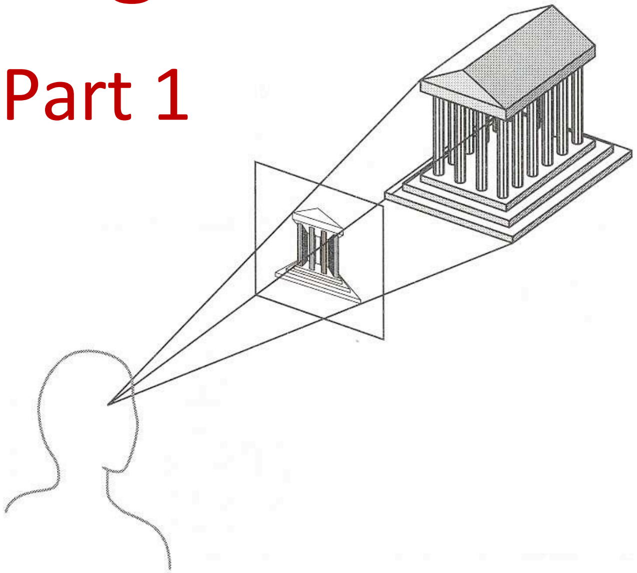
FACULTY OF ENGINEERING
AND ARCHITECTURE

E016712: Computer Graphics

Viewing in 3D

Part 1



Lecturers: Aleksandra Pizurica and Danilo Babin

GHENT
UNIVERSITY

Overview

- Conceptual modelling of the 3D viewing process
- Planar Geometric Projections
- Synthetic Camera Model
- Specifying Arbitrary View in 3D: Examples

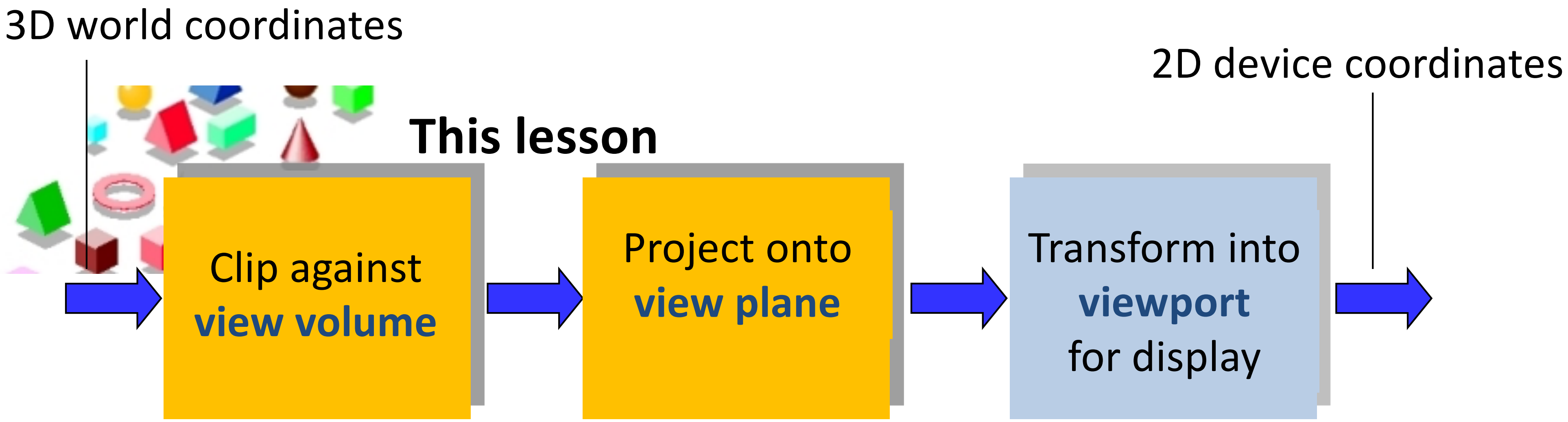
Viewing in 3D: context

- Create views of 3D objects on 2D display devices

The concept of a virtual camera (synthetic camera model) will be useful to specify what we can (or want) to “see”

We will also make parallels with art works (understanding of perspective projections)

Conceptual model of the 3D viewing process



3D world coordinates

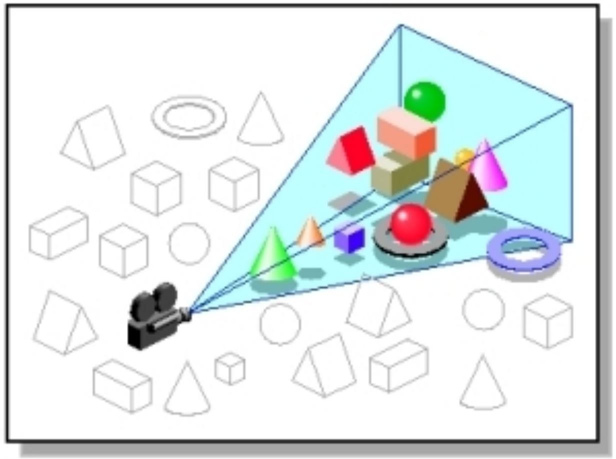
This lesson

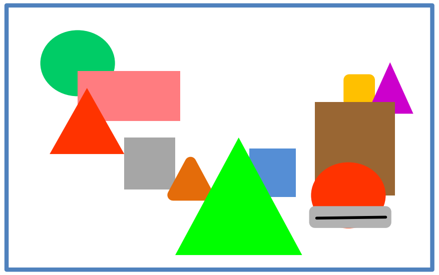
Clip against **view volume**

Project onto **view plane**

Transform into **viewport** for display

2D device coordinates



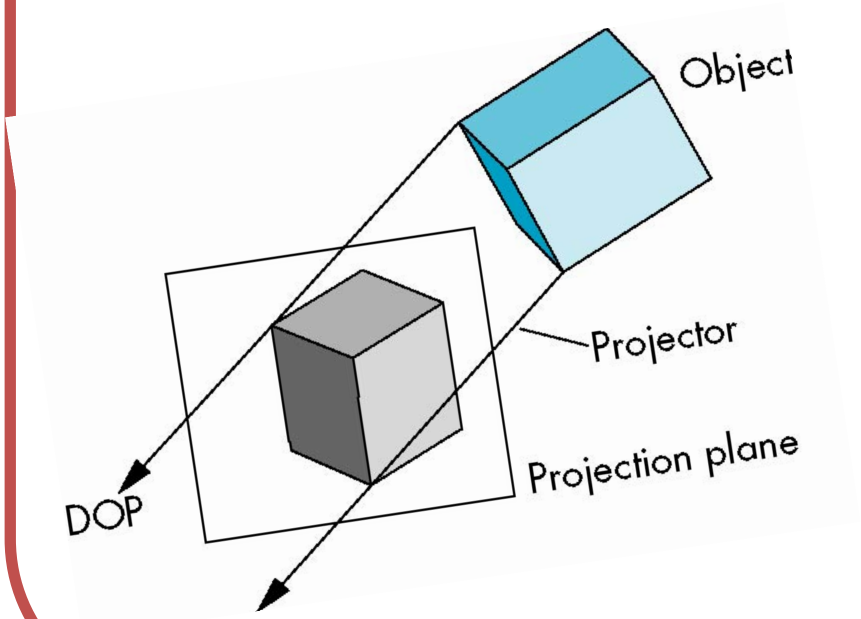


Planar Geometric Projections

Planar Geometric Projections

Parallel projection

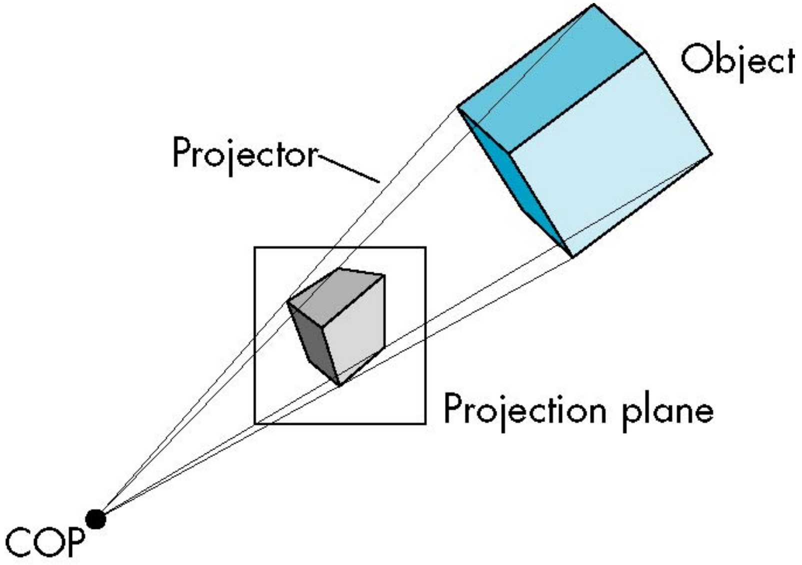
Mainly for technical drawings (accurate measures)



DOP – direction of projection

Perspective projection

More natural, not convenient for accurate measurements

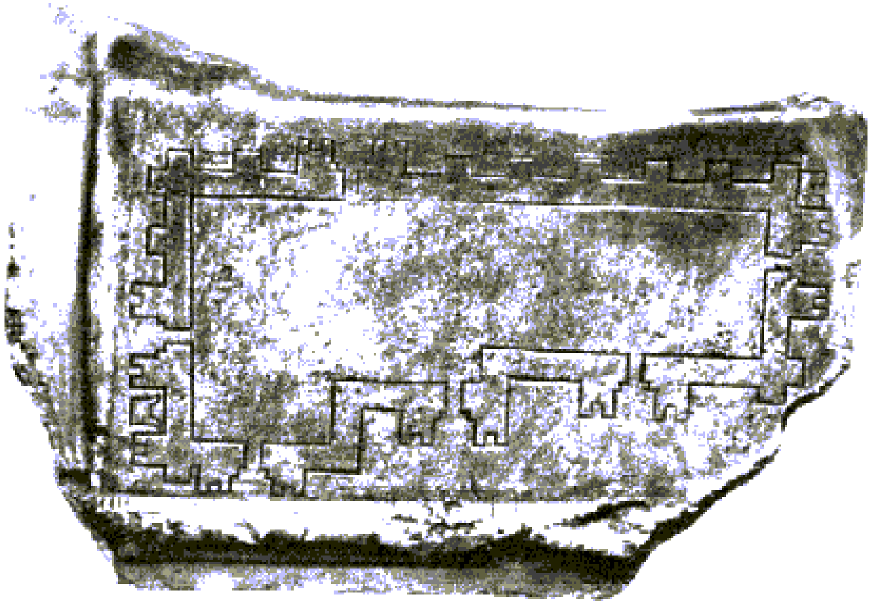


COP – center of projection

Projection plane = view plane = picture plane

COP = Projection Reference Point (PRP) = eye = view point

Some historical notes

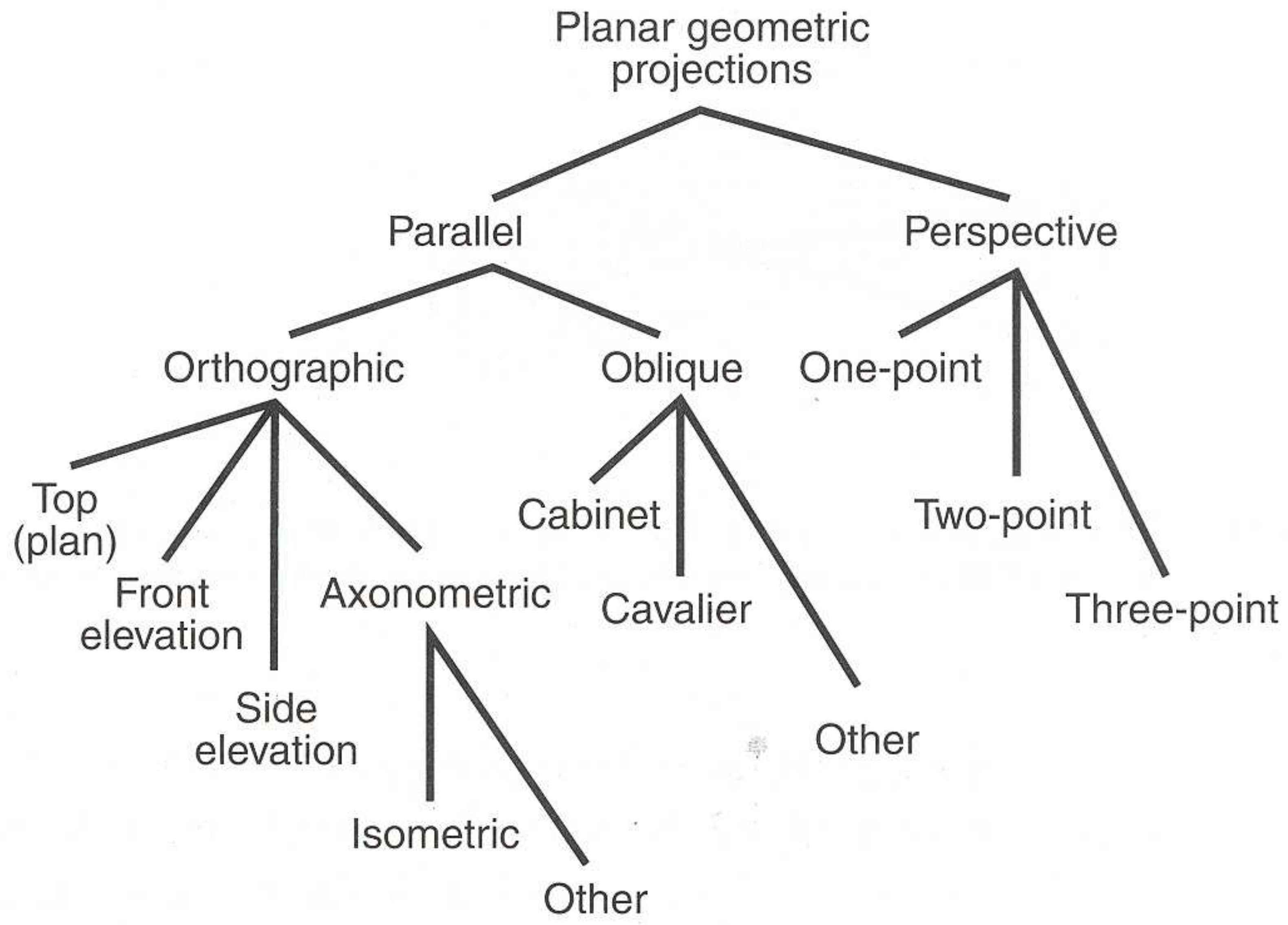


Orthographic projection from Mesopotamia, 2150 BC

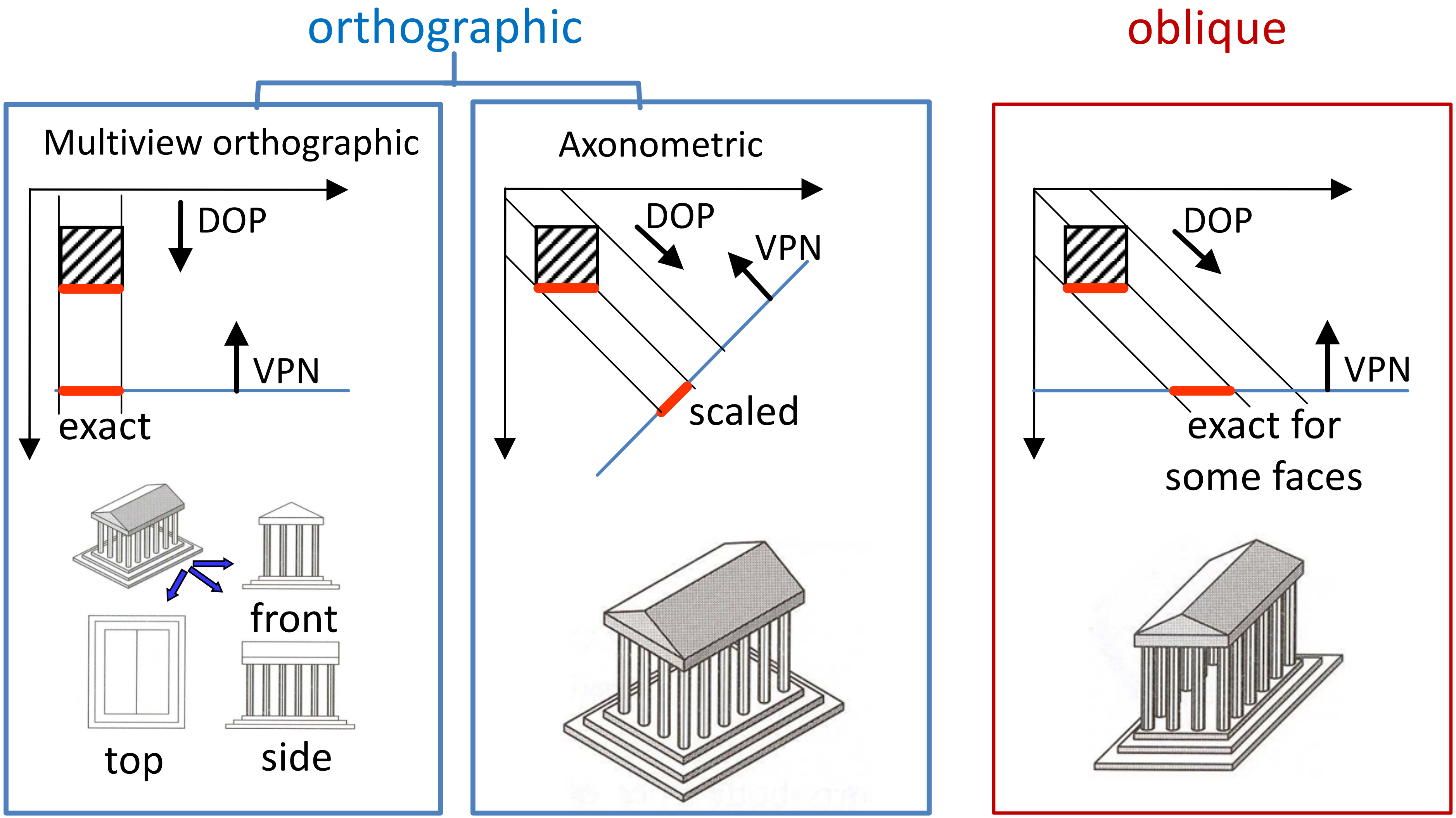
Ancient theories of vision
Emission theory: Euclid, Ptolemy
Intromission theory: Aristotle

Alhazen’s book of optics
Alhazen (Ibn al-Haytham; 965-1040)

Projections



Parallel projections



orthographic

oblique

Multiview orthographic

DOP

VPN

exact

front

top

side

Axonometric

DOP

VPN

scaled

DOP

VPN

exact for some faces

VPN – view plane normal

DOP – direction of projection

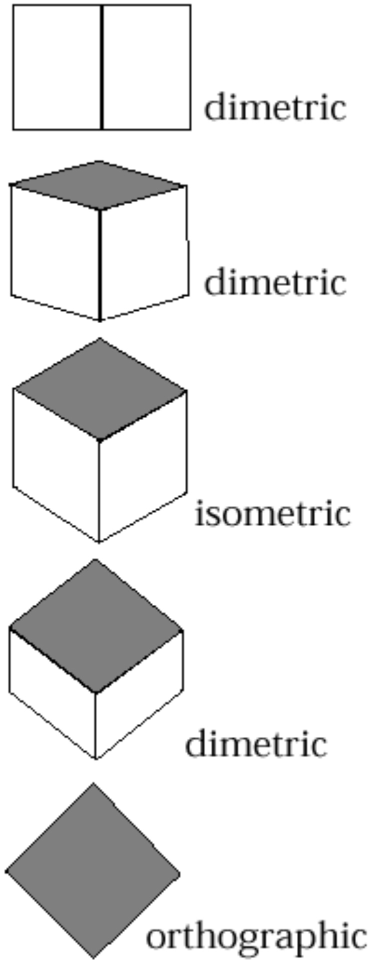
Parallel projections: Axonometric projection (1)

Three types of axonometric projections:

- **Isometric:** Angles between VPN and any of the three principal axes are equal (120º). The same scale ratio applies along each axis
- **Dimetric:** Angles between VPN and two of the principal axes equal; two scale ratios
- **Trimetric:** Different angles between VPN and any of the three principal axes; three scale ratios

Contrasting to multiview orthographic projection, some object faces can be foreshortened

Foreshortening: the size of an object's dimensions along the line of sight are relatively shorter than dimensions across the line of sight

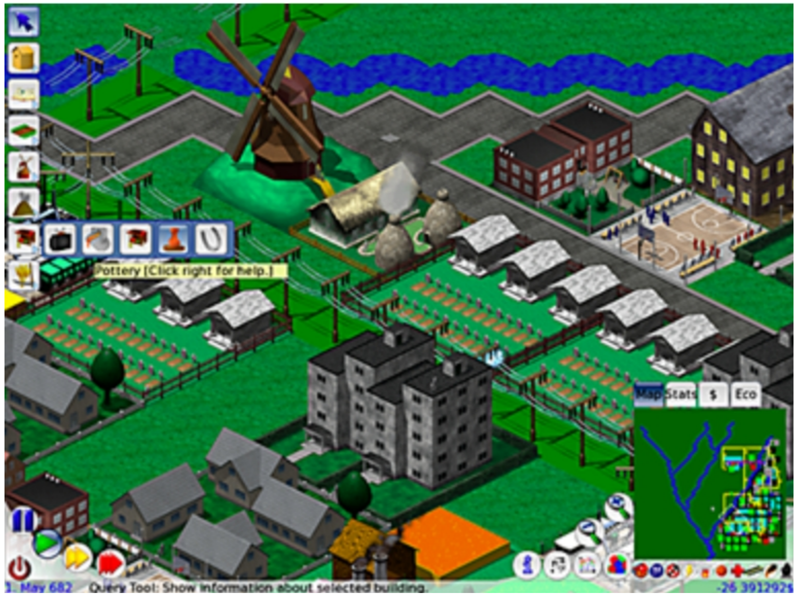


Carlbom Fig.3-8

Parallel projections: Axonometric projection (2)

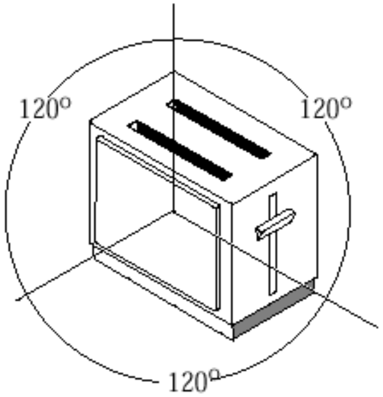
Isometric projection

- Often used for catalogue illustrations
- No foreshortening
  - Good for measurements
  - Can appear less realistic
- Used a lot in older video games (1980's) and still now in cases where it is of interest to "see" objects in distance as well as those close up (e.g. strategy, simulation games)



1. May 682 Query Tool: Show information about selected building. -26 391292$

Screen shot of the simulation game LinCity-NG



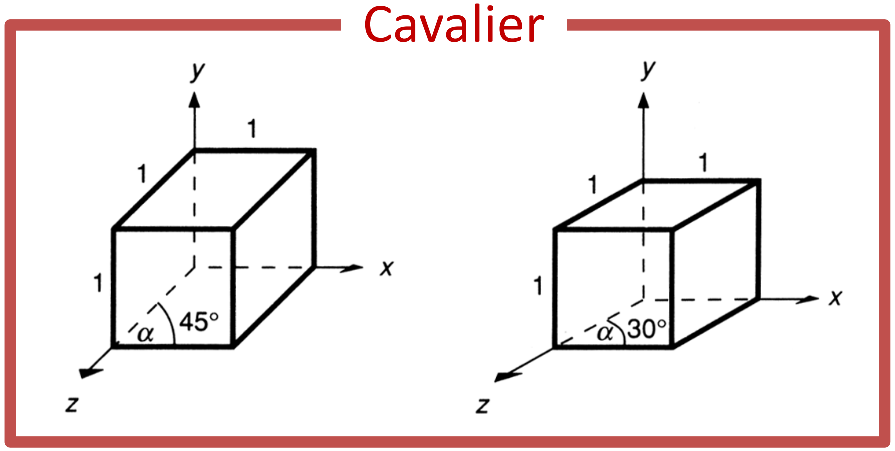
Example

Carlbom Fig.2.2

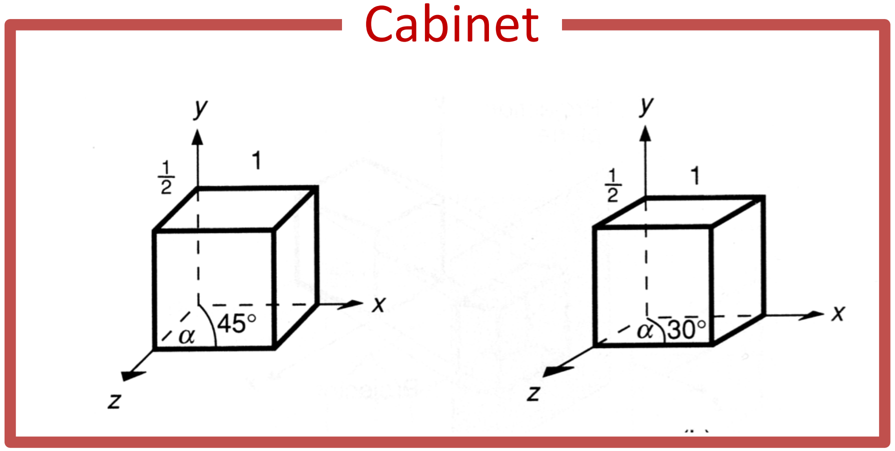
Parallel projections: Oblique projection (1)

- Two common types: cavalier and cabinet
- **Cavalier**: the direction of the projection makes a 45 degree angle with the projection plane.
  - No foreshortening: the projection of a line perpendicular to the projection plane has the same lengths as the line itself
- **Cabinet**: The direction of the projection makes a 63.4 degree angle with the projection plane.
  - Foreshortening of the z axis, and provides a more “realistic” view

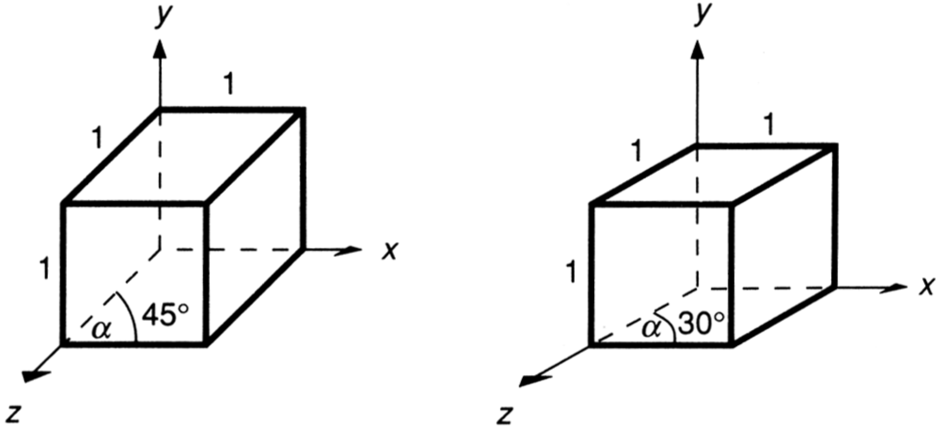
Cavalier



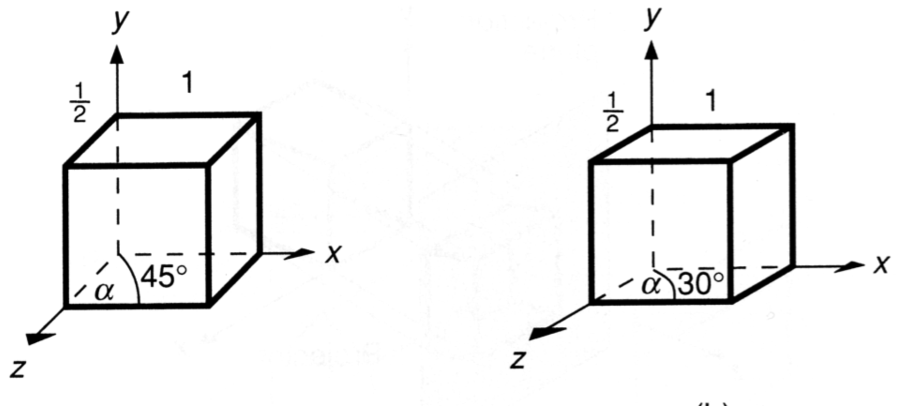
Cabinet



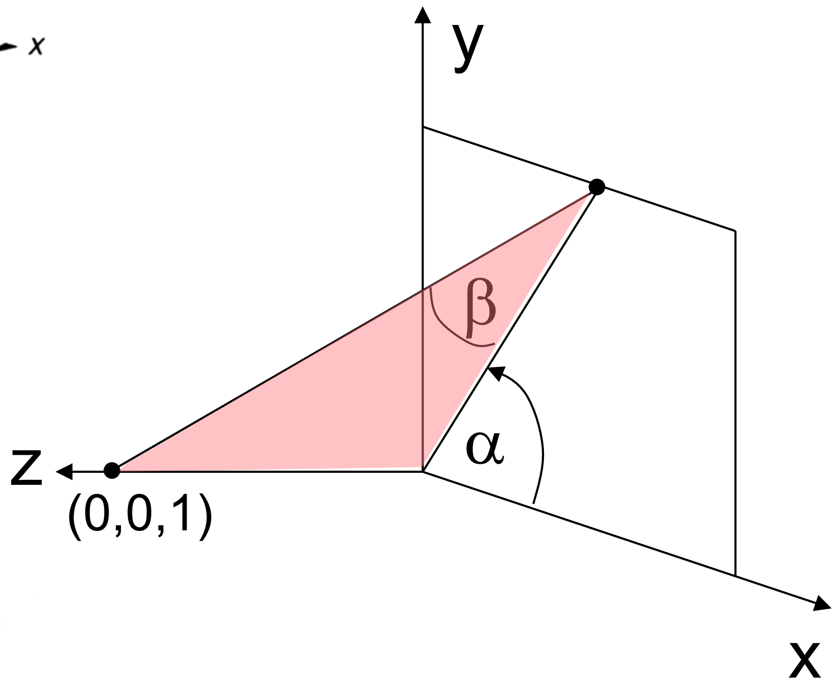
Parallel projections: Oblique projection (2)



Cavalier: β=45°

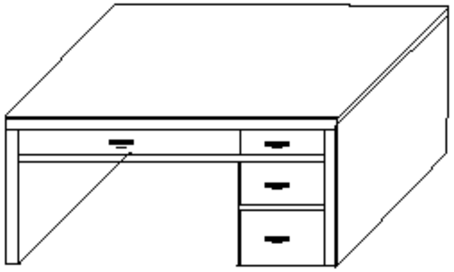


Cabinet: β=63.43°

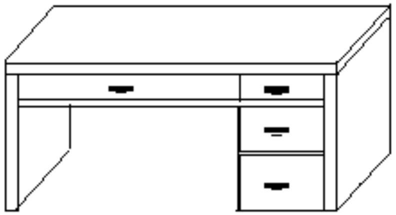


Parallel projections: Oblique projection (2)

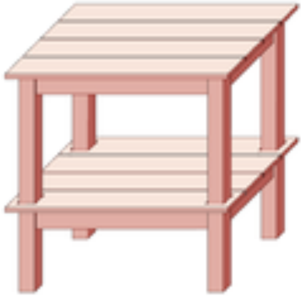
- Used extensively in catalogue illustrations



Cavalier



Cabinet

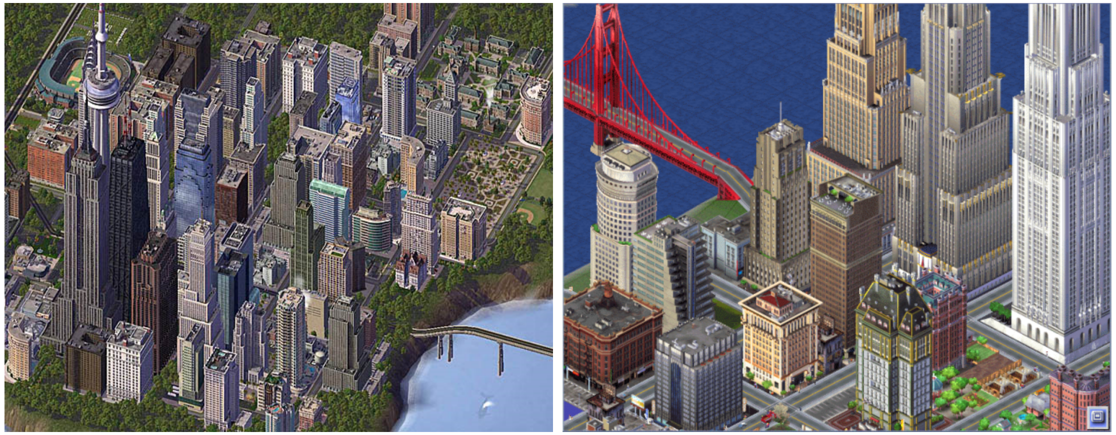


Cabinet

Carlbom Fig. 3-2

- Also used a lot in video games

Examples from SimCity – a city building simulation game

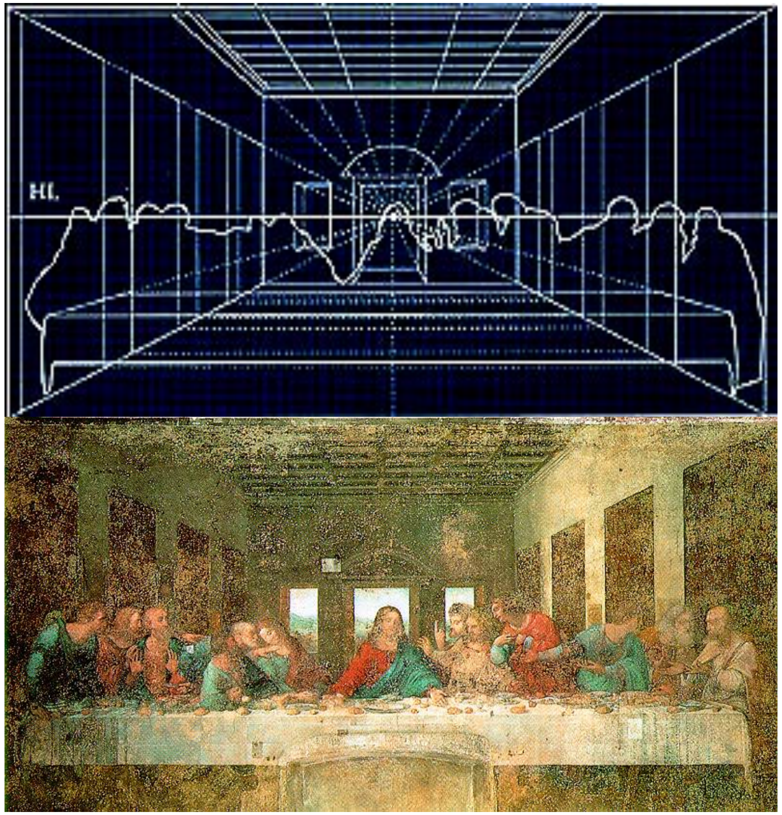


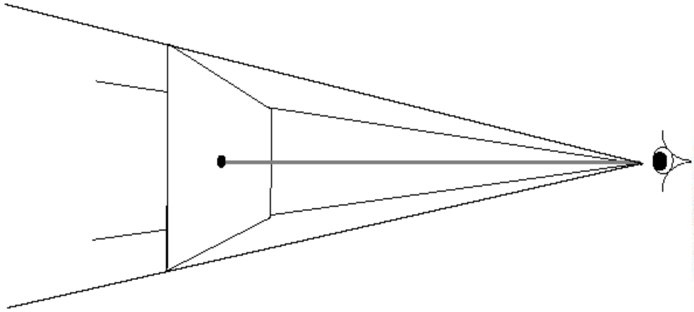
Perspective projections

- Parallel lines converge to a vanishing point

- Objects that are farther away appear smaller than those that are close → non-uniform foreshortening

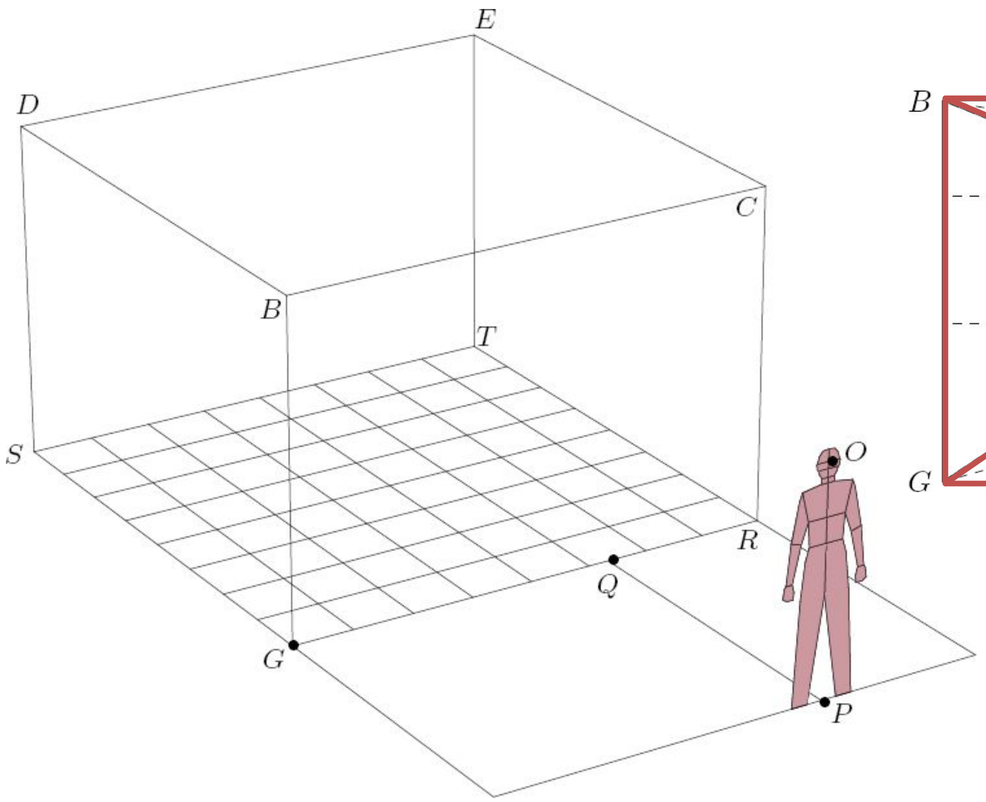
- Looks natural, used in fine arts
  - Art-historical context: Alberti, *Della Pittura* (1435), renaissance painters

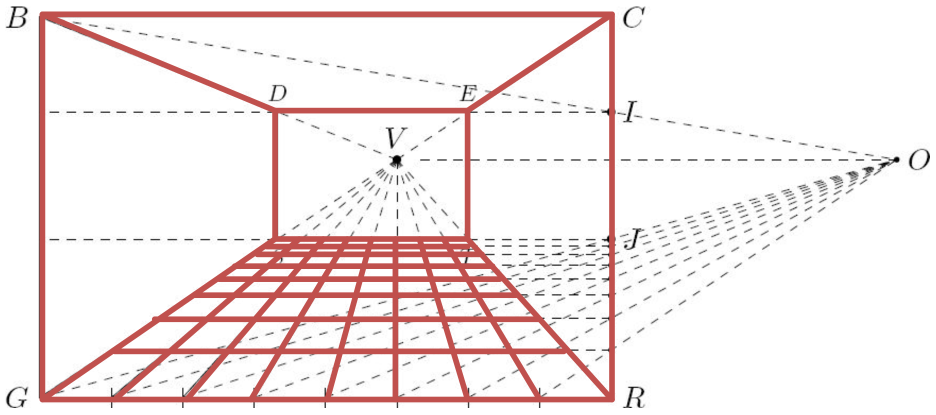




Perspective: Art-historical context

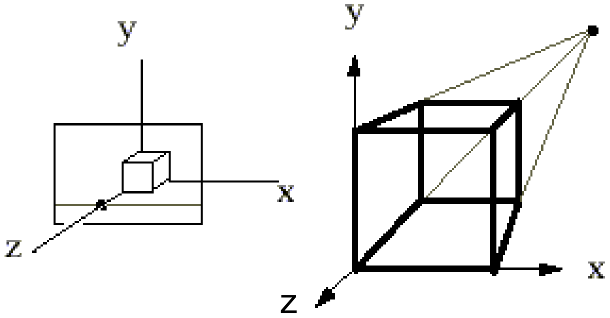
- **Alberti, *Della Pittura*** (1435):
  - First published technical work on perspective.
  - Gives a “recipe” to artists how to create a perspective view of a 3D scene



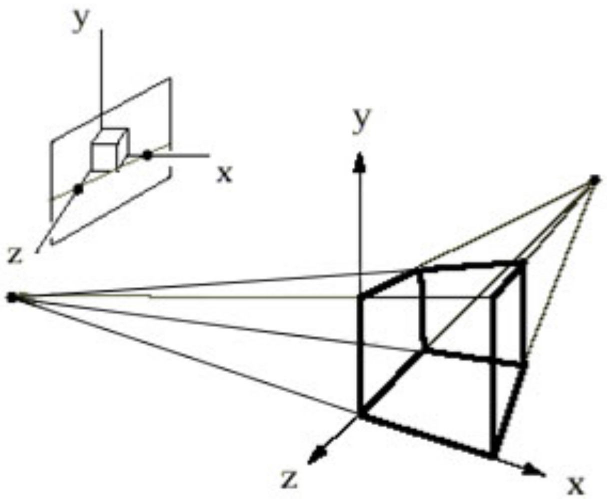


Categorization of perspective projections

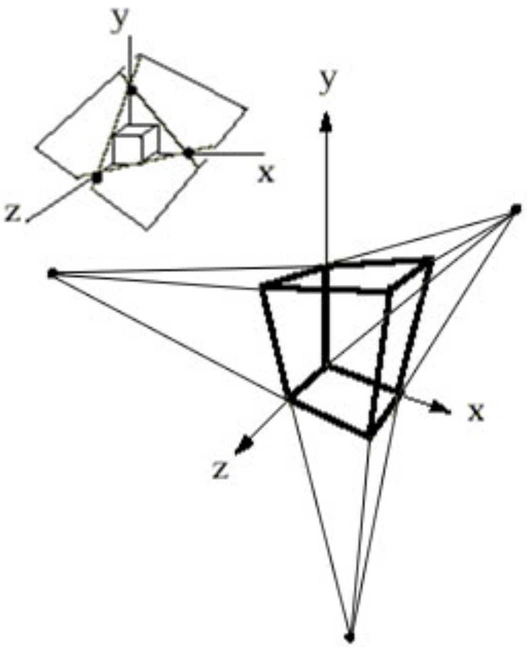
Parallel lines not parallel to view plane converge to a vanishing point:



One Point Perspective
(*z*-axis vanishing point)



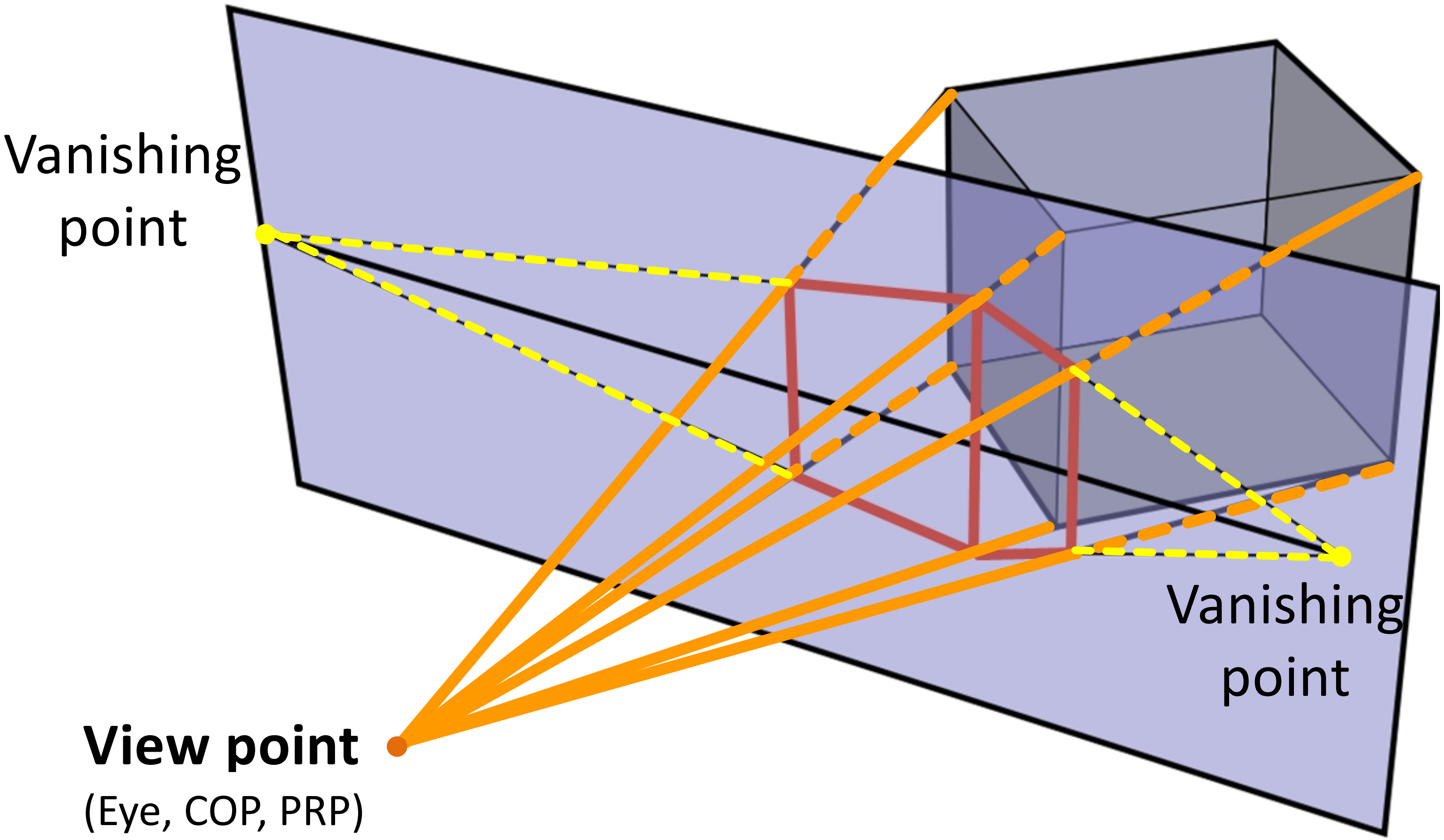
Two Point Perspective
(*z*, and *x*-axis vanishing points)



Three Point Perspective
(*z*, *x*, and *y*-axis vanishing points)

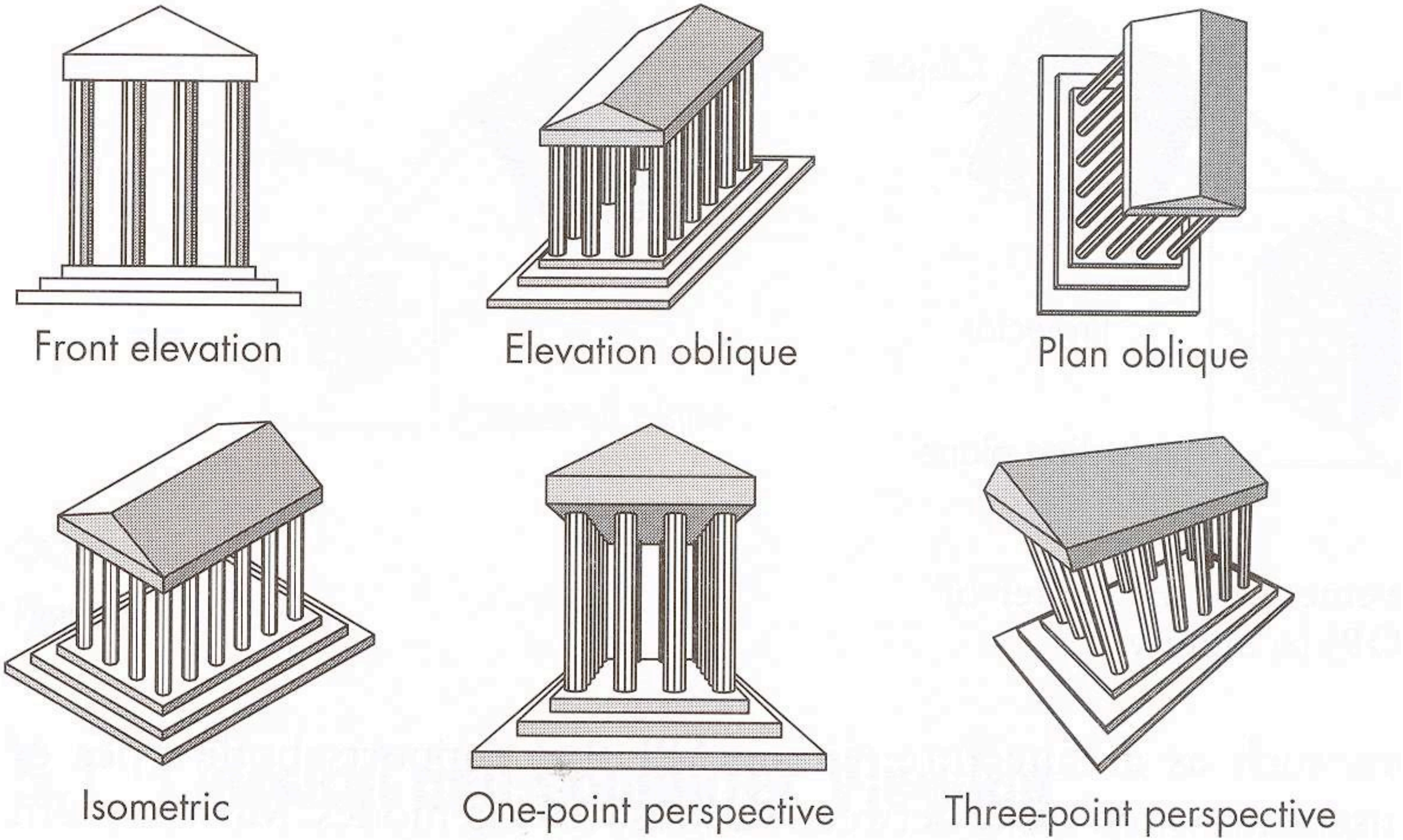
- Note: this is a canonic object
- What happens in case of an arbitrary object?
- Can we have a perspective with 0 vanishing points?

Viewpoint and vanishing points



Note two types of pyramidal structure: intersecting the view plane and within the view plane

Examples of some typical projections



Front elevation

Elevation oblique

Plan oblique

Isometric

One-point perspective

Three-point perspective

Perspective versus parallel projection

- Perspective:
  - Visual effect is similar to human visual system
  - Has 'perspective foreshortening'
    - size of object varies inversely with distance from the center of projection.
  - Angles only remain intact for faces parallel to projection plane
  - “Looks” good but not in particular useful for recording the exact shape and distances

- Parallel:
  - Less realistic view because of no foreshortening
  - However, parallel lines remain parallel
  - Angles only remain intact for faces parallel to projection plane

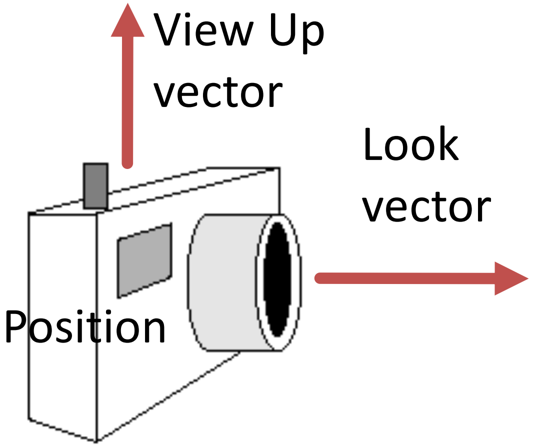
Synthetic Camera

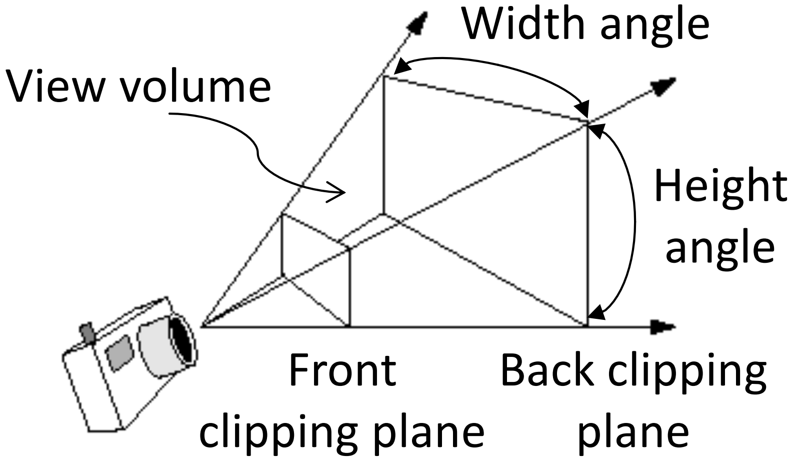
Synthetic camera model

In order to “take a picture” with our synthetic camera, we need to know

1. Position of the camera (from where it’s looking; ‘eye’ vector)
2. Orientation (direction in which the camera is pointing Look vector and the rotation around that direction – View Up vector)
3. Field of view (aspect ratio of the electronic “film”, viewing angles)
4. Front and back clipping planes

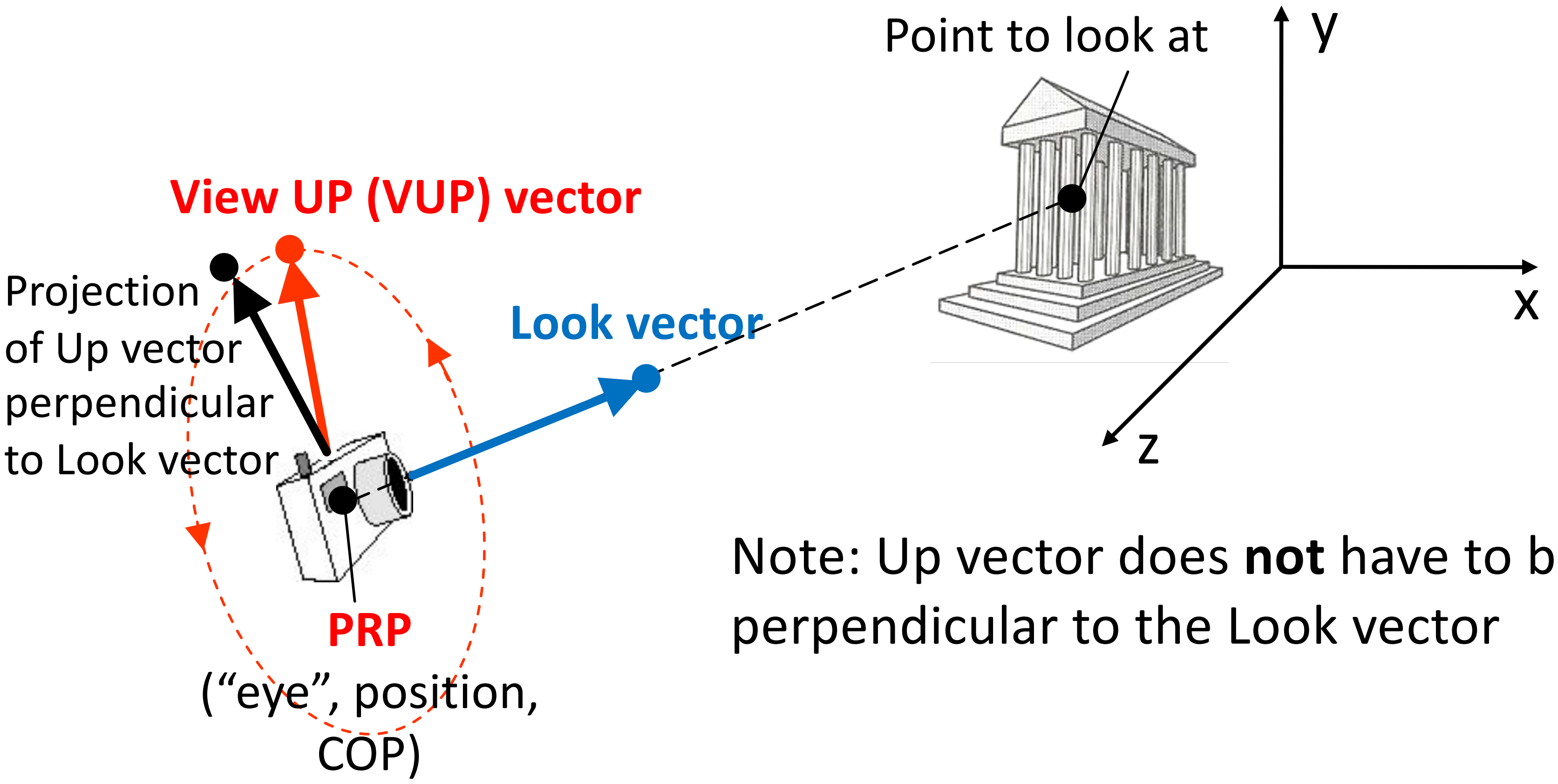
Optional: Focal length (objects at other distances than this are blurred)





Position, Look and View Up vectors

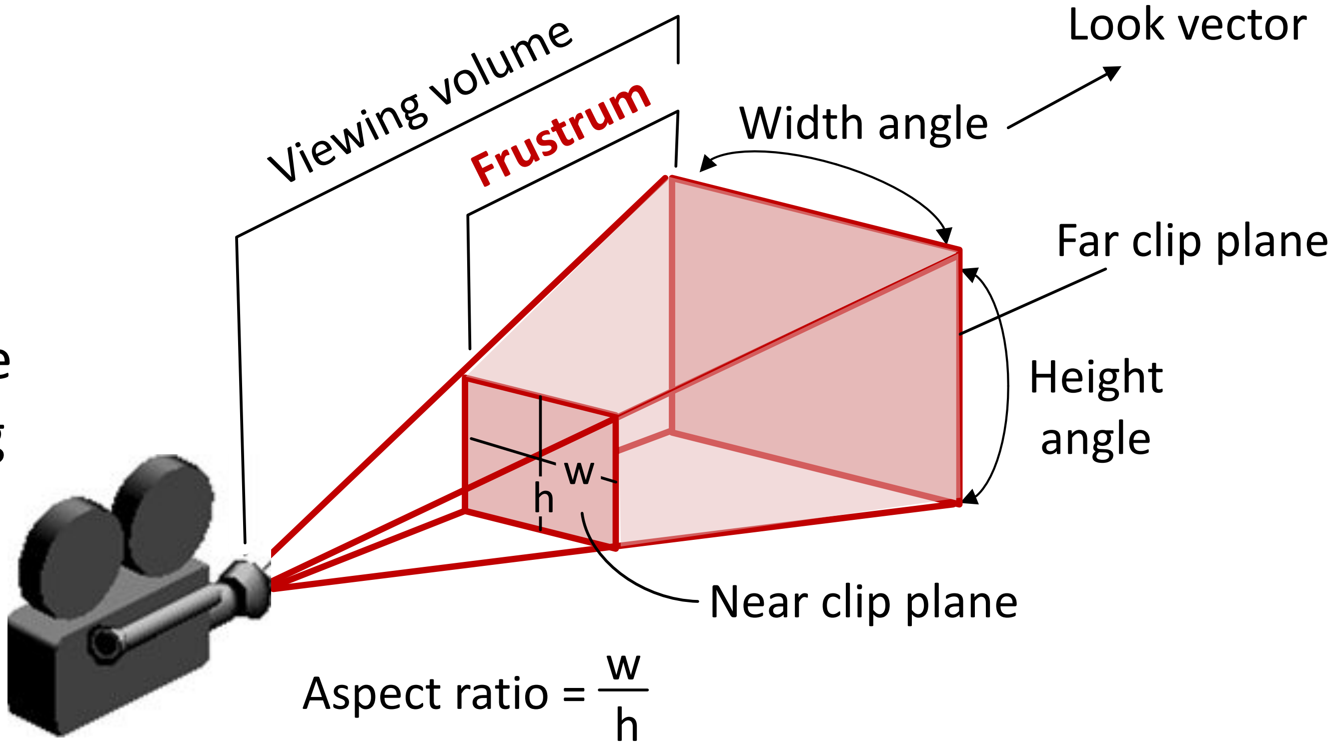
- Camera orientation is specified by a point in 3D space to look at (or a direction to look in) and an angle of rotation about this direction. These correspond to the **Look vector** and **View UP (VUP) vector**.



Note: Up vector does **not** have to be perpendicular to the Look vector

Aspect Ratio, Viewing Angle, Clipping Planes

- Two viewing angles (width and height)
- Usually, the height angle is specified and the width angle is determined using the aspect ratio

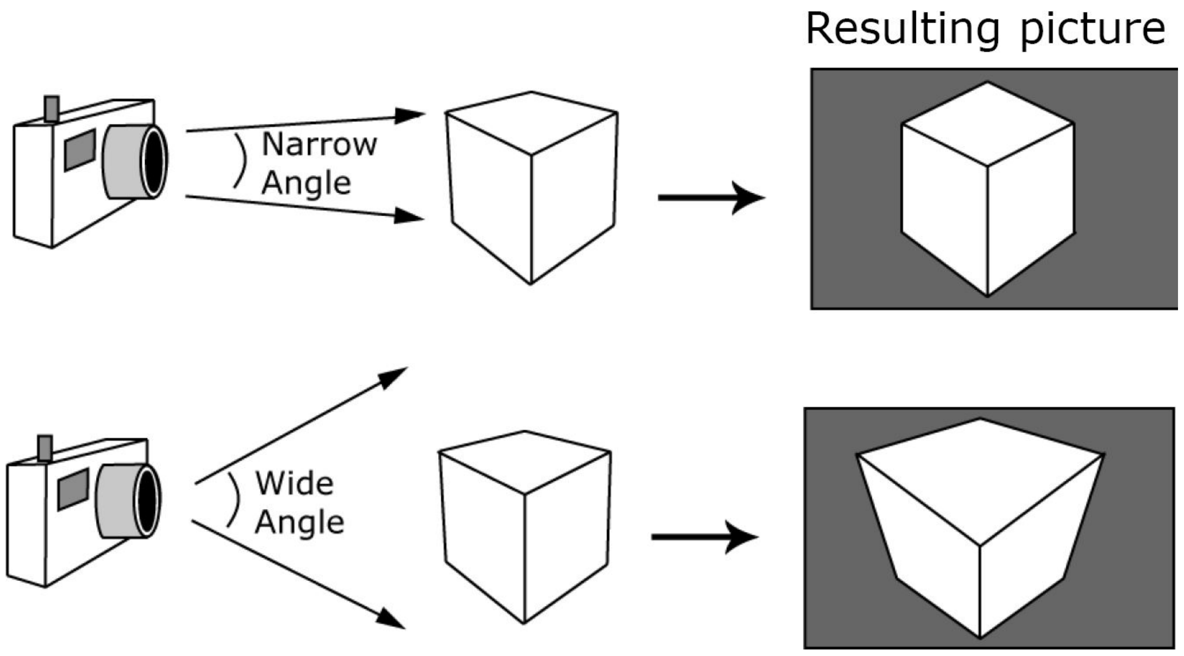


Frustrum:

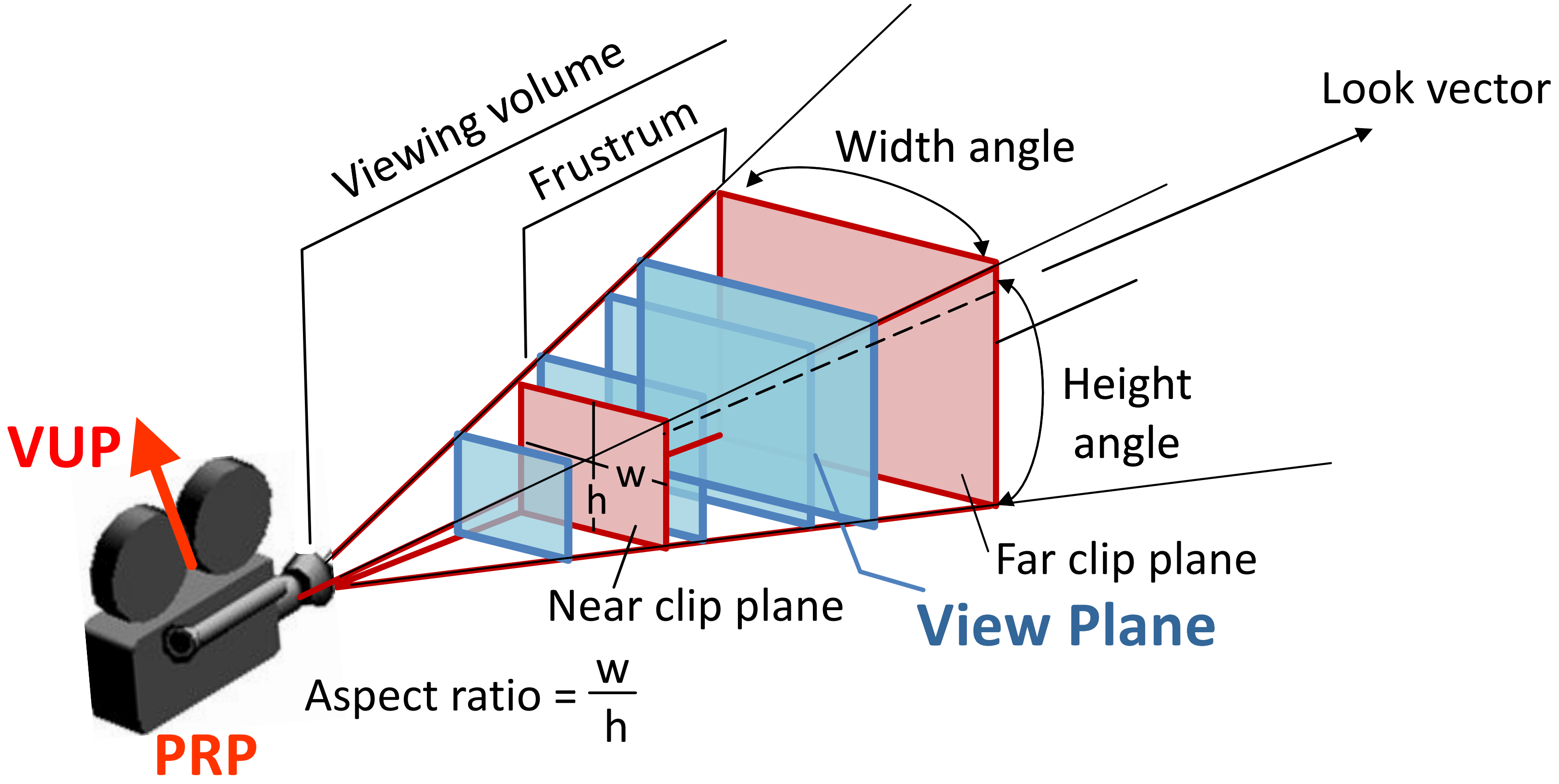
- part of the viewing volume between the front and back clipping planes
- in general (perspective projection) this is a truncated pyramid
- reduces to a parallelepiped for parallel projection

Viewing angle

- Viewing angle determines the amount of **perspective distortion** in the resulting picture
  - For zero viewing angle (parallel projection) → no distortion
  - The larger the viewing angle, the larger distortion

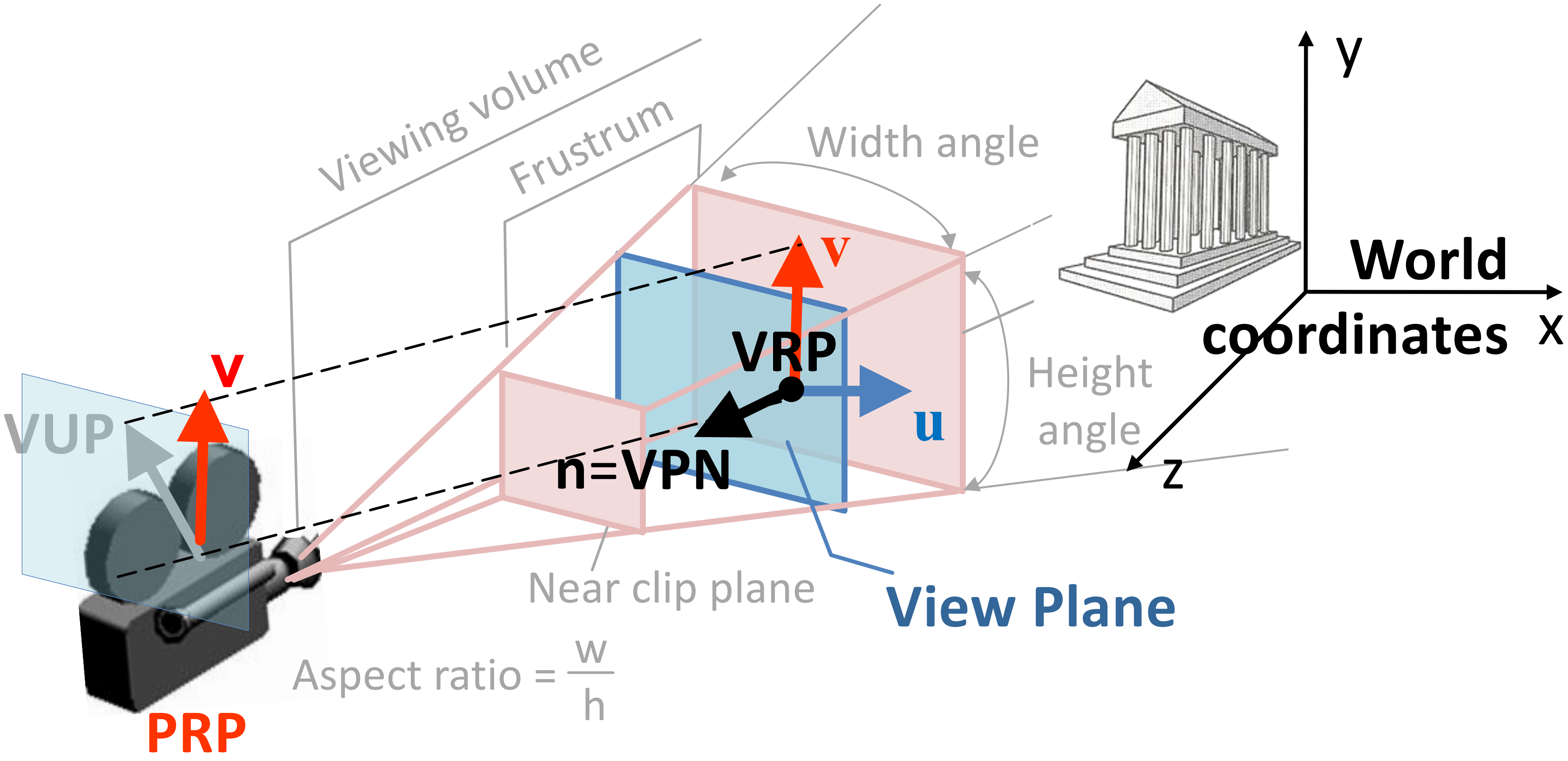


View plane



- The **view plane** can be anywhere with respect to the world objects to be projected: in front of, cut through or behind the objects

View Reference System (VRC)



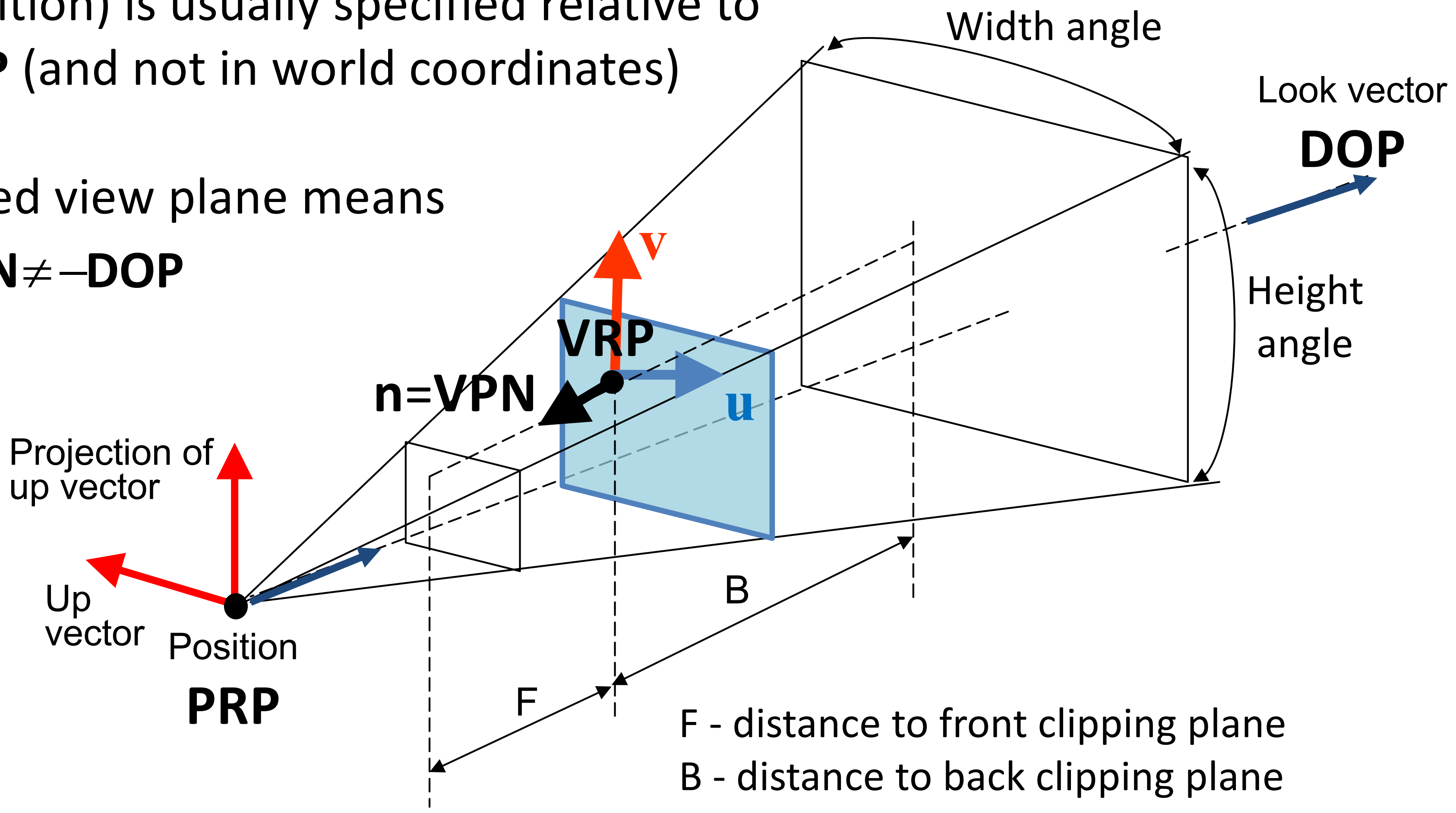
- View Reference Point (VRP) specifies the view plane together with VPN
- View Reference System (VRC) is the right-handed system **u**-**v**-**n**
  - **n** is VPN (View Plane Normal)
  - **v** is the projection of the View UP (VUP) vector in the view plane
  - **u** is defined such that **u**, **v** and **n** form a right-handed coordinate system

Perspective View Volume - Summary

PRP – Projection Reference Point (i.e., center of projection, camera position) is usually specified relative to **VRP** (and not in world coordinates)

Tilted view plane means

VPN≠–DOP



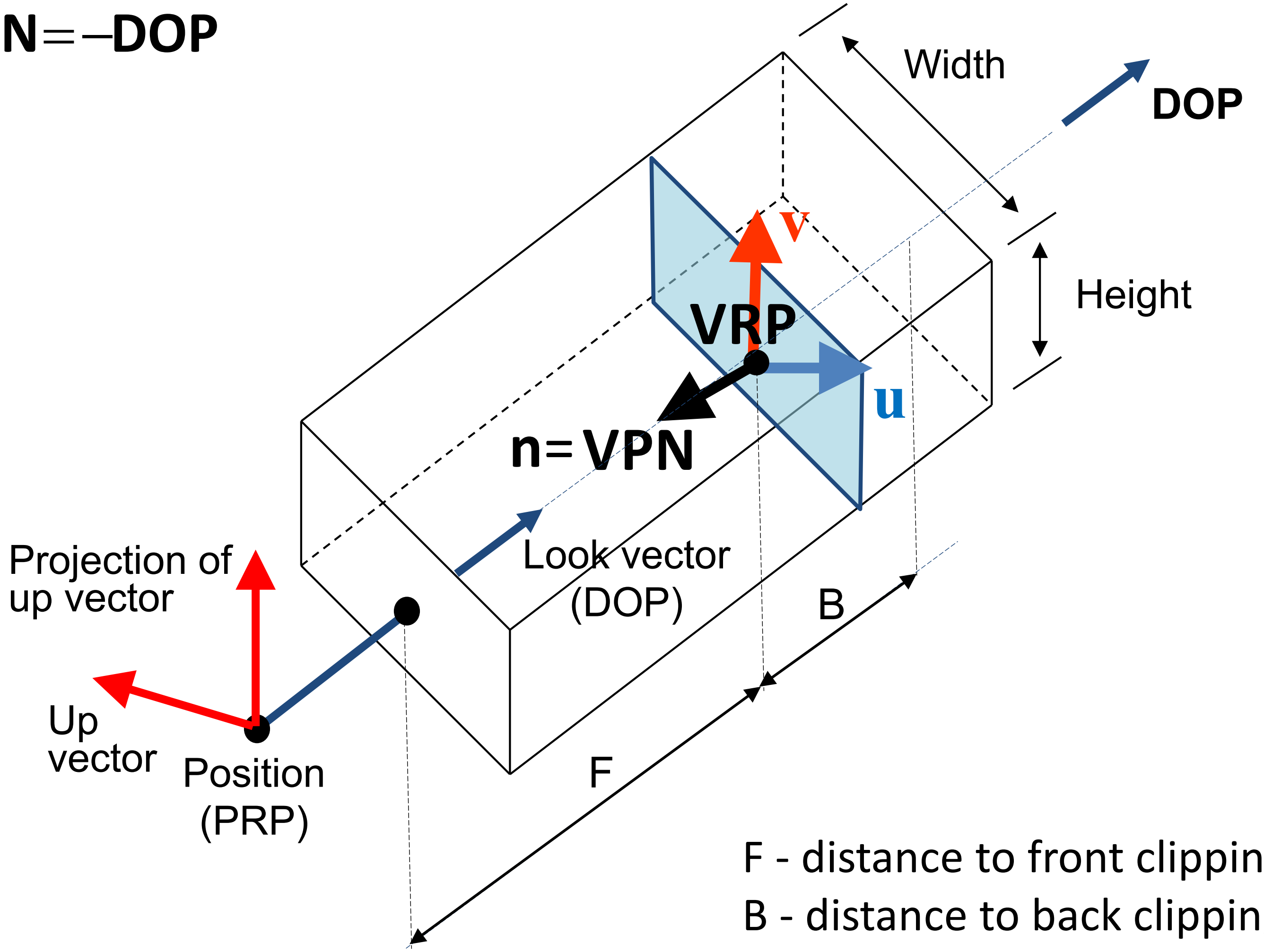
F - distance to front clipping plane

B - distance to back clipping plane

View Volume for Parallel Projection (1)

Orthographic case

VPN=–DOP



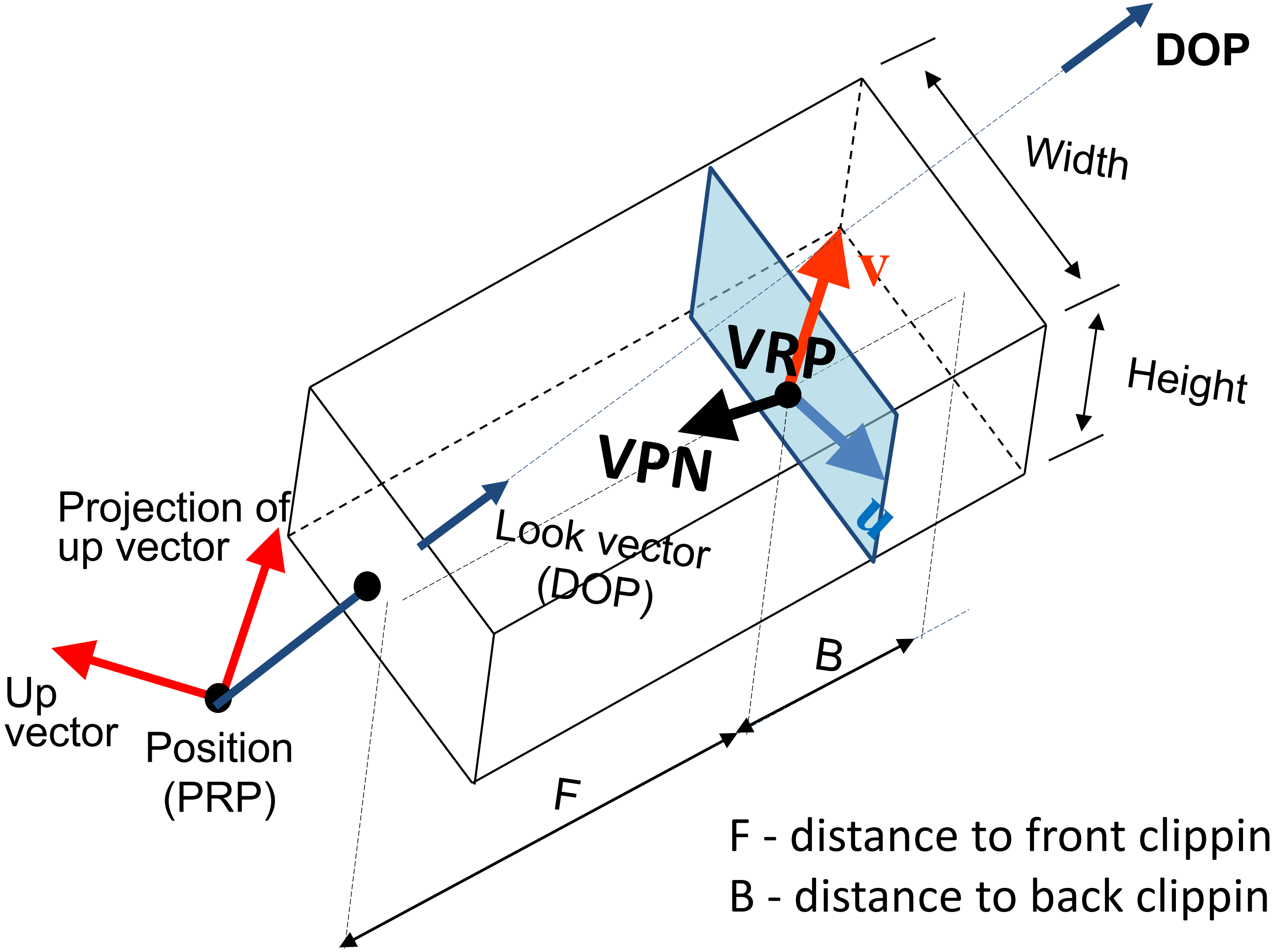
F - distance to front clipping plane

B - distance to back clipping plane

View Volume for Parallel Projection (2)

Oblique projection

VPN≠−DOP

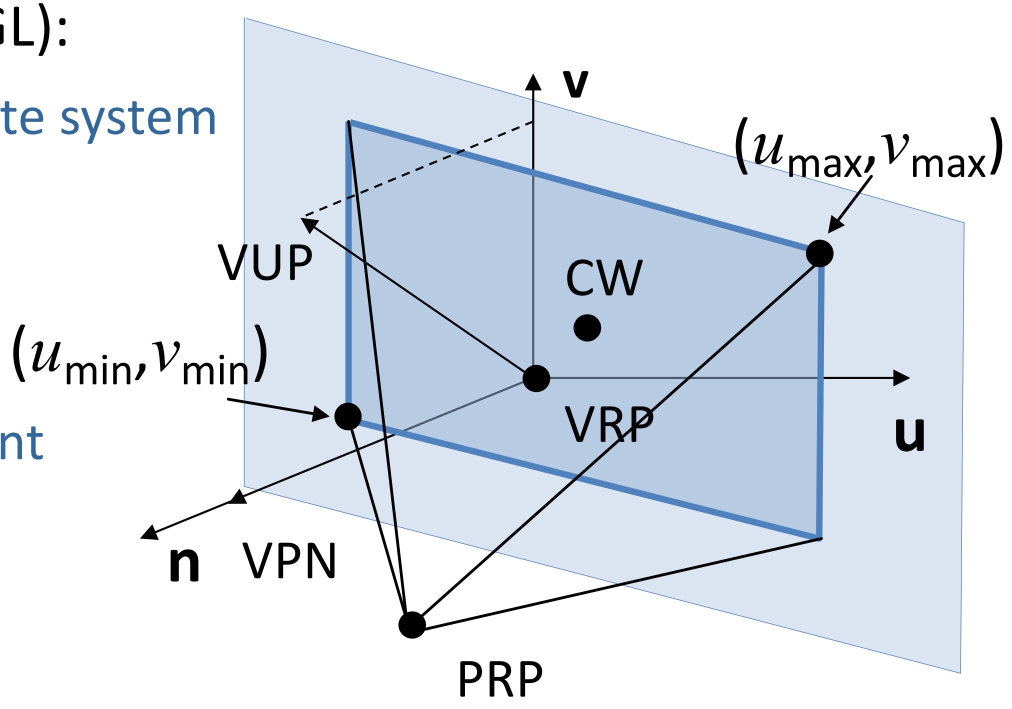


F - distance to front clipping plane

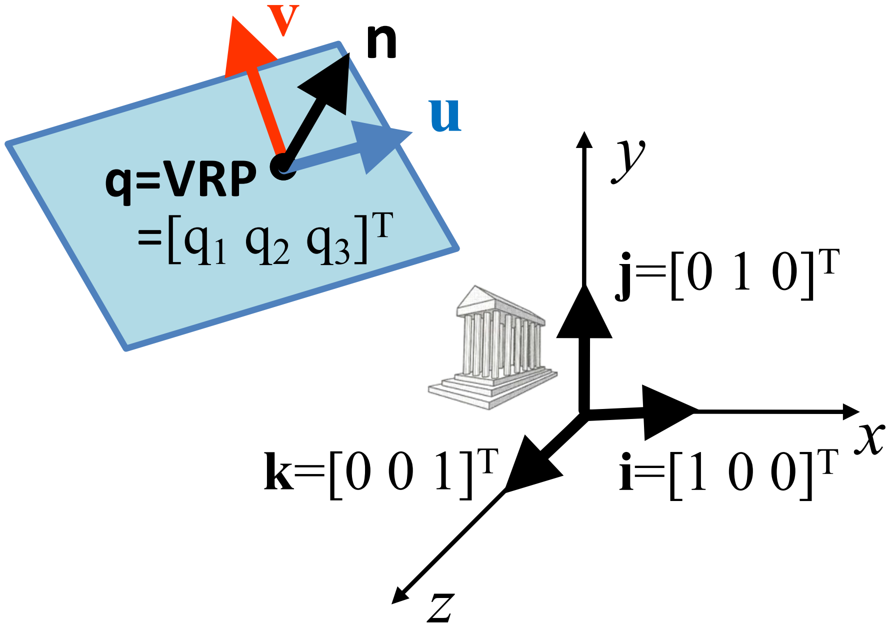
B - distance to back clipping plane

View Reference System vs. World Coordinates

- 3D objects that we are viewing “live” in a **World Coordinate System – WCS** (right-handed coordinate system with x, y and z axes)
- In camera space, we defined **Viewing Reference System** with unit vectors $\mathbf{u}$, $\mathbf{v}$ and $\mathbf{n}$ (which is also a right-handed coordinate system)
- Common notation in graphics application program interfaces - API (PHIGS, OpenGL):
  - VRC – view reference coordinate system
  - VRP – view reference point
  - VPN – view plane normal
  - VUP – view up vector
  - PRP – projection reference point
  - CW – center of **window**



Transformation from VRC to World Coordinates



VRP in homogeneous coordinates: $\begin{bmatrix} \mathbf{q} \\ 1 \end{bmatrix}$

We search $\mathbf{M}$ such that: $\mathbf{M}\begin{bmatrix} \mathbf{q} \\ 1 \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ 1 \end{bmatrix}$

Rotation

Translation

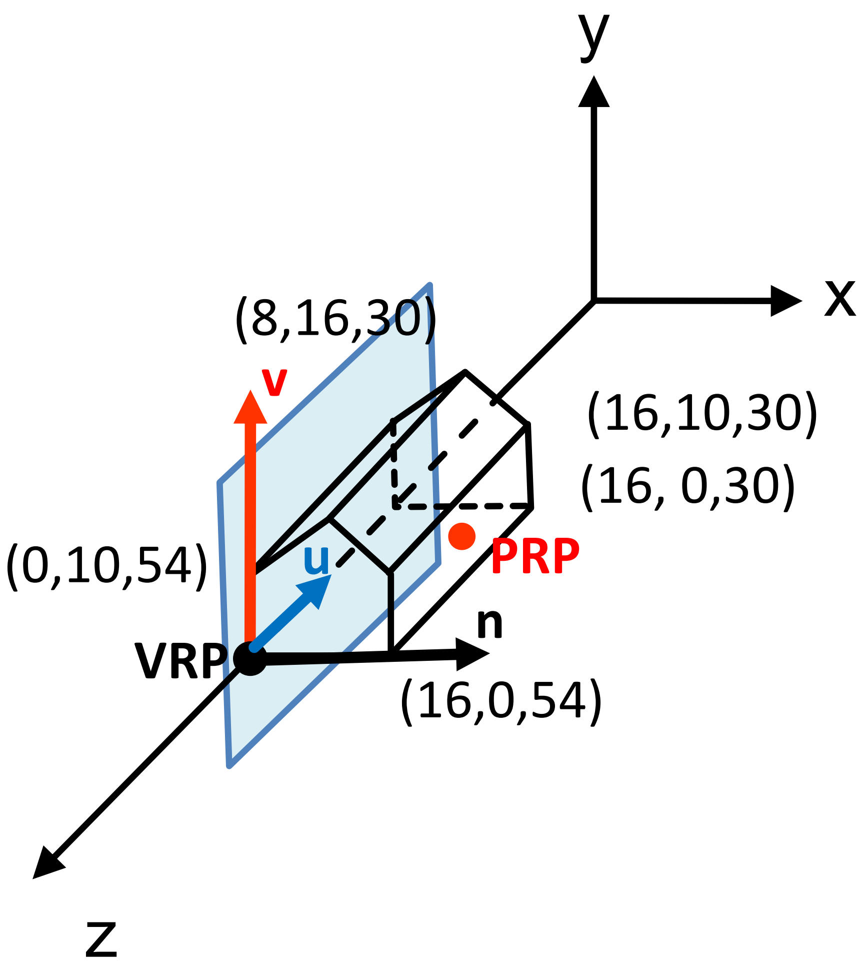
$$\mathbf{M} = \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ \mathbf{0} & 1 \end{bmatrix}$$

$$\left.\begin{aligned} \mathbf{Ru} &= [1\ 0\ 0]^{\mathrm{T}} \\ \mathbf{Rv} &= [0\ 1\ 0]^{\mathrm{T}} \\ \mathbf{Rn} &= [0\ 0\ 1]^{\mathrm{T}} \end{aligned}\right\} \mathbf{R}[\mathbf{u}\ \ \mathbf{v}\ \ \mathbf{n}] = \mathbf{I} \ \Rightarrow\ \mathbf{R} = [\mathbf{u}\ \ \mathbf{v}\ \ \mathbf{n}]^{\mathrm{T}} = \begin{bmatrix} u_1 & u_2 & u_3 \\ v_1 & v_2 & v_3 \\ n_1 & n_2 & n_3 \end{bmatrix}$$

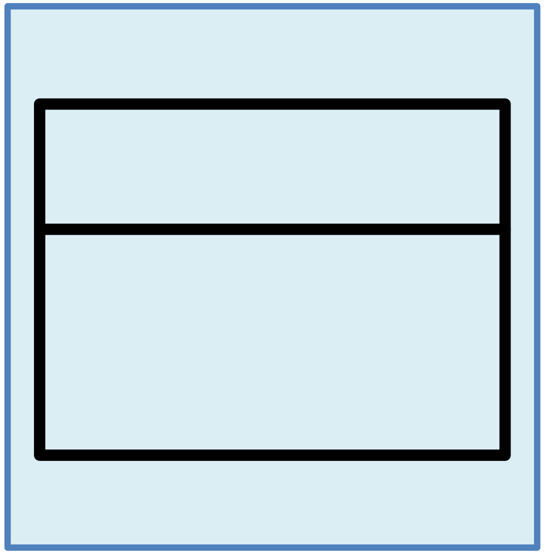
$$\begin{bmatrix} \mathbf{R} & \mathbf{t} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \mathbf{q} \\ 1 \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ 1 \end{bmatrix} \ \Rightarrow\ \mathbf{Rq} + \mathbf{t} = \mathbf{0} \ \Rightarrow\ \mathbf{t} = -\mathbf{Rq} = -[\sum_i u_i q_i\ \ \sum_i v_i q_i\ \ \sum_i n_i q_i]^{\mathrm{T}}$$

View specification examples

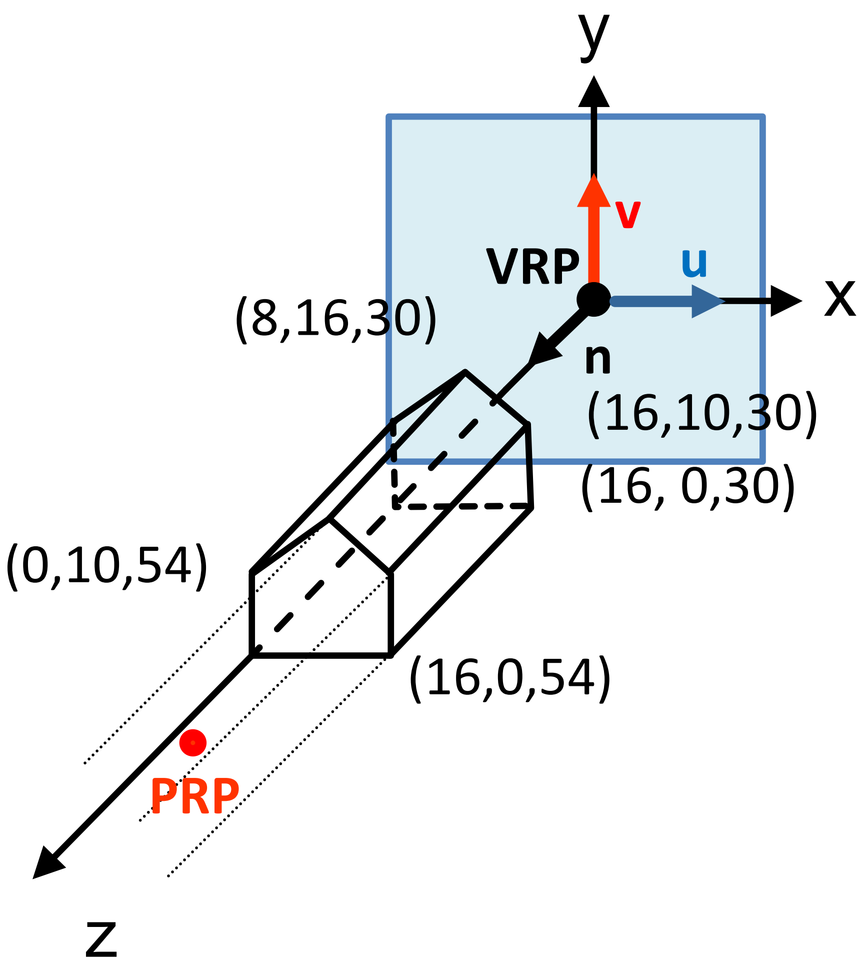
Specifying arbitrary view in 3D: Examples



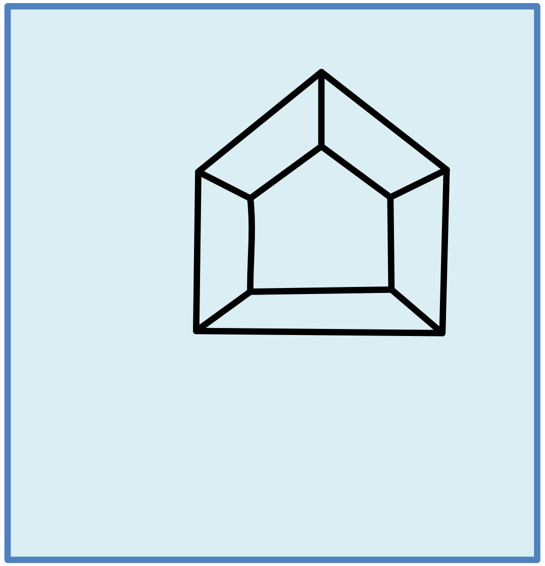
VRP (WC):	(0,0,54)
VPN (WC):	(1,0,0)
VUP (WC):	(0,1,0)
PRP (VRC):	(12,8,16)
Window (VRC):	(-1,25,-5,21)
Projection type:	parallel



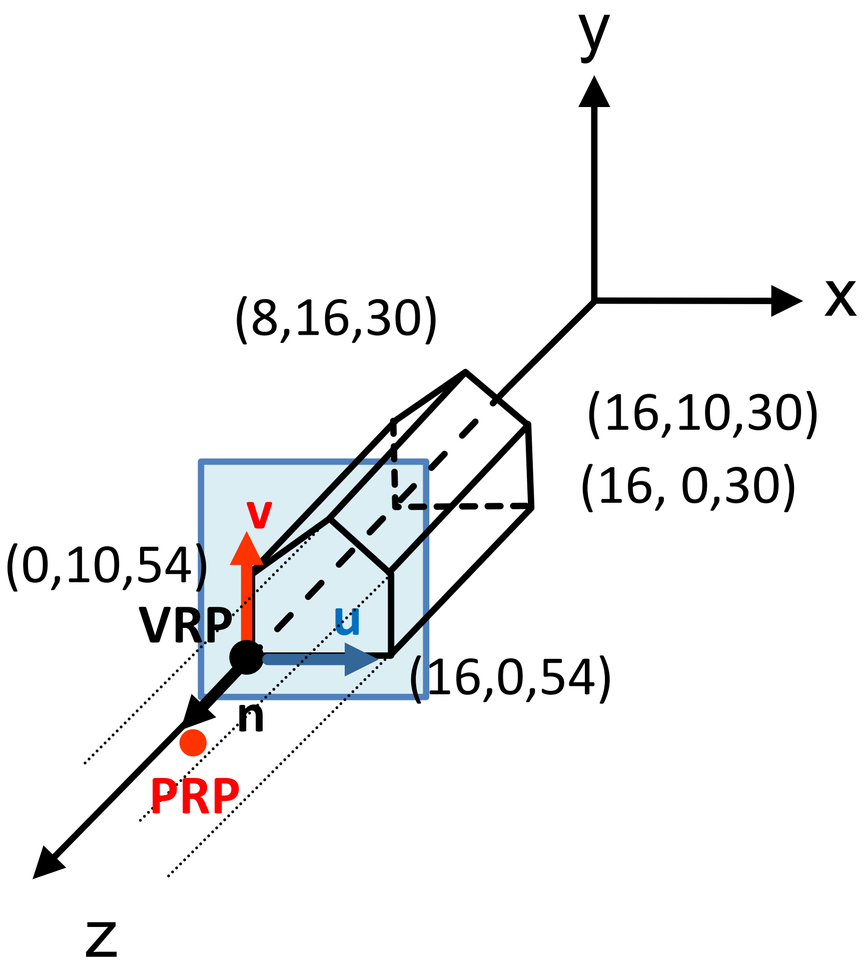
Specifying arbitrary view in 3D: Examples



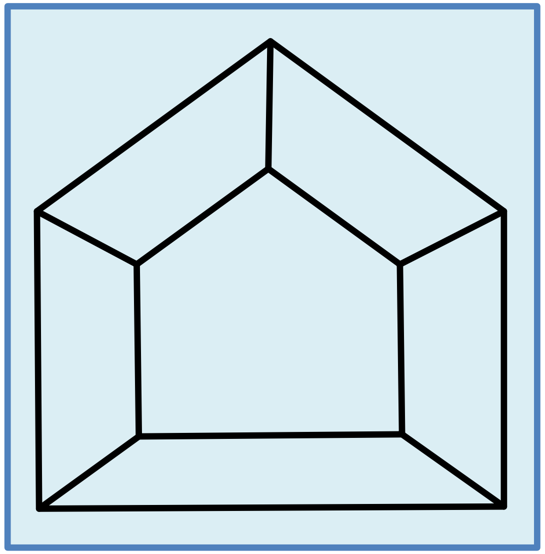
VRP (WC):	(0,0,0)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(8,6,84)
Window (VRC):	(-50,50,-50,50)
Projection type:	perspective



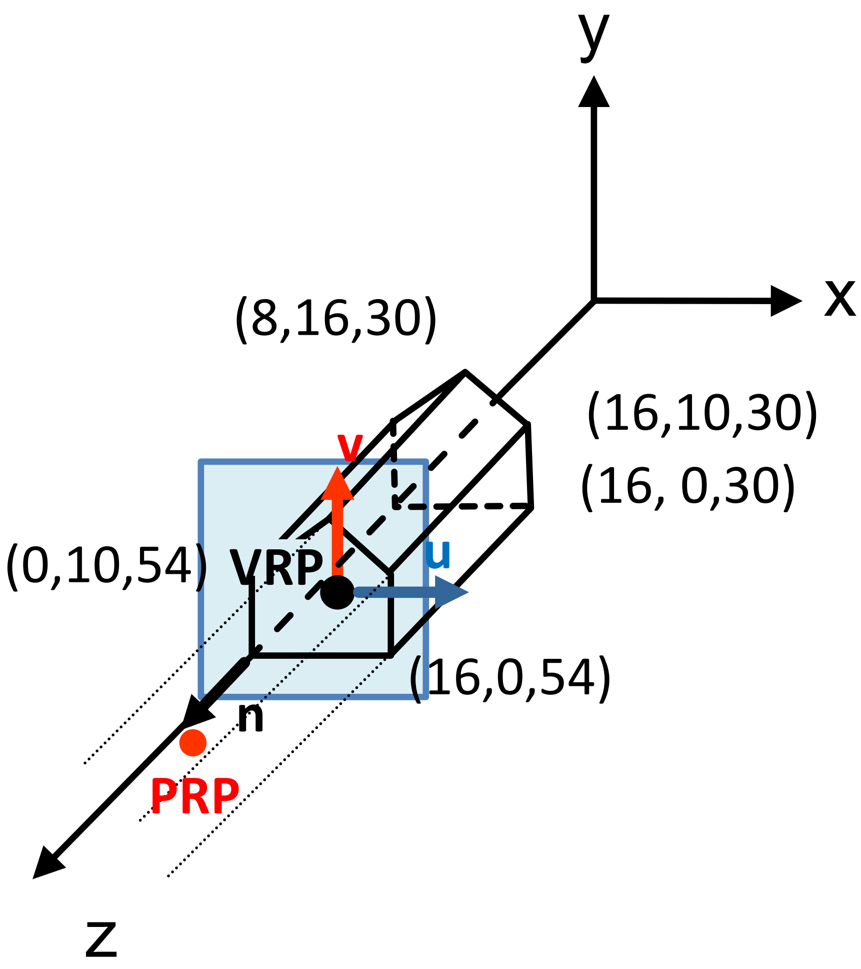
Specifying arbitrary view in 3D: Examples



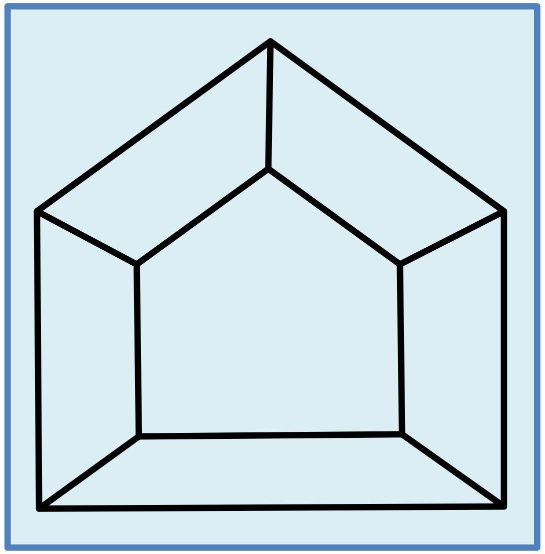
VRP (WC):	(0,0,54)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(8,6,30)
Window (VRC):	(-1,17,-1,17)
Projection type:	perspective



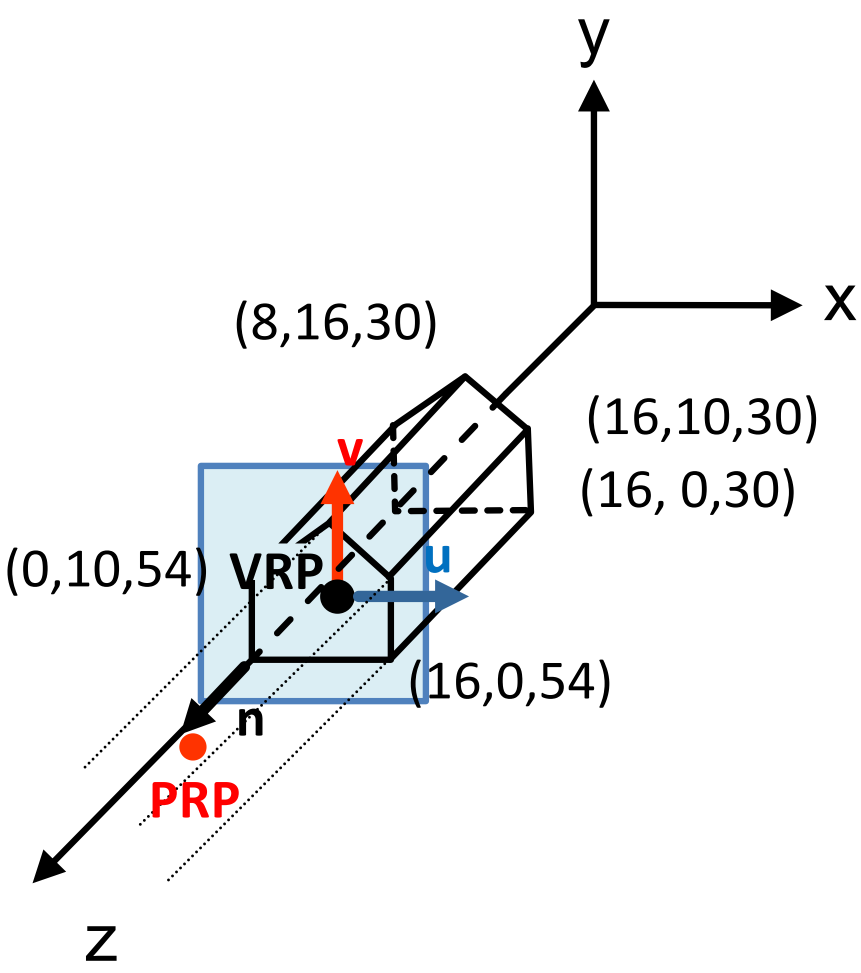
Specifying arbitrary view in 3D: Examples



VRP (WC):	(8,6,54)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(0,0,30)
Window (VRC):	(-9,9,-7,11)
Projection type:	perspective

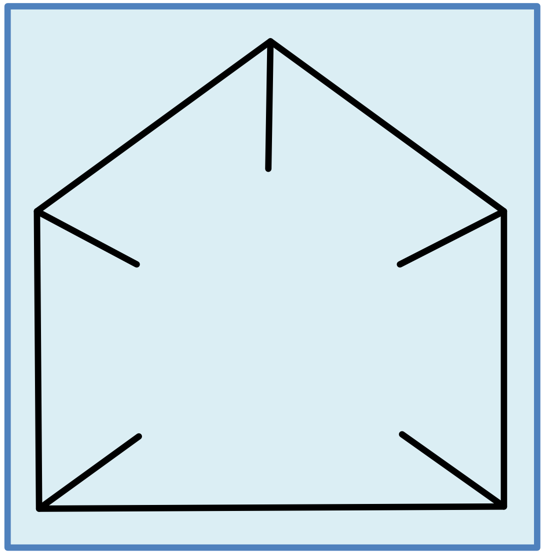


Specifying arbitrary view in 3D: Examples

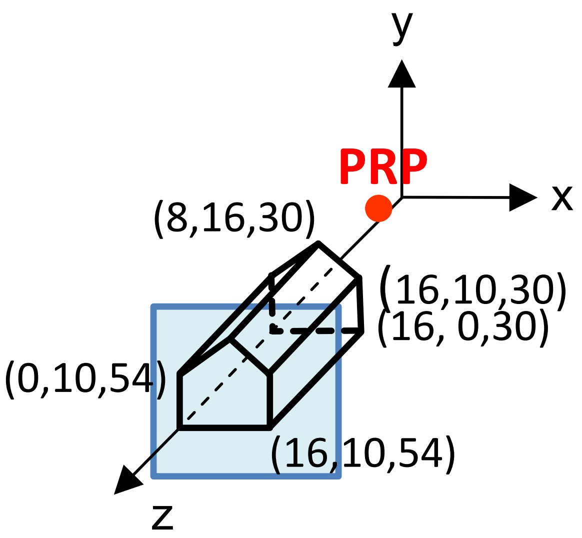


VRP (WC):	(8,6,54)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(0,0,30)
Window (VRC):	(-9,9,-7,11)
Projection type:	perspective

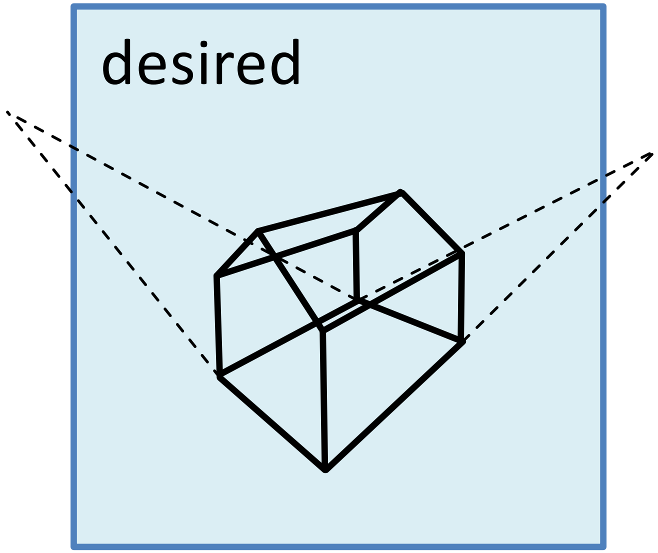
Back clipping plane at z=31



Specifying arbitrary view in 3D: Examples

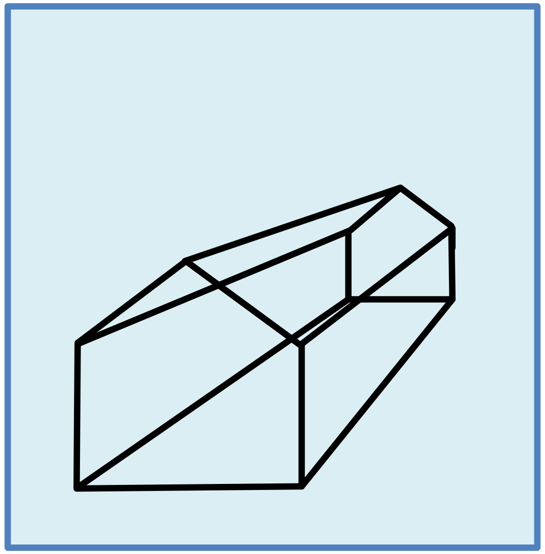


Which parameters?



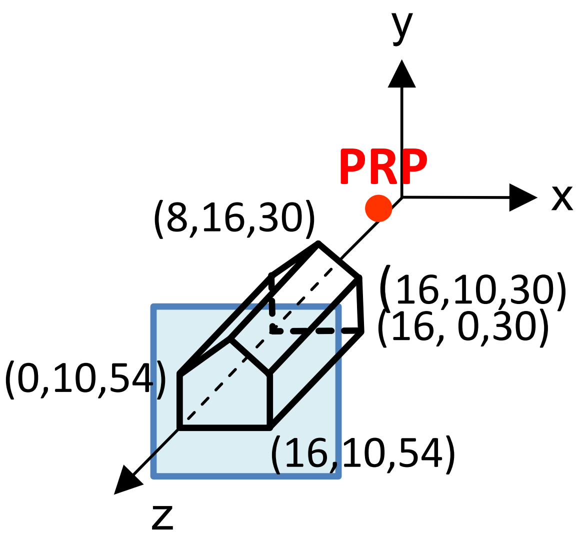
Try the following:

VRP (WC):	(16,0,54)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(20,25,20)
Window (VRC):	(-20,20,-5,35)
Projection type:	perspective

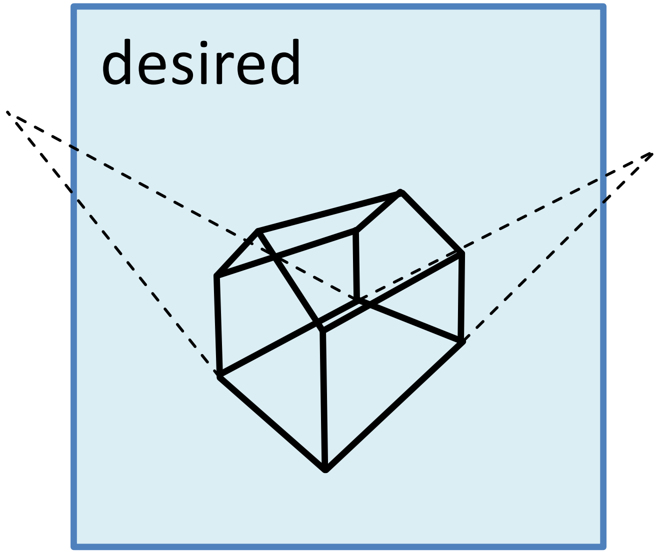


Similar, but what is wrong?

Specifying arbitrary view in 3D: Examples

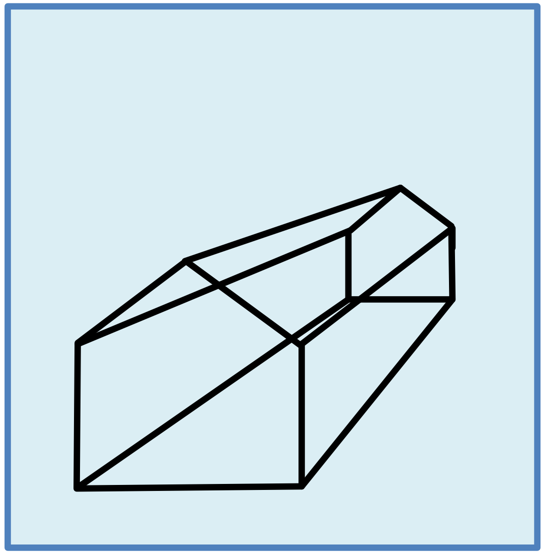


Which parameters?



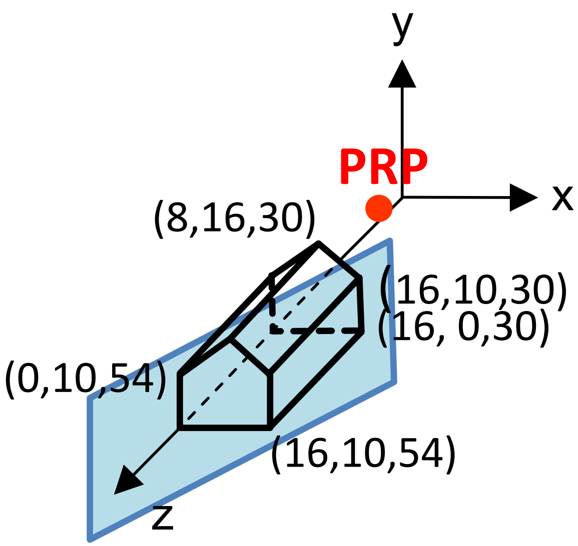
Try the following:

VRP (WC):	(16,0,54)
VPN (WC):	(0,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	(20,25,20)
Window (VRC):	(-20,20,-5,35)
Projection type:	perspective

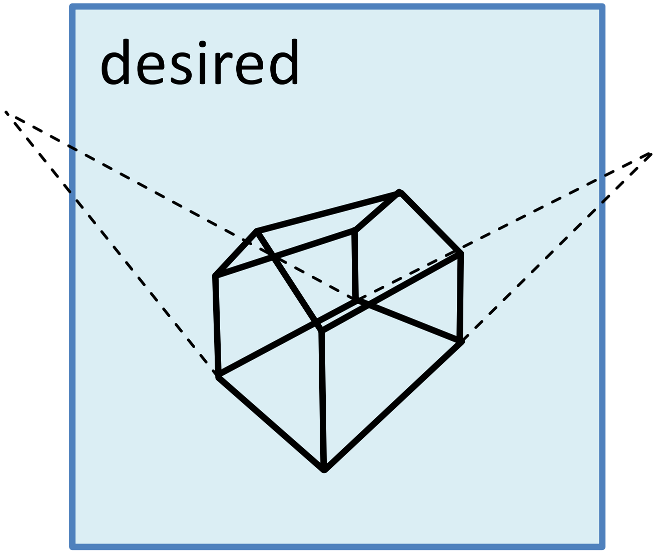


Need to reorient the view plane!

Specifying arbitrary view in 3D: Examples

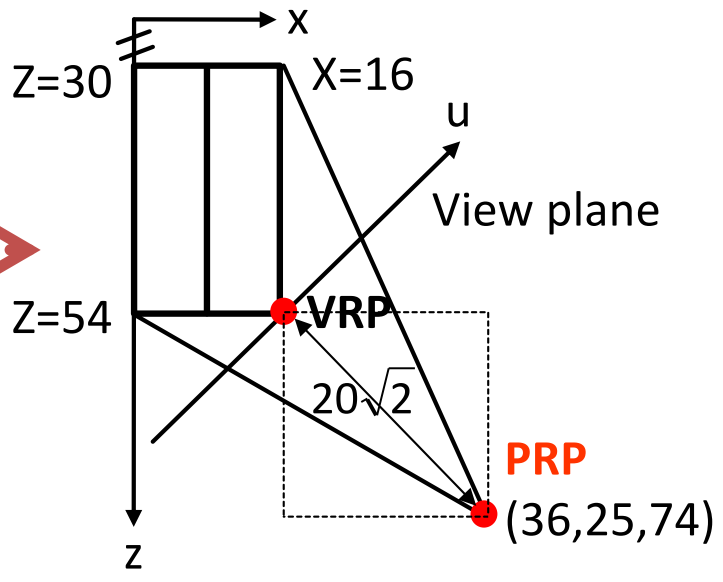


Which parameters?

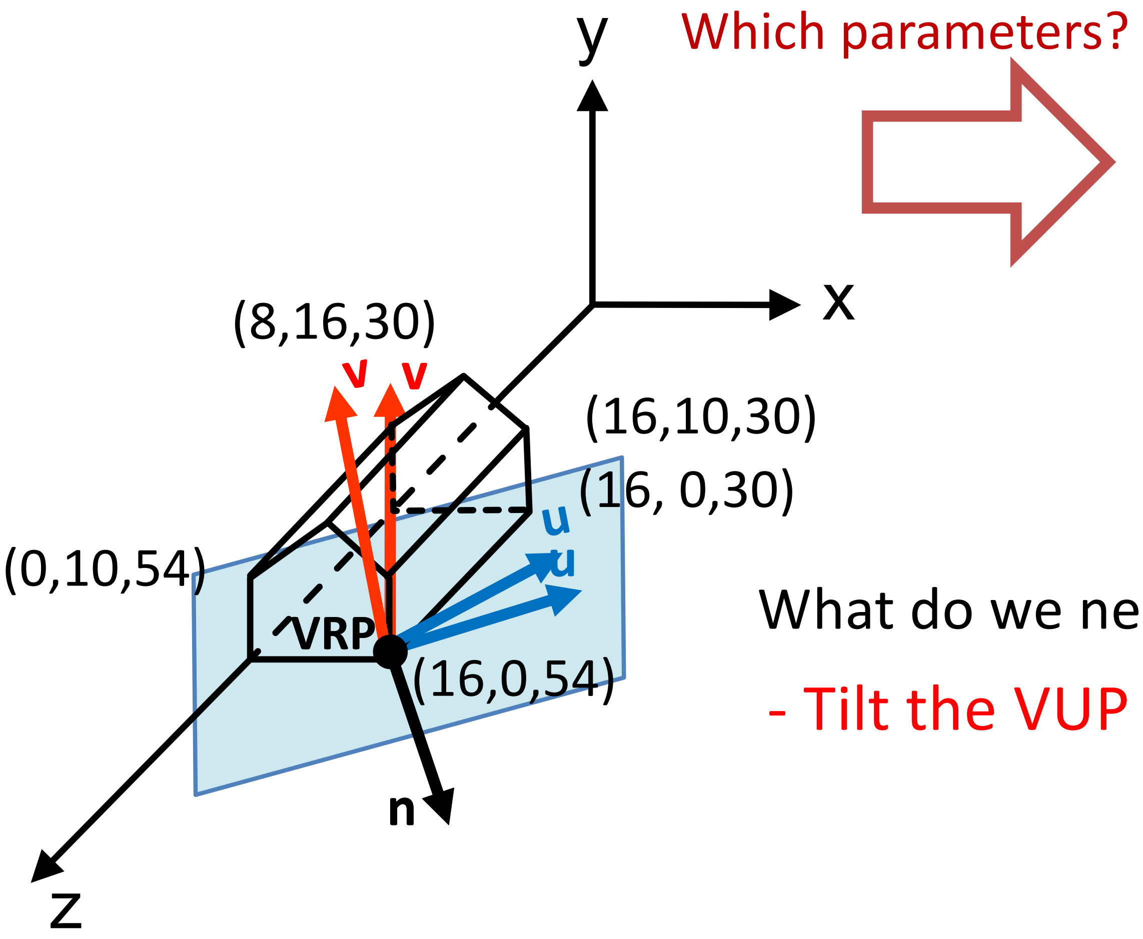


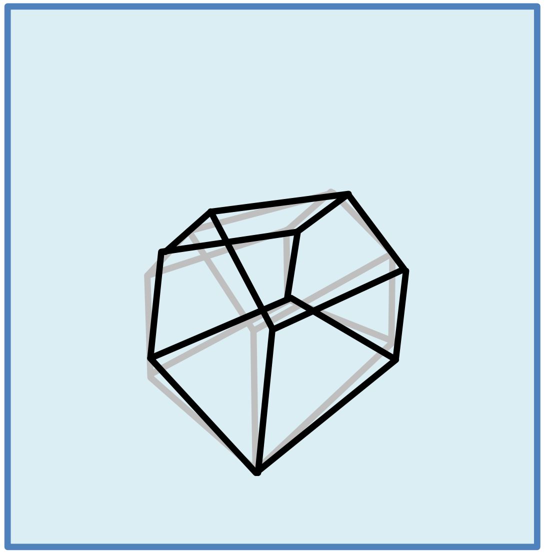
In this case the view plane shouldn't be parallel to x-y plane!

VRP (WC):	(16,0,54)
VPN (WC):	(1,0,1)
VUP (WC):	(0,1,0)
PRP (VRC):	$(0,25,20\sqrt{2})$
Window (VRC):	(-20,20,-5,35)
Projection type:	perspective



Specifying arbitrary view in 3D: Examples





What do we need to change to get this view?

- Tilt the VUP vector

Summary

- We introduced main concepts of viewing in 3D
  - Types of projections
  - Synthetic camera model: important parameters

- Next lesson
  - Mathematics of projections: projection matrices
  - Practical viewing process: transforming arbitrary view volume into canonical view volume