

Computer Graphics

CSE 167 [Win 23], Lecture 5: Viewing

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<http://viscomp.ucsd.edu/classes/cse167/wi23>

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To Do

- Questions/concerns about assignment 1?
- Remember it is due Friday! (Jan 27).
- Ask me or TAs re problems

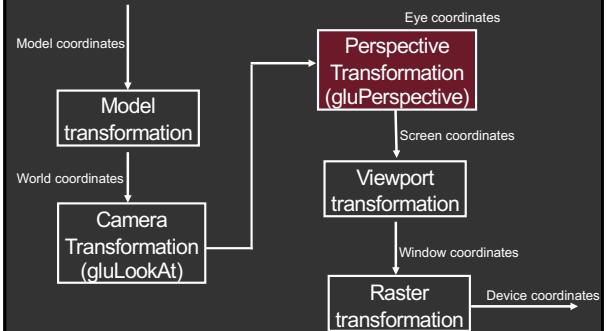
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Motivation

- We have seen transforms (between coord systems)
- But all that is in 3D
- We still need to make a 2D picture
- Project 3D to 2D. How do we do this?
- This lecture is about viewing transformations

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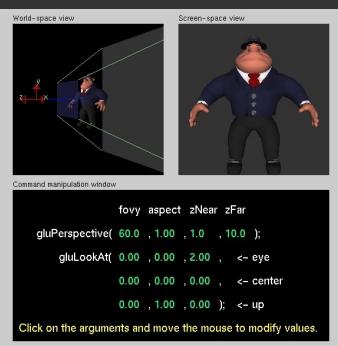
Summary: The Whole Viewing Pipeline



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Demo (Projection Tutorial)

- Nate Robbins OpenGL tutors
- Projection tutorial
- Download others



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What we've seen so far

- Transforms (translation, rotation, scale) as 4x4 homogeneous matrices
- Last row always 0 0 0 1. Last w component always 1
- For viewing (perspective), we will use that last row and w component no longer 1 (must divide by it)

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Outline

- Orthographic projection (*simpler*)
- Perspective projection, basic idea
- Derivation of gluPerspective (handout: glFrustum)
- Brief discussion of nonlinear mapping in z

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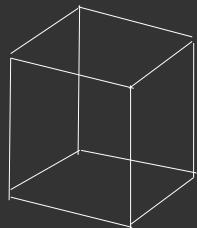
Projections

- To lower dimensional space (here 3D \rightarrow 2D)
- Preserve straight lines
- Trivial example: Drop one coordinate (Orthographic)

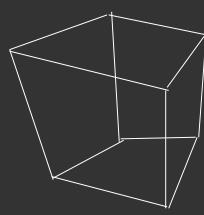
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Orthographic Projection

- Characteristic: Parallel lines remain parallel
- Useful for technical drawings etc.



Orthographic

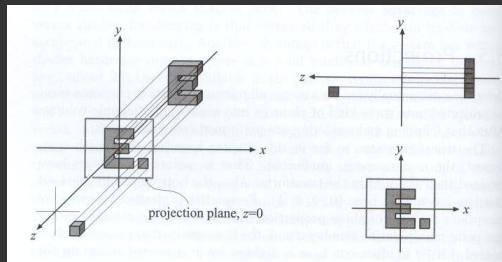


Perspective

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Example

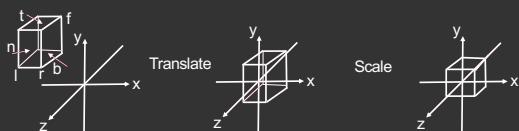
- Simply project onto xy plane, drop z coordinate



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In general

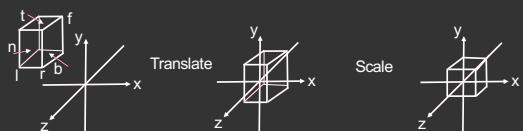
- We have a cuboid that we want to map to the normalized or square cube from $[-1, +1]$ in all axes
- We have parameters of cuboid (l, r, t, b, n, f)



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Orthographic Matrix

- First center cuboid by translating
- Then scale into unit cube



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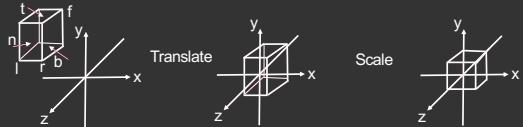
Transformation Matrix

$$M = \begin{pmatrix} \text{Scale} & \text{Translation (centering)} \\ \begin{pmatrix} \frac{2}{r-l} & 0 & 0 & 0 \\ 0 & \frac{2}{t-b} & 0 & 0 \\ 0 & 0 & \frac{2}{f-n} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} & \begin{pmatrix} 1 & 0 & 0 & -\frac{l+r}{2} \\ 0 & 1 & 0 & -\frac{t+b}{2} \\ 0 & 0 & 1 & -\frac{f+n}{2} \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{pmatrix}$$

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Caveats

- Looking down $-z$, f and n are negative ($n > f$)
- OpenGL convention: positive n, f , negate internally



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Final Result

$$M = \begin{pmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{f-n} & -\frac{f+n}{f-n} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \text{glOrtho} = \begin{pmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{-2}{f-n} & -\frac{f+n}{f-n} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

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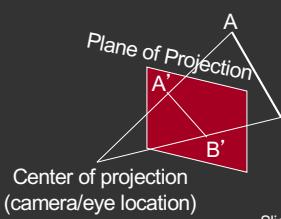
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Perspective Projection

- Most common computer graphics, art, visual system
- Further objects are smaller (size, inverse distance)
- Parallel lines not parallel; converge to single point



Slides inspired by Greg Humphreys

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Funny things happen...



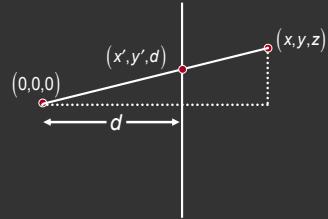
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Perspective Video 1

- <https://www.youtube.com/watch?v=F5WA26W4JaM&list=PLWfDJ5nla8UpwShx-1zLJqcp575fKpsSO&index=11>
- Steve Seitz UW 5 minute videos
- more detail regarding lenses and actual cameras than needed for course (good to know)

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Overhead View of Our Screen



Looks like we've got some nice similar triangles here?

$$\frac{x}{z} = \frac{x'}{d} \Rightarrow x' = \frac{d \cdot x}{z} \quad \frac{y}{z} = \frac{y'}{d} \Rightarrow y' = \frac{d \cdot y}{z}$$

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In Matrices

- Note negation of z coord (focal plane $-d$)
- (Only) last row affected (no longer 0 0 0 1)
- w coord will no longer = 1. Must divide at end

$$P = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{d} & 0 \end{pmatrix}$$

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Verify

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{d} & 0 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = ? \quad \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} -\frac{d \cdot x}{z} \\ -\frac{d \cdot y}{z} \\ -\frac{z}{d} \\ 1 \end{pmatrix}$$

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Perspective Video 2

- <https://www.youtube.com/watch?v=g7Pb8mrwcJ0&list=PLWfDJ5nla8UpwShx-1zLJqcp575fKpsSO&index=12>
- Steve Seitz UW 5 minute videos
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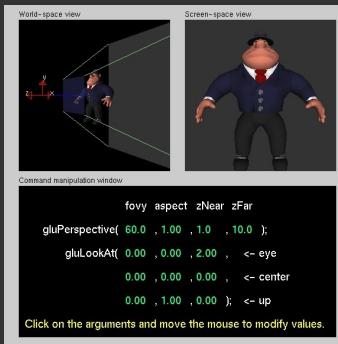
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- *Derivation of gluPerspective (handout: glFrustum)*
- Brief discussion of nonlinear mapping in z

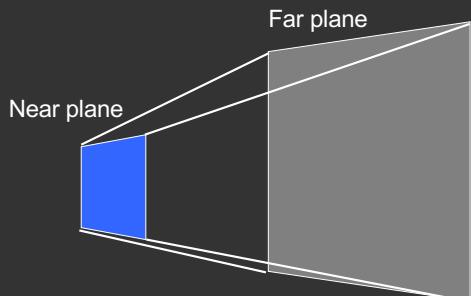
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Remember projection tutorial



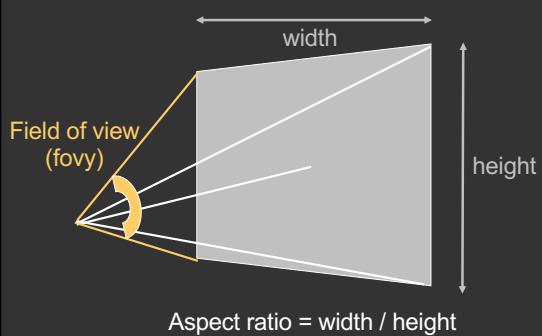
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Viewing Frustum



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Screen (Projection Plane)



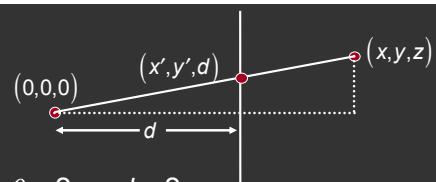
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gluPerspective

- gluPerspective(fovy, aspect, zNear > 0, zFar > 0)
- Fovy, aspect control fov in x, y directions
- zNear, zFar control viewing frustum

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Overhead View of Our Screen



$$\theta = \frac{\text{fovy}}{2} \quad d = \cot \theta$$

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In Matrices

- Simplest form:

$$P = \begin{pmatrix} \frac{1}{\text{aspect}} & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{d} & 0 \end{pmatrix}$$

- Aspect ratio taken into account
- Homogeneous, simpler to multiply through by d
- Must map z vals based on near, far planes (not yet)

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In Matrices

$$P = \begin{pmatrix} 1 & 0 & 0 & 0 \\ \frac{1}{\text{aspect}} & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{d} & 0 \end{pmatrix} \rightarrow \begin{pmatrix} \frac{d}{\text{aspect}} & 0 & 0 & 0 \\ 0 & d & 0 & 0 \\ 0 & 0 & A & B \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

- A and B selected to map n and f to -1, +1 respectively

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Z mapping derivation

$$\begin{pmatrix} A & B \\ -1 & 0 \end{pmatrix} \begin{pmatrix} z \\ 1 \end{pmatrix} = ? \quad \begin{pmatrix} Az+B \\ -z \end{pmatrix} = -A - \frac{B}{z}$$

- Simultaneous equations?

$$\begin{aligned} -A + \frac{B}{n} &= -1 & A &= -\frac{f+n}{f-n} \\ -A + \frac{B}{f} &= +1 & B &= -\frac{2fn}{f-n} \end{aligned}$$

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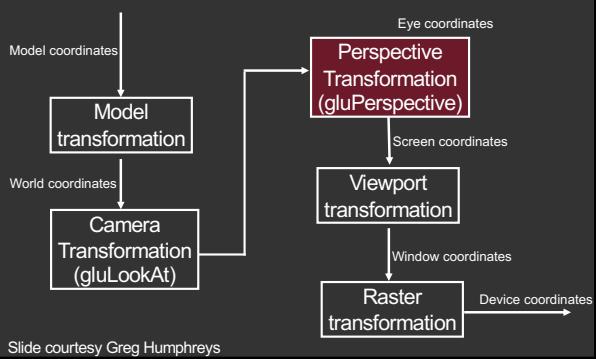
Mapping of Z is nonlinear

$$\begin{pmatrix} Az+B \\ -z \end{pmatrix} = -A - \frac{B}{z}$$

- Many mappings proposed: all have nonlinearities
- Advantage: handles range of depths (10cm – 100m)
- Disadvantage: depth resolution not uniform
- More close to near plane, less further away
- Common mistake: set near = 0, far = infinity. Don't do this. Can't set near = 0; lose depth resolution.
- We discuss this more in review session

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Summary: The Whole Viewing Pipeline



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