CS 543: Computer Graphics
Lecture 7 (Part I): 3D Viewing and Camera Control

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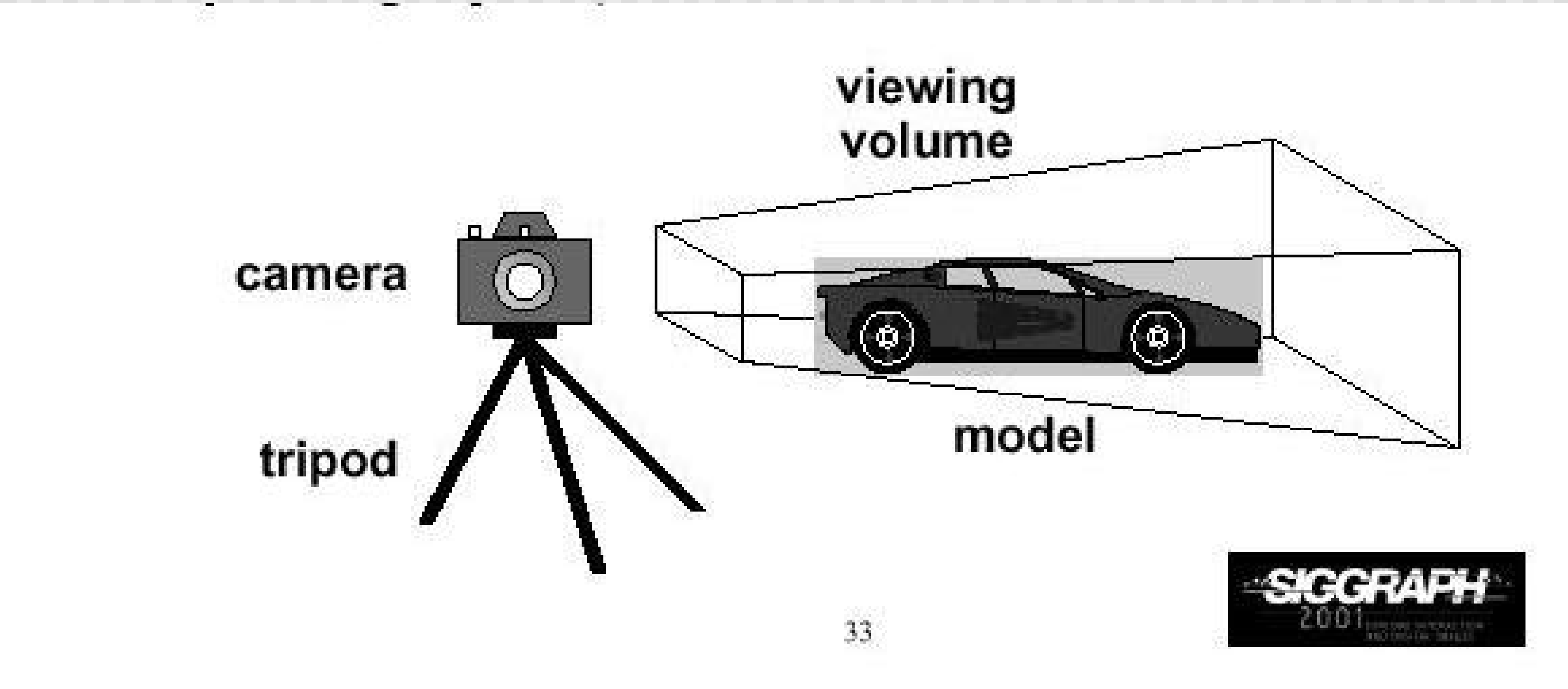
3D Viewing

- Similar to taking a photograph
- Control the “lens” of the camera
- Project the object from 3D world to 2D screen



Viewing Transformation

- Recall, setting up the Camera:
  - gluLookAt (Ex, Ey, Ez, cx, cy, cz, Up_x, Up_y, Up_z)
  - The view up vector is usually (0,1,0)
  - Remember to set the OpenGL matrix mode to GL_MODELVIEW first
- Modelview matrix:
  - combination of modeling matrix *M* and Camera transforms *V*
- gluLookAt fills *V* part of modelview matrix
- What does gluLookAt do with parameters (*eye, LookAt, up vector*) you provide?

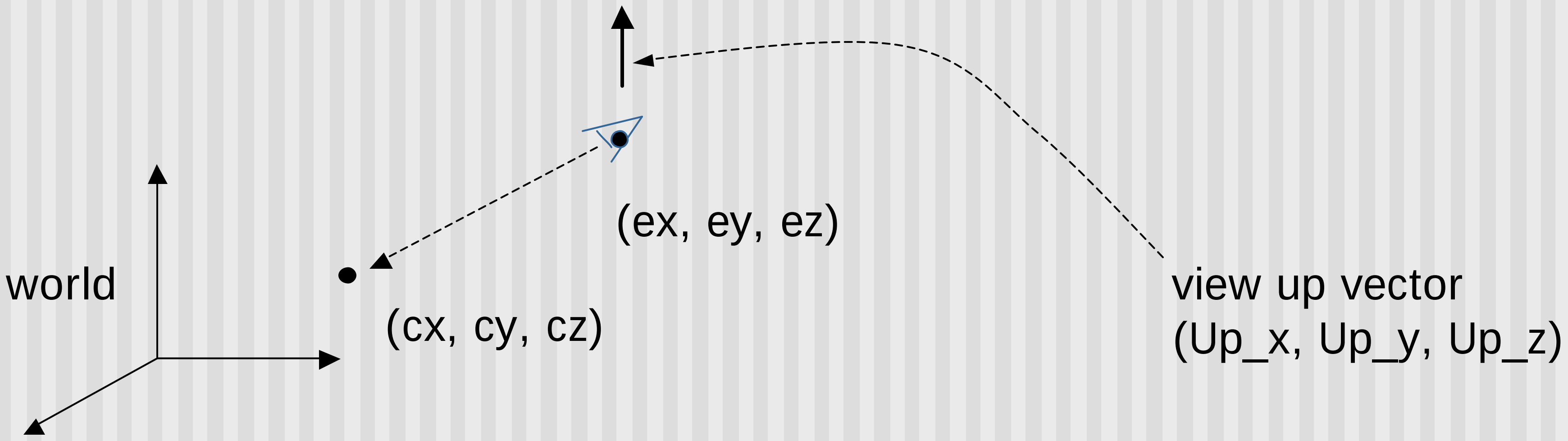
Viewing Transformation

- OpenGL Code:

```
void display()
{
    glClear(GL_COLOR_BUFFER_BIT);
    glMatrixMode(GL_MODELVIEW);
    glLoadIdentity();
    gluLookAt(0,0,1,0,0,0,0,1,0);
    display_all();    // your display routine
}
```

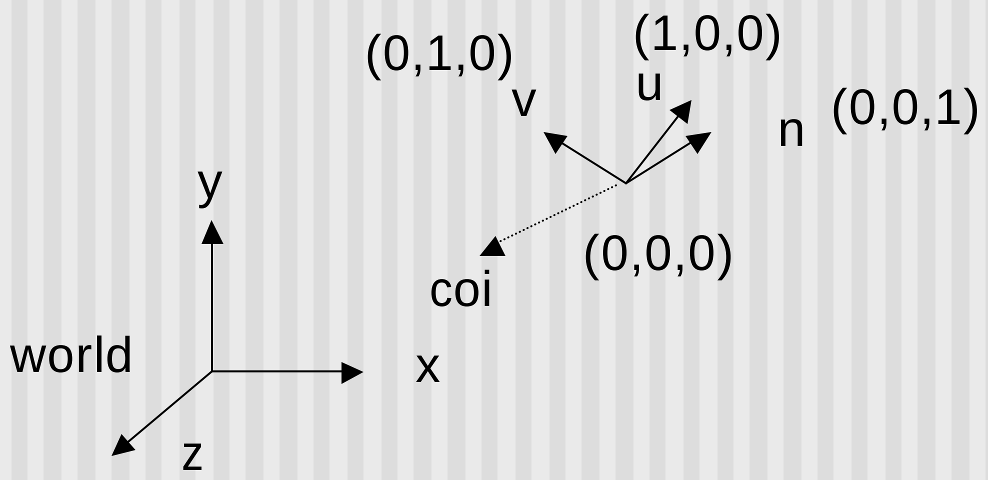
Viewing Transformation

- Control the “lens” of the camera
- Important camera parameters to specify
  - Camera (eye) position (Ex,Ey,Ez) in world coordinate system
  - lookAt point (cx, cy, cz)
  - Orientation (which way is up?): Up vector (Up_x, Up_y, Up_z)



Viewing Transformation

- Transformation?
  - Form a camera (eye) coordinate frame
  - Transform objects from world to eye space
- Eye space?
  - Transform to eye space can simplify many downstream operations (such as projection) in the pipeline



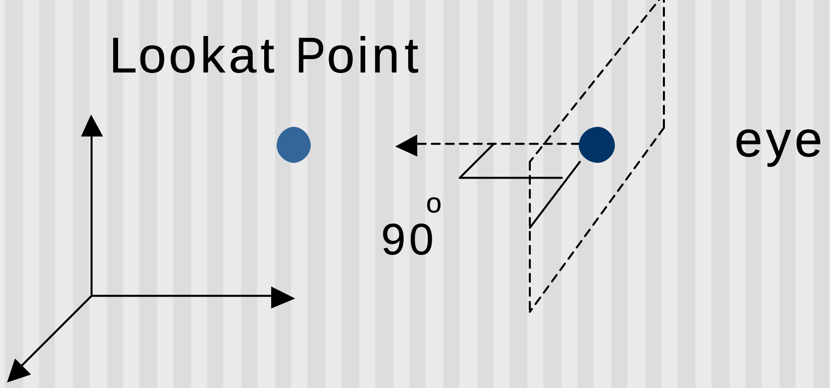
Viewing Transformation

- gluLookAt call transforms the object from world to eye space by:
  - Constructing eye coordinate frame (u, v, n)
  - Composes matrix to perform coordinate transformation
  - Loads this matrix into the V part of modelview matrix
  - Allows flexible Camera Control

Eye Coordinate Frame

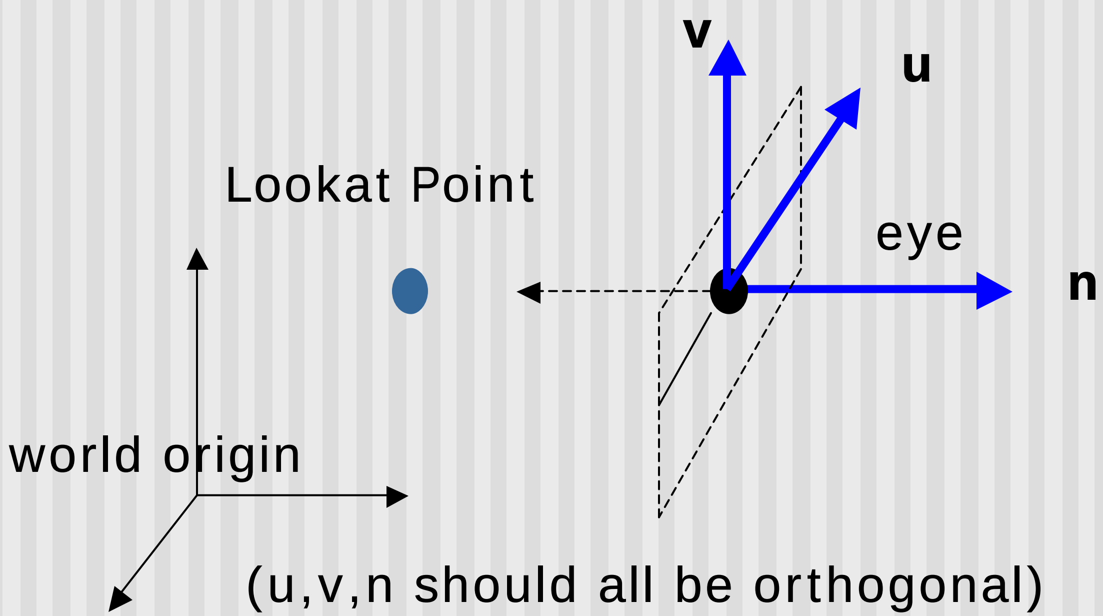
- Constructing u,v,n?
- Known: eye position, LookAt Point, up vector
- To find out: new origin and three basis vectors

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



Eye Coordinate Frame

- Origin: eye position (that was easy)
- Three 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

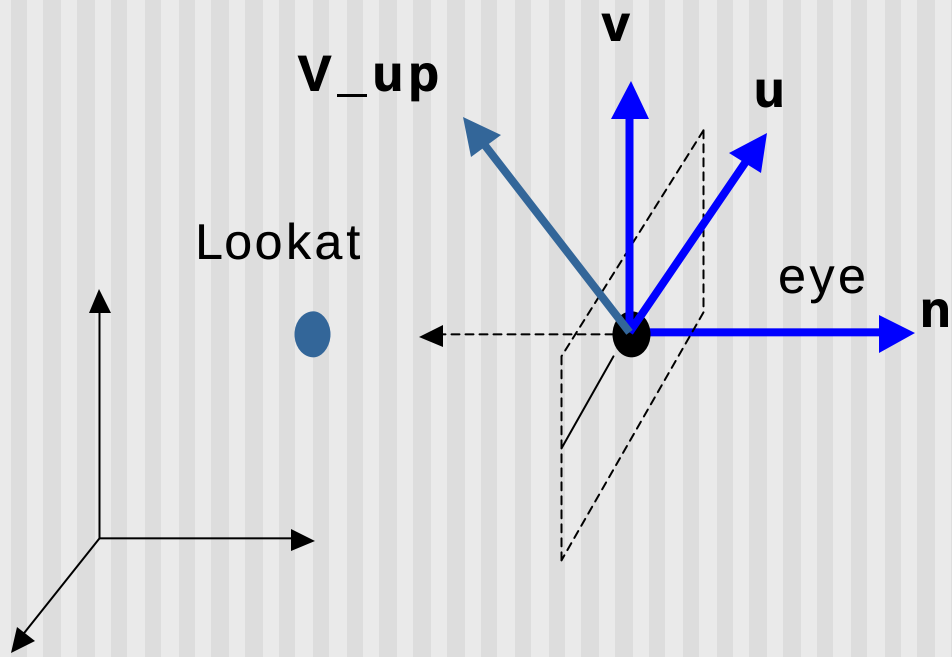
N = eye – Lookat Point

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 -

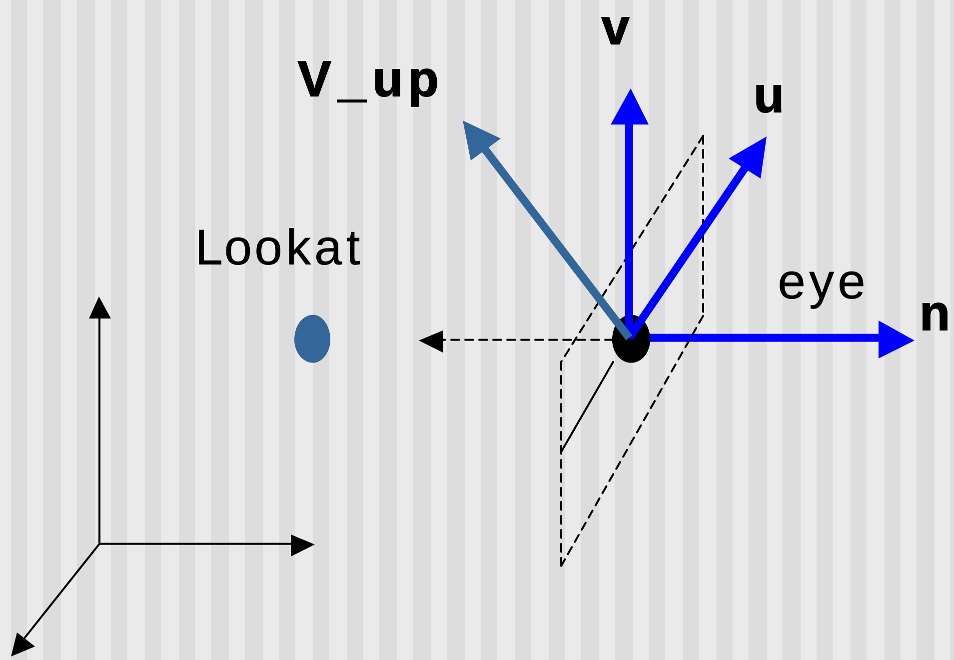
•u is a vector that is perp to the plane spanned by N and view up vector (V_up)

U = V_up x **n**

u = U / | U |

Eye Coordinate Frame

- How about v?



Knowing n and u, getting v is easy

v = n x u

v is already normalized

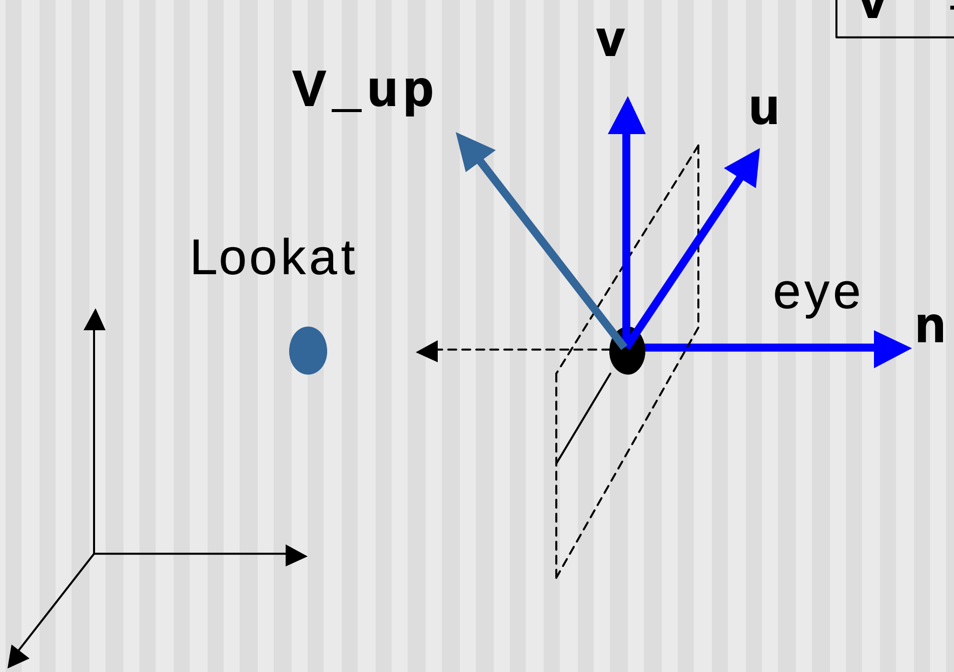
Eye Coordinate Frame

- Put it all together

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

Basis vectors:

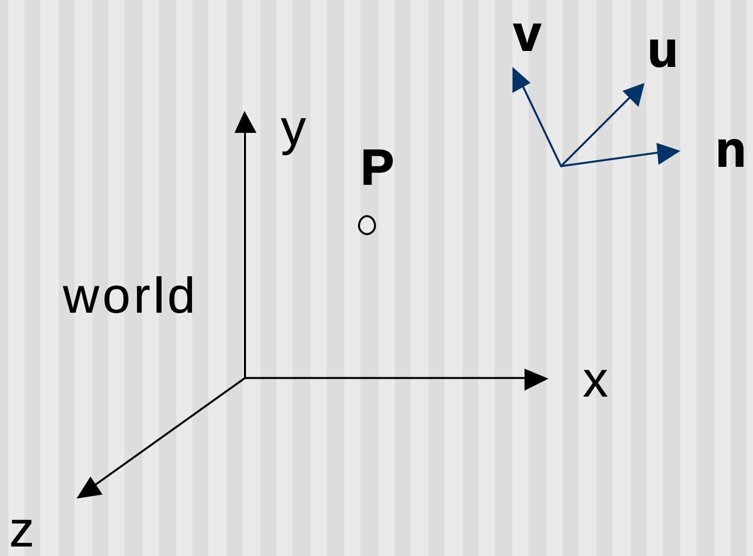
n = (eye – Lookat) / | eye – Lookat|
u = (V_up x **n**) / | V_up x **n** |
v = **n** x **u**



World to Eye Transformation

- Next, use u, v, n to compose V part of modelview
- Transformation matrix (M_{w2e}) ?

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

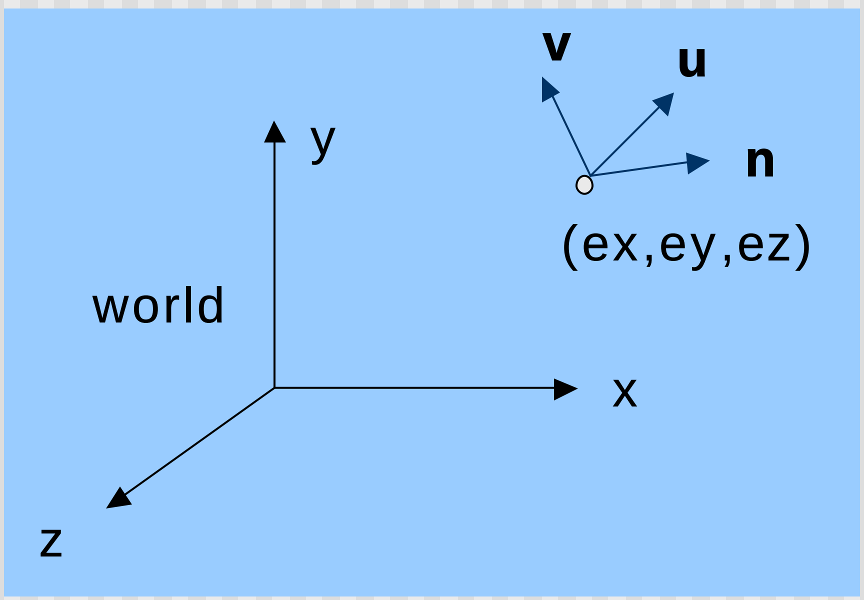


1. Come up with the transformation sequence to move eye coordinate frame to the world

2. And then apply this sequence to the point P in a reverse order

World to Eye Transformation

- Rotate the eye frame to “align” it with the world frame
- Translate (-ex, -ey, -ez)



Rotation:

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

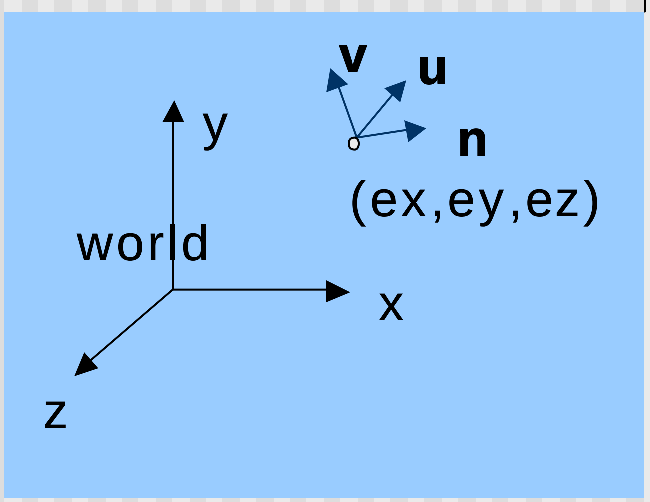
Translation:

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

World to Eye Transformation

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

$$M_{w2e} = \begin{vmatrix} ux & uy & ux & 0 \\ vx & vy & vz & 0 \\ nx & ny & nz & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \begin{vmatrix} 1 & 0 & 0 & -ex \\ 0 & 1 & 0 & -ey \\ 0 & 0 & 1 & -ez \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

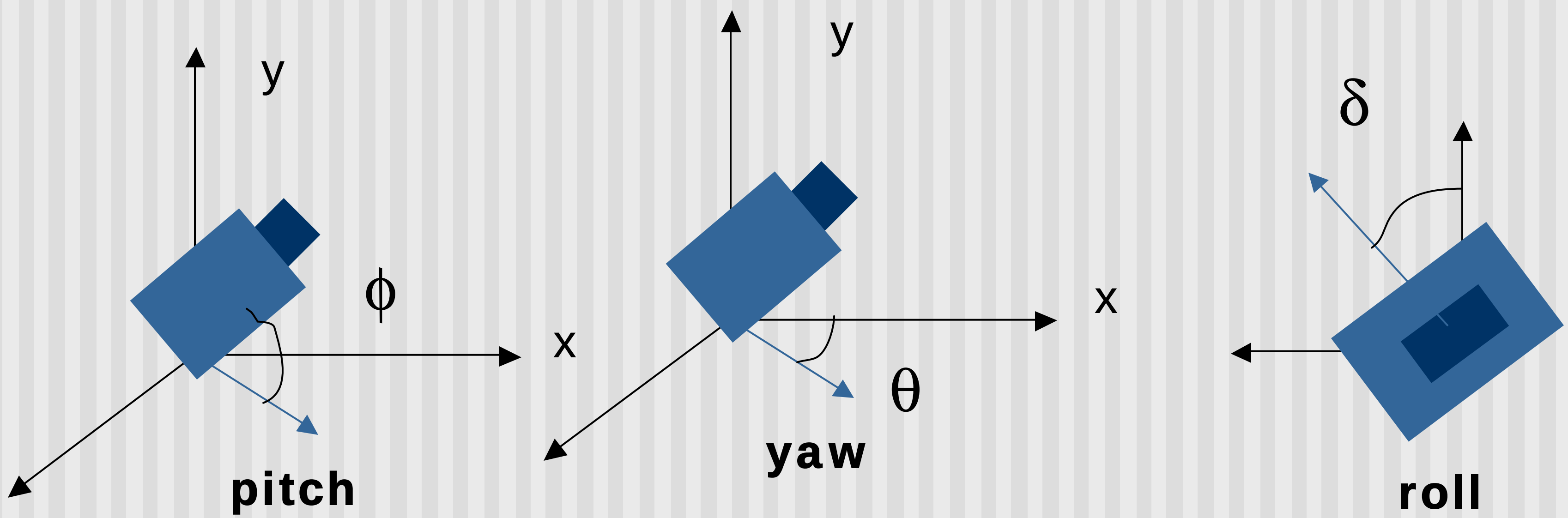


$$= \begin{vmatrix} ux & uy & uz & -\mathbf{e} \cdot \mathbf{u} \\ vx & vy & vz & -\mathbf{e} \cdot \mathbf{v} \\ nx & ny & nz & -\mathbf{e} \cdot \mathbf{n} \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

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

Flexible Camera Control

- Sometimes, we want camera to move
- Just like controlling a airplane's orientation
- Use aviation terms for this: pitch, yaw, roll
  - **Pitch:** nose up-down
  - **Roll:** roll body of plane
  - **Yaw:** move nose side to side



Flexible Camera Control

- May create a **camera** class

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

- Let user specify pitch, roll, yaw to change camera
- Example:

```
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
```

Flexible Camera Control

- gluLookAt() **does not** let you control roll, pitch and yaw
- Main idea behind flexible camera control
  - User supplies θ, ϕ or roll angle
  - Constantly maintain the vector (u, v, n) by yourself
  - Calculate new u', v', n' **after** roll, pitch, slide, or yaw
  - Compose new V part of modelview matrix yourself
  - Set modelview matrix directly yourself using **glLoadMatrix** call

Loading Modelview Matrix directly

```
void Camera::setModelViewMatrix(void)
{  // load modelview matrix with existing camera values
   float m[16];
   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] = -eVec.dot(u);
   m[1] = v.x; m[5] = v.y; m[9] = v.z;  m[13] = -eVec.dot(v);
   m[2] = n.x; m[6] = n.y; m[10] = n.z; m[14] = -eVec.dot(n);
   m[3] = 0;   m[7] = 0;   m[11] = 0;   m[15] = 1.0;
   glMatrixMode(GL_MODELVIEW);
   glLoadMatrixf(m); // load OpenGL's modelview matrix
}
```

Above setModelViewMatrix acts like gluLookAt

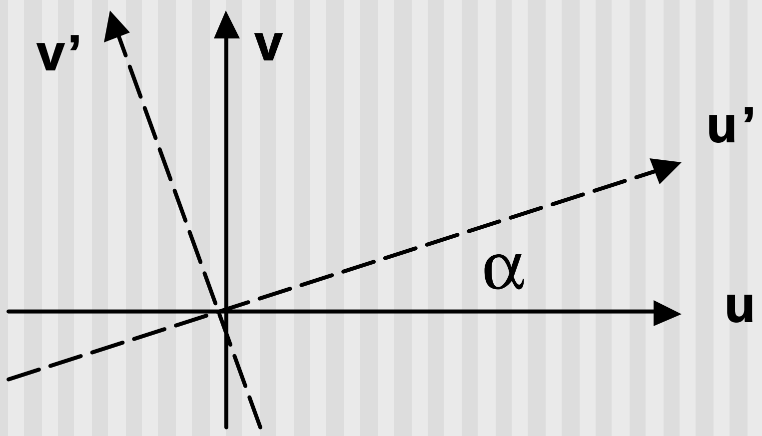
Slide changes eVec, roll, pitch, yaw, change u, v, n

Camera Slide

- User changes eye by delU, delV or delN
- eye = eye + changes
- 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( );
}
```

Camera Roll



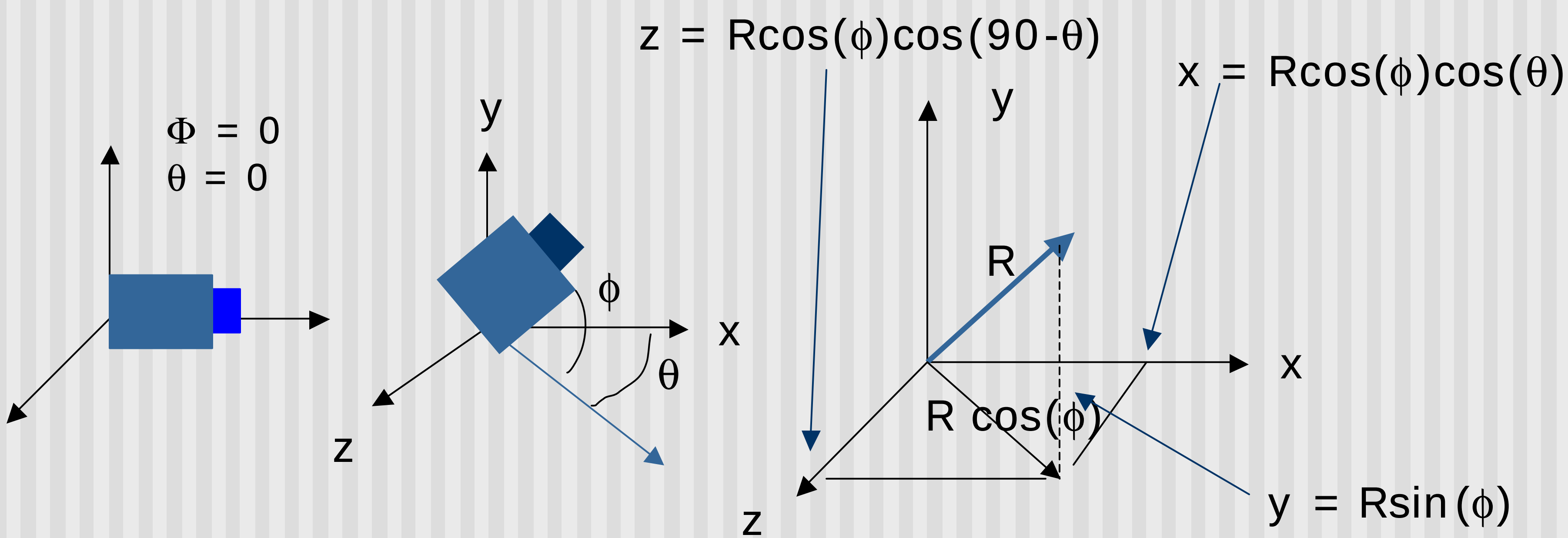
$$\mathbf{u}' = \cos(a)\mathbf{u} + \sin(a)\mathbf{v}$$

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

```
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( );
}
```

Flexible Camera Control

- How to compute the viewing vector (x,y,z) from pitch(ϕ) and yaw(θ) ? Read sections 7.2, 7.3 of Hill



References

- Hill, chapter 7