Viewing

CMSC 435/634

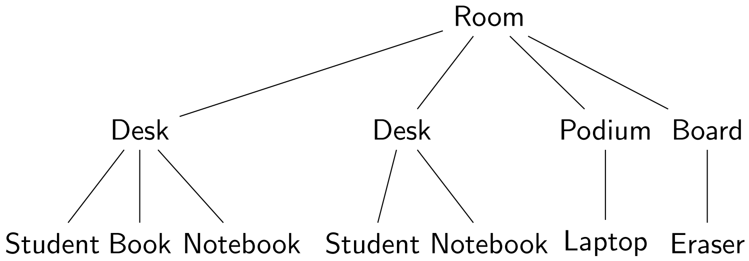
Coordinate System / Space

- Origin + Axes
- Reference frame
- Convert by matrix
  - $\vec{p}_{table} = TableFromPencil\ \vec{p}_{pencil}$
  - $\vec{p}_{room} = RoomFromTable\ TableFromPencil\ \vec{p}_{pencil}$
  - $\vec{p}_{room} = RoomFromPencil\ \vec{p}_{pencil}$

Spaces

- Object / Model
  - Logical coordinates for modeling
  - May have several more levels
- World
  - Common coordinates for everything
- View / Camera / Eye
  - eye/camera at (0,0,0), looking down Z (or -Z) axis
  - planes: left, right, top, bottom, near/hither, far/yon
- Normalized Device Coordinates (NDC) / Clip
  - Visible portion of scene from (-1,-1,-1) to (1,1,1)
  - Sometimes one or more components 0 to 1 instead of -1 to 1
- Raster / Pixel / Viewport
  - 0,0 to x-resolution, y-resolution
- Device / Screen
  - May translate to fit actual screen

Nesting


Room
Desk
Desk
Podium
Board
Student
Book
Notebook
Student
Notebook
Laptop
Eraser

Matrix Stack

- Remember transformation, return to it later
- Push a copy, modify the copy, pop
- Keep matrix and update matrix and inverse
- Push and pop both matrix and inverse together

```
transform(WorldFromRoom);
push;
transform(RoomFromDesk);
push;
transform(DeskFromStudent);
pop;  push;
transform(DeskFromBook);
...
```

Model→World / Model→View

- Model→World
  - All shading and rendering in World space
  - Transform all objects and lights
- Ray tracing implicitly does World→Raster
- Model→View
  - Serves just as well for single view

World→View

- Also called Viewing or Camera transform
- LookAt
  - $\overrightarrow{from}, \overrightarrow{to}, \overrightarrow{up}$
  - $\left[\begin{array}{c|c|c|c} \vec{u} & \vec{v} & \vec{w} & \overrightarrow{from} \end{array}\right]$
- Roll / Pitch / Yaw
  - Translate to camera center, rotate around camera
  - $R_z \; R_x \; R_y \; T$
  - Can have gimbal lock
- Orbit
  - Rotate around object center, translate out
  - $T \; R_z \; R_x \; R_y$
  - Also can have gimbal lock

View→NDC

- Also called *Projection* transform
- Orthographic / Parallel
  - Translate & Scale to view volume
  - $$\begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
- Perspective
  - More complicated...

NDC$\rightarrow$Raster

- Also called *Viewport* transform
- $[-1,1],[-1,1],[-1,1] \rightarrow [-\frac{1}{2}, n_x-\frac{1}{2}],[-\frac{1}{2}, n_y-\frac{1}{2}],[-\frac{1}{2}, n_z-\frac{1}{2}]$
  - Translate to $[0,2],[0,2],[0,2]$
  - Scale to $[0, n_x],[0, n_y],[0, n_z]$
  - Translate to $[-\frac{1}{2}, n_x - \frac{1}{2}],[-\frac{1}{2}, n_y - \frac{1}{2}],[-\frac{1}{2}, n_z - \frac{1}{2}]$

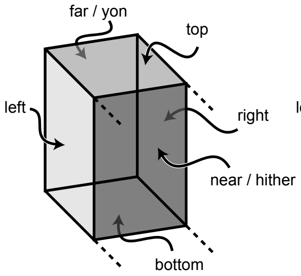
$$\begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y-1}{2} \\ 0 & 0 & \frac{n_z}{2} & \frac{n_z-1}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

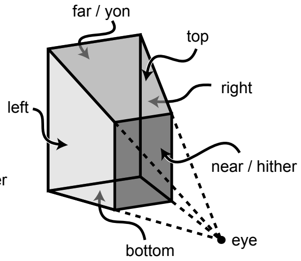
Raster→Screen

- Usually just a translation
  - More complicated for tiled displays, domes, etc.
- Usually handled by windowing system

Perspective View Frustum

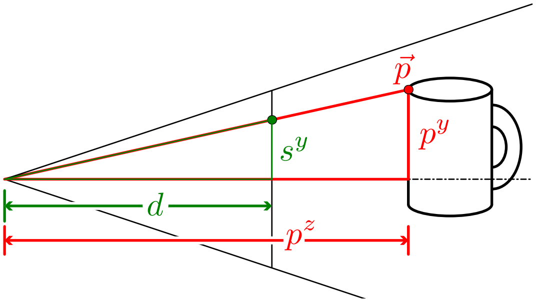
- Orthographic view volume is a rectangular volume
- Perspective is a truncated pyramid or *frustum*





Perspective Transform

- Ray tracing
  - Given screen (s_x, s_y), parameterize all points $\vec{p}$
- Perspective Transform
  - Given $\vec{p}$, find (s_x, s_y)
  - Use similar triangles
  - $s_y/d = p_y/p_z$ So $s_y = dp_y/p_z$



Homogeneous Equations

- Same total degree for every term
- Introduce a new redundant variable
- $a\,X + b\,Y + c = 0$
  - $X = x/w$, $Y = y/w$
  - $a\,x/w + b\,y/w + c = 0$
  - $\rightarrow a\,x + b\,y + c\,w = 0$
- $a\,X^2 + b\,X\,Y + c\,Y^2 + d\,X + e\,Y + f = 0$
  - $X = x/w$, $Y = y/w$
  - $a\,x^2/w^2 + b\,x\,y/w^2 + c\,y^2/w_2 + d\,x/w + e\,y/w + f = 0$
  - $\rightarrow a\,x^2 + b\,x\,y + c\,y^2 + d\,x\,w + e\,y\,w + f\,w^2 = 0$

Homogeneous Coordinates

- Rather than $(x, y, z, 1)$, use (x, y, z, w)
- Real 3D point is $(X, Y, Z) = (x/w, y/w, z/w)$
- Can represent Perspective Transform as 4x4 matrix

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1/d & 0 \end{bmatrix} \begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} p_x \\ p_y \\ p_z \\ p_z/d \end{bmatrix} \rightarrow \begin{bmatrix} d\, p_x/p_z \\ d\, p_y/p_z \\ d \end{bmatrix}$$

Homogeneous Depth

$$\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 1/d & 0\end{bmatrix}\begin{bmatrix}p_x\\ p_y\\ p_z\\ 1\end{bmatrix} = \begin{bmatrix}p_x\\ p_y\\ p_z\\ p_z/d\end{bmatrix} \rightarrow \begin{bmatrix}d\,p_x/p_z\\ d\,p_y/p_z\\ d\end{bmatrix}$$

- Lose depth information
- Can't get $d\,p'_z/p_z = p_z$
  - Plus $x/z, y/z, z$ isn't linear
- Use *Projective Geometry*

Projective Geometry

- If x, y, z lie on a plane, $x/z, y/z, 1/z$ also lie on a plane
- $1/z$ is strictly ordered: if $z_1 < z_2$, then $1/z_1 > 1/z_2$
- New matrix:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} p_x \\ p_y \\ 1 \\ p_z \end{bmatrix} \rightarrow \begin{bmatrix} p_x/p_z \\ p_y/p_z \\ 1/p_z \end{bmatrix}$$

Getting Fancy

- Add scale & translate
  - Field of view
  - near/far range

$$\begin{bmatrix} a & 0 & 0 & 0 \\ 0 & a & 0 & 0 \\ 0 & 0 & b & c \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} a\,p_x \\ a\,p_y \\ b\,p_z + c \\ -p_z \end{bmatrix} \rightarrow \begin{bmatrix} -a\,p_x/p_z \\ -a\,p_y/p_z \\ -b - c/p_z \end{bmatrix}$$

- $a = cotan(fieldOfView/2)$
- Solve for $n \rightarrow -1$ and $f \rightarrow 1$
  - $b = (n + f)/(n - f)$
  - $c = (2\,n\,f)/(f - n)$

On Field of View

- Given image dimensions, set distance
  - Camera image sensor and focal length
- Given field of view angle in square window
- Non-square aspect ratio
  - Given horizontal (or vertical) field of view
  - Given diagonal field of view
- Off-center projection
  - Tiled displays
  - Head tracking