



מה במצגת

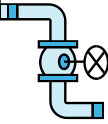
- Overview
- The 3D rendering pipeline
- Transformations

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קורס גרפיקה ממוחשבת

2008 סמסטר ב'
ליאור שפירא

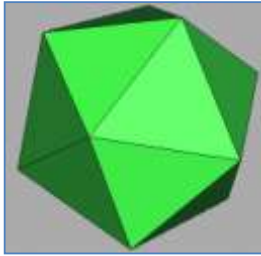
3D Polygon Rendering Pipeline



חלק מהשקפים מעדכמים משקפים של פרדו דוראנד, טומס פנקהאוסר ודניאל כהן-אור

3D Polygon Rendering

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



Rendering Scenarios



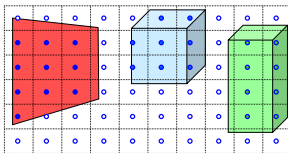
- אצווה (batch)
 - כל תמונה מיוצרת ברמת פירוט גבוהה ככל האפשר עבור סט ספציפי של פרמטרים
 - לוקח כמה זמן שצריך
 - שימושי לפטוריאליזם, סרטים וכו'
- אינטראקטיבי
 - מייצרים תמונות בשבריר שנייה (לפחות 10 בשנייה) כאשר המשתמש שולט בפרמטרים של הרינדור
 - יש צורך להשיג את האיכות הגבוהה ביותר בהתחשב בזמן הנתון (הקצב הנדרש)
 - שימושי לויזואליזציות, משחקים וכו'



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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!

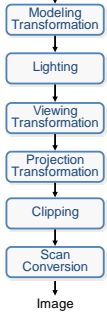
3D Polygon Rendering

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



3D Rendering Pipeline (for direct illumination)

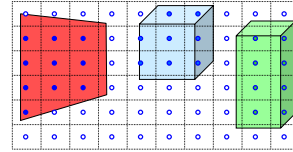
3D Geometric Primitives



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

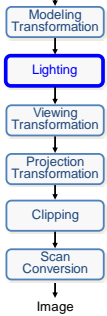
3D Polygon Rendering

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



3D Rendering Pipeline (for direct illumination)

3D Geometric Primitives

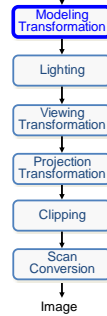


Transform into 3D world coordinate system

Illuminate according to lighting and reflectance

3D Rendering Pipeline (for direct illumination)

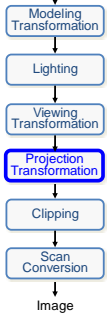
3D Geometric Primitives



Transform into 3D world coordinate system

3D Rendering Pipeline (for direct illumination)

3D Geometric Primitives



Transform into 3D world coordinate system

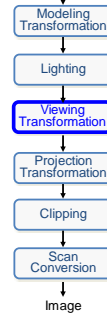
Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

Transform into 2D camera coordinate system

3D Rendering Pipeline (for direct illumination)

3D Geometric Primitives

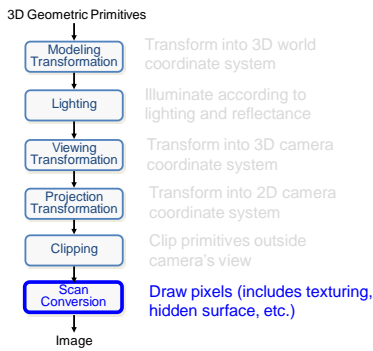


Transform into 3D world coordinate system

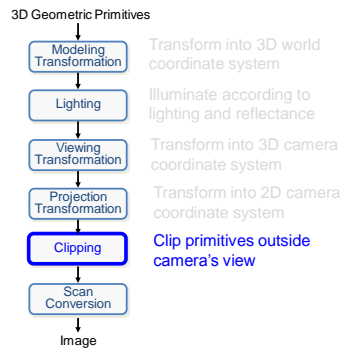
Illuminate according to lighting and reflectance

Transform into 3D camera coordinate system

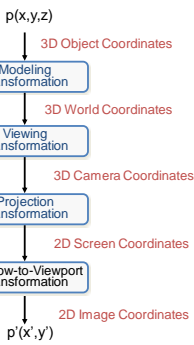
3D Rendering Pipeline (for direct illumination)



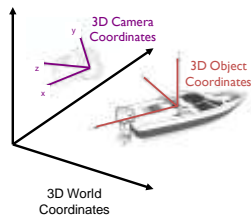
3D Rendering Pipeline (for direct illumination)



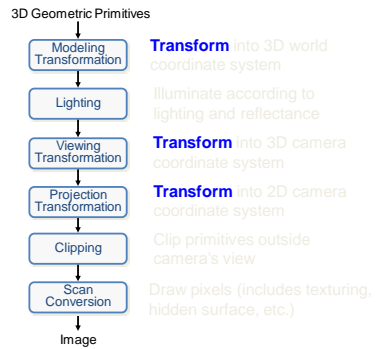
Transformations



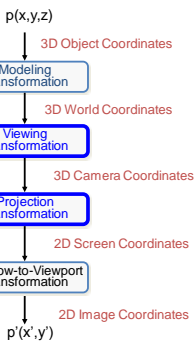
Transformations map points from one coordinate system to another



Transformations



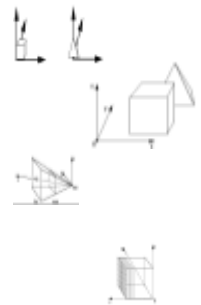
Viewing Transformations



Viewing Transformations

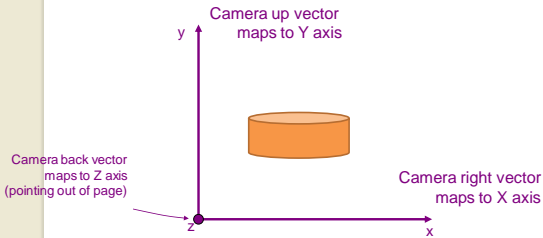
Coordinate systems

- Object space
 - local to each object
- World space
 - common to all objects
- Eye space / Camera space
 - derived from view frustum
- Screen space
 - indexed according to hardware attributes



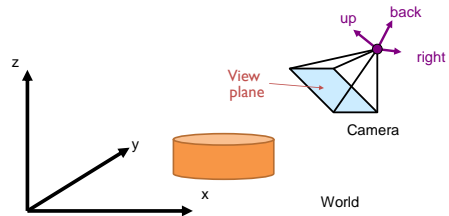
Camera Coordinates

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



Viewing Transformation

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



Finding viewing transformation

- Trick: map from camera coordinates to world
 - Origin → eye position
 - Z axis → back vector
 - Y axis → up vector
 - X axis → right vector

Invert to get T. Easy!

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

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Finding viewing transformation

- We have the camera (world coordinates)
- We want a transformation **T** taking objects from world to camera

$$p^c = T p^w$$

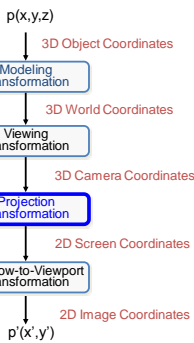
- Trick: find **T⁻¹** taking objects in camera to world

$$p^w = T^{-1} p^c$$

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

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Viewing Transformations



Viewing Transformations

Finding viewing transformation

- Lets give it a try...

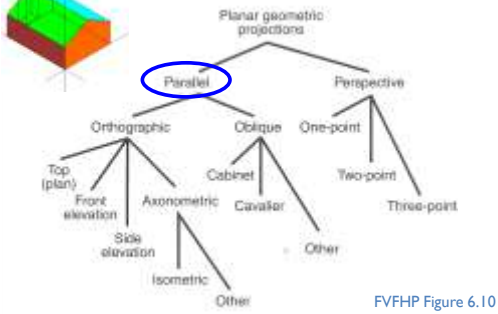
$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} R_x & U_x & B_x & E_x \\ R_y & U_y & B_y & E_y \\ R_z & U_z & B_z & E_z \\ R_w & U_w & B_w & E_w \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

$$\begin{bmatrix} E_x \\ E_y \\ E_z \\ E_w \end{bmatrix} = \begin{bmatrix} R_x & U_x & B_x & E_x & 0 \\ R_y & U_y & B_y & E_y & 0 \\ R_z & U_z & B_z & E_z & 0 \\ R_w & U_w & B_w & E_w & 1 \end{bmatrix} \begin{bmatrix} R_x + E_x \\ R_y + E_y \\ R_z + E_z \\ R_w + E_w \end{bmatrix} = \begin{bmatrix} R_x & U_x & B_x & E_x & 1 \\ R_y & U_y & B_y & E_y & 0 \\ R_z & U_z & B_z & E_z & 0 \\ R_w & U_w & B_w & E_w & 1 \end{bmatrix}$$

עובר לנק' העין, הצירים עוברים לקוטרים המגדירים את מרכזת הצירים של המצלמה

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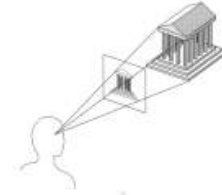
Taxonomy of Projections



FVFHP Figure 6.10

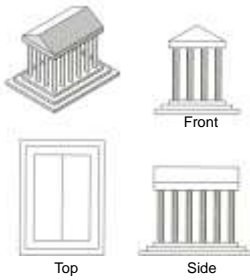
Projection

- General definition:
 - Transform points in n -space to m -space ($m < n$)
- In computer graphics:
 - Map 3D camera coordinates to 2D screen coordinates
 - Projection is formed by the intersection of certain lines with the view plane



Orthographic Projections

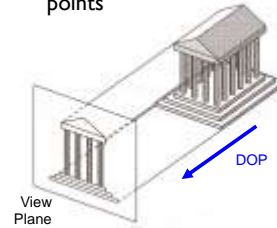
- DOP perpendicular to view plane



Angel Figure 5.5

Parallel Projection

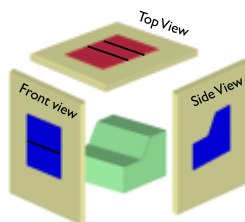
- Center of projection is at infinity
 - Direction of projection (DOP) same for all points



Angel Figure 5.4

Orthographic Projections

- Lengths and angles of faces parallel to the viewing planes are preserved.
- **Problem:** 3D nature of projected objects is difficult to deduce.

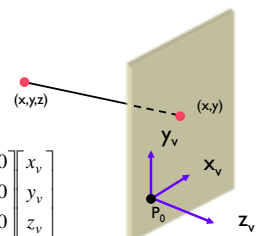


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Orthographic Projections

- Since the viewing plane is aligned with (x_v, y_v) , orthographic projection is performed by:

$$\begin{bmatrix} x_p \\ y_p \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} x_v \\ y_v \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix}$$

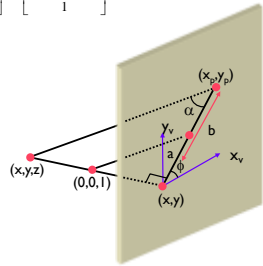


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Oblique Projections

$$\begin{bmatrix} x_p \\ y_p \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & a \cos \phi & 0 \\ 0 & 1 & a \sin \phi & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = \begin{bmatrix} x_v + z_v a \cos \phi \\ y_v + z_v a \sin \phi \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{aligned} l/a &= \tan(\alpha) \\ z/b &= 1/a \\ b &= za \\ x_p &= z \cdot a \cdot \cos(\phi) \\ y_p &= z \cdot a \cdot \sin(\phi) \end{aligned}$$



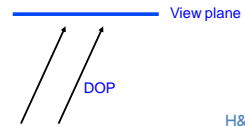
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Oblique Projections

- DOP **not** perpendicular to view plane

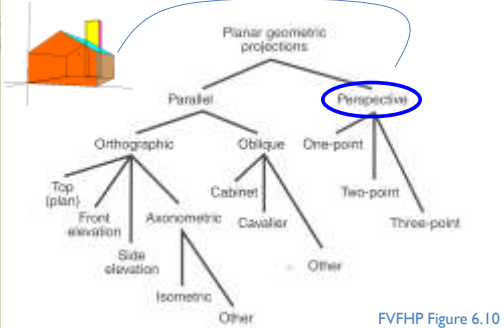


Cavalier (DOP at 45°) Cabinet (DOP at 63.4°)



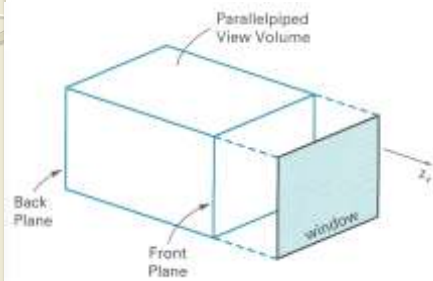
H&B Figure 12.24

Taxonomy of Projections



FVFHP Figure 6.10

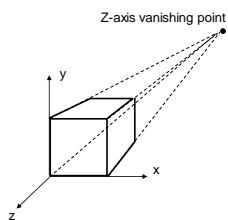
Parallel Projection View Volume



H&B Figure 12.30

Perspective Projection

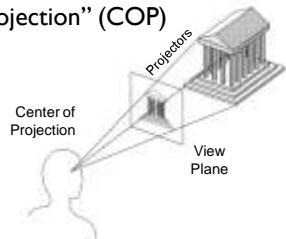
- Vanishing points → The projection of a point at infinity
- There can be up to 3 axis vanishing points



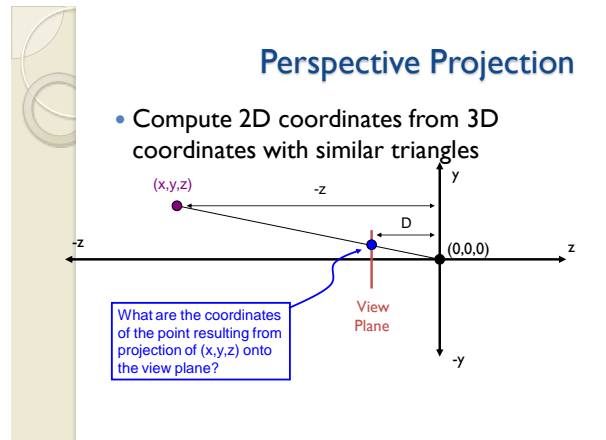
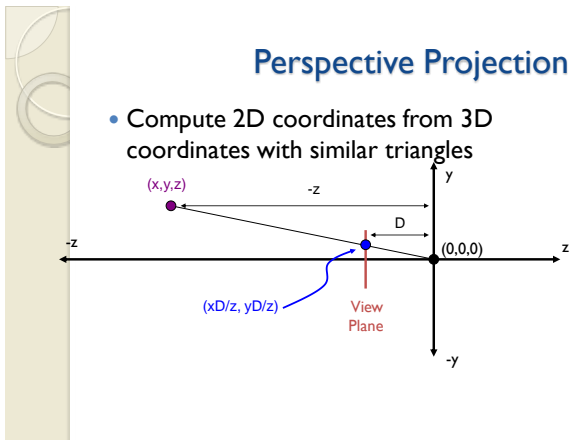
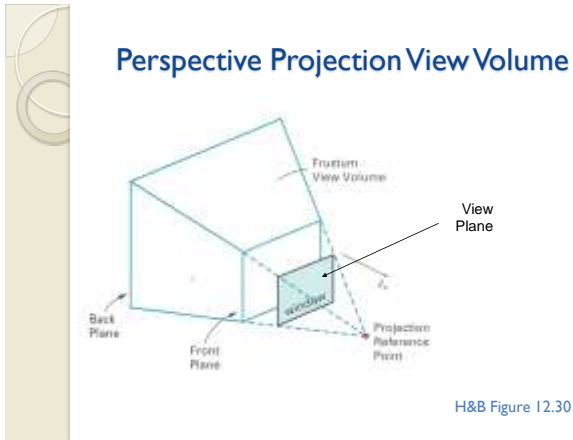
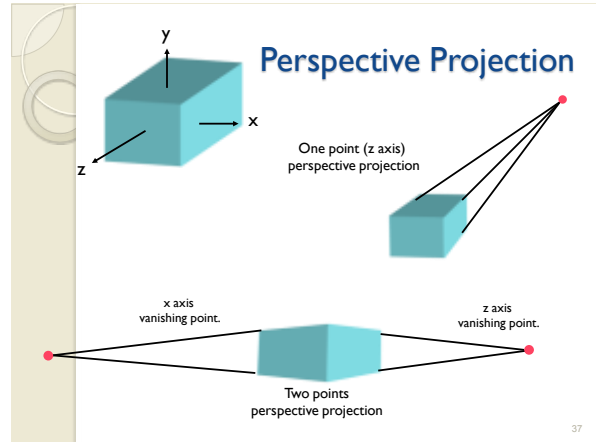
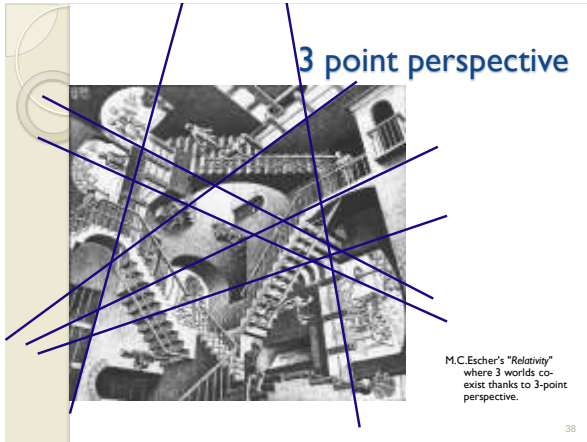
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Perspective Projection

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



Angel Figure 5.9



Perspective Projection Matrix

- 4x4 matrix representation?

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

$$\begin{aligned}x' &= x_c \\y' &= y_c \\z' &= z_c \\w' &= z_c / D\end{aligned}$$

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

Perspective Projection Matrix

- 4x4 matrix representation?

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

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

Perspective Projections

- Some observations
 - The matrix representation is singular, therefore a many to one mapping
 - Points on the viewing plane do not change
 - When d goes to infinity, we get an orthogonal projection

Perspective Projection Matrix

- 4x4 matrix representation?

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

$$\begin{aligned}x' &= x_c \\y' &= y_c \\z' &= z_c \\w' &= z_c / D\end{aligned}$$

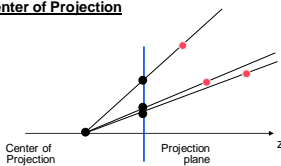
$$\begin{bmatrix} x_s \\ y_s \\ z_s \\ w_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1/D & 0 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}$$

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Changing Perspective

What is the difference between moving the center of projection and moving the projection plane?

Moving the Center of Projection

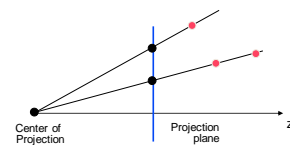


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Changing Perspective

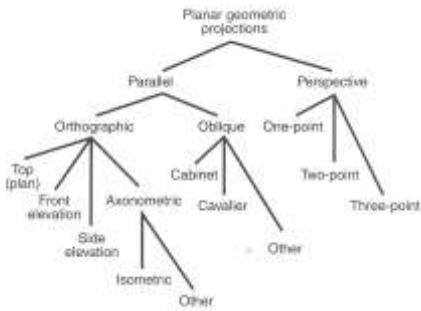
What is the difference between moving the center of projection and moving the projection plane?

Original



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Taxonomy of Projections

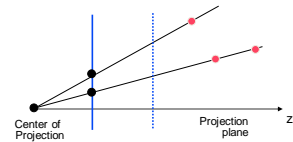


10

Changing Perspective

What is the difference between moving the center of projection and moving the projection plane?

Moving the Projection Plane



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Perspective vs. Parallel



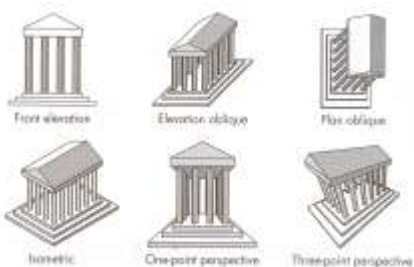
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Perspective vs. Parallel

- 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

Perspective vs. Parallel



Parallel



Perspective

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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