Understanding Z
- z axis flip changes coord system handedness
- RHS before projection (eye/view coords)
- LHS after projection (clip, norm device coords)

Perspective Projection
- expressible with 4x4 homogeneous matrix
- use previously untouched bottom row
- perspective projection is irreversible
- many 3D points can be mapped to same (x, y, d) on the projection plane
- no way to retrieve the unique z values

Perspective to Orthographic
- transformation of space
- center of projection moves to infinity
- view volume transformed
- from frustum (truncated pyramid) to parallelepiped (box)

View Volumes
- specifies field-of-view, used for clipping
- restricts domain of z stored for visibility test

Why Canonical View Volumes?
- permits standardization
- clipping
- easier to determine if an arbitrary point is enclosed in volume with canonical view volume vs. clipping to six arbitrary planes
- rendering
- projection and rasterization algorithms can be reused

Canonical View Volumes
- standardized viewing volume representation
- perspective
- orthographic orthogonal parallel

Orthographic Camera Projection
- camera's back plane parallel to lens
- infinite focal length
- no perspective convergence
- just throw away z values

Orthographic Derivation
- scale, translate, reflect for new coord sys

-normalized device coordinates
- convention
- viewing frustum mapped to specific parallelepiped
- Normalized Device Coordinates (NDC)
- same as clipping coords
- only objects inside the parallelepiped get rendered
- which parallelepiped?
- depends on rendering system

Review: Basic Perspective Projection
- similar triangles
- perspective projection is irreversible
- expresses with 4x4 homogeneous matrix
- use previously untouched bottom row
- many 3D points can be mapped to same (x, y, d) on the projection plane
- no way to retrieve the unique z values

Moving COP to Infinity
- as COP moves away, lines approach parallel
- when COP at infinity, orthographic view

Normalized Device Coordinates
- convention
- viewing frustum mapped to specific parallelepiped
- Normalized Device Coordinates (NDC)
- same as clipping coords
- only objects inside the parallelepiped get rendered
- which parallelepiped?
- depends on rendering system

Review: Graphics Cameras
- real pinhole camera: image inverted
- computer graphics camera: convenient equivalent
Orthographic Derivation
- scale, translate, reflect for new coord sys
  \[ y' = a \cdot y + b \]
  \[ y = \text{top} \rightarrow y' = 1 \]
  \[ y = \text{bot} \rightarrow y' = -1 \]

\[ P = \begin{bmatrix}
p_{\text{right-left}} & 0 & 0 & \text{right-left} \\
p_{\text{top-bot}} & 0 & \text{top-bot} & 0 \\
p_{\text{far-near}} & 0 & \text{far-near} & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix} \]

Brown applets: viewing techniques
- parallel/orthographic cameras
- projection cameras

http://www.cs.brown.edu/exploratories/freeSoftware/catalogs/viewing_techniques.html

Demo

Orthographic OpenGl
- \text{glMatrixMode(GL_PROJECTION);}
- \text{glLoadIdentity();}
- \text{glOrtho(left, right, bot, top, near, far);}
**Demos**
- Tuebingen applets from Frank Hanisch
  - [http://www.gis.uni-tuebingen.de/projects/grdev/doc/html/etc/AppletIndex.html](http://www.gis.uni-tuebingen.de/projects/grdev/doc/html/etc/AppletIndex.html)

**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
- 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

**Perspective Normalization**
- Perspective viewing frustum transformed to orthographic frustum.
- All scenes rendered with orthographic projection.
- Aka perspective warp.

**Projection Normalization**
- Warp perspective view volume to orthogonal view volume.
- Render all scenes with orthographic projection.

**Predistortion**
- Specific example:
  - Assume image plane at $z = -1$
  - A point $[x, y, z, l]^T$ projects to $[wx/z, y/z, -z/l]^T = [x, y, z]^T$.

**Separate Warp From Homogenization**
- Warp requires only standard matrix multiply.
- Distort such that orthographic projection of distorted objects is desired perspective projection.
- $w$ is changed.
- Clip after warp, before divide.
- Division by $w$: homogenization.

**Perspective Divide Example**
- Matrix formulation:
  - Warp and homogenization both preserve relative depth (z coordinate).

**Demo**
- Brown applets: viewing techniques
  - Parallel/orthographic cameras
  - Projection cameras