Viewing and Modeling

Computer Viewing

Three aspects of viewing process:

- Position camera (model-view matrix)
- Selecting a lens (projection matrix)
- Clipping (view volume)

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We will discuss projection and NDC next time...

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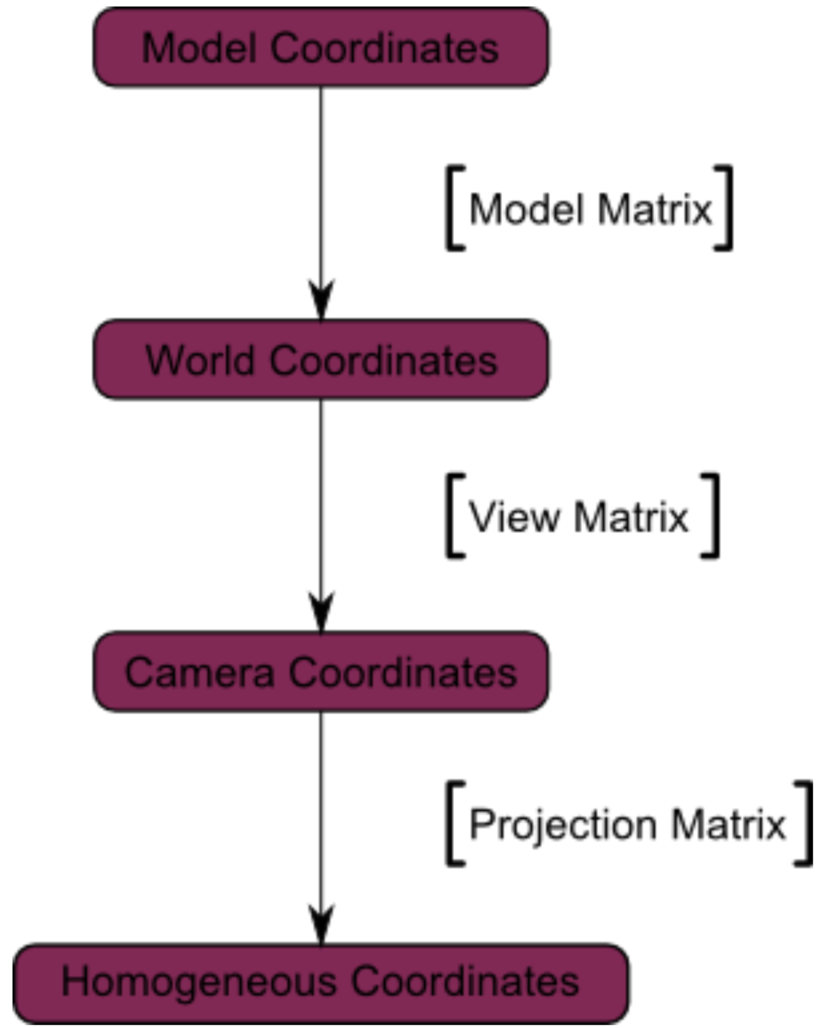
We'll discuss object and world space this time!

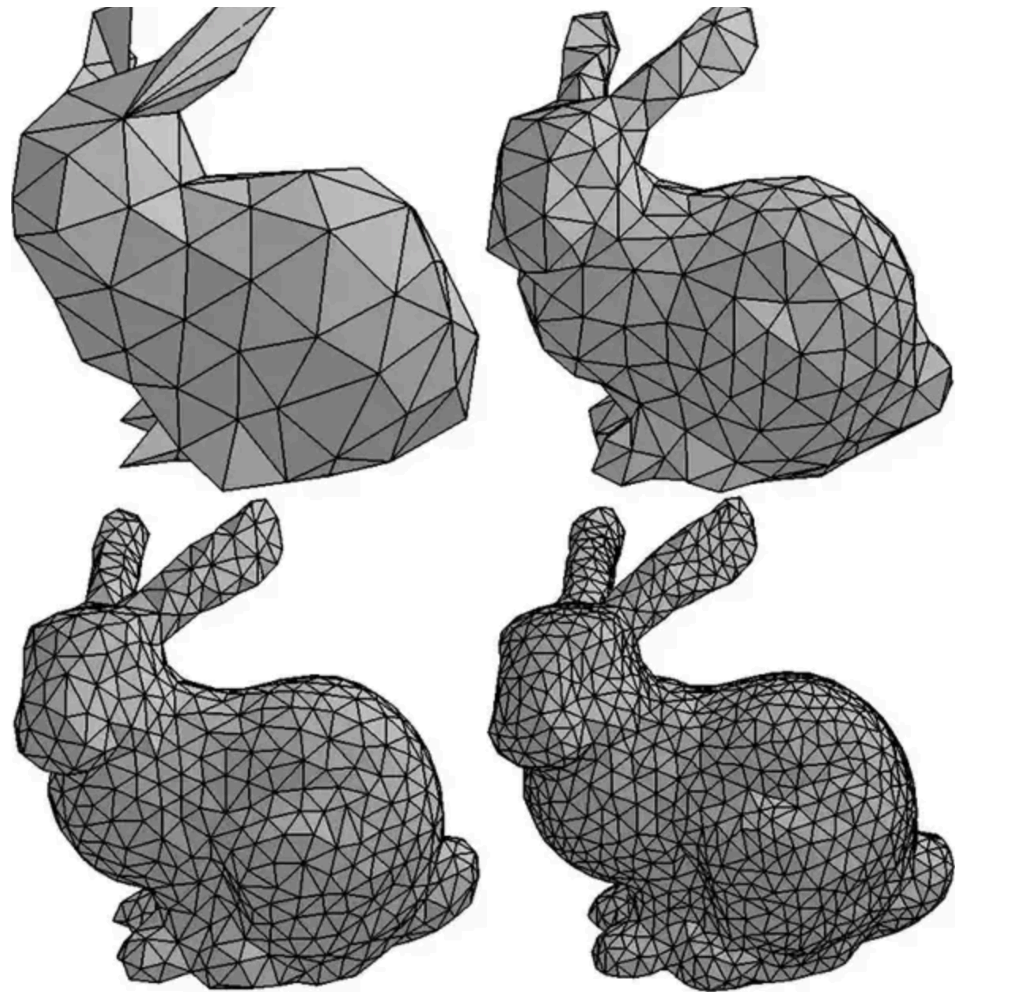
World and Camera Frames

- Base frame in OpenGL is world frame
- Use view matrix to change world representation to camera representation
- Fixed pipeline OpenGL treated model and view matrices as single (model-view) matrix



Model (Object) Coordinates

- Consider this bunny model...
- Each tri has relative position to the other tris
- Must define **space** in which all tris exist



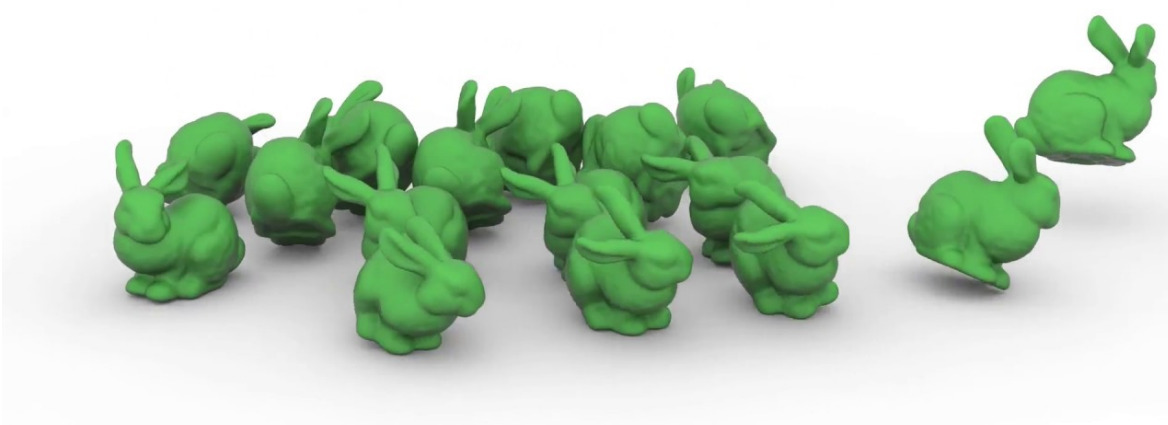
World Coordinates

Now consider this scene...

Motunui Island (Disney's Moana) has over 15 billion primitives (90 million unique quads and 5 million curves). A still frame of the base scene is 44.8GB + 23.6GB of animation data

Model Matrix

- Unique to each model
- Used to position the model and its tris in world coordinates
- Apply sequence of affine transformations to translate, rotate and scale model vertices



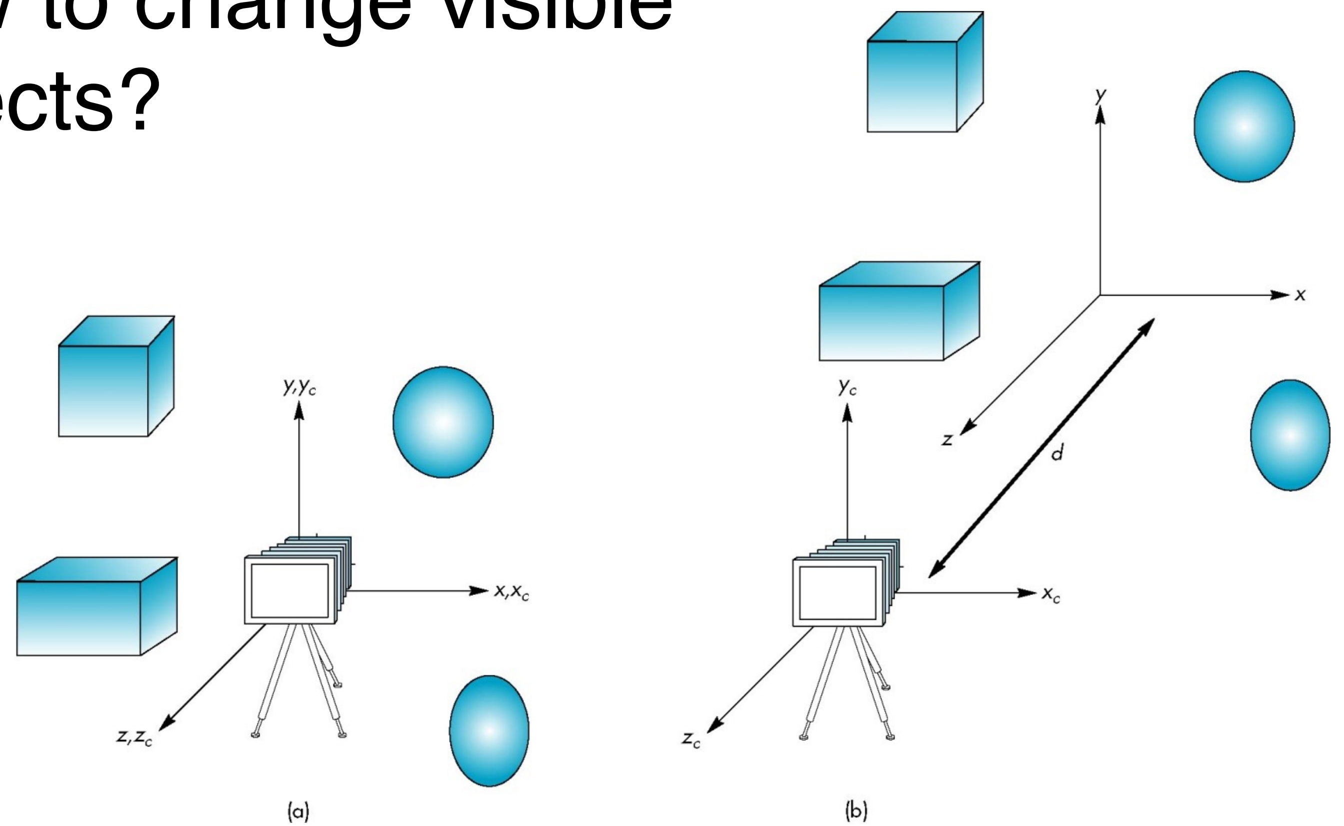
OpenGL Camera

Initial representation:

- Object and camera frames are the same (model-view matrix is identity)
- Camera located at origin
- Camera points in negative Z direction
- Default view volume is centered at origin with side lengths of 2 (normalized)

Changing the View

How to change visible objects?



Moving Camera Frame

Move the camera in the positive Z direction (translate camera frame)

Move objects in the negative Z direction (translate world frame)

…Which is better?

Moving Camera Frame

Move the camera in the positive Z direction (translate camera frame)

Move objects in the negative Z direction (translate world frame)

…they're equivalent!

View Matrix

- All vertices defined *relative* to the camera
- Therefore world moves relative to camera

Consider:

```
glm::mat4 ViewMatrix =
  glm::translate(0.f, 0.f, -14.f);
```

What is this doing?

Translation in View Space

the translation vector

$$\begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -14 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Point at (0, 0, 0) moves to (0, 0, -14)

Remember!

In graphics, everything is relative

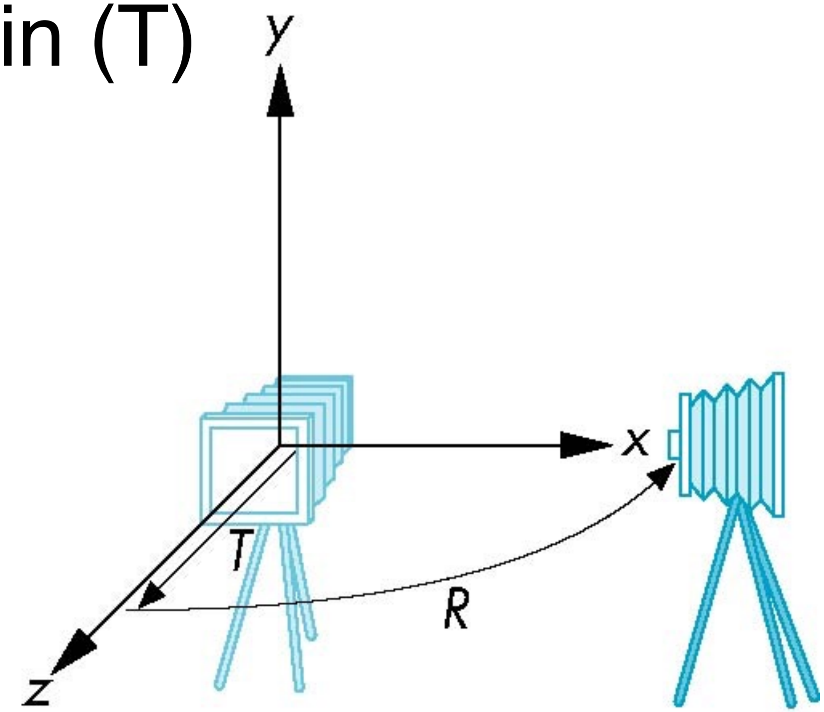
Remember!

In graphics, EVERYTHING IS RELATIVE

General Camera Motion

Position camera using translations and rotations

- Move camera to origin (T)
- Rotate camera (R)
- MV = RT



A Better Viewing Matrix

“Look at” Transform:

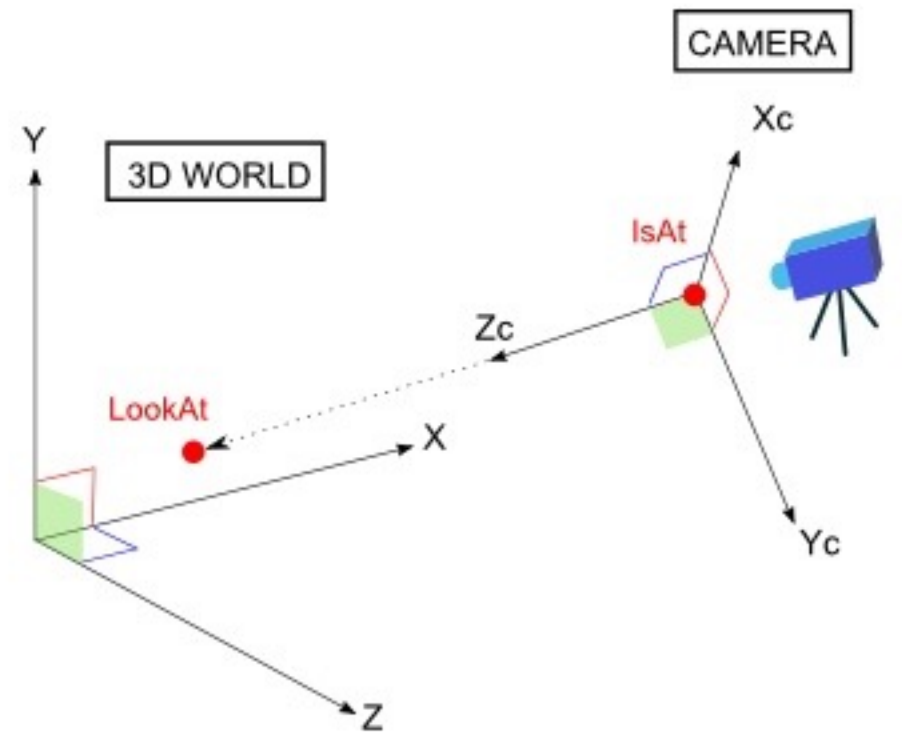
Construct an affine 4x4 matrix to map world space into camera space

What do we need to know about the camera’s placement in the world to construct this?

glm::lookAt

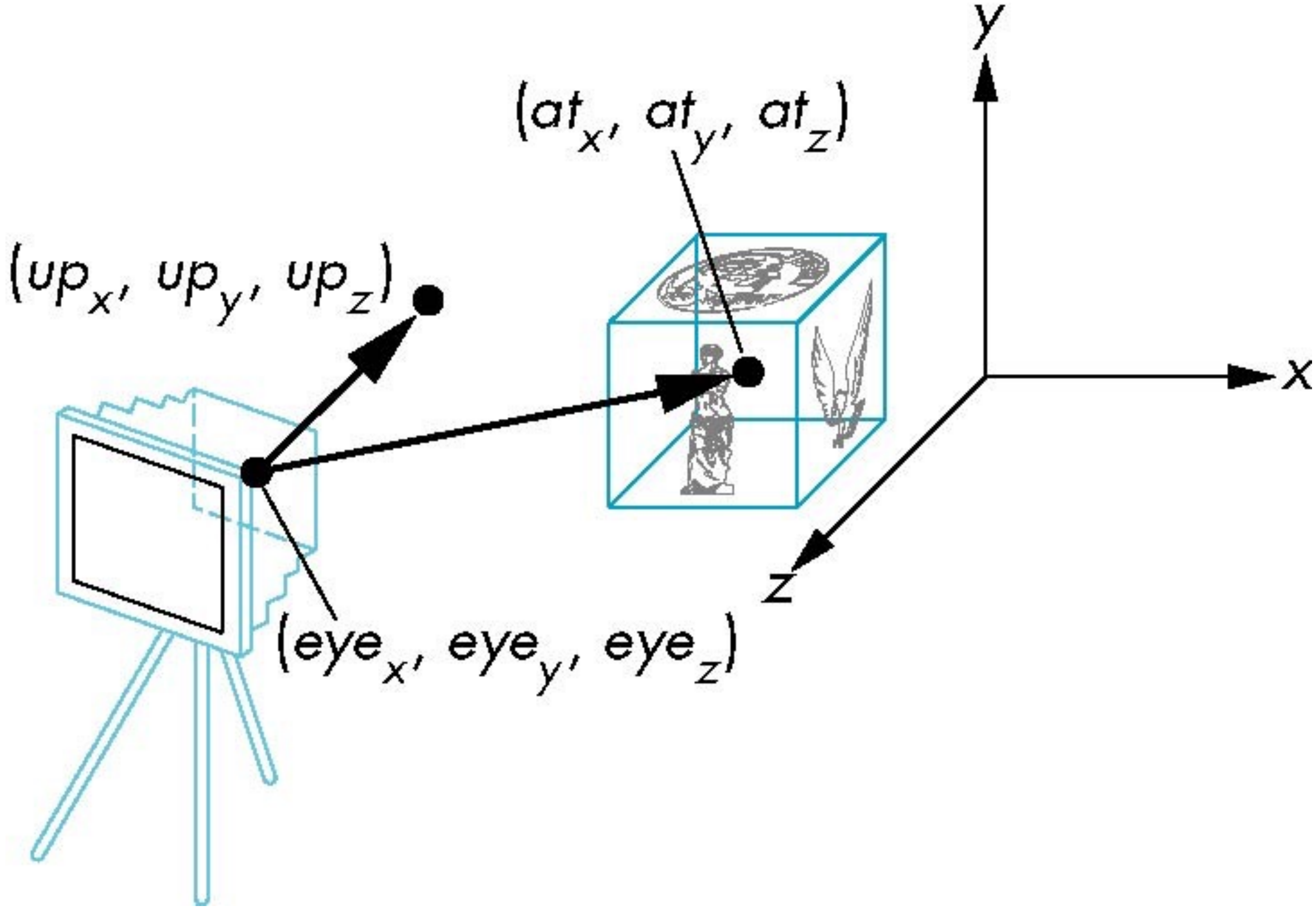
Defines:

- Camera position
- Camera target
- Camera up



Returns:

- View matrix



(up_x, up_y, up_z)
(at_x, at_y, at_z)
(eye_x, eye_y, eye_z)
y
x
z

lookAt Algorithm

In order to define view coordinate system:

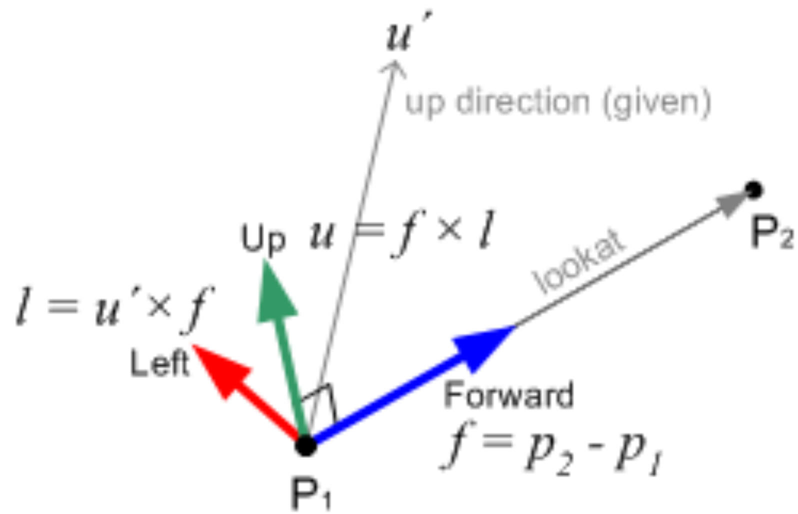
- Z axis (forward vector) = normalize(**at - eye**)
- X axis (left vector) = normalize(**up** x Z)
- Y axis (up vector) = normalize(X x Z)

What happens if Z or **up** are zero length?
What happens if Z and **up** are coincident?

Why Recompute Up?

The given **up** vector is not necessarily perpendicular to **forward** vector

Actual **up** vector will be orthogonal to **left** and **forward** vectors



OpenGL's Internal lookAt Matrix

$$\begin{bmatrix} X_x & X_y & X_z & 0 \\ Y_x & Y_y & Y_z & 0 \\ -Z_x & -Z_y & -Z_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Note: Z (i.e. look direction) is made negative to negate OpenGL's default of looking down the -Z axis

Combining Model-View-Projection

glm::mat4 MVPmatrix = projection*view*model;

$$\underbrace{\begin{bmatrix} 1.250 & 0 & 0 & 0 \\ 0 & 1.667 & 0 & 0 \\ 0 & 0 & -1.333 & -10.667 \\ 0 & 0 & -1 & 0 \end{bmatrix}}_{\text{projection}} \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -14 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\text{view}} \underbrace{\begin{bmatrix} 0.9107 & -0.2440 & 0.3333 & 0 \\ 0.3333 & 0.9107 & -0.2440 & 0 \\ -0.2440 & 0.3333 & 0.9107 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\text{model}}$$

Remember: matrix multiplication is associative but not commutative:

$A(BC) = (AB)C \qquad ABC \neq CBA$

A Note About Matrices

- OpenGL uses column-major notation (DirectX uses row-major notation)
  - Note that layout in memory is separate from this!
- OpenGL uses post-multiplication (and yes, DirectX uses pre-multiplication)
- OpenGL transforms are therefore multiplied in “reverse” order of application:

  e.g. p’ = PxVxMp

OpenGL Tutorial

Look through:

http://www.opengl-tutorial.org/beginners-tutorials/tutorial-3-matrices/

https://learnopengl.com/Getting-started/Coordinate-Systems

References

http://www.cgchannel.com/2018/07/download-disneys-data-set-for-motunui-island-from-moana/