University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

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Viewing/Projections I

Week 3, Fri Jan 24

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

Reading for This and Next 2 Lectures

- FCG Chapter 7 Viewing
- FCG Section 6.3.1 Windowing Transforms

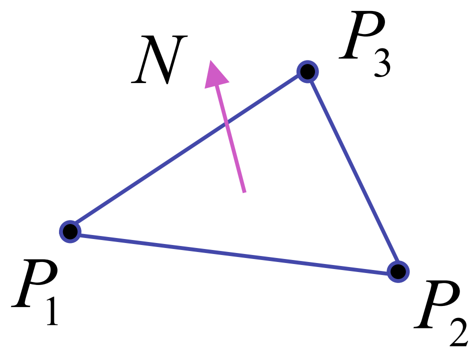
- RB rest of Chap Viewing
- RB rest of App Homogeneous Coords

Review: Display Lists

- precompile/cache block of OpenGL code for reuse
  - usually more efficient than immediate mode
    - exact optimizations depend on driver
  - good for multiple instances of same object
    - but cannot change contents, not parametrizable
  - good for static objects redrawn often
    - display lists persist across multiple frames
    - interactive graphics: objects redrawn every frame from new viewpoint from moving camera
  - can be nested hierarchically
- snowman example: 3x performance improvement, 36K polys

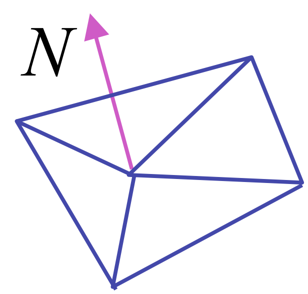
Review: Normals

- polygon:

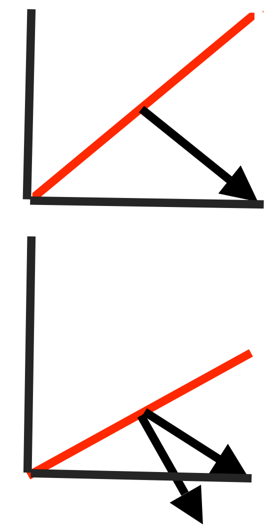


$$N = (P_2 - P_1) \times (P_3 - P_1)$$

- assume vertices ordered CCW when viewed from visible side of polygon
- normal for a vertex
  - specify polygon orientation
  - used for lighting
  - supplied by model (i.e., sphere), or computed from neighboring polygons



Review: Transforming Normals



- cannot transform normals using same matrix as points
  - nonuniform scaling would cause to be not perpendicular to desired plane!

$$P \qquad\qquad P' = MP$$
$$N \longrightarrow N' = QN$$

given M,
what should Q be?

$$\mathbf{Q} = \left(\mathbf{M}^{-1}\right)^{\mathrm{T}}$$

inverse transpose of the modelling transformation

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

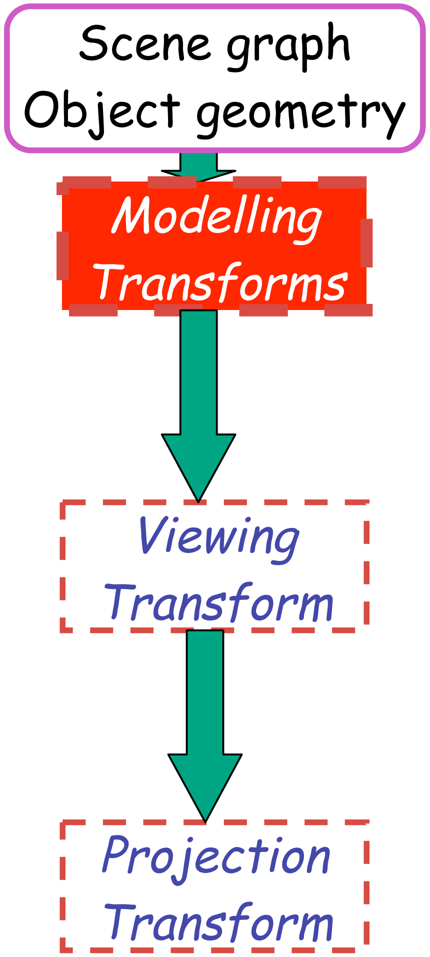
↓

Viewing Transform

↓

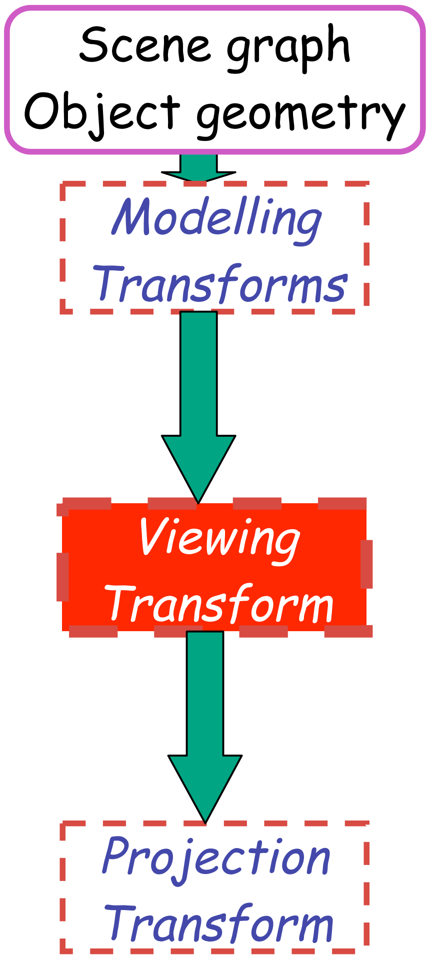
Projection Transform

Rendering Pipeline



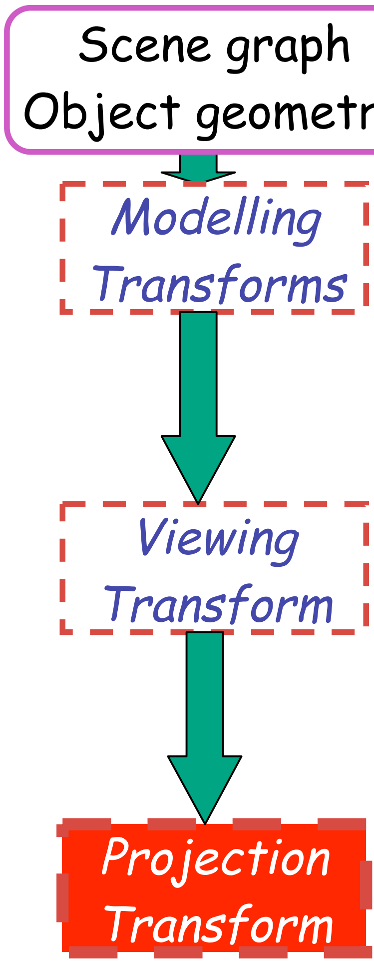
- result
  - all vertices of scene in shared 3D world coordinate system

Rendering Pipeline

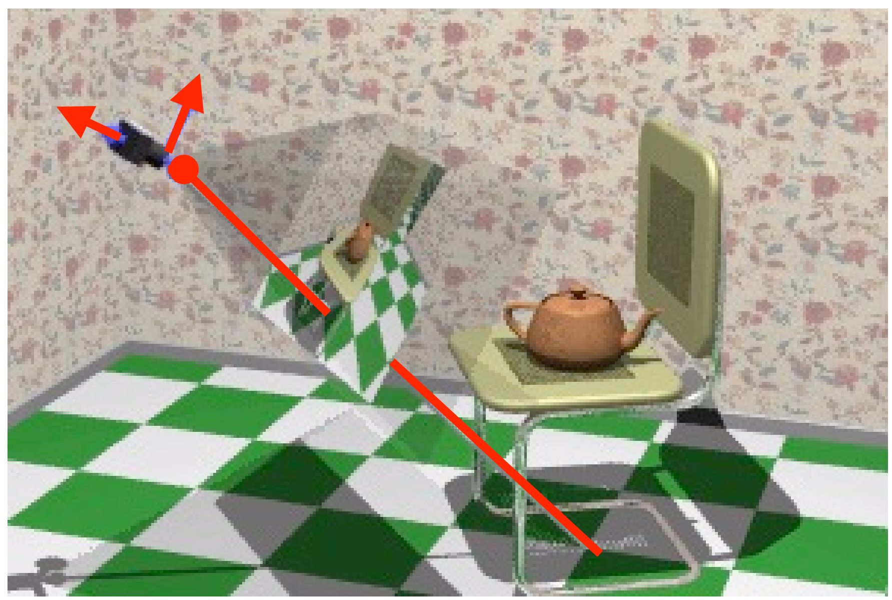


- result
  - scene vertices in 3D view (camera) coordinate system

Rendering Pipeline



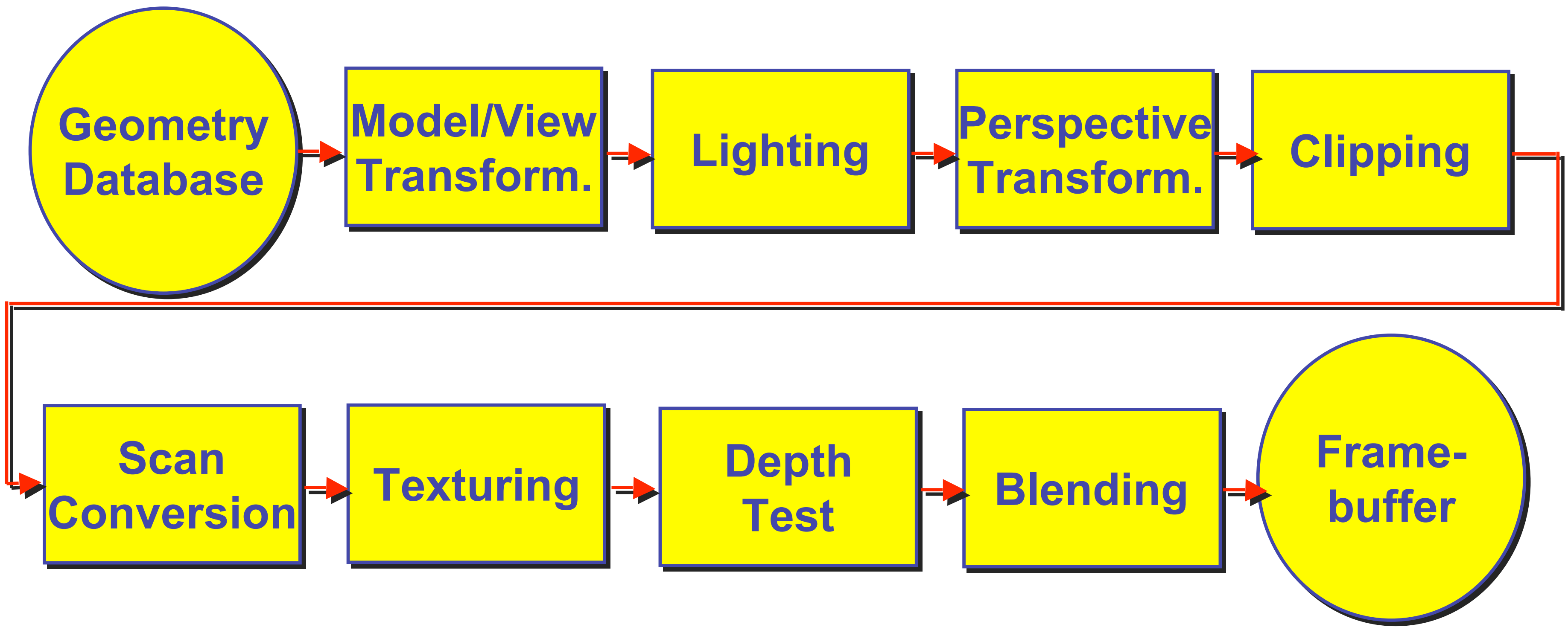
- result
  - 2D screen coordinates of clipped vertices



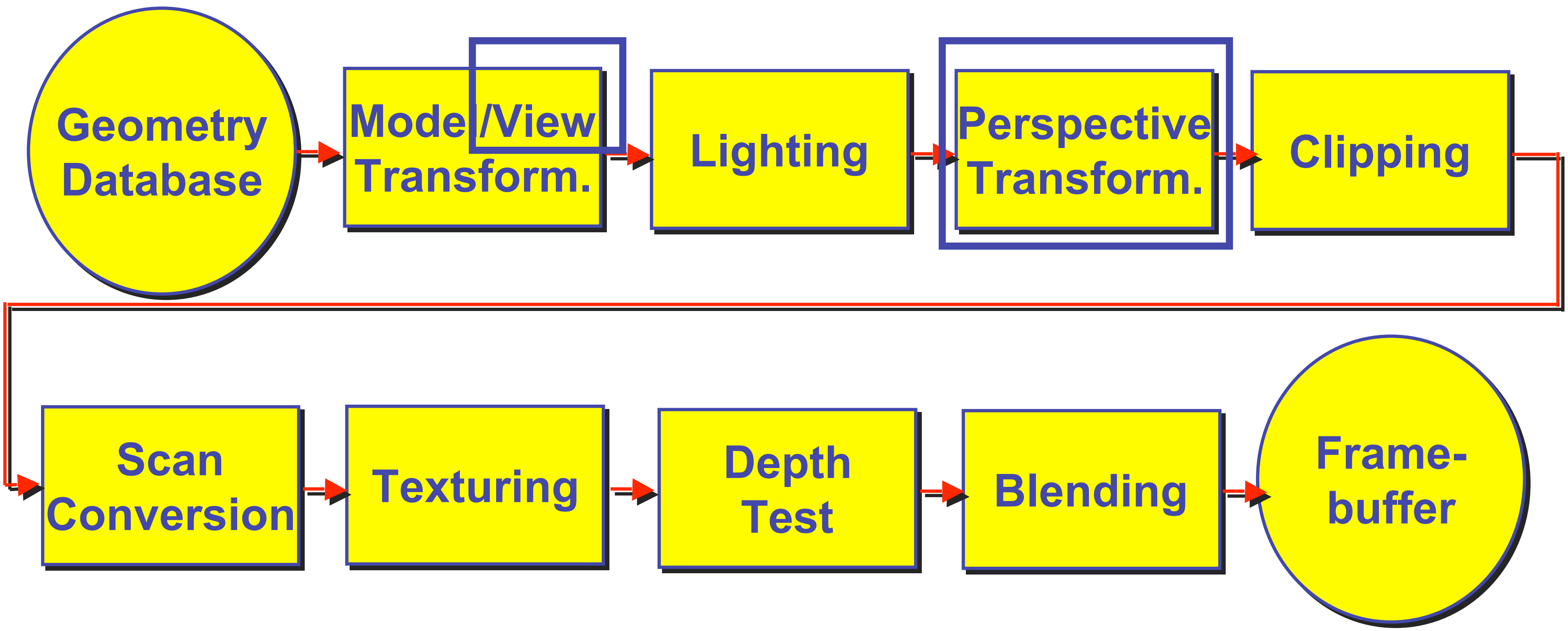
Viewing and Projection

- 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

Rendering Pipeline



Rendering Pipeline



OpenGL Transformation Storage

- modeling and viewing stored together
  - possible because no intervening operations
- perspective stored in separate matrix

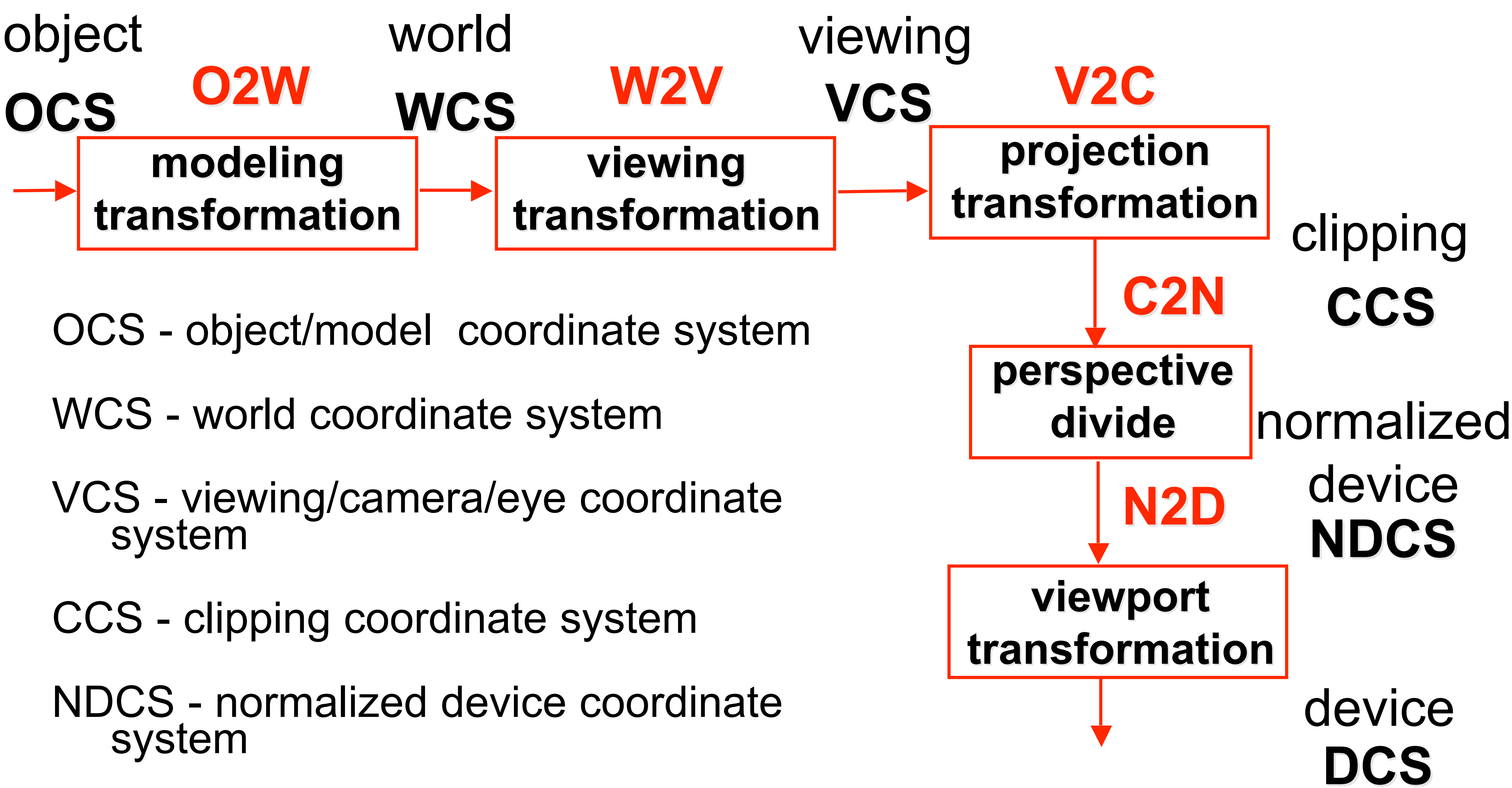
- specify which matrix is target of operations
  - common practice: return to default modelview mode after doing projection operations

```
glMatrixMode(GL_MODELVIEW);
glMatrixMode(GL_PROJECTION);
```

Coordinate Systems

- result of a transformation
- names
  - convenience
    - armadillo: 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

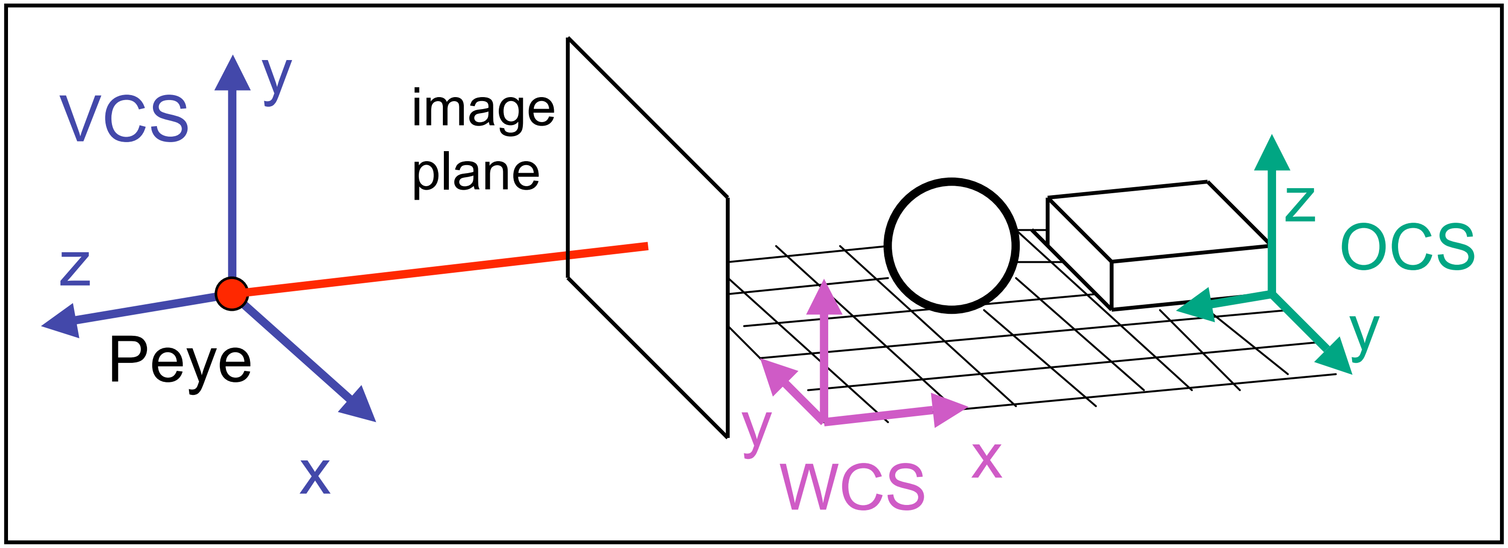
VCS - viewing/camera/eye coordinate system

CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device/display/screen coordinate system

Viewing Transformation



object	world	viewing
OCS	**WCS**	**VCS**

→ **modeling transformation** → **viewing transformation** →

$\mathbf{M}_{mod}$ $\mathbf{M}_{cam}$

OpenGL ModelView matrix

Basic Viewing

- starting spot - OpenGL
  - 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
- can use rotate/translate/scale to move camera
  - demo: Nate Robins tutorial *transformations*

Viewing in Project 1

- where is camera in template code?
  - 5 units back, looking down -z axis

Convenient Camera Motion

- rotate/translate/scale not intuitive
- arbitrary viewing position
  - eye point, gaze/lookat direction, up vector

Convenient Camera Motion

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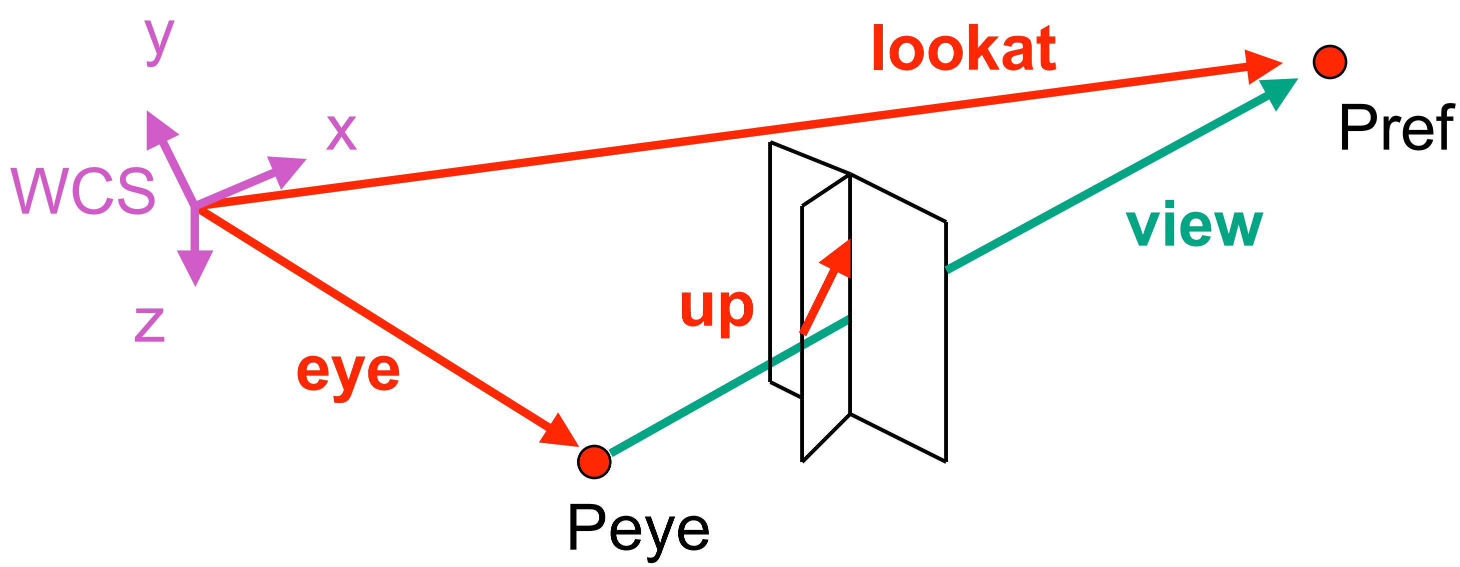
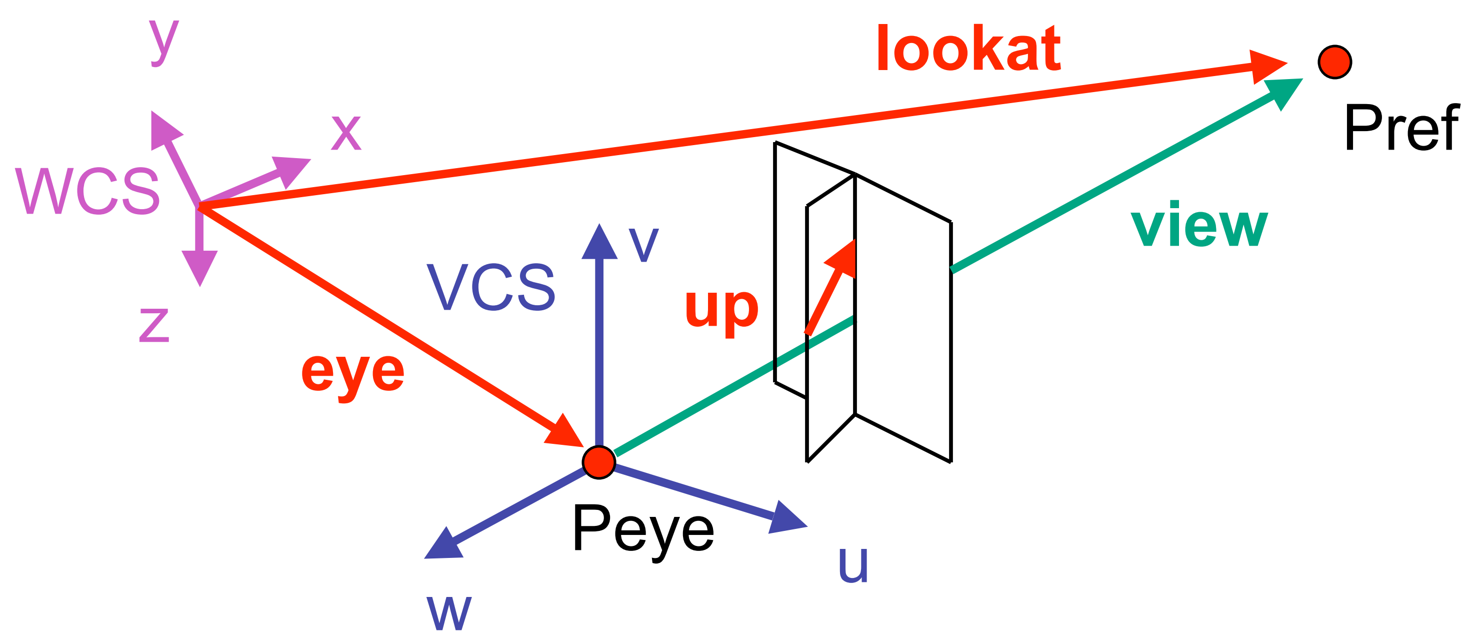


From World to View Coordinates: W2V

- translate **eye** to origin
- rotate **view** vector (**lookat** – **eye**) to **w** axis
- rotate around **w** to bring **up** into **vw**-plane



OpenGL Viewing Transformation

```
gluLookAt(ex,ey,ez,lx,ly,lz,ux,uy,uz)
```

- postmultiplies current matrix, so to be safe:

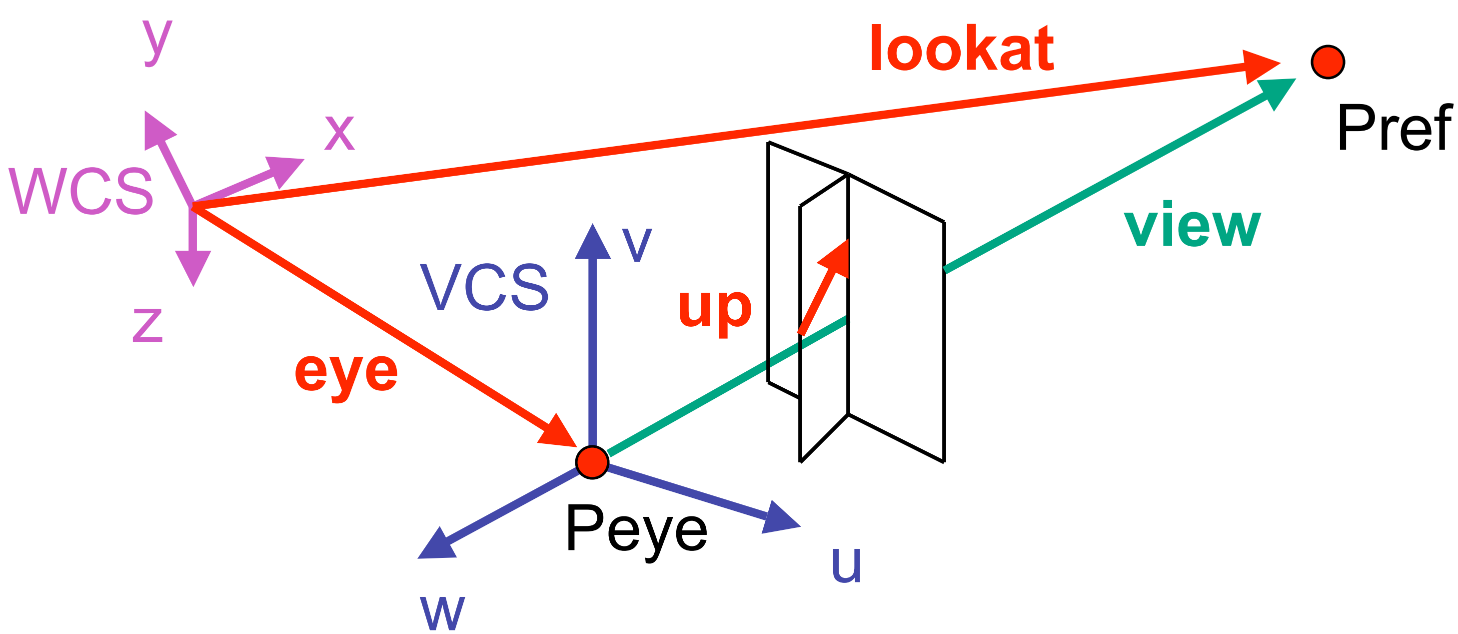
```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(ex,ey,ez,lx,ly,lz,ux,uy,uz)
// now ok to do model transformations
```

- demo: Nate Robins tutorial *projection*

Deriving W2V Transformation

- translate **eye** to origin

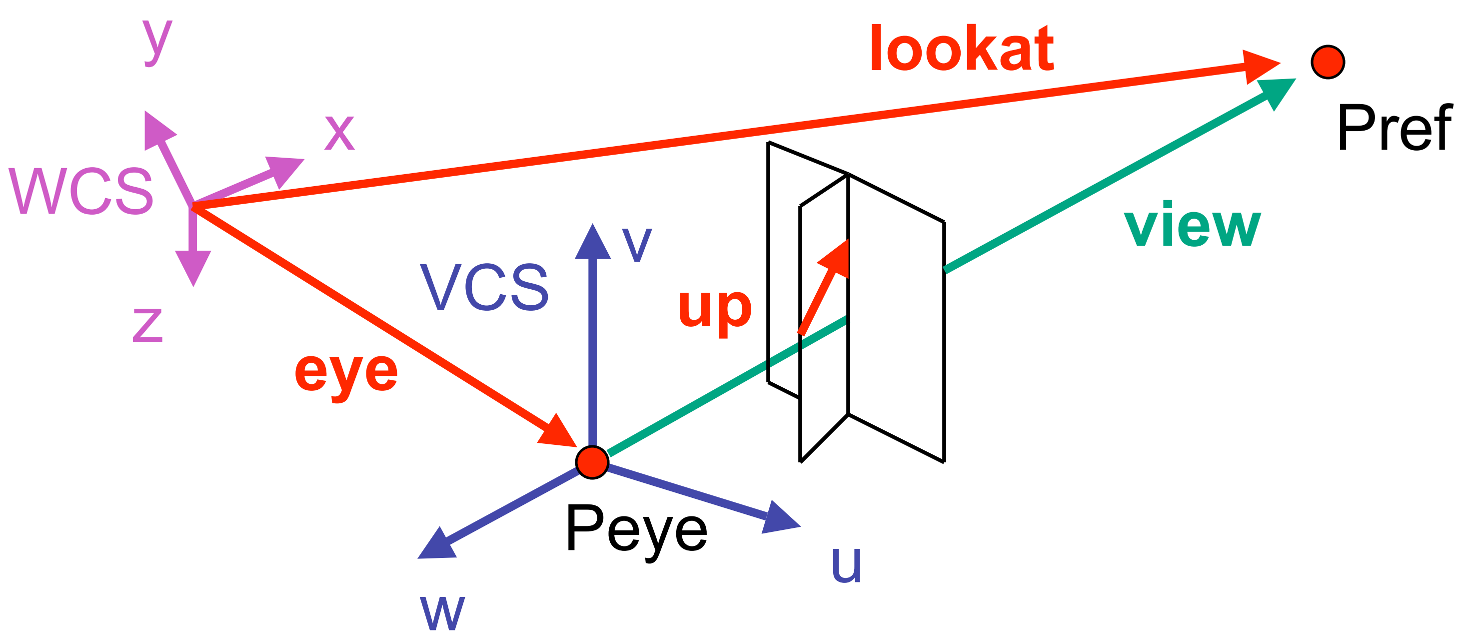
$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Deriving W2V Transformation

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

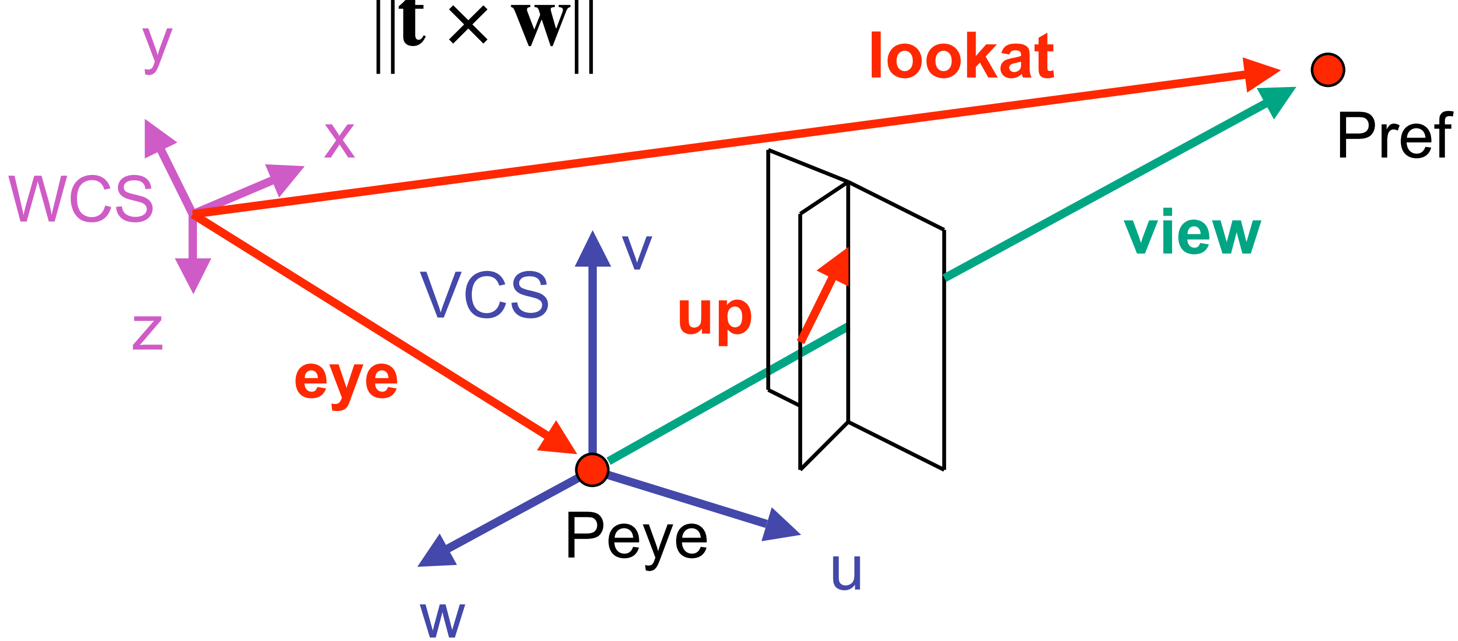
$$\mathbf{w} = -\hat{\mathbf{g}} = -\frac{\mathbf{g}}{\|\mathbf{g}\|}$$



Deriving W2V 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**

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



Deriving W2V Transformation

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

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

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

- reminder: rotate from **uvw** to **xyz** coord sys with matrix **M** that has columns **u,v,w**
  - rotate from **xyz** coord sys to **uvw** coord sys with matrix $\mathbf{M}^\mathbf{T}$ that has rows **u,v,w**

Deriving W2V Transformation

- M=RT

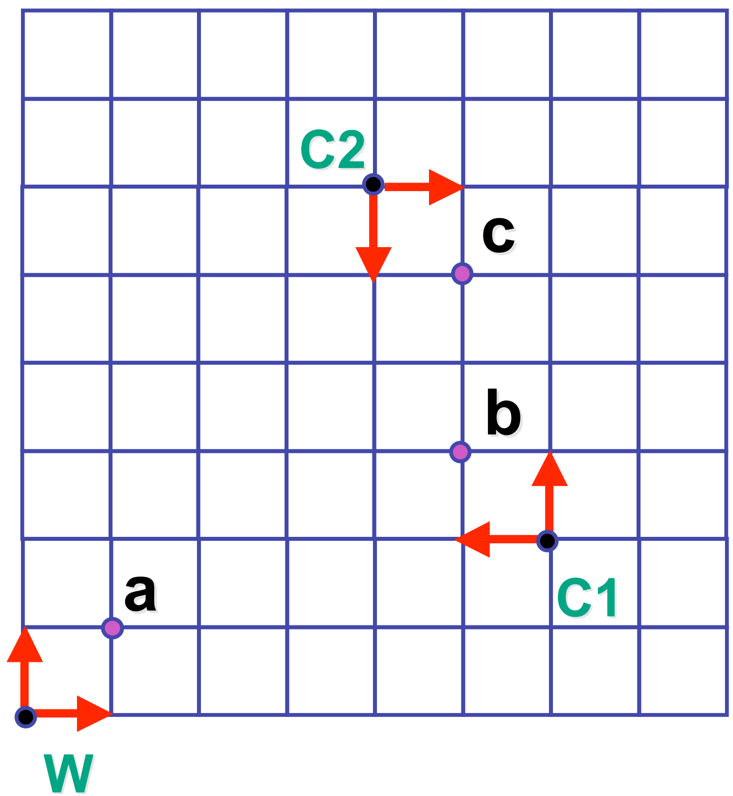
$$\mathbf{R} = \begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ w_x & w_y & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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

Moving the Camera or the World?

- two equivalent operations
  - move camera one way vs. move world other way
- example
  - initial OpenGL 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 OpenGL 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



$a = (1,1)_W$

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

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