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

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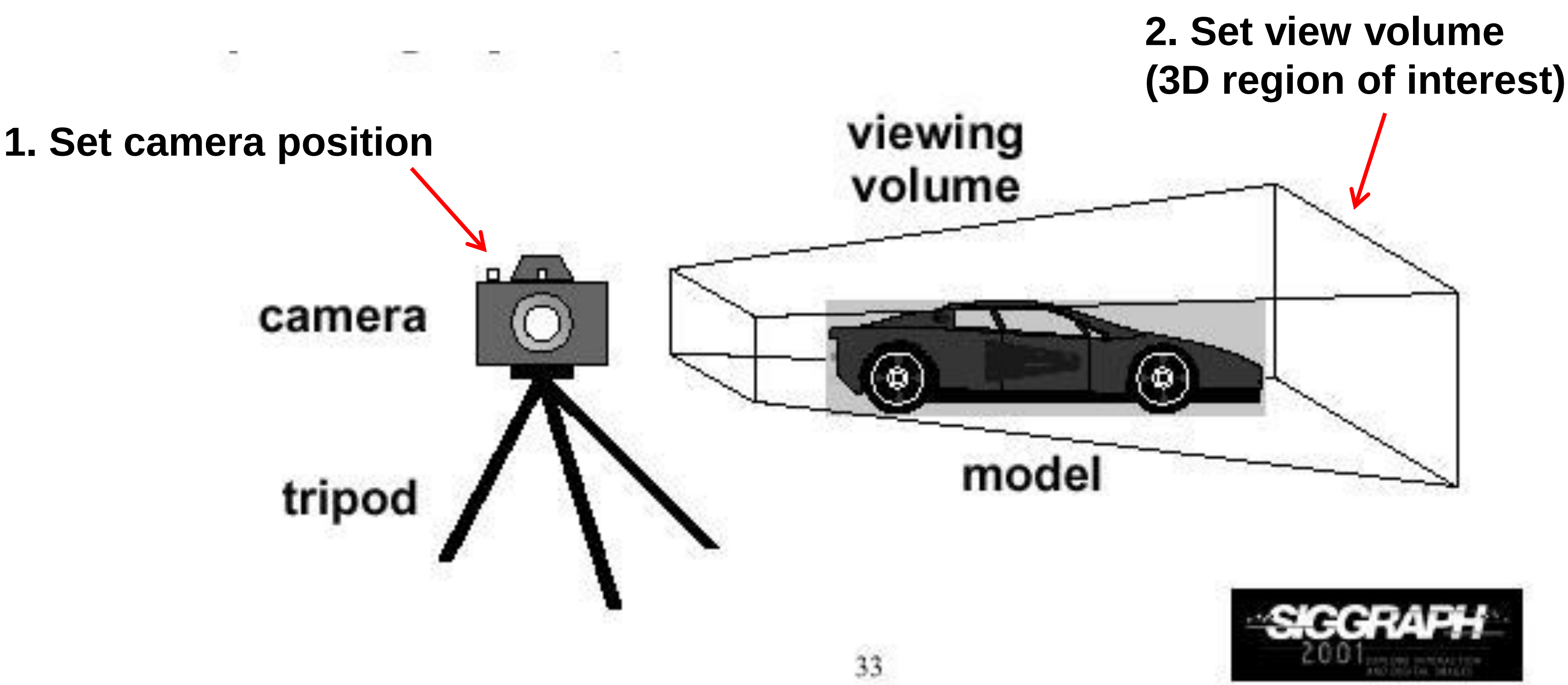
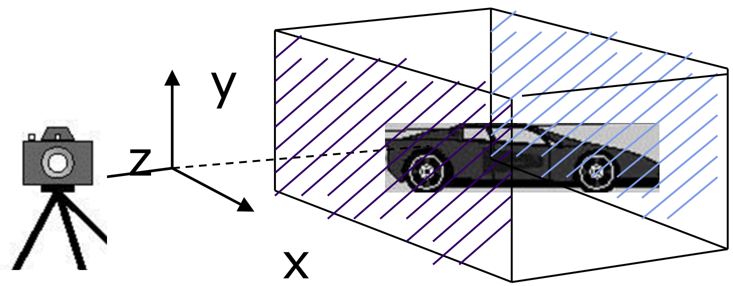
3D Viewing?

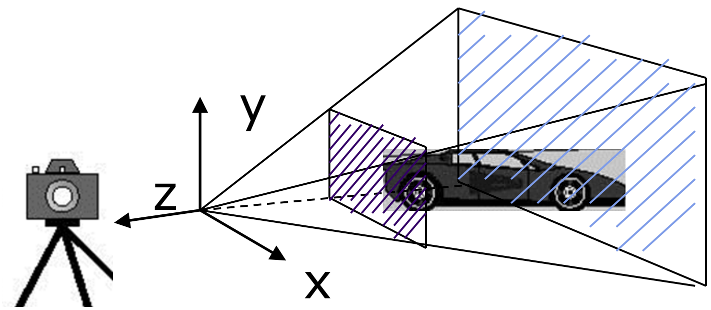
- Specify a view volume
- Objects **inside** view volume drawn to viewport (screen)
- Objects outside view volume **clipped** (not drawn)**!**



Different View Volume Shapes



Orthogonal view volume

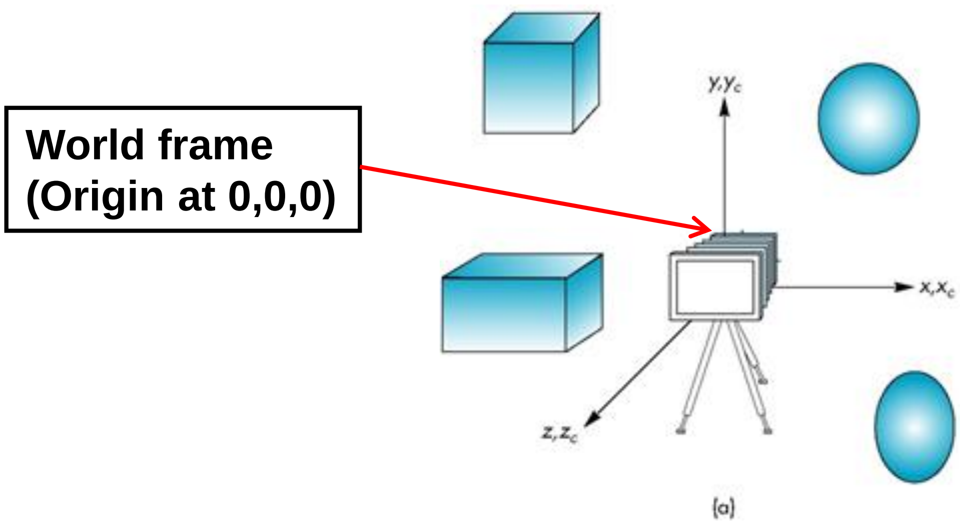


Perspective view volume

- Different view volume shape => different look
- Foreshortening? Near objects bigger
  - Perpective projection has foreshortening
  - Orthogonal projection: no foreshortening

The World Frame

- Object positions initially defined in **world frame**
- **World Frame origin** at (0,0,0)
- Objects positioned, oriented (translate, scale, rotate transformations) applied to objects in **world frame**



Camera Frame

- More natural to describe object positions relative to camera (eye)
- Why?
  - Our view of the world
  - First person shooter games

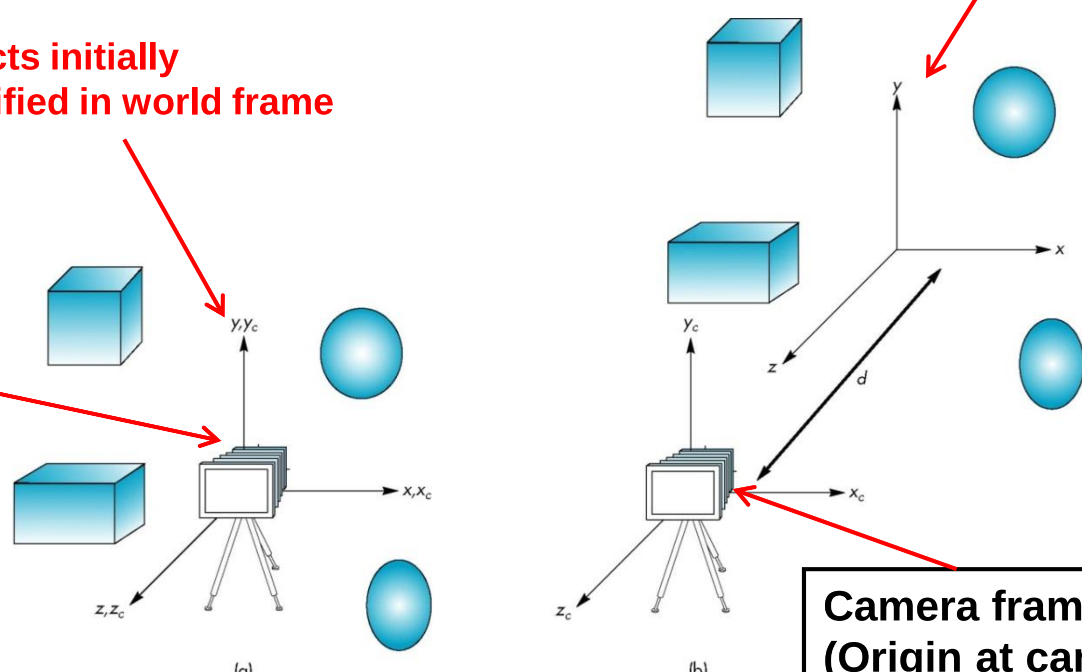
Camera Frame

- **Viewing:** After user chooses camera (eye) position, represent objects in **camera frame** (origin at eye position)
- **Viewing transformation:** Converts object (x,y,z) positions in world frame to positions in camera frame

More natural to view Objects in camera frame

Objects initially Specified in world frame

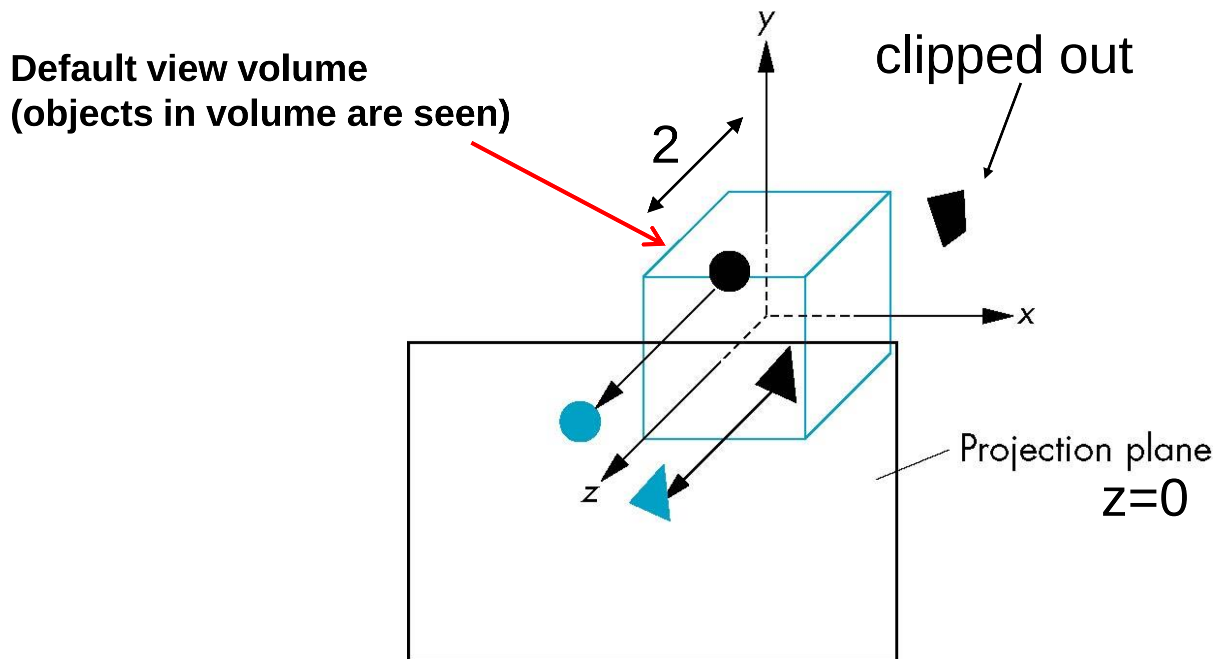
World frame (Origin at 0,0,0)



Camera frame (Origin at camera)

Default OpenGL Camera

- Initially Camera at origin: object and camera frames same
- Points in negative z direction
- Default view volume is cube with sides of length 2



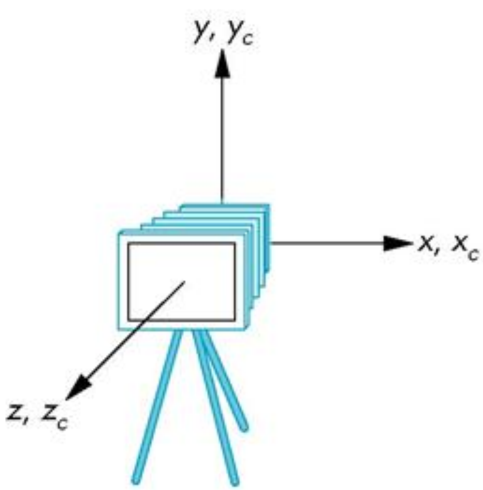
Moving Camera Frame

Same relative distance after
Same result/look

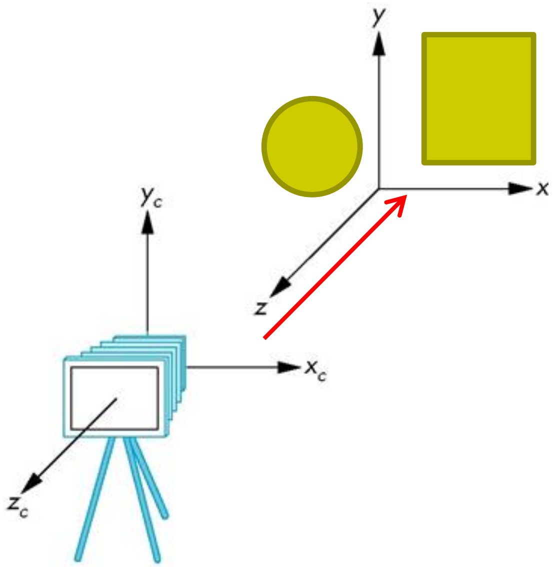
Translate objects -5
away from camera

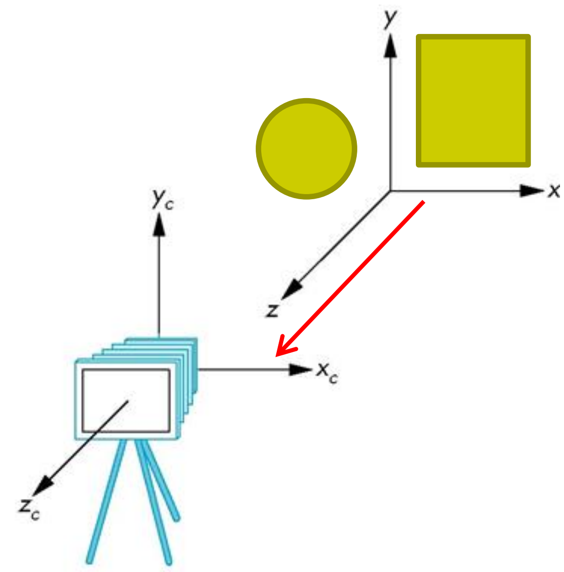
Translate camera +5
away from objects

default frames



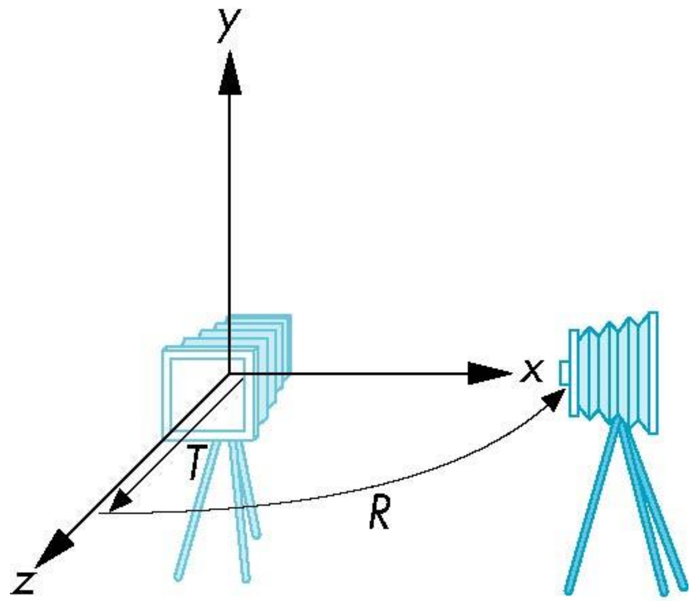
(a)





Moving the Camera

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

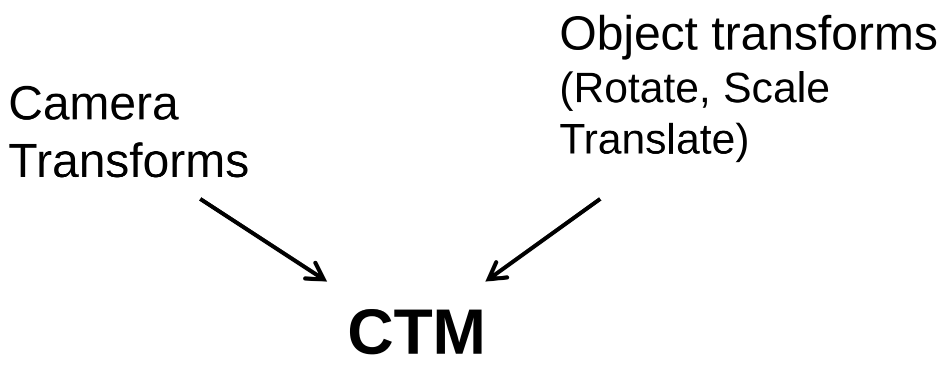



```
// Using mat.h

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

Moving the Camera Frame

- 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)**



The LookAt Function

- Previously, command **gluLookAt** to position camera
- **gluLookAt** deprecated!!
- Homegrown mat4 method LookAt() in mat.h
    - Sets camera position, transforms object distances to camera frame

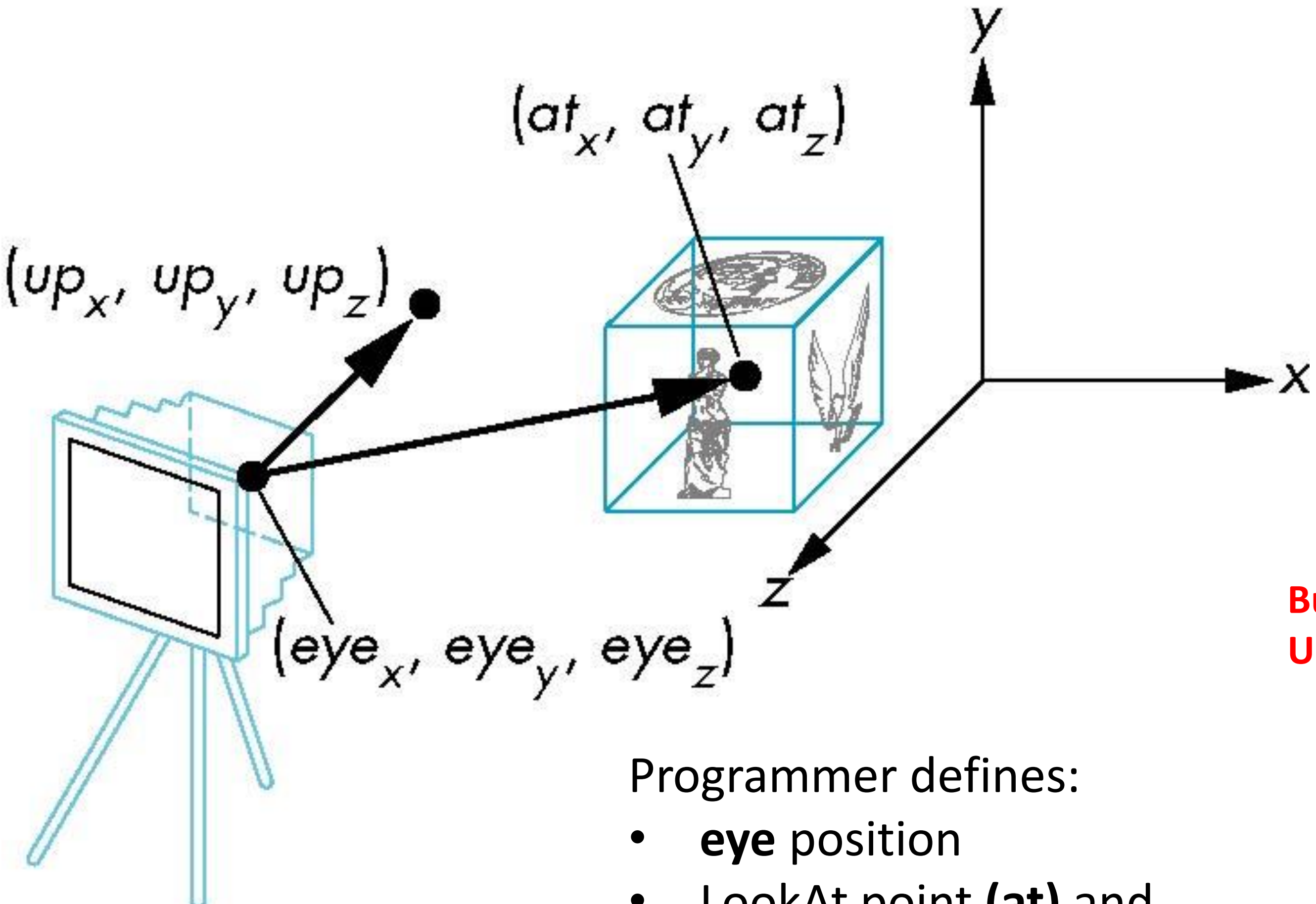
```
void display( ){
    .........

    mat4 mv = LookAt(vec4 eye, vec4 at, vec4 up);
    ...... . .
}
```

Builds 4x4 matrix for positioning, orienting
Camera and puts it into variable **mv**

The LookAt Function

`LookAt(eye, at, up)`

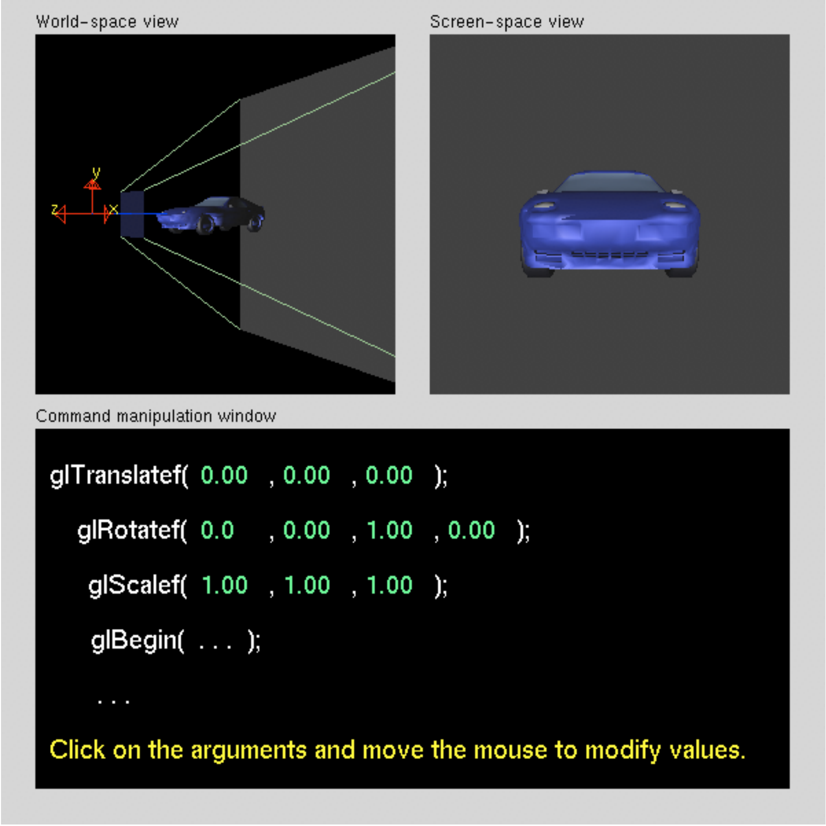


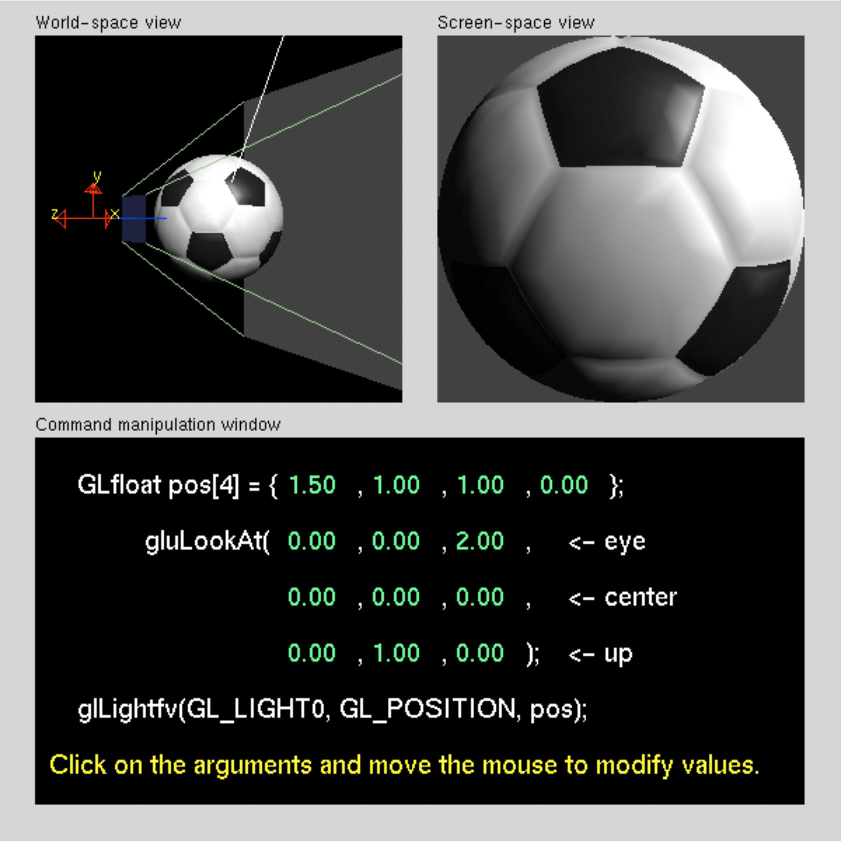
But Why do we set Up direction?

Programmer defines:

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

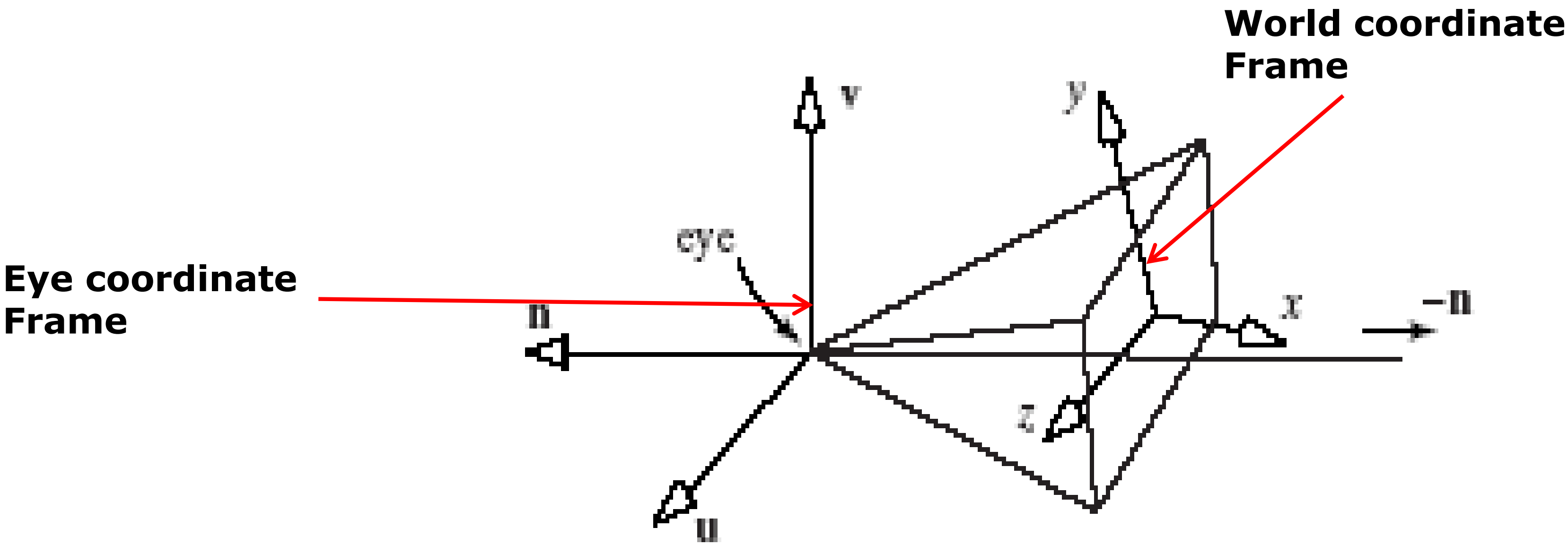
Nate Robbins LookAt Demo





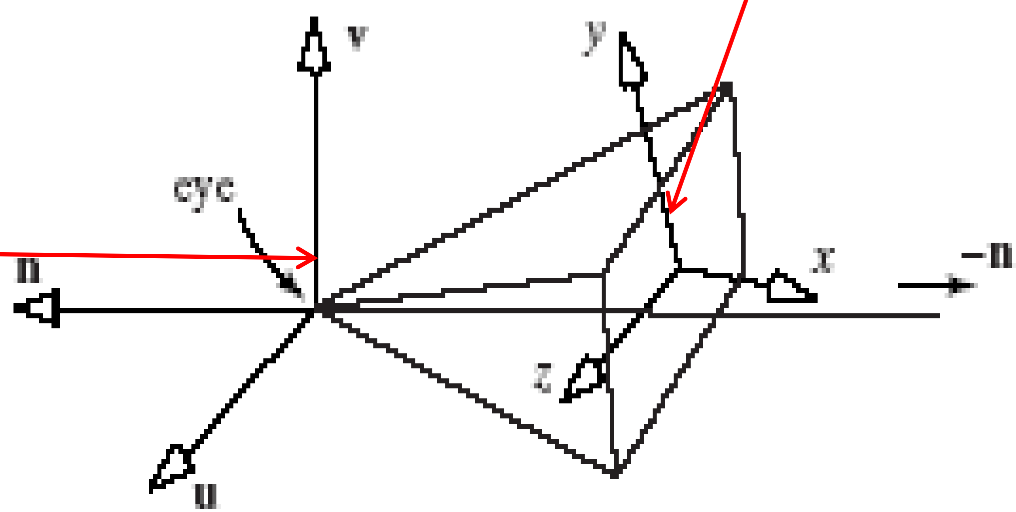
What does LookAt do?

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



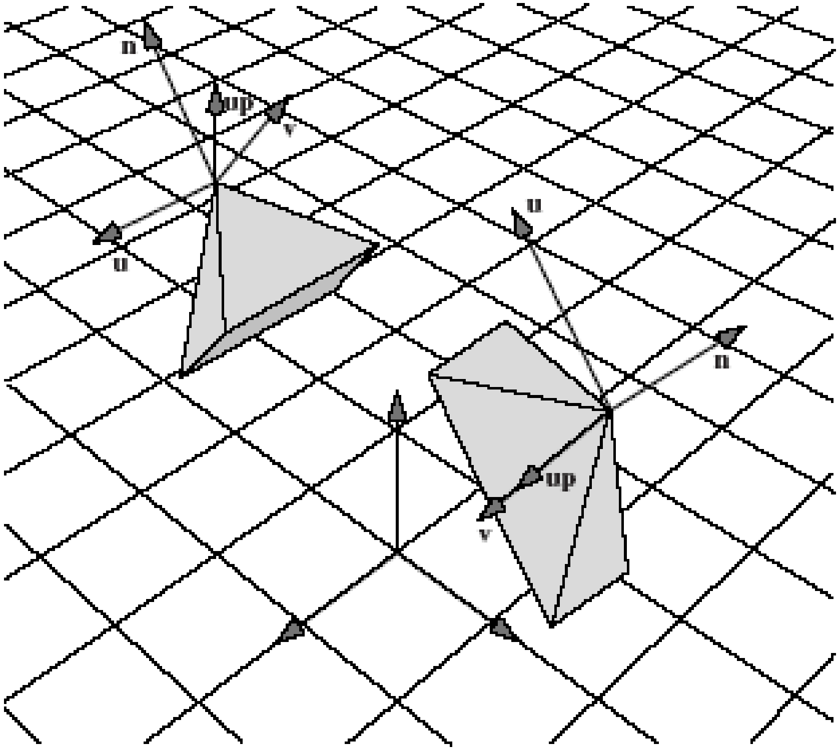
Camera with Arbitrary Orientation and Position

- Define new axes (u, v, n) 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

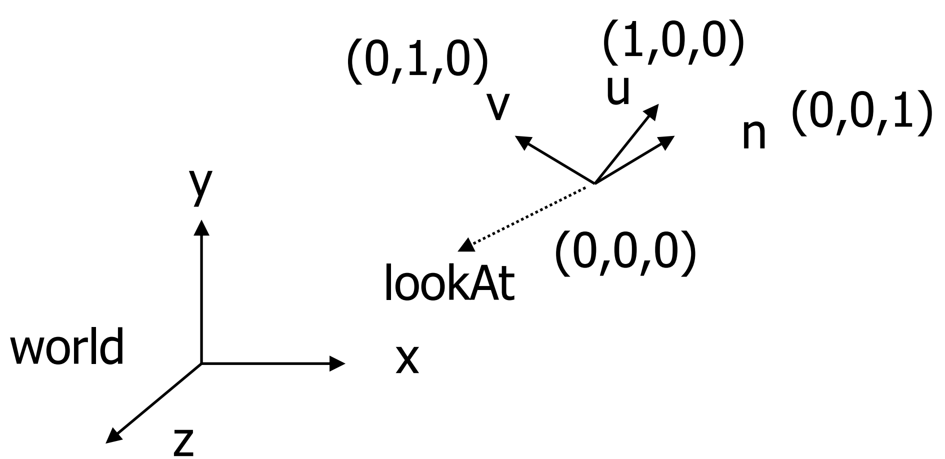
- Programmer sets `LookAt(eye, at, up)`
- If **eye**, **lookAt** point changes => **u,v,n** changes



Viewing Transformation Steps

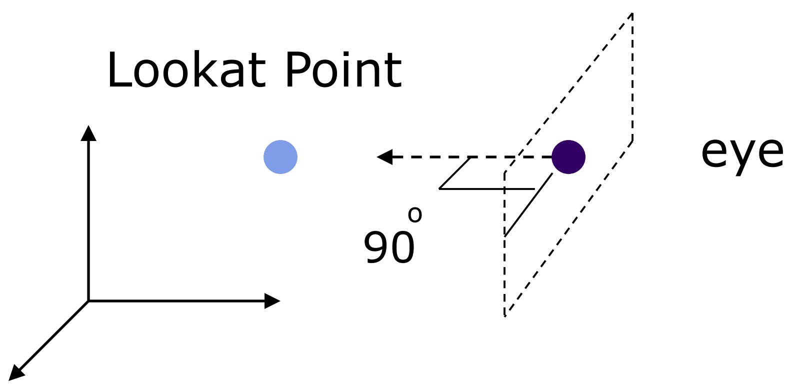
1. Form camera (u,v,n) frame
2. Transform objects from world frame (Composes matrix to transform coordinates)

- Next, let's form camera (u,v,n) frame



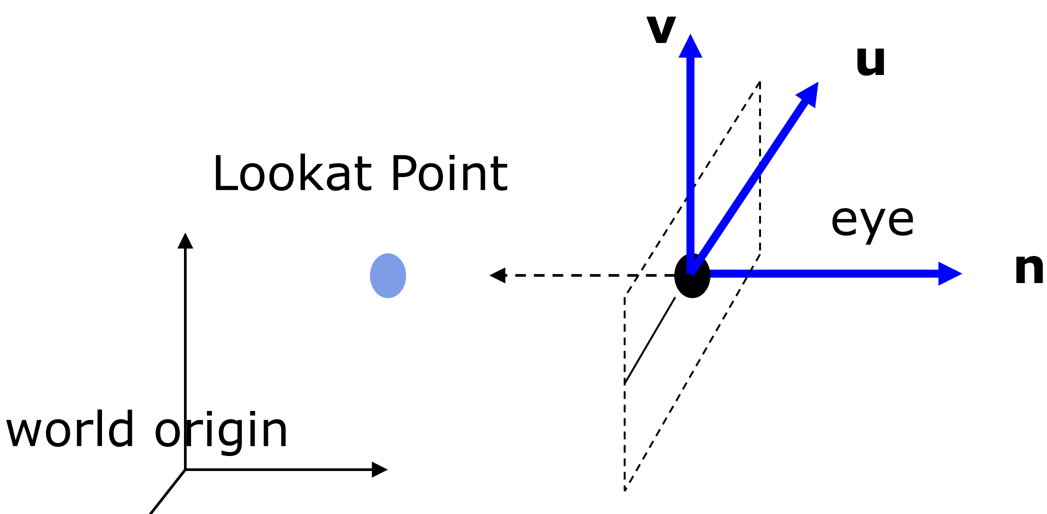
Constructing U,V,N Camera Frame

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



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)

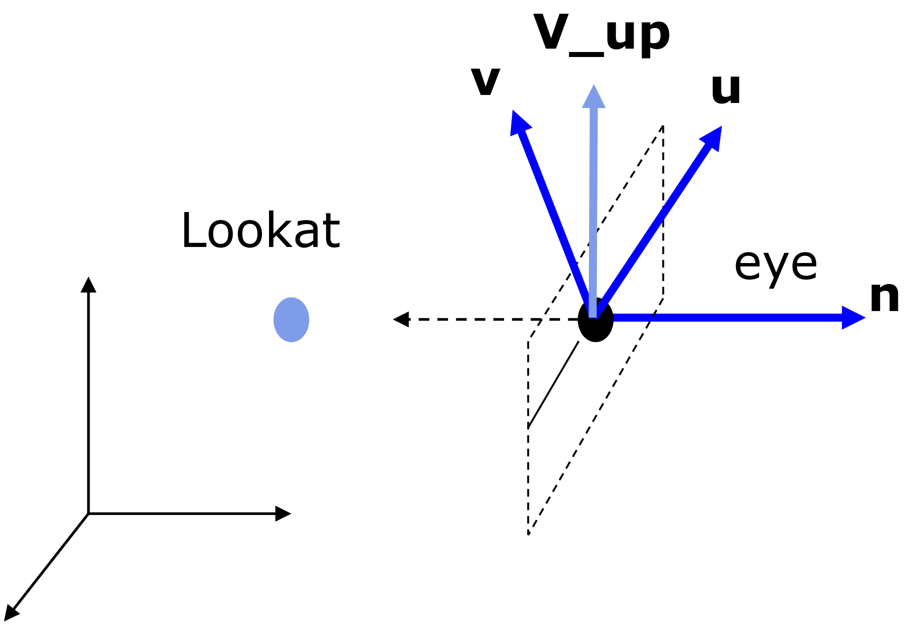
n is pointing away from the world because we use left hand coordinate system

N = eye – Lookat Point
n = N / | N |

Remember **u,v,n** should be all unit vectors
So… Normalize vectors!!!!!

Eye Coordinate Frame

- How about u and v?



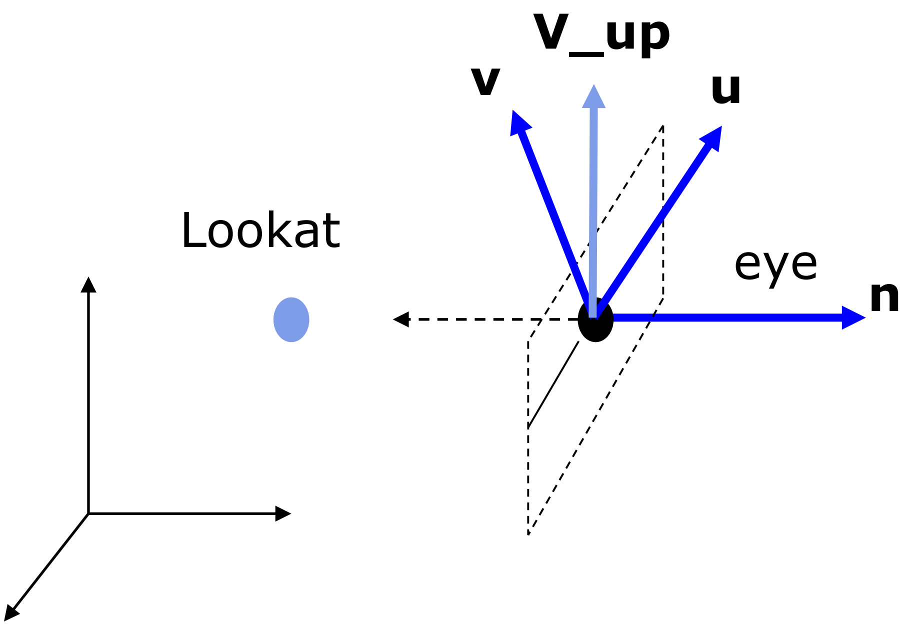
- Derive u first -
  - u is a vector that is perp to the plane spanned by N and view up vector (V_up)

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

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

Eye Coordinate Frame

- How about v?



To derive v from n and u

v = n x u

v is already normalized

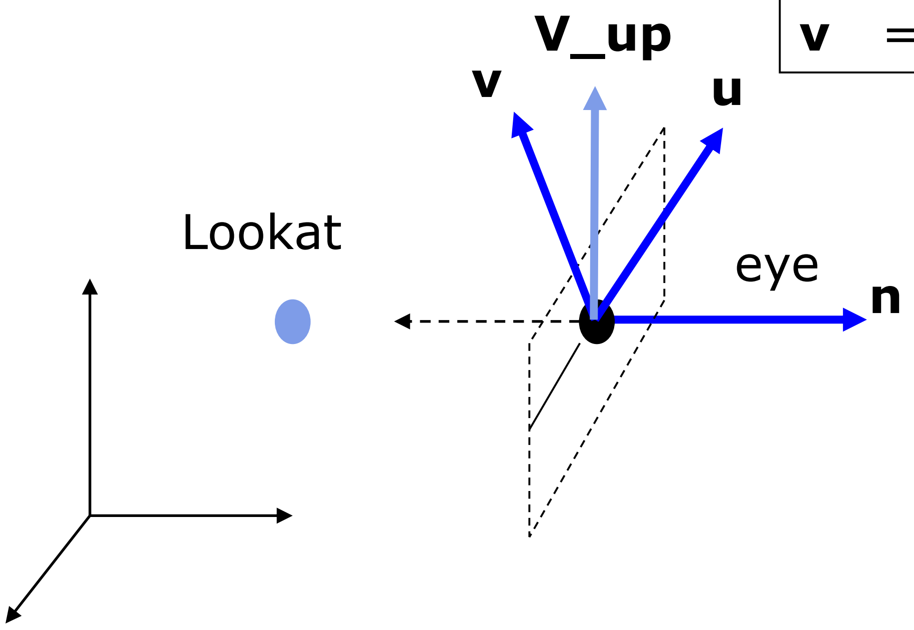
Eye Coordinate Frame

- Put it all together

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

Basis vectors:

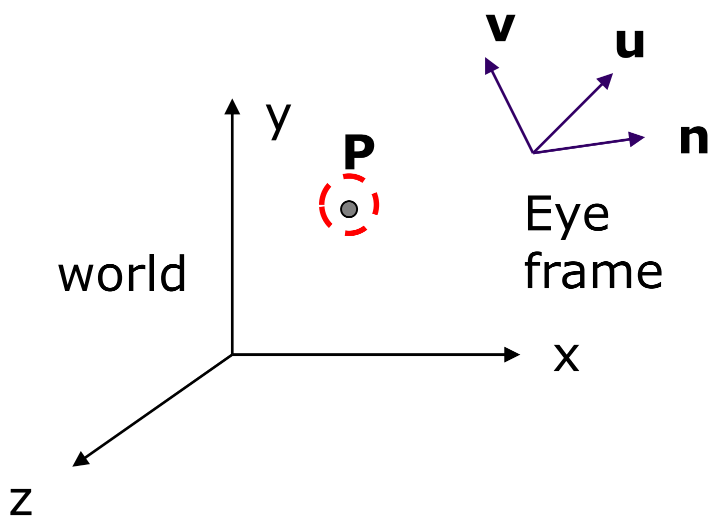
n = (eye – Lookat) / | eye – Lookat|
u = (V_up x **n**) / | V_up x **n** |
v = **n** x **u**



Step 2: World to Eye Transformation

- Next, use u, v, n to compose LookAt matrix
- Transformation matrix (M_{w2e}) ?
  - Matrix that transforms a point P in world frame to P' in eye frame

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

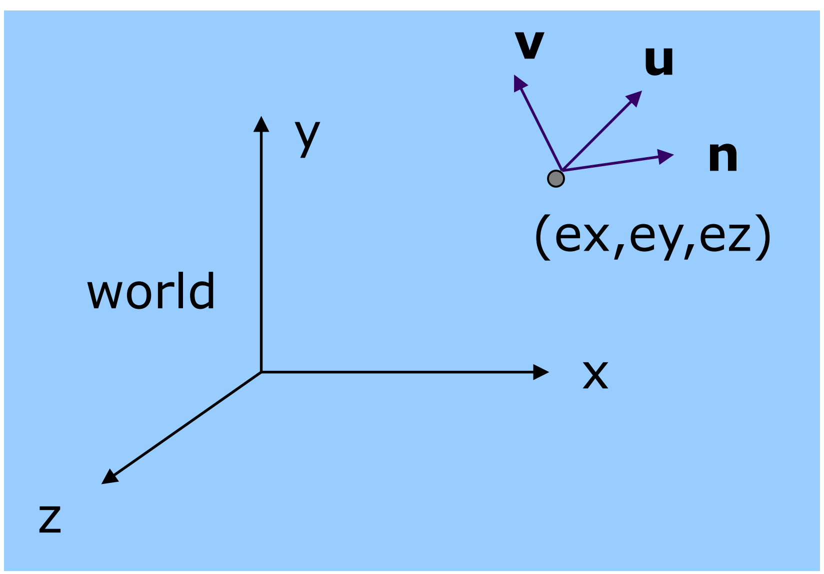


1. Come up with transformation sequence that lines up eye frame with world frame

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:

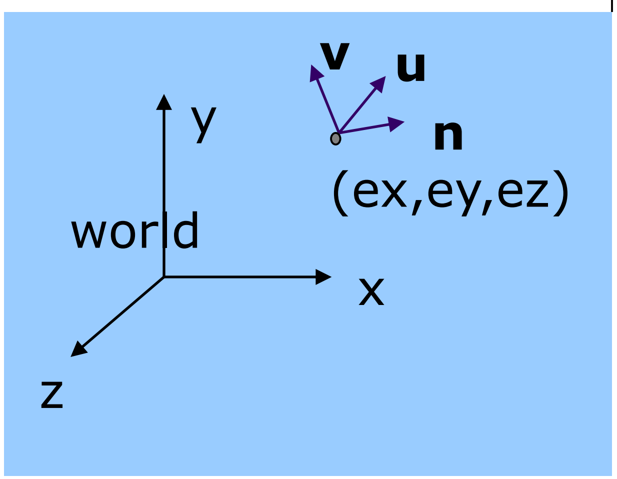
$$\begin{vmatrix} 1 & 0 & 0 & -ex \\ 0 & 1 & 0 & -ey \\ 0 & 0 & 1 & -ez \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

World to Eye Transformation

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

Order

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



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

Multiplied together = lookAt transform

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

e.v = ex.vx + ey.vy + ez.vz

e.n = ex.nx + ey.ny + ez.nz

lookAt Implementation (from mat.h)

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**

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

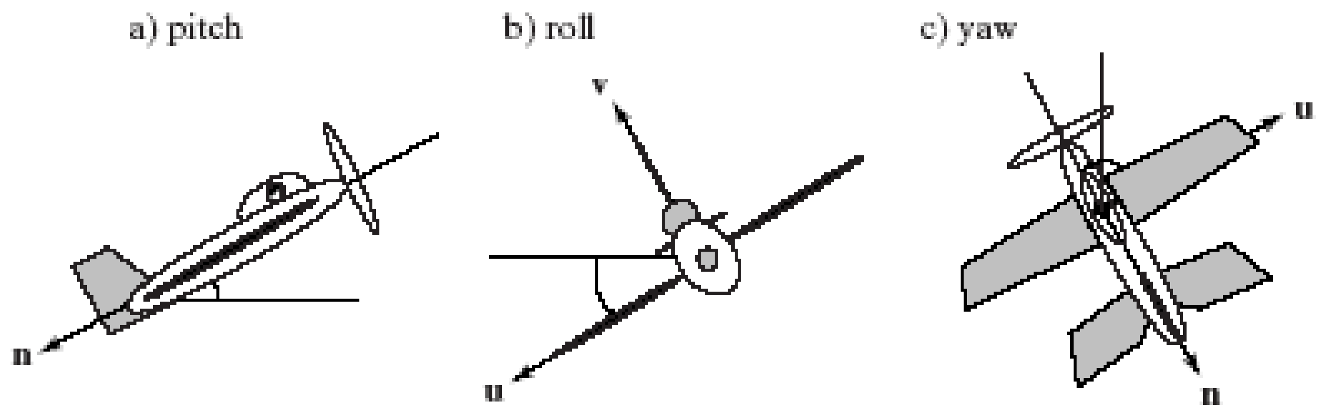
```
mat4 LookAt( const vec4& eye, const vec4& at, const vec4& up )
{
    vec4 n = normalize(eye - at);
    vec4 u = normalize(cross(up,n));
    vec4 v = normalize(cross(n,u));
    vec4 t = vec4(0.0, 0.0, 0.0, 1.0);
    mat4 c = mat4(u, v, n, t);
    return c * Translate( -eye );
}
```

Other Camera Controls

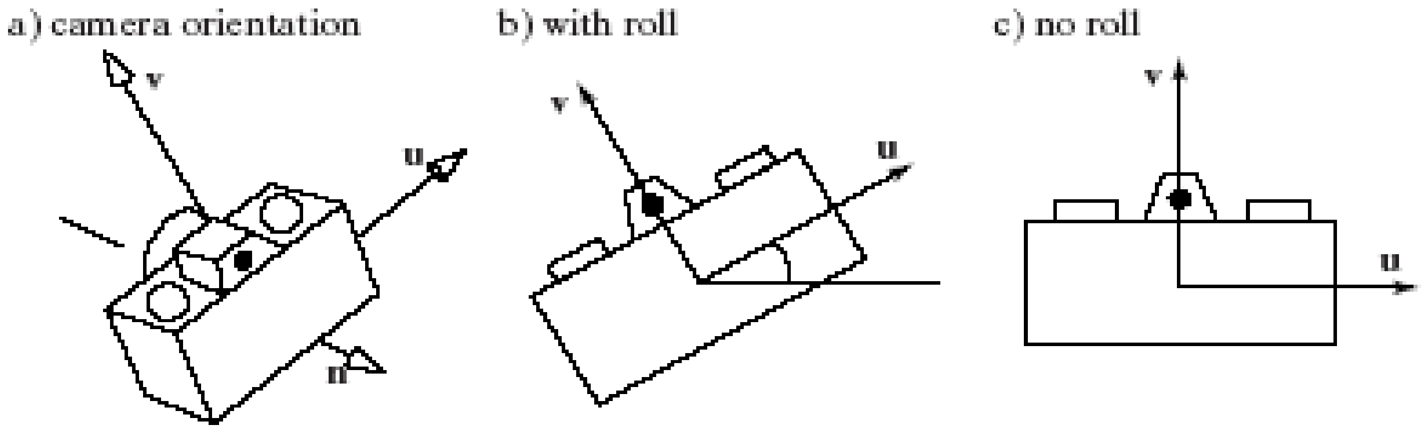
- The LookAt function is only for positioning camera
- Other ways to specify camera position/movement
  - Yaw, pitch, roll
  - Elevation, azimuth, twist
  - Direction angles

Flexible Camera Control

- Sometimes, we want camera to move
- Like controlling an airplane's orientation
- Adopt aviation terms:
  - **Pitch:** nose up-down
  - **Roll:** roll body of plane
  - **Yaw:** move nose side to side

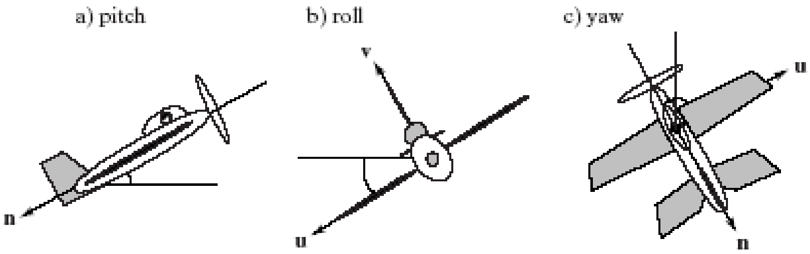


Yaw, Pitch and Roll Applied to Camera



Flexible Camera Control

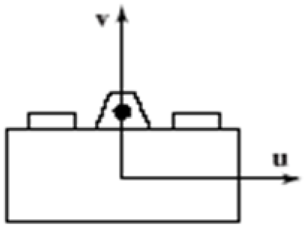
- Create a **camera** class




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

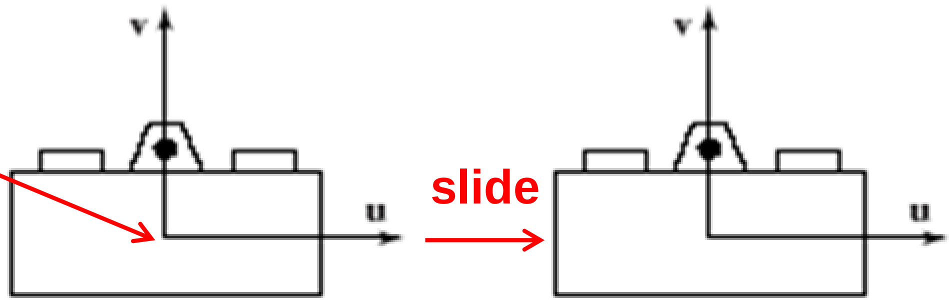
- Camera methods (functions) to specify pitch, roll, yaw. E.g

```
cam.slide(1, 0, 2); // slide camera backward 2 and  right 1
cam.roll(30);    // roll camera 30 degrees
cam.yaw(40);    // yaw camera 40 degrees
cam.pitch(20);  // pitch camera 20 degrees
```



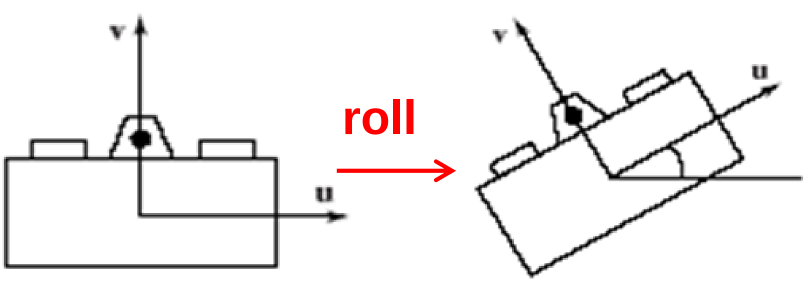
Recall: Final LookAt Matrix

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



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

- Pitch, yaw, roll rotates u, v or n
- Changes u, v or n



Implementing Flexible Camera Control

- 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
    1. **Roll, pitch, yaw:** calculate modified vector (u', v', n')
    2. **Slide:** Calculate new eye position
    3. Update lookAt matrix, Load it into CTM

Example: Camera Slide

- Recall: the axes are unit vectors
- User changes eye by delU, delV or delN
- eye = eye + changes (delU, delV, delN)
- Note: function below combines all slides into one

  E.g moving camera by ***D*** along its u axis = **eye + *D*u**

```
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( );
}
```

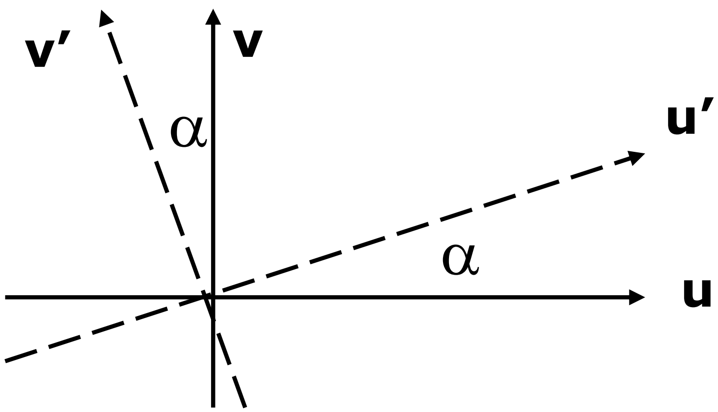
Load Matrix into CTM

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

```
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
}
```

- Slide changes **eVec**,
- roll, pitch, yaw, change **u, v, n**
- Call setModelViewMatrix after slide, roll, pitch or yaw

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