3D Polygon Rendering Pipeline

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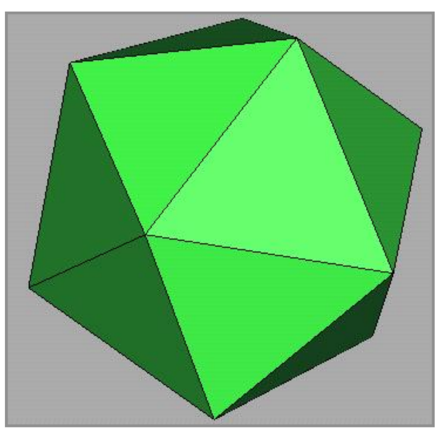
3D Polygon Rendering

- Many applications use rendering of 3D polygons with direct illumination



3D Polygon Rendering

- Many applications use rendering of 3D polygons with direct illumination

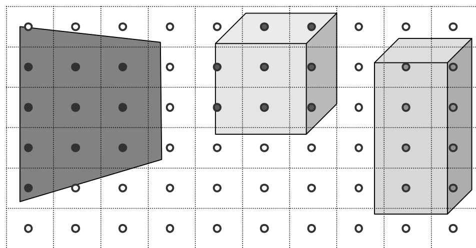
Quake II
(Id Software)

3D Polygon Rendering

- Many applications use rendering of 3D polygons with direct illumination

Ray Casting Revisited

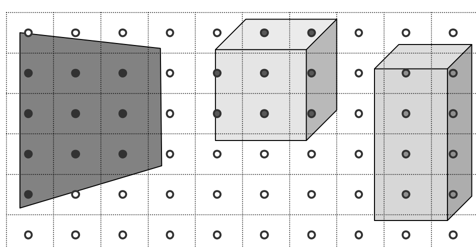
- For each sample …
  - Construct ray from eye position through view plane
  - Find first surface intersected by ray through pixel
  - Compute color of sample based on surface radiance



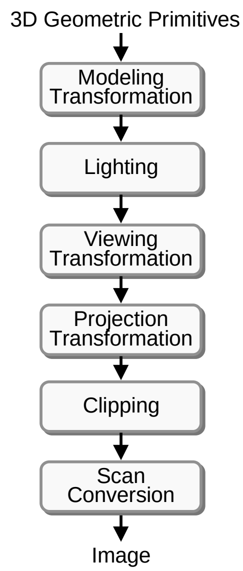
More efficient algorithms utilize spatial coherence!

3D Polygon Rendering

- What steps are necessary to utilize spatial coherence while drawing these polygons into a 2D image?

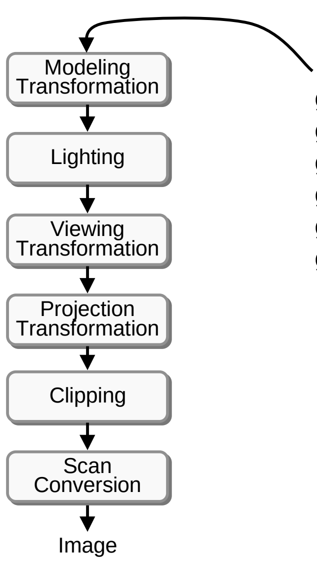


3D Rendering Pipeline (for direct illumination)



This is a pipelined sequence of operations to draw a 3D primitive into a 2D image

Example: OpenGL




```
glBegin(GL_POLYGON);
glVertex3f(0.0, 0.0, 0.0);
glVertex3f(0.0, 0.0, 0.0);
glVertex3f(0.0, 0.0, 0.0);
glVertex3f(0.0, 0.0, 0.0);
glEnd();
```

OpenGL executes steps of 3D rendering pipeline for each polygon

3D Rendering Pipeline (for direct illumination)

3D Geometric Primitives

↓ Modeling Transformation — Transform into 3D world coordinate system

↓ Lighting

↓ Viewing Transformation

↓ Projection Transformation

↓ Clipping

↓ Scan Conversion

↓ Image

3D Rendering Pipeline (for direct illumination)

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↓ Modeling Transformation — Transform into 3D world coordinate system

↓ Lighting — Illuminate according to lighting and reflectance

↓ Viewing Transformation

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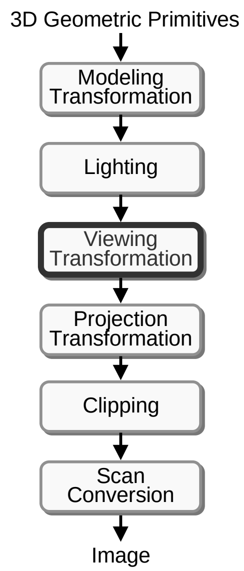
↓ Image

3D Rendering Pipeline (for direct illumination)

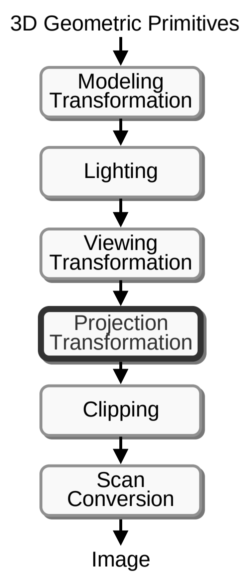


Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

3D Rendering Pipeline (for direct illumination)



Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

Transform into 2D camera coordinate system

3D Rendering Pipeline (for direct illumination)

3D Geometric Primitives

Modeling Transformation	Transform into 3D world coordinate system
Lighting	Illuminate according to lighting and reflectance
Viewing Transformation	Transform into 3D camera coordinate system
Projection Transformation	Transform into 2D camera coordinate system
Clipping	Clip primitives outside camera's view
Scan Conversion	

Image

3D Rendering Pipeline (for direct illumination)

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Scan Conversion	Draw pixels (includes texturing, hidden surface, etc.)

Image

Transformations

3D Geometric Primitives

↓

Modeling Transformation	**Transform** into 3D world coordinate system
Lighting	Illuminate according to lighting and reflectance
Viewing Transformation	**Transform** into 3D camera coordinate system
Projection Transformation	**Transform** into 2D camera coordinate system
Clipping	Clip primitives outside camera's view
Scan Conversion	Draw pixels (includes texturing, hidden surface, etc.)

↓

Image

Transformations

p(x,y,z)

↓ 3D Object Coordinates

Modeling Transformation

↓ 3D World Coordinates

Viewing Transformation

↓ 3D Camera Coordinates

Projection Transformation

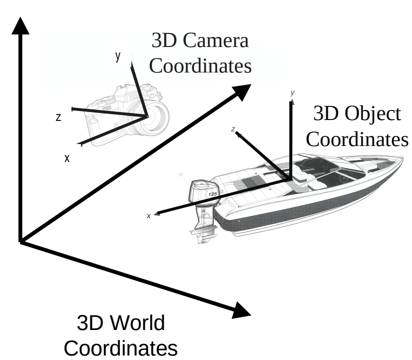
↓ 2D Screen Coordinates

Window-to-Viewport Transformation

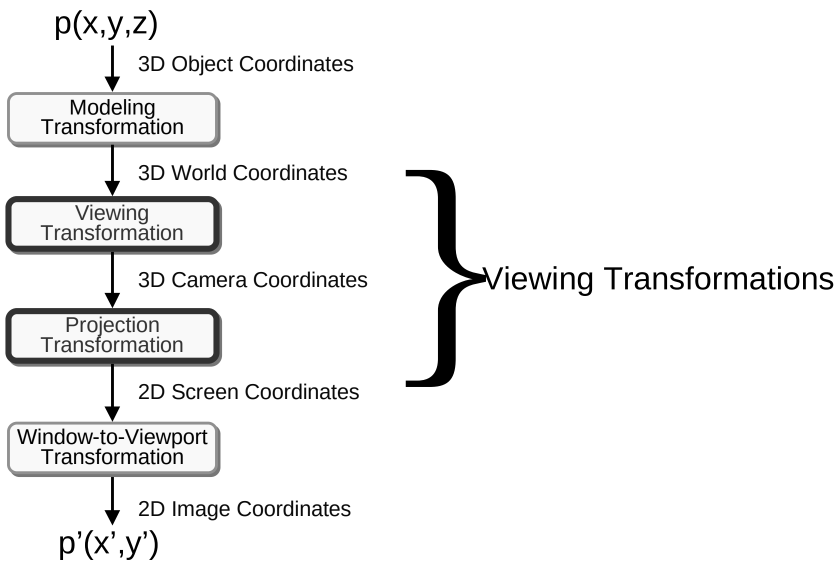
↓ 2D Image Coordinates

p'(x',y')

Transformations map points from one coordinate system to another

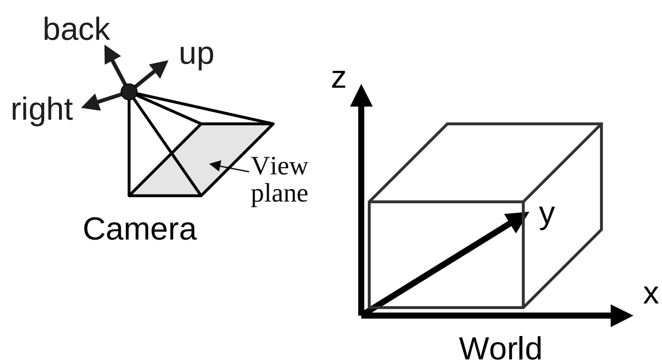


Viewing Transformations



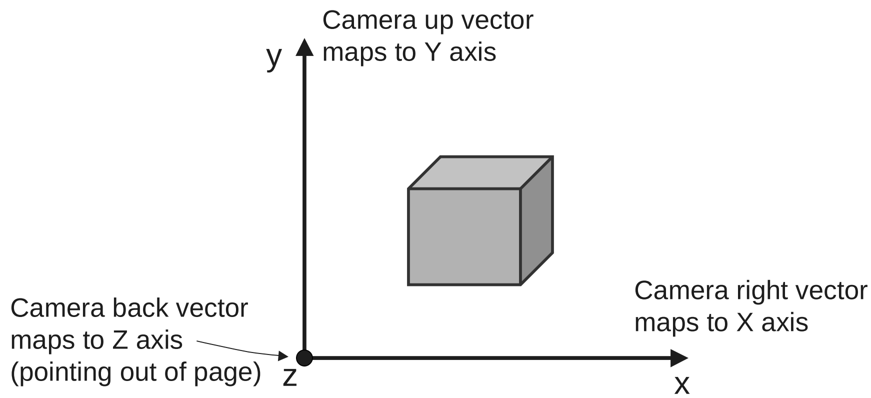
Viewing Transformation

- Mapping from world to camera coordinates
  - Origin moves to eye position
  - Up vector maps to Y axis
  - Right vector maps to X axis



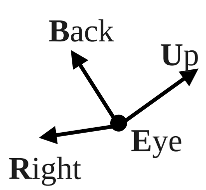
Camera Coordinates

- Canonical coordinate system
  - Convention is right-handed (looking down -z axis)
  - Convenient for projection, clipping, etc.

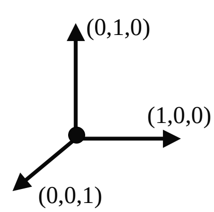


Viewing Transformation

- Transformation matrix maps camera basis vectors to canonical vectors in camera coordinate system



$$M = \begin{bmatrix} R_x & U_x & B_x & E_x \\ R_y & U_y & B_y & E_y \\ R_z & U_z & B_z & E_z \\ R_w & U_w & B_w & E_w \end{bmatrix}^{-1}$$



Viewing Transformations

p(x,y,z)

↓ 3D Object Coordinates

Modeling Transformation

↓ 3D World Coordinates

Viewing Transformation

↓ 3D Camera Coordinates

Projection Transformation

↓ 2D Screen Coordinates

Window-to-Viewport Transformation

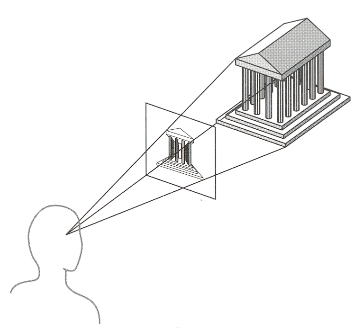
↓ 2D Image Coordinates

p'(x',y')

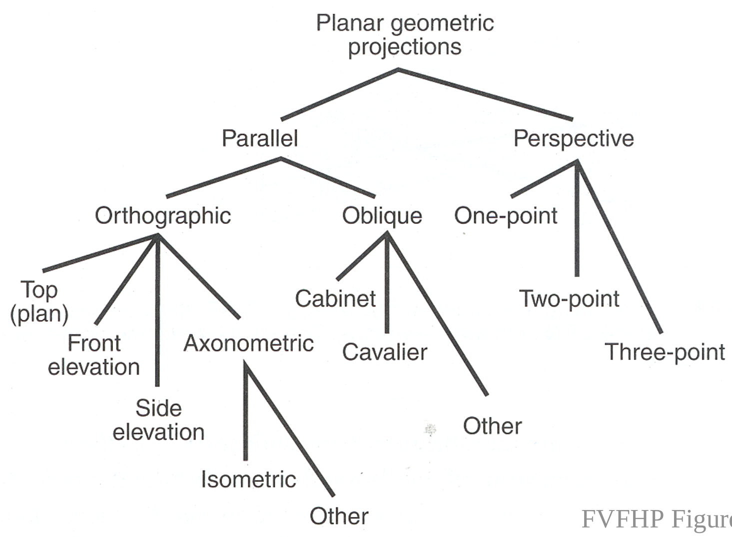
} Viewing Transformations

Projection

- General definition:
  - Transform points in *n*-space to *m*-space (*m*<*n*)
- In computer graphics:
  - Map 3D camera coordinates to 2D screen coordinates

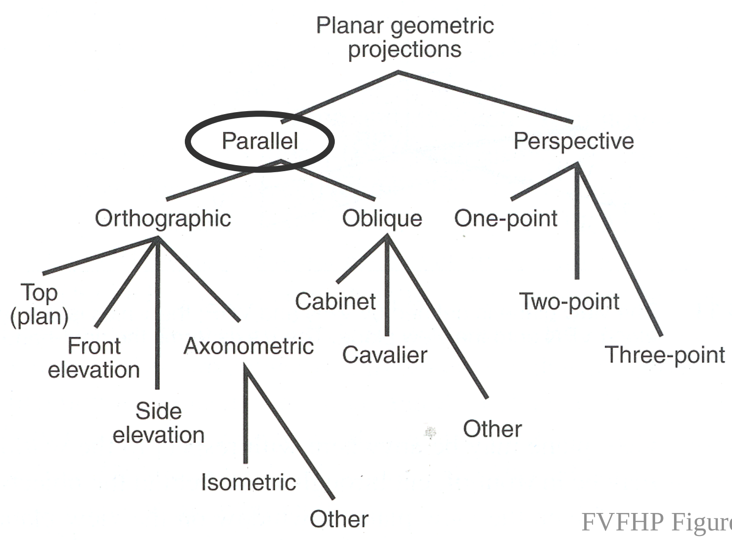


Taxonomy of Projections



FVFHP Figure 6.10

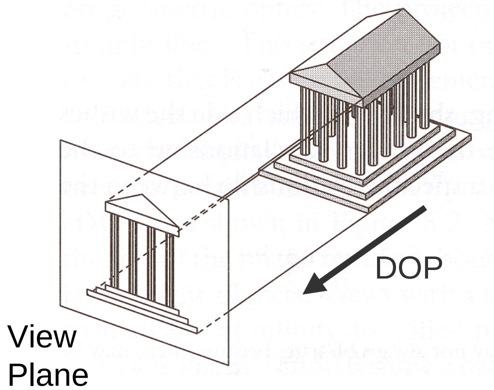
Taxonomy of Projections



FVFHP Figure 6.10

Parallel Projection

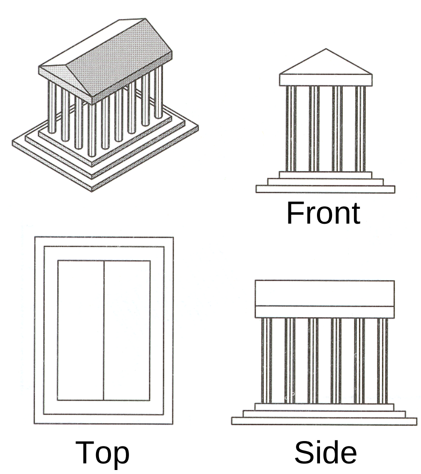
- Center of projection is at infinity
  - Direction of projection (DOP) same for all points



Angel Figure 5.4

Orthographic Projections

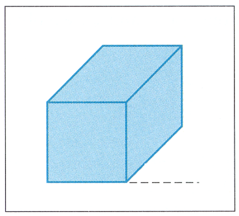
- DOP perpendicular to view plane



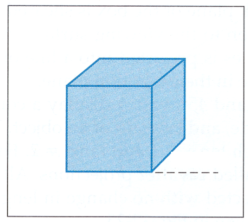
Angel Figure 5.5

Oblique Projections

- DOP not perpendicular to view plane



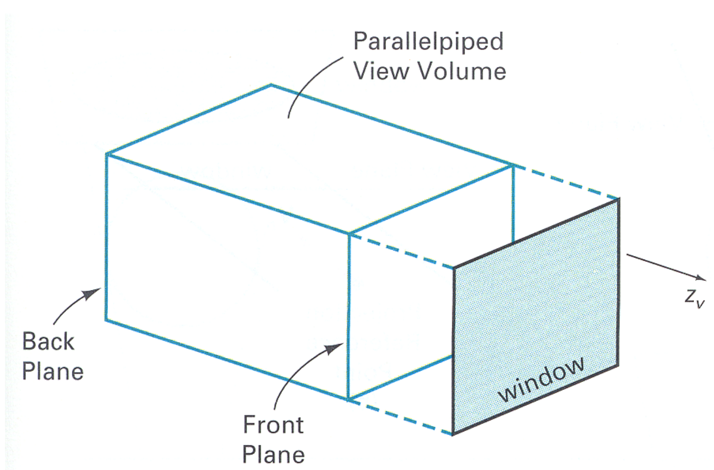
Cavalier
(DOP at 45°)



Cabinet
(DOP at 63.4°)

H&B Figure 12.24

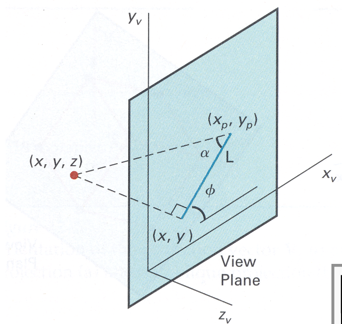
Parallel Projection View Volume



H&B Figure 12.30

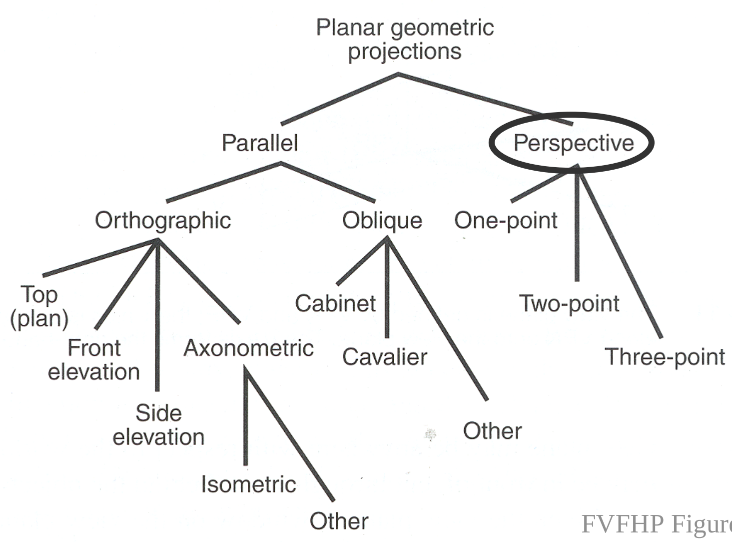
Parallel Projection Matrix

- General parallel projection transformation:



$$\begin{bmatrix} x_s \\ y_s \\ z_s \\ w_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & L_1 \cos\phi & 0 \\ 0 & 1 & L_1 \sin\phi & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}$$

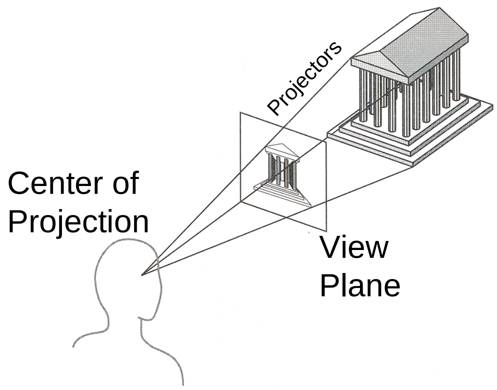
Taxonomy of Projections



FVFHP Figure 6.10

Perspective Projection

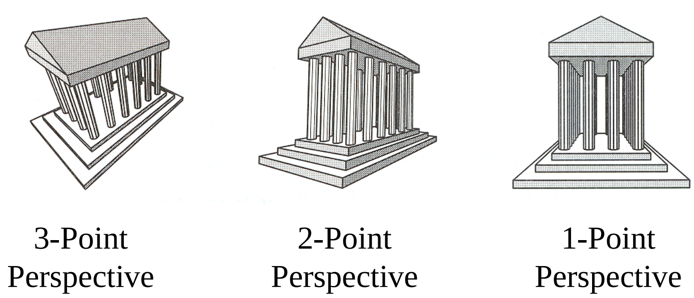
- Map points onto “view plane” along “projectors” emanating from “center of projection” (COP)



Angel Figure 5.9

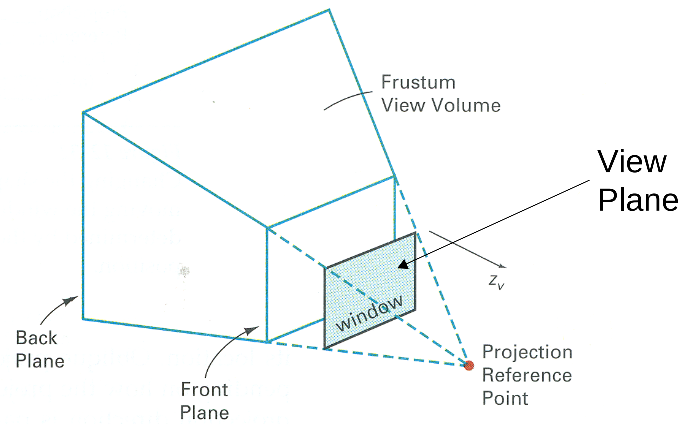
Perspective Projection

- How many vanishing points?



Angel Figure 5.10

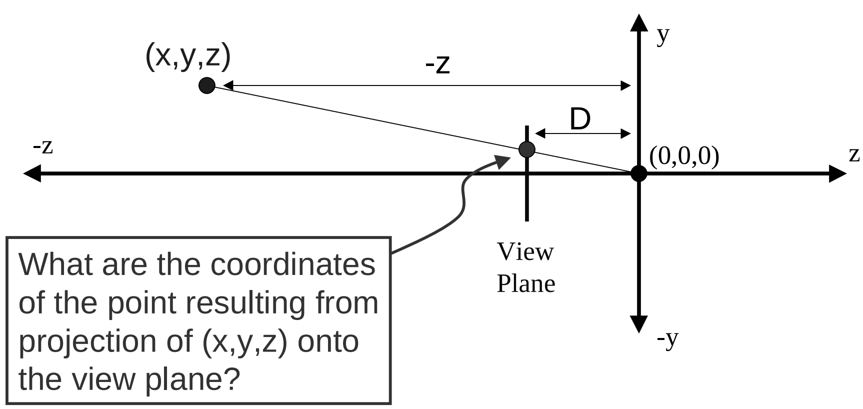
Perspective Projection View Volume



H&B Figure 12.30

Perspective Projection

- Compute 2D coordinates from 3D coordinates with similar triangles



Perspective Projection

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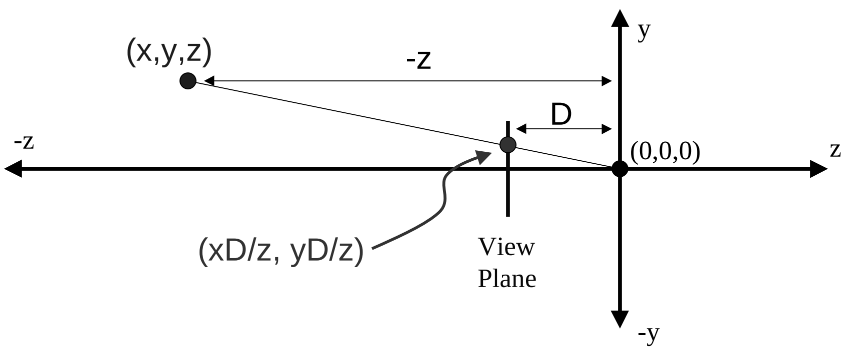


Perspective Projection Matrix

- 4x4 matrix representation?

$$x_s = x_c D / z_c$$
$$y_s = y_c D / z_c$$
$$z_s = D$$
$$w_s = 1$$

$$\begin{bmatrix} x_s \\ y_s \\ z_s \\ w_s \end{bmatrix} = \begin{bmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}$$

Perspective Projection Matrix

- 4x4 matrix representation?

$$x_s = x_c D / z_c$$
$$y_s = y_c D / z_c$$
$$z_s = D$$
$$w_s = 1$$

$$x' = x_c$$
$$y' = y_c$$
$$z' = z_c$$
$$w' = z_c / D$$

$$\begin{bmatrix} x_s \\ y_s \\ z_s \\ w_s \end{bmatrix} = \begin{bmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}$$

Perspective Projection Matrix

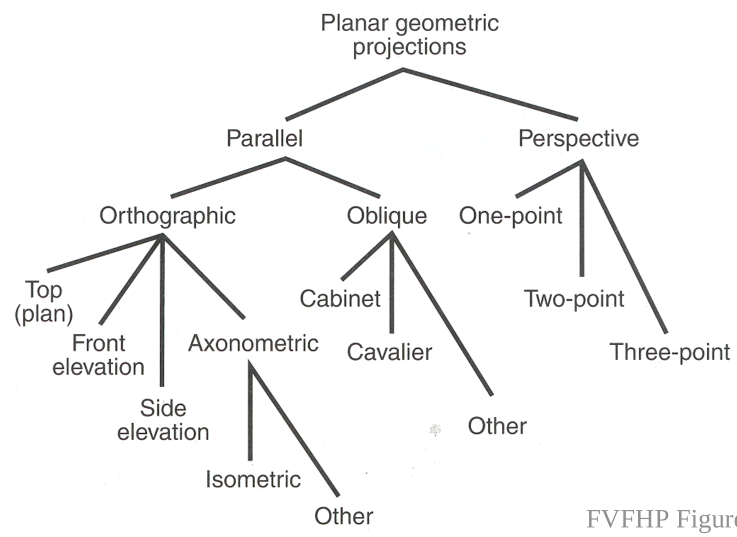
- 4x4 matrix representation?

$$x_s = x_c D / z_c$$
$$y_s = y_c D / z_c$$
$$z_s = D$$
$$w_s = 1$$

$$x' = x_c$$
$$y' = y_c$$
$$z' = z_c$$
$$w' = z_c / D$$

$$\begin{bmatrix} x_s \\ y_s \\ z_s \\ w_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1/D & 0 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}$$

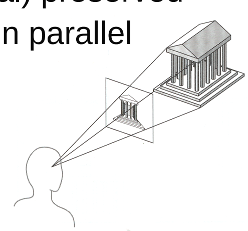
Taxonomy of Projections



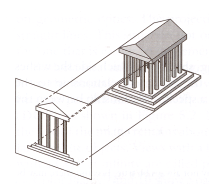
FVFHP Figure 6.10

Perspective vs. Parallel

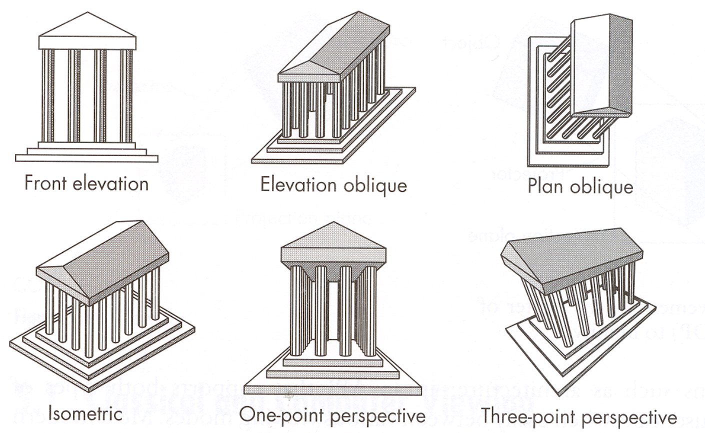
- Perspective projection
  - \+ Size varies inversely with distance - looks realistic
  - – Distance and angles are not (in general) preserved
  - – Parallel lines do not (in general) remain parallel



- Parallel projection
  - \+ Good for exact measurements
  - \+ Parallel lines remain parallel
  - – Angles are not (in general) preserved
  - – Less realistic looking



Classical Projections



Angel Figure 5.3

Summary

- Camera transformation
  - Map 3D world coordinates to 3D camera coordinates
  - Matrix has camera vectors as rows
- Projection transformation
  - Map 3D camera coordinates to 2D screen coordinates
  - Two types of projections:
    - » Parallel
    - » Perspective

Next Time

3D Geometric Primitives

Modeling Transformation	Transform into 3D world coordinate system
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Image