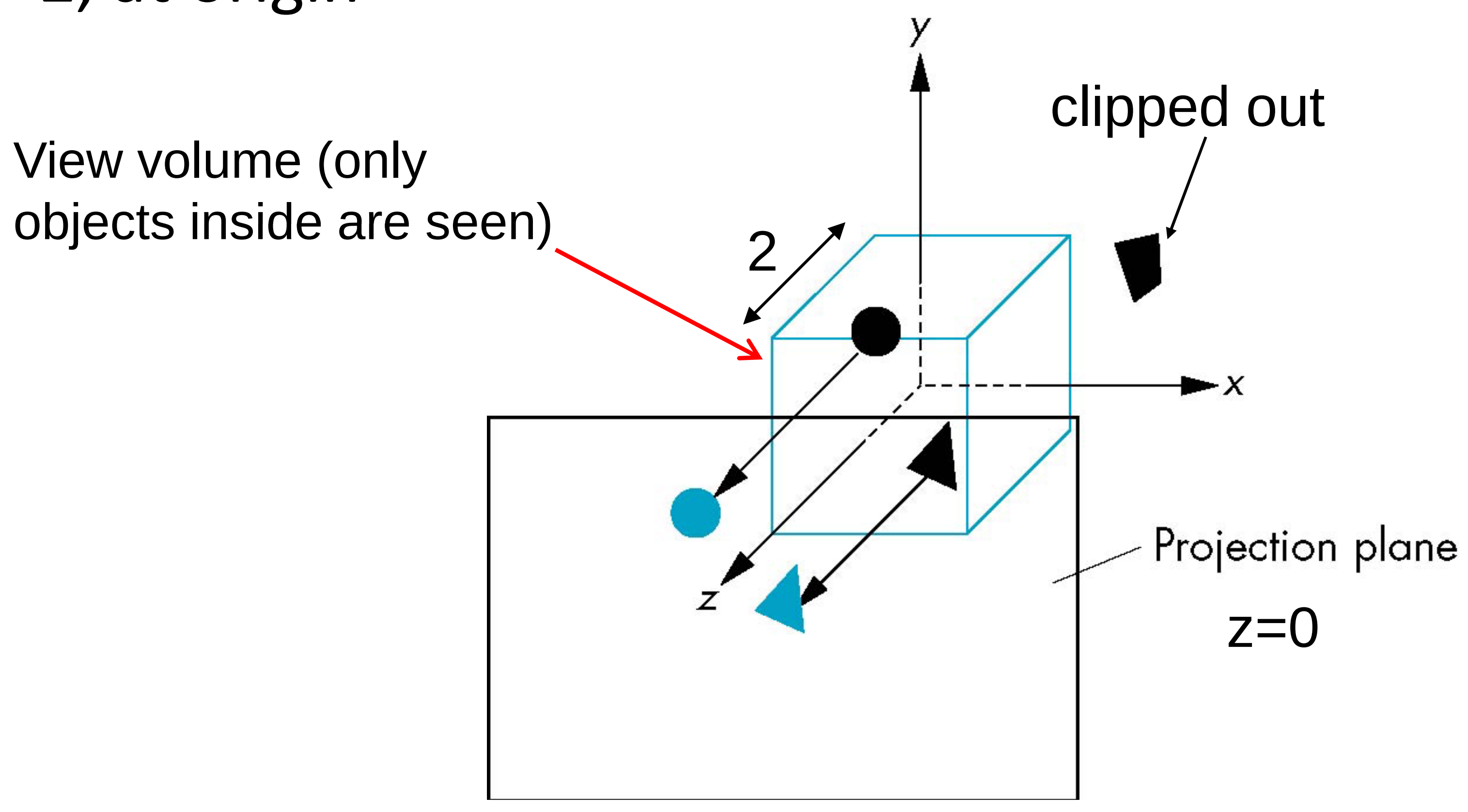
Camera Frame

- More natural to refer to object positions relative to eye
- After we define camera (eye) position, then represent objects in **camera frame** (origin at eye position)
- Objects positions in world frame to positions in camera frame using **model-view matrix**



The OpenGL Camera

- Initially object and camera frames the same
- Camera located at origin and points in negative z direction
- Default view volume is cube (orthogonal) with sides of length 2, at origin



Moving the Camera Frame

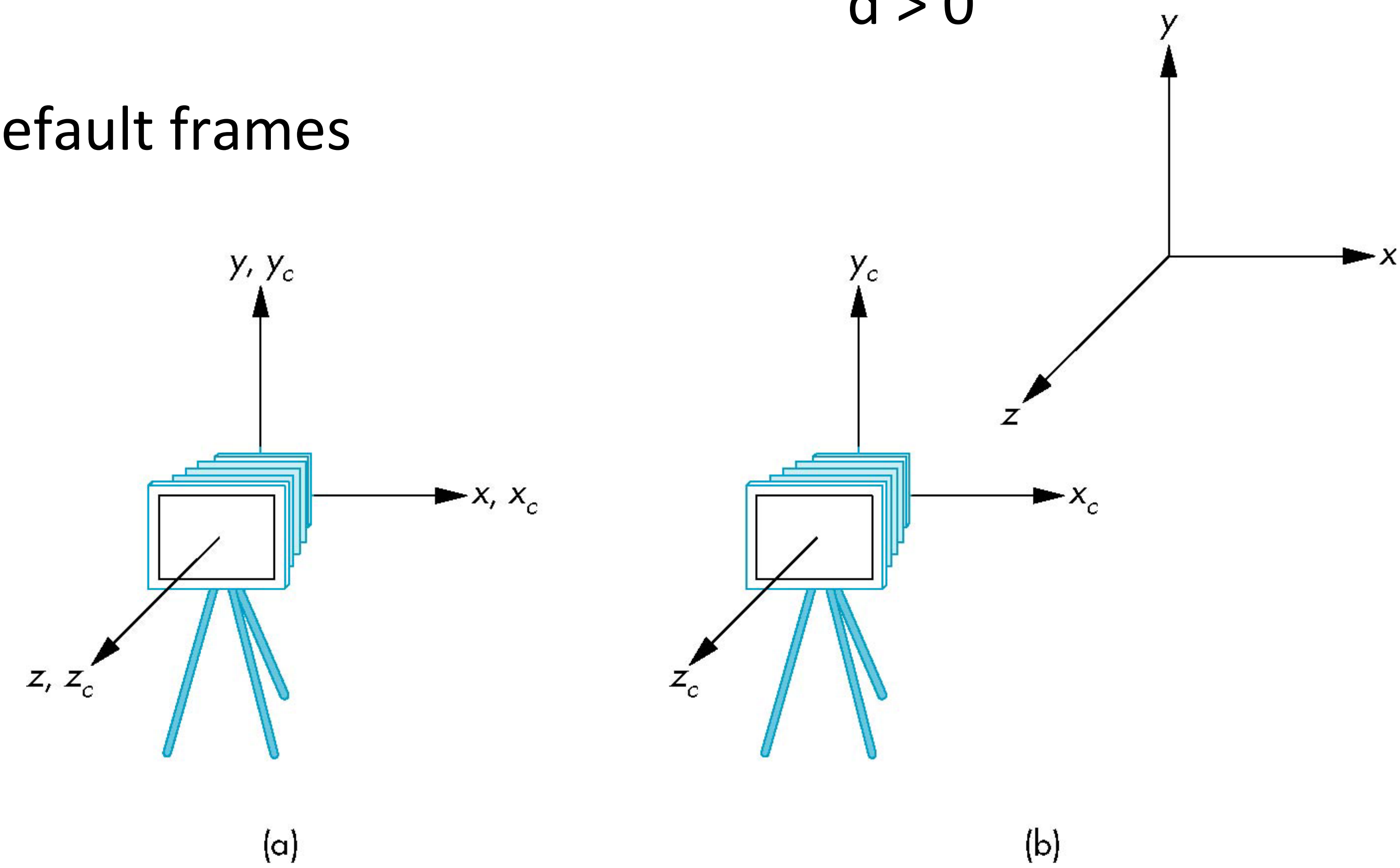
- If we want to move objects some distance from camera (e.g. 5m from camera) , we can either
  1. Move camera backwards -5m (in +z direction)
  2. Move objects forwards +5m (in -z direction)
- Both approaches yield same result
- Object distances **relative to camera** determined by the model-view matrix
  - Transforms (scale, translate, rotate) go into **modelview matrix**
  - Camera transforms also go in **modelview matrix (CTM)**

Moving Camera back from Origin

frames after translation by –d

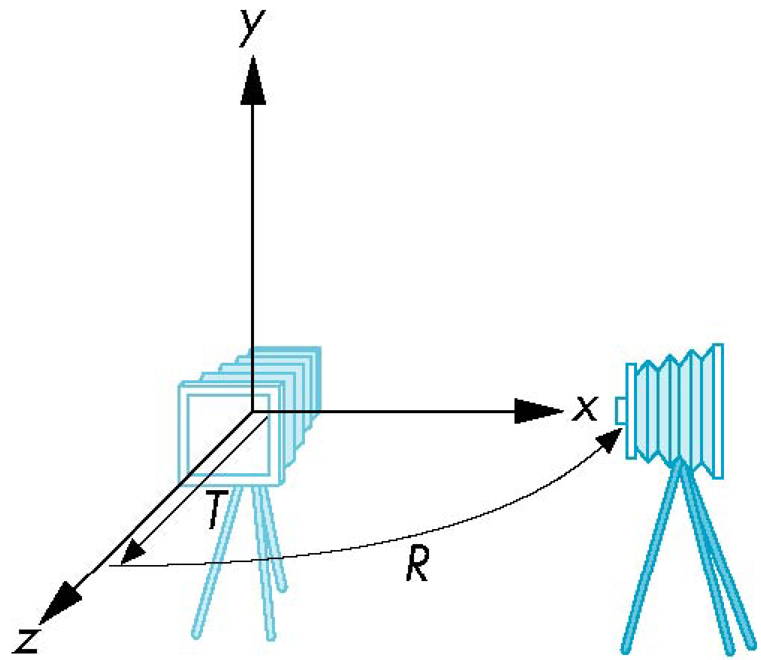
d > 0

default frames



Moving the Camera

- We can move camera to any position by a sequence of rotations and translations
- Example: side view
  - Rotate the camera
  - Move it away from origin
  - Model-view matrix C = TR




```
// Using mat.h

mat4 t = Translate (0.0, 0.0, -d);
mat4 ry = RotateY(90.0);
mat4 m = t*ry;
```

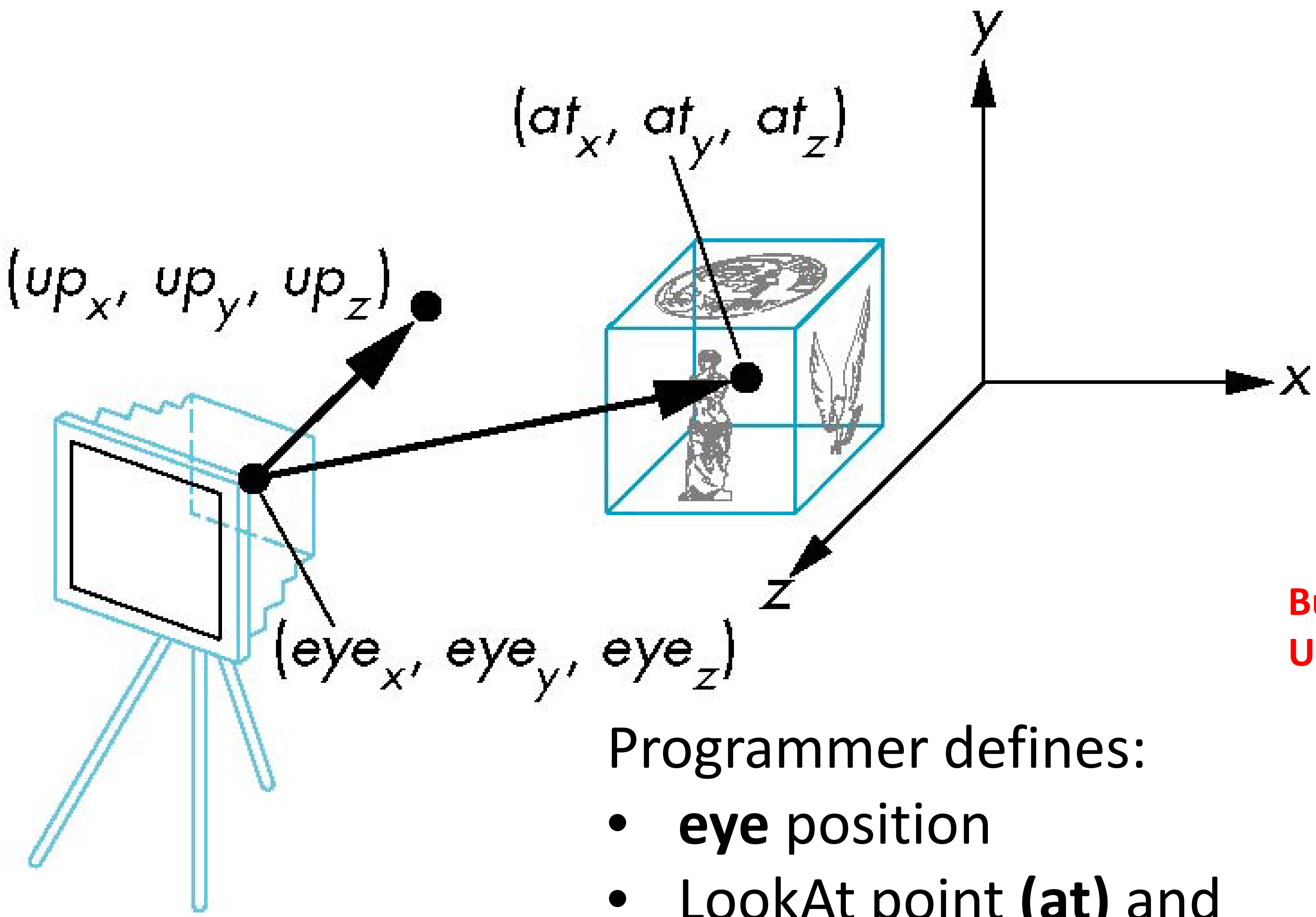
The LookAt Function

- The GLU library contained function **gluLookAt** to form required modelview matrix for camera positioning
- **gluLookAt** deprecated!!
- Homegrown mat4 method LookAt() in mat.h
  - Can concatenate with modeling transformations

```
void display( ){
    ………
    mat4 mv = LookAt(vec4 eye, vec4 at, vec4 up);
    …….. .
}
```

LookAt

```
LookAt(eye, at, up)
```

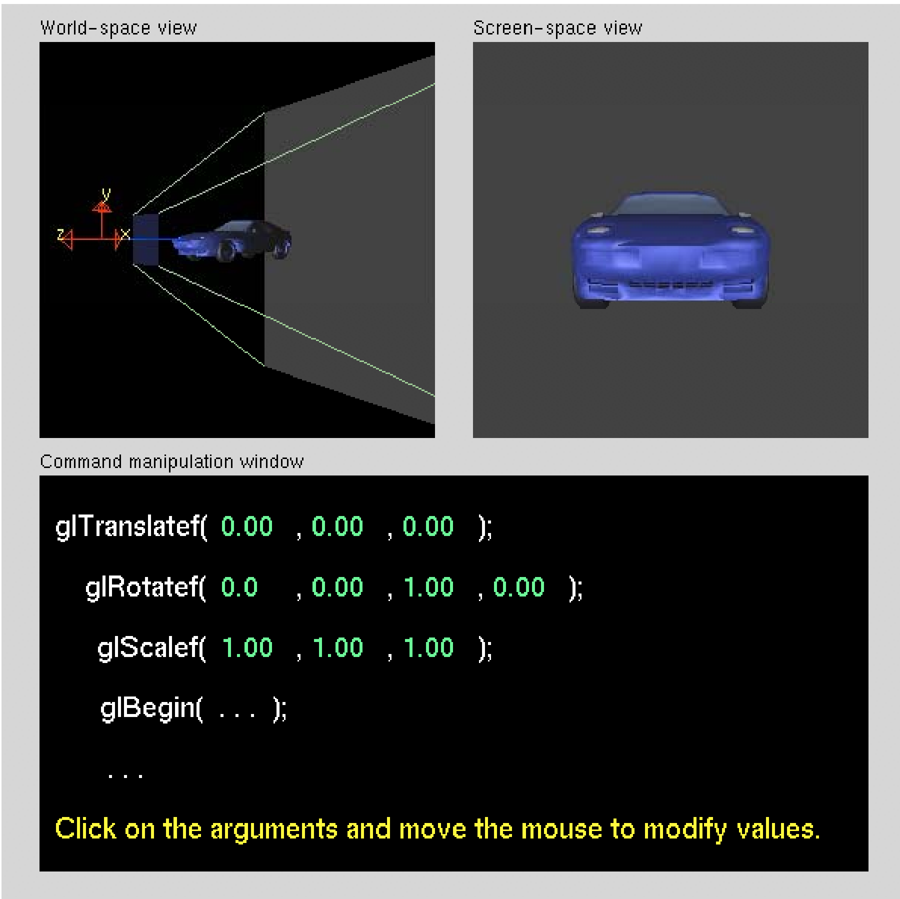


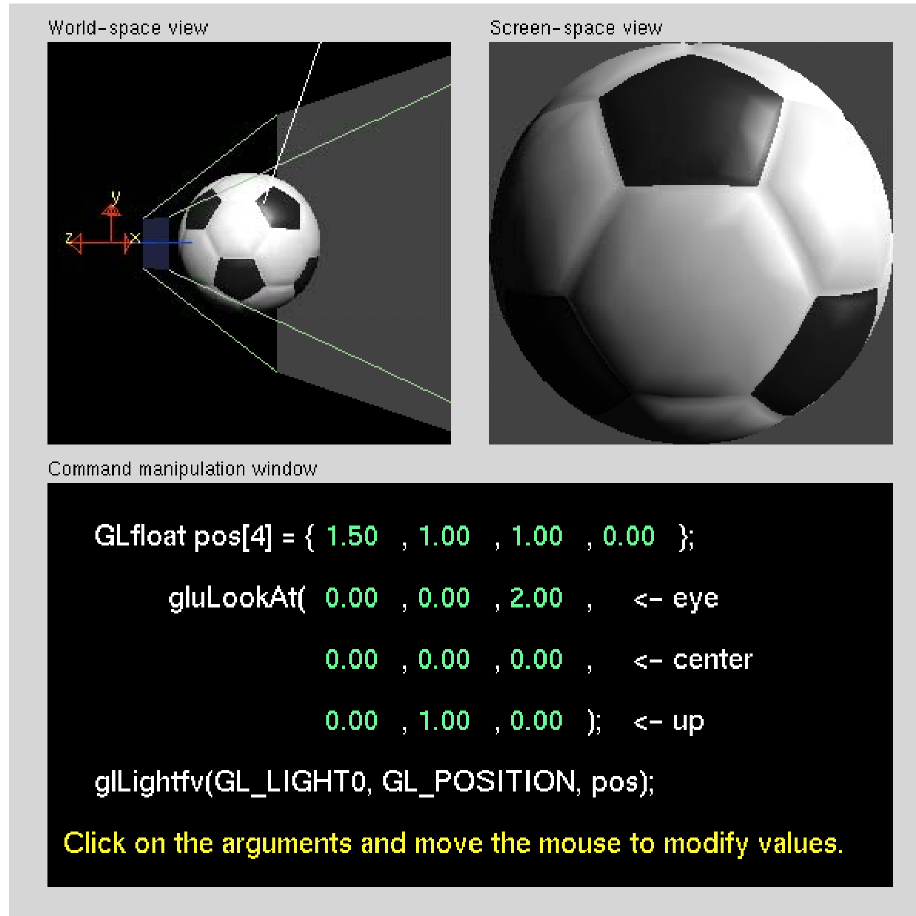
But Why do we set Up direction?

Programmer defines:

- **eye** position
- LookAt point **(at)** and
- **Up** vector (***Up*** direction usually (0,1,0))

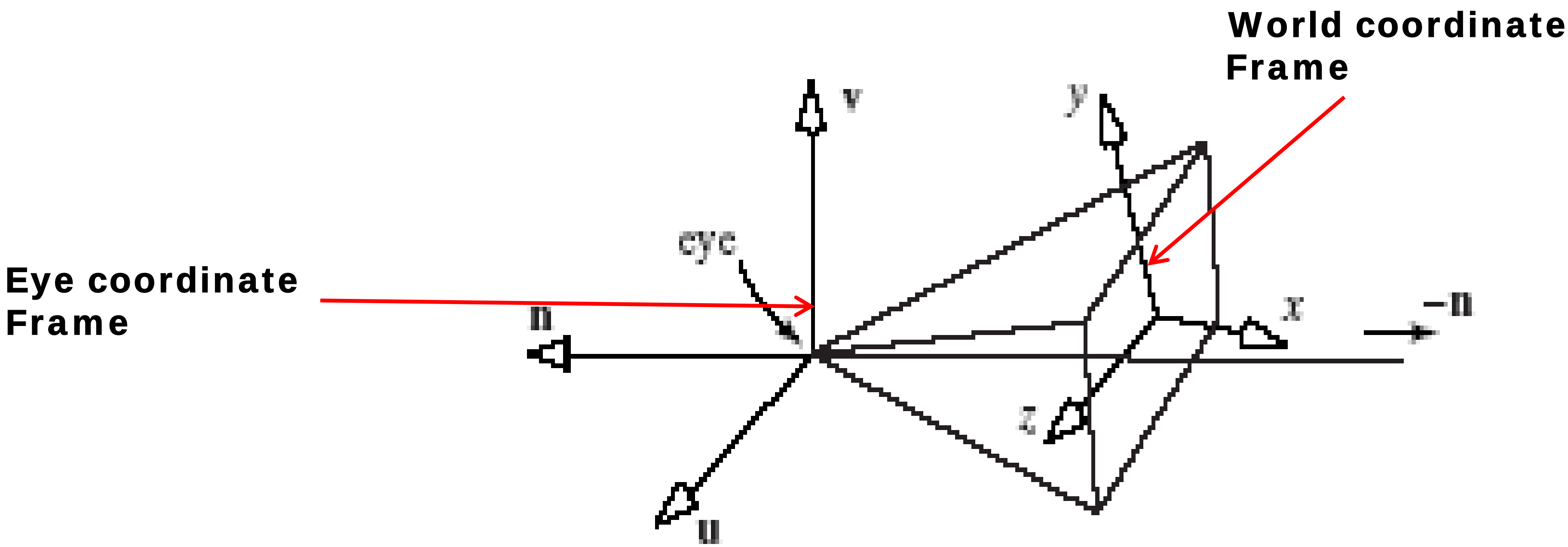
Nate Robbins LookAt Demo





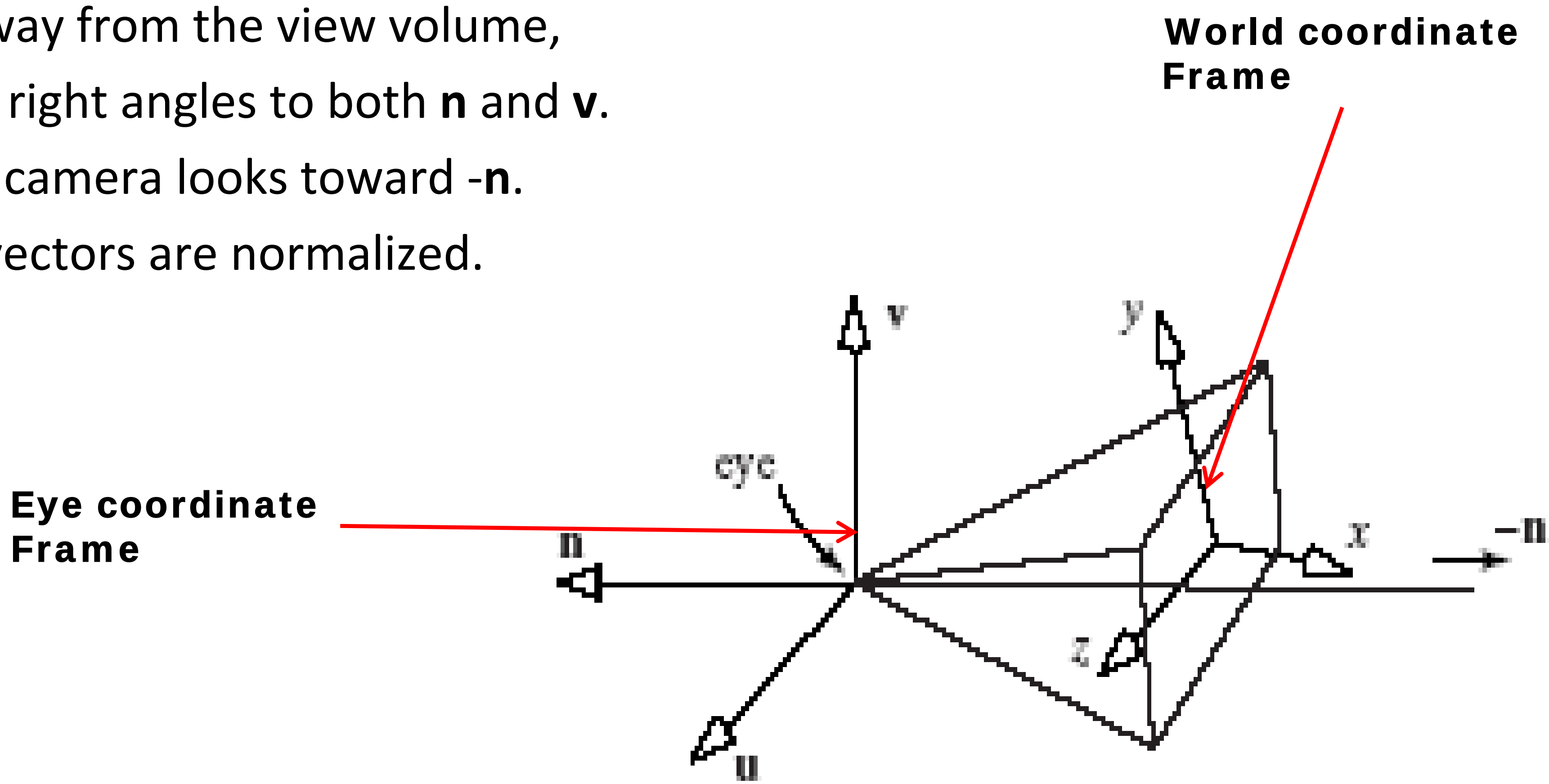
Camera with Arbitrary Orientation and Position

- Programmer defines eye, lookAt and Up
- **LookAt method:**
  - Form new axes (u, v, n) at camera
  - Transform objects from world to eye camera frame



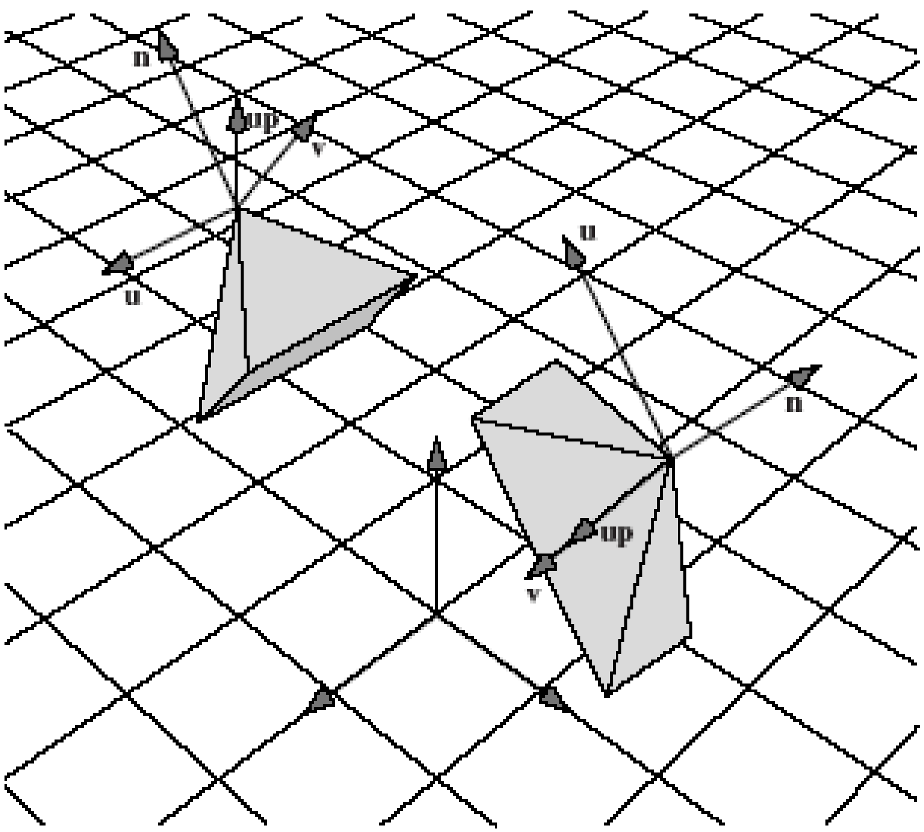
Camera with Arbitrary Orientation and Position

- Define new axes at eye
  - **v** points vertically upward,
  - **n** away from the view volume,
  - **u** at right angles to both **n** and **v**.
  - The camera looks toward -**n**.
  - All vectors are normalized.



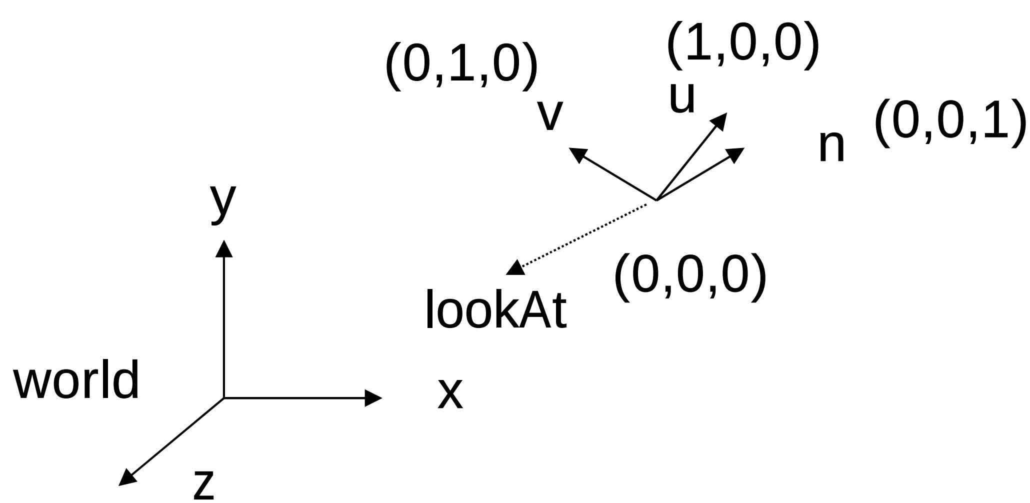
LookAt: Effect of Changing Eye Position or LookAt Point

- Programmer sets **`LookAt(eye, at, up)`**
- If **eye**, **lookAt** point changes => **u,v,n** changes



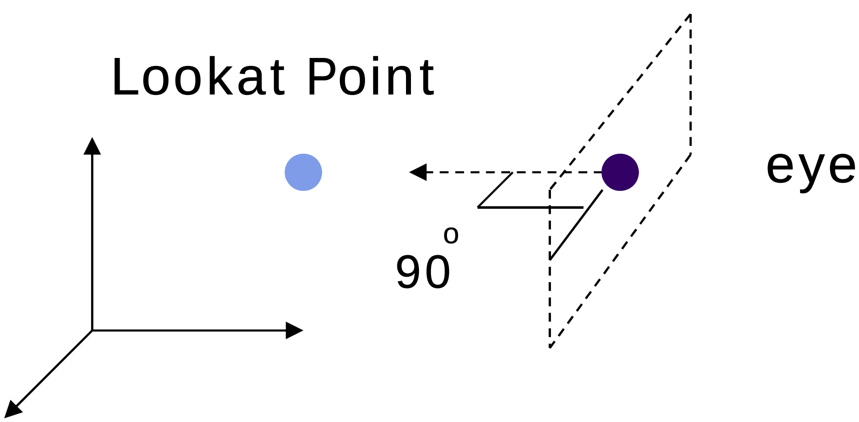
Viewing Transformation

- Viewing Transformation?
  - Form a camera (u,v,n) coordinate frame
  - Transform objects from world to eye space (Composes matrix for coordinate transformation)
- So, first, let’s form camera (u,v,n) frame



Eye Coordinate Frame

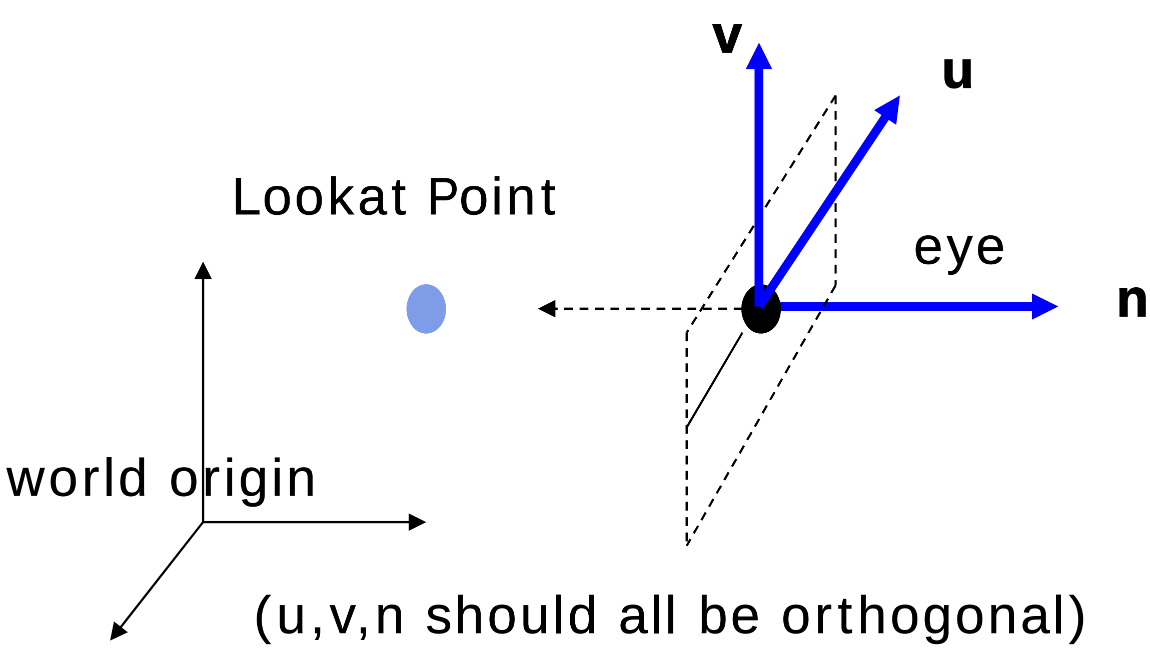
- Constructing u,v,n?
- Lookat function parameters: **`LookAt(eye, at, up)`**
- **Known:** eye position, LookAt Point, up vector
- Derive: new origin and three basis (u,v,n) vectors



Assumption: direction of view is orthogonal to view plane (plane that objects will be projected onto)

Eye Coordinate Frame

- **New Origin:** eye position (that was easy)
- 3 basis vectors:
  - one is the normal vector (**n**) of the viewing plane,
  - other two (**u** and **v**) span the viewing plane



(u,v,n should all be orthogonal)

n is pointing away from the world because we use left hand coordinate system

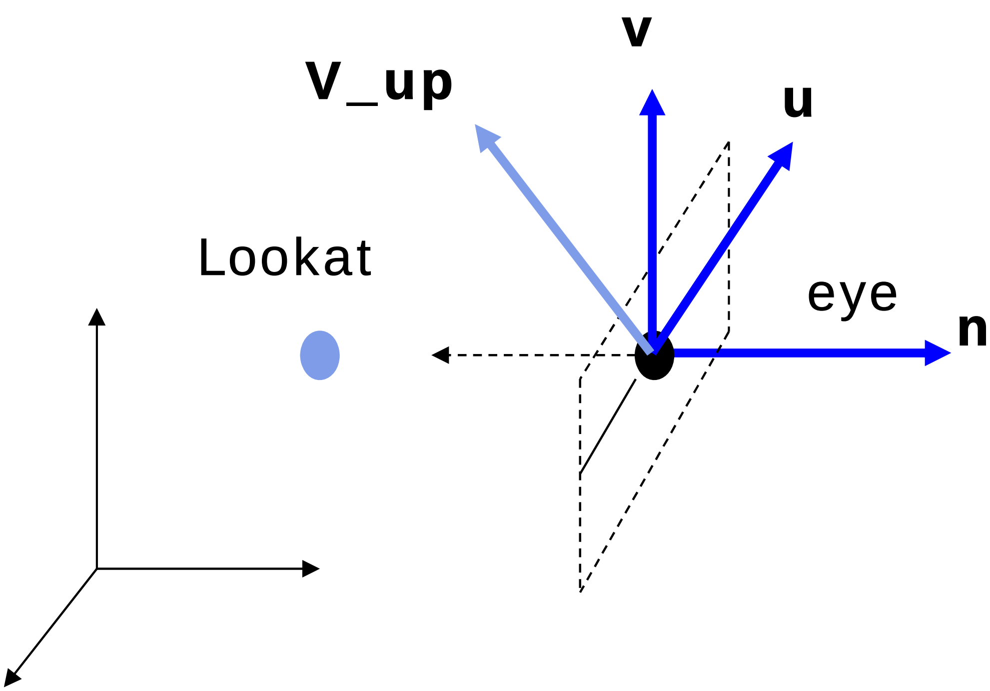
N = eye – Lookat Point

n = N / | N |

Remember **u,v,n** should be all unit vectors

Eye Coordinate Frame

- How about u and v?



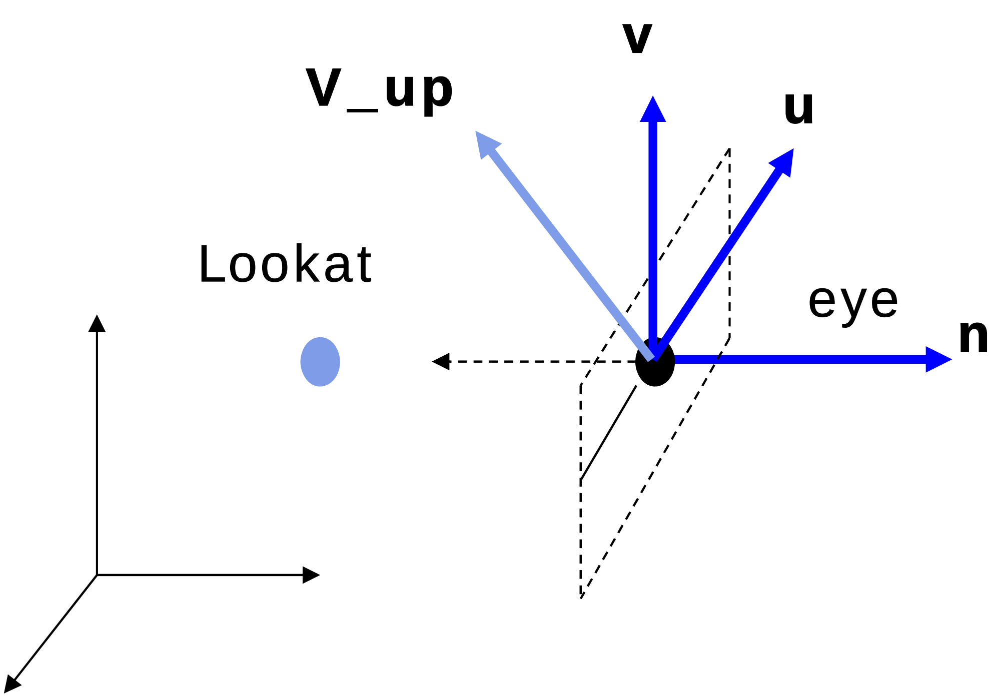
- We can get u first -
  - u is a vector that is perp to the plane spanned by N and view up vector (V_up)

$$U = V\_up \times \mathbf{n}$$

$$\mathbf{u} = U / |U|$$

Eye Coordinate Frame

- How about v?



Knowing n and u, getting v is easy

$$v = n \times u$$

v is already normalized

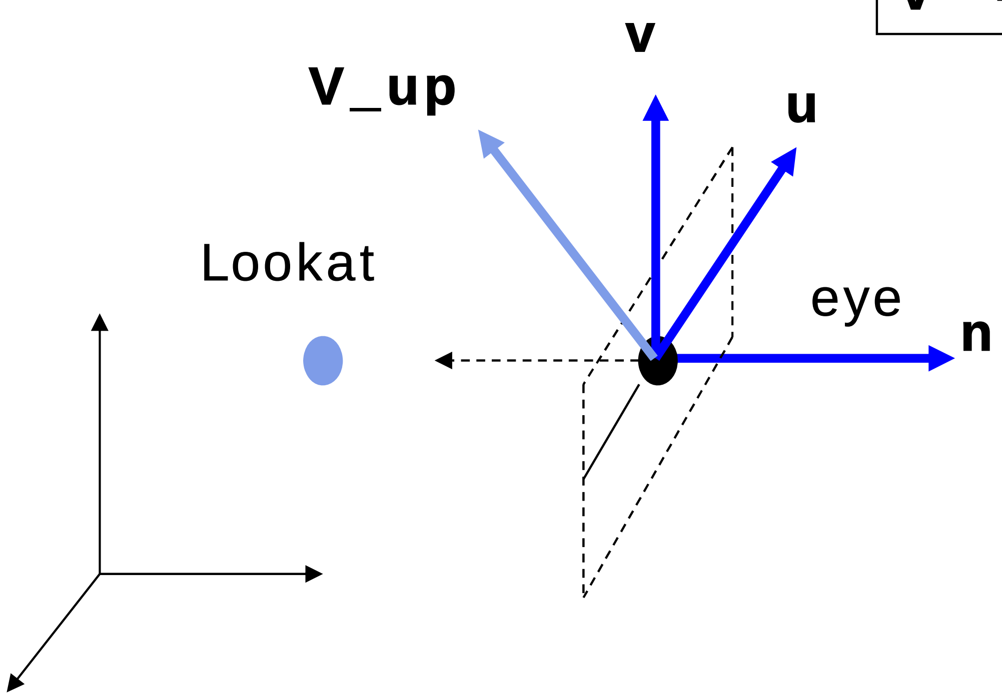
Eye Coordinate Frame

- Put it all together

Eye space **origin: (Eye.x , Eye.y,Eye.z)**

Basis vectors:

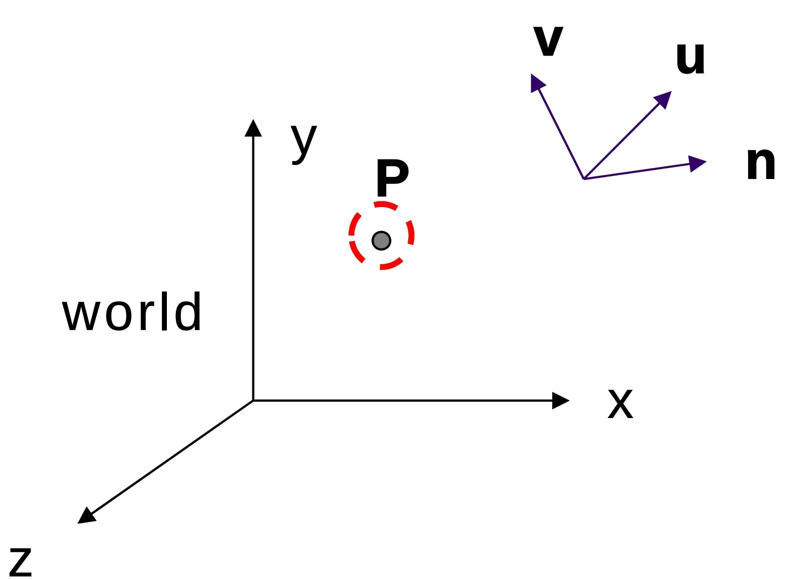
n = (eye – Lookat) / | eye – Lookat|
u = (V_up x **n**) / | V_up x **n** |
v = **n** x **u**



World to Eye Transformation

- Next, use u, v, n to compose LookAt matrix
- Transformation matrix (M_{w2e}) ?

$P' = M_{w2e} \times P$

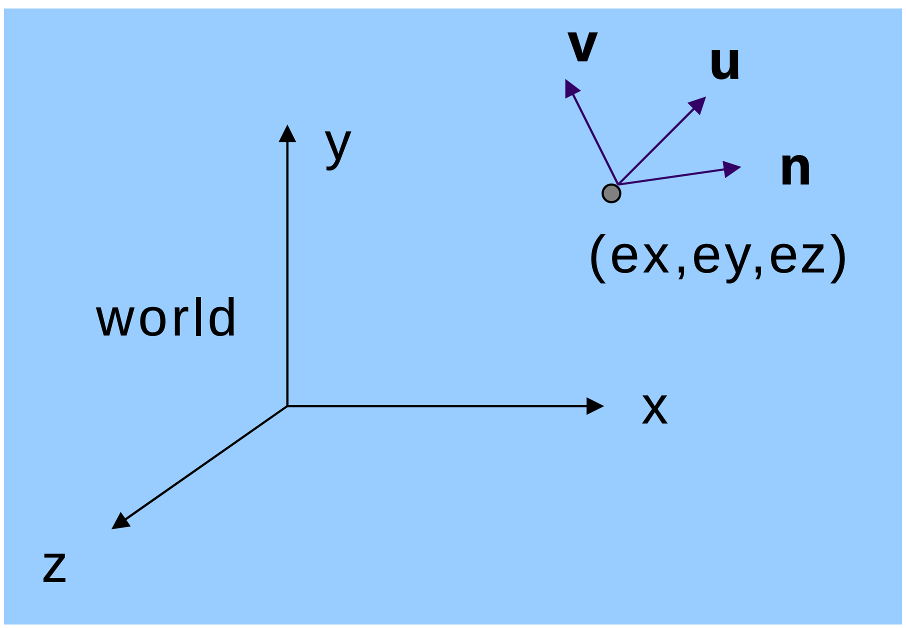


1. Come up with transformation sequence that lines up eye frame with world frame

2. Apply this transform sequence to point **P** in reverse order

World to Eye Transformation

1. Rotate eye frame to “align” it with world frame
2. Translate (-ex, -ey, -ez) to align origin with eye



Rotation:

$$\begin{vmatrix} ux & uy & uz & 0 \\ vx & vy & vz & 0 \\ nx & ny & nz & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Translation:

$$\begin{vmatrix} 1 & 0 & 0 & -ex \\ 0 & 1 & 0 & -ey \\ 0 & 0 & 1 & -ez \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

World to Eye Transformation

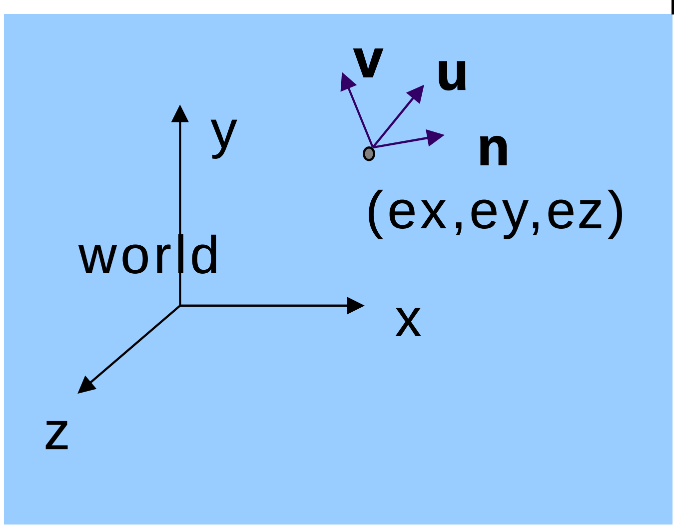
- Transformation order: apply the transformation to the object in reverse order - translation first, and then rotate

	Rotation	Translation

$$
Mw2e = \begin{vmatrix} ux & uy & ux & 0 \\ vx & vy & vz & 0 \\ nx & ny & nz & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \begin{vmatrix} 1 & 0 & 0 & -ex \\ 0 & 1 & 0 & -ey \\ 0 & 0 & 1 & -ez \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

$$
= \begin{vmatrix} ux & uy & uz & -\mathbf{e}\,.\,\mathbf{u} \\ vx & vy & vz & -\mathbf{e}\,.\,\mathbf{v} \\ nx & ny & nz & -\mathbf{e}\,.\,\mathbf{n} \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

Multiplied together = lookAt transform



Note: **e.u** = ex.ux + ey.uy + ez.uz

lookAt Implementation (from mat.h)

```
mat4 LookAt( const vec4& eye, const vec4& at, const vec4& up )
{
    vec4 n = normalize(eye - at);
    vec4 u = normalize(cross(up,n));
    vec4 v = normalize(cross(n,u));
    vec4 t = vec4(0.0, 0.0, 0.0, 1.0);
    mat4 c = mat4(u, v, n, t);
    return c * Translate( -eye );
}
```

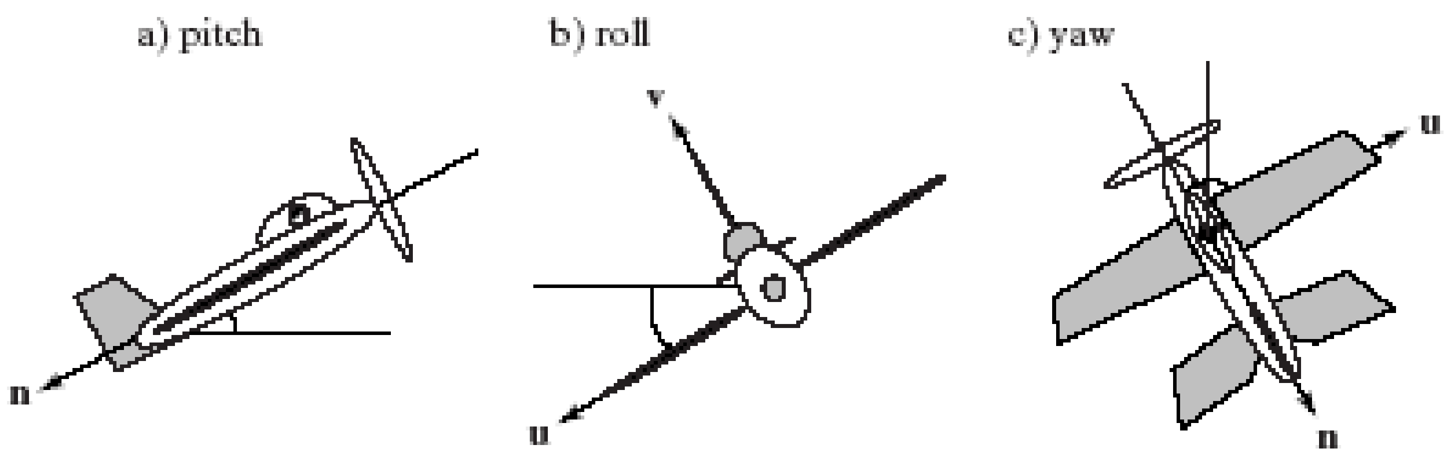
$$\begin{vmatrix} ux & uy & uz & -\mathbf{e} \cdot \mathbf{u} \\ vx & vy & vz & -\mathbf{e} \cdot \mathbf{v} \\ nx & ny & nz & -\mathbf{e} \cdot \mathbf{n} \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Other Camera Controls

- The LookAt function is only way of positioning the camera
- Other ways to specify camera position/movement
  - Yaw, pitch, roll
  - Elevation, azimuth, twist
  - Direction angles

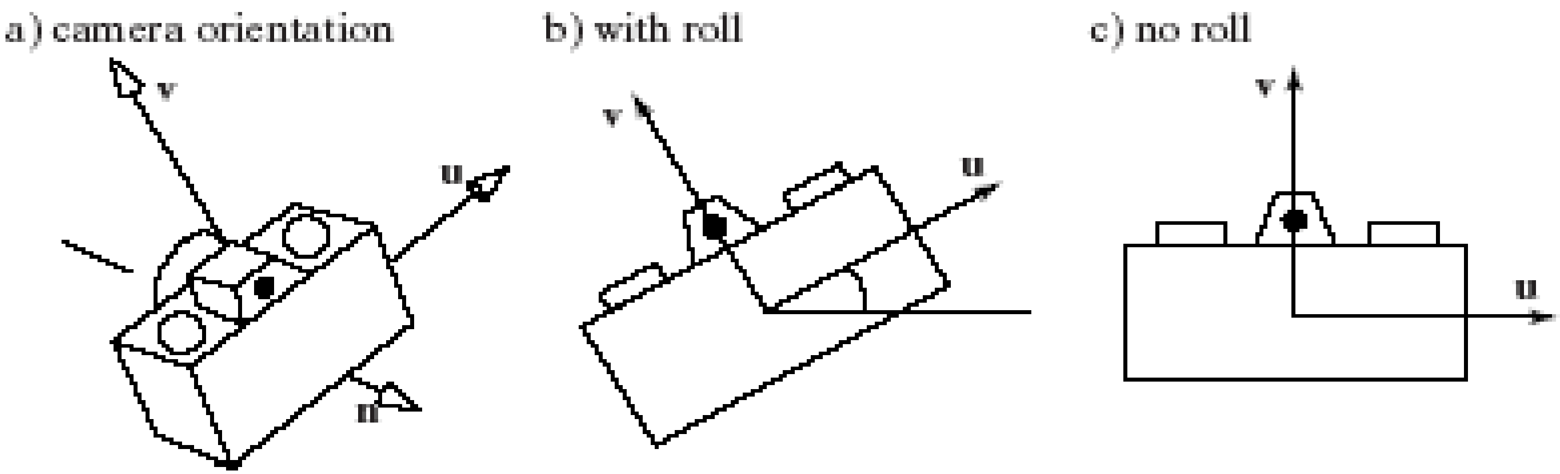
Flexible Camera Control

- 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



Yaw, Pitch and Roll Applied to Camera

- Similarly, yaw, pitch, roll with a camera



Flexible Camera Control

- Create a **camera** class

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

- User can specify pitch, roll, yaw to change camera. E.g

```
cam.slide(-1, 0, -2); // slide camera forward and  left
cam.roll(30);   // roll camera through 30 degrees
cam.yaw(40);   // yaw it through 40 degrees
cam.pitch(20);  // pitch it through 20 degrees
```

Implementing Flexible Camera Control

- General approach
  - Camera class maintains current (u,v,n) and eye position

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

  - User inputs desired roll, pitch, yaw angle or slide
  - Calculate modified vector (u, v, n) or new eye position **after** applying roll, pitch, slide, or yaw
  - Compose and load modified modelview matrix (CTM)

Load Matrix into CTM

$$\begin{pmatrix} ux & uy & uz & -\mathbf{e} \cdot \mathbf{u} \\ vx & vy & vz & -\mathbf{e} \cdot \mathbf{v} \\ nx & ny & nz & -\mathbf{e} \cdot \mathbf{n} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
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[1] = v.x; m[5] = v.y; m[9] = v.z;  m[13] = -dot(eVec,v);
   m[2] = n.x; m[6] = n.y; m[10] = n.z; m[14] = -dot(eVec,n);
   m[3] = 0;   m[7] = 0;   m[11] = 0;   m[15] = 1.0;
   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

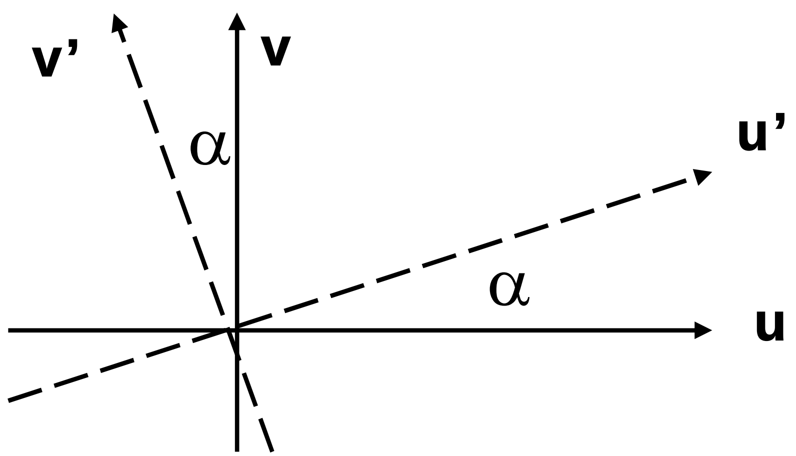
Example: Camera Slide

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

```
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 ***D*** along its u axis = **eye +** ***D*****u**

Example: Camera Roll



$$\mathbf{u}' = \cos(\alpha)\mathbf{u} + \sin(\alpha)\mathbf{v}$$

$$\mathbf{v}' = -\sin(\alpha)\mathbf{u} + \cos(\alpha)\mathbf{v}$$

```
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( );
}
```

References

- Interactive Computer Graphics, Angel and Shreiner, Chapter 4
- Computer Graphics using OpenGL (3rd edition), Hill and Kelley