3D Polygon Rendering Pipeline

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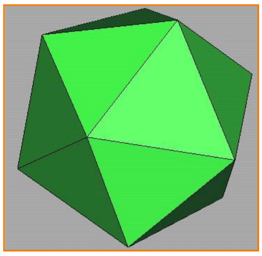
3D Polygon Rendering

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



3D Polygon Rendering

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

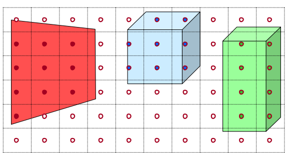
Quake II
(Id Software)

3D Polygon Rendering

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

Ray Casting Revisited

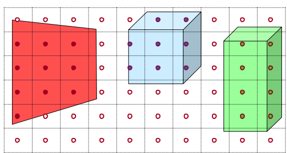
- For each sample …
  - Construct ray from eye position through view plane
  - Find first surface intersected by ray through pixel
  - Compute color of sample based on surface radiance



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 (direct illumination)

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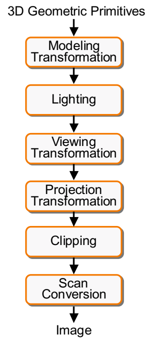

This is a pipelined sequence of operations to draw a 3D primitive into a 2D image

Example: OpenGL

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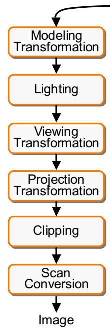


```
glBegin(GL_POLYGON);
glVertex3f(0.0, 0.0, 0.0);
glVertex3f(1.0, 0.0, 0.0);
glVertex3f(1.0, 1.0, 1.0);
glVertex3f(0.0, 1.0, 1.0);
glEnd();
```

OpenGL executes steps of 3D rendering pipeline for each polygon

3D Rendering Pipeline (for direct illumination)

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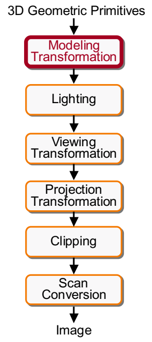

Transform into 3D world coordinate system

3D Rendering Pipeline (for direct illumination)

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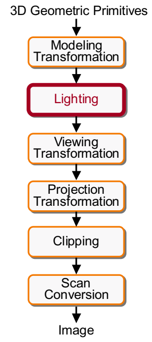

Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

3D Rendering Pipeline (for direct illumination)

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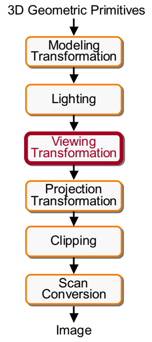

Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

3D Rendering Pipeline (for direct illumination)

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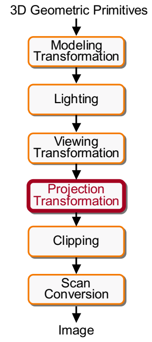

Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

Transform into 2D camera coordinate system

3D Rendering Pipeline (for direct illumination)

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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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3D Geometric Primitives
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- Modeling Transformation — Transform into 3D world coordinate system
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- Clipping — Clip primitives outside camera's view
- **Scan Conversion** — **Draw pixels (includes texturing, hidden surface, ...)**

↓
Image

Transformations

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3D Geometric Primitives
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- Modeling Transformation — **Transform** into 3D world coordinate system
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↓
Image

Transformations

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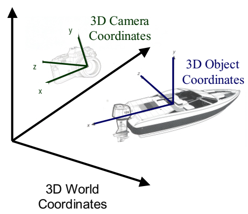
p(x,y,z)
↓ 3D Object Coordinates
Modeling Transformation
↓ 3D World Coordinates
Viewing Transformation
↓ 3D Camera Coordinates
Projection Transformation
↓ 2D Screen Coordinates
Window-to-Viewport Transformation
↓ 2D Image Coordinates
p'(x',y')

Transformations map points from one coordinate system to another



Viewing Transformations

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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

Camera Coordinates

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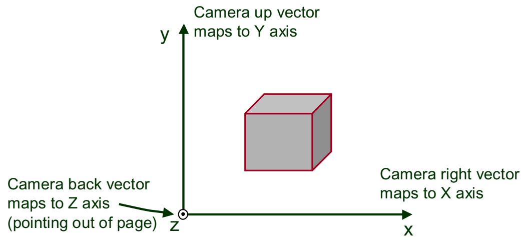
- Canonical coordinate system
  - o Convention is right-handed (looking down -z axis)
  - o Convenient for projection, clipping, etc.



Viewing Transformation

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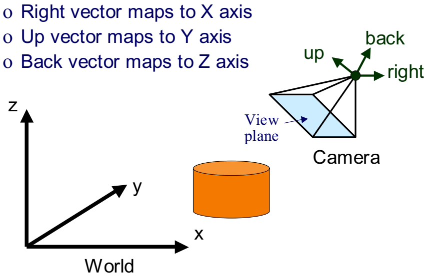
- Mapping from world to camera coordinates
  - o Eye position maps to origin
  - o Right vector maps to X axis
  - o Up vector maps to Y axis
  - o Back vector maps to Z axis



Finding the viewing transformation

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- We have the camera (in world coordinates)
- We want T taking objects from world to camera

$$p^C = T\ p^W$$

- Trick: find T^{-1} taking objects in camera to world

$$p^W = T^{-1} p^C$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

?

Finding the Viewing Transformation

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- Trick: map from camera coordinates to world
  - o Origin maps to eye position
  - o Z axis maps to Back vector
  - o Y axis maps to Up vector
  - o X axis maps to Right vector

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} R_x & U_x & B_x & E_x \\ R_y & U_y & B_y & E_y \\ R_z & U_z & B_z & E_z \\ R_w & U_w & B_w & E_w \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

- This matrix is T^{-1} so we invert it to get T … easy!

Viewing Transformations

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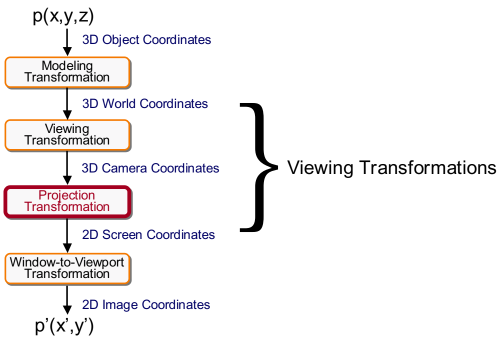

Projection

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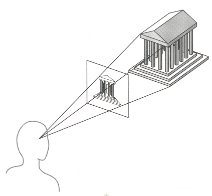
- General definition:
  - o Transform points in *n*-space to *m*-space (*m*<*n*)
- In computer graphics:
  - o Map 3D camera coordinates to 2D screen coordinates



Taxonomy of Projections

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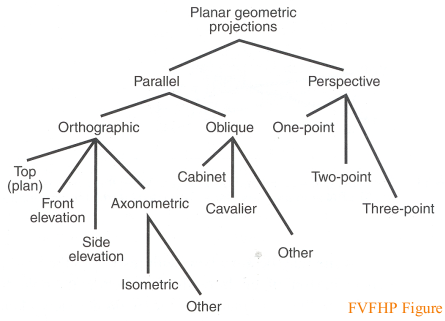
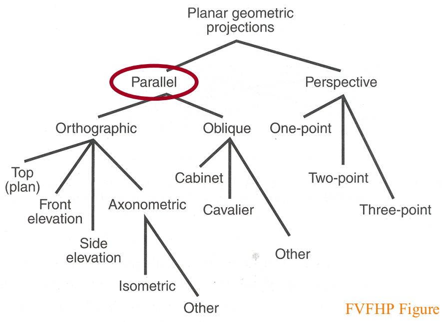


FVFHP Figure 6.10

Taxonomy of Projections

25



FVFHP Figure 6.10

Parallel Projection

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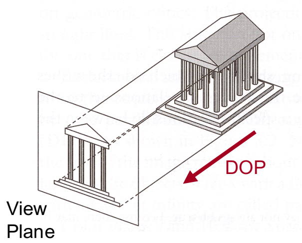
- Center of projection is at infinity
  - o Direction of projection (DOP) same for all points



Angel Figure 5.4

Orthographic Projections

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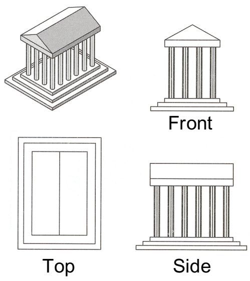
- DOP perpendicular to view plane



Angel Figure 5.5

Oblique Projections

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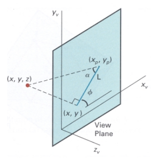
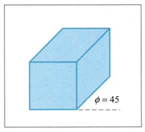
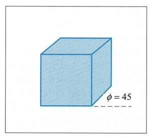
- DOP not perpendicular to view plane





Cavalier
(DOP $\alpha = 45^{\circ}$)



Cabinet
(DOP $\alpha = 63.4^{\circ}$)

H&B Figure 12.24

Parallel Projection View Volume

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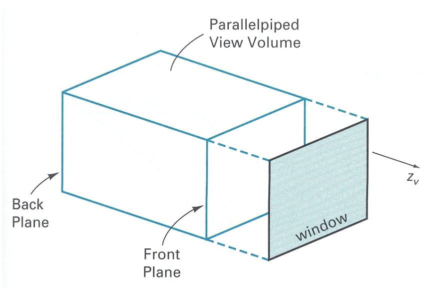

H&B Figure 12.30

Parallel Projection Matrix

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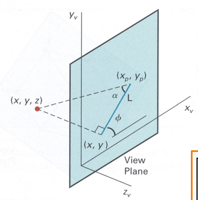
- General parallel projection transformation:



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

Taxonomy of Projections

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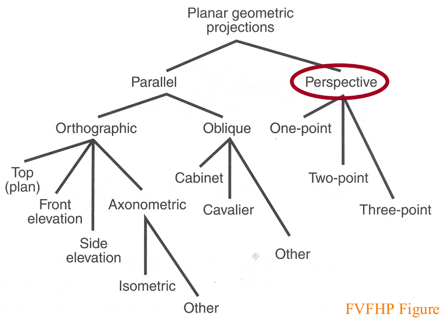

FVFHP Figure 6.10

Perspective Projection

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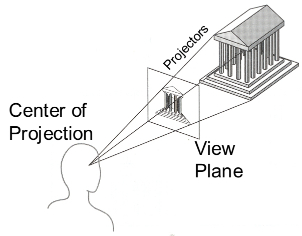
- Map points onto “view plane” along “projectors” emanating from “center of projection” (COP)



Angel Figure 5.9

Perspective Projection

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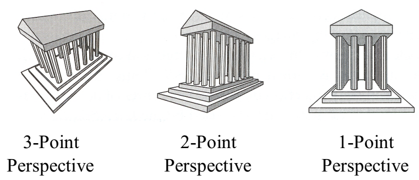
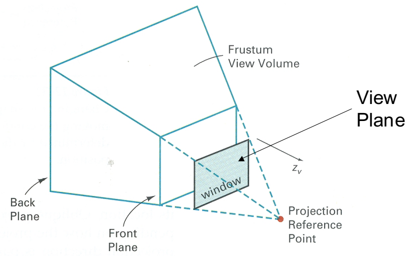
- How many vanishing points?



Angel Figure 5.10

Perspective Projection View Volume

34

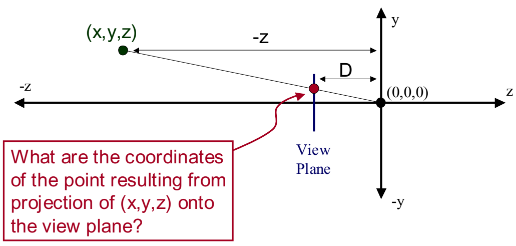


H&B Figure 12.30

Perspective Projection

35

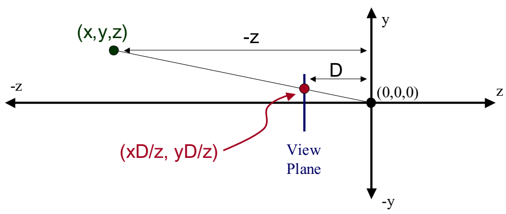
- Compute 2D coordinates from 3D coordinates with similar triangles



Perspective Projection

36

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



Perspective Projection Matrix
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- 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
38

- 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
39

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

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

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

Taxonomy of Projections
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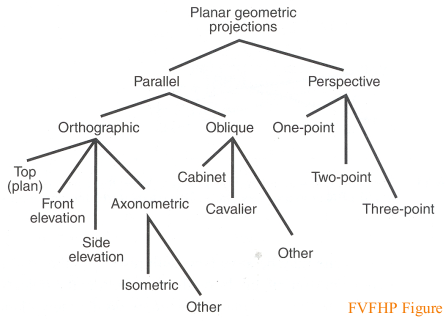

FVFHP Figure 6.10

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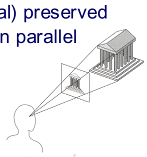
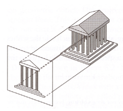
- Perspective projection
  - \+ Size varies inversely with distance - looks realistic
  - – Distance and angles are not (in general) preserved
  - – Parallel lines do not (in general) remain parallel



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



Classical Projections
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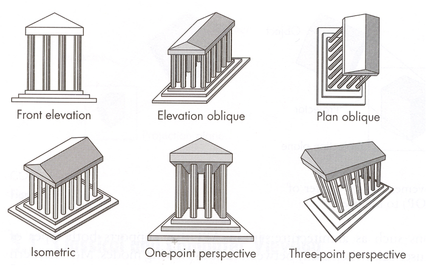

Angel Figure 5.3

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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

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What's next?

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
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Clipping	Clip primitives outside camera's view
Scan Conversion	Draw pixels (includes texturing, hidden surface, etc.)

Image