University of British Columbia
CPSC 314 Computer Graphics
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Viewing 1

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2016

Viewing

Using Transformations

- three ways
  - modelling transforms
    - place objects within scene (shared world)
    - affine transformations
  - viewing transforms
    - place camera
    - rigid body transformations: rotate, translate
  - projection transforms
    - change type of camera
    - projective transformation

Rendering Pipeline

Scene graph
Object geometry

↓

Modelling Transforms

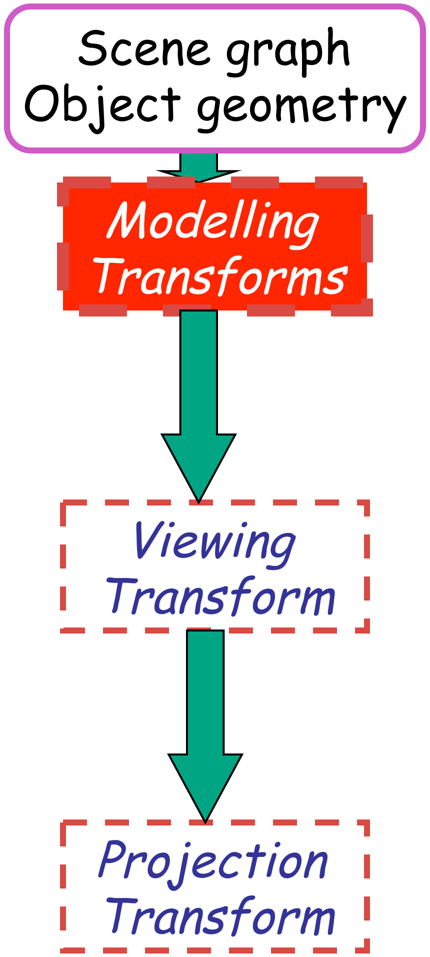
↓

Viewing Transform

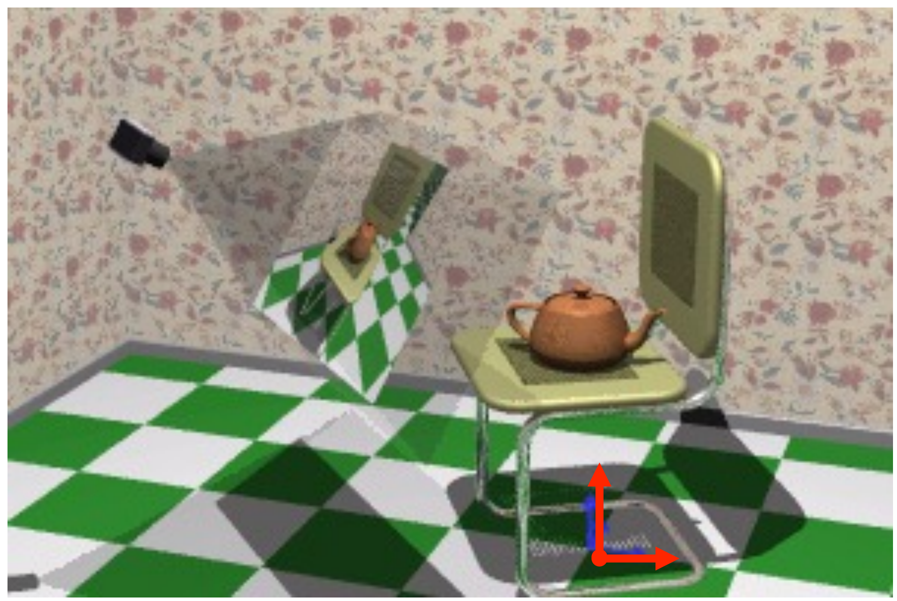
↓

Projection Transform

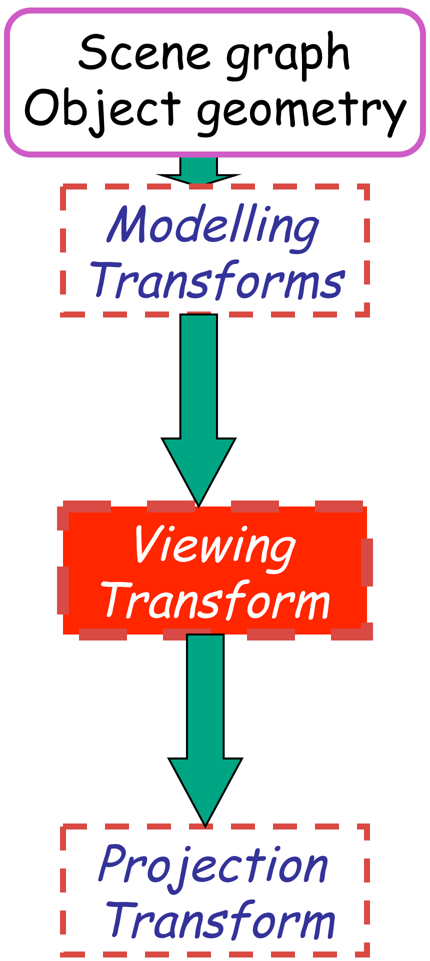
Rendering Pipeline



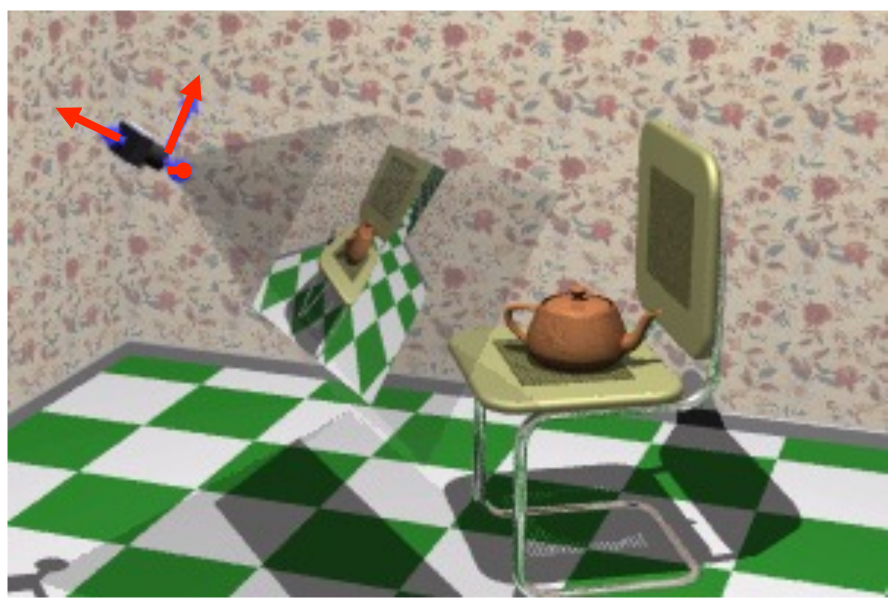
- result
  - all vertices of scene in shared 3D world coordinate system



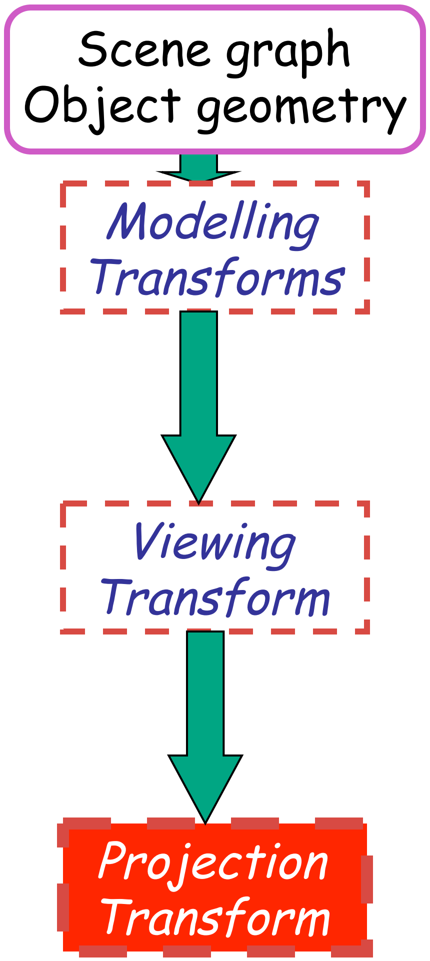
Rendering Pipeline



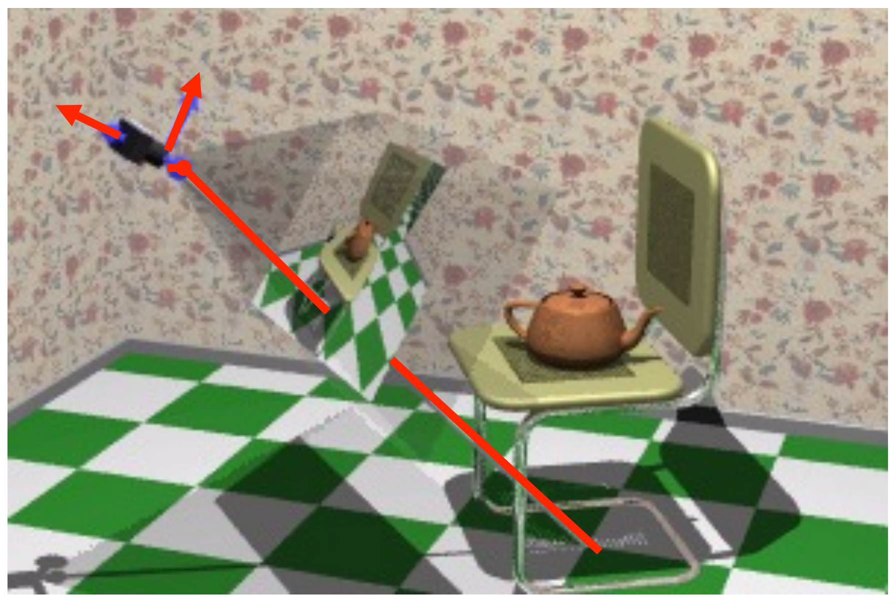
- result
  - scene vertices in 3D view (camera) coordinate system



Rendering Pipeline



- result
  - 2D screen coordinates of clipped vertices



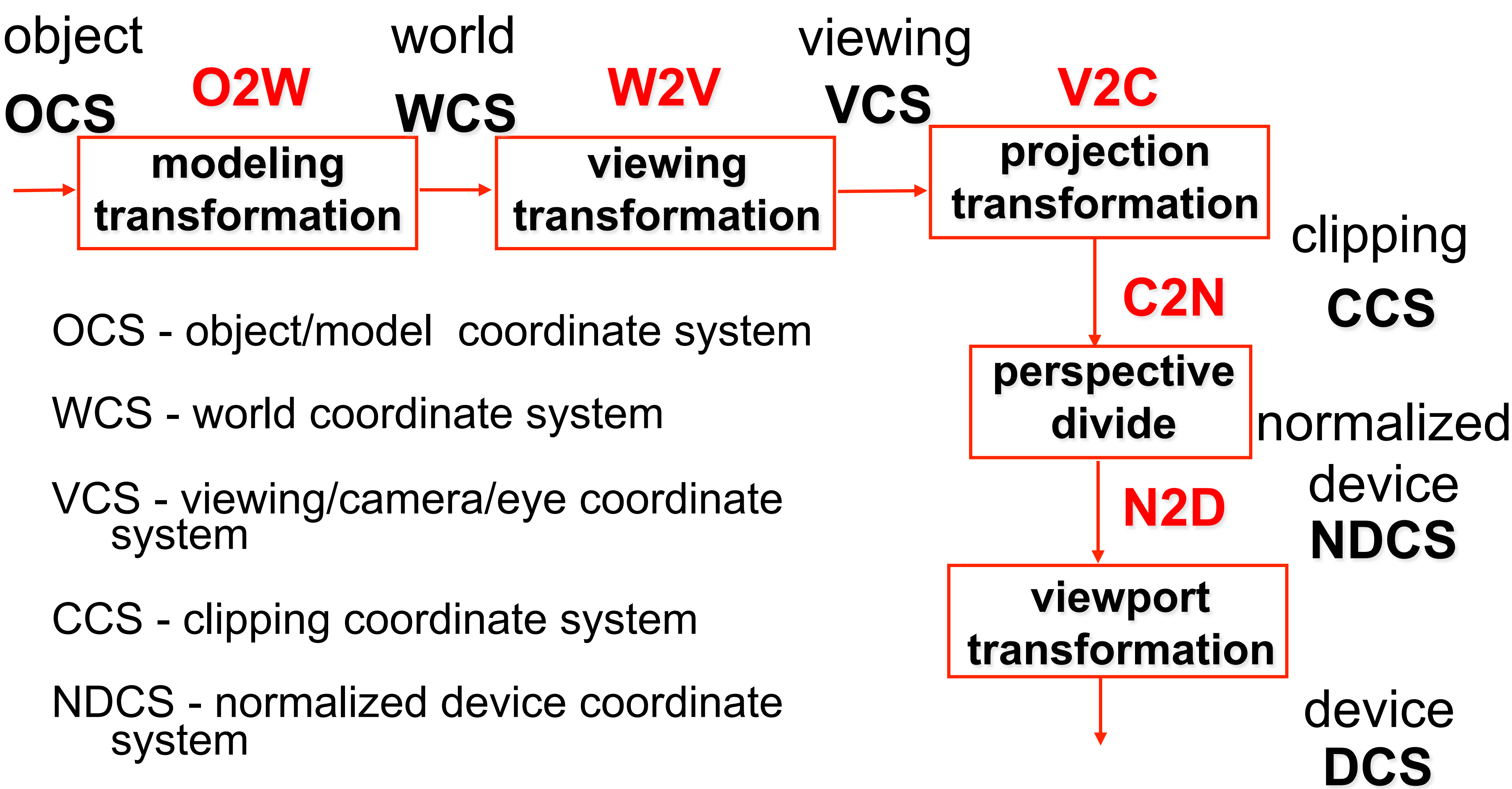
Viewing and Projection

- need to get from 3D world to 2D image
- projection: geometric abstraction
  - what eyes or cameras do
- two pieces
  - viewing transform:
    - where is the camera, what is it pointing at?
  - perspective transform: 3D to 2D
    - flatten to image

Coordinate Systems

- result of a transformation
- names
  - convenience
    - animal: leg, head, tail
  - standard conventions in graphics pipeline
    - object/modelling
    - world
    - camera/viewing/eye
    - screen/window
    - raster/device

Projective Rendering Pipeline



OCS - object/model coordinate system

WCS - world coordinate system

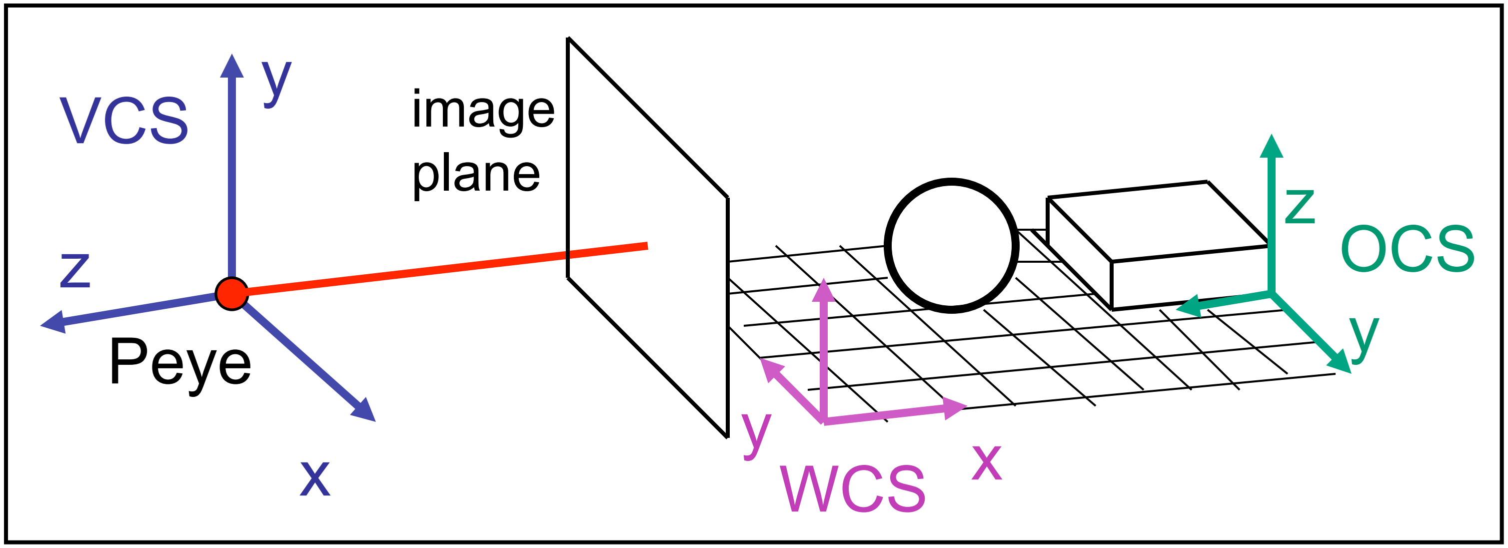
VCS - viewing/camera/eye coordinate system

CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device/display/screen coordinate system

Viewing Transformation



object → world → viewing

OCS → **modeling transformation** ($\mathbf{M}_{\mathbf{mod}}$) → **WCS** → **viewing transformation** ($\mathbf{M}_{\mathbf{cam}}$) → **VCS**

$\underbrace{\mathbf{M}_{\mathbf{mod}} \quad \mathbf{M}_{\mathbf{cam}}}_{\text{modelview matrix}}$

modelview matrix

Basic Viewing

- starting spot - GL
  - camera at world origin
    - probably inside an object
  - y axis is up
  - looking down negative z axis
    - why? RHS with x horizontal, y vertical, z out of screen
- translate backward so scene is visible
  - move distance d = focal length

Convenient Camera Motion

- rotate/translate/scale versus
  - eye point, gaze/lookat direction, up vector

  - **`lookAt(ex,ey,ez,lx,ly,lz,ux,uy,uz)`**

Convenient Camera Motion

- rotate/translate/scale versus
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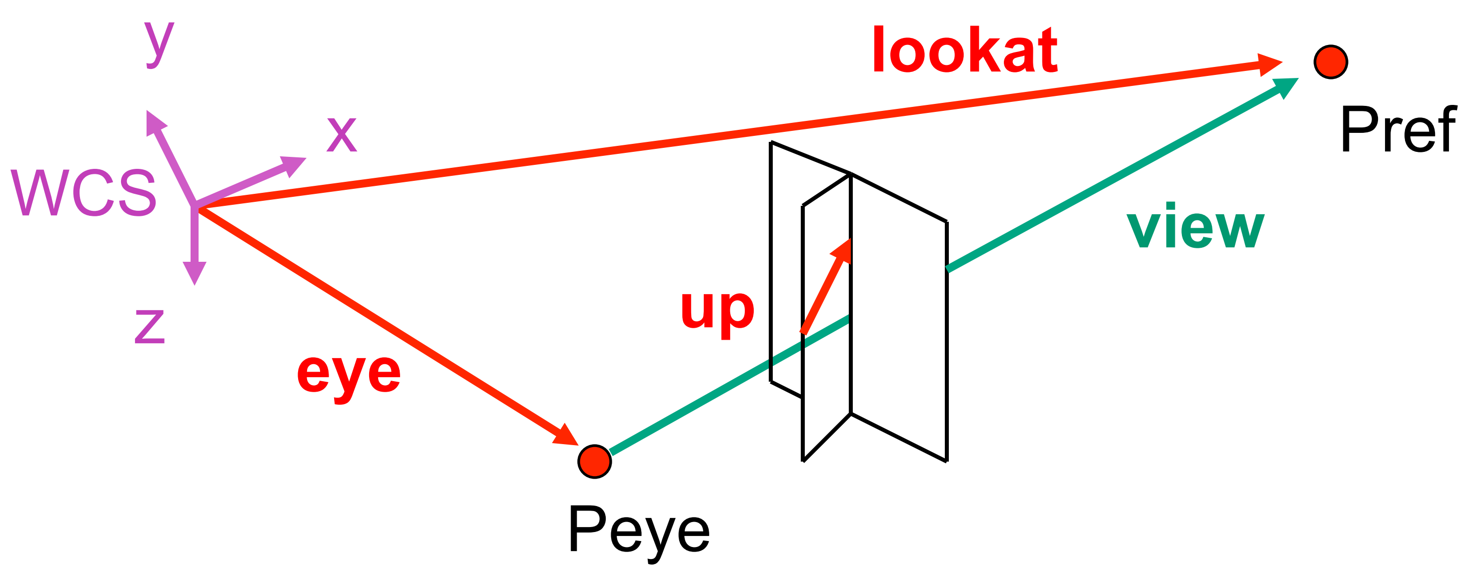
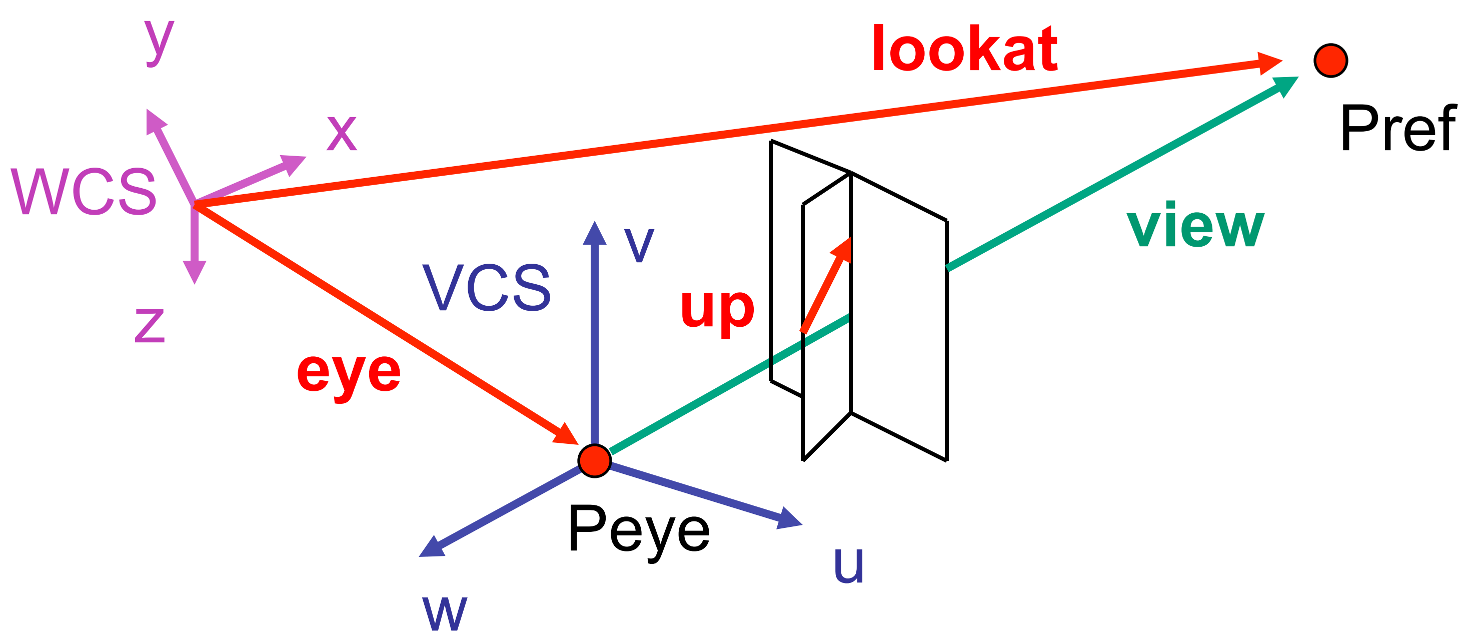


Placing Camera in World Coords: V2W

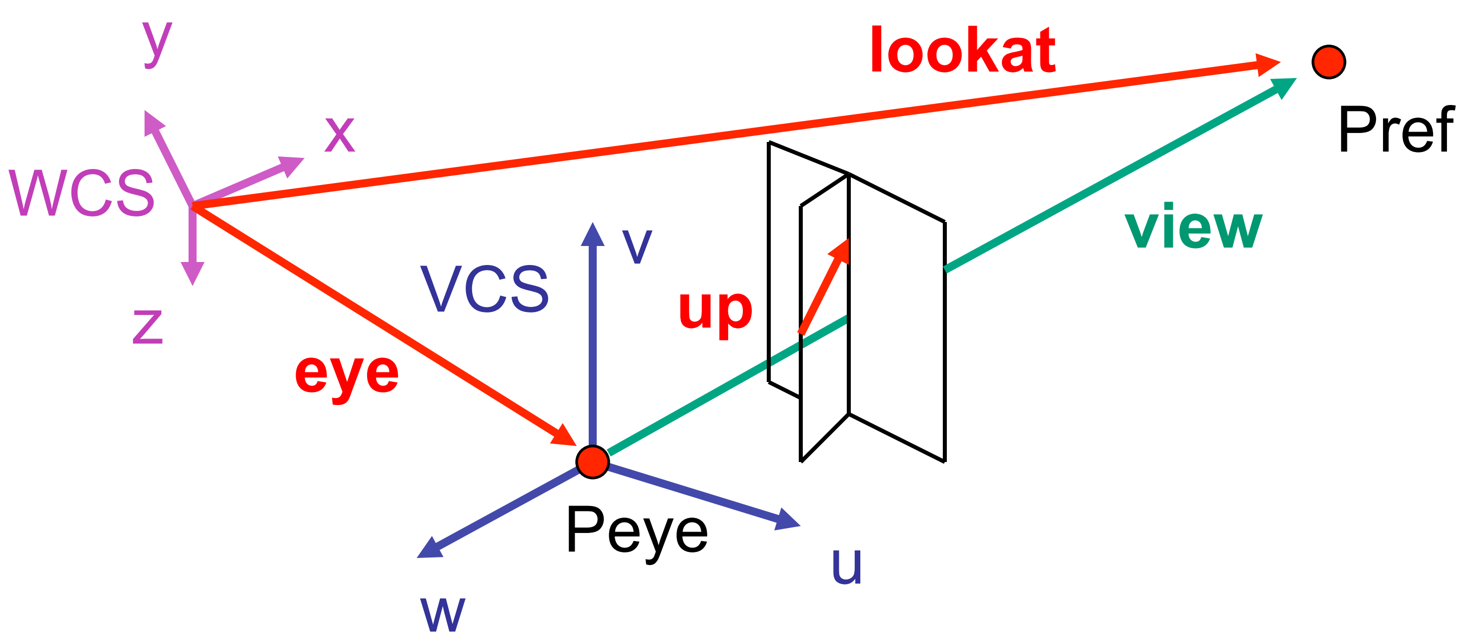
- treat camera as if it's just an object
  - translate from origin to **eye**
  - rotate **view** vector (**lookat** – **eye**) to **w** axis
  - rotate around **w** to bring **up** into **vw**-plane



Deriving V2W Transformation

- translate origin to **eye**

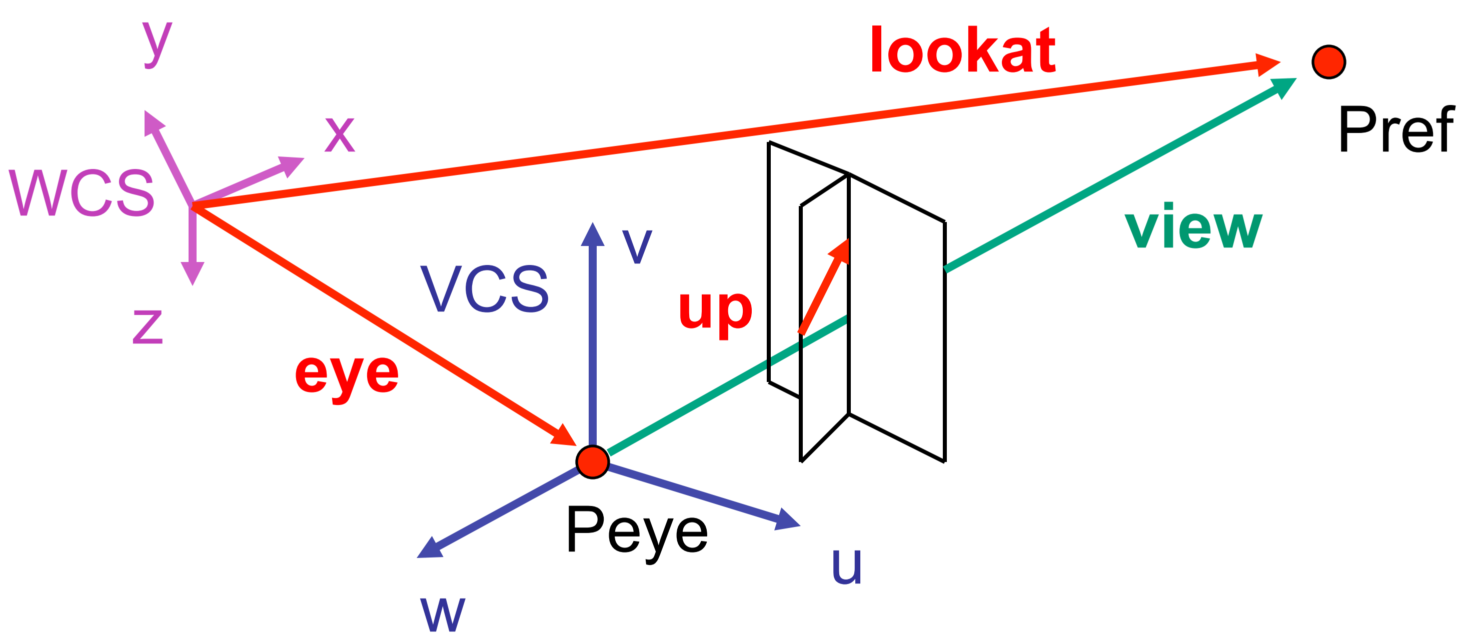
$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & e_x \\ 0 & 1 & 0 & e_y \\ 0 & 0 & 1 & e_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Deriving V2W Transformation

- rotate **view** vector (**lookat** – **eye**) to **w** axis
  - **w**: normalized opposite of **view/gaze** vector **g**

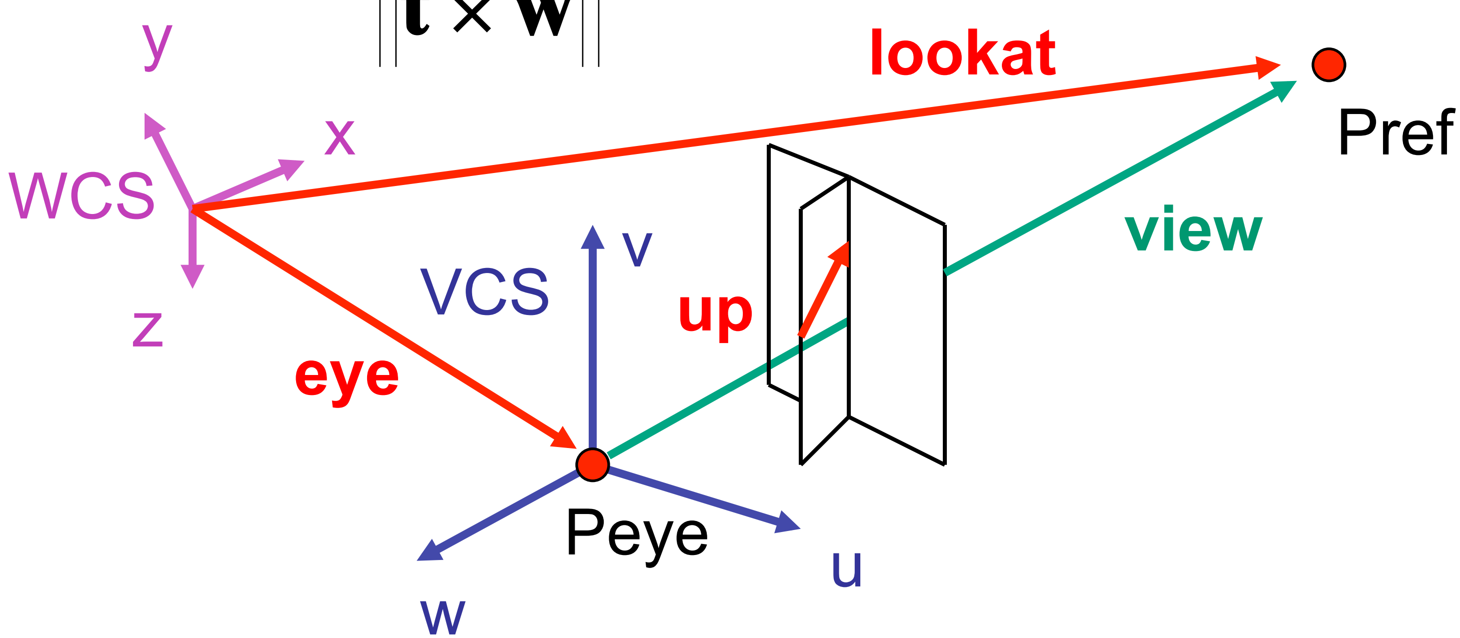
$$\mathbf{w} = -\hat{\mathbf{g}} = -\frac{\mathbf{g}}{\left\|\mathbf{g}\right\|}$$



Deriving V2W Transformation

- rotate around **w** to bring **up** into **vw**-plane
  - **u** should be perpendicular to **vw**-plane, thus perpendicular to **w** and **up** vector **t**
  - **v** should be perpendicular to **u** and **w**

$$\mathbf{u} = \frac{\mathbf{t} \times \mathbf{w}}{\left\| \mathbf{t} \times \mathbf{w} \right\|} \qquad \mathbf{v} = \mathbf{w} \times \mathbf{u}$$



Deriving V2W Transformation

- rotate from WCS **xyz** into **uvw** coordinate system with matrix that has columns **u**, **v**, **w**

$$\mathbf{u} = \frac{\mathbf{t} \times \mathbf{w}}{\left\| \mathbf{t} \times \mathbf{w} \right\|} \qquad \mathbf{v} = \mathbf{w} \times \mathbf{u} \qquad \mathbf{w} = -\hat{\mathbf{g}} = -\frac{\mathbf{g}}{\left\| \mathbf{g} \right\|}$$

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & e_x \\ 0 & 1 & 0 & e_y \\ 0 & 0 & 1 & e_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{R} = \begin{bmatrix} u_x & v_x & w_x & 0 \\ u_y & v_y & w_y & 0 \\ u_z & v_z & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad M_{V2W}=TR$$

- reminder: rotate from **uvw** to **xyz** coord sys with matrix **M** that has columns **u,v,w**

V2W vs. W2V

- M_{V2W}=TR

$$\mathbf{T}=\begin{bmatrix}1 & 0 & 0 & e_x\\ 0 & 1 & 0 & e_y\\ 0 & 0 & 1 & e_z\\ 0 & 0 & 0 & 1\end{bmatrix}\quad \mathbf{R}=\begin{bmatrix}u_x & v_x & w_x & 0\\ u_y & v_y & w_y & 0\\ u_z & v_z & w_z & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

- we derived position of camera as object in world
  - invert for lookAt: go from world to camera!
- $M_{W2V}=(M_{V2W})^{-1}=R^{-1}T^{-1}$

$$\mathbf{R}^{-1}=\begin{bmatrix}u_x & u_y & u_z & 0\\ v_x & v_y & v_z & 0\\ w_x & w_y & w_z & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\quad \mathbf{T}^{-1}=\begin{bmatrix}1 & 0 & 0 & -e_x\\ 0 & 1 & 0 & -e_y\\ 0 & 0 & 1 & -e_z\\ 0 & 0 & 0 & 1\end{bmatrix}$$

  - inverse is transpose for orthonormal matrices
  - inverse is negative for translations

V2W vs. W2V

- $M_{W2V}=(M_{V2W})^{-1}=R^{-1}T^{-1}$

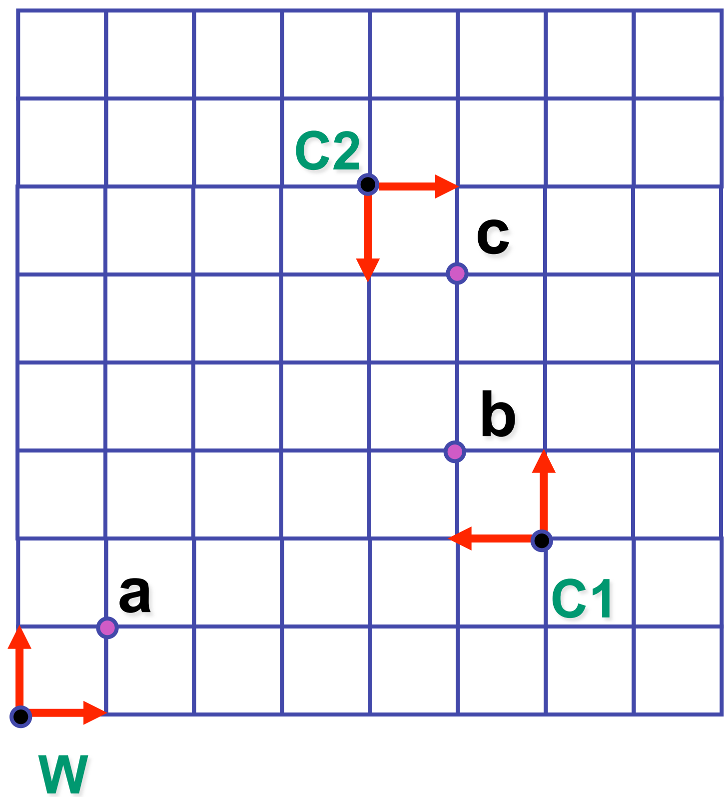
$$\mathbf{M}_{world2view}=\begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ w_x & w_y & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix}=\begin{bmatrix} u_x & u_y & u_z & -\mathbf{e}\bullet\mathbf{u} \\ v_x & v_y & v_z & -\mathbf{e}\bullet\mathbf{v} \\ w_x & w_y & w_z & -\mathbf{e}\bullet\mathbf{w} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{M}_{W2V}=\begin{bmatrix} u_x & u_y & u_z & -e_x*u_x+-e_y*u_y+-e_z*u_z \\ v_x & v_y & v_z & -e_x*v_x+-e_y*v_y+-e_z*v_z \\ w_x & w_y & w_z & -e_x*w_x+-e_y*w_y+-e_z*w_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Moving the Camera or the World?

- two equivalent operations
  - move camera one way vs. move world other way
- example
  - initial GL camera: at origin, looking along -z axis
  - create a unit square parallel to camera at z = -10
  - translate in z by 3 possible in two ways
    - camera moves to z = -3
      - Note GL models viewing in left-hand coordinates
    - camera stays put, but world moves to -7
  - resulting image same either way
    - possible difference: are lights specified in world or view coordinates?

World vs. Camera Coordinates Example



$a = (1,1)_W$

$b = (1,1)_{C1} = (5,3)_W$

$c = (1,1)_{C2} = (1,3)_{C1} = (5,5)_W$